4 Plants, Equipment, and Machines for the Production of Synthetic Yarns and Fibers

4.1 General

The synthetic fiber plants are such an accumulation of different machines, equipment and auxiliary installations that the description of a few typical installations needs to be followed by individual descriptions – here specifically from an engineering point of view. While 1964 the plant sizes were between 1000 and 10,000 t/a, and larger installations only existed in the USA, 1990 capacities for staple fiber productions of 50,000 . . . 200,000 t/a were already considered as normal [1]. In the PR China runs a polyester plant with a capacity of 600,000 t/a [2], however with several production lines (it is now going to be doubled). As opposed to these large installations for PET, PA or PAN and two or three PP

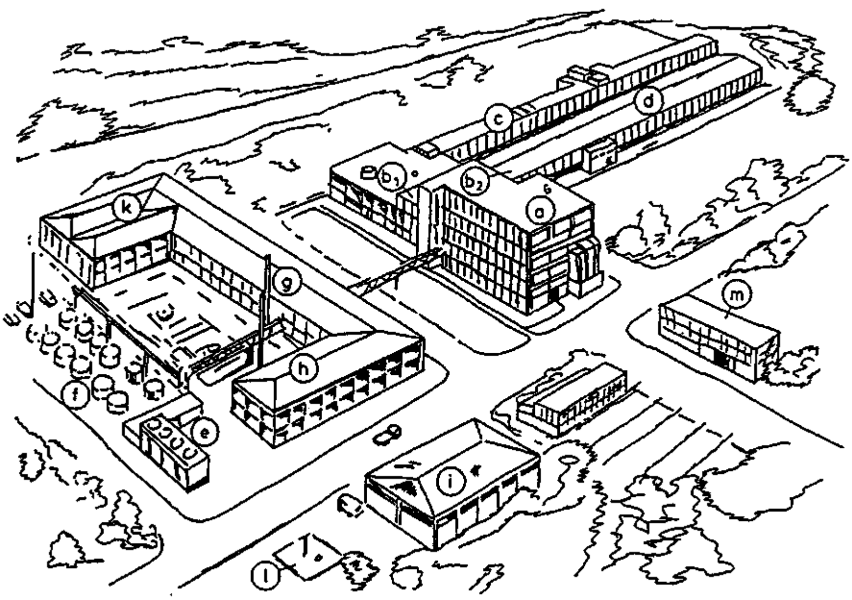


Figure 4.1 Polyester continuous filament and staple fiber plant for approximately 20,000 + 50,000 t/a (= 200 t/d or 150 million lb./yr.; Fischer Industrieanlagen GmbH [3]), *a*) Continuous polycondensation plant with bypass for chip production, b_1) continuous direct staple fiber spinning, b_2) extruder continuous filament spinning plant, *c*) air conditioning plants, *d*) draw twisting department and storage, *e*) cooling water systems, *f*) glycol recovery and fuel oil tanks, *g*) auxiliary plants (high temperature boilers, compressed air, nitrogen, demineralized water and emergency power plants, *h*) steam generating plant, *i*) TPA storage, *k*) mechanical workshop and spare parts storage, *l*) water well with pump station, *m*) administration and social building; total land area requirement: approximately 3 ha

installations, the usual PP fiber plants have a capacity of 2000...20,000 t/a. Specialty fiber plants are considerably smaller. A carbon fiber plant for 3000 t/a is very large, and so is a hollow filament membrane installation with 5000 t/a, and some specialty fiber installations are run with only a few 10 t/a or less.

While Fig. 1.19 shows a PA and PET plant [4] that started from small beginnings and grew to a capacity of about 80,000 t/a, Fig. 4.1 shows a perspective total view of a PET filament and staple fiber plant with a capacity of about 70,000 t/a. This requires a construction site of over 150 × 300 m^2 [3], allowing later capacity doubling.

Figure 6.11 shows a schematic cut through a PET-POY spinning plant with draw texturing and two-for-one twisting. In the older plants the "spinning tower" of over 20 m height should be noted, while modern installations only require ceiling heights of 12...14 m. The subsequent process steps require about 7 m ceiling height.

Figure 4.2 shows the floor plan and side view of a PET-POY plant with a capacity of about 70,000 t/a with subsequent draw texturing and draw twisting. Figure 4.3 shows a PA 6 VK tube polycondensation plant with chip production, spinning plant and with all the auxiliary installations for a similar capacity [2].

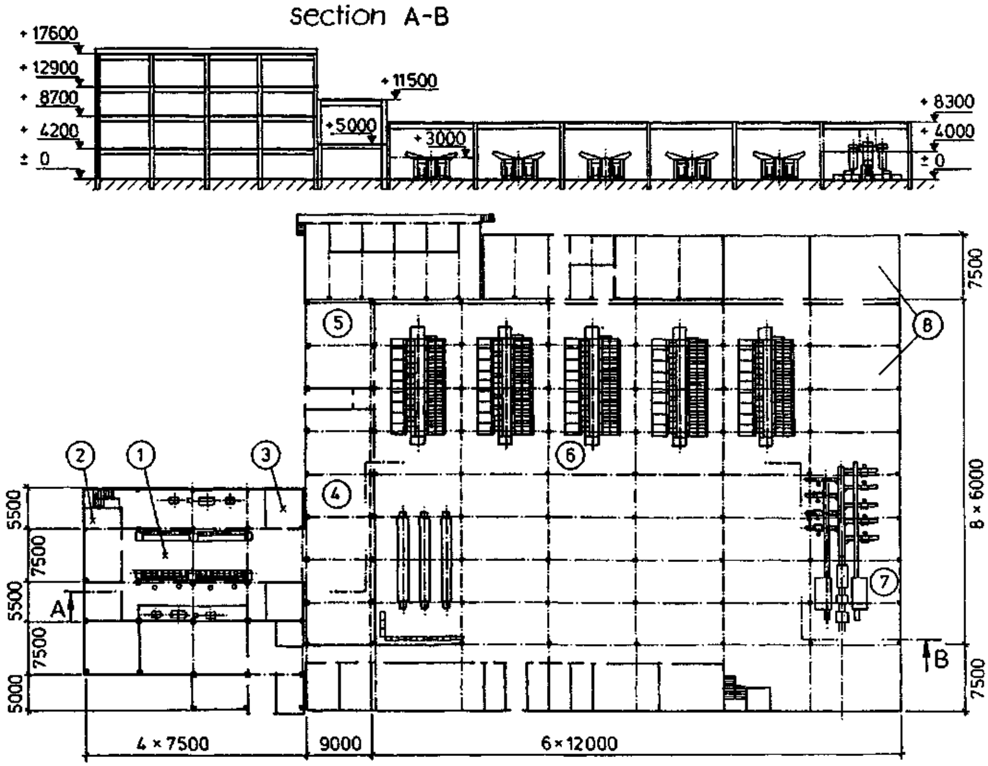


Figure 4.2 Layout of a PET-POY plant with spinning, draw twisting and draw texturing (John Brown Deutsche Engineering GmbH (formerly Didier Engineering GmbH), Essen [69].) *1*) POY take-up (beneath spinning floor), *2*) workshop, *3*) frequency inverters, *4*) intermediate spin bobbin storage, *5*) rewinding, *6*) draw texturing department, *7*) draw twisting department, *8*) sorting and packing. On the upper floors, not shown in this drawing, *9*) chip crystallization and drying, *10*) spinning extruders, spinning machines and quench chambers, *11*) chip hoppers, *12*) airconditioning plants, *13*) control room

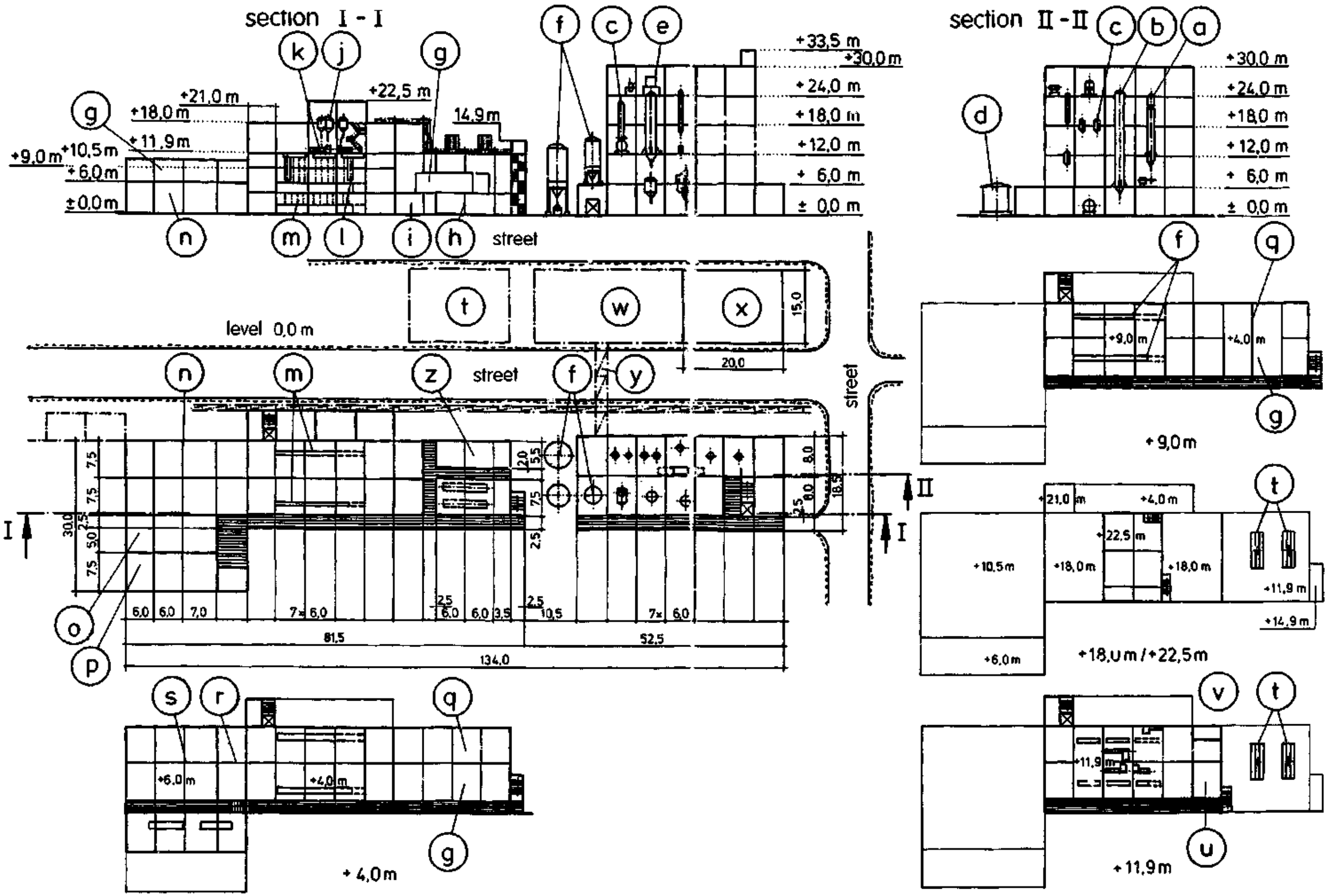


Figure 4.3 Layout of a PA 6 continuous filament plant (Zimmer AG, Frankfurt [27]) with *a*) VK tube polycondensation, *b*) extractors, *c*) recovery, *d*) lactam water, *e*) drying, *f*) intermediate storage: 100 + 50 m^3, *g*) air conditioning plants, *h*) water coolers, *i*) spin finish preparation, *j*) chip storage, *k*) extruder and spinning beams, *l*) air quench chambers, *m*) POY take-up machines, *n*) sorting, *o*) textile laboratory, *p*) chemical laboratory, *q*) air conditioning for quench chambers, *r*) air conditioning for frequency inverters, *s*) frequency inverters, *t*) cooling towers, *u*) cleaning plants, *v*) filter sand preparation, *w*) power station, *x*) lactam storage and melter, *y*) power bridge, *z*) plant office

At this point there is only a brief mention of the necessary and in part very big storage areas for raw and auxiliary materials (e.g., Fig. 4.38) and the auxiliary installations, because their size is not only determined by the plant capacity but also by the required rate times that will be pointed out specifically in Chapter 4.6 and Table 4.16.

4.2 Chemical Equipment

Chapter 2 already mentioned the numerous autoclaves respectively cascades and the continuously working apparati that are connected by pipes, valves, filters and pumps, and that possibly work with pressure or vacuum. Additionally there are thin layer vacuum evaporators, continuous mixers, etc. There are also special requirements for the materials and the heating systems. The material selection is mostly left to the design engineers and the users. Calculations, construction and testing of the equipment, especially of vacuum and pressure units, however, follow strict rules that apply to the specific location of the installation [5], unless the users and designers do not agree differently from the rules within the legal regulations. For example there are rules in Germany for pressure vessels (Fig. 4.4) defining the equipment by pressure and/or by volume. In other cases tests according to the German rules or other tests executed by the TÜV (Technischer Überwachungsverein [6] = Technical Inspection Association) or by Lloyds [7] are accepted.

4.2.1 Autoclaves

These reactor vessels usually consist of a cylindrical vertical vessel with a flanged dished cover, lower dished bottom or conical bottom, jacket and/or heating coils for heating or cooling and the agitator. Due to the large variety of forms only the combination of the possibilities in Fig. 4.5 will be mentioned. Examples for the most important applications are given. Heating jackets are recommended for vapor with condensation while jackets with spiral or welded half pipes are mostly for liquid heaters.

The ratio of cylinder height to the inside diameter for the same volume is often assumed to be $H/D \approx \sqrt{2}$ due to lack of specific requirements. For degassing and/or evaporation larger diameters are selected; for continuous vertical flow reactors (e.g., for PVC polymerization), H/D becomes $> \approx 6$, and for the VK tube for the polymerization of PA 6 (Figs. 2.19 and 2.20) H/D can be $< \approx 20$.

The ability to clean the walls or for residuals to grow on the walls (unless self cleaning is provided with a scraper with little clearance to the wall) mainly depends on the roughness of the inner surface: It should at least be equal to a 180 grain polish, but even electro-polishing with $R_t \leq 0.4\,\mu m$ may become necessary.

A similar effect is achieved by the bottom corkscrew (B) for the agitator AR in Fig. 4.5b that ensures that the lower tip in the conical bottom of this autoclave does not stay but is continuously transported upwards and thus participates in the overall reaction.

The autoclave top is almost always bolted with a flange and can be flat or equipped with a flat or dished cover and should be jacketed for heated as an autoclave for larger diameters. Additionally Fig. 4.6 shows the usual agitator shaft sealings [9]:

a) Simple stuffing box with one or more packing rings, held on top and bottom by bronze rings (for low pressure differences and low rpm),
b) liquid superposed and possibly cooled stuffing box with packing rings and bronze-liquid intermediate rings for fine vacuum of up to 0.05 mbar and < 50 bar and < 400 rpm,
c) single acting liquid superposed glide ring sealing and
d) double acting liquid superposed glide ring sealing.

The types b) through d) should be connected to small cooling and storage vessels for tightening liquid and they are suited for practically all used rpm's. Safety control sets [9] exist to alarm in the case of smallest leaks.

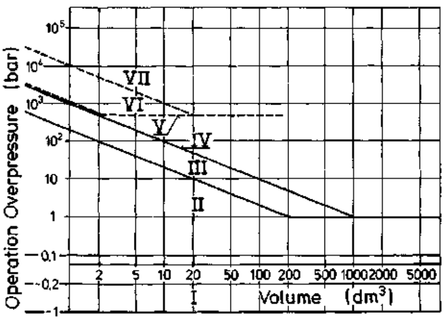


Figure 4.4 Pressure vessels: Classification and testing according to the German pressure vessel regulations [5, 6]

Group I: $p = -0.2$ bar
Group II: $0.1 \ldots 1$ bar
$p \geq 1$ bar; $p \cdot V \leq 200$
Group III: $p \geq 1$ bar; $p \cdot V = 200 \ldots 1000$
Group IV: $p \geq 1$ bar; $p \cdot V = 1000$

Pressure vessels with internal pressure due to gases or vapors, or liquids or solids with gas or vapor blankets, or liquids at temperatures above their boiling points

Group V: $p = 500$ bar
$p \geq 500$ bar; $p \cdot V = 1000$
Group VI: $p \geq 500$ bar; $p \cdot V \leq 10{,}000$
Group VII: $p \geq 500$ bar; $p \cdot V \geq 10{,}000$

Pressure vessels with internal pressure due to liquids only. The temperature of the liquid is below its boiling point

Tests	Test before start-up and after significant changes						Recurring tests				Special tests			
	Conducted by experts: Initial	Conducted by experts: Acceptance		Manufacturere's certificate			By expert personnel		By competent personnel	Frequency specified by user	After major repair or overhauling		Acceptance testing after change of location	
	Before and during construction-pressure testing	Statutory, fittings, erection	Erection by competent personnel	Pressure testing	Leak testing	Inspection certificate by competent personnel	Internal testing every 5/10 years	External testing of heated pressure vessels every 2 years	Internal pressure testing	External testing of heated pressure vessels	By expert personnel	By competent personnel	By expert personnel	By competent personnel
Test groups	1–3	4–6	7	8	9	10	11, 12	13	14, 15	16	17	18	19	20
Gases, Vapours I					•	•		•	•			•		•
II				•		•			•	•		•		•
III	•	•	•						•	•	•		•	
IV	•	•	•				•	•			•		•	
Fluids V				•		•			•	•		•		•
VI	•	•	•						•	•	•		•	
VII	•	•	•				•	•			•		•	

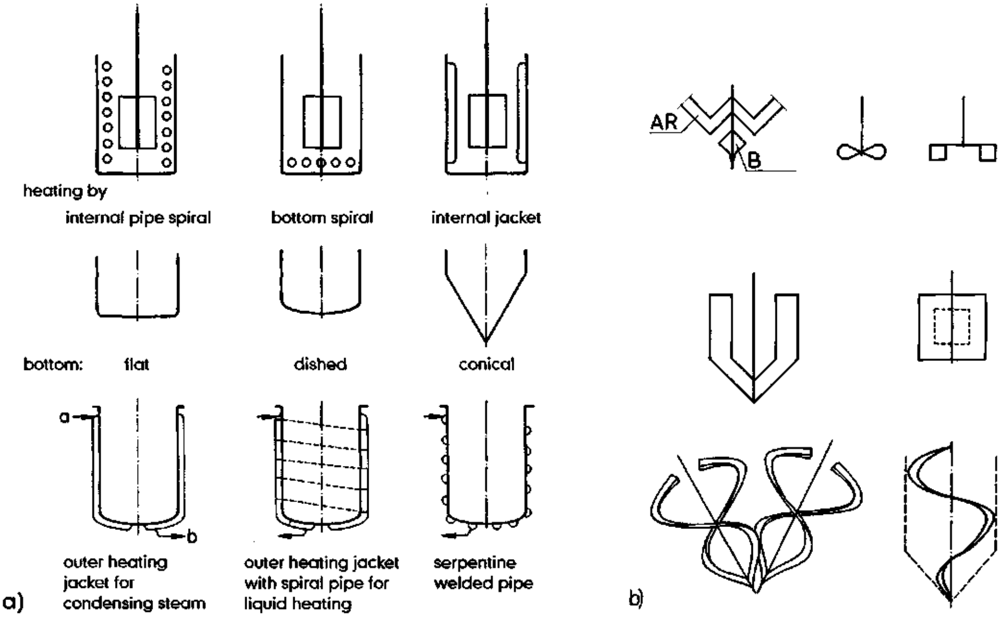


Figure 4.5 Typical autoclave shapes: heating by liquid or vapor (a), and agitator types (b)

Agitator Drives

The necessary power for the agitator drive can be seen in Fig. 4.7. It is almost always higher than the one calculated in Fig. 4.8 with $Ne = f$ (Re, agitator form) [9]. For more specific calculations see the specialized literature [10, 11].

If the power coefficient Ne from Fig. 4.8 is used, the agitator drive power becomes:

$$N[\mathrm{kW}] = Ne \cdot \gamma[\mathrm{kg/m^3}] \cdot (n[\mathrm{rpm}]/60)^3 \cdot d_2^5[\mathrm{m}] \cdot 10^{-3} \approx u^3[\mathrm{m/s}](d_2/d_1)^2 Ne \tag{4.1}$$

with

Ne = power coefficient (from Fig. 4.8)
$Ne = f(Re) = f(D_{\mathrm{agitator}} \cdot u[\mathrm{m/s}]/\gamma\ [\mathrm{m^2/s}])$

However the range has to be calculated for the complete polycondensation time as the highest needed drive power could be anywhere between the highest and lowest rpm (e.g., for PET from melted DMT and ethylene glycol: $\eta_a \approx 2\,\mathrm{P}$ to $\eta_e \approx 2500\,\mathrm{P}$ with the responding variation in Re, $n_a \approx 300$ to $n_e \approx 10\,\mathrm{rpm}$, $\gamma_a \approx 1000$ to $\gamma_e \approx 1200\,\mathrm{kg/m^3}$).

The efficiency of the drive system (usually between 0.75 and 0.9) has to be taken into consideration. The agitators can also have fixed rpm or can be driven by 2 to 3 fold pole changeable motors or can be infinitely variable and they are in many cases (e.g., for PET plants) explosion proof. To control the viscosity during the polycondensation processes a torque control in the drive shaft or the power measurement of the motor is necessary.

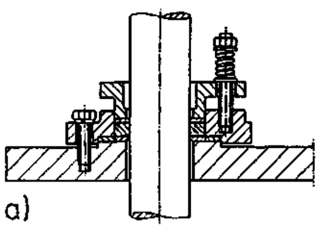
A simple and often used V-belt drive for an agitator shaft is shown in Fig. 4.9: The range of the disks is about 1 : 6 and for the pole change 1 : 2 : 3 : 4. The shaft flange indicated the exchangeability of the agitator.

Autoclave Heaters

The heat transfer from the inner autoclave wall to the liquid inside can be calculated with:

$$Nu = 0.36 \cdot Re_{\mathrm{M}}^{0.66} \cdot Pr^{0.33} \cdot (\eta_{\mathrm{M}}/\eta_{\mathrm{W}})^{0.14} \tag{4.2}$$

Agitator shaft sealings



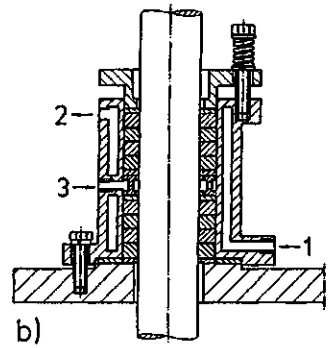


Figure 4.6

a) Simple stuffing box
b) liquid covered, water cooled stuffing box:
  1) cooling water entry
  2) cooling water outlet
  3) superposing liquid
c) single action glide ring sealing
d) double action glide ring sealing with intermediate bearing

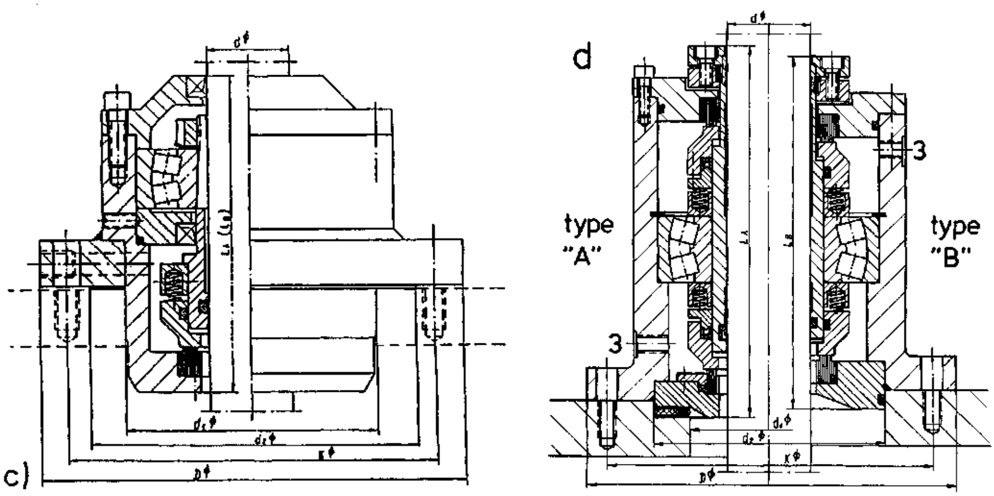
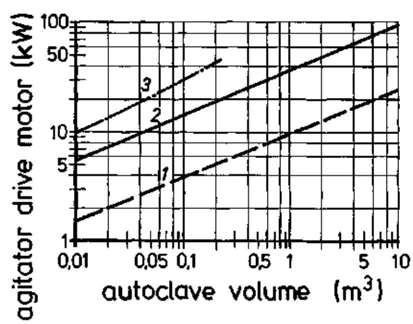


Figure 4.7 Approximate agitator driving power
1) for low viscosity ($\eta < \approx 20$ P), impeller stirrer or similar
2) $\eta \leq 5000$ P, anchor or spiral agitator
3) $\eta \geq 1000$ P, spiral or double cone agitator (up to approximately 10^5 P)



and through the possibly built in heating coil

$$Nu = 0.87 \cdot Re_M^{0.62} \cdot Pr^{0.33} \cdot (\eta_M/\eta_W)^{0.14} \tag{4.3}$$

with the indices *M* for the average content, *W* for the wall contact, $Re = nd^2/\nu$, $Pr = \nu/a$ (a = temperature conductivity coefficient) and $Nu = \alpha \cdot d/\lambda$.

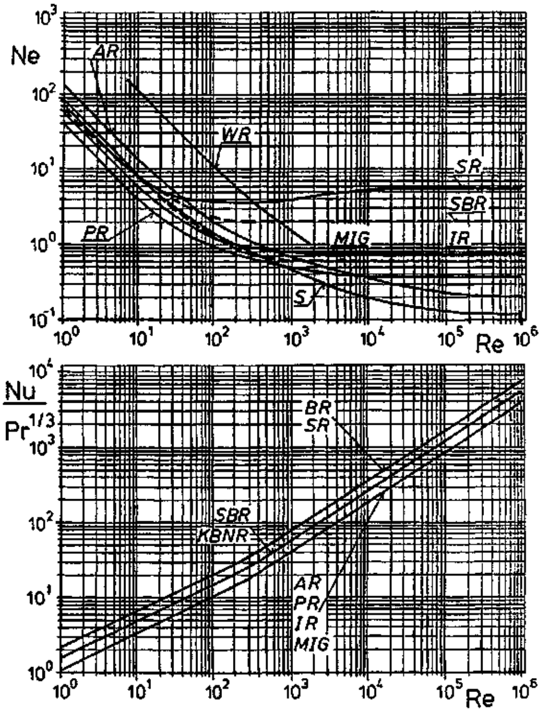


Figure 4.8 Diagrams for the determination of the power factor *Ne* for different agitators, and the heat transfer coefficient from the inner autoclave wall as *f* (*Nu*), both as a function of the Reynolds number *Re* (EKATO [9])

WR	Helical agitator
SR	Disk agitator
SBR	Tilted blade turbine
AR	Anchor type agitator
PR	High speed stirrer (propeller)
IR	Impeller type stirrer
MIG	EKATO Patent agitator
S	Mizer disk
BR	Beam agitator

$Re = (60 \cdot \eta)^{-1} n \cdot d^2_{agitator} \gamma$

$Nu = \alpha \cdot d_{agitator} / \lambda$

These equations have been confirmed by experiments for $d \leq 2.5\,m$, $0.5 \leq n \leq 5\,s^{-1}$ (30 ... 310 rpm) and $\eta_{20\,°C} = 10^{-4}$ to about $10^{-1}\,kg \cdot s/m^2$. α becomes smaller with increasing solids content, and approximately $\alpha_{suspension}$ $(1 - c) \cdot \alpha$ is valid, i.e., for 25% concentration $\alpha_{suspension}$ $0.75 \cdot \alpha$.

Table 4.1 gives the experimental values for *k* for the approximate calculations of heat transfer areas in autoclaves [10, 14].

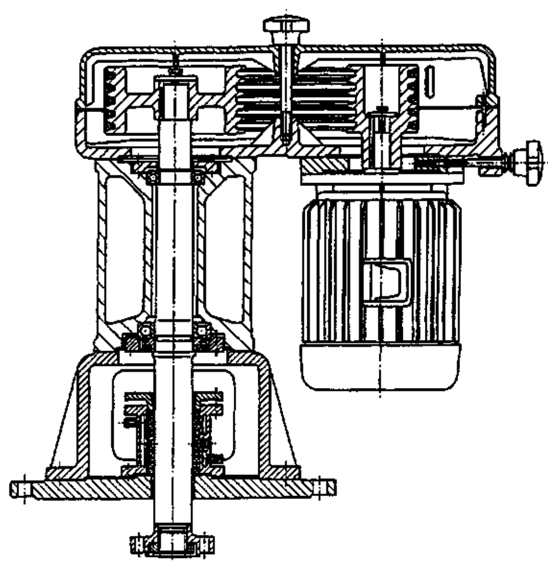


Figure 4.9
Agitator drive by a motor and V-belts

Table 4.1 Approximate k values [10, 14] [kcal m^{-2} h^{-1} K^{-1}]

a) Outer jacket:	k
condensing vapor outside, liquid inside vessel	400 ... 1200
condensing vapor outside, boiling liquid inside vessel	600 ... 1500
cooling water or brine outside, liquid inside vessel	150 ... 300
b) Coil inside:	
condensing vapor inside the coil, liquid inside the vessel	600 ... 2000
condensing vapor inside the coil, boiling liquid inside the vessel	1000 ... 3000
cooling water or brine inside the coil, liquid inside the vessel	400 ... 1000
c) Welded to the outside of the jacket:	
condensing vapor in the heating channels, liquid inside vessel	400 ... 1500
condensing vapor in the heating channels, boiling liquid inside vessel	600 ... 2000
cooling water or brine in the heating channels, liquid inside vessel	300 ... 800

Similar to the agitator drive power it is possible to calculate an exact heat transfer coefficient [9] with the help of Fig. 4.8, also in dependence of the Reynolds figure, the agitator shape and the Prandtl figure:

$$Nu = \alpha_i \cdot d_{i,\,\text{vessel}}/\lambda \cdot f(Re,\ \text{agitator}) \cdot Pr^{1/3} \tag{4.4}$$

Figure 4.10 shows three autoclaves designed accordingly:

a) a small salt melter with vapor condensation heater,
b) a reactor autoclave for low viscous liquids with removable inner heating coil, reduction worm gear box on the agitator shaft and a PIV variable drive,
c) a polycondensation autoclave with exchangeable agitator, torque control measurement, reduction worm gear box and a PIV variable drive.

4.2.2 Dissolving and Mixing

To dissolve a solid in a liquid inside of an autoclave the heavier specific weight solid is rotated with the liquid until the difference in speed of the two reaches a minimum. Then it is no longer possible to accelerate the dissolving process by increasing the mechanical power supply. For the dissolving of the grain suspended in the liquid the diffusion law is valid:

$$dm_F/dt = -\beta \cdot F \cdot (c_S - c)$$

(m_F not yet dissolved solid, t time, c average concentration of the already dissolved solid, c_S concentration in saturation, and β transfer coefficient)

The integration of this differential equation is very difficult because all these variables change over time and one has to deal only with assumptions [10]. However, the following general conditions can be seen:

- start with a small grain size as possible to increase the surface F,
- use the highest possible saturation concentration for the solvent, e.g., by increasing the temperature and the resulting reduction in viscosity; avoid lumping,
- more turbulence in the dissolving vessel.

Figure 4.11 shows some general values for the stirring conditions, e.g., the power requirements and the rpm of the agitator and the necessary mixing time [min] [11].

Production of Polymer Spin Solution

The polymer—usually a powder—is entered through a dosing pump (rotary valve, dosing screw or gravimetric) into the entry of a screw kneader [12]. Directly behind this the solvent (b) is added through a dosing pump (d) (Fig. 4.12). Lumping can be avoided by adding part of the solvent in and around the

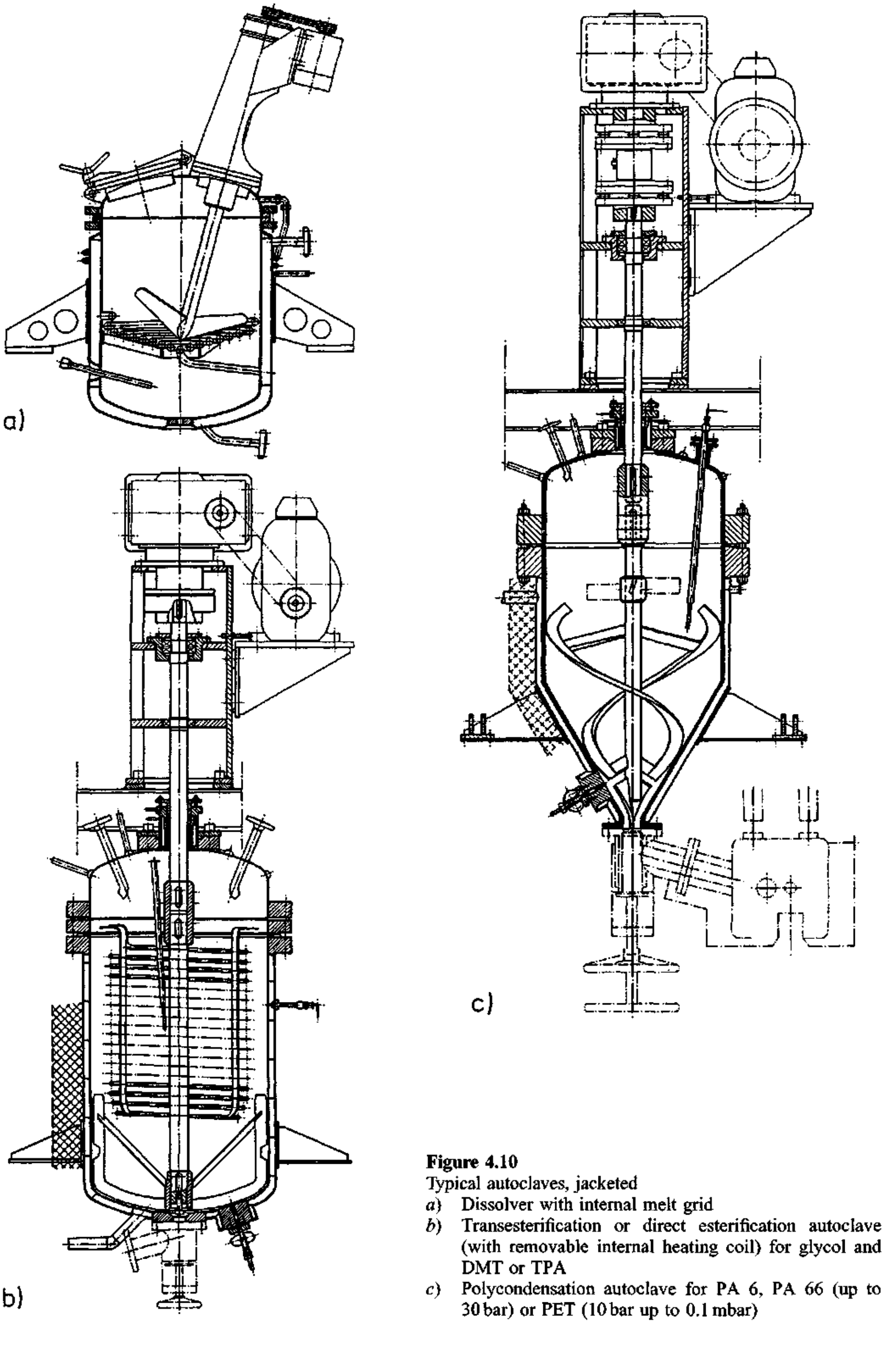


Figure 4.10
Typical autoclaves, jacketed
a) Dissolver with internal melt grid
b) Transesterification or direct esterification autoclave (with removable internal heating coil) for glycol and DMT or TPA
c) Polycondensation autoclave for PA 6, PA 66 (up to 30 bar) or PET (10 bar up to 0.1 mbar)

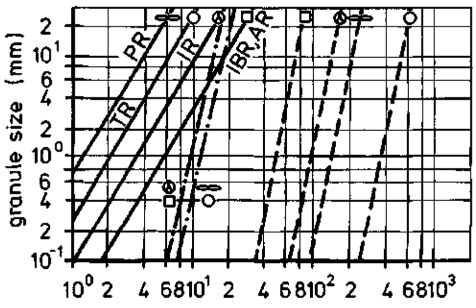


Figure 4.11
Optimum agitator conditions for dissolving solids [10]

PR	Propeller type stirrer
TR	Turbine type stirrer
IR	Impeller type stirrer
BR, AR	Blade and anchor type agitators
——	Power requirement (hp)
– – – –	Rotational speed (rev/min)
–·–·–	Mixing time (min)

powder entry. After this preparation the solution in the discontinuous process is pumped into one of two autoclaves for maturing and degassing in one and for transport of the finished solution in the other. In the continuous process one vessel is enough, but sufficient degassing and homogenization of the solution has to be ensured. If the dissolving process is exothermic and/or the solution is aging, the respective timing is important. These processes can be influenced by heating or cooling the corresponding vessels.

Mixing of Two Liquids

The mixing time can be calculated from $t = \tau \cdot V_{\text{liquid}}/Q_{\text{theor.}}$ with τ = proportionality constant, V_{liquid} = total mixing volume in the autoclave and Q_{theor} = theoretical capacity of the mixer [13].

The theoretical conveying of a propeller type agitator is for example $Q_{\text{theor}} = 0.4 \cdot n \cdot d^2 \cdot s$ ($s = n \cdot d \cdot \tan\theta$ and θ = angle of the propeller screw). For other agitator types the constants are in Table 4.2. The influence of the Froud figure ($Fr = w^2/g \cdot d$) can be considered by the exponent between -0.25 and -0.35; the influence of the Reynolds figure can be neglected for $Re > 10^3$ [13].

4.2.3 Pipes and Insulation

The exact calculations can be found in the literature [10, 11, 15]. Only some general indications are shown here as in Table 4.3 where the usual speeds of liquids or gases are shown. Figure 4.13 allows a general design of the "most economic" pipe diameter in the low viscous range [11]. To design cold or hot water or vapor pipes one can also refer to Table 4.4.

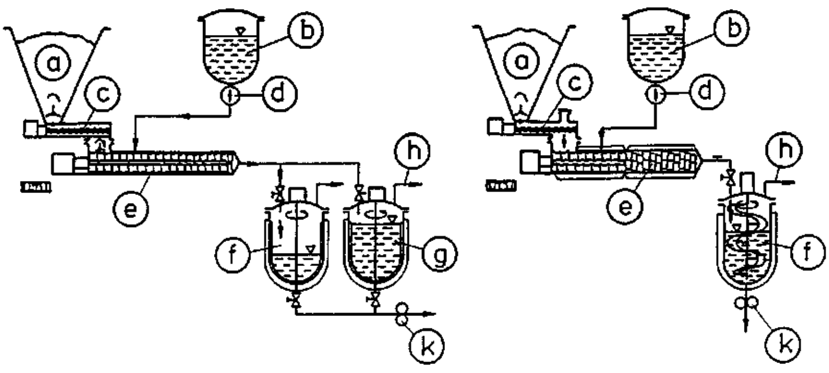


Figure 4.12 Equipment for discontinuous (left) and continuous (right) dissolution [12]

a) Storage bin for pre-weighed solids
b) Storage vessel for solvent
c) Dosing screw
d) Dosing pump
e) Mixing and (pre)dissolving screw
f), g) Receiver, dissolving and homogenization vessel
h) Degassing
k) Continuous discharge pump for removing solution

Table 4.2 Mixing Constant τ for Agitators

Type of agitator	τ	$Q_{theor.}$	
Blade agitator, $\theta = 90°$		$n\, d^2\, h\, \pi^2$	h = blade width
Turbine type agitator without stator		$n\, d^2\, h\, \pi^2 \sin\beta$	β = exit angle; g = slope
Blade agitator with tilted blade		$n\, d^2\, h\, \pi^2 \sin^k\theta$	θ = tilt angle $k = f(\theta)$; $1 \le k \le 2$
Propeller type stirrer	2,5 (constant)	$n\, d^2\, s$	$40° < \theta 90°$; $k \approx 2$ $\theta < 40°$; $k \approx 1$

Table 4.3 Flow velocities in pipes (also see Fig. 4.13)

Medium	Pressure	Density kg/m³	Velocity remarks m/s
Air, gases	10…500 mbar	1.2	4…10
Process air	8…10 bar	10…12	10…40
Compressed air	8…10 bar		15…40
Ventilation, climate	comfort		2…6
	industrial		4…8 (…12)
Vacuum			20…100
Water steam	saturated		20…30 (Table 4.4)
	superheated		30…60 (Table 4.4)
Cold water	1…4 bar	1000	1…2.5 (Table 4.4)
	suction		0.5…1.5 (Table 4.4)
Hot water		1000	1.2…3 (Table 4.4)
Dowtherm (Diphyl), liquid	1…2		1…2
	suction		0.5…0.6
Dowtherm (Diphyl), vapor			10…15
Polymer solution	3…10	≈1000	0.1…0.2
Polymer melt		700…1300	
(see also Figure 4.118)	≤1 bar		
	>100 bar		0.01…0.05
	in spinneret bore		0.05…0.1
			≤0.6

The first estimation of the insulation thickness for pipes with known outside diameter or for autoclaves with constant diameter using glass or rock wool and a painted or galvanized sheet can be done with Fig. 4.14. For significantly different heat transfer coefficients it is possible to multiply the insulation thickness with the ratio of the heat transfer coefficients.

4.2.4 Pipe Transport Systems for Granules, Powder, and Fibers

To discharge vessel wagons suction or pressure conveying systems are used; within a plant pressure conveying. Screw feeders are used for short distances for the quantities shown in Fig. 4.15. Pressure conveying systems have a higher inside pressure, have to be designed closely to avoid the sucking of room air and with inert gas or dry air can work over any distance.

The delivery air speed should be

$$v_{air} \ge 1.2\sqrt{\frac{2\,g\,V}{c_w F}\left(\frac{\varrho_G}{\varrho_{air}} - 1\right)} \approx 8 \cdots 14\,\mathrm{m/s} \qquad (4.5)$$

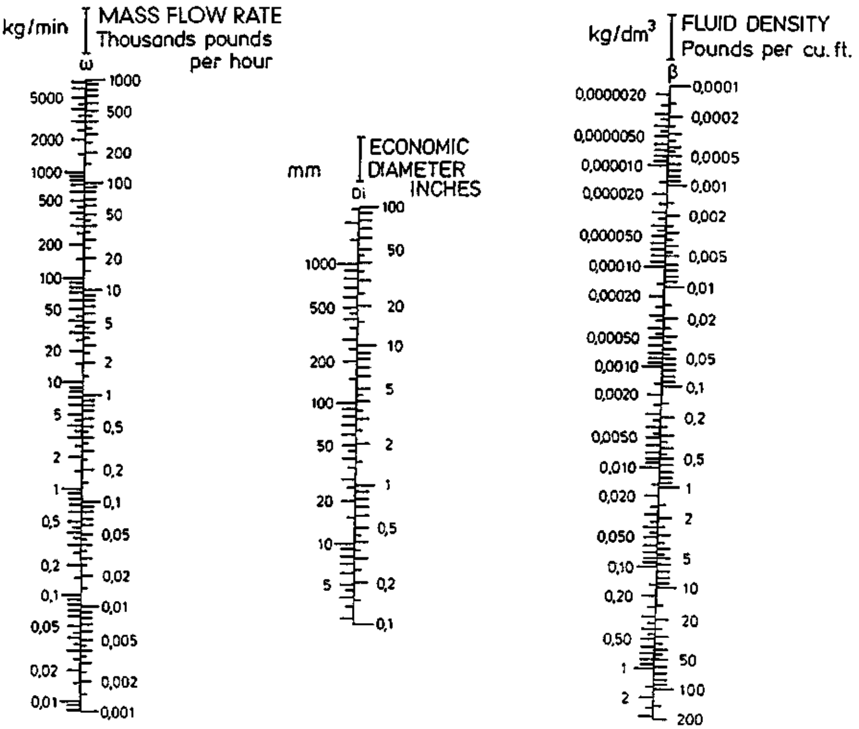


Figure 4.13 Nomogram for determining the most economical pipe diameter
$D_i = 6.37 \cdot w^{0.45} \cdot \gamma^{-0.31} \pm 10\%$
D_i in mm; w in kg/min; γ in kg/dm^3
Example: air 20 °C; $\gamma = 1.2$ kg/m^3; throughput = 10,000 kg/h; inside diameter $D_i = 520$ mm; air velocity $w = 10.9$ m/sec

The expression under the square root is equal to the floating speed (V granulate volume, F granulate cross-section transverse to the flow, ϱ density, index G for granulate). The resistance coefficient c_w depends on the Reynolds figure, which is for the usual chip size and 10 m/s gas velocity about 1500 (Table 4.5). The factor 1.2 is supposed to avoid the deposit of conveyed material in the system. During transport the chips spring irregularly from one wall to the other [18]. Too high gas velocity causes too much abrasion and also requires more blower power: With $\eta \approx 0.4$ the N_{fan} [kW] becomes $\approx 5 \cdot 10^{-6} \cdot V_{gas} \cdot \Delta p$; this is proportional v_{air}^3.

The pipe friction coefficient for the calculation of the pressure loss can be approximated to $\lambda = \lambda_{gas} \cdot (1 + 0.3 \cdot G/Q)$ with (G weight of chips, Q weight of conveyer gas).

The minimum amount of air for chip conveying is shown in Fig. 4.16.

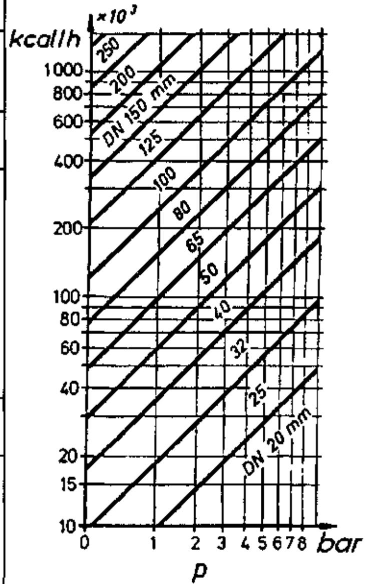
For the pneumatic transport of staple fibers one can approximate [20]: 0.35 kg fibers/m^3 air and 18...22 m/s air velocity inside the pipe.

Here suction operation is better because the staple fibers do not have to pass the fan wings and are not mechanically damaged; they are also not twisted, thus avoiding "braid" formation. A good opening of the fiber packages should be achieved by the appropriate preparation oil, possibly with the help of the transport air.

The feeding of the conveying material can be done with one of the systems in Fig. 4.15: The suction system requires a dual pipe that allows to suck the chips and the necessary air (left); gas pressure systems can work with rotary valves (a) or screw feeding (b) or with injector (c) [21].

Table 4.4 Pipe Dimensions for cooling water, hot water and vapor

Pipe table						Liquids		Steam
						Warm/cooling water	Hot water	
NW mm	*NW* inches	$D_{outside}$ mm	d_W mm	*O* m^2/m	*F* cm^2	*G* kg/h	*G* kg/h	
Average weight threaded pipes acc. to DIN 2440								
8	1/4	13.25	2.25	0.04	0.6	–	–	
10	3/8	16.75	2.25	0.05	1.2	–	–	
15	1/2	21.25	2.75	0.07	1.7	150	200	
20	3/4	26.25	2.75	0.08	3.4	400	500	
25	1	33.50	3.25	0.11	5.8	700	900	
32	$1^1/_4$	42.25	3.25	0.13	10.0	1 500	2 100	
40	$1^1/_2$	48.25	3.50	0.15	13.4	2 100	3 000	
50	2	60.00	3.75	0.19	21.6	3 900	5 500	
Seamless steel pipes. normal wall. DIN 2448								
32		38.00	2.50	0.12	8.6	1 500	2 100	
40		44.50	2.50	0.14	12.3	2 100	3 000	
50		57.00	2.75	0.18	20.8	3 900	5 500	
65		76.00	3.00	0.24	38.5	7 800	10 000	
80		89.00	3.25	0.28	53.5	12 500	18 000	
100		108.00	3.75	0.34	79.3	21 000	30 000	
125		133.00	4.00	0.42	122.7	38 000	50 000	
150		159.00	4.50	0.50	176.7	62 000	85 000	
200		216.00	6.00	0.68	326.9	38 000	189 000	
250		267.000	6.50	0.84	506.72	245 000	335 000	



NW = nominal pipe size; $D_{outside}$ = outside diameter; d_w = wall thickness; *O* = surface; *F* = cross-sectional area; *G* = flow rate

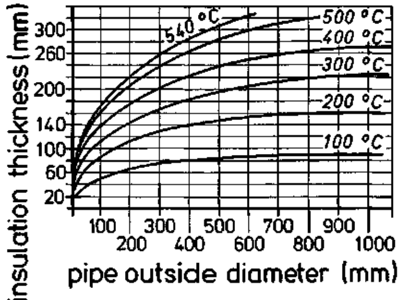


Figure 4.14
Approximate economical insulation thickness for pipes and vessels having a thermal conductivity of $k \approx 0.06$ kcal/m · h K

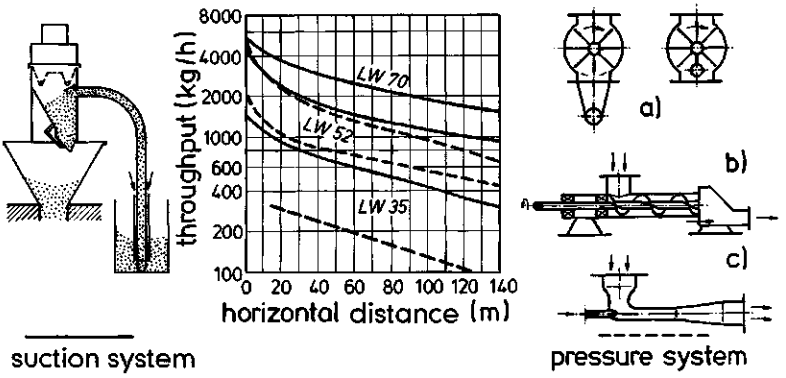
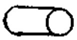


Figure 4.15 Mass throughput of suction (——) and gas pressure conveying pipes (– – –) for coarse-grained powder and granulate, and schematics of the feeding stations: Suction system with suction nozzle (left).
Pressure systems: *a*) Rotary valve
(right) *b*) Feeding screw
c) Injector

Table 4.5 Air Resistance of Chips ($10^3 < Re < 5 \cdot 10^4$)

Chip shape	D/L	c_w	$v_{floating}$ m/s
	Circular cylinder 1 : (1 . . . 2.5)	≈0.9	≳9 for PET
	Sphere	≈0.45	≳7.8 for PA
	Flat ellipsoid 1 : 2	≈0.6	≳6.4 for PP
	Cube 1 : (1 . . . 2)	≈1.2	≳9 for PET
	Fiber 1 : (400 . . . 3000)	≈1.0 . . . 5	Individual: ≳1 bundle: > 10

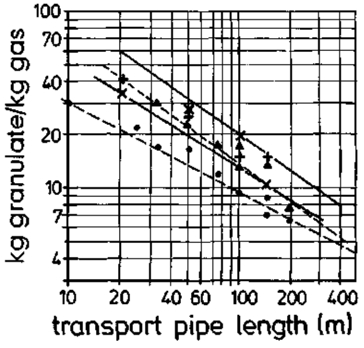


Figure 4.16
Air or transport gas requirement for chip feeding in pipes of 25 . . . 100 mm nominal diameter

4.3 Strand Casting and Cooling, Granulating

The polymer melt or powder is first cast in strands or a ribbon to change it into a form that can easily be transported, stored and granulated.

4.3.1 Strand and Ribbon Casting

For casting an extrusion head is attached to the discharge end of the polycondensation autoclave or the continuous plant [22] (Fig. 4.17). It is heated to the necessary temperature that does not have to be equal to the autoclave temperature. Often the casting head also contains a lower stop valve (2) of the autoclave (1) that is closed during the reaction and may have to be pressure and vacuum proof, possibly to two sides, depending on the reaction conditions. The valve can be operated by hand (3) or by motor (4) or pneumatically. The stuffing box (5) has to be designed for the extrusion pressure, e.g., for N_2-extrusion for 12 or 25 bar and e.g. 320 °C. The inner coat hanger shape of the melt room and the hole plate (7) cause an equal pressure distribution and extrusion rate through the casting die (8). In spite of this it is possible to have diameter variations of up to about ±20%. To avoid for the stringths to stick together the distance between the holes should not be less than 17 mm for 9 mm diameter holes and a wire of 4...2.5 mm diameter (Fig. 4.18).

Additional Equipment for the Casting Head:

- To avoid a cooling down, especially of the hole plate, during the non-extrusion times it is possible to add an insulation cap, possibly swivel mounted and/or heated electrically. For the vacuum proof version this provides added safety for the stop valve.
- Hole plates with different bore lengths to even out the pressure over the extrusion width.
- Hydraulic quick changers for the casting-extrusion set [23]. A standby set arranged on rails along the casting head is pushed from a preheating chamber over hardened tightening plates into the working

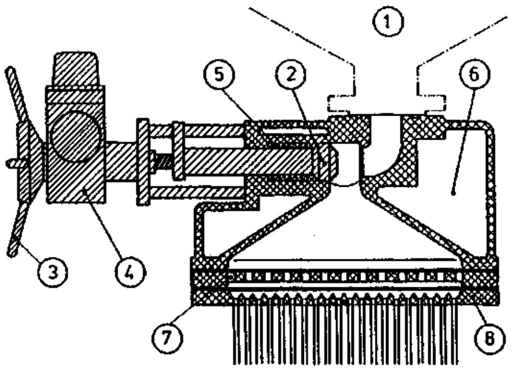


Figure 4.17
Strand casting head for melt (Automatik [22])
1) Connection flange on reactor
2) Stop valve, sealed by a cone to both sides
3) Hand or motor drive for item 2
4) Worm gearbox
5) Stuffing box
6) Heating chamber
7) Perforated plate
8) Casting die

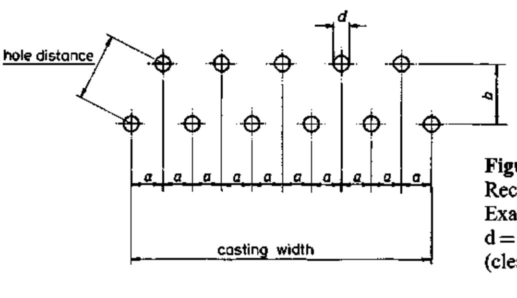


Figure 4.18
Recommended hole layout of a strand extrusion die [22]
Example:
d = 8 mm, a = 10 mm, b = 20 mm; hole spacing 22.4 mm (clearance between strands: 14.4 mm)

position while pushing out the set that is to be exchanged (very seldom). The changing time for continuous plants should not exceed 3 ... 5 s; for autoclaves 2 ... 3 min are acceptable.

- Casters for low viscous polymers ($\eta < \approx 1000\,P$) can be stopped from the inside with an eccentric rotating rod in front of each row of holes during the final emptying so that no more "fibers" exit the individual holes that later wrap around the feed rolls and rotor knives of the granulator [22]. This also avoids air entry into the melt distributor and thus lowers oxidation and degradation inside.

Ribbon casting from a die similar to Fig. 4.19 is outdated, but provides a large capacity, e.g., for 4 × 500 mm die cross section and 30 m/min casting speed about 5000 kg/h. The alternating pressure adjusting and tractor screws (12) allow the setting of the thickness adjusting plate ("lip") (11) to receive a ribbon of uniform thickness. This is cast onto a large polished drum that then dips into a cooling water bath that has to be designed for sufficient cooling time [24].

4.3.2 Ribbon and Strand Cooling

Due to the low heat conductivity and the relatively large cross dimension (of several mm) cooling is only done with water. The melt is guided into it after only a few cm air distance. The water cooling can be approximated according to Fig. 4.20, assuming that the polymer surface soon after dipping into the water falls below the solidification temperature (usually $< \approx 180\,°C$):

$$Q = Q_1 - Q_2 = G \cdot (c_1 \cdot T_1 - c_2 \cdot T_2 + S) = \alpha \cdot F_M \cdot T_M \quad (4.6)$$

with $F_M = d \cdot \pi \cdot l_2$ and $T_M = (T_1 - T_2)/\ln(T_1/T_2)$

$$Nu_M = 0.057\, Re^{0.78} Pr^{0.78} = \alpha_M \cdot l_2/\lambda_{bath} \quad (4.7)$$

For cooling water of 20 ... 30 °C follows $\alpha \approx 1390\, v^{0.78}/l_2^{0.22}$

For the usual large quantity of polymers follows:

$$G[\text{kg/h} \cdot \text{wire}] \approx 5210(v \cdot l_2)^{0.78} \cdot d \quad (4.8)$$

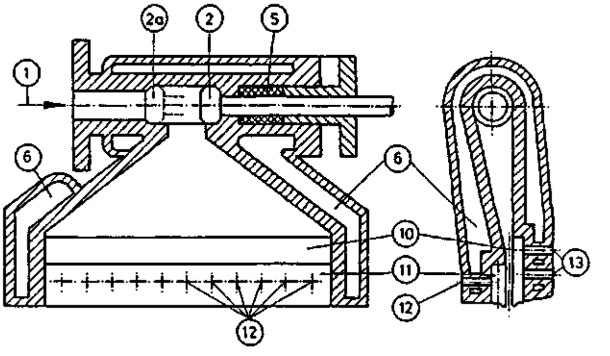


Figure 4.19
Ribbon casting die for polymer melt
1) ... *6)* as in Figure 4.17
10) Wear plate
11) Thickness adjusting plate
12) Pressure adjusting and tractor screws, alternating

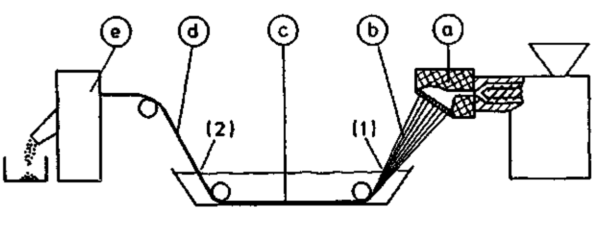


Figure 4.20
Schematic for calculating strand cooling, showing extrusion, cooling and chip cutting regions.
a) Strand casting head
b) Air path (region 1)
c) Water path (region 2)
d) Air path (region 3)
e) Chip cutter
1) Strand enters water
2) Strand exits water

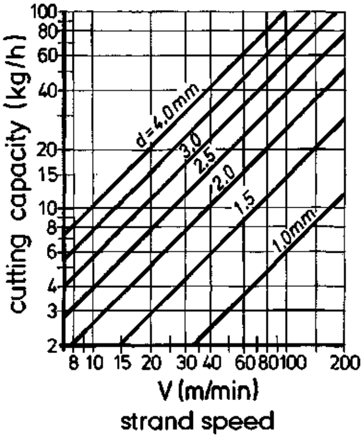


Figure 4.21
Granulator cutting capacity per strand of round cross-section PET having $\varrho = 1.36\,kg/dm^3$; for other polymer, $G = C$ (from diagram) $\cdot \varrho/1.36$. (d = strand diameter)

This results for 2 m bath way and 2 m/s relative speed $G \approx 38$ kg/strand × h or for 4 m/s $G \approx 66$ kg/strand × h. Figure 4.21 shows such an evaluation for PET.

The necessary solidification time can also be calculated in a different way [28]: Under comparative cooling conditions it is proportional to d^2 (for filaments this is equivalent to dtex), resulting in:

$$z_E = a \cdot d^2 \cdot (T_0 + b)/(c - T_K) = A \cdot d^2 \text{ for round rods}$$
$$\text{respectively} = 2.5 \cdot A_p \cdot s^2 \text{ for plates} \tag{4.9}$$

with z_E as the solidification time [min], d the wire diameter [mm] respectively s the thickness of the plates [mm], T_0 melt temperature [°C], T_K cooling medium temperature, a, b, c, A constants, ΔH heat content [kcal/kg], ΔH_S melting heat [kcal/kg]. From this follow the values in Table 4.6. With them it is possible to calculate the cooling time of 2.25 s for a PA 6 strand of $d = 2.5$ mm; at a take-up speed of 60 m/min this is equivalent to a wet cooling way of 2.25 m.

The here used strand temperature however, is only the average over the cross-section, and the air way following the water-cooling (2 to e in Fig. 4.20) serves to even out the temperature, and it normally has to be longer than the water cooling way, because the hot wire core only cools down to half the melting temperature after 1 ... 2 m water cooling way. Figure 4.22 shows the curves for the strand surface and the center temperature.

4.3.3 Granulating

To granulate the strands or ribbons the following chip cutting methods (GA) are available for the respective polymers; the mentioned chip forms and sizes are dominant (Fig. 4.23):

Table 4.6 Solidification Time of the Core T_e for Round Rods and Plates made from PA 6 and Other Crystallizing Polymers, as a Function of Diameter D and the Ribbon Thickness s [28]

Polymer	T_K (°C)	T_O (°C)	ΔH (kcal/kg)	ΔH_s (kcal/kg)	t_E [min] Round Rod D	Plates s	Plates, cooled on one side s
PA 6 [43]	20	240	150	20	$0.006 \cdot D^2$	$0.015 \cdot s^2$	$0.03 \cdot s^2$
Polyformaldehyde [28]	20	190	100	39	$0.0075 \cdot D^2$	$0.018 \cdot s^2$	$0.036 \cdot s^2$
Polyethylene 0.945 [16]	20	232	173	58	$0.008 \cdot D^2$	$0.02 \cdot s^2$	$0.04 \cdot s^2$
Polypropylene [16, 33a]	20	260	160	26	$0.01 \cdot D^2$	$0.025 \cdot s^2$	$0.05 \cdot s^2$

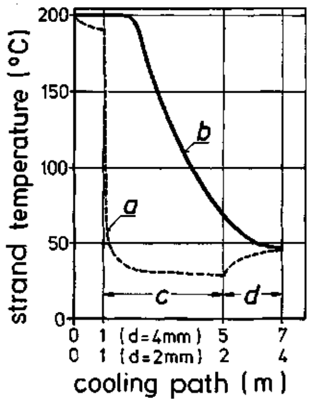


Figure 4.22
Cooling of plastic strands in water (d = 2 ... 4 mm, take-up speed 15 m/min)
a) Strand surface *c*) Water cooling path
b) Strand center *d*) Air cooling path

- Air pelletizing: The melt is chopped off hot as it exits from a multi-hole die and then falls into a water stream.
- Air-water pelletizing: The hole plate is attacked with water at the exit side and the solidifying melt is chopped off.
- Underwater pelletizing: The stringths are drawn into water and are cut in the water.
- Cold pelletizing: The strands are cooled in water, taken up, predried with blowing air and granulated.

The following granulating machines are used for this:

- Strand pelletizers with tape cutting: The ribbon (*a*, Fig. 4.24) is first divided into tapes by combing tape cutting drums; the tapes are then cut by a rotating chip cutting drum (*c*) into rectangular chips (*d*) [8].
- Strand pelletizers with saw tooth cutting drum (Fig. 4.25): The ribbon is fed in a 45 ° angle to the cutting drum that strikes the ribbon with the saw tooth shaped profile into the stator knife, creating rectangular chips [27].
- Dry pelletizers (Fig. 4.26): The strands (*a*) are drawn in by feed rolls and are chopped between the stator knife (*b*) and the rotary knife to cylinder chips (*d*). To muffle the noise a sound protection cover is absolutely necessary [22, 8, 27 and others].

  The feeding roll, the pressure drum, the rotary knife and the stator knife are subject to much wear and must be easy to exchange and always in stock for this reason. The length of the chips is determined by

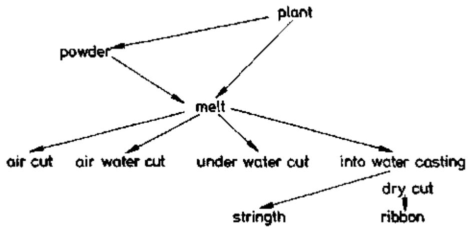
  $$L_{\text{chips}} = v_E \cdot 1000/R_n \cdot Z \text{ [mm]} \tag{4.10}$$

  with v_E [m/min] draw in speed, R_n [rpm] rpm of the rotary revolution and Z the number of teeth in the rotary knife circumference.

  The cutting production rate per strand follows (Fig. 4.21)

  $$G \text{ [kg/h]} = 0.25 \cdot d^2 \text{ [mm]} \cdot \pi \cdot v \text{ [m/min]} \cdot 600 \cdot \varrho \text{ [g/cm}^3\text{]} \tag{4.11}$$

  To feed the strands evenly and at a 90 ° angle into the pelletizer, the pressure drum in the feed is coated with soft rubber (Fig. 4.26a). Thus it can easily adjust to the slightly varying strand diameters [26].
- Underwater pelletizers (Fig. 4.27): The strands coming from the casting die fall into the water stream that enters from the slots (2 and 3) and are drawn with it over the cooling grooves (4) down into the draw-in rolls (5); then they are cut between the stator knife (8) and the rotary knife (7). At (9) more cooling water is added to keep the rotary knife clean and float away the chips (10). Other functions are as in the dry pelletizer. All parts working in water have to be made from stainless steel. According to [22] the materials in Table 4.7 are recommended to achieve the mentioned throughput.



	Hot Pelletizing		Cold Pelletizing	
typical for	PVC	LDPE PP	PA PET	PVC PET PA 66
Chip shape	Lens		Cylinder	Cuboid
Dimensions (mm × mm)	(2.5 . . . 3.5)∅ × (2 . . . 3)		(1.5 . . . 3)∅ × (2 . . . 3)	(3 . . . 5)2∅ × (2 . . . 3)
mainly	3∅ × 2.5		2.5∅ × 3	4 × 4 × 2.5

Figure 4.23
Different pelletizing systems and characteristic data for various polymers

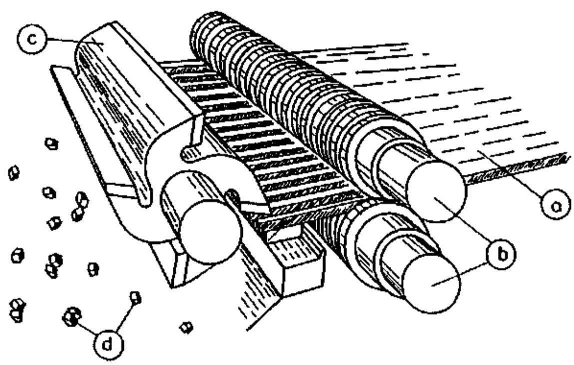


Figure 4.24
Ribbon pelletizing machine: Tape cutting process (Condux [8])
a) Polymer ribbon (tape)
b) Pinch rolls, combing
c) Rotary chip cutter
d) Cuboid chips

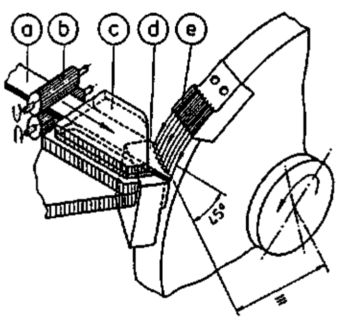


Figure 4.25
Ribbon pelletizing machine: saw tooth cutting process (Dreher [27])
a) Polymer ribbon, direction 45 ° to the rotor axis
b) Delivery rolls
c) Ribbon guiding shoe
d) Stator knife with saw teeth
e) Rotary knife with saw teeth, combing with d)

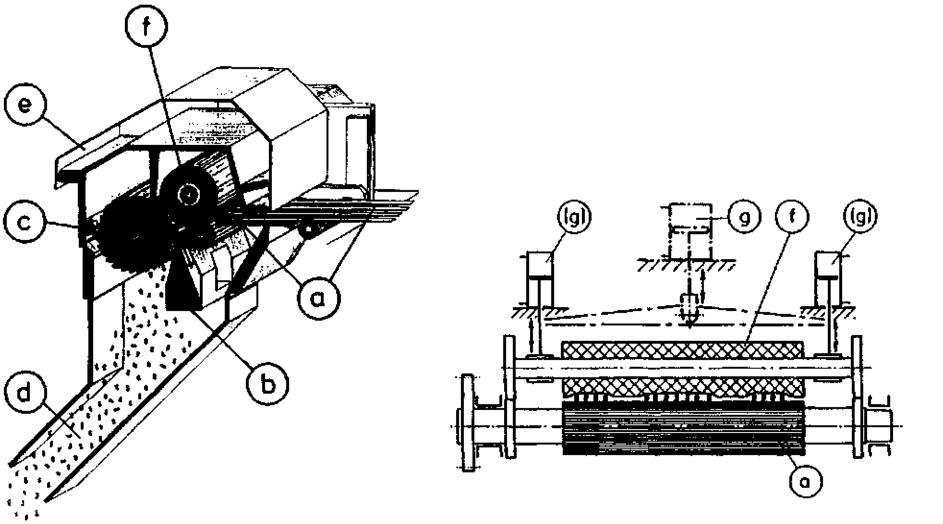


Figure 4.26 Dry type strand chip cutter (Automatik [22]) and soft (rubber coated) pressure roll for strands of different diameters

a)	Strand inlet	*e*)	Sound insulation housing
b)	Stator knife	*f*)	Soft rubber pressure roll
c)	Rotary knife (spiral)	*g*) or (*g*)	Pneumatic pressure system for f) (central or parallel)
d)	Cylindrical chips		

Table 4.7 Knife Materials used on an Underwater Chip Cutter, and their Lifetimes [22]

Product on USG 600	Process	Materials		Lifetime	
		Rotor	Stator	Rotor	Stator
PA 66	Discontinuous	Stellite cutting edges	=	2900 t	800 ... 900 t
PA 6	Continuous	Ceramic		6 ... 18 months	6 months
PET	Discontinuous	Stellite cutting edges	HM	1600 ... 2600 t	600 ... 1600 t

All polymers contain 0.3% TiO_2; HM = hard (cutting) metal

4.3.4 Cutting Forces [29], Drive Powers

Due to the high number of parameters and dependencies the calculation of the cutting forces is so complicated that only linearized functions will be considered here, resulting in possible deviations of $\pm 10\%$. With the terms of Fig. 4.28 and

- chip dimensions: width b, length l, thickness h,
- knife geometry: slot a, rotary drum radius R, cutting angle δ, blade angle β,
- kinetics: rotor surface speed v, blade track radius R, the force becomes

$$F_X = k_X \cdot x \qquad \text{with } x = b \text{ or } l \text{ or } h \tag{4.12}$$

and k_X from Table 4.8. The individual forces are quite small due to the small chip dimensions and only by the summation of several thousand cuts/min × cutting speed do they reach the magnitude of the drive power for chip cutters as evaluated statistically in Fig. 4.29.

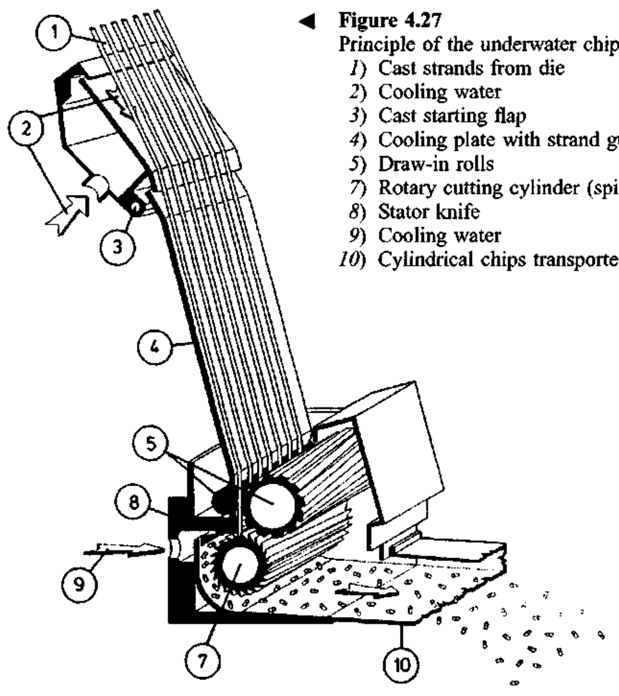


Figure 4.27
Principle of the underwater chip cutter (Automatik [22])
1) Cast strands from die
2) Cooling water
3) Cast starting flap
4) Cooling plate with strand guiding grooves
5) Draw-in rolls
7) Rotary cutting cylinder (spiral)
8) Stator knife
9) Cooling water
10) Cylindrical chips transported by the cooling water flow

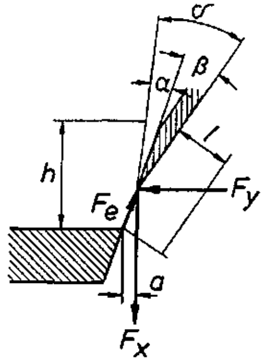


Figure 4.28
Definition of cutting forces and cutting geometry [29] (simplified)

4.3.5 Mechanical Chip Dehydration

With increasing capacities the original centrifuges have been replaced by continuous cascade centrifuges. Then the water drainage in the wet chip storage tanks sufficed because the drying time only increased negligible by the remaining surface water content. For today's production quantities—100 t PA/24 h contain about 10 t water, requiring 20 t steam for drying—mechanical predehydration is done again.

The most simple strand predehydration is shown in position (*c*) in Fig. 4.32: The water is extracted by a vacuum station; it can also be blown back with a pressure airflow opposite the strand running direction.

A continuous baffle dewatering [22] is shown in Fig. 4.30: The chips (a) float in from an underwater granulator, are caught by the highly compressed air from the jets (b) and moved on. At the baffle sieves (*c*) the water is thrown to the outside. At 800 mm width a throughput and residual humidity as in Table 4.9 are achieved.

The centrifugal chip dehydrator (Fig. 4.31, [23]) first separates at (1) the coarse agglomerates and a portion of the water, while the chips flow through the pipe (2) into the centrifuge (3, 4), where they are dewatered and then moved on from (E). The achievable residual humidity is similar to baffle dewatering.

4.3.6 Granulators

For autoclave polycondensation plants the extrusion and chip cutting times for most polymer batches are in the magnitude of 15 ... 40 min. Since the polycondensation cycle for PET and PA 66 is between 2 and 6 h, one movable granulator can be assigned to 4 to 6 polycondensation units. For PA 6 one granulator can be assigned to about 12 to 16 autoclave polymerization units. For 4 or more polycondensation rows at least one reserve granulator should be available.

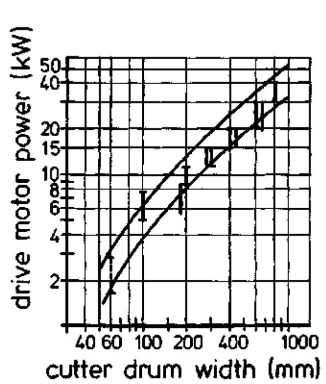


Figure 4.29
Drive motor power N of typical dry chip cutters as a function of the cutter drum width

Table 4.8 Chip Cutter Knives: Constants for the Cutting Force Calculation [29]

Material	Influence of					
	Edge width k_b N/mm	Edge length k_l N/mm	Edge height k_h ($h \leqq 10$ mm) N/mm	Cutting angle $\delta = 35°$ N/mm	Edge distance k_a N/mm	Rotor speed $k_r < 20$ m/s N/mm
PE	0.8	50	150	0.08	−40	50
PVC, soft	0.55	30	150	0.06	−30	0
Rubber	0.175	7.5	150	0.015	0	0

Much more efficient are the units for the continuous production, but they only allow very brief interruptions, e.g., for casting head changes or knife changes. To practically exclude any periods of disuse respectively limit them to the transfer and start-up times, it is possible to work from (large) polycondensation plants via a three way valve into two pelletizers and predewatering units, each of which has to be able to accommodate the full capacity.

For continuous polycondensation spinning plants often bypass pelletizers are necessary if the melt producing unit has to continue working at constant capacity to ensure melt homogeneity and quality. The melt quantity resulting from capacity changes in the spinning plant is then diverted to the pelletizer. Thus stopping 8 positions in a spinning beam can already require the chip cutting of about 10 stringths.

A simple chip cutting plant is shown in Fig. 4.32 between the extrusion head (a), passed the cooling bath (b), pre-dewatering (c) to the dry stringth cutter (e).

The chips produced here are either packed or moved on pneumatically. Table 4.10 shows the typical process data [22].

A complete underwater granulator with a strand quenching and cutting device according to Fig. 4.27—the angle of the cooling groove is variable—is shown in Fig. 4.33. During start-up the strands can be dropped into a waste container by tilting up the quench water entry; the pre-dewatered chips (from a plant similar to Fig. 4.30) falls onto a vibrator sieve to sort out lumps and too long chips; the quench water is recycled over a sieve band filter, possibly cooled and then re-entered into the cooling circle. The production and process data are shown in Table 4.11 [22].

An exactly defined strand take-up speed with guidance through the quench water is achieved by a system according to Fig. 4.34 [23]: The strands from the casting head (1) are cast onto a transport belt that is running in water, and they are then taken up at its end by take-up drums (5) while sucking off the surplus water (8). The upper mesh wire support ribbon holds the strands on the transport belt.

Another unit with defined die take up is shown in Fig. 4.35: The strands are cast onto a casting wheel (c) that is sprayed with water; they then moved to the cooling groove (d) with water spray and dewatered by suction at (e), cut in (f) and moved on pneumatically [24].

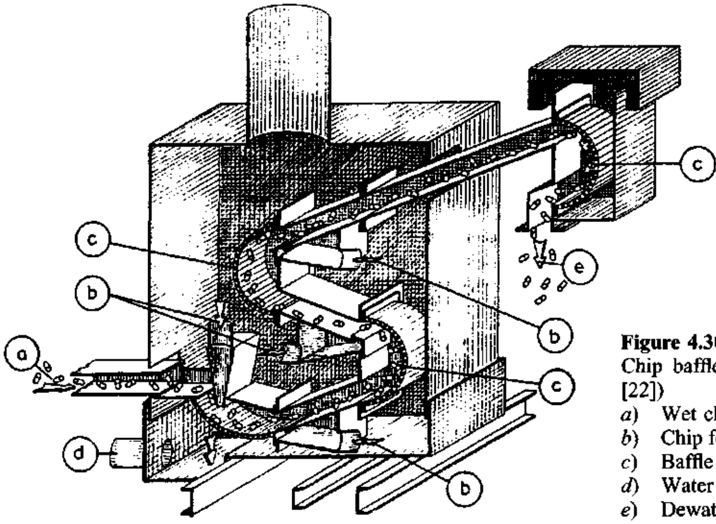


Figure 4.30
Chip baffle dewatering device (Automatik [22])
a) Wet chips
b) Chip feeding air from high pressure fan
c) Baffle sieves
d) Water drain
e) Dewatered chips

Table 4.9 Production Throughput of the Chip Baffle Dewatering Device [22] shown in Fig. 4.30: 800 mm Width

Polymer	Chip dimensions mm	Throughput kg/h	Residual moisture %
PA 66	2 × 2.5 × 3 to 3 × 4.8 × 4	6260	0.4
PET	2 × 2.5 × 3 to 2.5 × 4 × 4	6890 7590	0.2
PET-elastomer	2 × 2.5 × 3 to 2.5 × 4 × 4	4760 5890	0.4
PA 6 after extraction	2 × 2.5 × 3 to 2.5 × 3 × 3	5890 5660	0.5

For cooling to spinnable chips only purest water (at least completely desalted) may be used to avoid residues on the chips.

4.3.7 Chip Production from Powder

Polymerization products usually are in the form of a powder, and they are normally transformed to chips [30]. Throughputs of up to 30 t/h are quite usual. For PP this thermal treatment can be combined directly with a planned degradation (curve A in Fig. 2.70). For this double screw extruders with combing screws are used in an one step process. Screw diameters of 2 × 170...2 × 360 mm can process capacities of 4...7 to 18...28 t/h polypropylene with a drive power of 1500...7000 kW, Table 4.19. For homogenizing they are also equipped with kneading disks and work against gear pumps [32, 33]. For the filtration large candle filters are used [33].

The melt is transformed with hot cut underwater pelletizers [31] that have special starting valves to avoid a freezing of the melt in the bores. Figure 4.36 shows it in the open position: The melt comes in at *b*, and for processing the knife head with the drive is moved against the extrusion plate. Not until the starting of the water supply the bores receive the full throughput. Water supply, throughput and

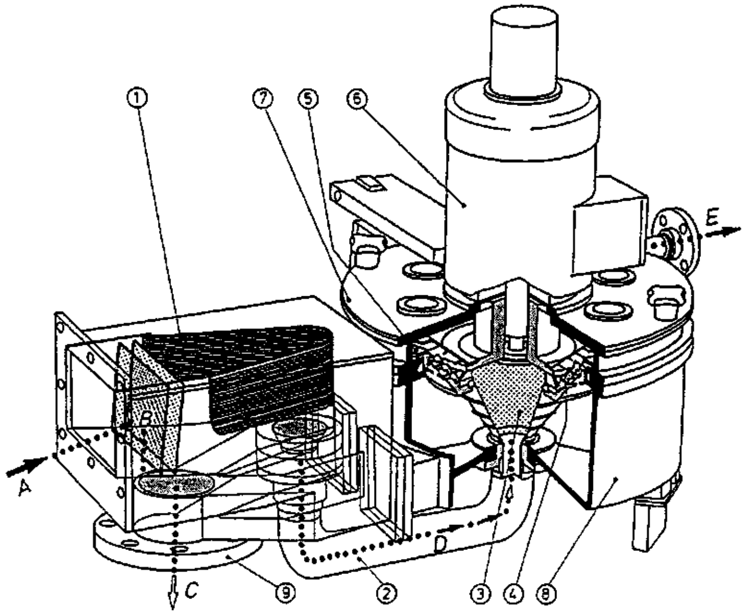


Figure 4.31
Centrifugal chip dewatering device (Scheer [23])
1) Compactor with agglomerate separator
2) Inlet pipe
3) Presieve
4) Chip dewatering basket
5) Chip receiver
6) Motor
7) Cover with lifting device
8) Housing
9) Water drain connection
A) Chip/water slurry from cooling zone
B) Agglomerates
C) Water drainage
D) Pre-concentrated chip/water slurry
E) Dewatered chips

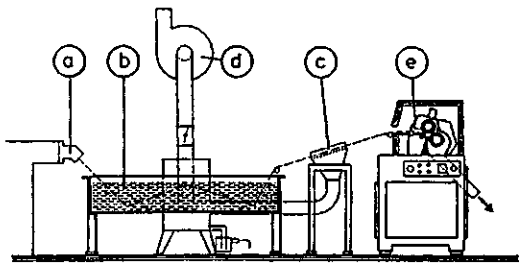


Figure 4.32
Strand casting, quenching and dry strand cutting plant (Automatik [22])
a) Casting die
b) Water quenching bath
c) Removal of surface water
d) Water separation and suction fan
e) Dry strand cutter with sound insulation housing

Table 4.10 Process Data for Strand Cutters [22]

Chip dimensions (∅ × height) mm	Product	Process data: Length of the water bath m	Water temperature °C	Air path m	Specific strand throughput kg/strand/h	Chip residual moisture w/w %	Plant data ASG 300[2)]: max. no. of strands	Drive power kW	Suction fan power kW	ASG 600[2)]: max. no. of strands	Drive power kW	Suction fan power kW
2.5 × 3	PA 66					0.3% without reaction water	60	15	7.5	128	22	
2.5 × 3	PA 6[1)]	5	40 ··· 50	5.5	25		60	15		128	22	
2.5 × 3	PBT	8		4	50		60	15	7.5	128	22	22
	PET	8	25 ··· 55	4	50		60	15		128	22	
	PP						60	15		128	22	

1) after dewatering 2) Type of strand cutter of Automatik [22]

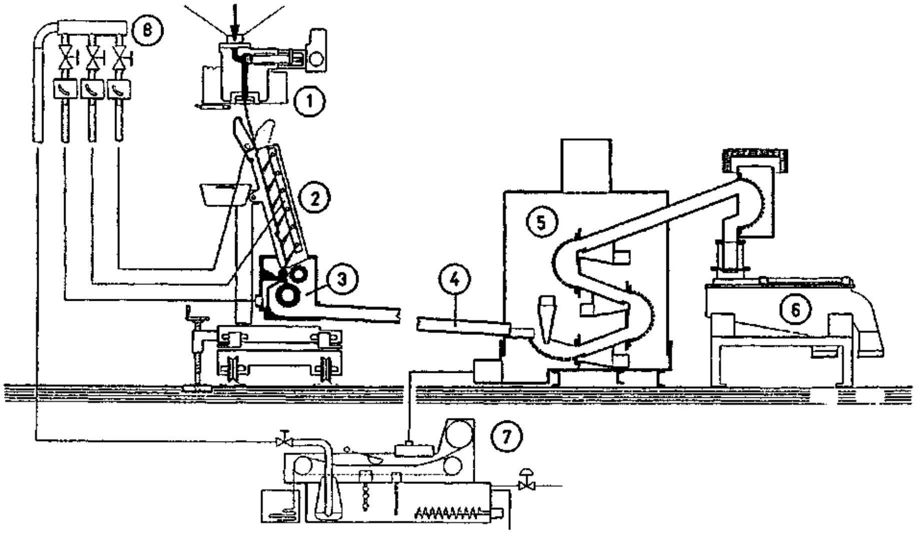


Figure 4.33 Underwater pelletizer (Automatik [22]) of low height design
1) Strand casting
2) Quenching and guiding device
3) Underwater strand pelletizer
4) Secondary strand cooling (in water)
5) Chip/water separator (baffle dewatering)
6) Vibrating sieve
7) Quench water sieve belt filter
8) Water distribution

Table 4.11 Process Data for Underwater Chip Cutters [22]

	PA 66	PA6 after extraction	PET/PBT	PP
Machine type	USG/H	USG/H	USG/V and USG/H	USG/H
Viscosity range [P]	700...2500	800...3000	800...5000	*MFI* 200–5: 10–200
Maximum production (per strand and h) [m/min]	100/150	45/110	120/170	35/90
Maximum number of strands: for USG 600	60	60	66	60
Chip dimensions [mm]	(3 × 4) × 4 long	(2.5 × 3) × 3 long	(2.5 × 4) × 4 long	Diam. 3 × 3
Melt temperature [°C]	280	260	280	230
Length of the guiding groove [m]	3	4	1.5/2	≧6
Cooling time after cutting [s]	6	–	6	–
Chip temperature after drier [°C]	< 80	< 80	< 60	< 50
Residual moisture [w/w %]	< 0.3 without reaction water	–	< 0.2%	< 0.05%
Water flow rate [m³/h]	30	32	25...30	30...35
Water temperature [°C]	< 30	< 20	< 25	< 25
Chip cutter drive power [kW]	22	15	22	
Dryer fan power [kW]		–	22	

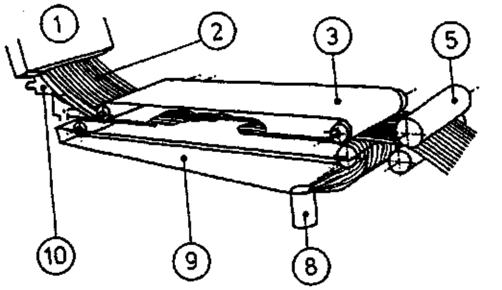


Figure 4.34
Strand take-up with complete guidance during quenching (Scheer [23])
1) Casting head
2) Extruded strands
3) Clamping conveyor belt
5) Clamping take-up drums
8) Dewatering
9) Casting and transport conveyor belt
10) Start of cast waste removal

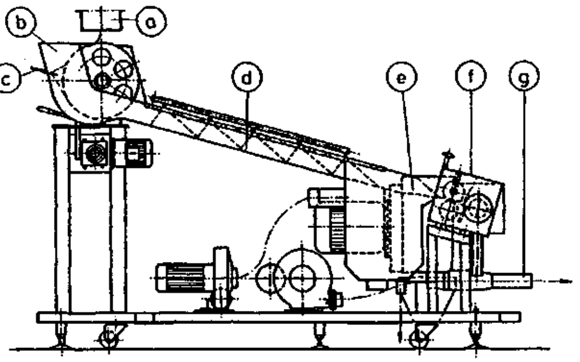


Figure 4.35
Strand cutting with defined take-up from die [24]
a) Casting head
b) Casting wheel
c) Water spraying
d) Cooling groove with water spray
e) Dewatering suction
f) Strand cutter
g) Pneumatic chip transport

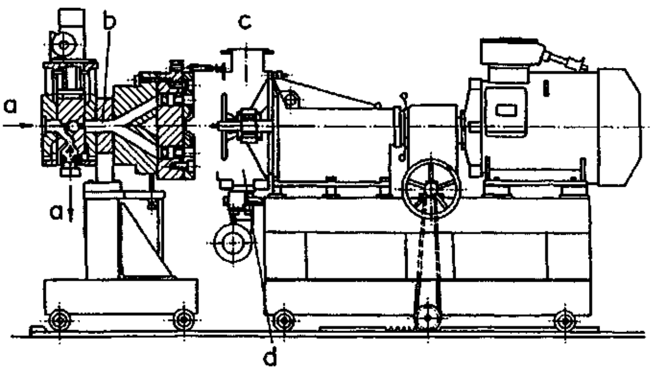


Figure 4.36
Underwater pelletizing of polypropylene with starting valve [93], cutter housing, (opened) and starting valve in open position
a) Starting product
b) Melt supply to die
c) Quench water supply
d) Chips in the water stream

changing have to be coordinated very exactly with respect to time and quantity. The chips are lens shaped with a diameter of about 4...5 mm × 3 mm thickness and are floated away with the quench water and are then separated from the water. The residual humidity is <0.05%.

4.4 Initial and Intermediate Products, Final Products: Delivery Conditions and Storage

Depending on location of the fiber production relative to the raw material suppliers and its customers, storage and warehousing can require a significant magnitude. For spin chip quantities see Table 4.16. Small quantities are delivered in bags or barrels; Table 4.12 shows delivery forms for larger quantities as well. It is recommended to make long term contracts with suppliers.

Table 4.12 Raw Material Delivery Modes

Material	Solids	Liquid		Barrels	ISO containers	Container wagons	Tank trucks
	Bags (for salt or chips)	Molten	Pure or in solution				
Caprolactam	●	●		●		●	
AH salt	●		●			●	
DMT	●	●		●		●	
TPA	●				●	●	
ACN			●				●
Glycol			●	●			●
PA, PET, PBT, PP-chips	●					●	●
PAN powder	●					●	●
PAN solution			●				

4.4.1 Shipping Forms, Packaging

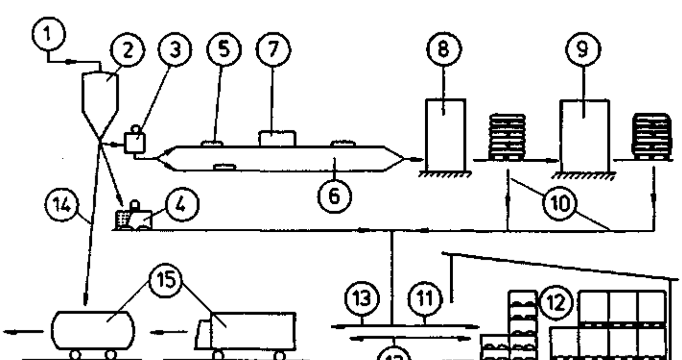
Dry materials are usually shipped in coated multi-layer bags with 20 to 40 kg or in barrels with inserted polyethylene bags with 100 or 200 kg contents. Liquids are shipped in barrels of 200 l volume.

Large volume users obtain powder or chips with special trucks, railroad cars or overseas containers.

If the distance is not too far, DMT and caprolactam can be shipped in melted state in heated and insulated special railroad cars as dissolved AH-salt, or via pipelines. The about 40% water content to the AH-salt make the transport quite expensive, but so it does not have to be dissolved again. If the initial products are not pumped directly into the further processing, intermediate storage have to be provided, possibly with mixing abilities to achieve better average uniformity.

The necessary reserve storage times depend on the local conditions: In countries with limited infrastructure there must be at least a stock for 2...4 months, while in industrialized countries with continuous delivery agreements 2...4 weeks should suffice. For PET production from DMT and glycol an intermediate storage possibility for contaminated methanol and glycol needs to be provided unless it can be pumped into railroad cars to be transported into outside or own recycling plants.

The packing and shipping possibilities for salts, powders and chips are shown in Fig. 4.37 [34].



1) Bulk material supply
2) Bulk material storage
3) Bagging
4) Filling containers
5) Packed bag
6) Transport of bags
7) Individual bag shrink-wrapping
8) Packing of bags onto pallets
9) Shrink-wrapping of pallets
10) Transportation of pallets
11) Storage
12) Storage of parcels
13) Shipping; Loading of parcels
14) Filling of bulk material into tank trucks
15) Transport to user

Figure 4.37 Material flow sheet—powder or chips [34]

Figure 4.38
Outside storage area of a PET staple fiber plant with integrated continuous polycondensation (*Fourné*, 1963/64, Japan)

The shipping volumes for the finished products become much larger: A 20 kg POY bobbin requires about 60 l packing volume; this requires for a yarn production of 10 t/24 h almost 1000 m^3/month cardboard cartons that have to be sorted and stored by yarn type and titer. 10 t/24 h staple fiber or tow in pressed 400 kg bales require about 800 m^3/month depot volume, again sorted by titer, staple length, and other parameters. In addition to this there is significant building volume that is needed for orderly storage and removal. Here this necessity is only mentioned as is the necessary auxiliary and computer equipment.

Figure 4.38 gives an impression of an outside raw material storage with supply pipes for a PET staple fiber production plant, as permitted by climatic conditions [35]. The background shows four story buildings for the continuous polycondensation and spinning plant, and further back the lower staple fiber aftertreatment plant.

4.4.2 Chip Storage and Transport [36–39]

The chips should be stored at the user's facility in large silos from where they can be mixed some more and transported to the individual user locations. The mixing can be done by feeding chips from several silos through rotary valves into a pneumatic transport pipe. Or for each silo the "Christmas tree" system can be used for the removal of the chips. According to Fig. 4.39 the removal pipes have several openings at different height levels to remove separately delivered batches (shown by different shading) simultaneously.

Further transport of the chips—depending on the type and degree of dryness—can be done by air, dried air or nitrogen that have to be free of dust and oil. Transport blowers are usually side channel blowers, rotary or screw type compressors. The required transport gas speeds have been mentioned in Chapter 4.2.4. Above 10 m/s chip speed the abrasion increases considerably, and it is too much at 25 m/s, which should definitely be avoided. An efficient dust removal device according to the centrifugal principle with baffle separator is shown in Fig. 4.40 [39]. This should at least be installed on each spin extruder storage container.

The usual ways of the chips between delivery and extruder are shown in Fig. 4.41. Transport in the different steps can be achieved depending on the quantity in various ways:

- For the addition of small quantities bag or barrel delivery stations are required, possibly with dust removal, barrel tilting devices (Fig. 4.42) or pneumatic chip suction (Fig. 4.15).
- For transport inside a plant in ton batches small containers for bulk materials have proven themselves that are also inexpensive, can be stacked, can be hung into a "gyro wheel" mixer (Fig. 4.42) for

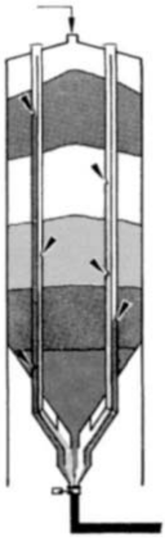


Figure 4.39
Chip blending system for mixing and feeding chips from different filling levels (or batches)

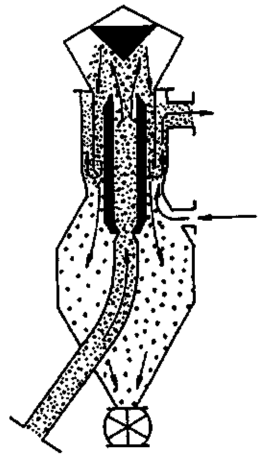


Figure 4.40
Baffle separator [39] for dust removal

mixing in additives, and can be used with a fork lift (Fig. 4.43 [40]). When filling hot chips one needs to ensure that the container surface does not exceed 60 °C.

- For the chip delivery to the spin extruder there are three possibilities:

  An open chip container, possibly with a slow moving agitator and hinged cover, preferably for PP and PE (Fig. 4.44).

  A closed chip container, water ring pump, vacuum and pressure tight to 1.5 bar (abs.), with about 4 h or longer extruder capacity supply, or

  A double container combination as in Fig. 4.45, consisting of a dust separator (top), a large storage container (center), separated by a chip gate valve from the lower storage container that should have a storage size equivalent to at least the filling time of the upper container so that during the

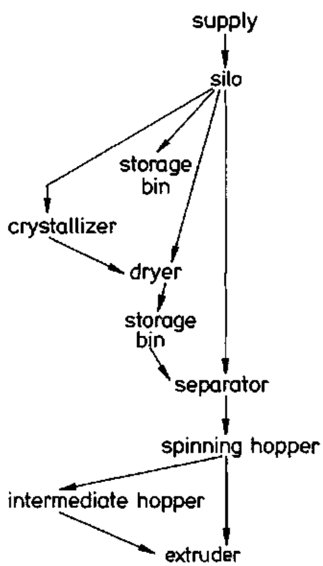


Figure 4.41
Chip ways between first storage silo and spin extruder

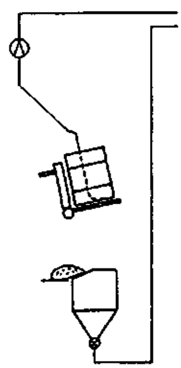


Figure 4.42
Chip feed for small throughputs

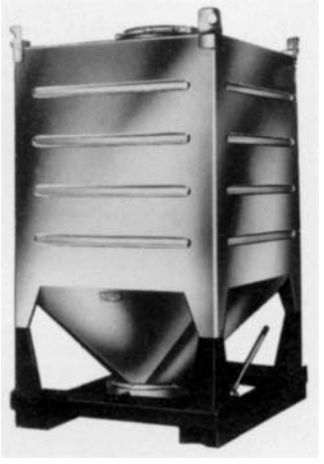


Figure 4.43
Staple container [40] (usual sizes: 200, 1100, 3000 l)

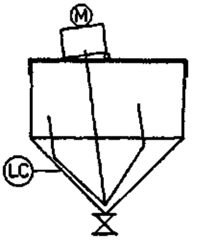


Figure 4.44 Chip hopper with anchor type agitator; open, e.g., for PP

filling and rinsing time of the latter spinning can continue from the lower container. The connection to the spin extruder is most useful with a transparent pipe and another chip gate valve.

For larger units the chips should be transported pneumatically; the transport gas has to match the spinning conditions of the chips.

It is useful to equip all fixed containers that can empty (as for example in spinning) with upper and lower level sensors. The containers need to be made from stainless steel or Al or AlMg as do the necessary pipes. For the directing and routing means, the cut-offs, the mixing deflectors, etc. experienced companies (e.g., [38]) offer a large number of components. They should also be left with the planning of the pipe transport systems.

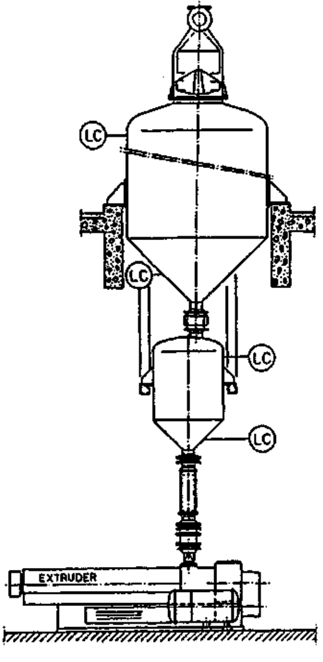


Figure 4.45
Chip hopper system of a large extruder spinning plant for PET; two hoppers superposed, the lower for continuous spinning, the upper for refilling (with closed emptying gate valve) [69]

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4.5 Drying, Crystallization, and Solid Phase Polycondensation

These processes are so similar and (if at least two of them are required) so closely connected that they should be treated and done together. With the exception of PA 66 chips for steam grid spinning and PP that has <0.05% residual humidity from production, chip drying is of utmost importance. For some materials drying and treating in a medium-high vacuum (empty container) of <0.1 mbar is better than in pure nitrogen with <5 ppm O_2 or even in air; other materials do not need any oxidation protection. For PA 66 for the one screw extruder spinning, final conditioning is recommended.

Mostly two processes are used: Either batch processing in a vacuum dryer, or in a continuous dryer at normal pressure. Some materials (especially PET) have to be crystallized first because they start tacking between 120 and 140 °C before they are dried at 170... 180 °C or melted at even higher temperature in the extruder. For postcondensation PET has to be dried to <0.004 weight % residual humidity before it can aftercondensate at higher temperatures. For PA, drying and postcondensation can be combined because the latter produces water anyway. For the production of most PA and PET yarns and staple fibers postcondensation is not needed because the usual liquid state polycondensation produces high enough molecular weights respectively viscosities of the polymer [41–46].

Drying is a purely physical process: The humidity diffuses from the chips to the outside as long as the vapor pressure difference created by temperature and/or a vacuum and/or the dryness of the drying medium forces it to do so. For a humidity of <0.01% in the chips the measuring method should always be mentioned (e.g., C.-Fischer method, DuPont moisture test, etc.).

Table 4.13 shows the usual residual humidity, drying temperature, and time requirements for some polymers.

Table 4.13 Vacuum Drying Conditions for Polymer Chips

Material	Initial % moisture, from delivery vessel	Initial % moisture, from chip baffle dryer	Desired final moisture %	Vacuum drying temperature/time [°C/h] heating up	drying	cooling	final vacuum [mbar]
PA 6	4...8	<0.3	<0.1	120/4	120/16	80/3	<0.5
PA 66	4...8	<0.3	0.08±0.01	95/4	95/30	80/2	<0.5
PET	2...3	<0.2	<0.004	180/4	180/4	80/3	<0.2
PBT	3...5	<0.3	<0.004				
PP	0.05	<0.1	<0.05	–	–	–	–

4.5.1 Vacuum Drying and Similar Processes

Because of the limited heat transfer under vacuum, it must be tried to have the individual chips in frequent contact with the heated walls to transfer the necessary evaporation heat into the chips. For this large heated inside drying surfaces, possibly with internal installations, and constant rotation of about 4 rpm for small and 2 rpm for large drums are recommended.

Figure 4.46 shows a process diagram of vacuum dryer installations with rotating drum (1) and turn drive (2). The jacket heating—as shown in the drawing—is fed by an electric heater unit with oil as the heat carrier (7) that additionally is equipped with a cooler. Depending on the desired temperature range this system can be replaced by a hot water circulation heater or a vapor heater. The vacuum system consists of a centrifugal dust separator with filter (3) with various pipes to the vacuum pump (6) that can be changed over. If there is a lot of water in the treated material in (1), it is useful to go through the spray

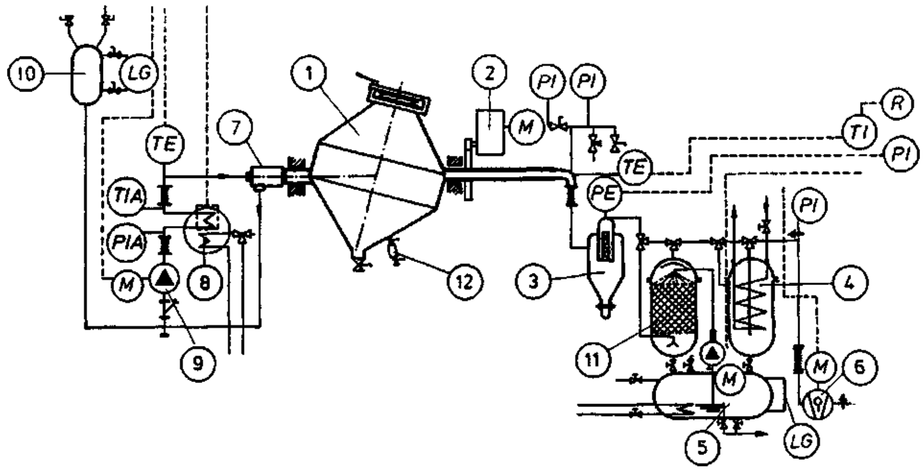


Figure 4.46 Flow sheet of a biconical vacuum dryer plant
1) Biconical drying drum, jacketed
2) Rotary drive, 2...4 rpm
3) Centrifugal dust separator with filter
4) Surface condenser
5) Receiver for water condensate
6) Vacuum pump, ≤0.1 mbar
7) Heater unit or hot water storage
8) Cooling water circulation
9) Hot water circulation pump
10) Expansion vessel
11) Spray condenser (only for large quantities of water)
12) Sampling port

condenser (11) and the surface condenser (4). As soon as the humidity content in the dry material in (1) has dropped under a few percent, the spray condenser is deactivated and only the surface condenser remains in the way to the vacuum pump. If the vacuum pump (6) has a gas ballast device, it is also possible to deactivate the surface condenser just before reaching the final humidity content in (1).

The following vacuum pumps can be used for this:

- Water sealed ring vacuum pumps for up to 30...40 mbar,
- One step oil rotary vacuum pumps up to about 0.5 mbar
- Two step oil rotary vacuum pumps up to <0.1 mbar
- Vacuum pump sets with two rotary pumps, one water jet sucker and one water ring vacuum pump for large dryers and productions and <0.1 mbar.

The following temperature ranges are used in praxis:

- Hot water heating as a secondary flow of a vapor-water heat exchanger for temperatures up to about 120 °C. This is a particularly mild heater with respect to heat transfer and is therefore preferred for PA;
- Electric heater with oil as the heat carrier for temperatures up to about 190 °C, e.g. for drying PET, or
- As above but with temperatures of up to about 250 °C for solid phase polycondensation processes. Here an intensive and fast cooling of the oil carrier and thus the chips is essential to avoid uncontrolled postcondensation.

The following drying drum designs have proven themselves in praxis:

- Cylindrical drying drums with dished bottoms on both sides and an angle of about 20...25 °C between the cylinder axis and the rotation axis: tumbling dryer,
- Biconical drying drum similar to Fig. 4.47, possibly with additional internal heater installations. The advantage is the complete emptying in the correct position.
- Two cylinders welded together at about 60 ° of their length axis with an angel of the rotation axis to the cross axis of about 15...20 °. The advantage is the very large volume in a small space.

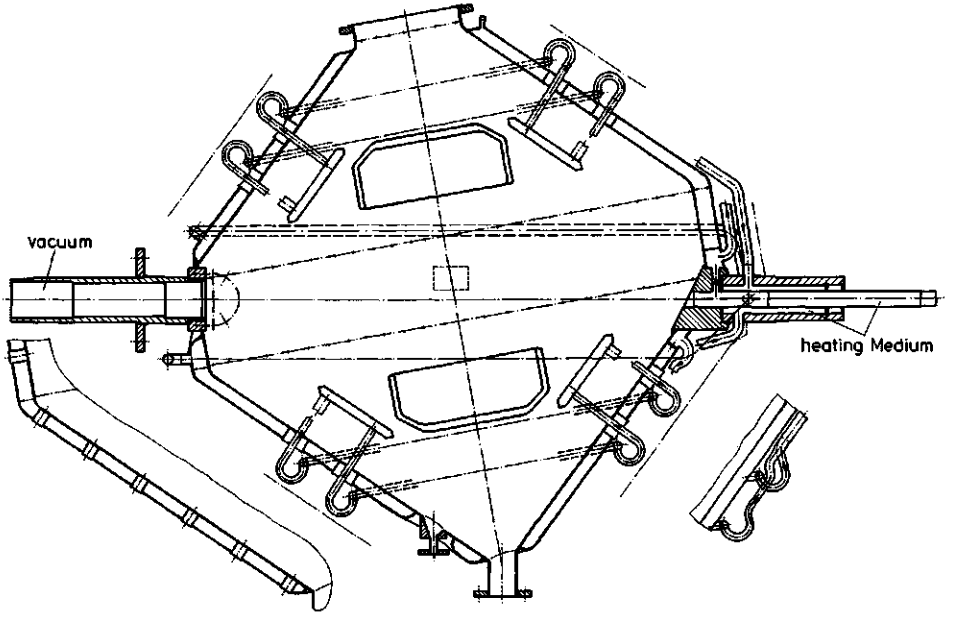


Figure 4.47 Biconical vacuum dryer drum, jacketed and with additional internal heater installations; manufacturing drawing for 3 m³ volume [24] and up to 20 m³
left: Vacuum connection by means of a stationary knee pipe and filter;
right: Heating medium supply and return

Figure 4.47 is a manufacturing drawing of a biconical drying drum of about 3 m³ volume [24] (with internal heater installations, heating jacket, the vacuum connection on the left and the heat carrier supply and return on the right). Table 4.14 shows the required drawing captions with manufacturing and examination regulations by the TÜV, that can be used as an example for pressure vessel manufacturing in general.

For similar drying drums of 50 l ... 20 m³ volume that proved themselves in praxis Table 4.15 shows the most important technical data.

The vacuum suction stud with the nominal width according to Table 4.15 is installed through the vacuum suction connector, and it always points upwards as a knee even when the drum rotates. Above the chip level it has a large round fine-filter with cap to avoid chips and dust to enter the pipe during suction. Through the axis a resistor thermometer can be pushed into the chips to allow continuous measuring of the chip temperature.

The design of the filling and emptying stud and a sampler during vacuum processing is shown in Fig. 4.48 [24].

The vacuum drying process starts with the filling of the chips into the drum that should not be above 80 °C under exclusion of the surrounding air after closing the drum drive and the vacuum pump are switched on. Since at 1 mbar up to 200 ppm O_2 are still in the dryer, it is recommended (especially for polyamides) to rinse with N_2 up to 0.2 ... 0.5 bar over pressure, then evacuate to the possible final vacuum and hold this and the temperature according to Table 4.13 constant for the mentioned length of time and then cool very intensively during the last 2 ... 3 h. Then the chips are rinsed with pure dry nitrogen and drained without air into a storage container.

Crystallization as for example of PET is only an intermediate state during the heating of the chips for drying. The continuous movement of the chips towards each other is granted by the rotation of the drum. Additional equipment for the vacuum dryer is not needed for this.

For the solid phase polycondensation it is sufficient if the heater temperature range is increased to about 10 ... 20 °C below the melting point of the specific polymer or to about 10 °C above the temperatures in Fig. 4.49. The time coordinates for PA 6 (a) and for PA 66 (b) include the drying

Table 4.14 Additional Inscription required for TÜV Inspection Drawing of the Drying Drum According to Fig. 4.47 [24]

Remarks:				
Welding type:	mE or TIG (tungsten-inert gas) welding			
Welding filler:	Material No. 1.4541 – Material No. 1.4541 – Thermanit H Material No. 1.4541 – C-steel – Thermanit X C-steel – C-steel – SH green K 45			
Welding factor:	0.85			
Welding seams:	clean finish, sanded smooth on working surfaces			
Surfaces:	Working surfaces: Industrial polish, roughness: $R_a \leq 0.3 \cdots 0.6\,\mu m$ (visible polish marks are ok) Machining quality: According to pre-norm DIN 3141, row 2 Not finished: Stainless steel – pickled + passivated C-steel – cleaned and painted on outside with undercoat + color (zinc chromate base)			
Customer nameplate:	122 × 85			
Process data:		Permitted pressure	Permitted temperature	Volume
	Drum:	−1 resp. 2 bar	+ 250°C	2990 l
	Heating jacket:			
	Heating plates:	2.0 bar	+ 250°C	400 l
Test pressure:				
	Drum:	3.9 bar "a"		
	Heating jacket:	2.6 bar		
	Heating plates:	2.6 bar	"Marlotherm" (provided by customer)	
Leakage test:	With 0.3 bar air overpressure and wetting of the welding seams with a soap solution.			
Examination:	As pressure vessel by TÜV. Leak testing, dimensional and surface examination by customer and manufacturer.			
Manufacturing and testing:	As pressure vessel according to the AD rules			
Non-destructive testing:	RN, LN, and ST 2%			
Tolerances:	0.2 mm concentricity between shaft and seat.			
Marking:	The material number is embossed under the manufacturer's name plate.			
Weight:	about 2200 kg			
All pipes position 3–17	with AZ.DIN 50049-3.1 B			

(Caution: the TÜV uses 0 bar = atmospheric pressure)

time, while for PET (c) it starts after the drying time. The latter is true for all polymers at risk of hydrolysis. Diagram (d) indicates the acceleration of the postcondensation of PET with increasing temperature; (e) shows that a certain postcondensation time may not be exceeded for PET or the molecular weight and the intrinsic viscosity are reduced by thermal degradation [42].

Especially for postcondensation it needs to be pointed out that it needs to be stopped by fast and intensive cooling to avoid undesirable effects. Even during the "still high temperature" phase of the cooling process, postcondensation continues.

4.5.2 Continuous Chip Drying

Already before 1960 vapor heated rotary drum dryers with 170 ... 180 °C inside temperature and air as the drying medium were used. These dryers consisted of a slowly rotating, slightly tilted tube with a cross-section similar to Fig. 4.50. On the higher side the chips were continuously filled, continuously moved by

Table 4.15 Design Data for Vacuum Tumble Dryer

Vacuum tumble dryer volume dm³	Vacuum pump m³/h	Vacuum pump drive kW	Drum drive kW	Installed heating power (for 240°C)²⁾ kW	Cooling area (water) m²	Vacuum pipe diameter mm	Add. internal heating area m²
50	8.5	0.4	0.55	11.7²⁾	0.2	32	–
300	50	1.5	1.1	24	0.28	50	–
600	100	3	3.8	38	0.35	80	–
1 500	200	5.5	5	71	0.6	100	(1.3)
3 000	500	6.2	8	110	1.0	125	2.7
8 000	2000¹⁾	20	10	200	3	200	6 ··· 7
12 000	3000	30	15	280	5	250	9 ··· 10
20 000	5000	45	25	460	10	320	15 ··· 18

1) advantageous for higher capacity: water jet or water ring pre-pump and 2-stage Roots blower
2) for ≤ 130 °C, use factor ≈65 ... 70%

buckets wheels, transported by the angle along the axis and removed at the end [47]. Around 1970 vacuum vibration spiral dryers [48] with batch feeding and removal of the drying material were built. The chips were moved upwards by vibration in a spiral groove. Both dryer types are no longer used today.

The achievable final humidity of the chips depends on the vapor steam difference between the chips and the drying medium, that should be made as large as possible: On one side by increasing the temperature of the chips and the drying medium, on the other side by reducing the humidity content in the drying medium. This can either be achieved by cooling and removing the latter from the drying medium or by removing the humidity with the help mol sieves. Sorption agents at temperatures between 100 and 140 °C can be lithium chloride, or for higher temperatures materials on the basis of

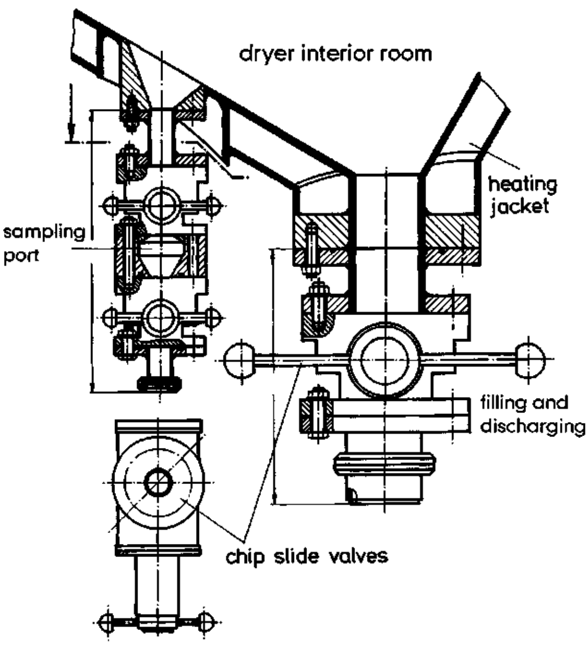
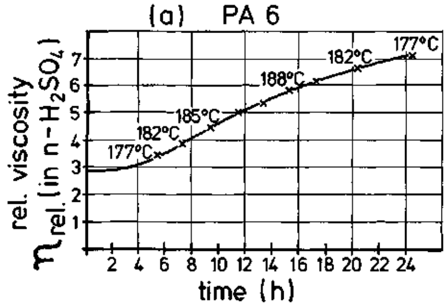
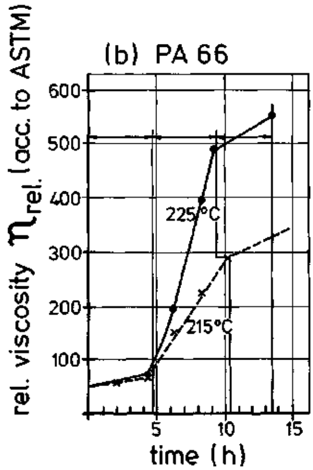
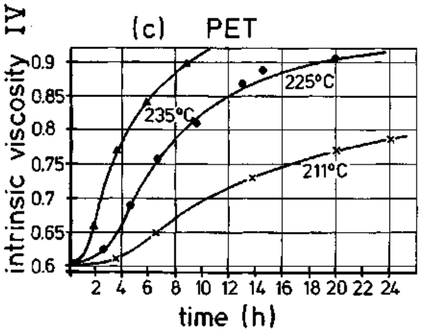
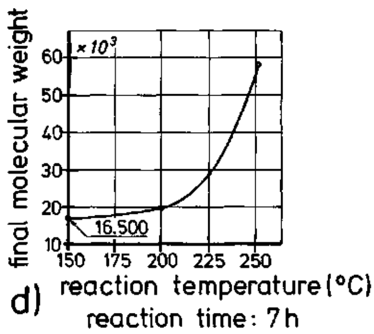


Figure 4.48
Chip discharging and filling valve (right) and sampling port (left) for Figure 4.47, with chip gate valves according to Figure 4.66 [24]









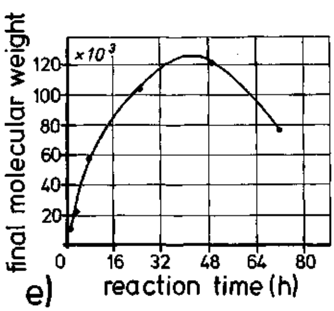


Figure 4.49
Examples of solid phase polycondensation in a vacuum dryer
a) PA 6
b) PA 66
c) PET [24]
d) maximum molecular weight of PET as a function of the temperature, after 7 hours treatment time
e) maximum molecular weight of PET as a function of time at 250 °C

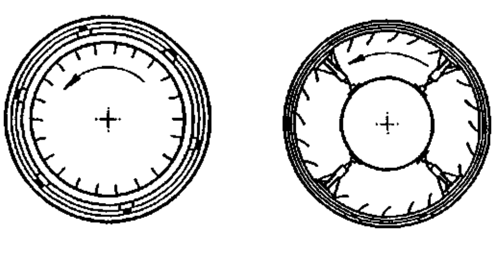


Figure 4.50
Continuous rotary drum dryers for crystallization and drying of PET chips; left: with bucket wheel, right: with additional internal heating tube

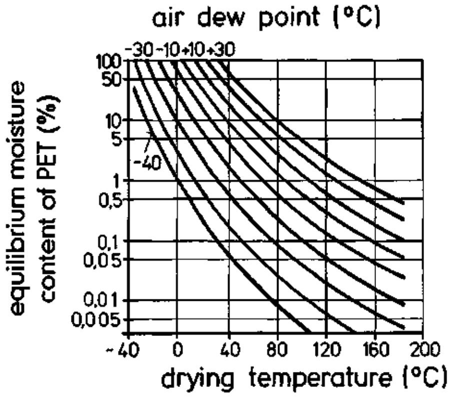


Figure 4.51
Equilibrium moisture content of PET as a function of the dew point and temperature of the drying gas (e.g., N_2 or air [52])

Mg–TiO_2–...(trade names: Baylith® or Zheolith [48]). Use of high temperatures is particularly important for the regeneration, i.e., for the desorption = water transfer to the air, that has to be done periodically after the respective water gain. The structure of the mol sieves is not changed by this [49]. Figure 4.51 shows the equilibrium humidity PET can achieve as a function of the dew point and the drying temperature of the drying gas [52].

For drying polyamides and similar oxygen sensitive materials pure nitrogen with < 5 ppm O_2 and a dew point of under −40 °C is used. To reduce cost it should run in a circle and continuously regenerated.

Such continuous dryers with pre- and after-treatment equipment are today built for capacities of 3...70 t/24 h [50, 51].

Due to larger capacities that coincide with further specialization, there are also divisions into crystallization and drying, the latter of which can be combined with a continuous postcondensation.

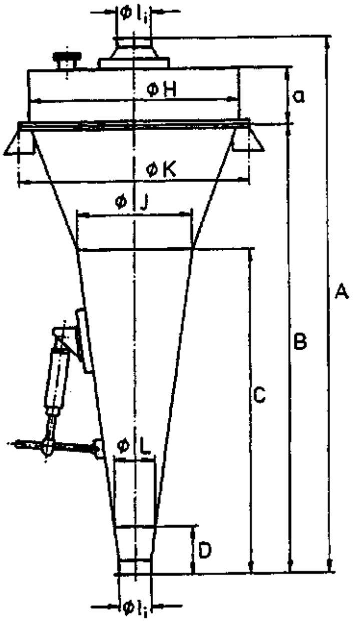


Figure 4.52
Whirl chip heater for PET crystallization [50]—capacities and dimensions—examples

Vol. l	G (PET) kg/h	I mm	B mm	a mm	C mm	H mm	J mm
290	20...40	125	1830	215	1317	900	500
800	40...80	200	2770	350	2002	1275	700
1200	60...120	250	3070	400	2270	1500	850

Semi or Fully Continuous Crystallization

Crystallization of for example PET is an exothermic process setting about 8 kcal/kg = 33.5 kJ/kg free. The specific heat in PET in the temperature range in question is 1.1 kJ/K · kg, so that the chip temperature can increase in an adiabatic process by about 30 °C. Under unfavorable conditions (e.g., the chips are stationary relative to each other and their surfaces are tacky) the chips can bake together to agglomerates. This significantly disturbs the diameter ratios, creating a heat buildup, and can cause the dryer to grow closed. For this reason continuous heat exchange and movement relative to each other have to be assured.

In the older method this was done with a conical container [50] as in Fig. 4.52 that was batch filled with chips from above. Then these chips whirled by hot air of 140 ... 160 °C entering from below for about 20 ... 30 min, causing them to crystallize. The double cones widened to the top, causing the chips to continuously rise and drop. After drying they could be drained downwards.

In a newer fully continuous process (Fig. 4.53) chips are continuously added [50] while pulsating hot air presses through a perforated bottom through a layer of chips of several cm. The hot air pulsation is created by a rotating flap. The throughput speed of the chips can be regulated by the angle of the perforated bottom. The dryer volume is about 5.7 ... 6.5 $dm^3 \cdot h/kg$. Crystallization requires per m^3 volume about 0.55 m^3/s hot air of up to 185 °C that requires for recycling with up to 1000 mm water column about 30 kW heating power and 30 kW fan drive power.

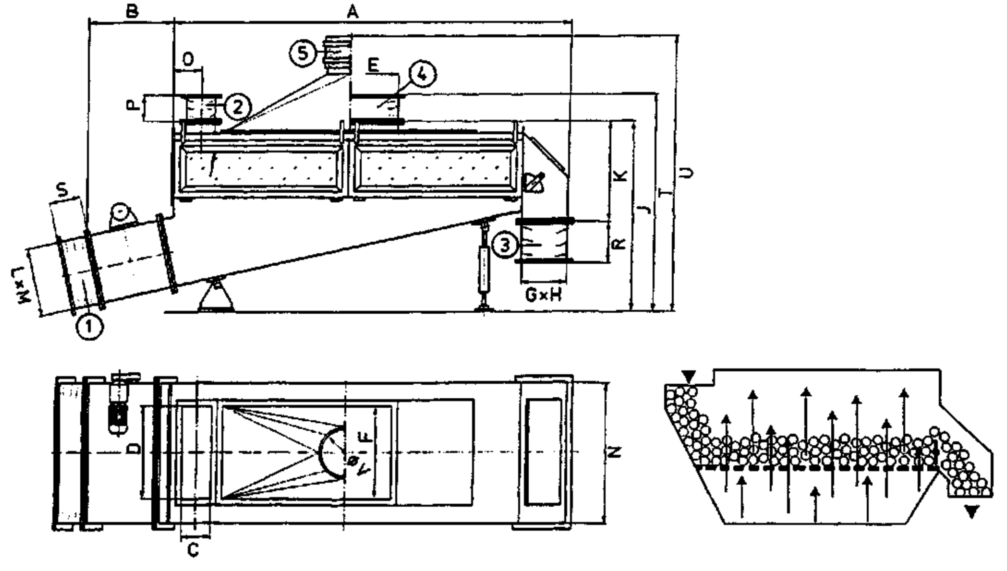


Figure 4.53 Fluidized bed crystallizer for PET—capacities, dimensions and principle [50]

Capacity kg/h	Air intake L × M mm	Outside length A mm	Outside width N mm	Bed width mm	Total height mm
50	245 × 440	1850	600	322	1400
150	400 × 770	2900	905	588	2472
300	600 × 1220	4160	1228	840	2940
500	600 × 1420	4770	1628	1220	2960

Another system [51] combines crystallization of PET and the subsequent drying in a vertical tube: According to Fig. 4.58 the chips are filled into the tube from the top and are kept in motion in the area *C0* by a slowly moving agitator and are crystallized by the passing hot air. The additional agitator at the lower cone exit from *C0* to *C1* breaks up luted parts. The movement effect of the chips can be reinforced by two anchor type agitators running in a coaxial fashion. The agitators run at about 3 rpm.

Continuous Drying

Continuous drying can be done in a vertical tower with slowly sinking chips and hot air flowing cross-sectional or upwards through the chips or in a rocking bed.

Such a dryer is shown in Fig. 4.54. The chips slide down a square tower at the rate of the take-up at the bottom while the hot drying gas flows from level to level in reversed direction across through the chips while being heated [50].

In other systems the hot drying gas is fed into the chips from below, moves upward against the chip flow, transfers the necessary drying heat, absorbs humidity from the chips and leaves the chips layer relatively cool [51, 52, 55]. It may become necessary to heat the drying gas some more by adding more hot drying gas to avoid saturation of the upper levels. If the chips are supposed to be cooled or

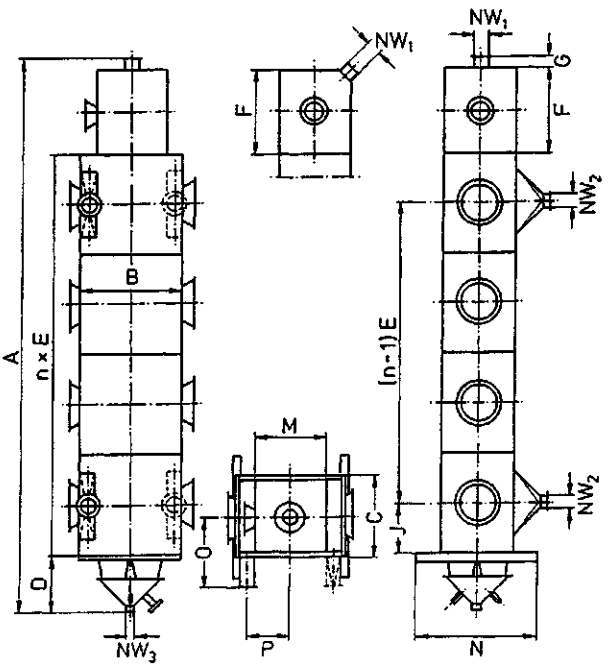


Figure 4.54 Column (tower) dryer for crystallized PET chips—capacities, dimensions, and required power supply [50]

Capacity kg/h	Volume l	Total height mm	Outside dimensions mm × mm	Drying zone length mm	Column dimensions mm × mm	Chip discharge NW_3 mm	Power supply kW
200...300	950	4840	712	900	460	125	70
600	4000	6075	1250	1100	854	200	140
1400	8600	6780	1500	1200	1200	250	
2000	12400	7195	2020	1200	1440	250	

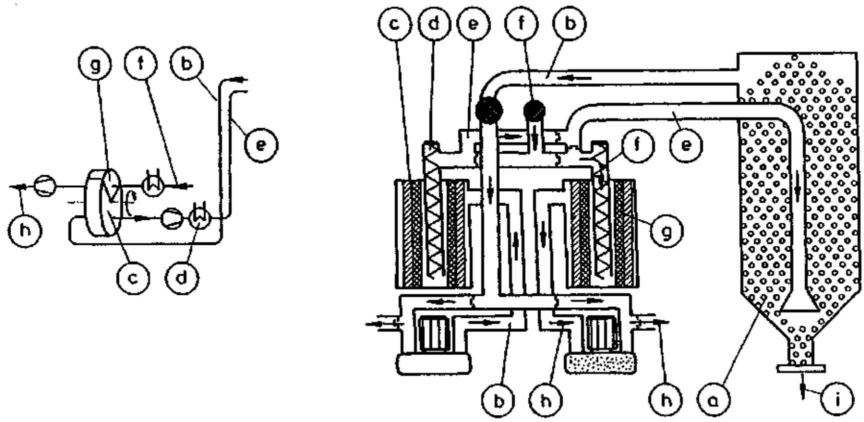


Figure 4.55 Chip dryer systems using molecular sieve-dried air; right: with periodically switched drying air and dehumidification step [52]; left: with continuously regenerated molecular sieve [55]

a) Chips
b) Drying air (moist)
c) Molecular sieve for air drying
d) Air heater
e) Drying air (dried)
f) Fresh air
g) Molecular sieve being regenerated
h) Waste air from g)
i) Extruder connection flange

Material	PA	PET	PI	PP	Polyether sulphone	PEEK
Initial chip moisture [%]	< 1	< 1				
Drying temperature [°C]	75	160	120	90	150	150
Spec. air req. [m³/kg]	2.22	1.67	1.33	1.25	1.6	1.6
Drying time [h]	8...10	6				
Residual chip moisture [%]	< 0.01	≤ 0.004				
Technical data (spec.) (per m³ air)	Heating power kW/m³		Regeneration kW/m³		Drive kW/m³	
for 40...3600 m³/h	> 0.04		0.02...0.08		0.01	

conditioned before the bottom exit, the hot gas enters above this zone, and the lower zone is treated separately with the appropriate gas. For drying it is insignificant whether the drying gas arrives at the necessary low relative humidity by cooling, by absorbents, or solely by heating.

It is also possible to lengthen the system in Fig. 4.53 for the crystallization of PET by a drying zone [56] and possibly feed with a separate drying air stream.

For the drying processes it is important to clean the circulating drying gas by a dust separator from abrasion residues.

Continuous Postcondensation

As mentioned for this the last drying zone is simply lengthened in the direction of the chip flow and fed with a separate gas stream at the appropriate temperature [50, 51].

Drying Equipment, etc.

The aforementioned units are combined to more or less elaborate plants for drying and possible crystallization, aftercondensing, conditioning, etc.

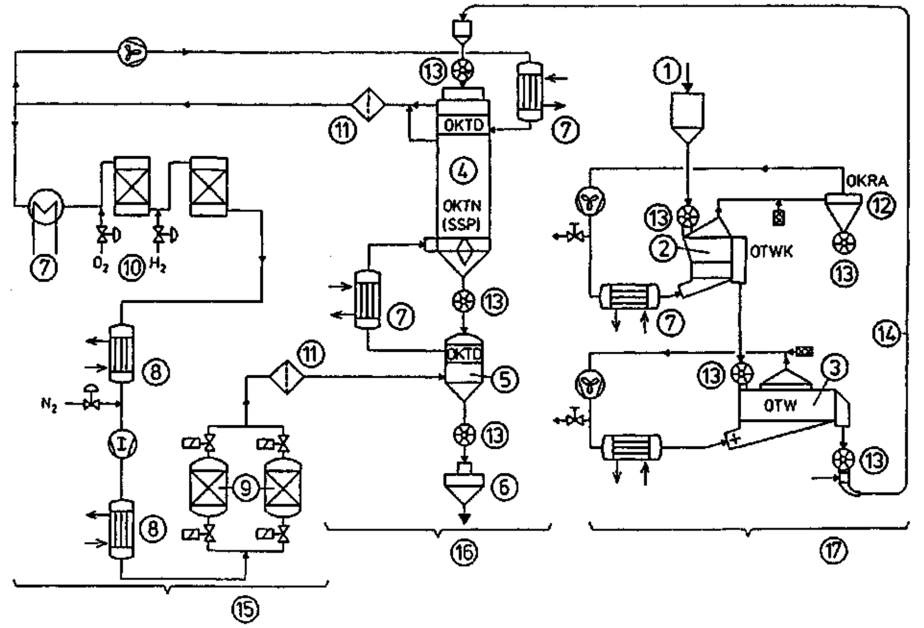


Figure 4.56 Flow sheet of a continuous PET crystallization and drying plant [50]

1) Supply of amorphous PET chips
2) Crystallizer according to Fig. 4.53
3) Pulsator
4) Column (tower) dryer according to Fig. 4.54
5) Chip cooler
6) Chip discharge
7) Heat exchanger (for air)
8) Cooler
9) Gas dryer
10) Catalytic gas purification
11) Filter
12) Chip centrifugal separator
13) Chip transport
14) Transport pipe for crystallized chips
15) Heating system
16) Drying zone
17) Crystallization zone

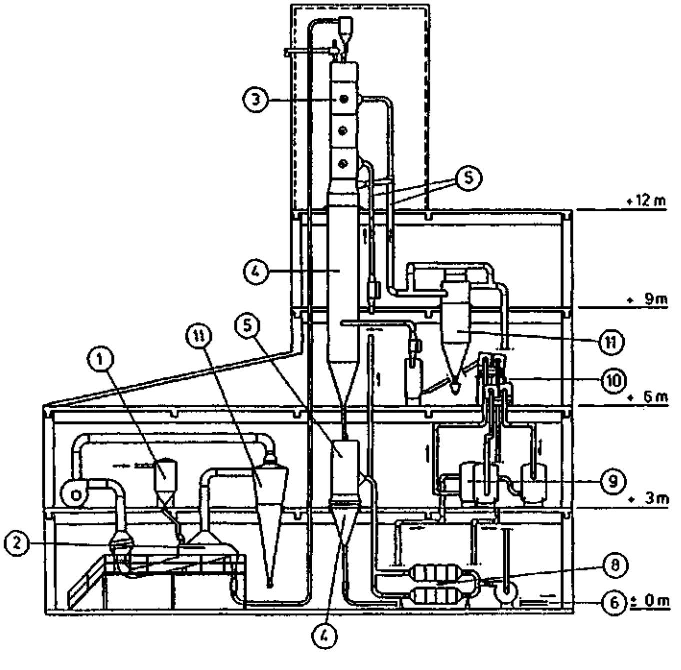


Figure 4.57
Building section of a large continuous chip dryer similar to that in the flow diagram 4.56 [50]

1) Crystallization
2) Drying installation
3) ditto
4) Chip cooling
5) Hot gas piping
6) Gas heating system
7) ditto
8) ditto
9) Gas cooler
10) Gas heat exchangers
11) Dust (cyclone) separator

Figure 4.55 shows such a drying unit where the heater gas is first dehumidified in mol sieves that work alternating, and then is fed from below into the chips inside the drying tower [52]. The returning drying gas is in part cycled and in part passed to the outside air. While one candle with the mol sieve provides the dehumidification, the other candle is regenerated and made humidity free by the through flow of hot air. After a time that needs to be determined the system switches to drying with the regenerated candle. Figure 4.55 shows a similar system where both candles are replaced by a round disk that turns slowly, so that a large portion of it works in the drying cycle while the other part is being regenerated [55].

In the flow diagram Fig. 4.56 [50] the chips are supplied at (1) and entered through a rotary valve (13) into the two step crystallization (2, 3) and then moved into the drying tower (4). After removal through the lower rotary valve (13) the chips are cooled in (5) and move through an intermediate container (6) to further processing. The drying gas moves through the filter (11) from the drying tower into the regeneration circle (15). The hot chips are cooled and the heat from (5) is recovered in the heat exchanger (7) that reheats the drying gas that reenters the drying cycle from below. Figure 4.57 shows the respective building section for such a large PET crystallization and drying installation [50].

The differences between a PET crystallization and drying installation and a similar installation with attached postcondensation become obvious in Fig. 4.58: The chips entering from *B1* are crystallized in zone *C0* and then dried in zone *C1*. The latter has been lengthened by zone *C2*. The moist drying gas removed from zone *C0* passes through separator *F1* and filter *F2*. In the heat exchanger *W2* part of the gas heat is recovered. Fresh air respectively nitrogen are sucked in through a filter *F3* and mixed with the gas coming from the process, cooled for water separation, dried, and reentered into the process. During postcondensation, part of this gas is used for cooling the chips in *B2* and then lead over the heater *W4* back to the postcondensation [51].

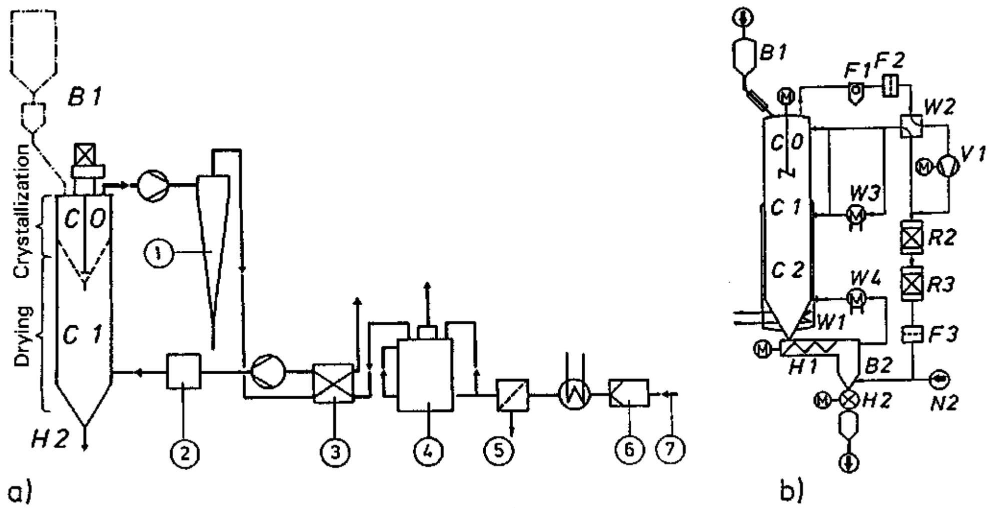


Figure 4.58 Continuous PET chip crystallization (C0), drying (C1) and solid phase after polycondensation (C2) [51] Schematic of *a*) Crystallization and drying; *b*) Crystallization, drying and solid phase polycondensation

B1	Chip feeding	*V*	Fans
C0	PET crystallization with agitator	*W2*	Counter-current heat exchanger
C1	Drying zone	*W1, W3, W4*	Heaters
C2	Postpolycondensation (solid phase)	*N2*	Nitrogen
H1	Discharge screw	*F*	Dust separator, filter
H2	Rotary valve	*H2*	Dry chip discharge
B2	Chip cooler		

4.6 Melt Spinning Plants

In melt spinning plants either the chips (in rare cases the powder) prepared for spinning are melted in extruders or the melt is pumped directly from the finisher of a continuous polycondensation plant—almost exclusively by gear pumps. The filament forming elements are usually mixing and homogenization elements, filters, dosing pumps and spinnerets that are arranged in the necessary surrounding temperature and connected by pipes for the respective high pressure. Figure 4.59 gives an overview over the possible process technological and equipment combinations of machines that are needed to transform the polymer to filaments or staple fibers. Even though some of these machines are known from other industries as the plastics or textile industry, they have so many specific design components that they have to be covered here. For the purpose of completeness and with reference to Chapters 4.14 and 4.15 the diagram also shows the processes for solution spinning.

In addition to these processes of industrial significance there are further methods to transform chips or melt or powder or paste, etc. into filaments [64], e.g., emulsion and suspension spinning [65], spinning from an interfacial polycondensation [66], reaction spinning [67] and electrostatic spinning [68] that thus far are only known from exceptional cases. Rod spinning [70, 66] has almost completely been replaced by chip melting and is only used for a few low volume products [71]. Sinter spinning [72] is only used for the production of PTFE filaments. Filaments from high temperature materials such as aluminum oxide or titanium oxide [77], etc., or supra conductive materials [67] can be spun with carriers.

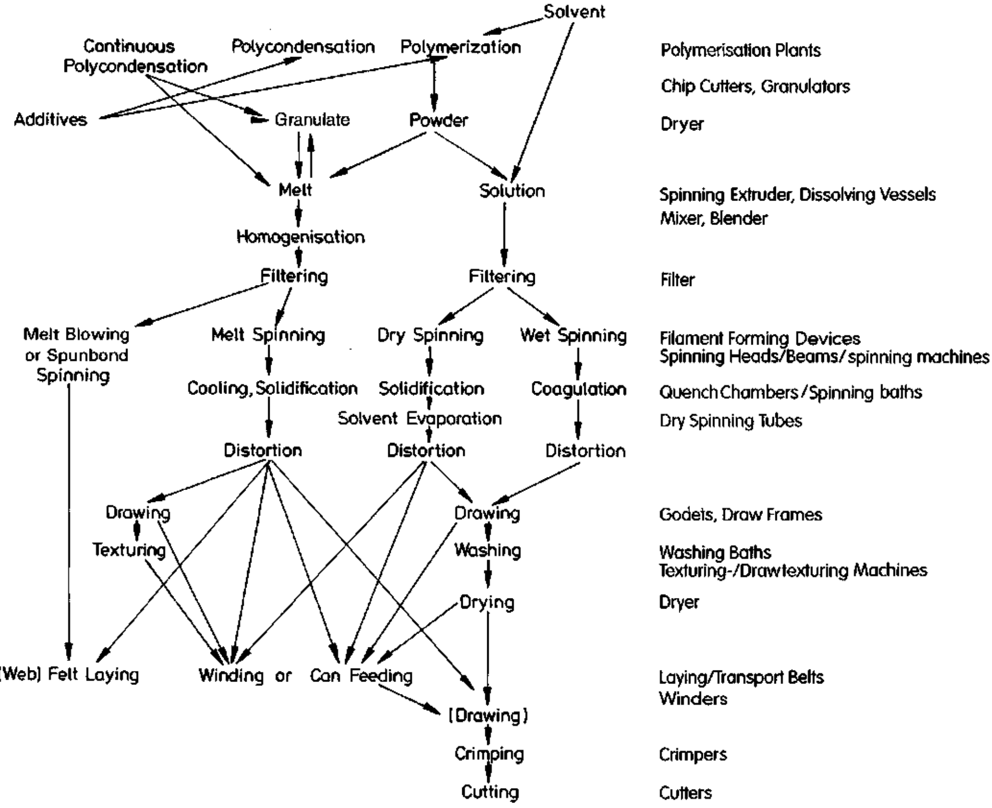


Figure 4.59 The different routes from polymer to continuous filaments, staple fibers, fleece (nonwovens, spunbondeds) and typical processing machines used in their production

4.6.1 Calculation of the Plant and Equipment Sizes

The products, i.e., the textile or technical filaments or staple fibers, etc., have to respond to the divers requirements of markets and fashion as well as to the available starting materials. For this the plant and equipment sizes and capacities have to carefully be harmonized: From this results the sequence of the calculations: on one side from the desired final products, on the other side from the entered raw materials. The latter is here assumed to be chips unless specified differently. In Tables 4.16 exemplified results for calculations with the following explanations are summarized:

- Provided are in general:

		Example
1.	Material:	PET, $[\eta] = 0.63 \pm 0.015$, chips, raw white, semi dull
2.	Capacity:	about 5000 kg/24 h
3.	Final product with yarn titer and number of filaments:	in average 167 dtex f52 POY for draw texturing, possible range 40 ... 200 dtex, individual titer range about 2.5 ... 4 dtex (after drawing)
4.	Make up of the final product:	Do existing bobbin dimensions have to be used or can they be chosen freely?
5.	Special requirements:	tenacity, breaking elongation, elastic modulus, Uster value, etc. and their permitted variations

- This results in the following calculation values:

a) The throughput of each spinneret is

$$\text{kg/24 h} \times \text{spinneret} = 1.44 \cdot 10^{-4} \cdot Ti(\text{finished}) \cdot i \cdot v \cdot \eta \quad (4.13)$$

with $Ti = [\text{dtex}]$, $i =$ residual stretch, $v =$ spin take-up speed [m/min]

The aforementioned sample material is (as mentioned in other chapters of this book) taken up with e.g., 3600 m/min and has a residual stretch of $i = 1.4$. The efficiency due to doffing, spinneret and pump changes, etc., shall be from experience $\eta = 0.97$. This results in 117.6 kg/24 h × spinneret, which in turn results in a minimum number of spinnerets of 5000 kg/24 h: 117.6 kg/24 h × spinneret = 42.5 spinnerets. If there are 8 spinnerets per position, the plant has 6 spinning positions and an effective capacity of 5640 kg/24 h for 167 dtex final titer. The arrangement of 8 spinnerets in the spinning head corresponds to 8 oiler pins in the quench air chamber and 2 high speed winding heads with 4 yarn cakes per spinning position.

b) The spinneret size with (at first typically) 4 mm distance between holes for 66 to 52 or fewer bores in two circles requires a total hole circle length of 66 × 4 = 264 mm, resulting in:

$$[D_{la}(n_a) + D_{li}(n_i)\pi = 264 \text{ mm} \quad (4.14)$$

$$\begin{aligned} D_{li} &= D_{\text{spinneret}} - 2 \times \text{flange width} - 4 \times \text{hole circle distance} \\ &= 64\,\text{mm} - 2 \times 5\,\text{mm} - 4 \times 4\,\text{mm} = 38\,\text{mm} \end{aligned}$$

i.e., number of bores $= 38\pi/4 \leq 29 \ldots 30$ bores.

As each of the two hole circles can accommodate more than 26 holes they are offset to each other and result in 5.558 mm distance in the outer and 4.592 mm distance in the inner circle. The hole distance between the two partial circles becomes $[(4.592/2)^2 + 4^2]^{0.5} = 4.612$ mm.

c) Spinning pumps: for 84.17 g PET/min × spinneret with $\gamma \approx 1.2\,\text{g/cm}^3$ density of the melt 70.14 cm^3/min have to be pumped. With a spinning pump size of 3 cm^3/revolution this results in 23.38 rpm, or with 2.4 cm^3/revolution in 29.225 rpm, both less than the allowable 40 rpm. If a planetary pump with 4 × 2.4 cm^3/revolution is chosen, for 8 spinnerets two of these pumps with two separate drives per position are needed. According to Fig. 4.158 the pumps need a power supply of 325 W each at the pump shaft: this results with an estimated efficiency of the mechanical part of the pump drive and an efficiency of the synchronized motor of each 0.5 and cos $\varphi \approx 0.5$ about 2.6 kW at maximum rpm.

Table 4.16 Design Data for Melt Spinning Machines (Examples)

	Textile yarns POY		Technical yarns	Carpet yarns		Staple fibers			Unit
	PET	PA 66	PET	PA 6	PP 3 color	PET rectangular quench chamber	PET radial quench chamber	PP compact	
Feedstock	Chips	Chips	Chips	Chips	Chips	Melt	Melt	Chips	
$\eta_{rel.}/[\eta]/MFI$	0.63	2.7	0.98	2.7	16 ··· 20	0.63	0.63	16	
Viscosity	200 ··· 300	80 ··· 120	$2 \cdot 10^4$	140	500	250	250	500	Pa · s
Titer (drawn)	167f52	30f13	1380f208	2520f148	2520f147	1.75	2.5	3.3	dtex
Titer range	40 ··· 200	15 ··· 50	840 ··· 1680	1300 ··· 3000	1300 ··· 3000	1.1 ··· 4.5	2 ··· 6	2.5 ··· 200	dtex
Spinneret diameter	64	52			3 × 100		210		mm
Spinneret dimensions			268 × 80	182 × 80		420 × 120		450 × 60	mm
Spinning process (compact)	POY	POY	FOY	BCF	BCF tricolor	LOY	LOY	compact	
Number of holes/spinneret	52	13	208	148	3 × 49	2570	3413	< 60 000	
Spinnerets/spinning position	8	8	2	2	6	1	1	1	
Internal quench chamber width	670	520	670	450	720	480	400	480	mm
Take-up speed	3600	5400	600	580	580	1700	1750	50	m/min
Spinn positions/machine	8	16	4	4	4	12	16	8	
Residual draw ratio	1.4	1.25	5	3.4	3.0	3.4	2.8 ··· 3.1	3.5	
Capacity	84.17	20.25	414	522	522	2330	2060	1270	g/min/spinneret
	7500	3620	4613	5830	5830	40180	43000	14200	kg/24 h × machine
Spinning extruder $\varnothing \times L/D$	105 × 28	Grid	90 × 24	100 × 24	3 × (75 × 25)	3 × (175 × 25)	–	180 × 30	mm
Spinning pumps/position	2 × (4 × 2.4)	2 × (4 × 0.6)	1 × (2 × 12)	2 × 20	3 × (2 × 20)	1 × 60	1 × 60	1 × 60	no. × cm^3/rev.
Spinneret								13 hole circles	
Hole arrangement	2 circles, offset	1 circle	4 rows. 35 holes each	≈ 9 mm	2 circles, offset	≈ 4 mm	≈ 3 mm	≈ 0.9mm	
Spin dpf × take-up speed	16190	15580	19900	36250	36250	10115	7215	≈ 380	dtex · m/min
Length of air quench zone	0.8	1.0	1.0	1.7	1.9	1.2	≈ 0.4	0.025	m
Quench air flowrate/chamber	890	214	1093	4130	4130	3130	1680	1680	Nm^3/h
velocity	0.46	0.12	0.57	1.3	0.84	1.5	0.9 ··· 1.3	30	m/s
air supply pressure	300 ··· 820	200 ··· 500	300 ··· 820	600 ··· 1000	500 ··· 900	700 ··· 1200	3000	1500	N/m^2
Length of floor inter-connection tube	1.0	2.50	2.50	2 ··· 2.5	2.5 ··· 3	1.0	1.0	–	m
Winders/position	2 × 4-fold	2 × 4-fold	2 (Rev.) × 2-fold	1 (Rev.) × 4-fold	1 (Rev.) × 4-fold	cans	cans	Draw frame	
Speed	≧4000	≧6000	≦4500	< 4000	< 4000				m/min
Godets	without < with < otherwise 2 CG	without < with < otherwise 2 CG	1 CG + 4 HD + 1 CD	1 CG + 2 HD + 1 T +	1 CG + 2 HD + 1 T +	1 CG	1 CG	1 idler roll	

CG = cold godet; HD = heated duo (double godet); CD = cold duo; T = texturing unit

Table 4.16 Melt Spinning Machines – Approximate Process Data – Continued

Material	Textile filaments POY PET	 PA66	 PP	Technical yarns PA 6	 PET-Cord	Carpet yarns PP 3 colored	Staple fibers PET	 PP	PP- compact
Viscosity. *MFI*. or similar	$[\eta]=0.63\pm0.02$	$\eta_{rel.}=50$	*MFI* 230/2 = 40	$\eta_{rel.}=3.4$	$[\eta]=1\pm0.02$	*MFI* 230/2 = 25	$[\eta]=0.63\pm0.002$	*MFI* 230/2 25	*MFI*230/2 16
Moisture content [%]	< 0.004	0.5 ··· 1	< 0.05	0.08	< 0.003	< 0.05	< 0.004	< 0.05	< 0.05
Capacity [g/min]	8 pos. × 8 spinnerets each 84.17	16 pos. × 8 s. each 20.25	each 57.62	4 pos. × 4 spinnerets each 244.7	4 pos. × 2 spinnerets each 414	4 pos. × 6 spinnerets each 87	12 pos. × 1 spinneret each 2370	12 pos. × 1 spinneret each 2040	8 pos. × 1 spinneret each 1270
Extruder metering temperature [°C]	285	Grid: 282	265	275	305	260	286	250	257
-pressure [bar]	125	Boster: 30	125	300	500	100	125	125	125
Spinning melt temperature [°C]	285	282	265	275	330	260	285	260	257
Monomer suction [m/s]	–	0.2	0.2	0.45	–	1.0	–	1.1	–
Quench air temperature [°C]	20	14	20	14	20	20	20	20 (14)	20

Table 4.16 Melt Spinning Machines – Raw Material Requirements per Production Month (30 d) – Continued

Raw material capacity [kg/24 h]	POY textile yarns PET 7500	 PA 66 3620	 LOY PP 4900	Technical yarns PA 6 5470	 PET tirecord 4630	Carpet yarns PP 3 color 5830	Staple fibers PET 40180	 PP 34200	PP- compact 14200
Chips (totally dry) or melt [t/month]	232	112	151.6	169.2	143.2	180.3	1443	1124	439.2
Spin finish [kg]	1860	896	1213	1354	1146	1442	14900	12690	5270
Spin dyes (0.5%)						900 kg/month			
Stabilizers			possibly small quantities (≈150 kg/month at 0.1%)					possibly small quantities (1100 kg/month 440 kg/month at 0.1% addition)	
Filter area [m²]	0.8							2 chambers	2
Connection load									
Power [kW]	370	400	≈350	440					
Cooling water [m³/h]	2.4	2.6	2.2	2.0					
Nitrogen [Nm³/kg]	0.6	0.3	–	0.3					
Compressed air: Thread Suction [Nm³/h]	750	900	900	1260					
Control air [Nm³/h]	32	32	32	28					

d) Spinneret arrangement: The spinneret housing should have a wall of at least 8 mm thickness for an inside pressure of 300 bar, resulting in a packing thickness of 80 mm, i.e., for 8 spinnerets 640 mm width of the opening in the spinning head housing.

e) The inner quench chamber width results from the distance of the most outer spinneret holes of these eight spinnerets plus about 2 × (20 ... 25) mm outer distance to the wall. This results in about 650 ... 660 mm inner wall distance. If the quench chamber has a center separation wall to protect the filaments per winding head from each other in the case of breakage, it is better to choose 670 mm.

f) Spacing of the spinning positions: The quench chamber as well as the corresponding winding heads have to fit into these. Two high speed winding heads of the selected dimensions (see Fig. 4.166) require 1200 mm take-up position spacing. Thus they are larger than the outside quench chamber dimensions of about 910 ... 950 mm, and therefore determine the overall spacing.

g) Each winding head has (for example) a chuck diameter of 94 mm, a yarn package outside diameter of 435 mm and 4 × 190 mm stroke. This corresponds to 4 × 29.81 yarn volume ≙ 4 × 21 kg yarn weight with each 21,000 [g] · 10 [km]/167 · 1.4 (dtex × residual draw) ≙ 898.2 km yarn length ≙ 249.5 min draw winding time per bobbin until doffing. At the draw texturing machine, this corresponds to 898.2 · 1.4/0.9 = 1397.2 min running time at 900 m/min. All these values are acceptable.

h) Spin extruder size: From 84.17 g/min × spinneret result 40.4 kg/h × position ergo 250 kg/h PET for the six position plant. As the maximum titer shall be 200 dtex, the extruder has to be able to produce 300 kg/h: either with screws 90 Ø × 30 *L/D* or 105 Ø × 24 *L/D*. This extruder will work at about 80 rpm at maximum production which is sufficient.

i) For PET it is recommended to use a non-stop filter, requiring at 120 s average dwell time about 1 m^2 filter area.

j) Sand filters are recommended in the spin pack.

k) Length of the quench chamber: from $v \cdot \text{dtex} = 3600 \cdot 167/52 \cdot 1.4 \approx 1.62 \cdot 10^4$ results a quench way of at least 0.8 m length.

l) Spin finish oiling system: For POY adjustable in the quench chamber from 0.9 ... 1.5 m below the spinneret. 0.8% of yarn weight finish application in 20% concentration in water require 84.17 · 0.008/0.2 = 3.367 g/min ≈ cm^3/min; at 40 ... 60 rpm of the finish oil pumps these must have a size of 0.06 cm^3/revolution with 8 streams per position.

m) Floor interconnection tube: One room arrangement: about 1.0 ... 1.5 m in length, rectangular, open on top and bottom, with 650 mm inside width and about 400 ... 450 mm depth = the lower quench chamber depth; in old buildings: from the quench chamber floor to the upper edge of the spin winder, with a lower flap and a yarn discharge slit. This requires a pressure differential regulation between the air conditionings in the spinning and the winding room.

n) Turning of the filament planes: The spinnerets are positioned parallel to the winder front, while the winding heads are positioned vertically. Thus the filament planes have to be turned between the oiler pins in the quench chamber and the stop motion beam about 700 mm above the winding heads within the longest possible distance with the smallest possible deviation angle.

o) Stop motion: One contact free stop motion device per filament passage, i.e., 4 each in every aforementioned stop motion beam.

p) Chip storage above the spinning extruder: For PET one upper (e.g., with 8 h ≙ 1 shift storage) and one lower with 1 h storage corresponding to the filling time of the upper storage and plenty of reserve time. About 400 kg/h chips require 600 l/h; i.e., the upper storage should have about 5 m^3 and the lower about 0.6 m^3 volume. With an automatic chip level supervision and feed the volume of the upper storage can be reduced considerably. During filling the upper and the lower storage are separated by a chip gate valve DN 120. The transport medium has to correspond to the requirements of dry PET. Before rinsing with dry gas the upper chip storage should be evacuated with a water ring pump to about 40 mbar.

As it can be assumed that over the course of a whole year not only one titer is spun on an installation, the annual spinning program has to correspond to this. The required changeover times have to be reduced to a minimum, allowing a few different titers as possible on one spinning machine. The capacity of the spin extruder installation should also be limited to e.g., somewhere between the spinning machine maximum and 40% of the maximum to avoid lengthy dwell times of the melt.

To determine the running times per titer on an installation it is useful to calculate the running length of the individual titers:

$$\text{km filament length} \times \text{dtex} = 10^7 \cdot \text{t/a} \quad (4.15)$$

$$\text{km/min (spin take-up)} \times i\text{(draw ratio)} \times 1440\ \text{min/a} \times 330\ \text{working days/a} = \text{km filament length/spinneret} \times \text{year} \quad (4.16)$$

Both these formulas shall be explained in the following example with a total capacity according to a) of 5640 kg/24 h ≙ 1860 t/a:

44 dtex: 77 dtex: 132 dtex: 167 dtex:	744 t/a = 40% ≙ 16.9091 · 10^7 km/a 372 t/a = 20% ≙ 4.8312 · 10^7 km/a 372 t/a = 20% ≙ 2.8182 · 10^7 km/a 372 t/a = 20% ≙ 2.2275 · 10^7 km/a
	1860 t/a = 100% ≙ 26.786 · 10^7 km/a ≙ 111.8 spinnerets ≙14 positions of 8 spinnerets each

The annual filament km-production results from 3.6 [km/min spin take-up] × 1.4 [residual draw] × 1440 min/24 h × 330 working days/a ≈ 2.4 × 10^6 km/spinneret × year.

The same result is achieved by calculating via the average spinning titer: From the running length per year and the production in t/a follows:

$$\text{dtex}_{\text{average}} = 10^7 \cdot [\text{t/a}]/[\text{km/a}] \quad (4.17)$$

$$\text{(in this example)} = 1860/26.786 = 69.44\ \text{dtex}$$

With this one can continue calculating as in a).

4.6.2 Survey of Melt Spinning Installations for Filaments

Melt spinning installations consist in principle of machines of the same name that differ only in technical details, depending on the starting material and the product of this production step. Figure 4.60 shall illustrate this [33]. The upper part consists of one chip storage or two (g), the spin extruder (f), the melt supply pipe (e) to the spinning head (c) with inner installations, the air quench chamber (i), the finish oiler system (j) and the floor interconnection tube (k) for the protection of the filaments on their way to the take-up machine.

For spin take-up there are various alternatives depending on the final product: The center Fig. 4.60 shows a POY spin take-up machine without godets for 2 × 6 filaments per spinning position (*n*) with the stop motion devices (*m*) positioned above. In the right figure an one step drawing system (*r*) is added for the production of FDY. The left figure shows a 4 filament carpet yarn spin take-up machine with a spin finish system (*q*), draw godets (*r*), air texturing aggregate (*s, t*) and two 2-filament spin take-up heads for this BCF yarn. Of course the corresponding extruders have the capacities which correspond to the spin take-up parts, and the spinning heads have the corresponding spin pumps, spin packs, and spinnerets.

Additional design possibilities for the spin take-up machines are the LOY spin take-up machines with 2 godets per spinning position (see Chapter 4.9), POY spin take-up machines with godets, especially to separate the spin take-up tensions and the winding tension, draw winding machines with 2 hot draw zones and those with pretension and 3 hot draw zones, as especially used for spinning tire cord.

Additional differences become obvious in the following figures:

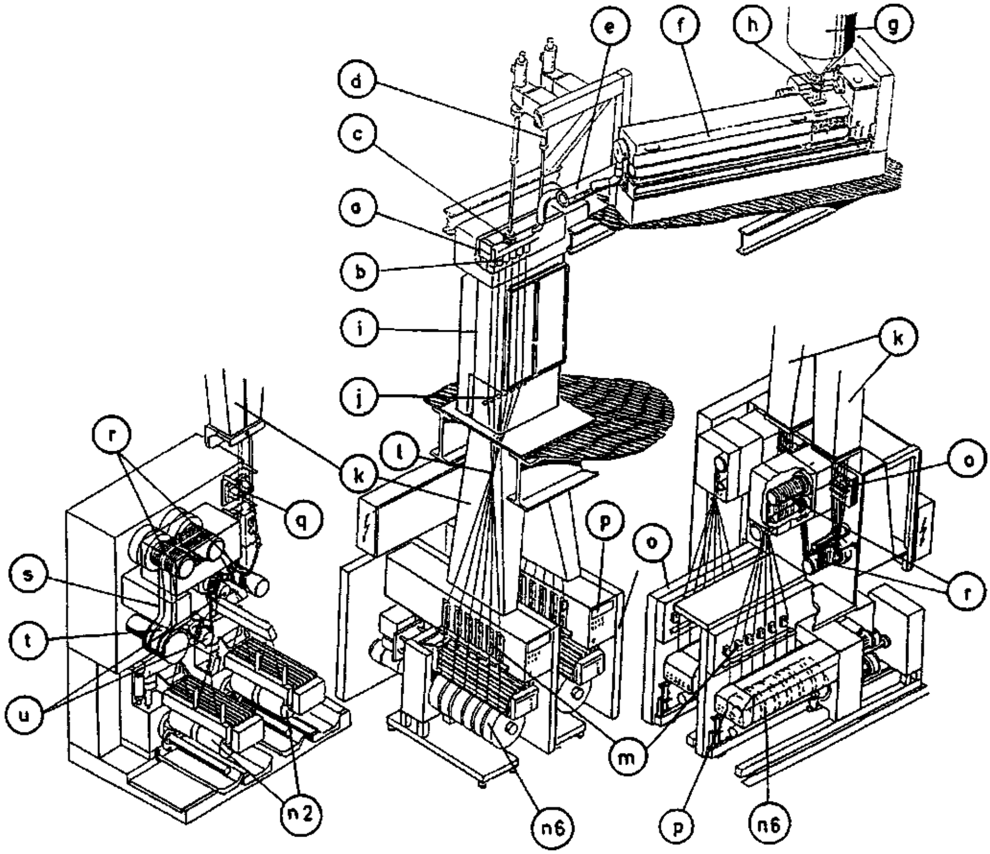


Figure 4.60 Principle design of a melt spinning machine (Barmag AG [33])

a) Spinning beam with
b) Spin packs
c) Spinning pumps
d) Spinning pump drives
e) Non-stop filter system
f) Spin extruder
g) Chip hopper
h) Chip gate valve
i) Air quench chamber
j) Spin finish application in quench
k) Floor interconnection tube
l) Turning of the filament plane
m) Yarn sensor system
n) High speed winders for textile, technical or carpet yarn with 2 to 8 spun packages each,
n6) Revolver winder for 6 packages
o) Noise absorbent walls
p) Winder control elements
q) Spin finish system on the take-up machine
r) Godets, hot or cold, with idler rolls or godet duo
s) BCF texturing aggregate
t) BCF cooling drum
u) Filament pretensioning system
v) Melt supply pipe
w) The same symbols are used in Figs 4.60 to 4.64
x) Drive for quendi-applied spin finish
y) Conditioned supply air
z) Dowtherm (Diphyl) loss condenser
α) Melt pipe
β) Bobbin take-off and transport
γ) Bobbin doffer
δ) Return air duct
ε) POY take-up machine
φ) Waste yarn container

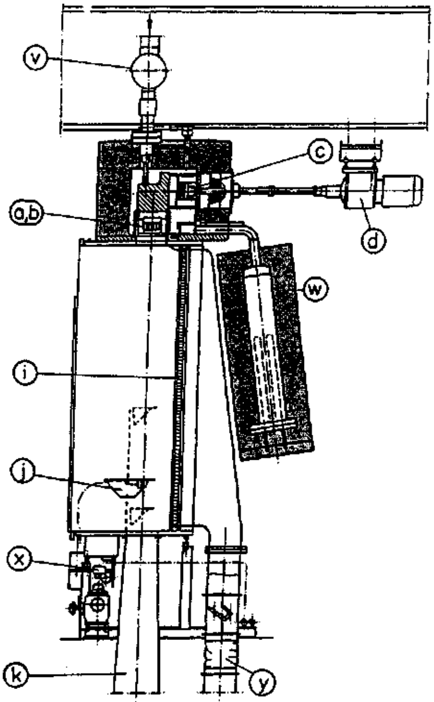


Figure 4.61
Section through a melt-spinning beam and quench cabinet. (K. Fischer [51]; symbols as in Fig. 4.60)

- Figure 4.61 shows the spinning part of a POY spinning plant with the melt supply pipe (*f*), spinning head (*a–c*, *h*) and the Dow vapor boiler (*d*), the air quench chamber (*i*) spin finish system with dosing pump (*j*) and the floor interconnection tube (*k*). Here usually 4 to 12 spinnerets (*a*) are arranged in parallel drawing planes to each other [51].
- Figure 4.62 presents a sectional and frontal view of a PET spinning plant without godets [22]. The legend explains the details.
- A tire yarn spinning plant with the corresponding spin take-up machine [22] for 2-filament spinning, drawing, winding is shown in Fig. 4.63, and a BCF spinning plant for 3-color yarns is shown in Fig. 4.64.
- The following should be noted in addition to the exemplary calculations in Table 4.16:
  1. The usual production rpm for the extruder should be $< n_{max}$.
  2. The spin pump rpm follows:

$$n_{spin\ pump} = \text{g/min} \cdot \text{spinneret}/\{(\text{g/cm}^3)_{melt} \cdot (\text{cm}^3/\text{revolution})_{pump}\} < \approx 40 \text{ rpm} \tag{4.18}$$

  3. The melt data are specific to the material and corresponding measured values or experiences.
  4. Some materials, especially PA and PP, require spin smoke to be sucked off until about 100 ... 150 mm below the spinneret.
  5. The spin finish is specific to the material and process and has significant influence on winding, number of breakages, and drawing.
  6. The quench chamber conditions depend on individual titer and individual take-up speed as well as on the material and its glass transition temperature.
  7. The godet surface speed follows:

$$v[\text{m/min}] = (10^5 \cdot \text{g/min})/(i \cdot \text{dtex}) = (10^6 \cdot \text{kg/h})/(6 \cdot i \cdot \text{dtex}) \tag{4.19}$$

  with i = residual draw ratio and dtex of the final titer.

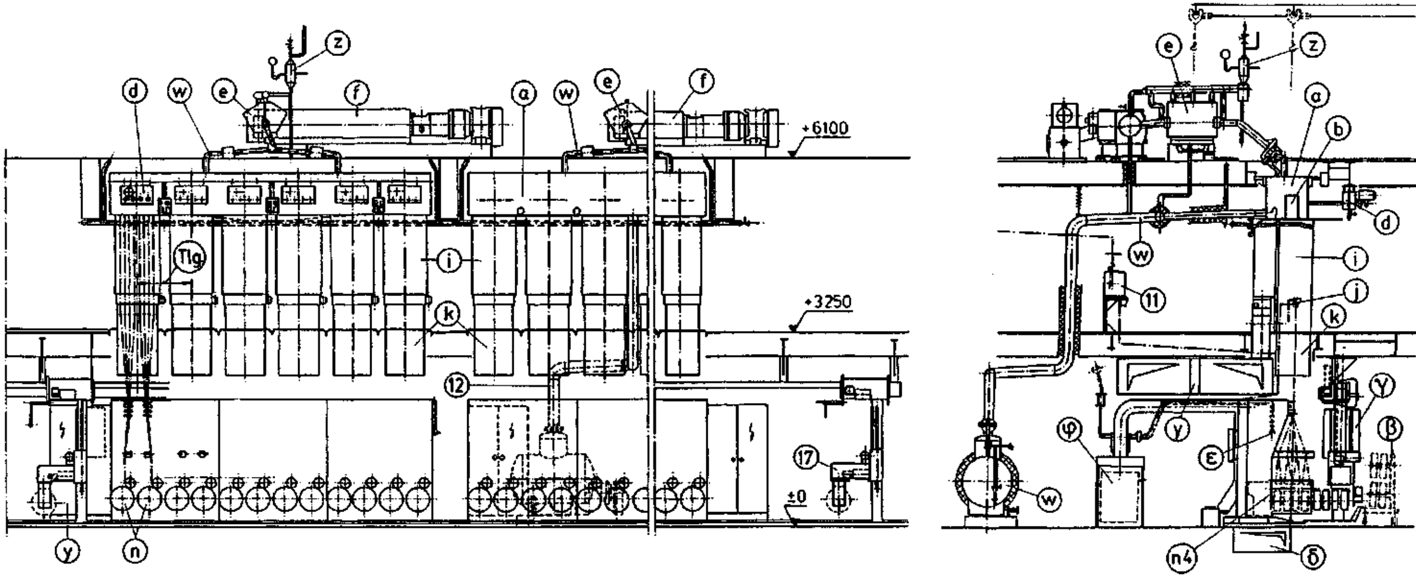


Figure 4.62 PET-POY spinning plant with 6 + 12 positions of 2 × 4 ends each; nominal capacity: 16.5 t/24 h for 167 dtex final titer (Automatik [22]); symbols as in Fig. 4.60.
The complete plant comprises 3 (extruders, melt filters, spinning beams and spinning pump drives) (Automatik), 3 × 6 air quench chambers (Fourné), 3 POY take-up machines with 12 high speed winders each, 1 doffer (AWB) and 1 external Dowtherm (Diphyl) vapor heating system

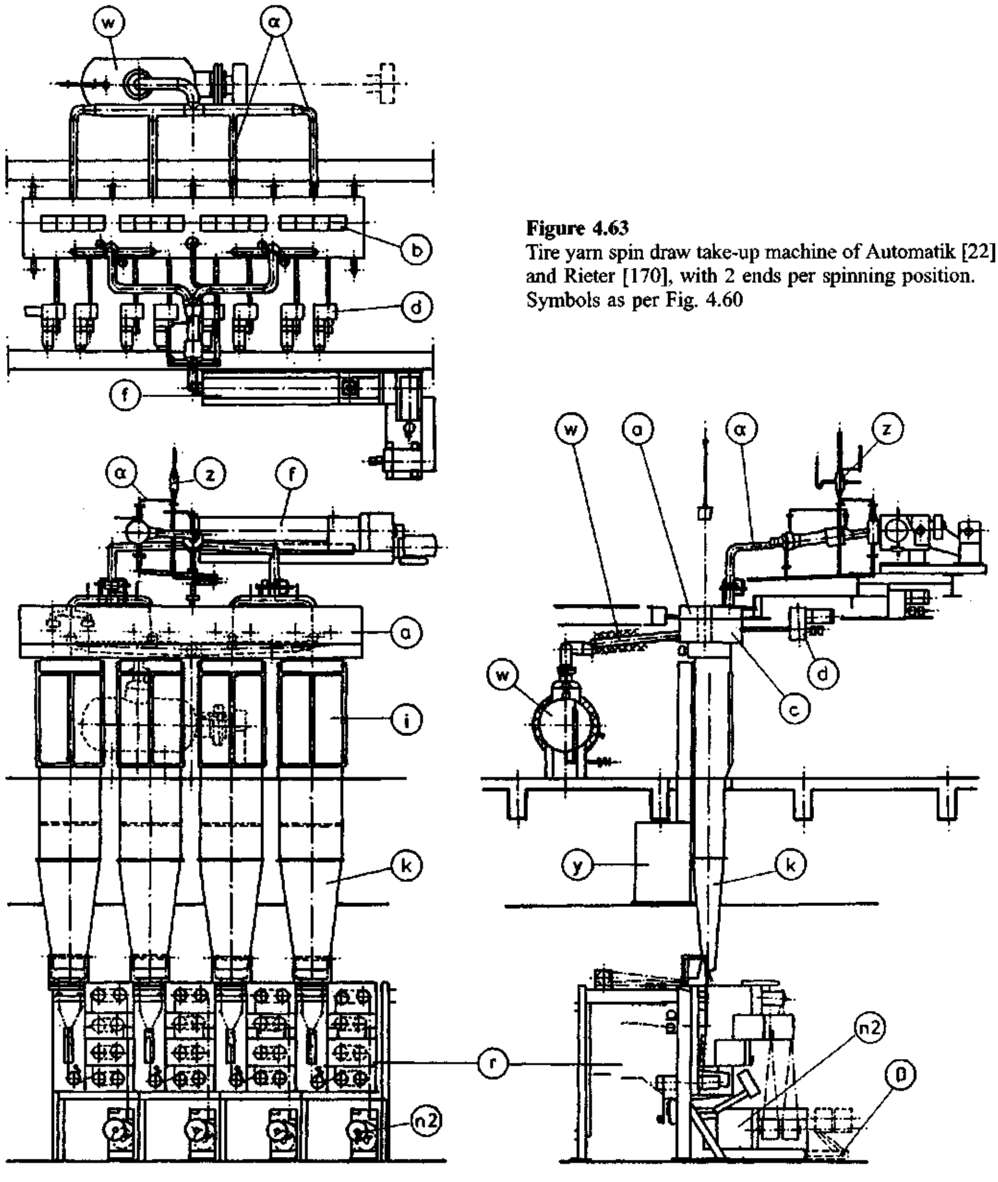


Figure 4.63
Tire yarn spin draw take-up machine of Automatik [22] and Rieter [170], with 2 ends per spinning position. Symbols as per Fig. 4.60

8. The double stroke number of the winding head results from the minimum traverse angle of about 7 ° (see Chapter 3.7).
9. The number of yarn packages per winding head has to be either equal to or an integer portion of the spinnerets per position.
10. Up to 5000 ... 6000 m/min winding speed friction driven winding heads can be used—dependent of the yarn type and finish; beyond that they should be spindle driven.
11. The maximum electric supply values follow from:
Sum of all motor connection values (without frequency drive) plus
Sum of all electric heater connection values (without inductive heaters) plus

Sum of all supplies for frequency drives (see Chapter 7.1.3) plus
Sum of all electric supplies for inductive heaters.
The total cos φ has to be considered here. In a good design the continuous operation supply should only be 55...70% of the maximum supply.

12. Compressed air supply: The compressed air nets for filament suction (machine installed and manual) and possibly for the texturing jets have to be completely separate from the control compressed air for the winding heads and the process compressed air for possible air suspended idlers and the compressed air for the controls to avoid a breakdown of the latter net during activation of the before mentioned aggregates. Pressure ranges and compressed air conditions see Chapter 6.5. For each of the aforementioned compressed air sets separate storage tanks have to be provided.
13. Process parts: As the installed sets of spin pumps, spin packs, spinnerets, filters, etc., all the way to the winding tubes have to be changed, cleaned or replaced periodically or occasionally, the following is needed:

- Manual filament suction device corresponding to the titer and speed range.
- Spin packs and spin pumps: at least two complete sets, one installed and the other in reserve or cleaning, in part in the preheating oven. 2.5 are better, 3 sets are safe plant equipment.
- Spinnerets: Depending on the plate and boring dimensions and the number of fibrils: 2.5...3 sets.
- Spin filters: The number of spin packs × 350/spinneret running time (days) are the usual yearly requirement. It needs to be considered that usually several filters per spin pack are installed.
- Quench chamber accessories: 0.5 sets of the air supply filters and the rectifiers for changing and cleaning need to be provided.
- Stationary thread guides and suction pipe tips: 5...10 sets are needed.

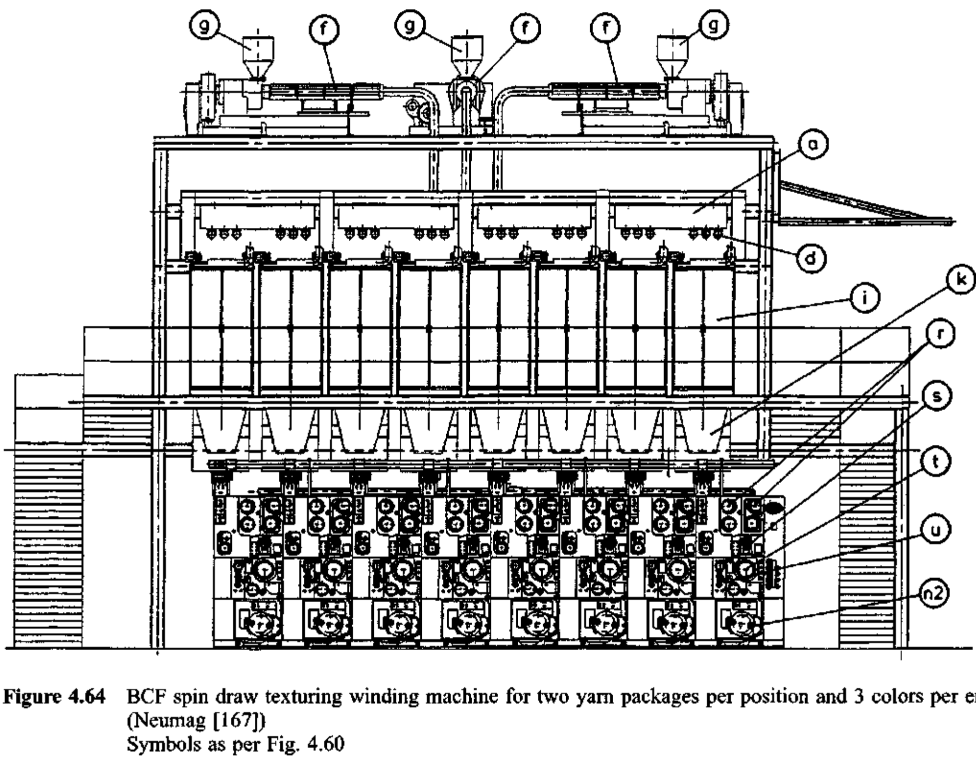


Figure 4.64 BCF spin draw texturing winding machine for two yarn packages per position and 3 colors per end (Neumag [167])
Symbols as per Fig. 4.60

- Traverse yarn guide and gliding inset: For start-up one set per week but at least 20 sets should be provided, possibly bicomponent adhesive.
- High speed winding head timing belts require due to the high rpm and the resulting usage a storage of 20 ... 50 pieces per winding head.
- Winding tubes for POY and FDY are one-way tubes. Monthly supply = 30 d × 24 h × number of winding heads × number of tubes/winding head/h running time per tube + (10 ... 20)% reserve.

  Further important spare and operation parts are:

- for the spin pumps gear sets, shafts, and speciality parts,
- temperature measuring elements for the extruder, for the spinning head and possibly for the heated godets,
- melt pressure measuring elements and melt temperature measuring elements that can easily be damaged, especially by incorrect start-up,
- speciality screws for pumps and spin packs: Minimum requirement: 2 ... 4 sets,
- extruder screws (due to their long manufacturing time of over 4 ... 5 months),
- for large plants: complete high speed winding heads, bobbin chucks, friction and traverse drums, godets and possibly induction heaters.

14. To run the plant certain auxiliaries are also needed, e.g.,

- preheater ovens that heat the spin packs and spin pumps to 20 ... 30 °C above spinning head temperature to keep the down times for necessary changes as low as possible. This can be done with standard heaters for up to 300 or 350 °C (for PP, PA, PET) [58] or in larger plants such heaters where the muffles match exactly the part that require preheating. The oven volume results from: About 18 × surrounding volume of the installed packs/spinneret running time [d] + about 20 × surrounding volume of the installed pumps/pump running time [d]

$$\frac{\text{ca } 18 \times \text{Envelopping Volume of the Installed Spin Packs}}{\text{Pack Running Time [d]}} \times \frac{\text{ca } 20 \times \text{Envelopping Volume of the Installed Spin Pumps}}{\text{Pump Running Time [d]}} \tag{4.20}$$

  According to this, for example 64 installed packs with 1 l each and 14 d spinneret running time plus 16 4fold pumps with 1.8 l and 90 d pump running time require a preheating oven of about (90 d + reserve) l. The next size according to the catalog [58] has the dimensions 500 × 600 mm^2 inside front × 400 mm depth.
- Cleaning installations [24]: For PET, for example, TEG cleaning installations with a full cleaning cycle of about 24 h are recommended, or for all polymers vacuum burnout ovens with a cleaning cycle of 6 ... 8 h. Large surface filter candle sets are usually cleaned in TEG. The determination of the volume follows analog to the one for the preheating ovens. If no holes of less than 0.25 m diameter have to be cleaned, an Al_2O_3 cleaning installation with subsequent exhaust cleaning can be chosen. In very small spinning plants possibly an air burnout oven up to 550 °C may suffice, but it requires considerable mechanical postcleaning.
- Air conditioning: The necessary requirements are explained in Chapter 6.2.
- Bobbin transport wagons and handling equipment: Spinning bobbins with more than 10 kg yarn weight should not be moved manually because the yarn can be damaged too easily. Bobbin handling equipment (Chapter 6.1), or for larger plants, automatic doffing equipment (Chapter 6.1) are suited for this. Bobbin transport wagons need to be laid out for about 1 day's requirement to transport the bobbins to the corresponding next process step. Combined wagons as creels have the advantage of reduced handling; or cans for tow for staple processing: (2.5 to 3) times the number of cans in the can creel should be available.

For the continuous running of the plant certain raw materials need to be stored as well. Table 4.16 shows the storage quantities for chips and spin finish for 30 days for the aforementioned examples. The necessary storage days have to be determined on location. In addition to this other materials and auxiliaries have to be stored.

Even if chips (except for PP) are delivered ready for spinning, an emergency drying should be provided in case the chips were in contact with outside air.

4.6.3 Chip Gate Valves

Chip storage and intermediate storage tanks are described in Chapter 4.4.2.

To block specific transport pipes and passages, Figs. 4.65 and 4.66 show two possibilities of such gate valves. The first is manually operated with the tank connection above, two solid plates, a frame for the gate positioned on the inside and the spindle sealed pressure and vacuum proof towards the outside. In the transport direction it is chip proof, but not pressure and vacuum proof [24].

Vacuum proof in the direction of the chip transport as well as to the outside up to 10^{-3} mbar is the chip gate valve according to Fig. 4.66 [57]: Turning of the gate lever causes after pushing the gate the opening or closing of the hydraulic sealing (*hD*) by a piston. The gate is only 2...3 mm thick.

Traditional ball valves are frequently used here, but they are not recommended, because they are not free of dead space during the turning of the ball, and the seals to the ball are usually made from PTFE or similar and thus are softer than the chips. Therefore they can easily be damaged and do not remain pressure and vacuum proof.

In all cases installing capacity level sensors for the maximum and minimum level in the chip storage is recommended to control the valves for the chip supply accordingly.

4.6.4 Spin Extruders

Around 1960 for the first time Dow vapor heated grid spinning heads for filament formation [59, 60] from PA and PET were replaced by modified extruders. A spin extruder in principle looks like in Fig. 4.67 [69] and thus like the known extruders in plastic processing. There are some significant differences, that are caused by the application:

- It has to be laid out for uninterrupted continuous 8400 h operation,
- the chip feed has to be water cooled and vacuum respectively nitrogen proof,
- screw and cylinder have to be resistant to corrosion,

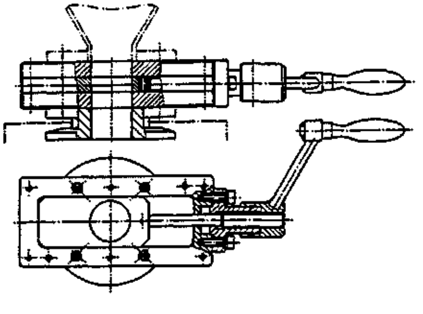


Figure 4.65
Chip gate valve, tight to outside only [24]

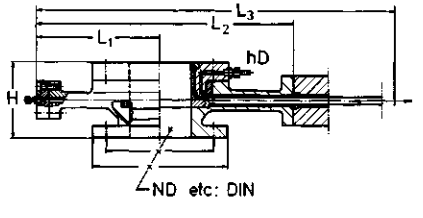


Figure 4.66
Chip gate valve, tight to inside and outside [59], for up to 10^{-6} bar (hD = hydraulic seal)

NW	20	50	65	100	150	200	250	300
H	80	10	120	120	120	150	150	165
L_1	67	125	147	202	275	355	425	500
L_2	140	260	310	418	550	720	865	1125
L_3	240	460	510	680	850	10060	1280	1630

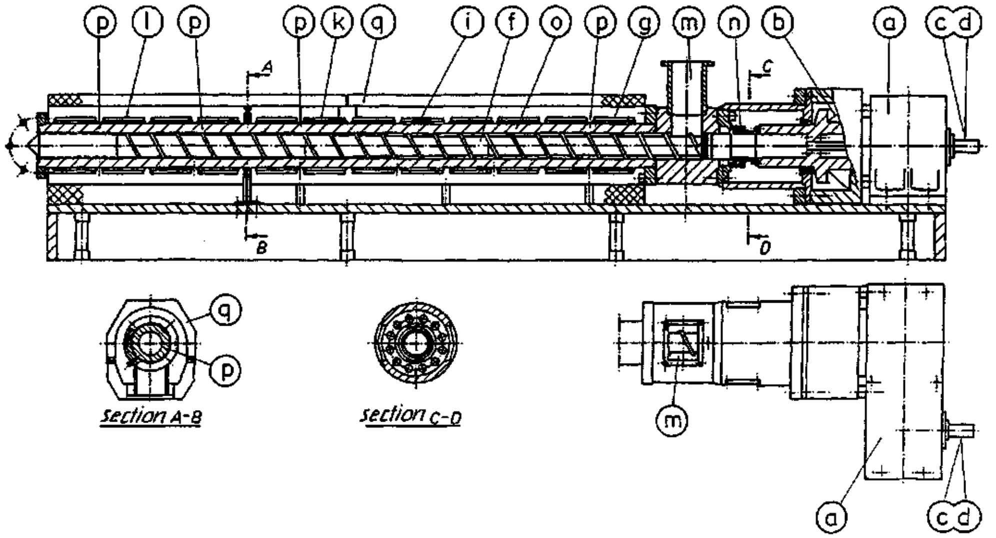


Figure 4.67 Spin extruder [22]

a)	Reduction gearbox	*g*)...*l*)	Heaters and heating zones
b)	Thrust bearing	*m*)	Feeding zone
c)	V-belt drive	*n*)	Shaft packing (sealing)
d)	Slipping and/or overload clutch in a) or c)	*o*)	Extruder barrel (cylinder)
f)	Extruder screw	*p*)	Temperature measuring elements
		q)	Insulation cover

- a cylinder heater with steps corresponding to the local requirements,
- best melt homogenity and constancy, especially with respect to the melt temperature and pressure.

These extreme conditions and the relatively small market led to only a few companies working in this specialty area [33 85, 86, 22]. Since 1970 until today only about 20,000 spin extruders of 20...300 mm screw diameter have been sold worldwide. In addition to this is a low number of double screw extruders [89, 93].

4.6.4.1 Single-Screw Spin Extruder

Asides from the aforementioned details the melt pressure and temperature are measured as closely as possible behind the screw tip in the direction of the flow. The melt temperature measuring element should stick at least 10...20 mm into the melt to avoid measuring undefined averages to the wall temperature. Nitrated materials for screws and cylinders as usual for plastic extruders will corrode after some operating time and significantly lower the filament quality. Therefore usually bimetal cylinders with corrosion resistant coating [78, 79, 80] and if needed screws from corrosion resistant materials are used which are ionitrated. The operating pressures for most textile raw materials are between 80 and 150 bar, and the melt temperatures are between 220 and 320 °C. In special cases up to 500 bar and/or 500 °C may be needed. The operating rpm for extruders of about 50 mm screw diameter are adjustable between 20 and 130 rpm and for $D = 250$ mm between 15 and 80 rpm. Considerably larger single-screw extruders were not successfully introduced for spinning, because the necessary melt distribution ways are too long as are the resulting melt dwell times.

Melt Quantity and Quality

These are primarily determined by the screw geometry and rpm, possibly in connections with a mixing head (Fig. 4.68), as well as by the heating distribution. Extruder screws can be divided into four zones,

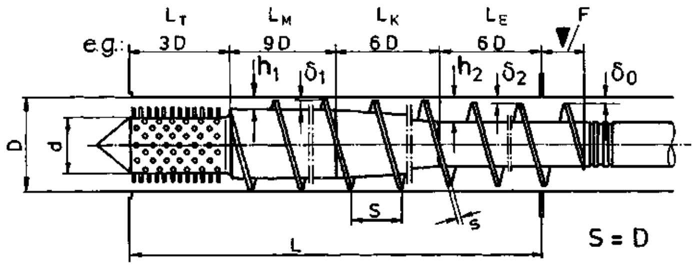


Figure 4.68 Extruder screw with mixing torpedo

D)	Diameter (cylinder, inside H7)		
L)	Total working length	*s*)	Flight width
F)	Feeding zone	*h*)	Flight depth
L_E)	Transport zone	d_{index})	Core diameter at index
L_K)	Compression zone	δ_0)	Clearance (between barrel inside- and outer screw diameter), in the feeding zone
L_M)	Metering zone		
L_T)	Mixing zone (mixing torpedo)	δ_2)	δ in the zone L_E, $L_K \ldots L_M$ or L_T
S)	Pitch (usually = D)	h_2, h_1)	Screw depth in the zone L_E, respectively L_M

but only the metering zone (L_M) is relevant for the capacity, and (L_M) together with the mixing torpedo (L_T) are relevant to the homogeneity of the melt. The compression zone (L_K) respectively the depth ratio h_2/h_1 cause the pressure build-up (Fig. 4.74). The draw-in zone (L_E) may not be too short so that the achieved chip friction until the beginning of the compression zone provides a safe passing of the compression zone. The mixing zone homogenizes the melt and removes inside/outside effects, e.g., irregularities in the temperature.

Under the condition that the aforementioned values are in the correct ratio to each other the melt conveying quantity can be approximated with the following formula [81]:

$$G = 72 \cdot \delta \cdot D^2 \cdot h_1 \cdot n - (734.4 \cdot D \cdot h_1^3 \cdot p \cdot \delta \cdot 10^4)/(\eta \cdot L_M) \tag{4.21}$$

with G = melt throughput [kg/h], δ = density of the melt [kg/m^3], D = screw diameter [m], η = melt viscosity [Pa · s], L_M = length of the metering zone [m].

Here are the groove incline = D, the angle = 17°40′, and the passage width $s \approx 0.1 \cdot D$. The first term describes the drag flow, the second the pressure (re)-flow. A third term for the leakage flow through the slit δ_1 between the screw outside diameter and the cylinder inside diameter is mostly negligible. Table 4.17 shows the results of some sample calculations. Figure 4.69 shows the evaluation of extruder capacities according to manufacturer information. Above D = 100 mm the production increase is somewhat less than according to the interpolation formula in Fig. 4.69, because the screw groove depths h_1 become relatively smaller to obtain sufficient melt homogeneity.

Table 4.17 Values of the First and the Last Corrective Term for PET in Formula (4.21). δ = 1250 kg/m^3, η = 250 Pa · s, L_M/D = 10, p = 100 bar

D mm	h_1 mm	$n_{max.}$ rev.	G_1 kg/h	ΔG kg/h	G kg/h	$\Delta G/G$ %
25	1.6	135	12.15	1.5	10.6	14.15
50	2.8	115	72.45	8	64.5	12.4
100	4.3	95	367.7	29	339	8.55
150	5.2	85	895.0	52	843	6.17
200	6.5	80	1872	101	1771	5.70

It is possible to increase the production rate by about 20...30% by arranging two extruders in a row, the first as a melt starting extruder with chip feeding, the second as a melt extruder that homogenizes the received melt at almost constant temperature (Fig. 5.3 [33]). A large area non-stop-filter similar to Fig. 4.129 should be installed behind this.

Screw Dimensions

There is extensive literature on the theoretical dimensioning of extruder screws [63, 69, 70] that we are only referring to. For the approximate dimensioning of spinning extruder screws a more statistical way is used here.

From formula (4.21) the approximate cut depth (groove depth) of spin extruder screws in the metering zone can be obtained:

$$h_1 \approx (1 + \Delta G/G) \cdot G/72\gamma D n_{\max} \quad (4.22)$$

The resulting h_1 is entered into formula (4.21), G can be obtained from this and h_1 is improved stepwise until the desired G is reached. The latter may only exceed the values in Fig. 4.69 by a few % to guarantee sufficient melt homogeneity. Figure 4.70 shows a statistical evaluation of the cut depths h_1 of spin extruders.

According to this the cut depth in the metering zone is chosen deeper with a mixing torpedo than without. For screw diameters larger than 70...100 mm the cut depth increases with the diameter slower than for smaller diameters what confirms the results in Fig. 4.69.

The effect of a mixing torpedo is shown in Fig. 4.71: While a normal screw without mixing torpedo has a temperature distribution of $^{+10}_{-5}$ °C, this range is reduced for a shear screw to $^{+7}_{-3}$ °C and for a pure mixing head to the screw to ±2 °C [81].

The normal screw has passages as in Fig. 4.72 that spiral around the core with the slope *D*. Mixing torpedos for spin extruders should limit the shearing work to keep the resulting temperature increase in the melt at a minimum. Figure 4.73 illustrates some screw mixing elements that proved useful in spinning. Its length is mostly 3 *D*. The designs *a*, *b*, and *e* work in a cylinder that is smooth on the inside, while *c* and *d* require an inside profile in the cylinder wall in addition to the screw profile.

Here it shall only be noted that there is a problem with different dwell times of the melt in the areas near the wall and in the center of a screw groove [84]. Due to the tacking of a liquid at the wall the dwell time in the wall zone ($\approx 0.05 \cdot h_1$) can be 3 to 6 times as long as in the center area [$\approx (0.2...0.9) h_1$).

The compression of the screw can be defined in two ways: The depth compression $x_t = h_2/h_1$, that for screws of $D \approx 25$ mm can be 3.0...3.4...3.8, and that is reduced with increasing diameter to reach about 2.7 at $D = 200$ mm. The volume compression corresponds to the ratio of the cylinder ring area at h_2 to the cylinder ring area at h_1 and is quite independent of the diameter, but it is rarely needed.

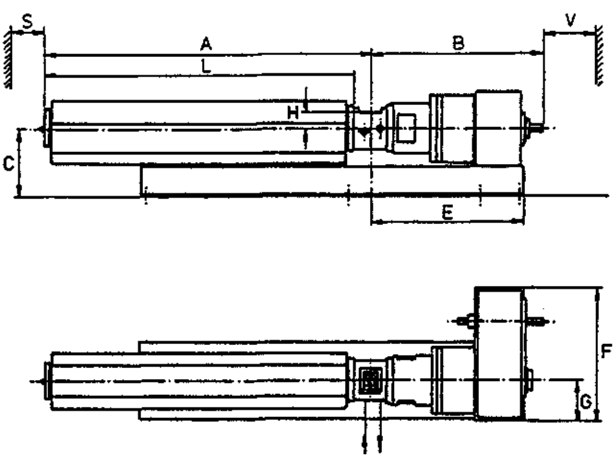


Figure 4.69a
Definition of dimensions for the extruder selection table

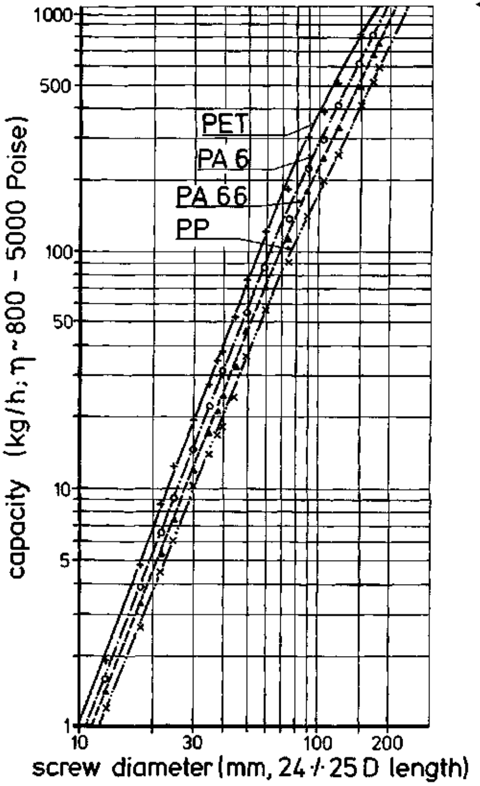
Figure 4.69a continued

Selection table for extruders with D ≤ 180 mm [22], D = 25 ... 300 mm [33] and D ≤ 22 mm [24]

Screw Ø mm	n_{max} min⁻¹	Drive kW	Zones No. off	Heaters kW	Capacity kg/h PET	PA 6	PA 66	PP
13[1)]	150	0,7	3	1,0	2,4	1,8	1,4	1,1
18	150	1,3	3	1,8	6,2	4	3,4	2,6
22	140	2	3	2,5	9,6	6	5,1	4,5
25	135	3	4	3,2	12,5	8	6,7	6,0
30	130	4	4	4,5	20	13	10,4	10,1
40	125	10	4	8	38	26	22	18
45	120	12	4 (5)	10	52	34	29	24
50[2)]	120	12[2)] 15	4 5	13 16	75 90	54 65	45 52	36 42
60	120	25 30	5 6	19 22	120 145	85 100	70 80	56 65
75	100	32 38	5 6	26 30	180 215	135 160	110 130	90 105
90	100	48 56	5 6	40 45	300 360	220 260	175 200	140 170
105	100	70 80	6 7	50 58	380 450	290 340	240 280	195 230
120	90	90 110	6 7	66 80	500 600	400 480	320 380	250 300
150	90	140 160	6 7	80 93	800 960	600 720	480 570	395 500
170	85	180 210	6 7	108 120	1050 1200	800 950	650 750	500 600
180	85	200 240	6 7	108 120	1200 1350	910 1050	740 850	580 700
200					1600 1900	1200 1440	850 1020	685 980
250					2400 2800	1800 2100	1250 1500	1000 1450
300					3300 3900	2300 2700	1600 2000	1300 2000

Dimensions (mm) (Fig. 4.69a) A	B	C	E	F	G	H	Screw dismantling S	V	Weight ca. kg
322	388	108	252	–	80	80	450	250	65
459	394	231	257	–	90	90	615	270	100
561		231	257	–	90	90	715	320	180
638		310	403	–	125	176	910	420	360
765		310	403	–	125	176	930	420	720
1020		335	475	–	138	185	1445	500	910
1148		335	475	–	138	185	1575	500	980
1315 1615	810	400	710	500	160	75	1700 2000	750	1050
1550 1910	920	460	820	550	180	87	1900 2260	750	1630
1920 2370	1090	450	945	600	180	100	2600 3050	1000	1980
2300 2840	1210	510	1068	740	260	125	2700 3240	1200	3100
2690 3320	1320	530	1170	825	285	140	3600 4250	1400	3900
3050 3770	1640	630	1415	1190	360	150	3700 4400	1400	4700
3800 4700	1730	700	1525	1170	350	180	4900 5800	1400	
4300 5320	1800	800	1570	1115	425	170	5500 6500	1400	
4560 5640	1850	800	1635	1165	400	170	5800 6800	1400	

Screw length = 25D
Screw length (upper figure) = 25D
Screw length (lower figure) = 30D



◀ **Figure 4.69b**
Usable melt capacity of extruders at spinning (from experimental results for L/D = 24 ... 25). Interpolation formula:
$G\ (\mathrm{kg/h}) \approx 1.17\ \gamma_{melt} \cdot d_{cm}^{2.36} \cdot (L:D/24)^{0.74}$

Material:	PET	PA6	PA66	PP
γ_{melt} [g/cm³]:	1.25	1.00	0.9	0.68

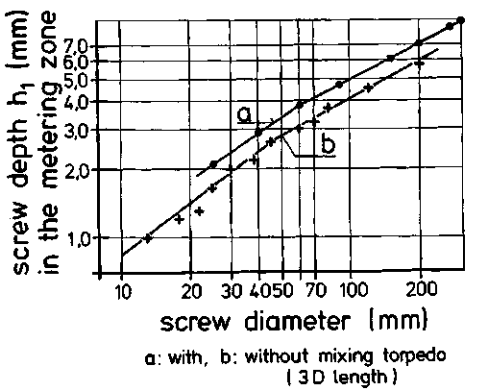


Figure 4.70
Extruder screw depth h_1 in the metering zone (L_M) as function of the screw diameter D (statistically)—a) with, b) without mixing torpedo of 3D length

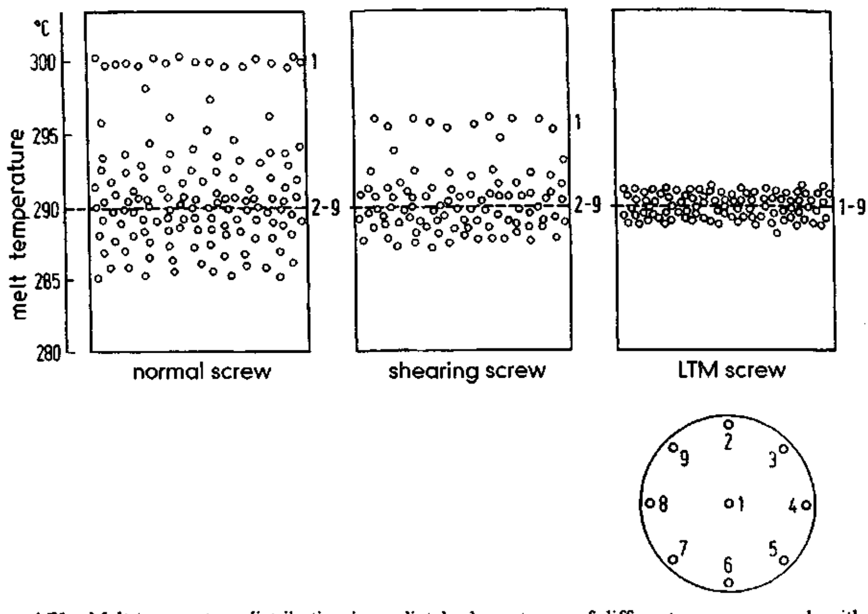
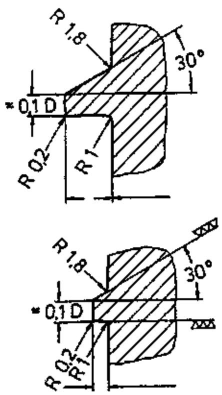


Figure 4.71 Melt temperature distribution immediately downstream of different screws: normal, with shearing screw and with mixing torpedo (LTM of Barmag [33])



◀ **Figure 4.72**
Screw flights a or b in Fig. 4.70

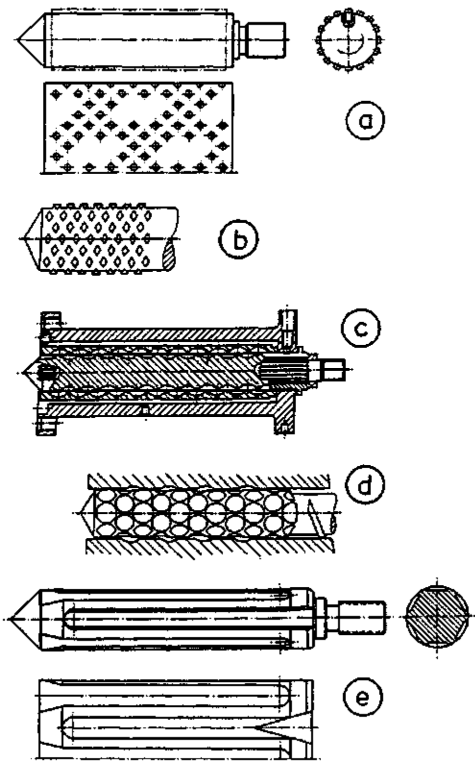


Figure 4.73
Extruder screw mixing elements
a) Pin mixer, e.g., Barmag's LTM [33] or Fourné's [24]
b) Rhomboid mixer with flights in clockwise and counterclockwise milling paths (simple to manufacture)
c) 3 DD mixer with countercurrent screw arrangements in the screw and barrel (Barmag [33])
d) Cavity transfer mixer (CTM) with ball-shaped cavities in screw at barrel (e.g., Gale/Rapra; Davy Standard, USA [85])
e) High shear (Maddock) mixer (the melt inlet channels are separated from the forwarding channels by a barrier)

The screw geometry considerably influences the pressure build-up in axial screw direction. Figure 4.74 shows some typical examples. The best method to measure is the installation of pressures sensors in the cylinder wall (e.g., type "Dynisco" [73]).

A speciality screw shape is shown in Fig. 4.75: the degassing screw. With it the melt is degassed of monomers, low boilers, humidity, etc. by arranging a vacuum in zone E_V. It is important of the construction that the subsequent transport zone M_S removes slightly more material from E_V than the first transport zone M_G feeds into it, so that zone E_V is not filled.

There are few theoretical concepts discussing the division of the screw zones. The feeding zone should build up sufficient pressure with the chip friction at the beginning of the compression zone to be able to overcome the latter. The compression zone should be long enough so that the chips are completely melted when entering the metering zone. A longer metering zone improves the feeding constancy and the melt homogeneity. 3*D* mixing zone length has been mentioned previously. A total screw working length of (24 ... 30) *D* considers the standard by now. A division into zone lengths according to Table 4.18 has proven useful.

As material for screws with $D \leq 40\,\text{mm}$ 1.4122 is preferred with 16.5% Cr and $\sigma_{0.2;\ 300\,°C} \geq 50\,\text{kg/mm}^2$, ionitrated and polished. Larger screws can be manufactured from the same material, but depending on the corrosion and friction requirements by the chips and the melt, the optimum material should be selected. For larger screws up to 600 °C material 1.4948 is recommended, ionitrated and polished. As a material for the cylinder material 1.4006 is preferred, inside centrifuged. The radial space at $D = 60\,\text{mm}$ should not be more than 0.05 mm and increase to 0.1 mm at $D = 200\,\text{mm}$. In the first 3*D* of the feeding zone the radial air is often increased to 0.3 ... 0.4 mm. The cylinder bore is in the DIN tolerance field H7.

Screw Drive Power

It theoretically has to be sufficient to melt the chips by transferring mechanical work into heat, i.e.,

$$N_{\text{screwshaft}} \geq G_{\max} \cdot (c \cdot \Delta T + S) \tag{4.23}$$

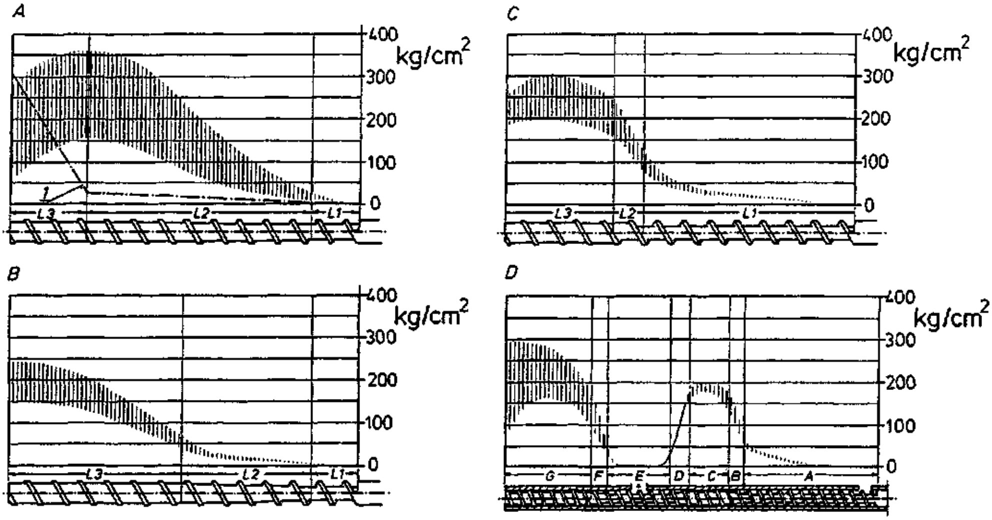


Figure 4.74 Approximate pressure build-up in single screw extruders
A) for a screw with short transport and feeding zones, and a long, progressive compression zone (1 = theoretical pressure)
B) for short feeding and compression zones and a long metering zone
C) for a short compression zone screw (≤ *D*)
D) for a 2-step degassing screw (compare Fig. 4.75)

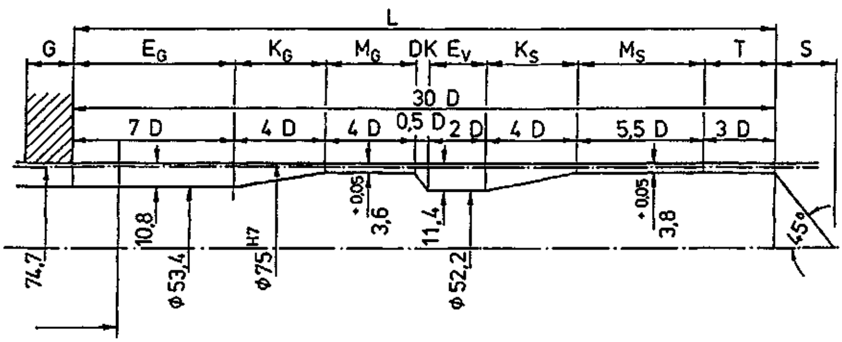


Figure 4.75 Example of a degassing screw (for internal barrel diameter = 75 mm, H7)

Table 4.18 Zone Lengths of Extruder Screws

D mm	*L*/*D*	L_E/D	L_K/D	L_M/D	L_r	For polymer
13...25	25	10	4	11	–	PET, PA, PP
30...50	25	9	4	9	3	PET, PA, PP
> 50	25	8	4	10	3	PET, PA
	27...28	8	4	13...12	3	PP
≧90	25	8	3...6	11...8	3	PET, PA
	28	8	3...6	12...9	3	PP
	30	8	4...5	14...13	3	PET, PP
200	30	8	5	14	3	PP

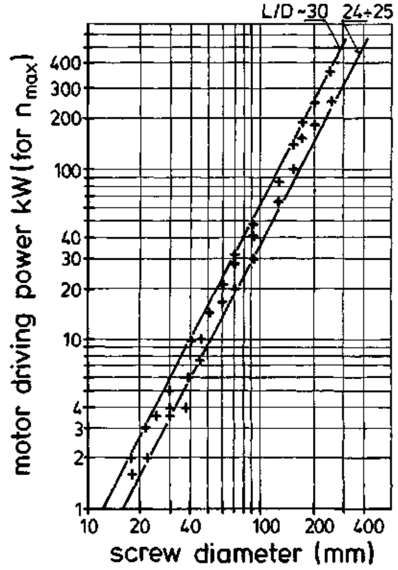


Figure 4.76
Motor driving powers of commercial extruders [22, 24, 33] with $L/D = 24\ldots25$ and 30. N_{max} (kW) $\leq 0.926\ D^{1.877}$ [cm]

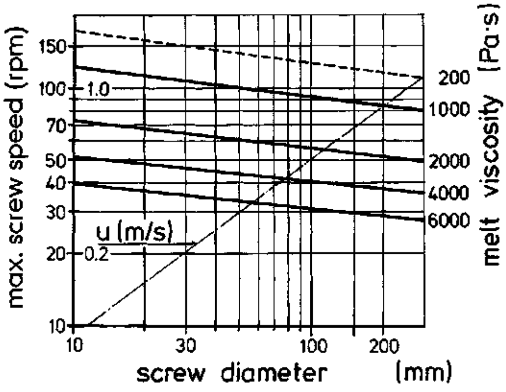


Figure 4.77
Maximum extruder screw speed as a function of the screw diameter D and the melt viscosity η

For large extruders the specific drive power N/G can be reduced slightly. Simplified: $N_{motor,\ max}/G_{max} = 0.23\ldots0.17$ kW/kg for $D = 25\ldots200$ mm.

Figure 4.76 shows a statistical evaluation of the spin extruder drive power.

Maximum Screw rpm

The numbers on production rates of spin extruders thus far, especially Fig. 4.69, refer to melt viscosities of 200 … 300 Pa·s. To avoid too high heating of the melt by shearing and friction the maximum screw rpm is reduced. Figure 4.77 shows some empirical values.

Grooved feeding zones as well as adiabatic extruders that heat and melt solely by frictional work, never obtained significance in spinning.

Heating Power for Extruder Cylinders

For spin extruders with $L{:}D = 24\ldots25$ the statistical diagram Fig. 4.78 can be summarized:

$$N_{heater} \approx 0.8 \cdot D[\text{cm}]^{\sqrt{3}}[\text{kW}] \tag{4.24}$$

For longer or shorter cylinders with degressive heating distribution from the chip feed to the front:

$$N_{heater,L_2} \approx (L_2/L_1)^{0.6} \cdot N_{heater,L_1} \tag{4.25}$$

Cylinder temperatures above 340°C also require a higher heating power:

$$N_{heater,T_2,max} \approx (T_2/T_1 = 340°\text{C})^{0.6} \cdot N_{heater,340°C} \tag{4.26}$$

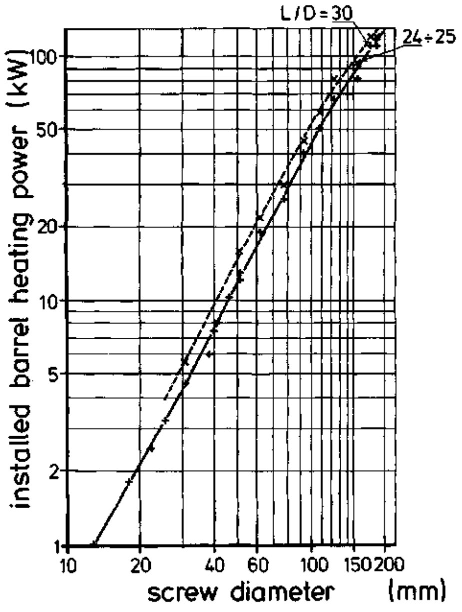


Figure 4.78
Statistical heating power of extruder barrels when using progressive heating rates, for $L/D = 24\ldots25$ and 30

Up to 340 °C Mecanit heating bands are used, above that up to 550 °C radiant/ceramic heating bands or resistor heaters cast in brass.

For degressive heating distribution the following scheme is recommended:

	from feed		to the		front flange
length	ca. $0.2L$	$0.2L$	$0.2L$	$0.2L$	$0.2L$
with about	42	27	15	8	8% of power input
at max. flux of	5…6	3…4	1.5…2	1	1 W/cm^2
for 340 °C max.					cylinder surface

Additionally there are two different operating systems for the heat temperature distribution along the cylinder (for spin temperatures ≈260…300 °C):

- water cooled feed with immediately following highest cylinder temperature, e.g., spin temperature (T_S) plus 60 °C, in the second heating zone $T_S + 40$ °C, in the third heating zone $T_S + 20$ °C, and starting from the fourth heating zone constant at T_S. This process is not critical, because the still cold chips are melted after the fourth zone and heated to melt temperature, or
- with increasing temperature, e.g., water cooled feed with directly following T_S—about 60 °C, then $T_S - 30$ °C, and then $T_S =$ spin temperature.

Model Laws

To transfer empirical process and design data of known extruders (with index 0) to other sizes (no index) without significant changes of the design details model laws are used that define the new dimensions in dependence of the screw diameter and effective length with exponents. They are more precise if the changes relative to the known extruder models are limited. Dimensions variable with the screw diameter are from Fig. 4.79, fix exponents are from the following table:

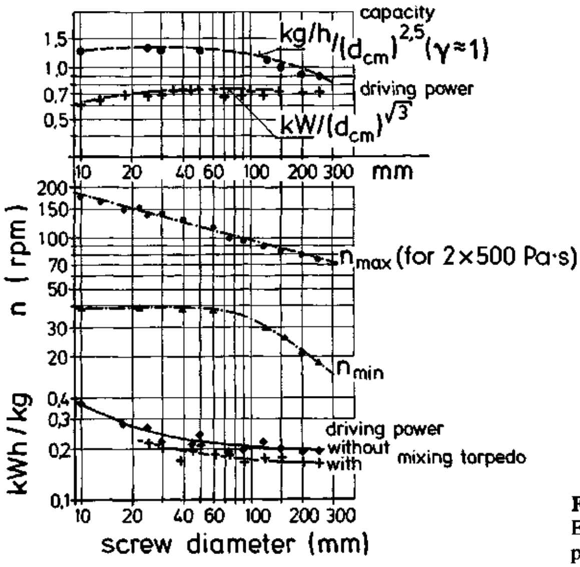


Figure 4.79
Experimental results for use with the model principles

Variable	Theoretical [82]	ψ	Experimental, Figure
Flight depth	$t/t_0 = (D/D_0)\psi$	0.52	4.70
Flight clearance	$\delta/\delta_0 = (D/D_0)\psi$	0.52	4.68
Zone length	$L_M/L_{M0} = (D/D_0)^{1+w}$	1.0	
Maximum rpm	$n/n_0 = (D/D_0)^{-x}$	1.73	4.77, 4.79
Output	$V/V_0 = (D/D_0)^{2+\psi-x}$	2.36…2.3	
Output, based on			
Screw length	$V/V_0 = (L/L_0)^{x-1}$	0.74	4.70
Drive power	$N/N_0 = (D/D_0)^{2+\psi-x}$	1.975	
Drive power, based on			
Screw length	$N/N_0 = (L/L_0)$	$=1$	
Torque	$M_D/M_{D_0} = (D/D_0)^{2+\psi}$		
Heating power	$H/H_0 = (D/D_0)^x$	1.73	4.78
Specific melt weight	$\gamma/\gamma_0 = \gamma/\gamma_0$		

Construction Notes

Spinning extruders have to fulfill the following conditions additionally to the mentioned requirements:

- guaranteed uninterrupted production of 8400 h = 350 d,
- screw and cylinder have to run well together and to be resistant to corrosion. Thus the cylinder is usually centrifuged with an appropriate metal alloy, e.g., Xalloy 314 [65] or Reiloy [66], water cooled fill studs and cylinder part,
- provide inert gas entry at the chip valve, and
- seal screw to the back,
- design cylinder wall thickness for an inside pressure of $\geq 1.5 \times$ maximum production pressure at maximum production temperature, i.e., at least for about 600…700 bar at 320 °C,
- space between screw and cylinder: normally about (0.0025…0.0015)D for small…large extruders
- pressure bearing housing either for double roll axial bearings (Fig. 4.80a) or for self-aligning axial back pressure roller bearings combined with two radial bearings. Theoretical life span $\geq$200,000 h, for $D > 25$ mm circulating oil lubrication with pump and oil filter.
- pressure bearing housing, especially for self-aligning axial roller bearings, have to be machined in one clamping,

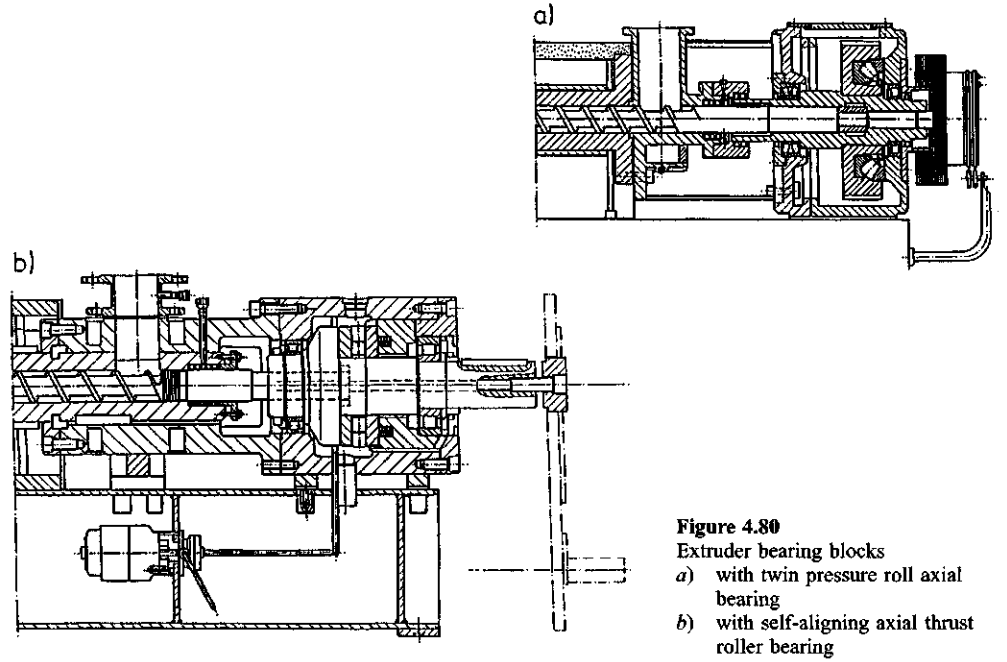


Figure 4.80
Extruder bearing blocks
a) with twin pressure roll axial bearing
b) with self-aligning axial thrust roller bearing

- reducing gears with angled teeth directly or set onto the pressure bearing shaft,
- Motor gear entry needs to be connected by a V-belt drive of sufficient dimensions,
- screw connected with pressure bearing shaft by counter running screw that can be removed to the front for screw replacement; then press the screw out from back with a threaded spindle,
- temperature eveness in the metering zone better than ±2 °C,
- pressure control in front of the screw tip more precise than ±3 bar up to about 70 bar, and above that ±2%,
- possibly provide melt guiding temperature system,
- for melt extruders continuously even heating from intake to front.

4.6.4.2 Double-Screw Extruders

Only very few companies use it as a melt extruder for spinning filaments, and it is usually replaced in new spinning plants by single screw spin extruders. Nowadays the double screw extruder is primarily used to transform powder to chips, to compound, i.e., to enter additives and/or dyes into the melt, e.g., to produce master batches, and to mix several melted polymers. It is also used as a reactor for plastics preparation [31, 89] and as a finisher in the final step of a polycondensation, usually with an increased volume (Fig. 2.51).

For melt spinning the normal volume double screw extruder with synchronized combing screws is almost used exclusively with the following advantages: very good self cleaning, distribution and division effects, pressure guidance, even under high pressure or vacuum, and good lengthwise and cross-sectional mixing effects. The double jacket housings can easily be heated. The screws allow a high driving force to be entered into the polymer. However, they can only be used for melt dwell times under 7 min and due to their construction in comparison to a single screw extruder of similar power they are relatively expensive. Detailed descriptions are given in [63, 83, 84].

Figure 4.81 explains the effects of the double screws:

- self cleaning of the screws by reciprocal stripping motion,
- transport in a system that is lengthwise open: The screw threads form continuous channels from the entry to the tip.

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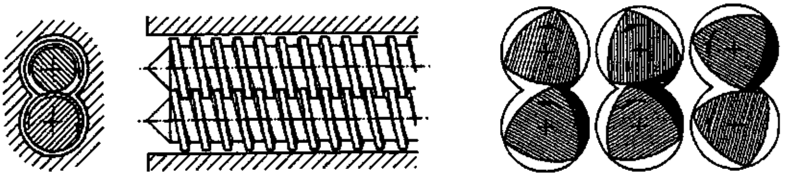


Figure 4.81
Principle of a unidirectional combing twin screw system and explanation of the operation of kneading discs

- Transport characteristic mostly represents a drag flow with only partial forced flow,
- resulting in a very narrow dwell time distribution yet good mixing of the melt.

This results in special applications. The free surface of the melt is a good approximation of the surface over the sump of a vapor grid spinning head (Figs. 2.32 and 2.33), so that humid PA 66 can be processed. Melting PET chips (dried, of course) does not require crystallization. PP powder can be processed to chips or filaments with targeted reduction of the molecular weight.

Technical data and powers of typical double screw extruders [89, 93] are in Table 4.19.

For design reasons the double screw extruder cannot be built smaller than 25...30 mm screw diameter. The narrow parallel guidance of the two screws requires a special back pressure bearing design, an example for which is shown in Fig. 4.82 [94].

The chip entry needs to be dosed so that the screws are not completely filled. This can be done with a chip dosing screw as in Fig. 4.83. For larger double screw extruders the screws can be assembled in a module system, so that transport, melting and mixing can be combined. Figure 4.81 demonstrates the effect of two kneading disks [93]: this is especially important for compounding.

A miniature double screw extruder with $D = 2 \times 15$ mm and 0.5...2 kg/h output for laboratory purposes is delivered by [95].

4.6.5 Spinning Heads and Spinning Beams

Spinning heads are loaded with granulate, melt it and dose its distribution to the spinnerets. Spinning beams are loaded with melt and dose its distribution also to the spinnerets. Production spinning heads are dow vapor heated to about 320...340 °C, as are spinning beams.

Table 4.19 Technical Data of Twin Screw Extruders

For polymer	D mm	n_{max} rpm	Drive (motor) kWh/kg	Heating[1)] kWh/kg	Capacity $(G/D_m^3 n_{max}) \cdot 10^{-3}$ kg/h	Screw depth t/D
	15		0.2			
PA, PET and others	25 40 75 130	300...450 300...400 300...350 300	0.23...0.28 0.22...0.27 0.21...0.26[3)] 0.2...0.25[3)]	0.42 0.1 0.074 0.043	2.4...3 4.4...5.2 4.1...5.3 4.1...5.3	0.17 0.18 0.17 0.15
No PA, PET	240 300	180...200 160	0.17[3)] 0.15[3)]	0.033 0.028[2)]	6.4 6.7	0.14 0.136

1) = for $L/D = 28$ 2) = $L/D = 36$ 3) = Motor power increased by up to ×1.4

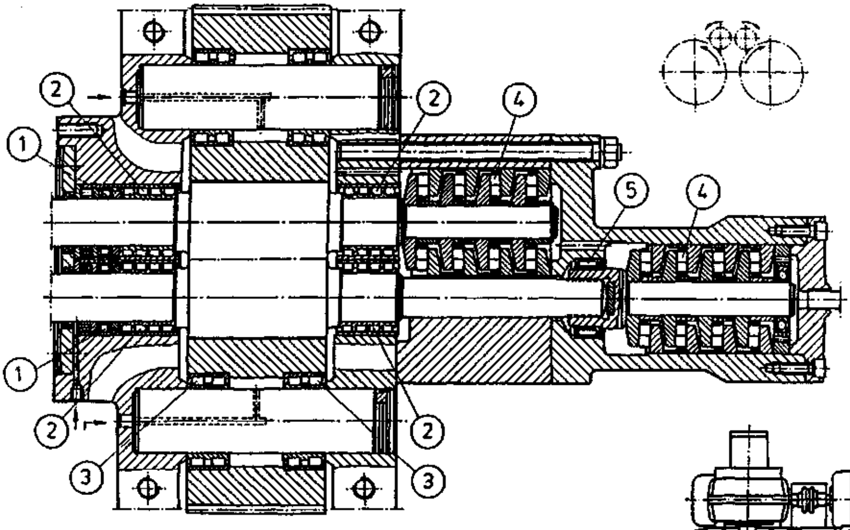


Figure 4.82 Installation of special axial roller bearings in a gearbox for twin screw extruders (FAG [94])
1) Axial cylinder roller bearing type 811... (shaft h6, housing H9)
2) Cylinder roller bearing/special type (shaft m6, housing H)
3) Cylinder roller bearing SL 1850... C3 (shaft h6, housing N7)
4) Axial tandem roller bearing T4A4... (shaft f6, housing F7)
5) Needle bearing NA49... C3 (shaft k6, housing H7)

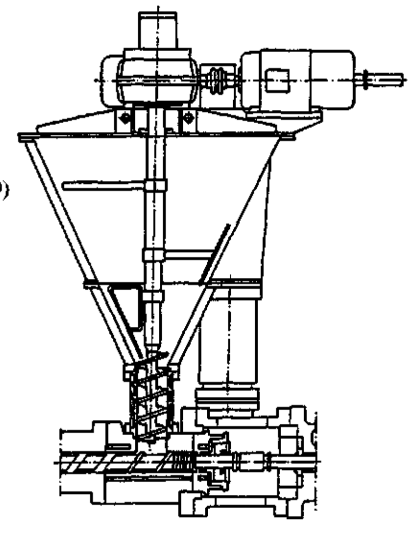


Figure 4.83
Chip hopper with agitator and stuffing or dosing screw

4.6.5.1 Spinning Heads

The principle of a dow vapor heated spinning head and its self regulating leveling of the melt was explained in Fig. 2.32. To increase the melt surface area and the chip pressing to the surface Fig. 2.33 shows a design that in a similar form is still used today.

Due to the low melt production melt can only be delivered to $(1 \ldots 4) \times 2$ spinnerets with each spinneret needing a dosing pump. The usual arrangement of the spinnerets for double spin take-up machines used to be two rows with approximately 610 mm cross distance and per row two spinnerets with an approximate gauge of 410 mm. This kept the melt distances very short, so that the dwell time made these spinning heads especially suited for PA 66 fine monofilaments (2 per spinneret) and multifilaments up to 40 dtex; this was for the earlier common LOY spinning at 800...1300 m/min take-up speed as well as for today's POY yarns up to 6000 m/min.

The melt grid allowed for PA 66 the use of wet granulate that dries before and during melting evenly to the optimum spinning humidity; the resulting water vapor functions as an inert gas.

Detailed descriptions, capacity evaluations, etc. of this and similar spinning heads see [59–61, 70, 75] including an electrically heated [76] with a star grid and a melt level control by electric conductivity.

Electrically heated spinning heads for trials and temperatures above 350 °C: see Chapter 4.6.4.3.

4.6.5.2 Spinning Beams

The above mentioned spinning heads cannot handle today's quantity requirements of PET, PA 6, PP, and PA 66. Therefore 2 ... 12 spinning positions with the corresponding gauges are combined in an usually dow vapor heated beam that accommodates the distribution of the melt and the necessary number of spinning pumps and spinnerets. Especially for PA 66 there are some polymer specific limits: The melt dwell time between the end of the extruder compression zone and the exit from the spinneret should not be more than 4 min (maximum 7 min) to avoid depolymerization (see Chapter 2.2.4.4). This time limit exists in similar form for the other melt polymers as explained in Chapter 2 specifically by polymer. According to this the melt dwell time and the resulting pipe systems, temperature constancy and its control, are the most important dimensions for spinning beam design. As this is also valid for solution spinning, the following chart provides an overview over the important elements and conditions of filament production.

Filament production			
From	Melt	Melt or solution or solid	Solution
T up to	220 ... 500 °C		approx. 150 °C
using	spinning head or beam	spinning cylinder and piston	spinning pipe
Heating	Dowtherm vapor, electrically	as per left or right	none or liquid
Pressure range[1)]	up to 400 (600) 1000 bar	up to 200/500 bar	up to 30 bar
Housing	6 bar		
Spinning pump	100 ... 150 bar over pressure ranges as in pipes	–	up to 30 bar
to Extrusion	in air or inert gas (or water)	as per left or right	in air, inert gas or spinning bath

[1)] Melt pipes

The spinning capacity per spinneret can be calculated according to Chapter 4.6.1, part a), or according to

$$G\,[\text{g/min}] = 10^{-5} \cdot i \cdot \text{dtex} \cdot v\,[\text{m/min}] \text{ or kg/h} = 6 \cdot 10^{-6} \cdot v \cdot \text{dtex} \cdot \text{m/min} \tag{4.27}$$

with

dtex = final titer of the desired filament
v [m/min] = take-up speed
i = residual draw ratio

Further in numbers:

tons/year ≈ 8 · kg/h respectively
lb./year ≈ 18,500 · kg/h ≈ 770 · kg/24 h

The size of the spinning pump results from $V_{\text{spec. pump}} \leq (\text{g/min})/40 \cdot \gamma$
with

γ = melt density [g/cm³]
40 = maximum allowable production rpm of spinning pumps [rpm].

The cross-sections of the pipes and the static mixers corresponding to the boring dimensions of the spinning pumps or follow from:

$$d_i[\text{cm}] \approx 0.146\sqrt{(\text{g/min})/\{(\text{cm/s}) \cdot \gamma[\text{g/cm}^3]\}} \geq 0.6 \text{ cm} \tag{4.28}$$

for $2\text{ cm/s} \leq w \leq 5 \ldots 6\text{ cm/s}$ (Fig. 4.118)

If the supply pipe is split into 2 different connection pipes the supply inside diameter = $\sqrt{2}x$ of the further diameter.

If the supply pipe is split into 2 equal further pipes the following is valid:

$$L_A \cdot d_{iA}^2 = L_B \cdot d_{iB}^2 \quad \text{and} \quad d_{iA}^2 + d_{iB}^2 = d_{iO}^2 \tag{4.29}$$

Pipe curves should be done softly, i.e. with as large a diameter as possible. Especially for PA 66 the pipes and branches must be easy to clean or possibly even to remove, because otherwise even 20 min of dwell time can lead to residues of depolymerization.

The following examples shall demonstrate this:

Spinning product	167/52 dtex PET	2300/144 dtex PA 6	2000 × 1.75 dtex PP
Take-up speed	3600 m/min	600 m/min	1300 m/min
Residual draw ratio	1.5	3.4	3.4
Capacity g/min (hg/h)	90.18 (5.4108)	469.2 (28.152)	574.6 (34.476)
Density	1.25 g/cm^3	1.0 g/cm^3	0.68 g/cm^3
Pump size	$\geq$ 1.8036 cm^3/rev.	$\geq$ 11.73 cm^3/rev.	$\geq$ 21.125 cm^3/rev.
Pipe diameter to pump	= 0.8 cm	= 1.6 cm	= 2.2 cm

For the distribution from the spin extruder connection or from the continuous polycondensation to the individual spinning positions it is necessary that the dwell times of the melt are as short as possible, and consequently the pipe lengths and their inside diameter and curving radii should be as equal as possible. Figure 4.84 shows three possibilities for pipe layouts. The fork like distribution of the melt flows results in the shortest dwell times, but in unequal dwell times if one of the spinning positions is stopped. The star shaped distribution has the advantage of equal dwell time—even when deactivating one spinning position—but the disadvantage of the longest dwell time on the way to all spinning positions. For that reason often a mixed pipe layout is chosen.

It is important that the melt pipes can run empty without pressure supply; i.e., all pipes should have a slight slope to the next opening, as shown in Fig. 4.85 in the left half. In no case they may droop or build sacks (Fig. 4.85, right) where the melt can stay during standstill. Spinnerets connected to such pipes start "sniveling" after brief production runs, while spinnerets with sloped supply pipes have 5 to 10 times the running times, as observed in PET staple fiber spinning.

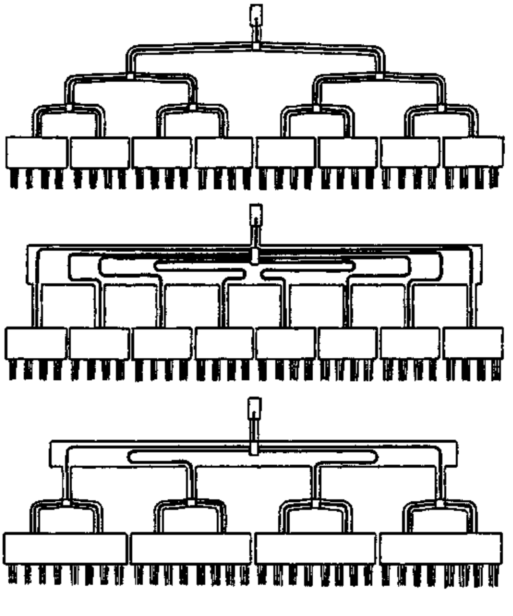


Figure 4.84
Possible melt manifold configurations for spinning beams and/or to spinning positions.
Top: forked distribution behind each joint
Middle: central distribution with equal pipe Lengths to each spinning position
Bottom: mixed system

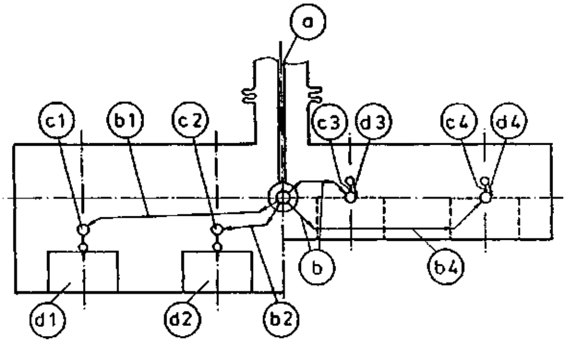


Figure 4.85
Melt distribution in a spinning beam
a) Melt supply:
Left: falling pipes: b1, b2 to the spinning pumps; c1, c2, to the spin packs d1, d2
Right: b, c, d, 3, 4: partially rising pipes and looped are incorrect!

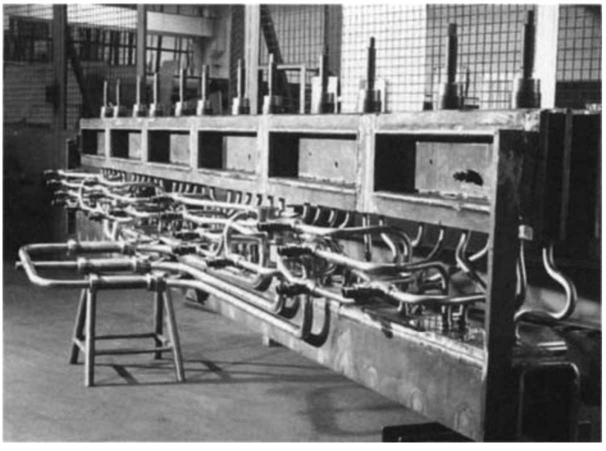


Figure 4.86
Melt manifold of a 6-position spinning beam for 3 color BCF spinning with 2 × 3 spinnerets/position (Automatik [22]); top view, open

How tight the system of a 6-position spinning beam for 3 colors BCF can become when observing these conditions is shown in Fig. 4.86.

When calculating the fully formed melt pipe flow of the flowing non-Newtonian liquid, e.g. for PA 6 with $R = 3.8$ cm, $L = 15$ m, $Q = 200$ kg/h at 240 °C, after these 15 m there is a pressure reduction of ≈43.7 bar and a speed distribution according to Fig. 4.87 with t = dwell time of the melt (= inverse proportional to the speed), in the center approximately 2.8 min, in the average 5.2 min, and in the flow near the wall $t \approx 20$ min. Thus for reasons of stability the dwell time of the melt in this flow needs to be considered carefully [96].

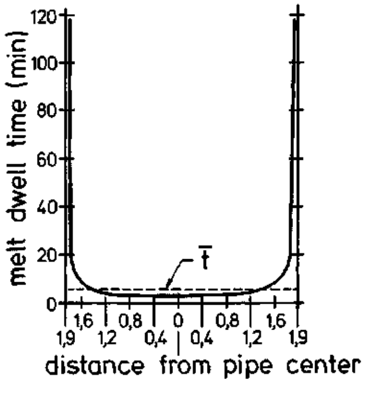


Figure 4.87
Dwell time distribution of a PA6 melt stream in a pipe of 38 mm internal diameter
(∓ = average dwell time ≈ 5.8 min)

The filament quality is also influenced by the temperature constancy of the melt supply up to and including the spinning beam. In time and space it has to stay in the experience values for individual polymers in Table 4.20. This table shows the achievable temperature constancy for types and sizes of jacketed pipes and spinning beams in dependence of the heating method. According to this, for example PA 66 can only be spun with a spinning head or spinning beam that is heated with dow vapor with condensate formation and a direct and complete drainage of the condensate without sump.

Table 4.20 Achievable and Permissible Temperature Deviations, Melt Pipes and Melts

Spinning head, spinning beam, heating chamber	Type of heater	Achievable temperature constancy ±°C	Melt	Necessary temperature constancy ≤ ±°C
$D \times L \leq 250 \times 400$	electric			
< 550°C	radiant	5	PP	3.5...4
< 340°C	Mecanite	3	PA 6	2.5...3
< 350°C	aluminum shells	2.5	PET	2.0
< 500°C	brass shells	2.5	PA 66	1...1.5
< 600°C	gray cast shells	2.5	PEEK	3
≤ 450 × 400 × 200	iron shells	3...4		
≤ 400 × 300 × 2000	oil. liquid	2...2.5		
≤ 600 × 400 × 5000	Dowtherm (Diphyl) vapor, with sump,	2...2.5		
	with direct condensate drainage	1...1.5		

Further aspects for the selection of the heating method are:

- For temperatures up to 257 °C a liquid circulation heater is advantageous.
- For temperatures of 257...340 °C the dow vapor heating is optimal.
- Above 360...400 °C a direct electric heater is to be used, even though the temperature variations increase with increasing temperature.
- Above 700...800 °C only a direct resistance heater is possible, in which for example the spinneret from Pt-Rh-80 : 20 is used as the resistor and the intensity of the current is only a few amperes.

Further heating methods: see Chapter 6.3.

The advantage of the dow vapor heater is the constant temperature of the complete piping system from the extruder connection or the polycondensation plant including possible large surface area filters, distribution pipes, etc. until the lower edge of the spinneret. For a good functioning it is necessary to have a common connection pipe above the highest point of the system (of same temperature) that leads to a dow vapor loss condenser (Fig. 4.88) that ensures by a water cooled condenser (b) that the dow vapor continuously moves through the whole system and returns as condensate. The associated safety systems are explained in the Figures.

Since the extruder measuring head, i.e. the connection piece to the melt pipe system, is certainly one of the highest points in the heating system, its design details are explained in Fig. 4.89. The (TEA) above the measuring head causes an alarm as soon as decomposed products and air mixed with the dow vapor reach it from above and the temperature drops below the operating temperature of the system. Latest then the system has to be de-aerated. By removing the front flange *f* and the coarse sieve *s* for the protection of the piping system against big particles it is possible to remove the extruder screw towards the front.

Table 4.21 makes recommendations for the construction materials from the extruder cylinder to the melt pipes to the spinning beam, except for those cases where for corrosion reasons even more corrosion resistant materials have to be chosen.

Already Fig. 4.84 showed that between the extruder measuring head and the individual spinning beams distribution pipes may be needed that also require constant temperature and distribution. For example they start according to Fig. 4.89 at the measuring head and are connected to three spinning beams. To accommodate the heat expansion between the melt pipes and jacket and the building fix points of the spin extruder and spinning beam, such expansion elements as shown in Fig. 4.90 have to be included [81].

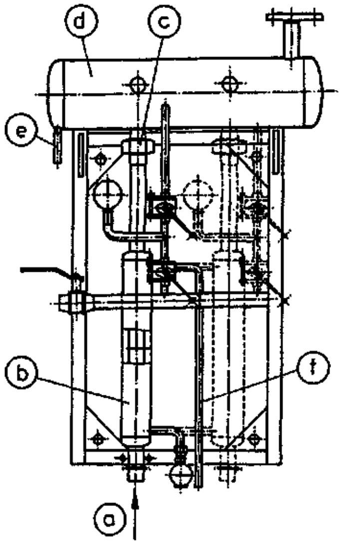


Figure 4.88 Dowtherm vapor loss condenser
a) Dowtherm vapor from user
b) water cooled condenser
c) rupture disk for overpressure (or safety valve)
d) overflow receiver
e) condensate return
f) vacuum connection

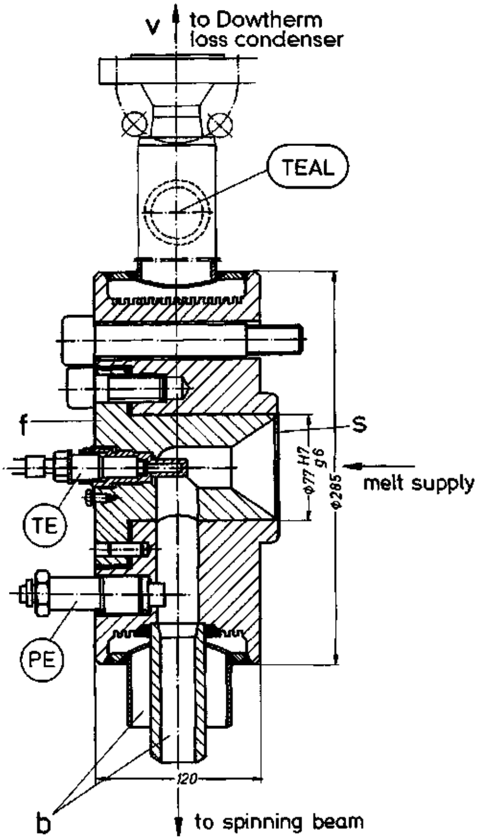


Figure 4.89 ▶
Extruder connection (= measuring) head with sensors for melt temperature (TE), pressure (PE) and Dowtherm vapor temperature safety alarm (TEAL). Example: 75 mm screw diameter extruder with
f) front flange for screw removal from front
s) coarse sieve (for coarse particles in the melt, e.g., metal parts)

Designs

Spinning beams in principle are rectangular containers, preferably from vessel sheet metal H II for temperatures up to 320 °C, as well as vacuum and pressure up to approximately 6 bar (cold), with an inspection requirement by TÜV [6] with all the necessary build-ins, usually from material 1.4541. Since they are manufactured at room temperature but usually operated at 260 ... 300 °C, it should be accounted for an increase in length of about 4.2 mm/m length between the two temperatures—on one hand to adjust fix dimensions of the building and the take-up machines, on the other hand to adjust between the housing and the inner pipes that have to absorb length differences of about 1 mm/m length, best by curves in the piping.

A cut through spinning beams for textile filaments is shown in the Figs. 4.91 to 4.94 [22, 2, 3]: Fig. 4.92 shows a spinning beam with melt valve and pump connection beam that depending on the number and the type of spinning beams and spin packs can be exchanged. The spin packs for textile filaments are relatively light and are bottom loaded and secured with flange screws. The distribution beam above it can stretch over several spinning beams.

Table 4.21 Materials, etc., for Spinning Machines up to 600 (700)°C

Materials for	Temperatures <450°C	<600°C	<700°C
Apparatus construction	H 1.4571 and II.	1.4541 or 1.4948	1.4909
Machine parts	1.4541	1.4828 or similar	1.4909
Extruder, barrels.	1.4006	1.4921	
screws	1.4122	1.2787	
Clearance (cylinder/screw)	Standard × 1.3	× 1.4	
Electric heating for < ±10°C	ceramic heating band		
for < ±5°C	Electric resistor heating rod cast in Br or Ms radians sealed		±8°C
Electric power supply	1.3	1.5	
Insulation = Al_2O_3-felt	≧150	≧180	≧210 mm
Pack filters, woven,	1.4408	1.4541	
edging gasket	AlMgZr	1.4541	
Spin pumps	Barmag/Feinprüf. for cleaning up to 550°C Nichols-Zenith for 700°C. up to 300 bar	Zenith	–
– Driveshaft tang		1.4828	

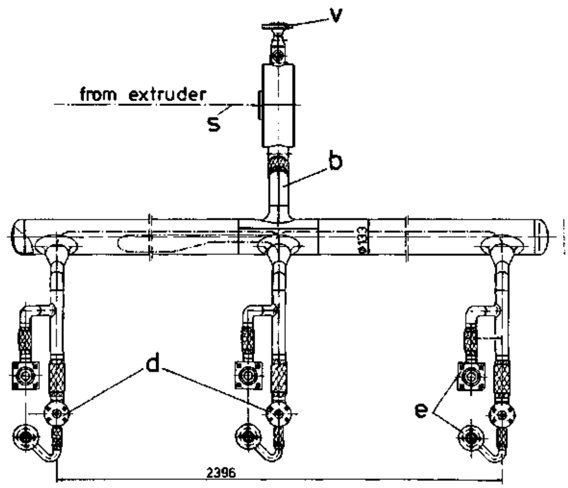


Figure 4.90 Example of a melt distribution manifold; symbols as in Fig. 4.89 and additionally
d) Flanges for connecting melt pipes to the spinning beam
e) Flanges for connecting Dowtherm vapor and condensate return to the spinning beam

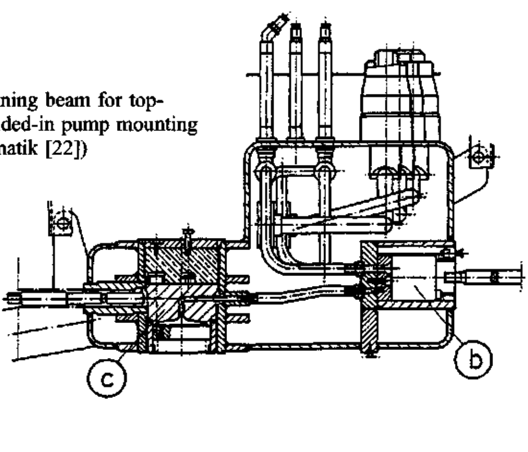


Figure 4.91
Cross-section through a spinning beam for top-loading spin packs, with welded-in pump mounting flange (pump block). (Automatik [22])

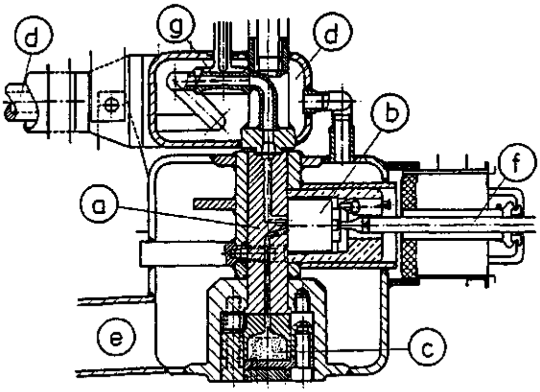


Figure 4.92
Cross-section of a spinning beam with an exchangeable pump block [22]
a) for spinning pumps
b) spin packs
c) bottom-loading
d) melt feeding pipes in Dowtherm vapor housing
e) condensate return
f) spinning pump driveshaft
g) freezing valve

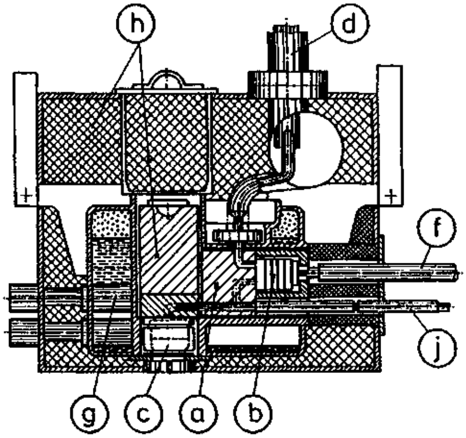


Figure 4.93
Dowtherm vapor heated spinning beam with electrical heating of liquid Dowtherm in the sump (g). Symbols as in Fig. 4.92, and additionally, h) partly removable insulation. The toploading spin pack (c) is seated against the pump block (a) by means of a jacking screw (j) [2]

Figure 4.94 explains for a spinning head with top loading spin packs the connection of the spinning beam with a dow vapor heating system. Here the spin pack is pressed with a pressure screw against the melt supply pipe and tightened.

The principle of a spinning beam that is particularly flexible with respect to spinnerets and spinning pumps is shown in Fig. 4.95a [24], where spin packs, distribution beam and pumps can be changed from the top. At the same time it is indicated how the dow vapor sump heating system can be designed with resistor calrods in the sump of the box. In the cold state the level of the liquid dow should be 20...25 mm above the upper edge of the calrods. For control it is also necessary to have a level control at the outside that looks out of the insulation with a mirror reflex indicator. Figure 4.95b is a photo of two such spinning positions [33].

Figures 4.96 show a particularly simple spinning beam for staple fiber spinning with bottom loading spin packs and pump drive from the top. The disadvantage of this design are the hanging pipes between melt supply and each spinning pump.

Should the spinning head be liquid heated, it is necessary to provide installations in the heating medium flow that direct it in such a way that it will reach otherwise dead corners at sufficient speed to ensure the necessary heat transfer numbers (Fig. 4.97).

Of course the spinning beams have to be sufficiently insulated. To the bottom usually 40 mm insulation thickness are sufficient, and to the other sides 150 mm. The insulation should be closed to the bottom by a stainless steel sheet to keep spinning vapors out, with fitting and dished openings for

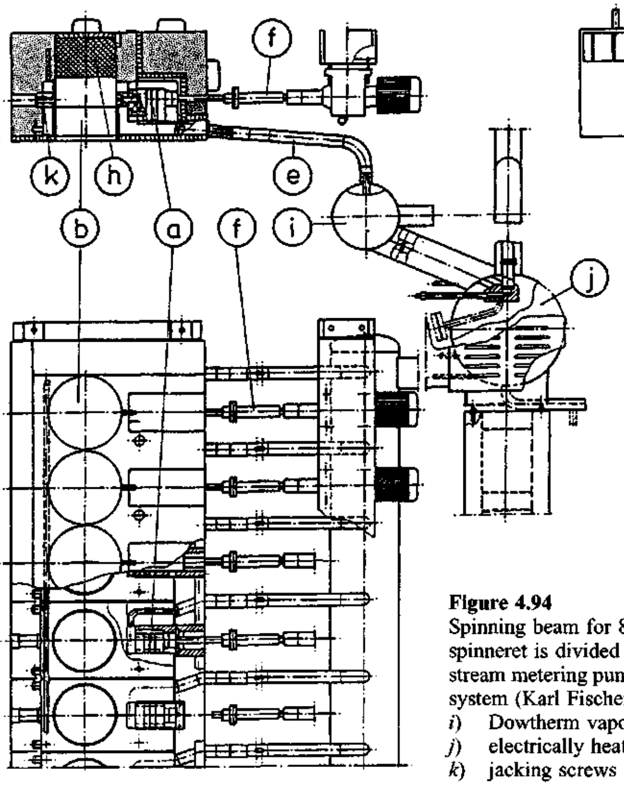


Figure 4.94
Spinning beam for 8 spinnerets/position, top-loading; each spinneret is divided into 2 kidney spinnerets with 8 double stream metering pumps; with external Dowtherm-vapor heating system (Karl Fischer [3]); symbols as in Fig. 4.90…4.93 and
i) Dowtherm vapor distribution pipe,
j) electrically heated Dowtherm vaporizer,
k) jacking screws for spin pack sealing

changing spin packs. To the other sides covering with galvanized steel sheets or better from Al 99.5 is sufficient. The latter has to be easy to exchange in this area for pump changes and in the case of top loading for spin pack changes. The surface temperature of the insulation should be $< 60\,°C$.

The mentioned changing of spin packs has led to the development of specific spinneret diameters and shapes that can each be arranged in a row per spinning position, but that also determine the minimum gauge. Figure 4.98 is a selection table of a producer [22] that exists similar to other producers [3, 4, 33, etc.]. Thus for a textile titer program spin packs with 4 to 16 spinnerets for coarser and finer titers can be used in the same spinneret mouth. The same is true for the changing of 2 rectangular spinnerets (e.g. for carpet yarn) for up to 2 × 3 round spinnerets for 2 filaments—3 color carpet yarns; Fig. 4.91 shows the cut through the corresponding spinning beam for top loading.

Heat Requirements

The spinning beam leads the melt without loss of heat from the supply to the spinnerets. Even for a possible temperature increase due to the pressure reduction in the spin pack no heat is needed.

A heat requirement calculation is easiest done for a liquid heated spinning beam, using Fig. 4.97 as an example. It has for an 800 mm gauge an insulation surface area of $2.6\,m^2$/center position and 3.2 m^2/end position with an average of 50 °C surface temperature at an assumed room temperature of 30 °C. The opening of the spinneret mouth shall be $500 \times 180\,mm = 0.1044\,m^2$/position at 280 °C. Due to the chimney air flow around the spinning beam $\alpha = 20\,kcal/m^2h\,K$ can be assumed. This results in a heat loss of 6561 kcal/h. Added are estimated values for heat ruptures, pump shafts, hinges, etc. of 1440 kcal/h. Together this is 9.3 kW. Marlotherm as a heat transfer oil has a specific heat of $0.696\,kcal/dm^3K$. If

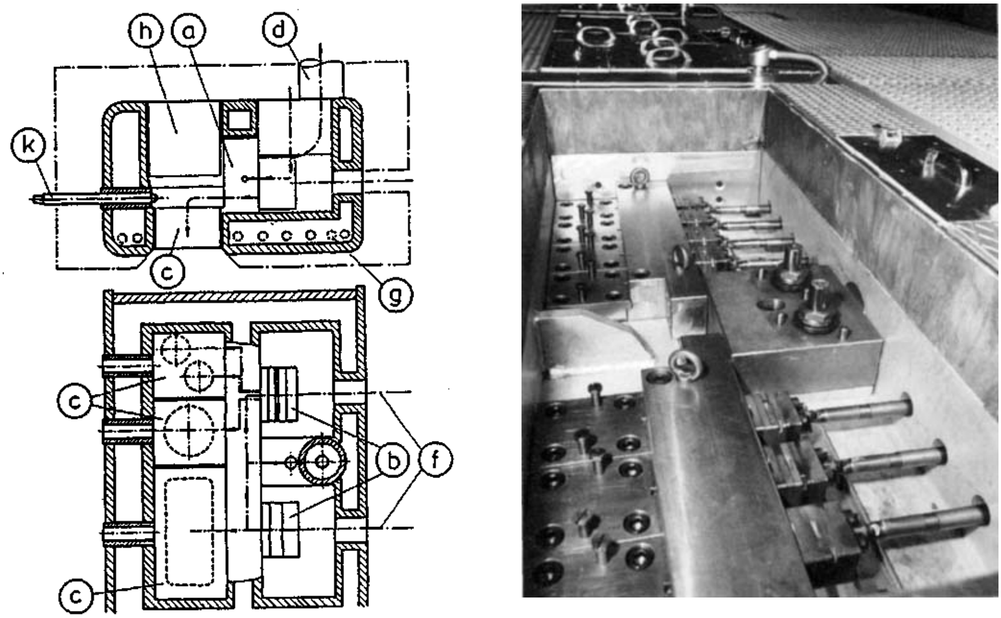
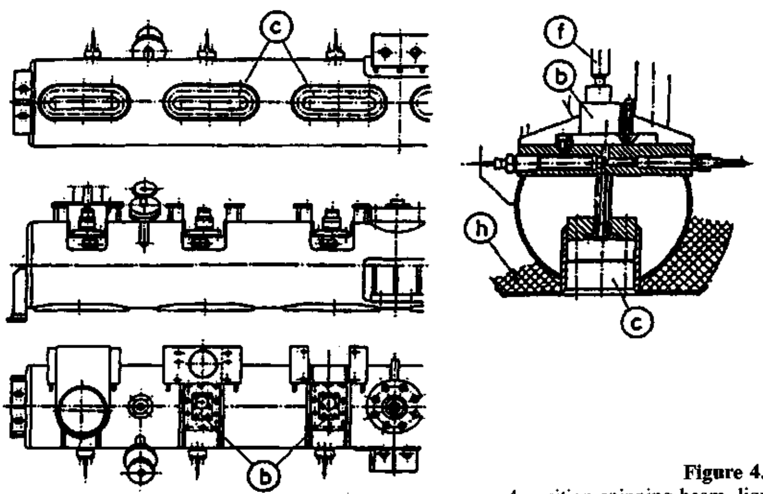


Figure 4.95 Example of an exchangeable spinning beam with U-shaped Dowtherm vapor housing and exchangeable interior parts; symbols as in Fig. 4.92 ... 4.94
a) Schematic drawing
b) 2 position spinning beam for 4 double stream metering pumps and 8 spin packs/position (Barmag [33])

Figure 4.96 Section of a simple 6 position staple fiber spinning beam (symbols as in Fig. 4.92)



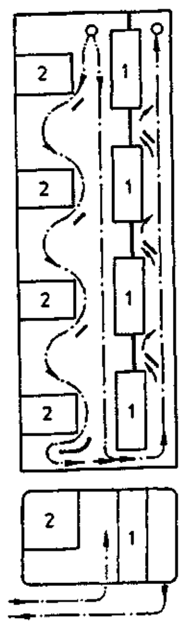


Figure 4.97
4-position spinning beam, liquid heated, with special flow guiding and distribution vanes

1 °C (K) temperature drop between inflow and outflow is permitted, the circulation quantity becomes 11.5 m^3/h plus supply loss quantity, resulting in the calculated pump size that needs to be designed for a pressure loss of $\Delta p \approx 1 \ldots 2$ bar.

The heating power for the same spinning beam results from e.g. 100 kg/100 mm length plus 40 kg/100 mm length for the insulation with $c_{\text{steel}} \approx 0.12$ and $c_{\text{insulation}} \approx 0.2$ kcal/kg K. The beam is heated from 20 to 280 °C, the insulation to the average value. Thus the necessary heating power is 33,380 kcal/h × position. This requires for 4 positions and 12 h heating time additionally approximately 16 m^3/h pump and heating power, respectively about 30 kW plus pipe losses plus safety. This will require a heater of about 50 kW with a pump power of about 30 m^3/h.

This calculation is valid with the corresponding data for dow vapor heaters, where the pump with its power needs can be left out, but the piping has to be dimensioned appropriately.

Melt Temperature Changes Due to Differences to the Heating Room Temperature

When spinning often crimping filaments can be observed that they are due to the difference in temperature of the melt near the wall to that in the center. According to Fig. 4.99 this temperature difference creates a bicomponent structure of the filament formed from the two components, that has different shrinkage properties in its two halves and thus crimps.

The temperature change of the melt when flowing through a pipe of constant wall temperature can be calculated with the following formula [99]:

$$Nu = \alpha \cdot d/\lambda = 3.66 \cdot \sqrt[3]{(1 + 0.086 \cdot Pe \cdot d/l)} < \approx 3.7 \quad (4.30)$$

for $Pe = v \cdot l/a \leq 10$ with $a = \lambda/\gamma \cdot c_p = Pr \cdot Re$.

Thus for example for a pipe of $d/L = 18\, d_i/22\, d_a \cdot 1000$ mm length with 40 kg/h melt through flow (for PET 8 × 167 dtex POY) the melt temperature is increased by about 0.2 °C (K) per 1 °C (K) over temperature of the dow vapor as long as the through flow is secured, which is negligible. Even a pipe of approximately 3.5 m length of the same cross section as they occur in an 8-position spinning head, results only in $< \approx 0.6$ °C (K) melt temperature change. The mentioned numbers only show the average temperature change of the passing melt; the wall layer can be influenced more than the center by a multiple due to the longer dwell time and the lower heat conductivity (cf. Fig. 4.87).

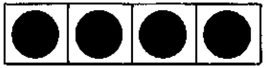
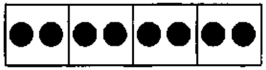
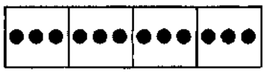
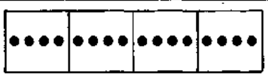
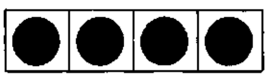
Since the time integral over the temperature difference × dwell time difference has an influence on the eveness of the melt, this becomes particularly critical in the near wall zones and can easily lead to depolymerization up to carbonization of the layers stuck to the wall. Since the passing melt always picks up smallest particles from the near wall layer, this continuously leads to infringements of the filaments with smallest enclosures up to filament breaks. Even the installation of static mixers cannot remove this effect, but only distribute it more evenly. This is the reason for the requirement to regularly clean the complete melt piping system to make the melt contact inside wall metal blank.

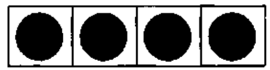
4.6.5.3 Electrically Heated Spinning Heads

If the advantages of the dow vapor heated spinning heads are not necessary and the limits according to Table 4.20 are observed or operating temperatures of above 350...380 °C are needed, and/or for laboratory purposes, the spinning heads can also be heated electrically. The above mentioned rules are also valid here.

Figure 4.100 shows a laboratory spinning head of the most simple kind for an extruder connection (d) from one solid stainless steel block that depending on the spinneret and pump size can has a diameter of approximately 130...200 mm × approximately 350...500 mm length, containing the necessary spaces and bores and is practically heated with two heater bands, one on top and one at the bottom. The spinning head needs to be insulated as previously required.

A similar spinning head for 2 round spinnerets in rectangular spin blocks for "top loading" is shown in Fig. 4.101. The melt flows from the extruder (d) via the double stream spinning pump (b) to the two spin blocks (a). These can also be replaced by a single pump and an rectangular spin block with rectangular spinneret according to Figs. 4.98 and 4.150. The electric heating is done by mica resistor belts

Spinning beams: Spinneret configuration — Continuous	Spinnerets per position	Spinning gauge (minimum): mm — Spinneret dimensions (maximum): mm 600	700	800	900	1000	1100	1200	1300
	4	100	120	130					
	6	65	80	90	100				
	8	50	60	70	80	90	100		
	8						70	80	
	12	32	36	45	50	60	65	70	80
	16		28	33	38	45	50	55	60
2. Technical yarns									
	2	210 × 80		245 × 80				370 × 95	
	2	140		160					
	4	100	120	130	140				

Spinning beams: Spinneret configuration — Carpet yarn	Spinnerets per position	Spinning gauge (minimum): mm — Spinneret dimensions (maximum): mm 800	900	1000	1200
	2	245 × 100 245 × 80 210 × 80			
	2	160			
	4	130	150		
	6 tricolor	100	110	120	

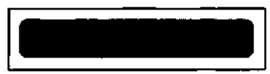
4. Staple fibers		Spinneret gauge: mm 300	400	500	600	
	1				420 × 120	
	2				210 × 120	
	1	180	220			
	1		240	300		

Figure 4.98 Spinneret and spin pack arrangement in modular spinning head construction (for pack exchangeability, with corresponding minimum spinneret gauge.

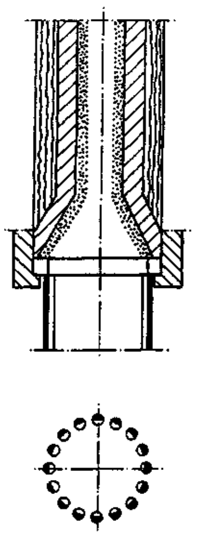


Figure 4.99
The development of a bicomponent crimping effect in the individual filament of a multifilament yarn by overheating the supply pipe wall

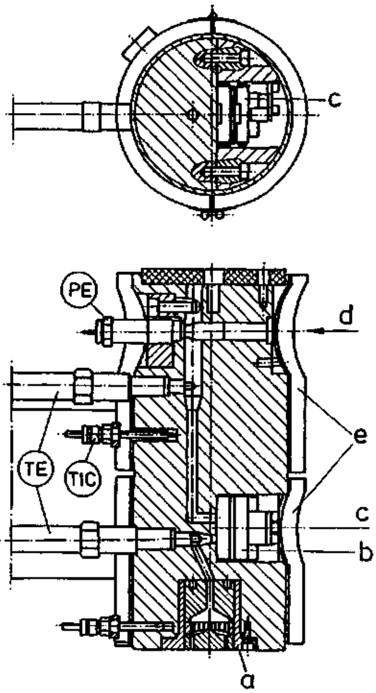


Figure 4.100
Electrically heated 1-position laboratory spinning head (Fourné [24])
a) Spin pack
b) Spinning pump
c) Spinning pump drive
d) Spin extruder connection
e) Heating belts

pressed on by steel plates, that depending on the mass of the heated head parts must be controlled in different zones (TIC). The temperature eveness is also strongly influenced by the quality of the insulation (see 4.6.5.2).

The connection between spin extruders, measuring heads, and spinning head of a 4-spinneret bicomponent system with electric heating up to approximately 340 °C is shown in Fig. 4.102. Extruder (d), measuring heads and connection tubes (e) are all equipped with mica heating belts. The spinning head has longitudinal bores to accommodate the calrods. The bore diameter is approximately 0.5 mm larger than the calrod diameter (g). The spin blocks (a) are top-loaded and pressed against the melt distribution beam (i) with pressure screws (f). On its other side there are four double stream spin pumps (b) attached by screws. These are driven by the pumps drive shafts (c) from a switch gear, and they are variable in small increments (right half : left half = 85: 15...50: 50...15: 85%). The switch gear is driven by a small reluctance motor (k) with reduction gear via a chain. Parts of the spinning head that are not in contact with the melt are manufactured from steel.

A high temperature spinning head (< 600 °C) is equipped with resistor calrods cast into heater shells with stainless steel jacket (1.4541 e), (Fig. 4.103a) with design details in Fig. 4.103b. The extruder connection (d) with conic flange is arranged for fast changes so that the melt does not start cracking. Also the spin pump needs to be heated accordingly (e) and protected to the outside by a heat conduction block. The hot shroud consists of a similar heating jacket with an inner tube from 1.4541. The casting material for the shell can be brass up to 500 °C and beyond this up to 600 °C gray cast iron.

The bores transporting melt inside a distribution beam must be planned very precisely, as shown in Figure 4.104 for 4 double stream pumps (c–f) and 4 bicomponent spin blocks, so that they do not intercept. Both (sideways entering) melt flows (a, b) are guided by the pumps (c–f) to the spin block connections (1–4), so that each of the flows *a* and *b* are flowing equally distributed to (1–4). This block can easily be exchanged for another one.

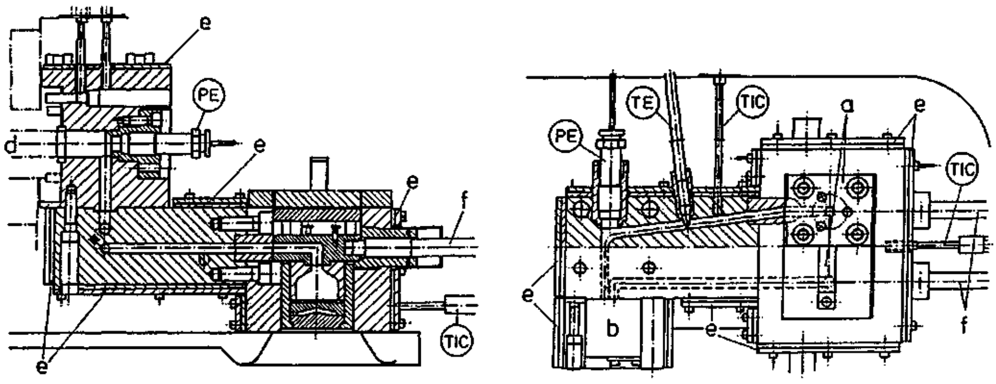


Figure 4.101 Electrically heated spinning head for 1 or 2 packs, top-loading (Fourné [24])
a)…e) See Fig. 4.100
f) Jacking screws for 1 or 2 spin packs

The same is true for the distributions blocks that can be recognized in Figs. 4.92, 4.93, and 4.95. The main advantage is that these melt distribution beams can be operated independently from the welded spinning head, especially the ground and polished ($R_t < 1$ μm) pump connection surfaces.

4.6.6 Polymer or Melt Valves

For short term blocking of the melt or solution flow stop valves can be arranged in the pipes. For longer stoppages with the risk of degradation or cracking they must be able to be rinsed. Also for splitting or detouring the flow the blocked off pipes must be able to be deaerated and rinsed.

Normal pass through valves have too much dead space; ball valves are as freely passable as the pipe when opened, but when closing polymer can settle between the housing wall and the ball. Also the usual seals from PTFE are only functional up to about 200 °C, from special materials up to about 300 °C.

Figures 4.105 show the most commonly used principles of such valves that are all completely situated in the heated area.

a) Squeeze valve: A ball calotte (2) with the same radius as the pipe extends half way into the pipe. To the outside it is sealed by a stuffing box. With the threading (5) it is turned to the inside and thus blocks part of the pipe diameter. This does not provide total blockage against high pressure.
b) A piston valve (2) with lapped-in cone seat [81], blocking against the flow. For big valves of this kind the sealing head (2) is set onto the valve rod (2) with the ability to rotate. In a good design this valve is pressure (up to >700 bar) and vacuum proof against the room (1).
c) A dead space free blocking and distribution valve based on two piston valves (b) [81].
d) A stopcock, sealing by turning the piston rod (5), but difficult to seal completely.
e) A freezing valve with free pipe passage from (1) to (1). To block cold compressed air is blown in at (6→) that freezes the melt pipe piece. After disconnecting the compressed air this part is heated up again by the surrounding heated space and becomes freely passable.
f) A rotary slide valve allows to let the flow pass in one of the two directions (1).

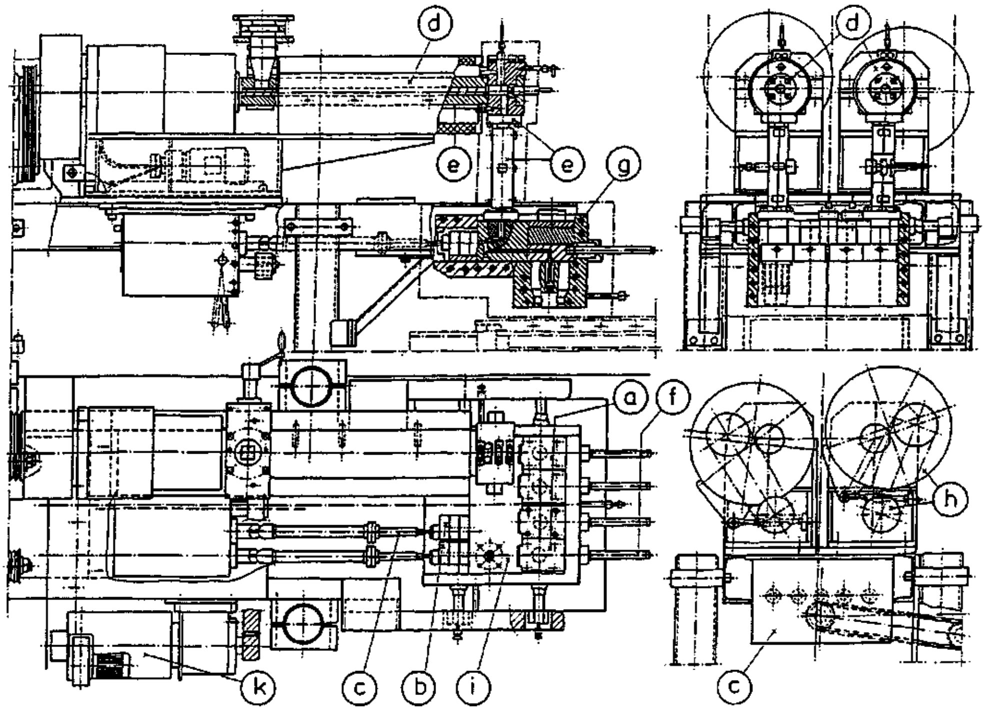


Figure 4.102 Bicomponent spinning position, complete, electrical heat (Fourné [24]),
a)…*f*) As in Fig. 4.101
g) Electric heating rods in bores (clearance = 0.5 mm)
h) Extruder drives
i) Bicomponent melt distribution block (see Fig. 4.104)
k) Change gearbox for spinning pump drive

An application for the principle (b) is shown in Fig. 4.106 for an injection valve: The main melt stream (1) passes by the injection position (8). The to be injected flow comes from (8) and enters the main stream at (2) as long as the piston is positioned as in (5). If this head is turned against the sealing surface the stream (8) is blocked, and the injection position is blocked dead space free [24].

Of course such valves can be equipped with manual operation as for example in Fig. 4.106, or with power operation. Many manufactures for these exist.

4.6.7 Static Mixers

As opposed to rotating mixers (Fig. 4.73) these mixers work without dynamic own movement according to the principle of the flow separation and reunification in different sequence or combination. Of the many different types [104] only three have found major acceptance for melt processing [101–103]. These are distinguished by size of the mixing cells and their sequence (Fig. 4.107). The concentration distribution behind a Sulzer SMX mixer after two (a), after four (b), and after eight (c) mixing elements over the pipe cross-section is shown in Fig. 4.108 [102]. Already after four mixing elements the total deviation is less

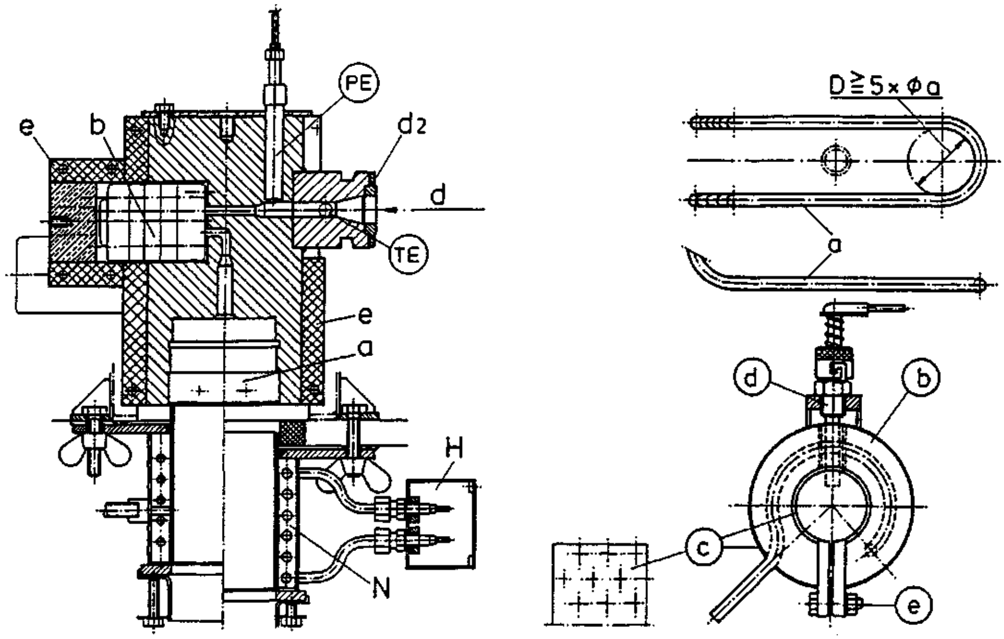


Figure 4.103
Left: Electrically heated (round) spinning head for spinning temperatures up to 500 °C, with heated shroud and for heaters melt-bearing parts (Fourné [24])
d Spin extruder connection,
Od$_2$ Spinning head and pack (a)
PE Pressure sensor (Dynisco for up to 700 °C)
b Spinning pump for up to 500 °C
e Heater shells for up to 600 °C (electric calrod heaters for up to 750 °C casted into special brass)
N Hot shroud for up to 500 °C
H Power connection for heaters
Right:
Heater shell design for up to 600 °C and bending instruction for stainless steel calrods for up to 750 °C; bend, to be compacted after bending (Fourné [24])

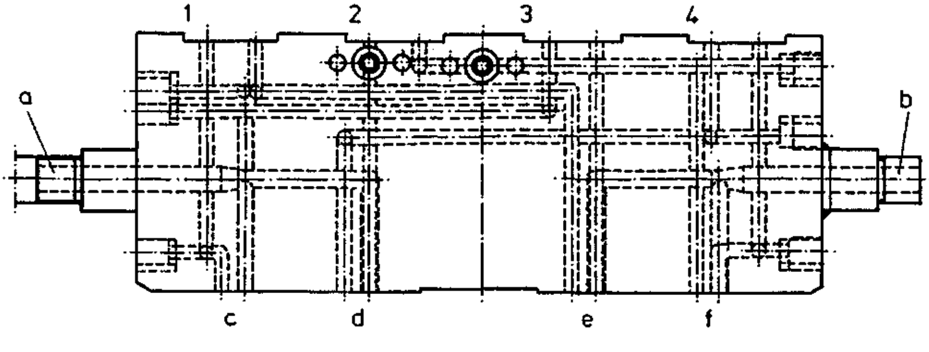


Figure 4.104 Bicomponent melt distribution beam for the extruder spinning head in Fig. 4.102, with melt entrance from both sides, for 4 double stream metering pumps and 4 bicomponent spin packs (Fourné [24])

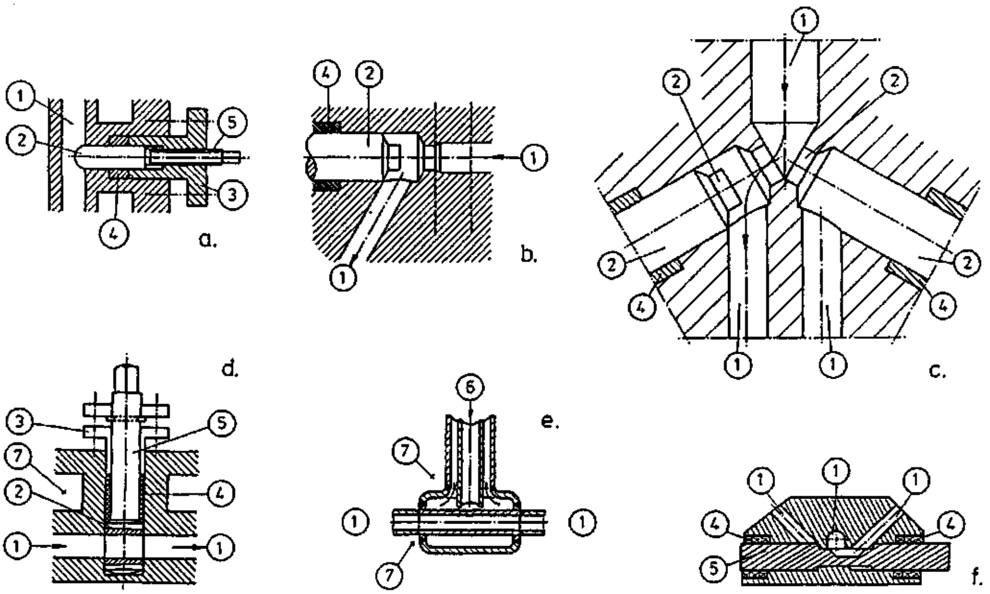


Figure 4.105 Valves for polymer melt (principles)
a) Throttle valve (for cross-section reduction only)
b) Piston valve with lapped-in cone seat
c) Dead-space-free distribution valve with 2 valves as in b)
1) Melt stream
2) Piston valve
3) Stuffing box flange
4) Stuffing box
5) Valve handle (screw or torsion rod)
d) Stopcock
e) Freezing valve with melt stream (1), cold compressed air (6) and Dowtherm vapor space (7)
f) Rotary slide valve
6) Compressed air
7) Vapor-heating space
8) Injected meet
9) Heating band

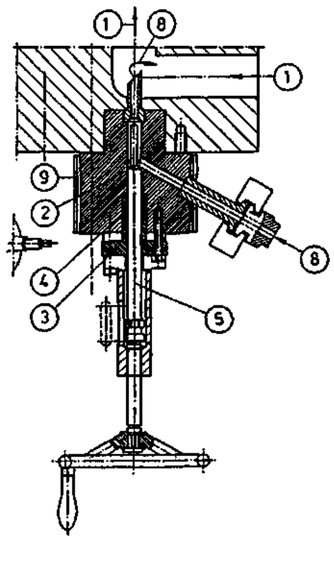


Figure 4.106
Injection valve (Fourné [24]); annotation as in Fig. 4.105

than 10%, and after eight less than 1%. With the coefficient of variation as a measure for distribution quality after a standardized length L: $D = 10$ one obtains $S/C_V = 0.04$ for the Sulzer SMX mixer respectively for the "Toray-High-Mixer" [103] and for the Kenics mixer [101] 0.5; i.e. the Sulzer mixer requires for the same mixing effect the shortest and the Kenics mixer the longest time and way.

The through flow resistance $\xi_D = f(Re, \text{type})$ can be calculated as

$$P_{SM} = 0.5 \cdot n \cdot w \cdot \xi_D(Re) L/D^2 \text{ for } Re <\approx 50 \qquad (4.31)$$

according to Fig. 4.109.

However this is only valid as is the good efficiency for metallic clean mixers. Also for mixers there is a border layer flow similar to the pipe flow (Fig. 4.87) with long melt dwell times at the metal surfaces—however without the increase in temperature—that can lead to thermal damaging of the polymer within a short period of time.

Therefore the following advise for practical operations is given:

- Installation useful behind an additive or melt supply or in front of or behind the spin pump and/or as close as possible to every spin pack (to even out the temperature of inner and outer pipe flow),
- easy exchangeability,
- use a mixer with at least eight mixing elements,
- consider the pressure loss, but not a problem for extruder screws and gear pump transport,
- frequent cleaning: latest after 2 ... 4 spinneret changes,
- it is advantageous to combine a dynamic mixer at the screw end with a static mixer in front of every spin block.

A mixer can never remove previous polymer damages but only distribute it evenly over the cross section so that the results are minimized.

4.6.8 Spinning Pumps and Other Gear Pumps

4.6.8.1 Spinning Pumps

As spinning pumps only gear pumps of extreme exactness are used [105] that can transport the melt or solution flow etc. with constant volume and pressure and at the same time even out variations in the supply—even at increasing pressure loss of subsequent filters, e.g. in front of the spinneret. Thus per spinneret a separate pump stream is needed because the hydrodynamic separation is not exact enough. Spin pumps are combinations of plates/gears and shafts with manufacturing tolerances of $<\approx 0.5\ \mu m$ and therefore have to be handled with care. Smallest dust contamination between the plates already results in pump blocking.

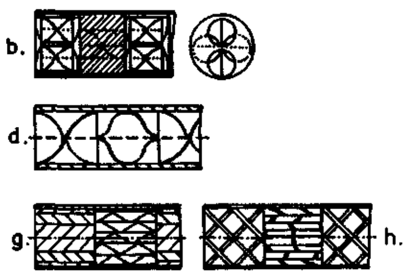


Figure 4.107 Static Mixers
b) Toray [103] g) Sulzer SMV [102]
d) Kenics [101] *h*) Sulzer SMX [102]

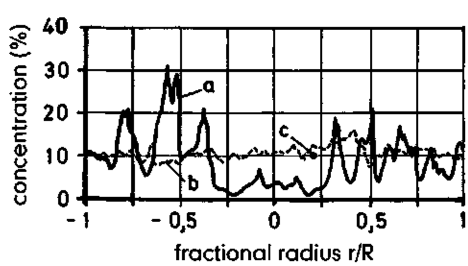


Figure 4.108
Radical concentration differences at the end of Sulzer SMX static mixers having 2, 4 and 8 elements: $d = 50$ mm, $s = 6.5$ mm, $m = 10$ mm; a) after 2, b) after 4 and c) after 8 mixing elements [83]

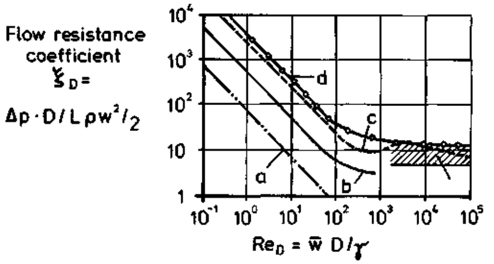


Figure 4.109
Flow resistance coefficients ξ_D as function of the Reynolds number $Re_D = \bar{w} \cdot D/\gamma$ for various static mixers. ξ is valid for $Re_D \geq 10$, and $\Delta P_{SM}/\Delta P_{pipe}$ valid for $Re_D \geq 50$

Static mixer	ξ_D	$\Delta p_{SM}/\Delta P_{pipe}$
a) pipe	0.02	1
b) Kenics-Mixer	3	7
c) Toray High-Mixer	11	38
d) Sulzer SMX	12	10...60
e) Sulzer SHV	6...12	–

Figure 4.110 describes the principle of a simple gear spinning pump: The melt or solution pressed in at (a) fills the spaces between the teeth, is moved to the outside by the rotation and is pressed out of the housing at (c), because in the further rotation the spaces are almost completely filled by the combing teeth of the counter gear. The transported melt or solution weight is thus:

$$G\,[\text{g/min}] = V\,[\text{cm}^3/\text{revolution}] \cdot n\,[\text{revolutions/min}] \cdot \gamma\,[\text{g/cm}^3] \qquad (4.32)$$

with [cm³/revolution] = specific pump size and γ = density of the melt.

For a pre-pressure of about 100 bar the allowable pressure differential is depending on the pump size and type 150 or 350 or 450 etc., up to 1000 bar.

The correct selection of materials is particularly important, because of the resistance against corrosion as well as expansion due to temperature: spinning pumps must be able to work cold and at up to about 330...480 °C or up to over 600 °C. Table 4.22 shows some recommendations.

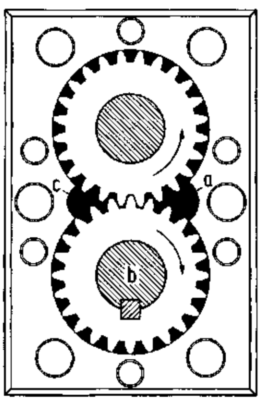


Figure 4.110 Working principle of a gear pump for a melt metering
a) Melt entrance
b) Gear driveshaft
c) Melt discharge

Table 4.22 Recommended Materials for Spinning Pumps

Steel containing	For			
	Polyester PP	Polyamid	Polyramid	650 °C 700 bar
C	2.0	1.25		
Cr	12.0	4.3		
M	0.85	0.9		
W		12.0		
V		3.8		
Ni		–	Hastelloy C 276	CPM 10-V CPM-T-15
	x200 Cr 12 1.3202	similar to 1.2601	(Zenith)	(Zenith)

Special materials: Hastelloy C 276, Stellite [89]

Especially for smaller titers the size of the spinneret is often smaller than the width of the pump. Therefore spin pumps with 2, 3, or 4 exit streams were developed to fit onto the same contact surface respectively width. In principle a corresponding number of plates are put on top of each other (see Fig. 4.112) with an entry hole and an exit hole per gear pair respectively gear level, that all lead into the connecting plate (Fig. 4.111 for a double stream pump) [107].

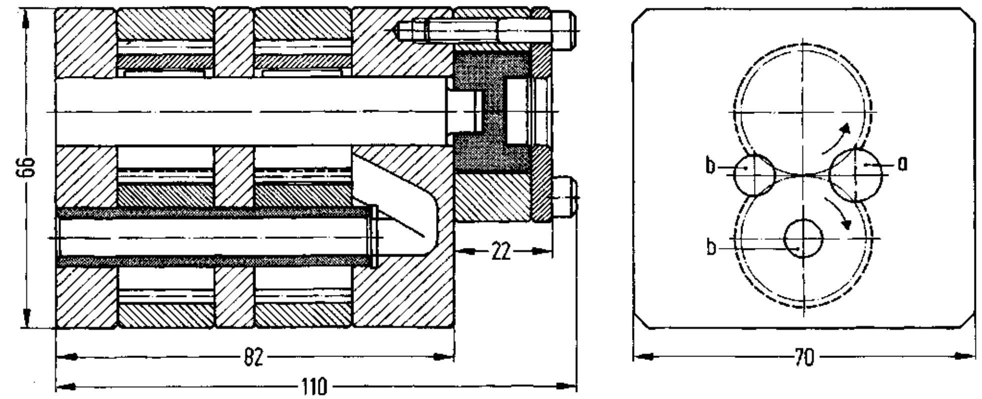
The number of exit channels can be doubled by using 3 gear combinations in every gear level, as shown in Fig. 4.112 in an explosion drawing. This pump has accordingly with 2 gear levels and 1 melt entry in the rear plate (20) four melt exit holes to the following spin packs.

With four and more gear levels the pumps are built very high, resulting in possible temperature differences between the gear pairs near the connecting plate and near the drive. This can be avoided with planetary gear pumps (Fig. 4.113) [106–107] that arrange all 3 to 8 pump gears in one level around one planetary gear as the drive. The melt entry is in the center and each of the *n* exits in a corresponding gear wedge.

Table 4.23 shows an overview over the complete spin pump program of one producer [106], arranged by contact surface and capacity. Pumps with same contact surface and number of exit streams can be interchanged. The round pumps with 100 respectively 120 mm diameter are planetary gear pumps. Because of the great exactness of the spin pumps they may only be connected to surfaces of an eveness and roughness of $\leq$ about $\pm 0.5\,\mu m$; this can only be achieved by machining and subsequent polishing. For a spin beam design with welded pump connection plates this is almost impossible. In those cases protective plates of at least 30 mm thickness are set under the pumps, and their entry and exit holes are sealed at the machine side by Al or temperature corresponding sealing discs that are machined to the aforementioned precision. They also allow the installation of spin pumps with different connection dimensions. The pumps of different producers [106–109 et al.] are also interchangeable if the tenth of a mm deviation between the metric and inch system is acceptable.

4.6.8.2 Spin Finish Pumps

Spin finish pumps correspond in their design to the spin gear pumps with 1 or 2 exits per gear level and up to 12 dosing streams per pump. Because of the low viscosity of the spin finishes, usually water—spin finish—emulsions, and because of their low lubrication effect the manufacturing precision has to be even



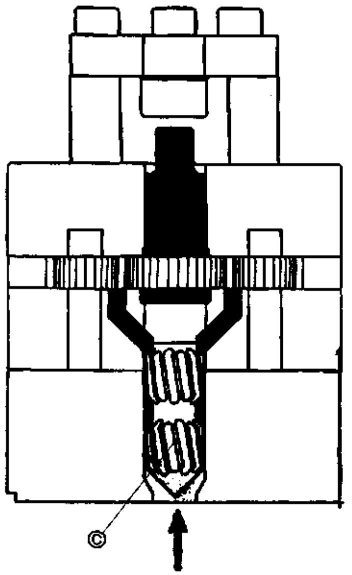


Figure 4.111 Double stream metering pump [107] with mixing staff
a) Common melt entrance
b) Two separate discharge ports
c) Mixing entrancer

higher than for spin pumps. The exposed drive shaft has to be sealed. The production rpm is between 20 and 90 rpm, mostly around 50 ... 65 rpm. A 12-fold pump is shown in Fig. 4.114 [106, 107]. With respect to drive and applications see chapter 4.6.12 [110, 111].

4.6.8.3 Discharge Pumps and "In-Line" Pumps

In many cases, these pumps replace the traditional discharge screws (Fig. 2.21) and the melt extruders (Section 4.6.4).

The large input cross-section (Fig. 4.115) is $\approx(6 \ldots 10) \times$ the outlet cross-section, however for "in line" pumps only $(1.2 \ldots 1.3) \times$ output cross-section. They have to be vacuum proof (< 0.1 mbar) for allowable counter pressures of 200 bar and jacket heated, usually for dow vapor up to 340 °C. A special tooth base design facilitates the sideways flow of the melt during combing. A pump series [107] comes in sizes of 30 ... 3100 cm^3/revolution for maximum throughput of 11 t PET/h of about 2500 P at 40 rpm. Another "Vacorex" pump [112] is shown on the right side of Fig. 4.115 with dimensions and power specifications for Fig. 4.116. The housing is made from St-G, gears and shafts from special steel,

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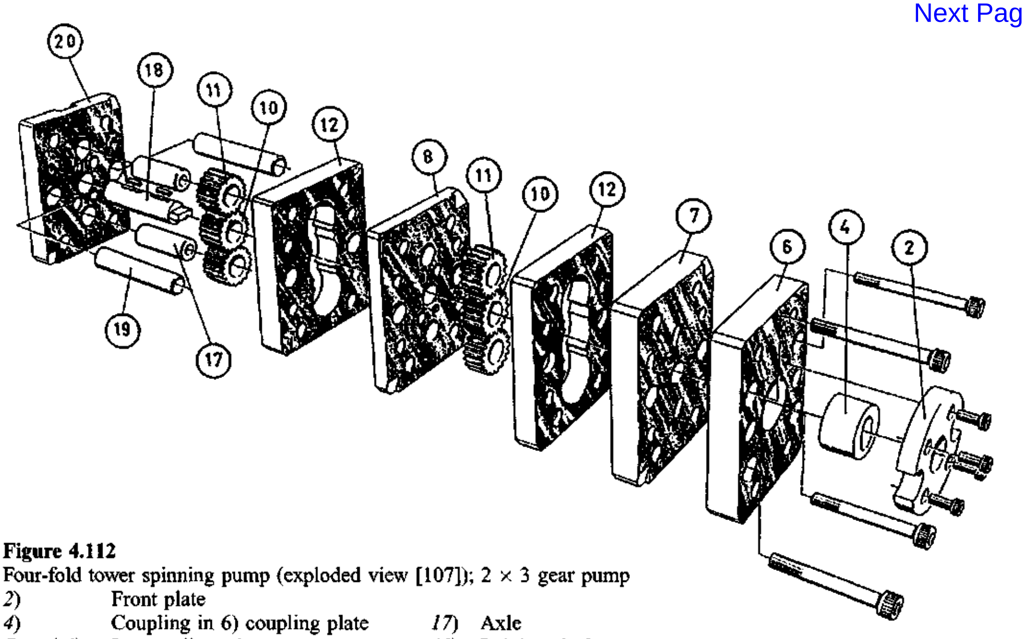


Figure 4.112
Four-fold tower spinning pump (exploded view [107]); 2 × 3 gear pump

2)	Front plate		
4)	Coupling in 6) coupling plate	*17*)	Axle
7) and *8*)	Intermediate plates	*18*)	Driving shaft
10)	Pump gear with key way	*19*)	Centering bush
11)	Pump gear without key way	*20*)	Rear plate
12)	Pump gear plates		

hardened and polished, and it has a simple or double sliding ring seal. The input pressure can be between 10^{-5} and 7 bar for viscosities up to 10^5 P; the counter pressure should be ≤ 250 bar. The high throughputs and drive powers require appropriate infinitely variable drives, possibly pressure controlled, preferably double joint cardano shaft (Fig. 4.117).

Evaluations of the throughputs of spin pumps and discharge pumps at 2/3 of the maximum capacity results in melt speeds as in Fig. 4.118. The curve (2b) shows that at the vacuum sucking side for 40 . . . 100 mm pipe diameters only 1.2 cm/s, for extruder feeding 2 . . . 3 cm/s can be expected, however on the pressure side 3 . . . 5 cm/s.

Spin pumps and the aforementioned pumps should also be cleaned on a regular basis, usually every six months.

4.6.9 Melt and Solution Filters

Contaminations in the pre-products—in melt or in solution, degradation removed from pipe walls, etc., can cause interruptions in the production process and result in a deterioration of yarn quality. A contaminant particle of 10 μm is as large as the diameter of a 1 dtex filament, or equals 25% of the diameter of a carpet yarn filament. Using monochromatic light, one can show that the filament tension-

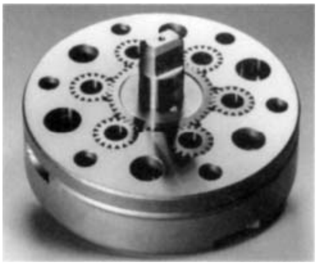
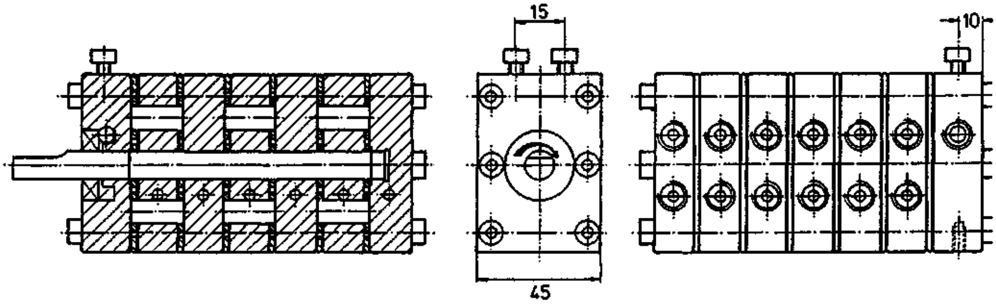


Figure 4.113
Sixfold planetary gear spinning pump, opened [106]

Table 4.23 Commercial Spinning Pumps [106]

Type cm^3/revolution	Base area mm	Weight kg	Type cm^3/revolution	Base area mm	Weight kg
0.16	66 (64) × 70	1.0	3 × 0.3	78 × 95	3.3
0.3		1.2	3 × 0.6		3.4
0.6		1.3	3 × 1.2		3.8
0.9		1.2	3 × 1.75		3.8
1.2		1.3	3 × 2.4		3.9
1.75		1.4	3 × 3		4.4
2.4		1.6	4 × 0.3	64 × 70	2.5
3.0		1.8	4 × 0.6		2.7
4.5		2.0	4 × 0.9		2.9
2 × 0.16	66 (64) × 70	1.5			3.2
2 × 0.3		1.5	4 × 0.3	78 × 95	2.6
2 × 0.6		1.6	4 × 0.6		2.9
2 × 0.9		1.7	4 × 0.9		3.0
2 × 1.2		1.9	4 × 1.2		3.3
2 × 1.75		2.1	4 × 1.75		3.7
2 × 2.4		2.4	4 × 2.4		3.9
2 × 3		2.7	4 × 3		4.4
2 × 4.8		3.3	4 × 0.6	$D = 100$	4.8
2 × 0.3	78 × 95	1.8	4 × 1.2		4.8
2 × 0.6		1.9	4 × 1.2	$D = 120$	9.0
2 × 0.9		2.0	4 × 2.4		9.4
2 × 1.2		2.1	4 × 4.8		10.0
2 × 1.75		2.3	8 × 0.6	$D = 100$	5.7
2 × 2.4		2.5	8 × 1.2		5.7
2 × 3		2.8	8 × 1.2	$D = 120$	10.3
3 × 0.3	64 × 70	1.5	8 × 2.4		11.0
3 × 0.6		1.6	8 × 4.8		12.6
3 × 1.2		2.0			
3.5	64 × 97	3.2	75	$D = 200$	28
5.5		3.5	100		32
10		4.1	150		39
2 × 3	80 × 145	4.6	250	$D = 240$	54
2 × 5.5		5.4	350		58
2 × 10		6.4	500		72
2 × 15		6.6	375	$D = 340$	130
2 × 20		7.0	500		160
6	80 × 122	3.5	750		195
10		4.0	750	$D = 460$	340
13		4.0	1000		340
20		4.7	1500		380
30		5.7	2300		380
2 × 6	80 × 122	5.5	3000	$D = 640$	960
2 × 10		6.4	150	flange	45
2 × 13		6.5	250	connection	60
2 × 20		9.0	500		205
30	96 × 152	8.3	750		250
40		9.2	50	flange	45
50		10.0	150	connection	60
30	126 × 160	13.0	250	jacket	160
40		15.0	350	heated	160
50		16.0	500		270
50	133 × 200	18.0	750		270
70		21.0	1000		270
100		25.0	1500		600
150		28.0	2300		600
			3000		1000



Manufacturer:	Barmag	Feinprüf [106]
	capacities cm^3/rev./stream	
	0.05	0.05
	0.08	0.08
	0.16	0.16
	0.30	
	0.60	
	1.0	

Figure 4.114
12-fold spin finish pump [107]; capacities available for 1 ... 12 streams are given in table

induced (optical) lines surrounding the contaminant particle are so compressed that the local yarn tension becomes as high as double the average tension; this can cause incipient cracks which result in yarn breaks. Contamination can arise anywhere in the production stream, through, e.g., depolymerization, gel formation, cross-linking or carbonization occurring as a result of a locally-high residence time, among other causes. Clean melt or solution flowing past these areas of local contamination can remove degraded matter from the boundary layer, with negative consequences. Figure 4.119 shows some extreme cases: In (a) the melt carbonizes in the sharp flow bend (2) of a spinning pump, and in (b) the same occurs in the small gap between the pipe wall and the inner diameter of the sealing gasket. Contamination sheared off above, as well contamination arising from pipe walls after long usage, can be partly reduced or avoided by careful design and construction. They can also subsequently be filtered out, at latest by a pack sieve (3) above the spinneret, as in (c). Degradation occurring downstream of the filter sieve (e.g., c6) cannot be

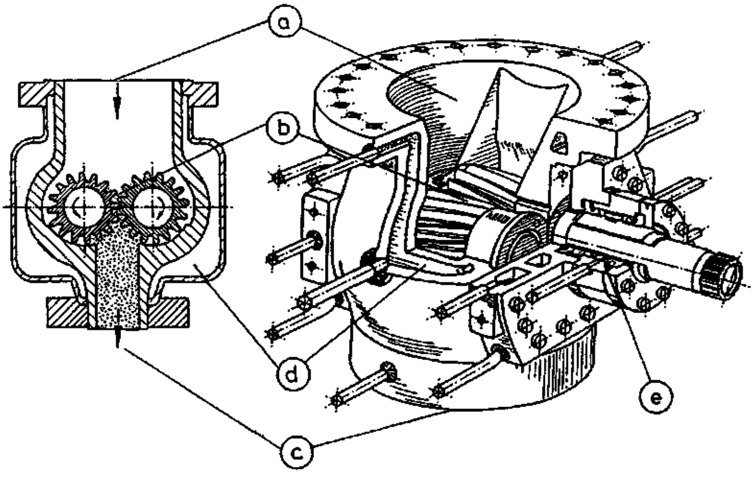


Figure 4.115
Discharge gear pump [112]
a) melt inlet (under either pressure or vaccum)
b) pump gears
c) high pressure delivery
d) heating jacket

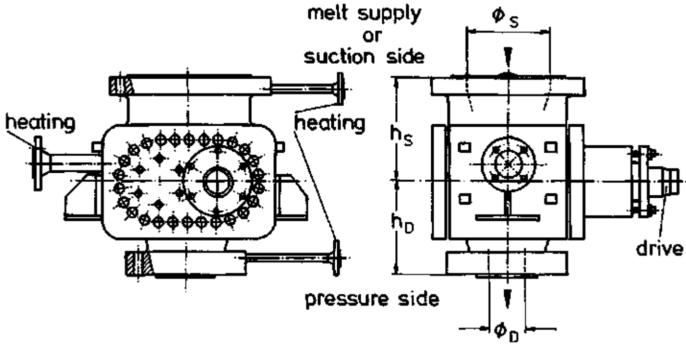
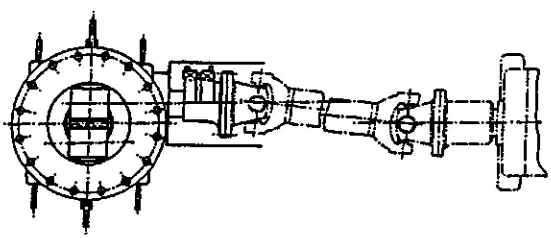


Figure 4.116
Dimensions, capacities and driving power of the "Vacorex" discharge gear pumps. Data for PET [107]

Capacity spec.	abs	Dimensions h_S	h_D	ϕD	ϕS	n_{max}	Driving power kW at $^2/_3$ n_{max}, 100bar, 5000 P			Melt velocity at $^2/_3$ max. power	
										suction side	pressure side
cm³/rev.	≙t/h	mm	mm	mm	mm	rpm	pumping		frictional	cm/s	cm/s
46.3	0.36	235	100	50	225	200	1.3	+	0.95	1.28	5.13
176	1.03	380	175	80	350	150	3	+	1.8	1.2	5
716	2.80	520	250	125	430	100	7.8	+	4.5	1.59	6.35
1482	4.94	584	300	150	530	85	13.5	+	7	1.94	7.76
3200	8.78	730	400	200	640	70	25	+	10.5	1.94	7.74
6108	14.36	915	500	250	770	60	40	+	15.5	2.03	8.13

removed by filtration, but can be avoided by careful construction: sharp run-out holes in the underside of the distributor plate and a cone mounted on the upper side of the spinneret, the base of the cone extending up to the first ring of holes (annular spinneret), or the use of "shower-head" hole distribution spinnerets having a minimum gap between the distributor plate and the upper side of the spinneret.



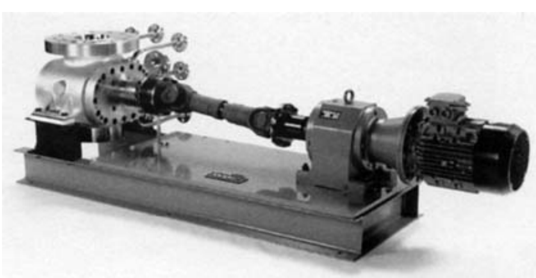


Figure 4.117
Drive of 1482 cm³/rev. discharge gear pump having a double cardan shaft, gearbox and motor. The required power is ca. 25 kW at 68 ... 15 rpm [112]

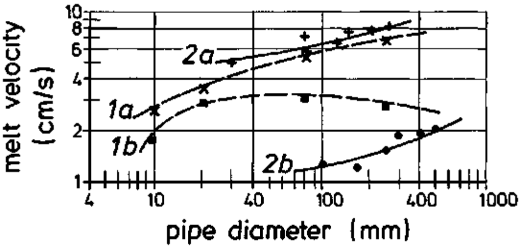


Figure 4.118
Melt velocity in spinning- and discharge pumps as a function of the pipe diameter *D*, at 2/3 of their maximum capacity
1) Barmag, Feinprüf spinning pumps
2) Maag discharge pumps
a) Discharge (pressure) side
b) Melt entrance (suction) side

Gels cannot be filtered out in this manner; one must use more effective sand filters. From experience, filters having a lower load are more effective, i.e., contaminants should be filtered out as early as possible, and this should be followed by further downstream filtration. The last filter before the spinneret improves the uniformity of pressure distribution through its pressure loss: the greater the filter resistance, the lower is the filament to filament titer difference.

4.6.9.1 Filter Media and Construction

The simplest filter comprises one or more layers of woven stainless steel wire: in plain weave construction with mesh sizes down to 25 μm (= 40 000 mesh/cm^2), as a reinforced fabric, with mesh sizes down to 14 μm or as a braided construction capable of achieving apertures down to 5 μm. The fine woven wire mesh must be supported and protected against damage. Multi-layer constructions of, e.g., 6000 – 40 000 – 6000 – 200 mesh/cm^2 (the last resting on the distributor plate) have proved highly effective. For up to ca. 330...350 °C, the sieve layers are edged in aluminum; the edge also serves as the sealing gasket. As the press and edging tools are relatively expensive, one should select existing filter sizes from the manufacturer's catalog when designing new machines. Table 4.24 gives an extract from such a catalog [113], which has ca. 300 sizes of gasketed round filters between D_i = 19.7 and 325 mm, ca. 20 additional gasketed filters for annular spinnerets, ca. 60 kidney filters, ca. 50 longitudinal (oval) filters with rounded corners and ca. 20 rectangular filters [113, 114]. Often a 20...30 mm high layer

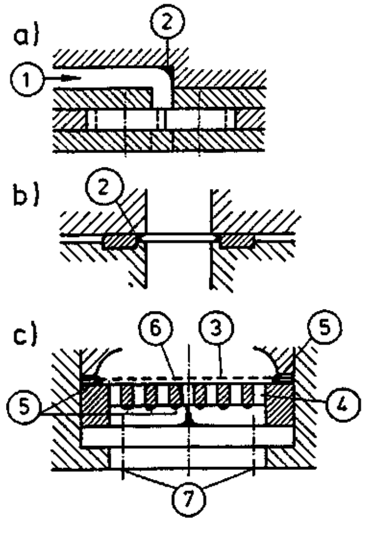
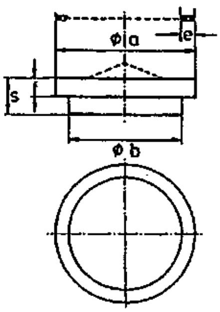
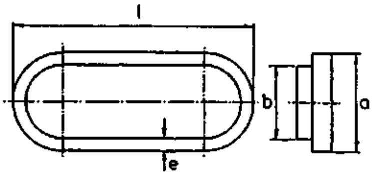


Figure 4.119
Development of depolymerization and carbonized polymer residue above the spinneret
a) in a gear spinning pump
1) Melt
2) Deadspot in a bend
b) At a flange gasket seat
2) Circumferential dead space
c) Above a flat spinneret with circular hole distribution,
3) Filter
4) Distributor plate
5) Dead spots
6) Stagnation point
7) Spinneret bores
Black areas denote degradation

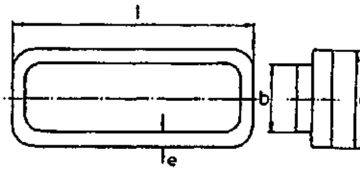
Table 4.24 Pack Filter and Spinneret Shapes and Dimensions—Selection



Bore D_i mm	Filter or Spinneret a mm	b mm	e mm	Max. no. of holes at 4 mm pitch (shower head pattern)
36	35.4	25.4	5	32
42	41.4	30	5	44
52	51	43.5	5	94
60	59	50	4	
64	63	54	4	140
70	69	60	4	174
85	84	75	4	273
90	89	78	5	294
100	99	88	5	375
115	114	102	5.5	502
125	124	112	5.5	610
160	158.5	147	5.5	1050
170	168.5	157	5.5	1200
190	188.5	176	5	1510
250	248	235	6	2680



a mm	l mm	e mm	Area mm^2	$n_{max} \cdot 4$ number of holes
26	458	4	8 030	400
56	236	5	11 297	700
60	314	5	15 163	946
65	200	5	10 350	644
65	415	5	21 668	1 350
85	410	6	28 792	1 800
95	420	6	33 299	2 080



a mm	l mm	e mm	Area mm^2	$n_{max} \cdot 4$ number of holes
66	108	5	4 370	340
66	268	5	14 430	900
81.7	181.7	5	12 310	769
94.8	369.8	7.5	32 740	2 046

of quartz sand—or better, shattered stainless steel powder—is placed above the sieve filter and held in place by means of a bordered fabric-filter (sand retainer) (Fig. 4.120a). Such "sand" filters retain at least some of the gel particles. Typical throughput loadings for these filters lie between 1.5 and 2.5 $g/cm^2/min$.

Stainless steel powder [116] is available from 304L, 316L and 410L steels. The powder is sold as fractions, sieved according to ISO 565—1983. Fractions from 45 . . . 90 up to 700 μm are available. The

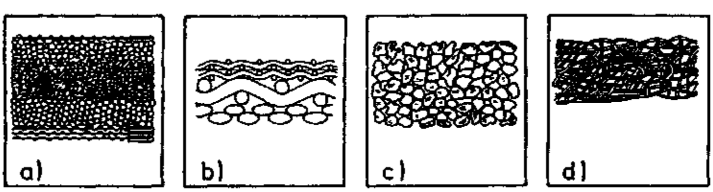


Figure 4.120
Various filter media assembly
a) Sand filter above stainless steel wire mesh filter
b) Fuji filter
c) sintered metal powder
d) sintered metal fiber (nonwovens)

bulk density varies from 3.0 (for fine grade) to 1.7 g/cm^3 (for coarse grade). After use, the powder can be cleaned of PET or PA by boiling in TEG or by vacuum pyrolysis.

The same powder is used to make sintered metal filters [117, 118], which are available as plates or tubes, with finenesses down to ca. 1 µm. As the contaminant particles can penetrate deep into the sinter material, the cleaning of such filters is very difficult, particularly for inorganic particle contamination (Fig. 4.120c).

The Fuji filter, constructed from woven sieves of varying fineness which are sintered together, is an effective filter (Fig. 4.120b, [119]), as are filters made from sintered stainless steel fiber (Fig. 4.120d, [120]), which can also be produced having pore finenesses down to 1 µm. These filters exhibit depth filtration, where the filter is more slowly blocked by the filter cake. This permits longer filter life, higher throughputs and greater throughput flux.

Table 4.25 gives guide values for filter capacities, both based on experience and taken from [122]. As not all raw material and process conditions are known, the table should not be treated as an exact specification, but rather as a guide.

Figure 4.121 shows the comparative performance of three different filter types, all having a fineness of 15 µm. The non-woven filter (a) retains more than 98% of particles ≥ 10 µm, while a woven wire filter achieves the same retention rate only for particles > 15 µm.

At a filter loading of (1.5) – 2.5 – (4) g/min/cm^2, the corresponding average flow velocity is 0.35×10^{-4} m/s and the Reynolds number is $Re = (0.4 \ldots 10) \times 10^{-8}$: a definite creep flow, with $\xi \geq 10^3$ (see Section 7.10.2). The pressure drop required here is not dependent on the extruder or on the

Table 4.25 Filter Capacities

Polymer/Product	Filter material	Filter fineness µm	Filter flux (specific throughput) $\frac{g}{min \cdot cm^2}$	Filter flux (specific throughput) $\frac{kg}{h \cdot m^2}$	Maximum throughput kg/m^2	Filter life (approximate) days	Remarks
Pack filters							
PET POY	D + S	20	1…2	1200	1 200 000	62	good
				600	500 000	31	average
			2.5	1500	500 000	24	
			2.5	1300	200 000	62	with GVF 20 µm
PA 66 POY	D + S	10…20	1…1.5	600	600 000	31	
PA 66 tire yarn	D + S V + S	20	2.5	1500	$(5 \ldots 8) \cdot 10^5$	20…30	with spinneret blanketing
PET tire yarn	D + S	20	2.5	1500	$\approx 10^6$	50	
PET staple fiber	V	20	5	3000	1 500 000 2 000 000	21 28	with GVF 20 µm
PA 6 carpet yarn	D	20	1.5…2	1500	1 100 000	31	
PP carpet yarn	D	70	3	200	1 000 000	30	
-carpet staple fiber	D	70	3	2000	2 000 000	30	natural
-carpet spunbond	D	70	2.2	1300	2 000 000	60	
-carpet staple fiber	D	70	2.5	1300	50 000…10 000	=3…1	pigmented
Large volume pre-filters for							
PET	D	20	1…1.6	600…1000	100 000…200 000	5…7	
DGT (fresh)	V	10		320…500	95 000	9	
(from recovery)	V	80			15 000		
Pack filters for							
PAN solution	D	30		2000…3000	100 000	2…6	

D = wire fabric D + S = D + sand V = pre-filter GVF = large volume pre-filter spinning pump inlet pressure of $\leq 10 \ldots 50$ bar. The required spinneret size can be calculated from the allowable filter loading. For example, a 100 spin decitex POY at 3600 m/min spinning speed has a spinneret throughput of 36 g/min. Taking $\rho = 1.2$ g/cm^3, the required filter area is 24 cm^2, equivalent to a filter diameter of 5.53 cm. Here one would use 60 mm front diameter, $\cong 70$ mm outside diameter. In this spinneret, 2 rings of capillaries can be fitted. Using a hole spacing of 4 mm, up to 68 capillaries for spinning 1.47 spin dpf (ca. 1 dpf final) can be accommodated.

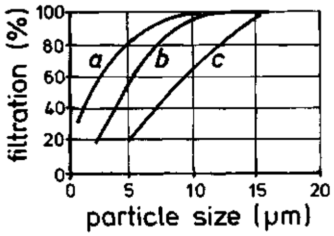


Figure 4.121
Dirt retention as function of the particle size for different filters (% efficiency = % dirt retention)
a) Fiber felt
b) Sintered bronze of 200 × 1400 meshes/cm^2
c) Stainless steel wire mesh fabric of 1400 × 10,000 meshes/cm^2

There are many ways of increasing the filtration area of a spinneret of given outside diameter; this is shown in Fig. 4.122. The flat filter (a) can be pleated (b) and turned into a filter candle (c). Many small candle filters can be fitted to the distribution plate (d), an enlargement of which can be seen in Fig. 4.123. In order to avoid dead zones, the space between the candle filters can be eliminated by fitting solid pins [119]. Figure 4.122e illustrates a sandwich filter, composed of many biconical double filters, for use in large diameter spinnerets. Here the melt flows from outside to inside, then is led away centrally. One can also fill the intermediate volume with filter sand on the inlet side.

The filtration of gel particles improves with lower shear—and hence absolute velocities; this is valid for freshly-inserted spin packs. If, owing to the thickness of the filter cake, a critical pressure is exceeded, the gels are deformed by shearing and are forced through the filter medium. This can be observed when,

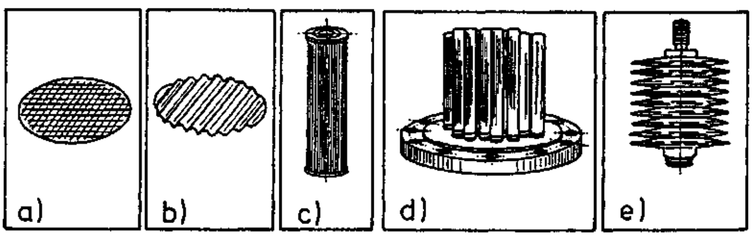


Figure 4.122 Comparison of various filter types which can be used in the same pack volume (70 mm diameter × 100 mm height) to give increased filter area

Filter type	Filter material	Filter area cm^2	Effective filter area at 300°C cm^2	p_{max} kg/cm^2
a Flat filter	Stainless steel mesh	33	33	3...5
b Pleated flat filter	Stainless steel mesh	150	90	5
– Cylinder	Sintered stainless steel powder	113	100	40
c Pleated cylinder (candle)	Stainless steel mesh	970	590	210
d Many small cylinders (candles)	Fuji filter medium or stainless steel mesh	580	580	350
e Biconical disk filter assembly	as in d	450	450	300

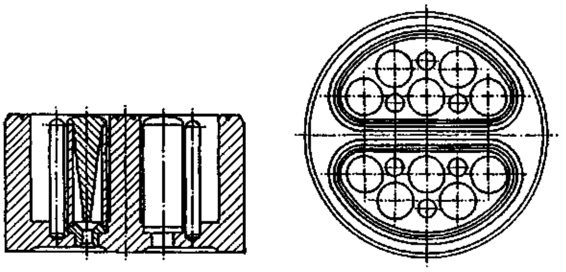


Figure 4.123
Candle filter arrangement for two kidney-shaped spinneret hole-fields in a round spinneret [119]. Pins are used to reduce the dead volume

after a period of problem-free spinning, an "avalanche" of filament breaks occurs simultaneously with a noticeable reduction in pressure upstream of the filter. If, however, one continues spinning, the situation regarding filament breaks can return to normal after some time. This purging period is, however, generally so long that the spin bobbin must be doffed.

4.6.9.2 Use of High Load Filtration to Protect the Spinning Pumps

Metal particles in the granulate (chip) which are smaller than the clearance in the motoring zone of the extruder are—unless previously removed by magnetic separation—carried along by the melt and can cause serious damages to the spinning pumps. The simplest way to filter out these particles is shown in Fig. 4.124. A relatively coarse filter sieve (b) is supported on a breaker plate (c) located close to the tip of the screw. Since, because of the high filter load, these sieves must be changed frequently, many automatic-change filters have been developed; a few of these are shown. In the simplest system, a disk containing two filters is rotated between 2 plates, one for melt inlet and the other for melt outlet. One filter is in operation, while the other—after changing—is on standby. The principle of filter changing is shown in Fig. 4.125, where the filter elements are changed stepwise in such a manner (with pre-filling of the channels and degassing) that continuous operation is possible without air entry. The "Auto-screen filter"

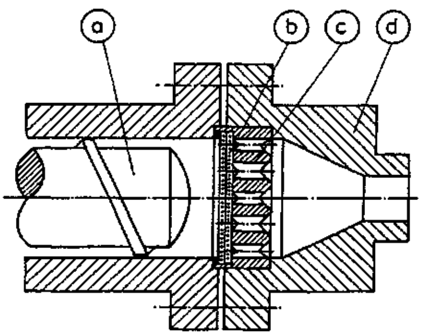


Figure 4.124
Flat filter at an extruder exit
a) Extruder screw
b) Sieve package
c) Perforated support plate
d) Connecting (measuring) head

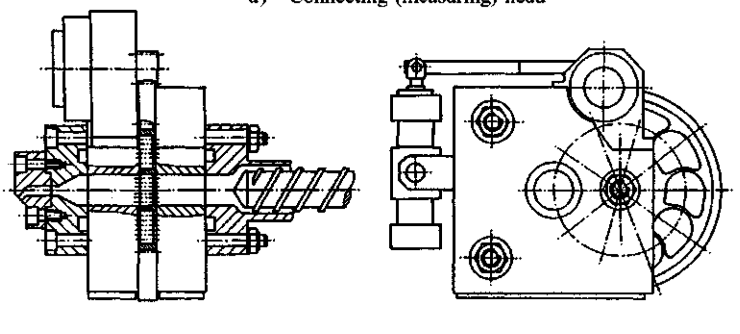


Figure 4.125
Continuous change filter (Gneuß GmbH, Bad Oeynhausen)

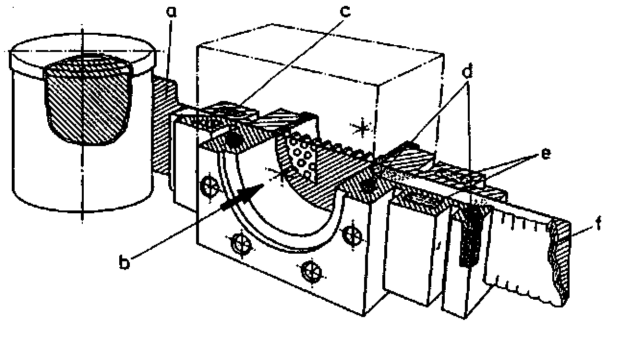


Figure 4.126
"Auto-screen" filter [105]
a) Stainless steel wire mesh filter tape
b) Polymer melt
c) Cooling
d) Heating
e) Tape exit cooling
f) Solidified melt

(Fig. 4.126, [105]) consists of a single- or multilayer filter belt which crosses the melt stream at right angles, and is driven by the blockage pressure. All of these filters are sealed by small gaps. The melt is extruded through these gaps and then solidifies to form a seal.

4.6.9.3 Large Area Filters

For long duration filtration of high throughput solutions or melts, a large filter area is required, preferably in the smallest volume possible. Figure 4.122(c) and (e) are examples of this concept. It is possible to have a filter area of up to 300 m^2 per cubic meter of housing. The surface area ratio of candles made from flat material, from pleated material and from filter plates (disks) is 1 : 3.6 : 2. For throughputs and life times, see Table 4.25. Figure 4.127, taken from a catalog [33] for candle filters similar to that shown in Fig. 4.129, gives the relationship between melt residence time, filter area and specific throughput.

Candle filters, both pleated or flat, are made predominantly in 2 sizes: ca. 0.15 or 0.4 m^2 (Fig. 4.115). These candles are fixed to distributor plates and placed in a large housing [33, 115]; each candle has one inlet and one outlet, similar to the example in Fig. 4.129 [33]. Other sizes are available with up to 93 candles, giving a total filter area of 46.5 m^2 (pleated) or 9.3 m^2 (flat filter). For uninterrupted spinning, two of these housings are encapsuled in a Dowtherm (Diphyl)-heated casing (Fig. 4.129) fitted with the necessary polymer inlet and outlet pipes, together with melt charge-over-, degassing- and purging valves. The melt pressure is measured both before and after the filter, the latter being used to control the extruder. The pressure difference Δp is used to trigger an alarm to signal the need for changing from the spent filter to the (clean) standby filter.

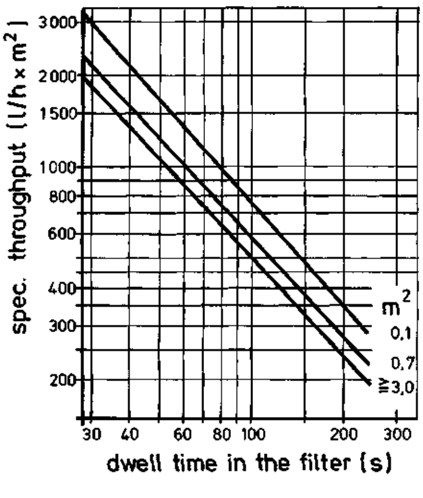


Figure 4.127
Specific filter throughput (flux) as function of the melt dwell time and filter area for a Barmag NSF filter [33]

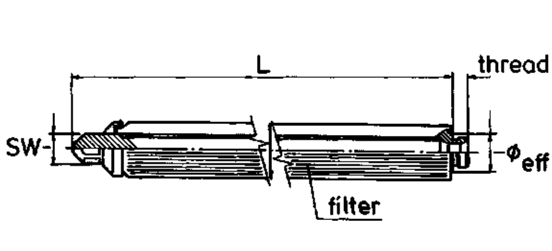


Figure 4.128
Filter candles for large area filters [115], either with smooth or pleated filter area

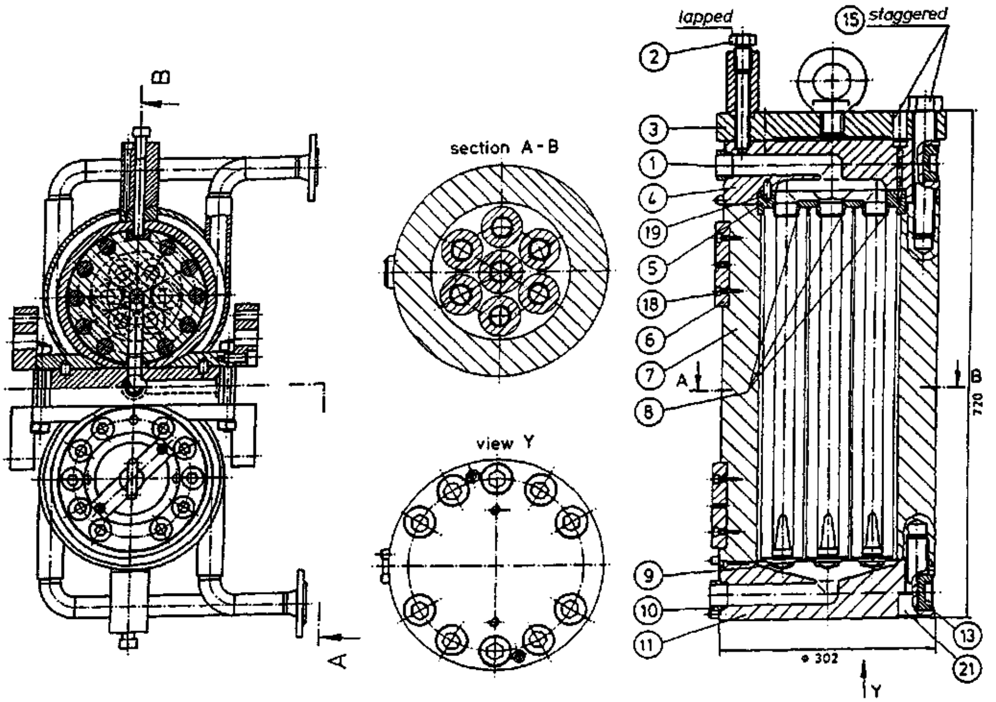


Figure 4.129 Non-stop candle filter type NSF 7 of Barmag [80]

1) Melt inlet
2) Deaeration
3) Top plate
4) Distribution plate
5) Candle filter plate
6) Guiding bar
7) Filter housing
8) Candle filters with
9) Filter candle heads
10) Melt exit
11) Melt flow and exit plate
13) Fixing calotte (jacking screw recess)
15) Top assembly screws bolts
18) Fixing screws
19) Positioning pin
21) Bottom assembly bolts

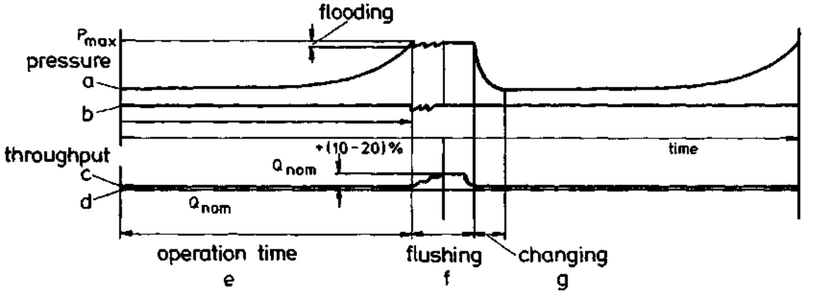


Figure 4.130 Pressure development during a filter operation cycle

a) Before and *b*) after the filter
c) Throughput before and *d*) after the filter
e) Filter operation time
f) Flushing or purging time
g) Switching chambers or changing the filter

The pressure build-up during filter operation is shown in Fig. 4.130. Under normal conditions, p_{max} should be $\leq 100 \ldots 150$ bar. The time to reach this pressure should be determined by plant trials, as the values given in Table 4.25 are guide values only and do not take into account factors such as, e.g., polymer cleanliness.

Mechanisms [33, 115] have been developed for automatic chamber switch-over to ensure interruption-free spinning.

Once removed, soiled filter elements must be cleaned very carefully. Older types contaminated with PET or PA should be cleaned in TEG, while decalin is used for elements having spun PP. The newer (welded) filter candles are robust enough for vacuum pyrolysis cleaning (compare Section 6.6.6).

Based on the same principle, in-line filters have been developed, where one filter candle is in operation and the second is on standby [24]. An example of an electrically-heated version is shown in Fig. 4.131.

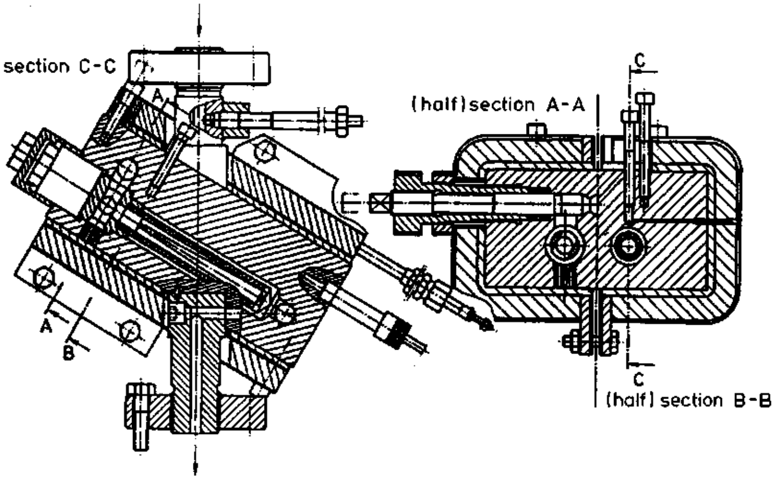


Figure 4.131 Electrically heated 2-candle, non-stop filter [24]

4.6.10 Spinnerets

Spinnerets are the actual filament-forming components. They convert the melt or solution into the required number of filaments, and largely determine the filament cross-section and single titer uniformity. For high melt inlet pressures spinneret plate thicknesses of 8...25 mm are used, while plate thicknesses of 0.8...2 mm are used for low inlet pressures, e.g., for solutions and for melts where ≥ 50 holes/cm^2 are used. Table 4.26 lists the various materials of construction according to application, as well as some important properties. Typical capillary hole spacings are given in Table 4.27.

4.6.10.1 Spinnerets for Melt Spinning

For uniform melt flow distribution and uniform filament cooling, the following points should be noted:

- No dead zones having excessive dwell time in the melt flow. This means that the outer bores should have their inlet to the corresponding counterbore as close as possible to the latter's outer inlet edge (or to the inner side of the aluminum gasket).
- In the case of annular spinnerets, a central cone should be fixed to the inlet side of the spinneret plate, its base extending close to the first (inner) ring of capillaries, in order to avoid a dead spot in the center of the spinneret.

Table 4.26a Construction Materials for Spinnerets

Spinning process	Solution spinning		Melt spinning		
	wet spinning	dry spinning			
Temperature	≤90 °C	≤350 °C	≤400 °C	≤600 °C	≤1400 °C
Spinneret materials	gold-platinum-iridium nickel tantalum glass	1,4580 tantalum	1,4580 1,4571 AlSl 316	1,4550	platinum-rhodium

Do not use: Ta with NaOH, HF
1.4580 with $H_2SO_4 + H_2O$
Ni with HNO_3, HCl, $H_2SO_4 + H_2O$

Table 4.26b Properties of Spinneret Materials

Material	At T °C	$\sigma_{0.2}$ kg/mm^2	Hardness
Au Pt Ir		2,3 . . . 5	≈250 HV
Ni		10 . . . 21	
Hastelloy C		> 32(< 420 °C)	
Ta			110 HV (treated 300 HV)
1,4122	300	54	
1,4550	300	14	
1,457	300	15	130 . . . 190 HB
1,4580	300 (450)	15	
A S 17/4 PH			270 . . . 290 RC/=450 HB
Pt-Rh-80/20	(700) . . . 1350	8 + 3	

Table 4.27 Typical Spinneret Hole Spacing

Spinning method and filament cooling	Spinning speed range m/min	Typical spinneret hole spacing (mm) for fine titers (≈1 . . . 4 dpf)	coarse titers (≈12 . . . 25 dpf)
Solution			
wet spinning	2 . . . 80	≳0.5 × dpf	≳0.8 × dpf
dry spinning	100 . . . 1000	≳3 × dpf	dpf
Melt spinning with			
wet cooling	10 . . . 80	≳10	
air cooling, laminar	200 . . . 8000	3≲a≲dpf	
air cooling, weakly turbulent	1000 . . . 2000	≈1.5	≈3
air cooling, strongly turbulent	0.8	1.5	
(compact)	20 . . . 100		
filament fusion	5 . . . 1000	≲0.2	
microfibers		≈ 3/dpf	—
tirecord yarn		≳1.5 × dpf	

dpf = final decitex per filament

Round and rectangular spinnerets have been presented in Table 4.24. There are, in addition—particularly for compact staple spinning "trough" spinnerets (Fig. 4.132), which are used for spinning fine titer filaments at hole densities of up to 150 holes/cm^2 = 44 000 holes in a spinneret of 450 mm × 65 mm^2. These capillaries are 2 mm long and have no counterbore. To increase the spinneret throughput when spinning fine multifilament yarns, the spinneret can be divided into 2 to 4 separate hole areas, each served by separate pump streams from double or four-fold spinning pumps, as shown in Fig. 4.133.

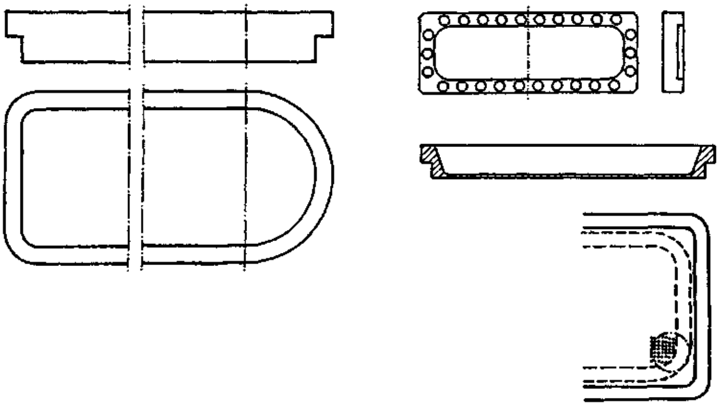


Figure 4.132
Spinneret and pack filter shapes according to Table 4.24; additional common shapes are shown here

Figure 4.134 gives commonly-used hole layouts for rectangular and annular spinnerets. Calculation of the wake angle of a filament in the quench enables optimum capillary to capillary distances to be determined.

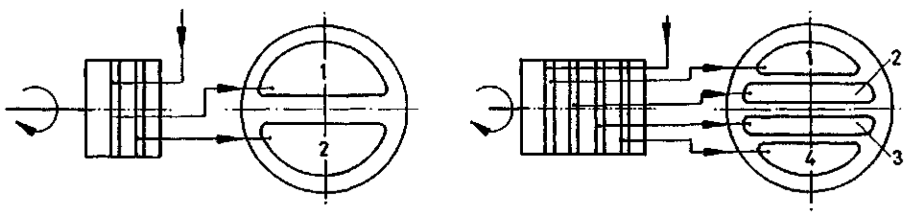


Figure 4.133 Round spinneret, divided into 2 (respectively 4) bore fields, with spinning pump for 2 (respectively 4) melt streams

If we take a wake half angle of ca. 10°, the width of the wake is ca. 1.8 mm after a hole to hole row distance of 5 mm. If this latter hole is displaced 0.9 mm sideways relative to the hole of the first row, the latter hole falls outside the wake of the first hole. Only after 5 rows does a hole once again fall within the wake of the first hole. Spinnerets for high added value yarns therefore have a maximum of 4 rows, so that the temperature difference of the quench air flowing from filament row to filament row is minimized.

Longitudinal sections of possible spinning bores, showing inlet cone, counterbore, exit cone and capillary are shown in Fig. 4.135. In the case of profiled capillaries, the bottom of the conterbore is flat, so as to make the cross-section of equal length. In melt spinning, a round hole produces a round filament (Fig. 4.136), while profiled capillaries produce a shape corresponding to the hole shape. As soon as the distance between 2 or more capillaries is ≤0.2 mm, the filaments fuse together to form a profiled filament, entrapping voids between the filaments. Hollow filaments, e.g., can be formed by means of such fusion: the filaments from two semi-annular capillaries fuse together to form a hollow cylinder. A

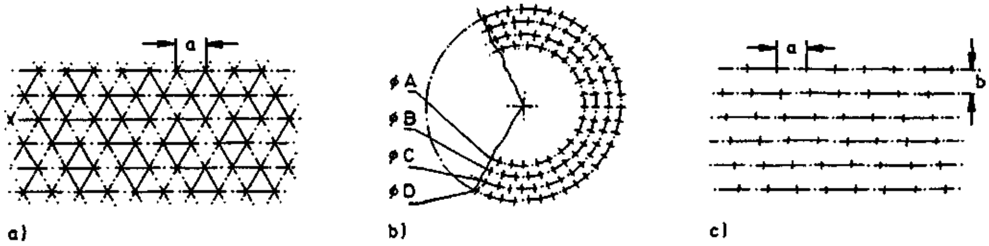


Figure 4.134 Hole layouts for melt spinnerets
a) densest (staggered) arrangement : triangular pitch
b) arrangement for round spinnerets : radial spacing and tangential spacing
c) slightly staggered hole rows

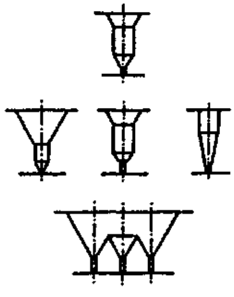


Figure 4.135 Cross-sections of typical melt spinneret capillaries

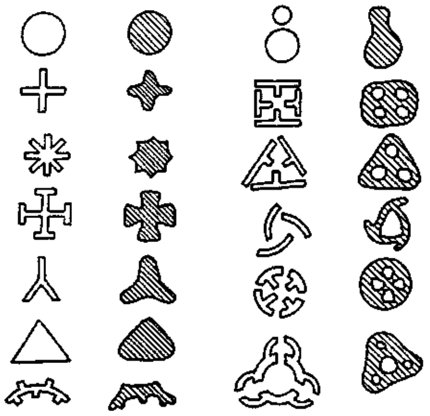


Figure 4.136 Profiled melt spinneret holes and their corresponding filament cross-sections

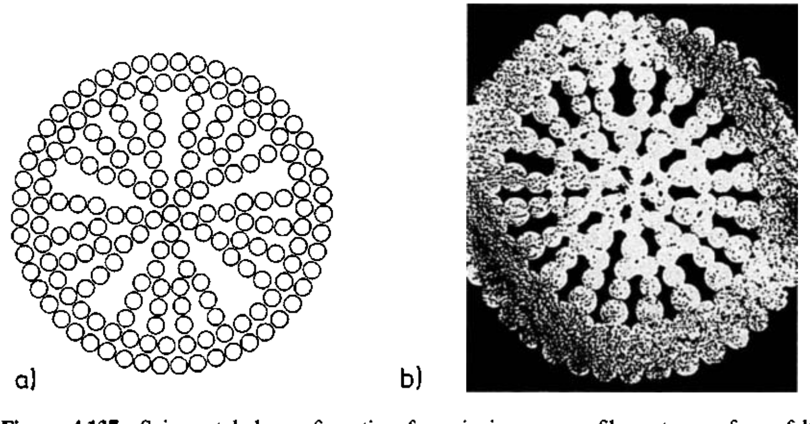


Figure 4.137 Spinneret hole configuration for spinning a monofilament yarn for a felt-tipped pen, and the corresponding tip micro cross-section [123]

particularly ingenious example can be seen in Fig. 4.137: the capillary configuration (a) produces, after solidification, the capillary monofilament fiber of external diameter 0.5 mm in (b), which is used for felt-tipped pens [123].

For radial (outflow) quenches, one uses annular spinnerets having the holes on concentric circles, and fits a flow cone in the center of the spinnneret (Table 4.24). The inner ring of capillaries is ca. 15 mm distant from the quench candle. If, for example, the quench candle has an outside diameter of 100 mm, then the diameter of the first ring of spinneret holes will be 130 mm. If there are 10 concentric rings of holes, each ring separated by 3.5 mm, the diameter of the outside ring will be 193 mm, and there will be 202 holes in the outer ring. The spinneret will contain a total of 1690 holes and have a spinneret pitch of 500 mm.

The same spinneret can be used for outside-to-inside (inflow) quenching, provided the outflow quench has an inner diameter of ca. 225 mm. Owing to the need for supplying the air from outside, the spinning position pitch will increase to 600 mm.

Ring spinnerets having quench air supplied from above through the spin pack require a much larger diameter, are very complicated and have only a relatively small filtration area. They are thus seldom used anymore (Fig. 4.144).

For the circular and rectangular spinnerets given in Table 4.24, as well as for similar versions, the thermal expansion tolerances of the spin pack interior bores given in Table 7.12 must be taken into account, so that the spinnerets can be removed from the housing when hot or when contaminated by polymer. The same argument applies to support plates, distributor plates and the outside diameter of the bordered gaskets.

Spinneret capillary tolerances are summarized in Table 4.28. The throughput of a capillary varies with the 3rd power of its effective diameter and linearly with length; the single filament titer varies correspondingly.

Table 4.28 Capillary Tolerances for Spinnerets for Melt Spinning

Round hole diameter mm	L/D	Diameter tolerances standard	Diameter tolerances special	Capillary length tolerances standard	Capillary length tolerances special	Inlet cone tolerance	Finish
0.04...0.1	1...2	±0.002	±0.001				counterbore: 0.15...0.2 μm
0.1...0.2	1...3	±0.002	±0.001				cone: 0.04...0.1 μm
0.2...0.5	1...5	±0.002	±0.001	±0.025	±0.01	±1°	capillaries: 0.03...0.08 μm
0.5...1	1...10	±0.003	±0.002				discharge face 0.03...0.1 μm
>1	1...20	±0.003	±0.002				
Profiled hole lobe width W mm	**L/W**	**W tolerances standard**	**W tolerances special**				
0.05...0.06	1...6	±0.003	±0.0015				
0.06...0.10	1...10	±0.003	±0.0015				plate diameter: ±0.01/±0.05 mm
0.10...0.20	1...20	±0.004	±0.002	±0.025	±0.01	±2°	plate thickness: ±0.01/±0.05 mm
>0.20	1...20 or more	±0.004	±0.002				hole spacing: ±0.02/±0.05 mm

4.6.10.2 Spinnerets for Solution Spinning

The commonly-used solutions of PAN, PVC, PVA, etc., have only very low viscosities (100...500 P) and their spinning temperatures lie below ca. 150 °C, consequently the pressures required for spinning are only around 3 to 15 bar. Here the well-known viscose and acetate spinning system [124] can be taken over and developed further (Fig. 4.138). For wet spinning, hat-shaped spinnerets up to ca. 25 mm diameter are used for textile multifilaments, and plate-shaped spinnerets up to ca. 200 mm diameter for both the production of staple fibers and for dry spinning. For the latter, however, ring spinnerets as per Fig. 4.157, having, e.g., 208 mm OD × 158 mm ID, are more suitable, as the inner opening allows the spinning gas to flow parallel through the filaments to the outside.

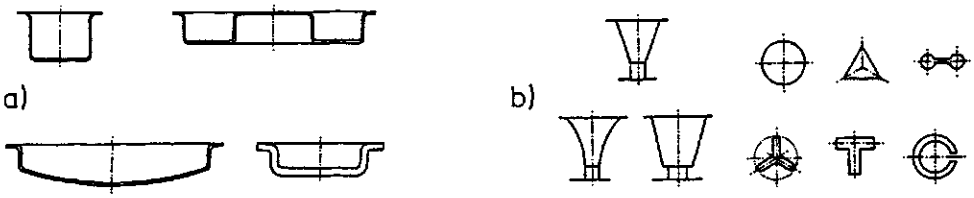


Figure 4.138 Cup and ring (annular) spinnerets for solution spinning (a) and bore shapes (b)

For the wet spinning of staple fibers, cluster spinnerets are increasingly being used (Fig. 4.139). These spinnerets are made from a stainless steel plate into which many hat-shaped spinnerets are inserted. In this way, a spinneret having an OD of 160 mm can be made to contain ca. 100 000 holes per spinning plate. Special size spinnerets can contain up to 200 000 holes. The lands between the individual "hat" spinnerets facilitate the flow of spinning solution to each yarn bundle. In addition, plate spinnerets having hole distributions as in Fig. 4.140 are still being used.

"Hat" and "plate" spinnerets used in wet spinning have a hole density of (0.1)...0.2...0.5...(1.2) mm^2/hole, with a strong tendency towards 0.2 mm^2/hole.

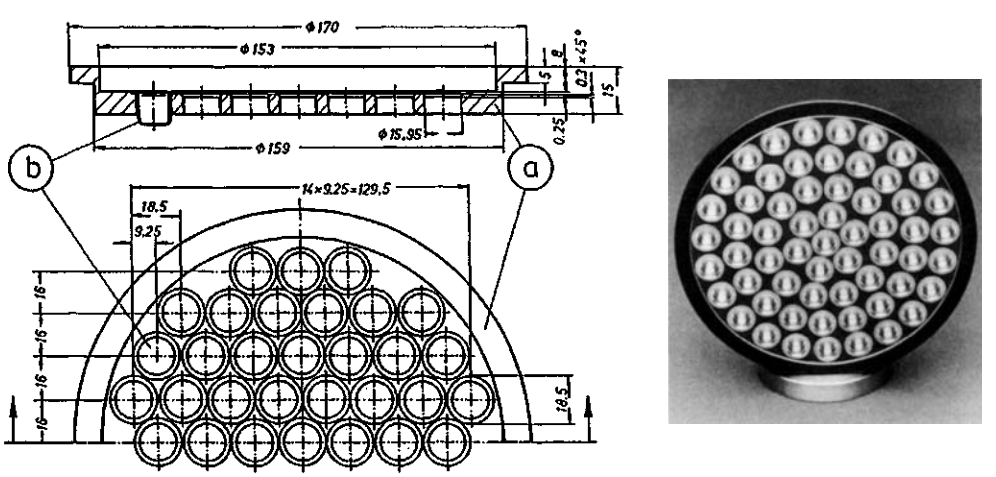


Figure 4.139 Cluster spinneret [109], example:

a) Body: cluster plate of suitable special steel

b) Inserts: e.g., 55 spinnerets of Au-Pt-Ir with 1818 holes each = 99,990 holes total; spinneret dimensions, e.g., 18/16 mm diameter × 10 mm height, 0.25 mm bottom thickness; cross-section as Fig. 4.138b

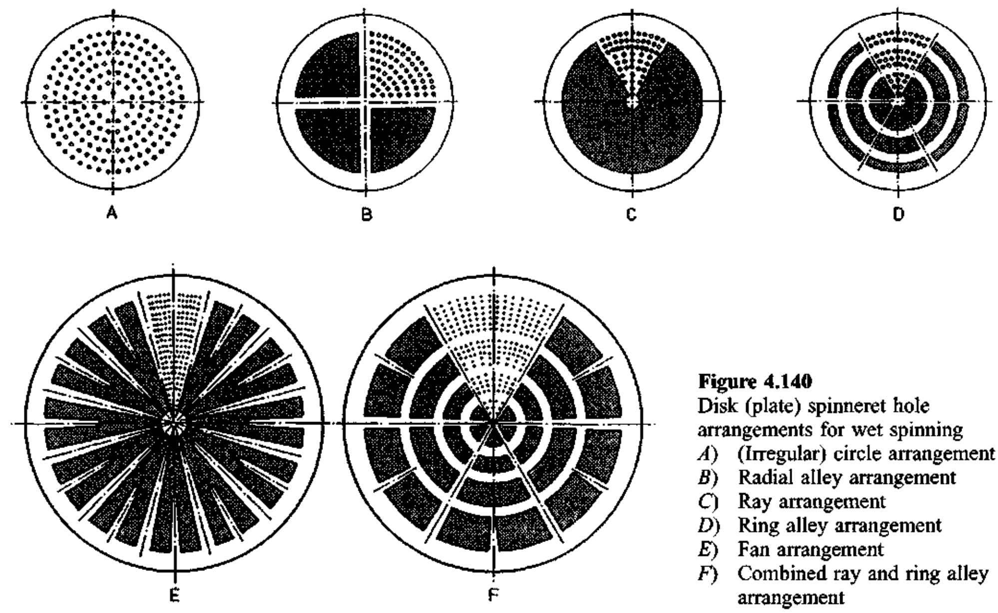


Figure 4.140
Disk (plate) spinneret hole arrangements for wet spinning
A) (Irregular) circle arrangement
B) Radial alley arrangement
C) Ray arrangement
D) Ring alley arrangement
E) Fan arrangement
F) Combined ray and ring alley arrangement

For dry spinning, "hat" and "plate" spinnerets of up to 100 mm diameter (max.) are used, with hole spacings as per Table 4.27. For higher hole numbers, ring spinnerets are chosen; these give a lower titer variation coefficient. Using such a spinneret of dimensions 208 mm × 158 mm for PAN dry spinning as an example, up to 2800 holes can be accommodated.

The spinneret plate thickness for wet- and dry spinning lies between 0.8 and 2 mm, depending on spinneret size. Spinneret construction material properties can be found in Table 4.26. Figure 4.138 shows hole shapes for round and profiled holes; these are mainly punched. The bores can be cylindrical, conical cylindrical or hyperbolic cylindrical. Profiled holes require a flat base for the capillary. The most commonly used bore tolerances are given in Table 4.29.

4.6.10.3 Special Spinnerets

This category includes spinnerets for melt spinning at temperatures up to ca. 700...1300 °C, from glass (or similar substances) to basalt. Here spinning is carried out according to the gravimetric principle, i.e., the hydrostatic pressure above the capillaries must be held constant by a constant level of melt. As construction material, practically only PtRh20 can be used, as it has the necessary resistance to oxidation in air, as well to corrosion by the melt. At 1200 °C, it still has a $\sigma_{0.2} = 14\ \text{N/mm}^2$ [128].

Figure 4.141 shows such a spinneret for a 22 multifilament and a second spinneret having 750 holes. The bores are made as nipples of ca. 1.5 mm external length and 1.6...2.2 mm internal diameter. For heating by the passage of electric current, both sides have a tongue connector 2.5...4 mm thick, to which a water-cooled, electrical connection shoe is clamped. The specific electrical resistance of PtRh20 at 20 °C is 0.21 $\text{Ohm/mm}^2\text{/m}$. The 22 filament spinneret shown would thus require a regulated connection of 1...5 V at 15 000...5000 A.

Damaged spinnerets should definitely be returned to the manufacturer, as the cost of material is 150 to 200 DM/g (1985/86 prices), while the manufacturing cost is less than 10% of this. Spinnerets made from sintered Al_2O_3 plates have not proved successful, as the edges of the melt exit holes abrade too rapidly.

Glass spinnerets [131] have also been used for normal solution wet spinning processes.

Table 4.29 Capillary Tolerances for Spinnerets for Solution Spinning

Round hole diameters mm	L/D	Tolerances L	Tolerances D	Finish	Material
0.03 ... 0.05	0.7 ... 1	+0 −0.020	±0.002 (standard)	discharge side	
0.05 ... 0.10	0.8 ... 1	±0 −0.020		mirror finish	precision metal alloy
0.10 ... 0.20	1 ... 1.5	+0 −0.020	±0.000 (special)	0.02 ... 0.05 µm	
>0.20	1 ... 2	±0.010		0.04 ... 0.08 µm	Tantalum
profiled hole lobe width W mm	L/W	L	W	hole walls:	
0.025 ... 0.04 0.04 ... 0.07 0.07 ... 0.10	0.6 ... 1 0.8 ... 1.2 1 ... 1.3	+0 −0.020	between ±0.002	inlet cone: 0.04 ... 0.06 µm capillaries: 0.02 ... 0.05 µm	precision metal alloy
0.10 ... 0.15 >0.15	1 ... 1.5 1 ... 1.5		and ±0.005	inlet cone: 0.05 ... 0.07 µm capillaries: 0.03 ... 0.05 µm	Tantalum

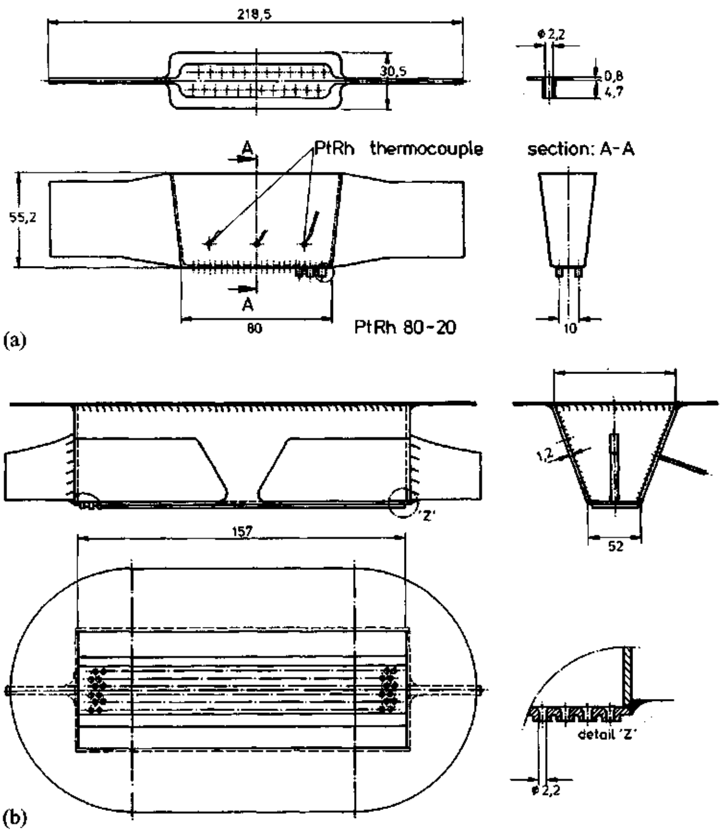


Figure 4.141
High temperature spinneret made of Pt-Rh-80-20 for glass or basalt spinning at temperatures of up to 1300 °C [109]
a) With 24 holes for filaments
b) With 750 holes for cables or tow

4.6.11 Spin Packs (Housings) and Bolting

4.6.11.1 General

Spin packs incorporate, in one housing, the components in the flow direction: pack top cover (including melt distribution), pack filter, support or distributor plate and the spinneret. It must also be possible to exchange the spin pack quickly and easily. Basically, one differentiates between 2 types of packs:

- Bottom-loading packs, inserted from below. For pack weights up to 10 kg and temperatures up to ca. 320 °C, these are manually inserted using a pack insertion tool. Packs of weight greater than 10...15 kg are fitted using a lifting device (Fig. 4.154).
- Top loading packs are inserted from above. For pack weights up to ca. 20 kg, a special insertion tool is used. An electrical hoist is used for packs weighing ≥20 kg and for typical staple packs weighing up to ca. 160 kg. In special cases, packs can weigh up to 800 kg.

Pack housings—round or rectangular—must be designed according to the regulations covering pressure vessels [5]. They should be made from suitable construction materials to withstand the spinning temperature + ≥50 °C. They must also be resistant at the maximum cleaning temperature, and should be designed to take the total extrusion pressure, as this pressure can be exerted on the housing at a pack leak.

The pack design pressure range is matched to the spinning pump. For normal textile staple and filament, 400 bar internal pressure is chosen. The pack steel used must be corrosion resistant to the melt.

The inner and outer dimensions of individual pack parts should conform to the tolerances given in Table 7.12 for hot threads; bores are always made to the normal DIN (German Standards) tolerances. Threads of greater than 30 mm outside diameter should be made as trapezoidal or saw-toothed threads, according to application, while threads of ≥52 mm outside diameter must be thus made; thermal expansion tolerances are given in the same table above.

All surfaces which come into contact with polymer must be polished to $R_t \approx 0.4\ldots0.6$ μm. Metal sealing flanges should be fine finished, or better, lapped; mating flanges must be made plane parallel.

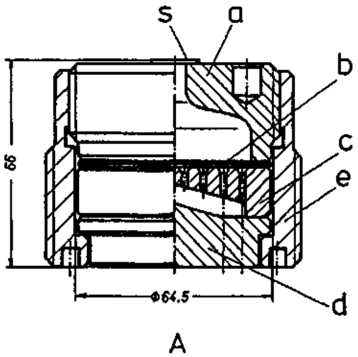
4.6.11.2 Spin Packs for Circular Spinnerets

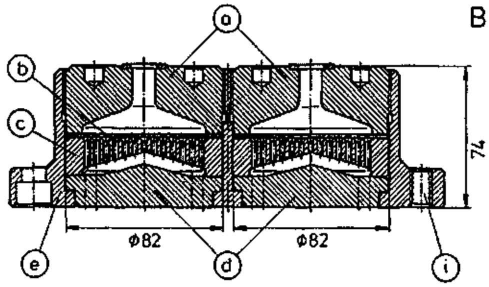
These housings are made for one or two spinnerets. Fastening to the pack port can be done by means of threading from below, by a flange below or by means of a jacking screw from the side opposite to the melt inlet into the pack cover plate (also for top loading packs) (Fig. 4.142a–e). The construction is similar, and has previously been described.

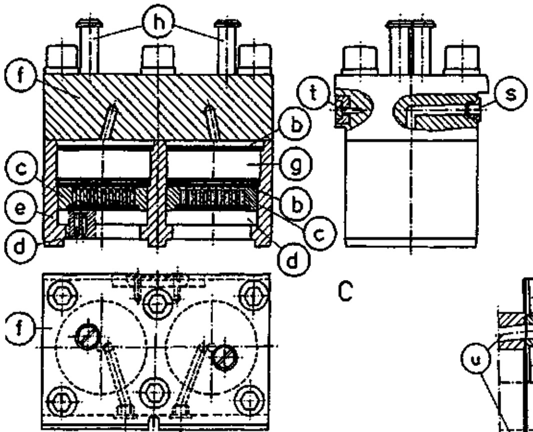
A special sealing method is shown in Fig. 4.143, where the upper and lower pack bodies are pressed together by means of two conical half-shells. Bolts passing through the shell into the upper body secure the sealing of the pack.

Figure 4.144 shows an annular staple spin pack developed for up to ca. 3000 holes per spinneret. The melt inlet to the pack can be shut off by a piston valve to exchange the spin pack or spinning pump. The upper melt distribution duct has its maximum height at the point of melt entry and descends, in 2 half rings, conically with decreasing diameter. The melt then flows through three consecutive support plates, between which sieves are sandwiched, into the cavity above the spinneret. The quench air is introduced through the hollow interior of the melt flow distribution cone. Internal insulation is required for the quench air and an internal heating band for heating the annular spin pack to compensate for possible heat losses to the air flow. An annular spinneret can also be modified to take 4 polymer inlets for 4 kidney-shaped spinnerets, which can be served by an outflow quench. This "Quaterly Shaped" system (Fig. 4.145), which can be extended to 8 round spinnerets, is used by certain manufacturers of tirecord, carpet yarns and technical yarns.

Self-sealing spin packs are becoming increasingly important. Figure 4.146 shows a schematic of such a pack and the method of insertion for bottom loading. The saw-toothed thread of the pack housing (e) is screwed into the counterthread (e) in the pack port, whereby the pack is sealed by the aluminum gasket (s). On being pressurized by melt, the flange presses downwards against the spinneret (d), forcing it against the spin pack housing (e), thus sealing the whole system.







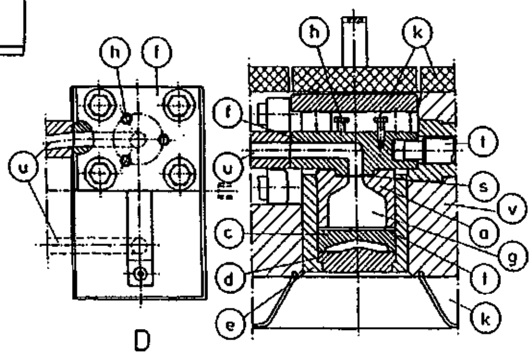


Figure 4.142
Spin packs for round spinnerets

A) With screw-in thread
B) Double spin pack with flange
C) Double spin pack for top loading
D) Two spin packs for top loading, exchangeable against one rectangular spin pack according to Fig. 4.150

a) Screw-threaded top cover
b) Flat filter
c) Distributor plate
d) Spinneret
e) Spin pack housing
f) Top plate respectively top housing
g) Sand filter
h) Pack removal bolts
i) Pack fastening bolts
k) Insulation
s) Sealing (gasket)
t) Recess for jacking (sealing) bolt
u) Melt inlet pipe
v) Spinning beam/heated chamber

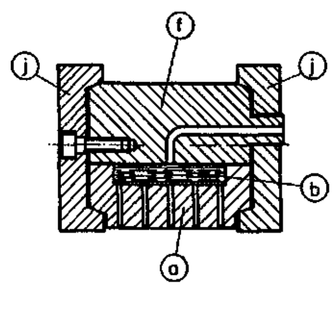


Figure 4.143
Round or rectangular spin pack, held together by two internally conical ring clamps (3, 4; DBP 3 224 833 of July 9, 1983, Barmag [88])
j) Ring or plate clamps. For other explanations, see Fig. 4.142

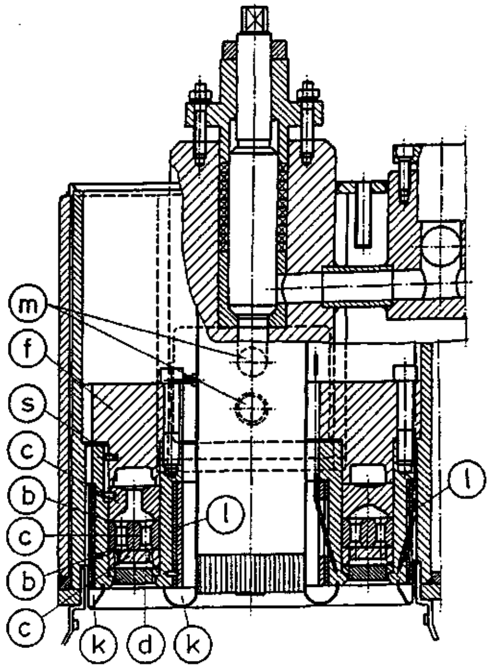


Figure 4.144
Annular spin pack with shut-off valve, designed for radial air quenches [24] with air supply through the pack
l) Electric heating
m) Spinning pump connection. For other labels, see Fig. 4.142

Figure 4.145
Annular or round spin pack divided into four or eight spinnerets for a radial air quench chamber

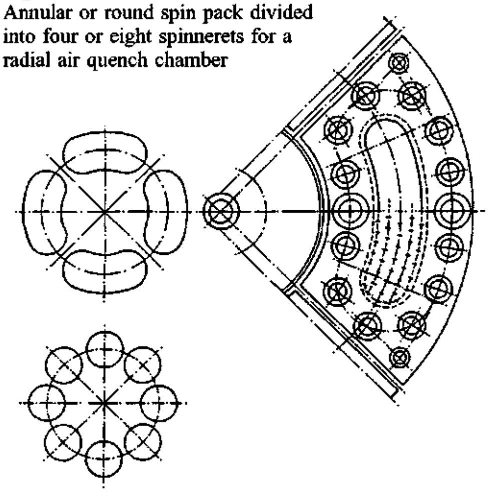


Figure 4.147 shows another self-sealing system. The melt enters sideways through (j); sealing is effected by the contact pressure from (h). The melt then flows through the biconical filter (h) centrally onto the spinneret (h). The high pressure forces the top cover plate, via a ring gasket, against the conical screwed ring, thereby sealing the whole system.

A similar sealing principle is shown in Fig. 4.148. In contrast to the above spin packs, this version demonstrates the use of candle- or flat filters. The melt flows through the support plate (h), then through the expansion gap between an inner- and outer cone onto the spinnneret. The exact centering of the 2 cones relative to each other is achieved by means of a toothed construction of the outer cone. The pressure drop in the expansion slit is given by:

$$\Delta p = 12 \times \eta \times G \times L/D \times \pi \times s^3 \times \rho$$
$$(\eta[\text{kg} \times \text{s/m}^2] = 0.0098 \times P, G[\text{kg/s}], L, D, s[\text{m}], \rho[\text{kg/m}^3]) \quad (4.33)$$

These spin packs are well-suited to high pressure spinning, as the pressure drop is converted into an increase in temperature via shear work.

The pressure drop can also be achieved by the use of filters of appropriate resistance; the pressure drop is then similarly converted into a melt temperature rise. The disadvantage here is that the pressure drop increases with filter blockage, as does the melt temperature rise. A further self-sealing pack utilizes a V-shaped ring gasket, which is pressed outwards to seal. Initial melt pressurization is needed to make the seal, which then improves as the pack pressure rises (Fig. 4.149) [72].

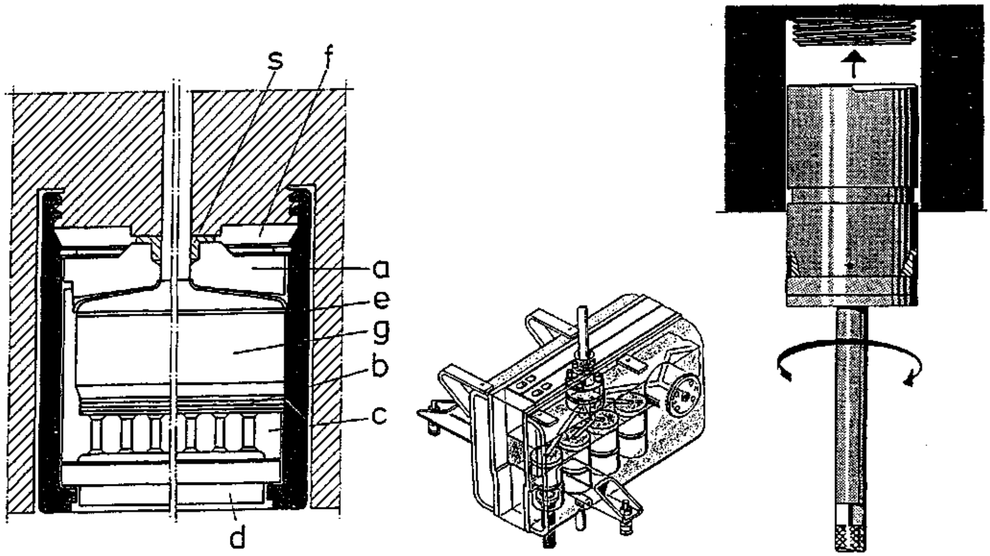


Figure 4.146 Self-sealing spin pack series for spinnerets of $D = 30 \ldots 120$ mm, with sand filter (g) or without sand filter and correspondingly reduced height (Barmag [88]); right: installation method for bottom loading. *a*) top plate *b*) filter sieves *c*) distributor plate *d*) spinneret *e*) sand-retaining sieves *g*) sand or stainless steel powder filter *s*) aluminum gasket

Spinnerets with sandfilters							
Spinneret diameter mm	Filter area cm^2	Minimum pitch for spinnerets/pos. 4 mm	6 mm	8 mm	9 mm	12 mm	16 mm
30	4.2 7.3	400	500	600	650	800	1000
36	6.6 10.5	450	550	650	700	850	1100
40	8.6 13	450	550	700	750	900	
50	14 20	500	600	750	850	1050	
55	17 24	500	650	800	900		
59	20 28	500	700	850	950		
64	23 33	550	700	900	1000		
70	28 39	550	750	950	1050		
80	36 51	600	800	1000			
85	41 57	650	850	1100			
100	58 79	700	950				

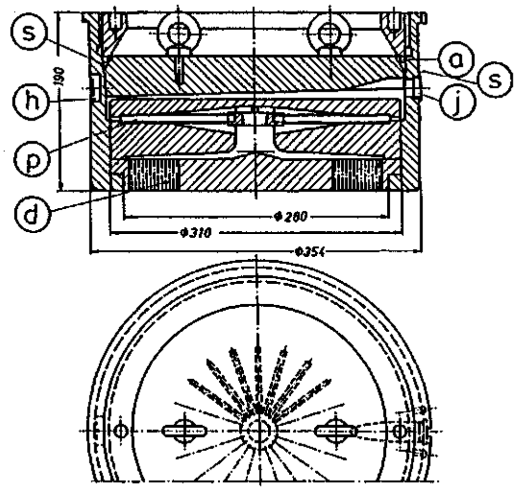


Figure 4.147
Round spin pack, self tightening by ring sealing (s) in the conical ring, with double plate fabric filter (p), melt supply from the side (j) and pressure screw from the other side (h) [88]

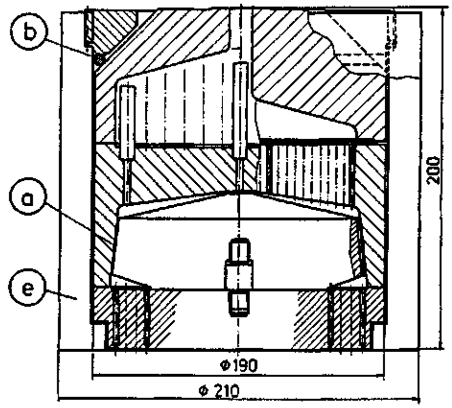


Figure 4.148
High pressure spin pack (for up to 1000 bar inlet pressure), used at, e.g., 600 bar inlet pressure, reduced to the 30 ... 50 bar pressure required to force the melt through the spinneret capillaries by friction in the filters and between the inner cone (a) and the housing wall cone (e) Increase in extruded meet temperature = (600–30) bar × 4 °C/100 bar = 22.8 °C

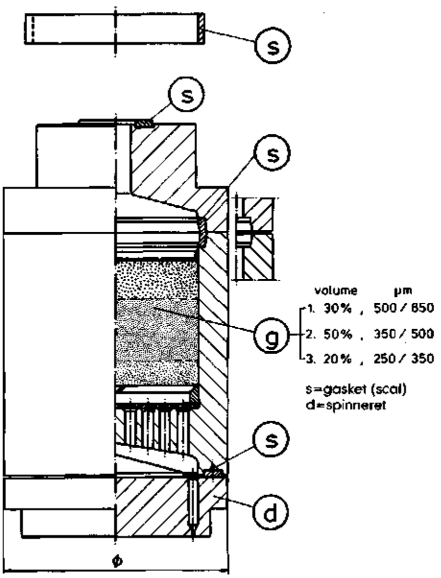


Figure 4.149
Internal construction of a self-sealing round spin pack with sand filtration (g); (Automatik [22])

4.6.11.3 Spin Packs for Rectangular Spinnerets

Round spinnerets have a more uniform melt and pressure distribution above the spinneret than rectangular spinnerets, but rectangular spinnerets permit a more uniform cooling of the filaments when the optimum quench design is used (see Section 3.3, particularly Fig. 3.12), as there is always the same number of filaments per unit width for the quench to penetrate. In the case of rectangular spinnerets, uniform melt and pressure distribution above the spinneret must be achieved by correct design of the melt distributor above the spinneret, and by use of a high pressure drop filter. Figure 4.150 shows a simple top loading spin pack, which can also be modified to take two round spinnerets in the rectangular housing. If the rectangular spinneret is relatively long (e.g., ≥400 mm× ≥80 mm), it is recommended that, after entry to the pack, the melt first be distributed lengthwise via a conical channel having parallel

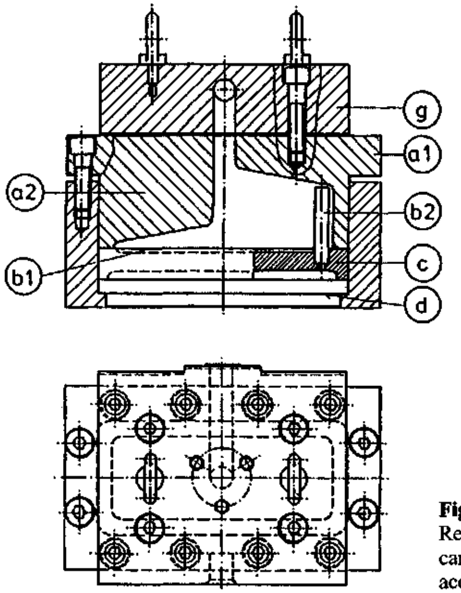


Figure 4.150
Rectangular spin pack (left: without sand filter, right: with sand or candle filter, for top loading) exchangeable with two spin packs according to Fig. 4.142d; explanation as in Fig. 4.142

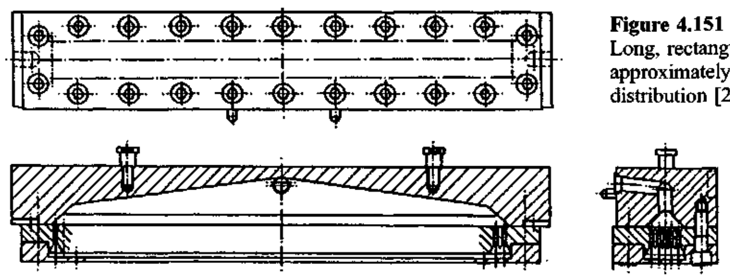


Figure 4.151
Long, rectangular spin pack (up to approximately 700 mm) with biaxial melt distribution [22]

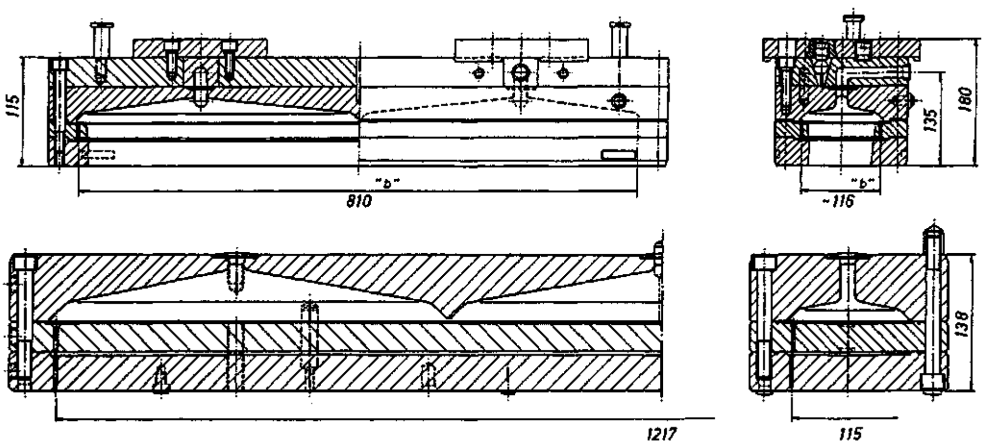


Figure 4.152 Rectangular spin pack for spinnerets longer than 500 mm, with several melt supply inlets and distributors

walls and at the lower ends of which a double conical distribution in the cross direction be used (Fig. 4.151). One must also provide sufficient bolts along the length between the spinneret and the upper housing so that the latter does not buckle under the high internal pressure. If the spin packs become still longer, it is possible to fit many subsections into the housing in such a manner that the distributors fit together seamlessly (Fig. 4.152).

Another method, proven for spinnerets of up to 3 m long, is illustrated in Fig. 4.153. Here the inlet channel F_0 is first divided into two streams of cross-section F_1 each. After a half pitch, polymer is taken off to the long spinneret by a channel of cross section F_n. The melt main body then flows through a section of cross section F_2, at the end of which a channel, again of cross-section F_n, leads melt to the long spinneret, etc. Cross-sections are calculated according to the formula given in Section 6.4.2. The melt distribution to the long spinneret is done as per Fig. 4.152. Melt flow through the channels F_n can be improved by the use of small apertures free of dead spots.

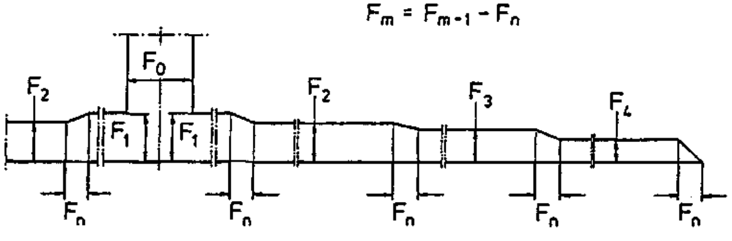


Figure 4.153
Melt distribution for extremely long spin packs according to $F_m = F_{m-1} + F_n$ and $F_0 = 2 \times F_1$

4.6.11.4 Auxiliary Devices for Pack Insertion

For manual insertion of bottom loading spin packs, a simple pack insertion device comprising a rod and a plate for holding the pack suffices, provided that the top of the pack is recessed to avoid damage (Fig. 4.146). Use of a "snapper" or latch to hold the pack in position before bolting simplifies the operation. The spin pack can also be temporarily held by two opposed bayonet slots before bolting.

Lifting devices (Fig. 4.154) are available for heavier packs. The pack is placed on the tray of the lifting device, which is then moved sideways to the appropriate spinning position, where the pack is electrically or hydraulically raised into the pack port of the spinning beam by means of a parallel linkage [134].

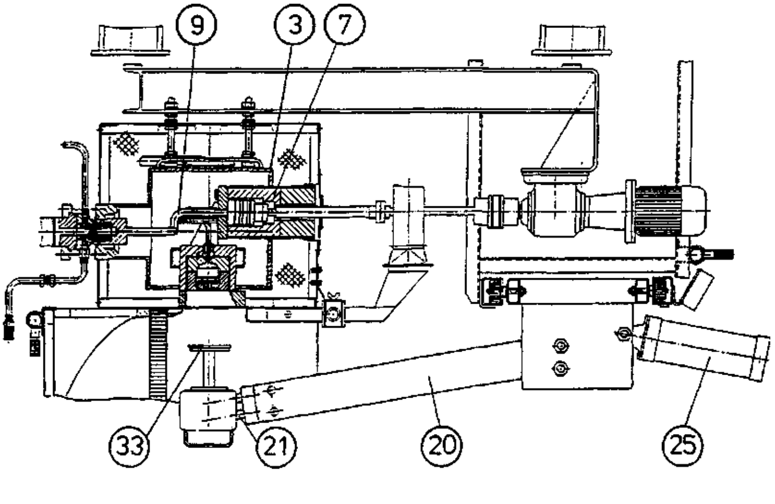


Figure 4.154
Pack insertion device for bottom loading of heavy spin packs (Neumag [167])

It is also possible to raise the spin pack using a chain or steel cable which passes upwards through a pipe in the spinning beam, and then to bolt the pack from below.

4.6.11.5 Spinneret Bolting

In piston spinning, dry spinning and wet spinning, there is often no space for the complicated (melt) distribution described above. It suffices therefore to fit the spinneret, the distributor plate and the filter sieve into a special domed cap nut, and to bolt this to the solution delivery pipe fitted to the spinning machine. Figure 4.155A shows such a fitting suitable for a solution pressure of up to 20...30 bar, and capable of spinning upwards, horizontally or downwards, depending on the shape of the delivery pipe. This construction can be made for spinneret diameters from ca. 20 mm to greater than 200 mm. Figure 4.155B shows a similar spinning head, but modified for liquid heating or cooling of the spinning solution, as is done in dry spinning at higher temperatures. The internal displacer in the inlet pipe can be used for solution temperature—and/or pressure measurement.

The piston spinning device in Fig. 4.156 is suitable for melt or solution spinning; the spinneret bolting is shown in the figure. Depending on detailed construction (e.g., flanging or bolting, with or without support plate, etc.), this device can be used for pressures up to 300 bar (or even up to 1000 bar) and for temperatures up to 500 °C. Provided that the piston travel is long enough to reach the spinneret, "dead-spot free" spinning is possible.

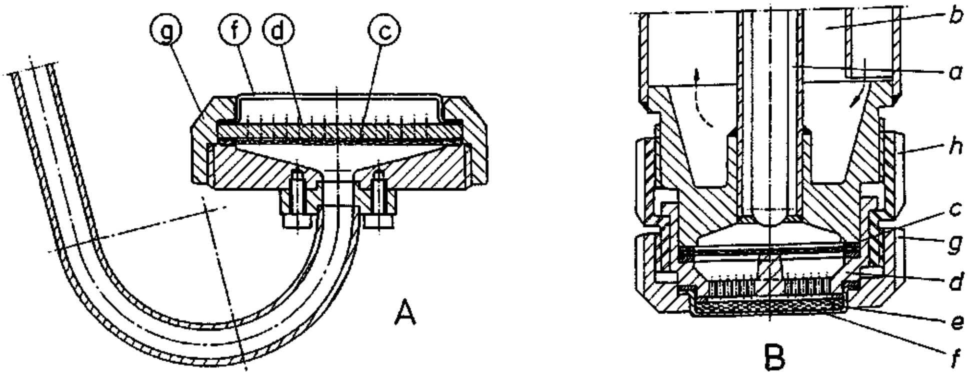


Figure 4.155 Solution spinneret bolting [24]
A) On a spinning pipe for upwards wet spinning
B) For dry spinning with heating respectively cooling jacket for the dope supply pipe
a) Dope supply pipe
b) Heating or cooling jacket
c) Spinning filter just in front of
d) Breaker plate, or respectively as basket
e) Filter sieve direct in front of
f) Solution spinneret
g) Outer spinneret bolting
h) Spin pack bolting

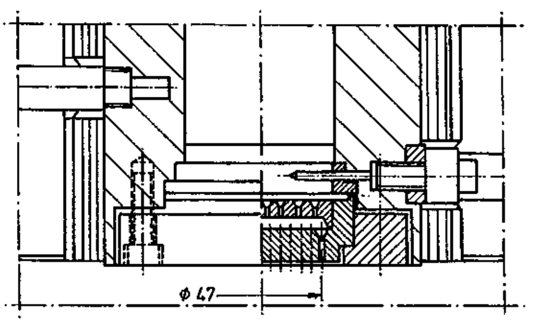


Figure 4.156
Spin pack below a piston type spinning unit, suitable for melt or solution spinning [24]

The bolting of an annular spinneret for staple fiber dry spinning is shown in Fig. 4.157. The spinneret, support plate and filter are connected to the distributor ring by means of an interior- and exterior screw thread. The complete pack can be fitted to the solution delivery pipe by means of a quick change connection device. Despite the high local gas temperatures, cooling normally is not required, as the solution throughput is around 100 kg/h for large plants; the very short residence time practically excludes any warming effect.

4.6.12 Spinning Pump Drives

As a consequence of the high finishing accuracy and narrow tolerances, spinning pumps use more energy to overcome friction than in pumping and pressure generation. This is obvious from Fig. 4.158: for every extra 100 bar pressure difference, the driving torque increases by only 43% [136, 137]. Also, 2- and 4-fold spinning pumps require almost exactly twice and four times the torque required for a single pump of the same capacity. In general, the following speed range should be adhered to for spinning pumps:

$$10\ \mathrm{r/min} \leq n_{\mathrm{spinning\ pump}} \leq 42\ \mathrm{r/min}$$

For spinning pumps of up to 20 cm^3/r, $n_{\mathrm{spinning\ pump}}$ should be <36 r/min for pumps in continuous operation; pumps of capacity $\geq 20\ cm^3/r$ should run at ≤ 30 r/min. The optimum speed range for all pumps is 15...25 r/min. At rotational speeds below 8 r/min, the periodic effects due to rotation and gear teeth become too large [138] (corresponding Uster component $\approx 0.4\%$) (Fig. 4.159).

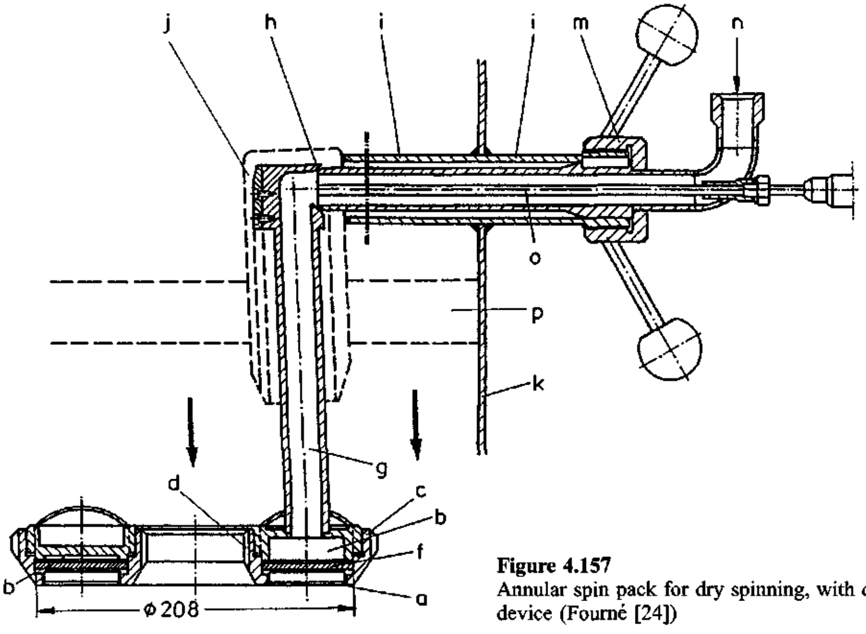


Figure 4.157
Annular spin pack for dry spinning, with quick-change device (Fourné [24])

a) Annular spinneret (see Fig. 4.138a, right)
b) Solution distribution channel (conical)
c) Outer spinneret bolting
d) Inner spinneret bolting
e) Spinning ring filter
f) Perforated breaker ring plate
g) Solution supply pipe
h) Calotte in cone
i) Support tube
j) Support housing for annular spin pack (possibly heated or cooled)
k) Dry spinning tube jacket
m) Fixing nut for (h)
n) Outer solution supply connection for a flexible hose
o) Solution temperature sensor

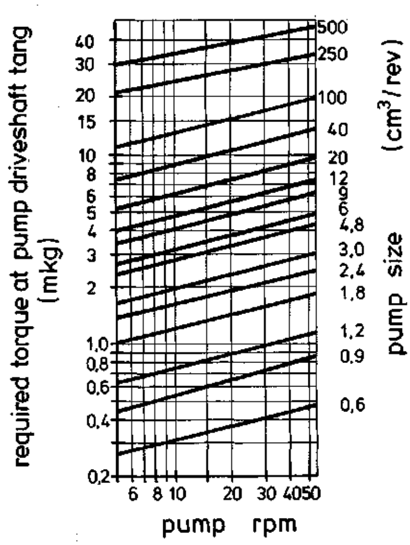


Figure 4.158
Required torque at the pump driveshaft tang; formula for other pressure differences:
$M_{D2} = (1 + 0.0043 \times \Delta p \text{ (bar)}) \times M_{D1}$
Driving power: $N \text{ (kW)} \approx 10^{-3} \times n \text{ (rpm)} \times M_D \text{ (mkg)}$

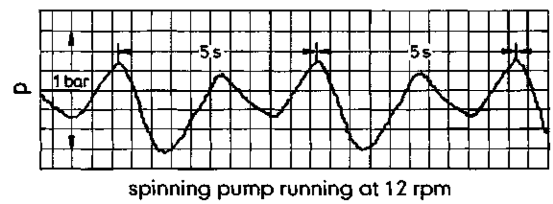


Figure 4.159
Effect of spinning pump rotation on melt pressure fluctuation between pump and filter (pump speed $n = 12$ rpm); the effect becomes smaller with increasing pump speed

The spinning pump drives must be by synchronous motors supplied by frequency converters of $\leq 0.01\%$ deviation. Both permanent magnet- and reluctance motors can be used. The motors must be capable of holding the speed constant to achieve constant throughput, even should the extruder pressure rise too high. On switching off a pump drive, the spinning pump must not be driven, like a hydraulic motor, by high pressure at the pump inlet. Each spinning pump must be capable of being switched off independently of the other pumps, this being done electrically or mechanically. Friction drive clutches are not acceptable.

Each spinning pump is connected to the pump drive by a spinning pump driveshaft, e.g., by a telescopic shaft having a universal joint and a shear pin (Fig. 4.160), or by a hollow shaft gear through a floating shaft (Fig. 4.162) with a flexible coupling and a shear pin. The shear pin should be sized for 0.8

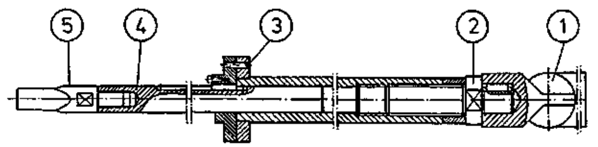


Figure 4.160
Telescopic type spinning pump driveshaft with universal joint (1), distance ring (2), shear (overload) pin (3), spline shaft (4) and exchangeable pump driving plug (tang) (5), made of hardened, high tenacity steel suitable for spinning temperature

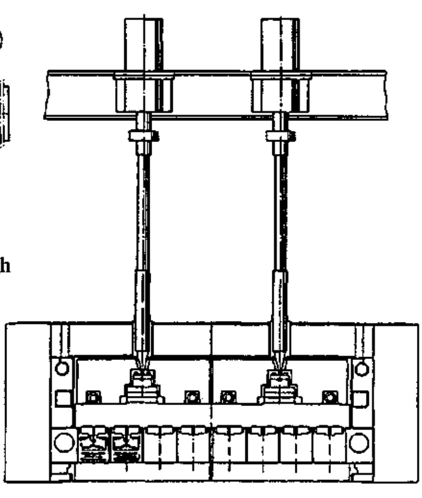


Figure 4.161
Vertical spinning pump drive [33, 24]

to 0.9 times the allowable spinning pump drive torque. The spinning pump driveshaft tang is a change part subject to wear; the tip of the driveshaft tang should have a clearance of 0.5...1 mm between itself and the pump drive socket in the hot stage to avoid overloading the drive shaft and the pump.

For computer monitoring, a toothed gearwheel can be fitted to each pump driveshaft between the shear pin and the spinning pump, for monitoring the pump speed and printing out the results periodically.

Various drives are available for the many, parallel spinning pumps in a spinning machine:

- A single drive per pump, having either a horizontal drive shaft (Fig. 4.154) or a vertical drive shaft similar to that in Figs. 4.160/4.161, depending on the pump mounting position. Each drive consists of a self-starting synchronous motor and a worm gear [141–143], a planetary gear [120] or a "Cyclo" gear [140]. The synchronous motor runs at 600...3000 r/min; a step-down ratio of 1 : 70 is required to obtain the above spinning pump speeds. The gearboxes should be designed for 20 000 h of continuous operation.
- The previously-described motor and gearbox units often require a much greater pitch than the many adjacent spinning pumps. For this splitting one uses mechanical reduction gearboxes with, e.g., 4 floating driveshafts (Fig. 4.162) and double worm drive between the motor and the driveshafts [22]. According to Fig. 4.163, one can also use a main shaft worm drive and helical gear split gearbox [24]. By using change gears between the left hand and the right hand sides of the gearbox, it is possible to obtain different speeds for spinning bicomponent yarns. Individual pumps can be brought into operation by means of manual dog clutches.

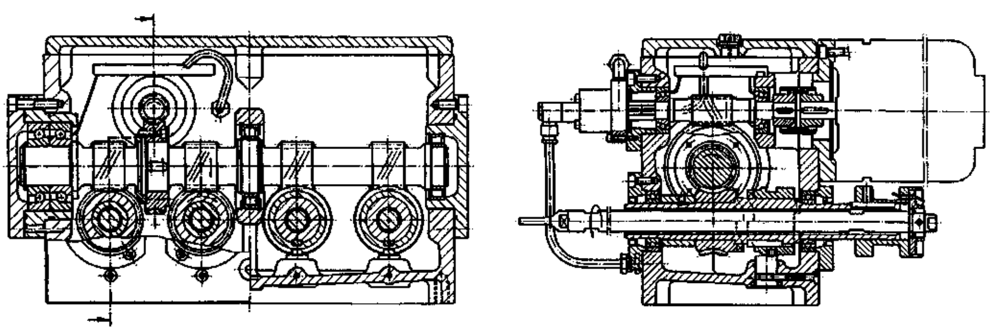


Figure 4.162 Spinning pump worm gearbox for 4 pumps with hollow and stub shafts [22]

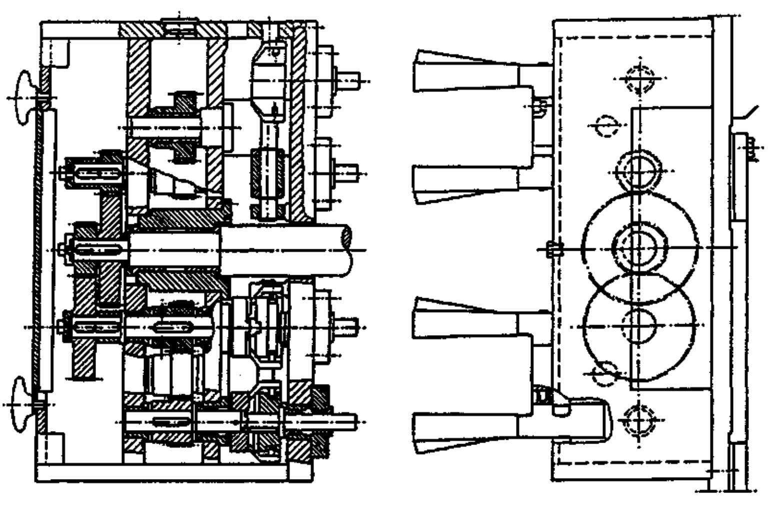


Figure 4.163 Bicomponent spinning pump drive gearbox with 4 change gears, adjustable within the range of 85 : 15 ... 50 : 50 ... 15 : 85 in small steps; with mechanical clutches [24]

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The popular, previously-used single pump drives using synchronous motors and PIV (positively infinitely variable) gearboxes or fine-control gearboxes are today not accepted as meeting the requirements of titer uniformity. For single discharge pumps, however, suitably sized PIV gearboxes, often with normal asynchronous motors, are acceptable as variable speed drives (and are easier to make explosion-proof).

4.7 Quench Cabinets

4.7.1 General

Filaments extruded from the spinneret capillaries are quenched as single filaments almost parallel to one another, and are solidified under almost time-constant conditions, without filament flutter or fusion; they are—if possible—cooled to a temperature below the glass transition temperature. For these reasons, the quench and quench cabinet must meet certain criteria.

With the exception of Du Pont [144] (since 1938), yarn was spun downwards through vertical interfloor tubes of 4...8 m length and cooled by the relative motion of yarn to air until about 1956. Other yarn producers imitated Du Pont [145–148], and after 1956 most producers very quickly converted to spinning with a cross flow quenching zone below the spinneret. As a result of the improvement conferred by this system, today it is possible to spin at 6000 m/min using interfloor tubes of 2...3 m, at up to 1800 m/min (LOY) using 1.3 m long tubes and at 40...50 m/min using 0.4 m long tubes: the savings in the reduced volume of the spinning building, the proportional reduction in conditioned air costs and the improvements in fiber and yarn quality are evident.

Figure 4.164 explains the elements of a quench chamber. The molten filaments (2) emerging from the spinneret (1) are (sometimes) blanketed by steam or an inert gas at spinning temperature (3). Monomers emerging from the molten filaments are aspirated by (4). The quench air (6) passes through the filaments (2) at right angles, removing heat as in a tube bundle cross flow heat exchanger, and transports the heated air out through the permeable quench cabinet door (7) into the spinning room. In POY spinning, the filaments are dressed with spin finish at (9), the finish being dosed by the spin finish pump (14), then passed through a yarn guide (10) below the applicator. The converged yarn then travels down to the traverse guide (11) before being taken up on bobbins (12) by the winder. The quench air (13), conditioned

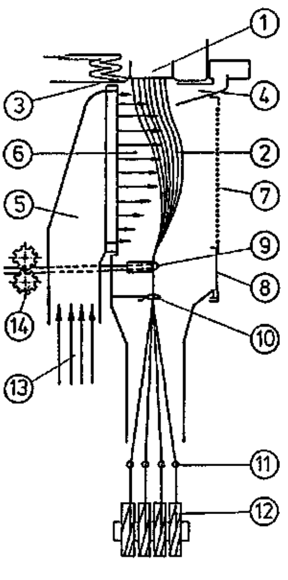


Figure 4.164
Schematic of air quench chamber
1 Spinning head with spinneret
2 Filaments
3 Spinneret protective gas (blanketing gas)
4 Monomer aspiration
5 Quench air plenum
6 Quench air flow
7 Front door (permeable), with
8 Window
9 Spin finish applicator
10 Yarn guides
11 Yarn control, cutter, aspirator
12 Bobbin take-up (winder)
13 Quench air supply
14 Spin finish pumps

according to polymer type, enters the quench plenum (5) under specified conditions and is distributed across the upstream side of the air rectifier (15) in order to achieve a desired air velocity profile at the filaments.

In LOY spinning, finish application (9) in the quench is mostly omitted, and the finish is applied above the take-up machine.

This basic principle has been developed further by various fiber producers according to their own requirements. One can distinguish between 9 different types of quench chambers (Fig. 4.165, [150]), of which (B, F, G and H) have the widest application in practice, (B) particularly for rectangular cross flow quench and (G or H) for radial quench.

Laminar cross flow from the air rectifier is necessary for quenching textile filaments, particularly for achieving good dye uptake uniformity. Weakly turbulent cross flow air can be used to cool staple fiber tow. In compact staple spinning lines having a high filament density and tension, a strongly turbulent air flow is permissible. The type (c) quench is only employed when the product of the spinning speed v [m/min] $\times$ spin dtex/fil. $> 30\,000$ for PP, $>$ ca. $50\,000$ for PA and $>$ ca. $90\,000$ for PET.

See Section 3.3 for calculation of individual dimensions:

- Uster value optimization as a function of the air velocity ([151], Fig. 3.14),
- heating up of the quench air as it passes through the filament rows ([152], Fig. 3.10),
- the cooling of filaments to below the glass transition temperature, including cooling of the hintermost row,
- the maximum distance of the hintermost filament row from the air rectifier (formula 3.21),
- the distance of the spinneret from the top of the quench,
- the required cooling air flow rate (formula 3.10),
- the cross flow quench zone length (Fig. 3.18).

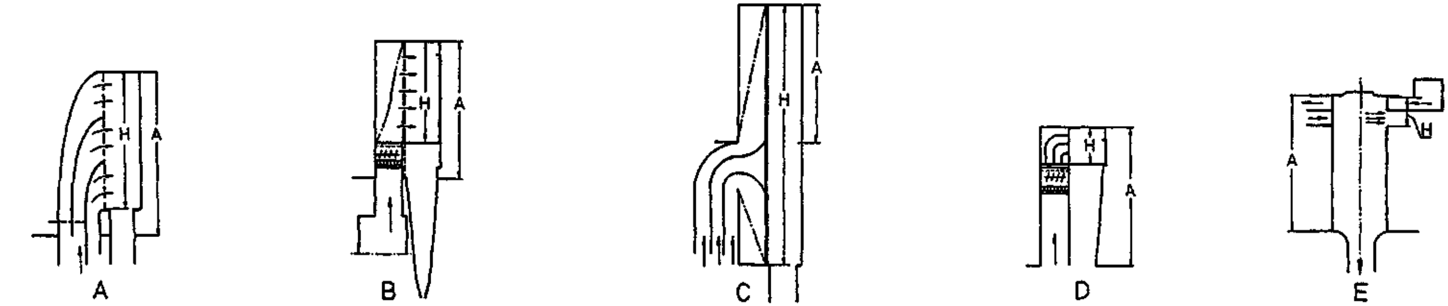
The quench internal width is derived from the spinneret hole geometry: the distance between the outermost filaments and the quench chamber sidewalls should not be greater than 20...30 mm [153]. If this distance is greater than 40...50 mm, a suitably thick partition plate should be inserted here, as well as inside the air rectifier. A second type of partition plate, to avoid cascade breaks when one yarn breaks, is also recommended to avoid all the threadlines above one winder breaking. Mechanical stability requires that the external width of the quench cabinet be ca. 120 mm greater than the internal width. In special cases, the 120 mm can be reduced to 80, or even to 45 mm. Figure 4.166 shows an example of the layout of the interior width of a quench chamber for 8 spinnerets of 70 mm external diameter (52 mm perforated diameter) spinning two groups of 4 threadlines for take up by two 4-bobbin winders. The spinning position pitch required is greater than 840 mm, e.g., 900 or 1000 mm (compare Fig. 4.98). If one replaces the single spin packs with double (2 spinneret) spin packs, about 40 mm of width can be saved, and an interior quench width of 670 mm can be achieved, corresponding to a spinning position pitch of ≥ 800 mm.

When spinning 167 final dtex at 3600 m/min ($i = 1.5$), the throughput per spinneret is 5.41 kg/h, or 43.28 kg/h yarn for the configuration in Fig. 4.166. Using $\rho = 0.64$ (Table 3.4), $f_{PET} = 1.213$, $Q/G = 8$ and $T = 25\,°C$, Fig. 3.10 gives $Q_{BS} = 15.2$, i.e., 658 Nm^3/h of quench air is required for filament cooling. With 36 filaments per spinneret, dtex/fil $\times$ $v = 25\,000$, and from Fig. 3.18—$H_1 = 0.88$ m. As no more than 4 filaments lie one behind the other, the required quench length is 1.00 m. The oiler can be located immediately after this length.

According to Fig. 3.13 and Table 3.6, the air velocity profile can lie between A and B. This gives an average air velocity of $v = 0.3$ m/s using a quench width of 620 mm, and $v = 0.25$ m/s at a width of 720 mm, or—for profile A—about 0.36 m/s or 0.3 m/s.

This completes the geometric data required for the design/construction of the quench.

The air velocity profile can be further improved through plant trials [155–157]. In this way, Uster values of better than 0.6% can be achieved. A requirement here is that the air velocity profile be constant across the quench width in cross flow quenching or constant along the circumference for radial quenching. The shorter the quench zone becomes, the less effect has the vertical air velocity profile. One can therefore use the constant profile B for quench zones of less than 500 mm. The air velocity profile has practically no influence on the air quantity required for cooling; this also follows from the law of conservation of energy. For cooling PA66, the cross flow should occur as close to the spinneret as



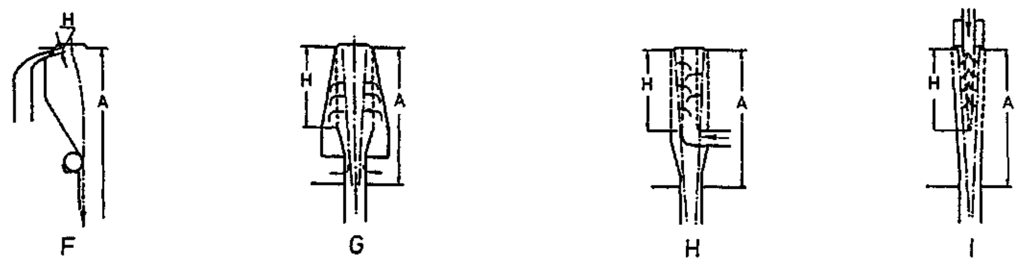
A) Turbulent chamber
H ≈ 1.4 . . . 2.2 m
Zone air velocity profile set by hinged inlet vanes
Q > 20 × G_{melt} [kg/h]
v > 0.4 m/s
Step profile

B) Standard quench chamber
H ≈ 0.4 . . . 1.8 m
Air velocity profile set by a deflector plate (Figure 3.13)
Q [Nm^3/h] ≈ (15 . . . 30) G_{melt}
v = 0.1 . . . 0.5 . . . 0.7 . . . 1.3 m/s
Continuous velocity profile

C) Extra long quench chamber
H > 2.5 . . . 5 m
Air velocity profile set as in *B*), for 2 or 3 zones
Q_2, above ≈ 35 G
Q_2, below ≈ 12 G
v ≤ 1.3 m/s
Preferred for POY when final dpf ≥ 8 . . . 20

D) Turbulent I-chamber
H ≤ 0.4 m
W (H) = constant
Q [Nm^3/h] ≤ 40 G_{melt}
v ≥ 0.8 m/s
Preferably v > 1.5 m/s for POY spun at high yarn tension

E) Highly turbulent quench chamber
H ≈ (2 or 3) × 0.1 m
Countercurrent (!)
Q ≈ 36 × G
v > 6 m/s
For high spinneret hole density PET staple fiber spinning



F) Slit quench chamber
H < 0.05 m
Q ≥ 40 G
v ≥ 10 m/s
For PET and PP compact staple fiber spinning

G) Radial quench chamber (inside → outside) H ≤ 1.2 m
v ≈ 0.4 . . . 1.0 m/s
Q ≈ 8 (for PET) . . . 25 (for PA) × G [kg/h]
Preferred for staple tow (in vertical spinning)
Number of spinneret holes > 2000

H) Radial quench chamber (outside → inside)
H ≤ 1.2 m
Q ≈ 16 G
v < 1.0 m/s
weakly turbulent

I) Radial quench chamber
As *H*, but with air inlet from above, through core of spinneret

Figure 4.165
Various quench chamber types [150]

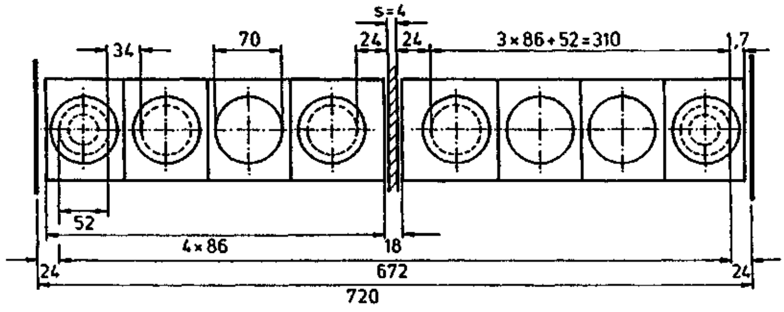


Figure 4.166 Determination of the required air rectifier width from the spinneret layout in the pack box. In the example, there are 8 spinnerets of 70 mm outside diameter/60 mm inner diameter, which require pack bodies 86 mm wide. There is 1 winder per 4 spinnerets, and an AlMg3 partition wall avoids "cascade" breaks between the winder positions. The required air rectifier width is 720 mm

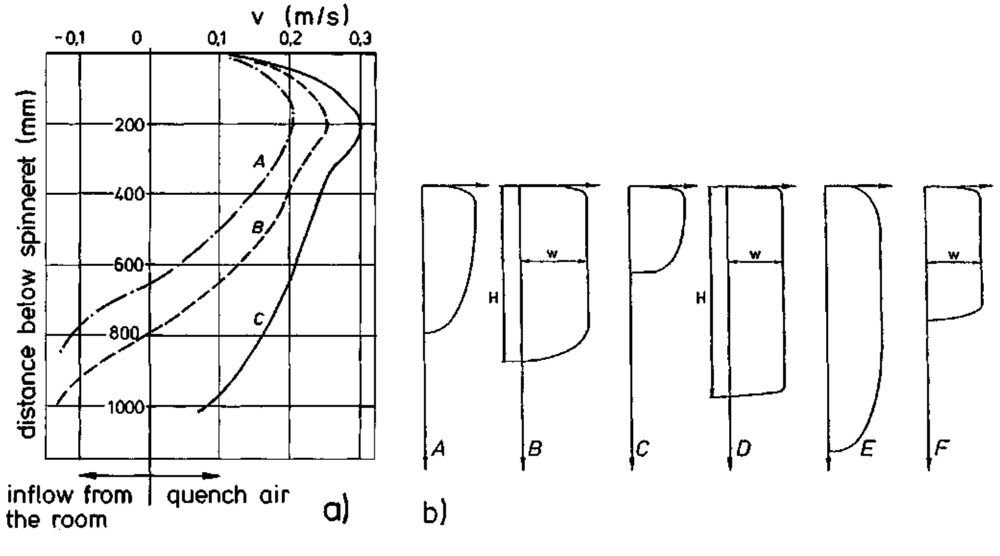


Figure 4.167 Preferred quench air velocity profiles
a) for fine filament textile yarns from PA66
A) for end titer 40f17 dtex at 6000 m/min
B) for end titer 40f17 dtex at 4800 m/min
C) for end titer 40f17 dtex without yarn
b) for various applications:
A, *F*) for textile PET multifilaments, POY
B) for PET staple fiber, with rectangular spinnerets
C) for microfilaments
D, *E*) for higher dpf, and for higher spinning speed
(*H*) can be determined from Fig. 3.18)

possible without cooling the filaments too rapidly, i.e., the quench should begin a few cm below the spinneret with v = 0 m/s, then increase quickly ([158], Fig. 4.167a). Many other vertical velocity profiles are in common use, as it can be seen in Fig. 4.167b.

The above velocity profiles have been measured without yarn running. With yarn running, the air velocity profile is significantly modified, as shown in Figs. 3.15 and 3.16; the yarn velocity also determines the amount of air dragged vertically downwards and the yarn tension.

4.7.2 Preferred Quenches

Of the nine quench types shown in Fig. 4.165, only the ones below are industrially significant.

- The rectangular cross flow quench cabinet (Fig. 4.165B).
  This quench, first used in 1938 [144], is today still the most widely used type. The general drawing in Fig. 4.168 explains the most important details, The inlet air (Z) is first filtered by a quick-change filter (6.3); the air flow rate to the quench is then regulated (6.4) before being rectified by (6.1). In the plenum (1.5) the pressurized air flow direction is changed from vertical to horizontal by the air rectifier (2). The air velocity profile in the quench cabinet (1) can be set, amongst other means, by the deflector plate (5), as shown in Fig. 3.13.

The filaments emerging from the spin pack on the centerline are displaced by the cross flow to the trajectory curve shown in the diagram, their displacement being (a). The front door(s) should be permeable to air and have the lowest possible air resistance; this improves the Uster value. The opening (3), above the quench door, permits observation of the spin packs and/or enables monomer aspiration to be incorporated. The filaments are taken up by the winder through the interfloor tube (8).

The three topmost sides of the plenum (1.5) (or air rectifier (2)), as well as the tops of the quench cabinet sidewalls, must be sealed gas-tight against the insulation of the bottom of the spinning beam to avoid outside air leaking in. For reasons of handling the spinnerets, the total height of the quench cabinet

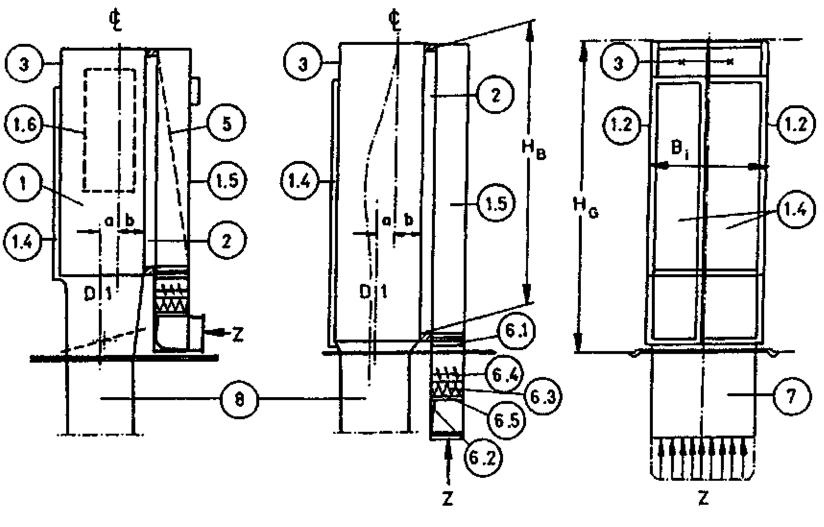


Figure 4.168 Laminar quench cabinet having regulator flaps above the floor (left) and below the floor (middle) (see also Figure 4.212 B)

1 Quench cooling chamber	*6.3* Quick-change filter
1.2 Side walls	*6.4* Airflow regulator
1.4 Front door	*6.5* Measuring aperture plate
1.5 Air inlet plenum	*2* Laminar air rectifier
5 Deflector plate	*3* Opening for monomer aspiration
6.1 Inlet rectifier	*1.6* Window
6.2 Shut-off valve	Total height: $H_G \approx 1.75 \ldots 2.1$ m

above the floor should be 1.7...2.1 m, preferably 1.9 m. The quench cabinet housing is made from stable steel sheet, gray cast iron or glass fiber composite. The quench cabinet itself and the interfloor tube are made from rust-free stainless steel and/or $AlMg_3$; these parts are preferably anodized black or dyed electrolytically, as the yarn is mostly white.

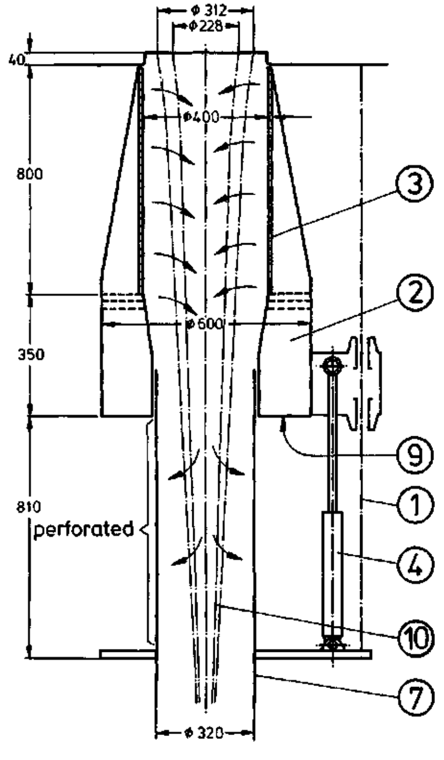
These quench chambers are used for circular and especially for rectangular spinnerets, where many packs are placed in series in a cabinet. Detailed sizing, energy requirements and capacity calculations are given in Section 3.3; these are particularly applicable to this type of quench.

The externally-similar, multi-zone quench chamber (Fig. 4.165A) suffers from the disadvantage that turbulence is created where the different flow rates in the different zones leave the air vanes and emerge into the quench chamber; turbulence occurs particularly in the overlapping zone boundary layers.

Particularly long quench chambers, similar to the one shown in Fig. 4.165C, comprise 2 or 3 quench chambers of type B.

A quench chamber incorporating alternate, opposed counterflow zones—claimed, as well, in [144]—can reduce the cooling length required for heavy yarn bundles by up to 40%, but exhibits turbulence due to the opposed counterflow.

- Outside to inside (inflow) radial quench chamber (Fig. 4.169)
  Inflow quench chambers are used in combination with circular spinnerets having an annular hole distribution. The quench air enters a hollow, cylindrical rectifier surrounding the filament bundle,



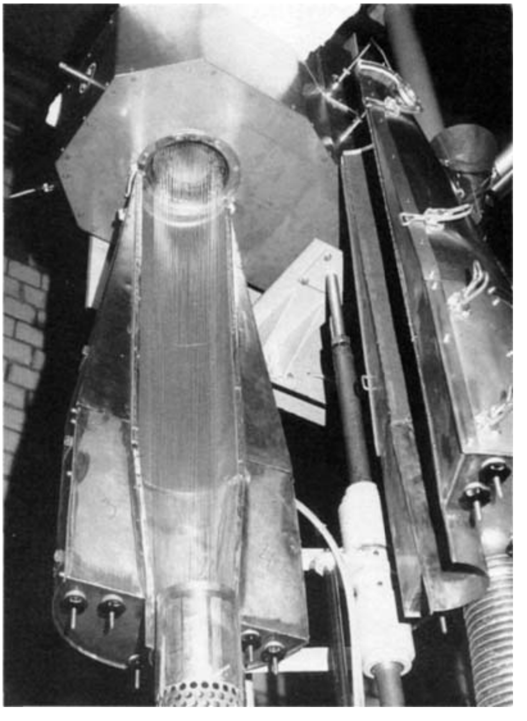


Figure 4.169 Radial quench chamber with outside → inside quench flow
a) Principle, and dimensions of a PET staple fiber quench, given as an example
1 Stand
2 Inlet air plenum
3 Air rectifier
4 Pneumatic piston
7 Interfloor tube with perforated upper part
9 Inlet air flange
10 Filament bundle
b) Outside-to-inside radial quench chamber (shown opened), with filaments from annular spinneret [24]

penetrates the filament cylinder radially, and the air flows into, and down with, the hollow space within the annular bundle. The air within the bundle is squeezed out above the yarn convergence point. As in cross flow quenching, the air is warmed in penetrating the filament bundle in the upper quench zone. In the lower quench zone, the air once again penetrates the filament bundle during its expression to outside. For this reason, inflow quenches are not suitable for materials of low glass transition temperature.

For spin pack insertion/removal and for yarn throw-down at the start of spinning, these inflow quenches can be pneumatically (or otherwise) lowered by 400...500 mm. A variant which produces good Uster values when spinning continuous multifilament is shown in Fig. 4.170 [33]. Here 2 to 8 sintered metal tubes (3) or Fuji paper rectifiers are encased in a pressurized box (8) to which the inlet air is admitted; these tubes are extended below the box to form the interfloor tube (7). The air exhausts into the room at the end of the tubes. The air tube is sealed above against the spin pack by means of an insulation ring and a concertina bellows (4) which is smooth on the inside.

- The inside to outside (outflow) quench chamber (Fig. 4.171)
  Outflow quench is particularly suited to staple fiber spinning, as a round spinneret can easily accommodate 12 concentric rings of capillaries. With the dimensions given in Fig. 4.171, 3000 holes can be fitted in one spinneret to give a throughput of 160 kg/h/spinneret when spinning fine titer. The upper quench tube (3), made from sintered metal and incorporating a flow cone (11), needs only ($T = 30°C$, $\rho = 1, f = 1.11$) ca. 1240 Nm^3/h cooling air for PET, corresponding to a velocity of ca. 0.5 m/s at entry to the first filament ring. The quench air, after passage through the sintered tube, is still 30% turbulent; this does not adversely affect the spun filaments, as the measured CV $\approx$ 10...12% shows. The corresponding inlet air velocity in (9) is 14.5 m/s, and the system requires an inlet pressure of 300...500 mm w.g.

  Spin finish application is either as per page 368, using a ring which also keeps the filaments away from the air inlet pipe, or—better still—as shown in Fig. 4.171 using a U-shaped spin finish applicator ring (pos. 12).

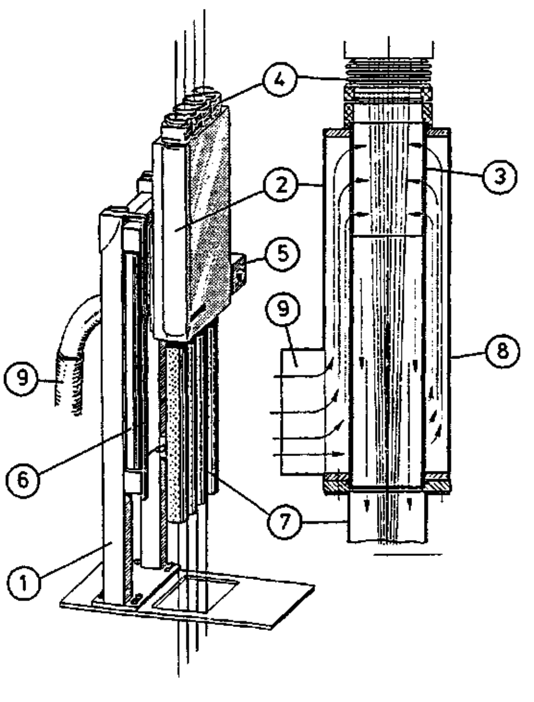


Figure 4.170
Outside-to-inside quench chambers for spinning PET filament yarns [33]
Description is as per Figure 4.169*a*, but additionally:
4 Corrugated tube connector to spinneret face, insulated
5 Switch for hydraulic lift
8 Housing for 4 quench tubes
Comment: The quench tube (*3*) is usually constructed from porous sintered metal

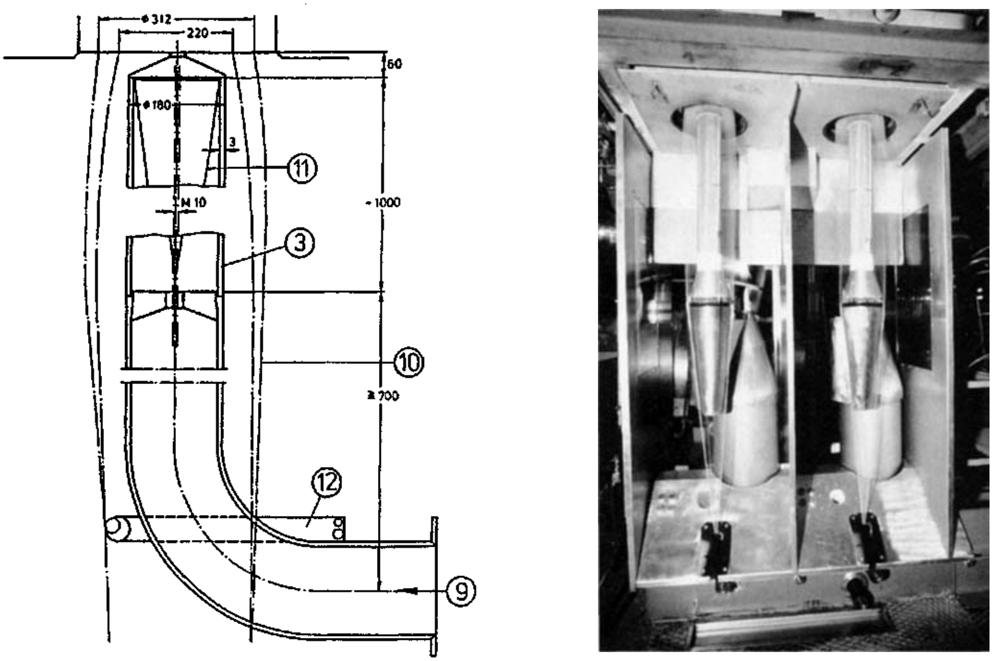


Figure 4.171 Radial quench chamber having inside-to-outside flow (outflow quench)
a) Principle, and dimensions of a PET staple fiber quench, given as an example. Description as per Figure 4.169, and additionally:
3 Porous sintered metal tube
11 Cone insert for shaping air velocity profile
12 Ring-shaped spin finish applicator
b) Radial quenches of Ems AG [152] spinning PET staple fiber

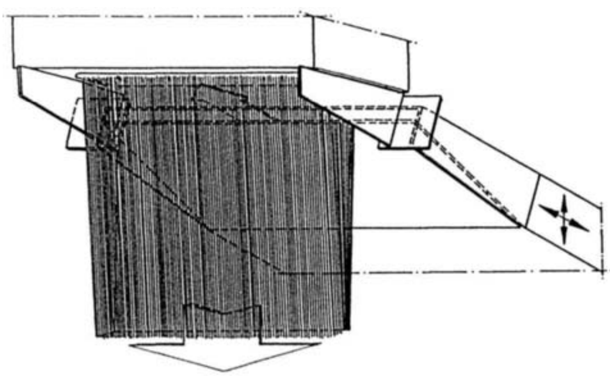


Figure 4.172
Slit quench of a compact staple fiber spinning machine

- The slit quench chamber (Figs. 4.172 and 4.165F)
The slit quench is used practically only in conjuncton with compact staple spinning machines (Section 5.1, Fig. 5.2). In one example, the 450 × 80 mm rectangular spinneret has ca. 60 000 holes with a hole to hole spacing of ca. 0.8 mm, i.e., it has about 50...60 rows of holes. The spinning speed is typically 30...50 m/min; for this, a slit height of 20...30 mm suffices. At a spinneret

throughput of 80 kg/h (≈2 kg/h/cm spinneret width), an air flow rate of 40...50 $Nm^3/h/cm$ width is used, corresponding to an air velocity of 20...40 m/s, which is strongly turbulent. As the spinning tension is high and the distance of the spinneret to oiler is only ca. 200...300 mm, the filaments are relatively stable. For polypropylene, the quench flow is angled ca. 5...10° to the spinneret, so that the filaments are partly solidified directly after extrusion from the capillaries [33].

This principle can also be used for annular spinnerets (Fig. 5.8). A construction intermediate between the slit quench and conventional cross flow quench is given in Figs. 4.165E and 5.10. Here, in the first 100 mm below the spinneret, the quench flows from front to back, simultaneously removing the monomer evolved. In the next 100 mm, the quench flows from behind through the filament bundle to the front and into the spinning room. Using this system, fine filament PET staple can be spun with up to 25 hole rows and 1500 holes/10 cm spinneret width at a spinning speed of 1700 m/min using a quench velocity of 10...15 m/s, achieving a CV value of 10...11% in the finished fiber.

4.7.3 New Quench Chamber Developments for Very High Spinning Speeds (Fig. 4.173, [318–323])

In order to achieve the required higher heat transfer from filaments to cooling air, one can

- increase the heat transfer coefficient α by increasing the air pressure in the cooling chamber (b) to 0.5...3 bar overpressure,

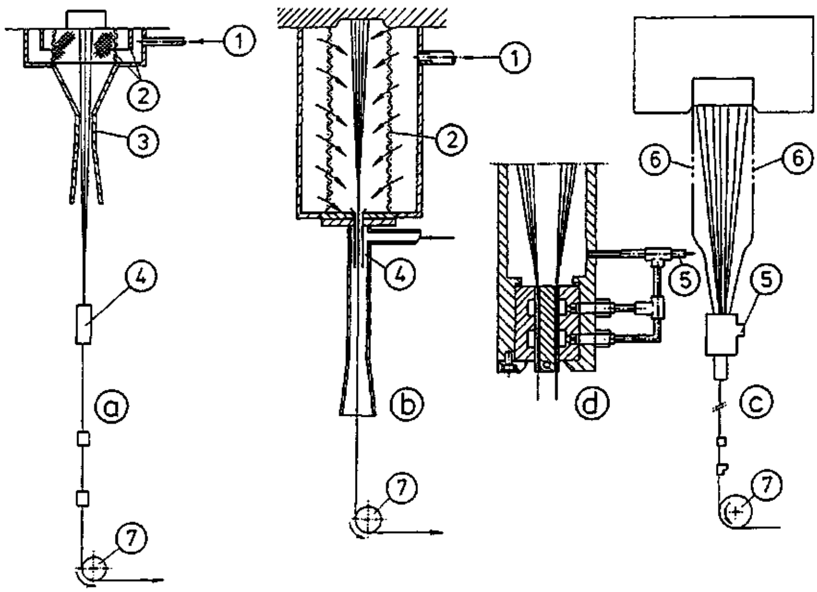


Figure 4.173 Quench chambers for spinning speeds of 6000...12 000 m/min
a) Over-pressure quench with venturi jet take-up
b) Radial quench (inflow) with venturi jet take-up
c) Self-aspirating quench with air aspiration
d) Example of air aspiration in an over-pressure quench for 2 yarns.
1 Cool compressed air inlet
2 Protective cylinder and sieve
3 Venturi jet
4 Yarn suction jet
5 Vacuum-assisted air aspiration
6 Room cooling air aspiration
7 Take-up godet

- use the increased air flow aspirated at higher spinning speeds, then suck this air out directly below the convergence point: (c) and (d) (Fig. 9.15),
- use a venturi jet (a).

The cooling air, at 1...3 bar overpressure, is forced into the cooling chamber (a, b), flows—after distribution by sieves—to the filaments and moves downwards with the filaments through a jet (a) or is sucked away from the filaments (d). The take up force is possibly enhanced by a second jet (b), which reduces the yarn tension to the winder. These new quench types have been suggested for PET at >6000 m/min, optimally for 9000 m/min and for even up to 12 000 m/min spinning speed. For PA66 and PP, they have only been recommended for 6000...9500 m/min.

4.7.4 Construction Elements for Quench Chambers

Other than the plenum and casing—and, in the case of rectangular cross flow quenches, the sidewalls—many other elements are required to bring the quench air flow, in the desired condition, into contact with the filaments. Included here are aspirators, spin finish applicators, etc. In particular:

4.7.4.1 Quench Air Rectifiers

Air flow rectifiers originally served to achieve a uniform velocity distribution across the surface of the quench. To this end, a perforated plate, an air gap and a sheet of air-permeable foam material about 10 mm thick, all encased in a change frame and placed in the air flow direction, sufficed. The air flow from such a device was, however, still slightly turbulent. For radial quenches, a perforated tube wrapped in an air-permeable foam material was used. When the foam material became blocked, it was simply replaced with new foam.

Today air rectifiers for achieving the required laminar flow in the desired flow direction when spinning fine textile and technical yarns, and for damping the pressure fluctuations in the inlet air, consist of perforated plates, combinations of fine wire sieves and possibly, inbetween these two, Alucell honeycomb plates and air-permeable foam sheets. Using such combinations, the turbulence in the inlet air of (mostly) ≥ 1.2 can be reduced to ≤ 1.01 on leaving the rectifier. The woven wire mesh becomes progressively finer in the flow direction; the fine mesh must, however, be stable and be protected against mechanical damage, including during cleaning. To achieve exit air flow at right angles to the screen, only plain weave or parallel braid construction (twill) can be used. The fineness of the front sieve should be about 60–100 μm. To achieve laminar exit flow, the maximum mesh size for plain weave should be 350 μm for 0.6 m/s, 180 μm for 1.3 m/s and 100 μm for 1.8 m/s. By appropriate construction, Tu may be made less than 1.01 [161].

Every screen frame comprises two or more of the above-mentioned components (Fig. 4.174). The distance between 2 consecutive meshes should be at least 60 to 80 times the mesh size; this is normally rounded to the nearest 10 mm in practice. If the void between 2 meshes is filled with Alucell (a honeycomb construction made from aluminum foil), pressure compensation cannot occur parallel to the plane of the (vertical) screen front. In this case, a definite vertical air velocity profile occurs at the rectifier exit in the quench chamber (Fig. 4.174b). If the void between 2 meshes is left open (i.e., no Alucell), pressure compensation at right angles to the flow direction occurs, and the exit air velocity profile becomes more uniform (Fig. 4.174a).

Figure 4.174 also explains how the rectifier can be changed quickly; it should be possible to do this within the time required for a pack change. After loosening and pushing away both fastening clamps (1), the quench sidewalls (2) are removed and the rectifier (3) is pulled out towards the front.

Table 4.30, a calculated example, gives the coefficient of resistance, the pressure loss and the turbulence damping for a 4-layer air rectifier. With a damping of $D = 109.7$, the turbulence of the inlet air is reduced from 16 to 0.15% in the quench chamber.

In order to avoid fluttering, caused by turbulence, in the still-molten filaments emerging from the spinneret capillaries, two measures are necessary:

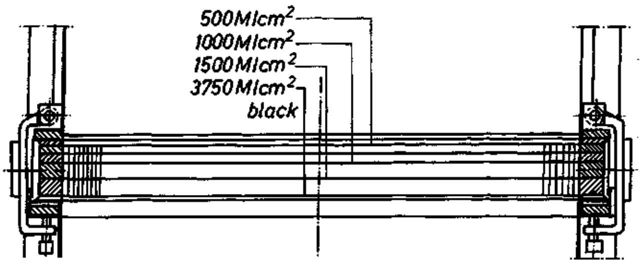


Figure 4.174a
Air flow rectifier having 4 stainless steel meshes (finest, in front: 3600 mesh/cm²): $Tu_{front} \sim 0.16$ to $T_u \leq 0.01$ [24]

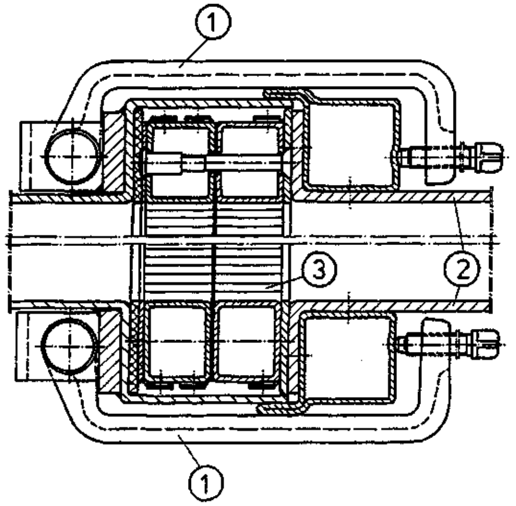


Figure 4.174b
Air flow rectifier having 3 stainless steel meshes with Alucell flow straighteners in-between the meshes ($SW = 7$ mm). Also shown are the clamps for fixing the rectifier to the quench chamber sidewalls [24]
1 Fixing clamp
2 Sidewalls of quench chamber
3 Air rectifier

Table 4.30 Quench Chamber Air Rectifiers Calculated Example for $v = 0.6$ m/s, 1 Perforated Plate and 3 Woven Meshes (Numbers from Section 7.10)

Layer	β	Re	γ	ζ	p (kg/m²)	Damping
Mesh 4		0.0397	1500	37.5		6.20
Mesh 3	0.8	10.46	5	21.5		4.74
Mesh 2	0.38	27.80	3	12.9	1.62	3.73
Perforated plate 1	0.111	turbulent	16.65	150	3.38	–
			Sum	221.9	5.00	110

- An air flow diverter plate, more than 50 mm long and inclined upwards at 10...12° to the horizontal to avoid air flow break-away at the top of the air rectifier (Fig. 4.175a). Alternatively, in the case of multi-layer air rectifiers, the interior frames of the rectifier are expanded stepwise from inside to outside.
- Sealing, on all 3 sides, of the top of the quench cabinet to the underside of the spinning beam insulation (Fig. 4.175b) is necessary to avoid outside air leakage into the top of the quench chamber.

Every protuberance increases the air velocity on the perimeter of the air rectifier. Assembling the air rectifier internal frames incorrectly, so that there are protuberances, is not acceptable, as this will lead to turbulence at the frame edges.

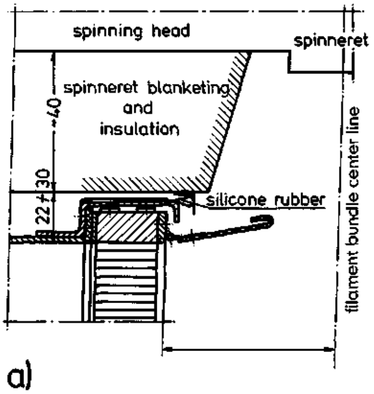


Figure 4.175a
Flow separation plate fitted to the top of the air rectifier to avoid eddying directly below the spinneret

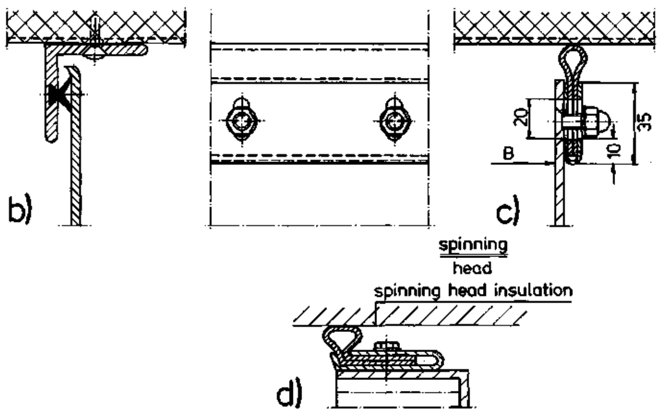


Figure 4.175b Examples of quench door seals (*b* and *c*) and a quench rear wall seal (*d*)

The front mesh of the air rectifier, made from stainless steel, should preferably be electrolytically dyed black in order to be able to see the mostly white or translucent filaments. The front mesh must be tautly tensioned, as the air flows out normally to the tangent, and a wavy mesh would result in a non-uniform velocity distribution. Figure 4.174b illustrates how the mesh can be tensioned: it is spot welded to a stainless steel strip along its perimeter, which is then laid over the frame and screwed down into the sides of the frame.

The front mesh must also be protected against contamination. The top of the screen becomes contaminated by condensed monomer, and the whole screen area can be soiled by melt dripping onto it. Strong turbulence is generated in the neighborhood of these dirt particles [138, 154]. Dirt on the inlet side of the screen leads to the same effect. To prevent monomer condensation, thin copper strips can be fixed to the top of the screen frame and extended to touch part of the hot spinning beam; these strips conduct heat, remain warm and prevent condensation. To avoid melt dripping onto the front screen, there must be a minimum gap between it and the first filaments (compare formula 3.21).

4.7.4.2 Quick-Change Air Filters

These are used to clean the inlet air to the quench rectifier. Either flat filters or pleated (folded) filters (Fig. 4.176) are used; the latter have a much greater surface area. These filters should have at least one mesh which is as fine as—or finer than—the finest mesh in the rectifier (3), as well as a coarser support mesh (2). The housing locking mechanism permits a filter change in less than 5 s [24]. As the quench inlet air—even from the best air conditioning plants—is not as clean as required for the air rectifier (because of the long air ducts), use of these filters can extend the working life of the rectifier by a factor of 3, and thereby also maintain good Uster values for a longer time. The air rectifier should be exchanged for a cleaned one as soon as the Uster value exceeds an acceptable limit (Fig. 4.177).

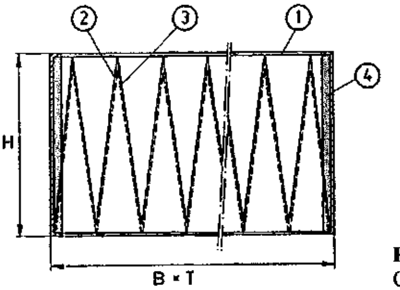


Figure 4.176
Quick-change air filter (folded type) [24]

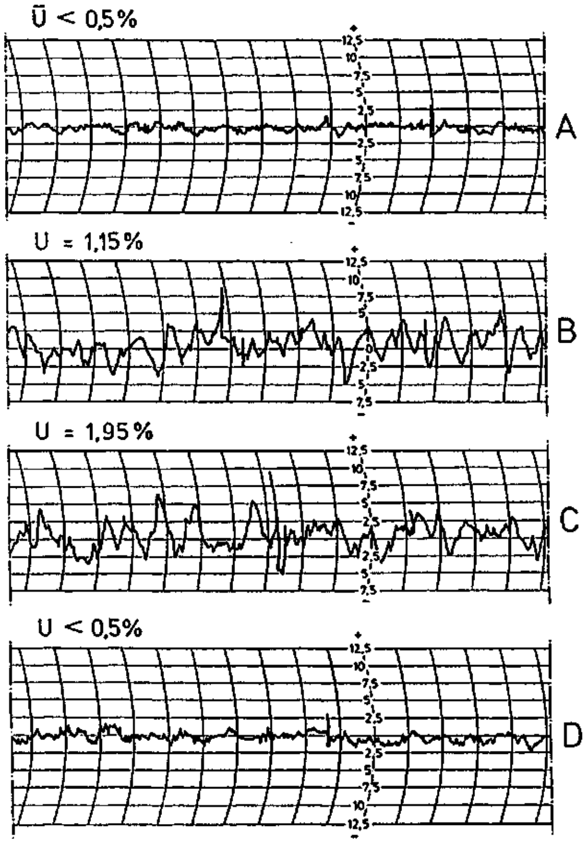


Figure 4.177
Uster diagrams as a function of the duration of operation (i.e., degree of contamination of, especially, the front layer) of an air rectifier

Uster diagram	A	B
Time in operation	< 1 h	10 days
Uster value Ū	< 0.5	1.15
Uster diagram	C	D
Time in operation	20 days	freshly cleaned
Uster value Ū	2.45	0.5

4.7.4.3 Air Flow Regulation

In order to reduce pressure variations in the quench inlet air, one can increase the inlet resistance of every quench chamber, either by using a series of parallel butterfly flaps (which have a relatively low resistance when open) or by using a sandwich of 2 high resistance perforated plates which can slide relative to one another. It is possible to make the inlet resistance to the quench cabinet so high that the individual differences become irrelevant. Increasing the resistance does, however, lead to the need for higher inlet air duct pressures, but this—in turn—results in better damping of pressure pulsations.

A quench supply shut-off flap can often prove useful, e.g., when throwing yarn down the interfloor tube. In the absence of the shut-off flap, the freely-falling yarn can be blown out of the quench chamber. A foot-operated lever is recommended for operating the closure flap.

4.7.5 Quench Chamber Accessories

These accessories can sometimes be of advantage, but are not always necessary or useful. Included here are:

4.7.5.1 Monomer (Fume) Aspirations

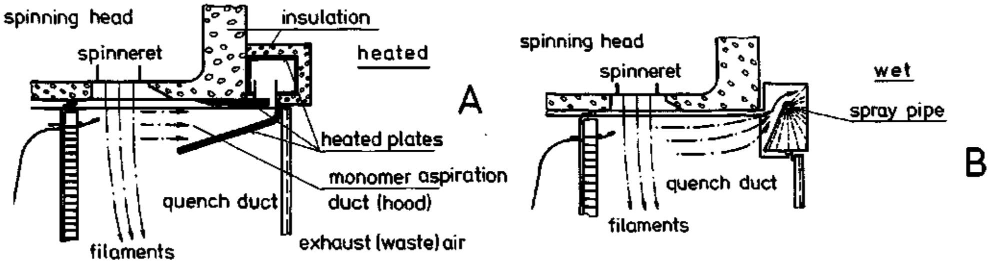
In the first 5...15 cm below the spinneret, about 0.2...1.2 w/w% (depending on polymer and temperature) of low molecular weight monomers or degradation products diffuse from the still molten polymeric filaments into the air. About 40...70% of this monomer is removed by the quench air, the remainder condensing on cool parts, such as the quench sidewalls, the top of the air rectifier frame and even on the screen itself. Only by heating to above 220 °C can this be avoided, but this is not, however, practical. One way of coping is to mechanically scrape off this growing layer at regular intervals. If not removed, PA66 monomer grows to a thickness of a few mm within a week. In the case of small quench cabinets, this encrustation can disturb the air flow in the upper regions.

Monomer remaining in the quench air is removed, together with its carrier air, by a monomer aspirator. As shown in Fig. 4.178, there are various methods:

- An unheated aspirator hood, 80...150 mm high and having the width of the quench, is positioned immediately below the spin pack, close to the extruding filaments. The hood sucks away the quench air in this region, heated to 50...100 °C by heat exchange with the filaments, with a velocity of 1.2 to 1.5 times the quench air velocity. Every hood is connected to a common monomer extraction duct by means of a quick-change coupling. Soiled hoods are exchanged and cleaned in the workshop. Initial duct velocities of 12...20 m/s prevent monomer deposition in the duct, as long as there are no obstructions in the duct. The aspirated air can largely be cleaned of monomer by a water jet injector pump or by water spraying.
- When the above-described extraction hoods and ducts are heated to above 180...220 °C (e.g., by leakage-free heated plates and/or heating cuffs), the contaminated aspirated air can be led directly to a washer. The heating power (flux) required here lies between 0.1 and 0.2 W/cm^2, based on the duct interior surface. Overheating electrical protection must be provided for the ducts.
- The monomer-laden quench air in the upper quench zone is directly aspirated into an exhaust duct, which has a water spray jet located behind a plate beyond the duct opening. The water spray condenses or dissolves the monomer. Figure 4.179 shows a schematic of a complete monomer aspiration plant. There is a water jet injector pump for every 2 quench cabinets. As well as showing the required supply and preparation accessories, process conditions are given as an example. All components coming into contact with water should be made from 1.4541 steel, as a minimum requirement.

4.7.5.2 Spinneret Blanketing

Blanketing of the spinneret with steam superheated to the temperature of the spinneret is particularly beneficial in PA66 spinning. The steam dissolves most of the monomer diffusing out of the filaments and carries the mixture downwards as a boundary layer, thus largely preventing monomer baking onto and coking on the spinneret face. Superheating the steam up to nearly 300 °C can be done either by passing



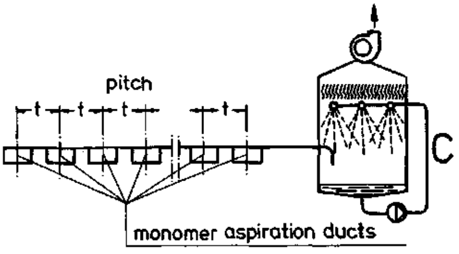


Figure 4.178
Monomer aspirations
A Aspiration hood, dry, heated
B Aspiration through a water-sprayed duct
C Aspiration through a water-sprayed chamber

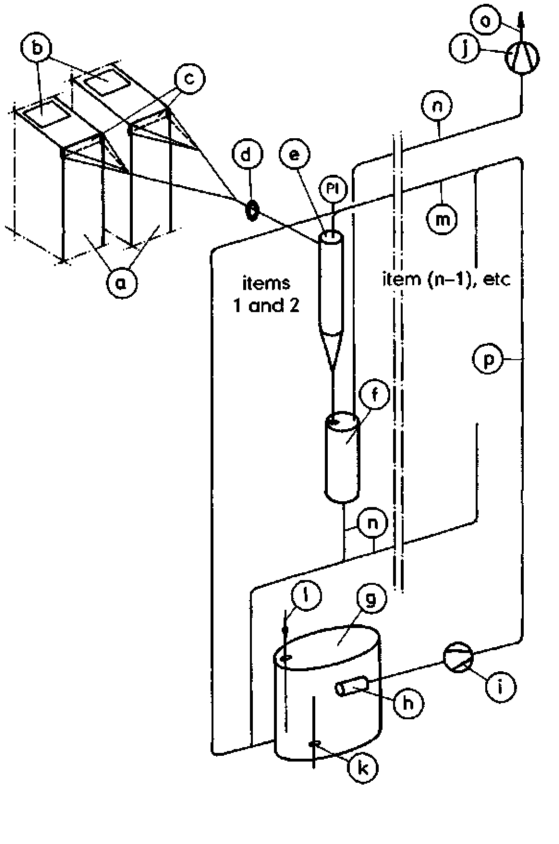


Figure 4.179 Process scheme of a complete monomer aspiration system
a) Quench ducts
b) Openings for spinnerets
c) Extraction hoods, with
d) Quick-fit coupling
e) Water jet pump
f) Water de-aeration
g) Collector tank for *n* positions
h) Water filter
i) Circulation pump
j) Suction fan
k) Overflow
l) Fresh water, cold
m) Water main (~ 1.5 m/s)
n) Drain pipe (~ 0.8 m/s, $c \sim 3\%$)
o) Exhaust air ($\approx 8 \ldots 10$ m/s)
p) Spray water ($c \approx 2\%$)
Example 2: 2 spinning positions, each 90 Nm^3/h aspiration through 0.1 m × b_i (= internal quench chamber width – ca. 20 mm) ≈ 8 m/s × pipe cross-sectional area.
Water consumption: ca. 3 m^3/h.
Make-up water: ca. 150 l/h × position + 30%

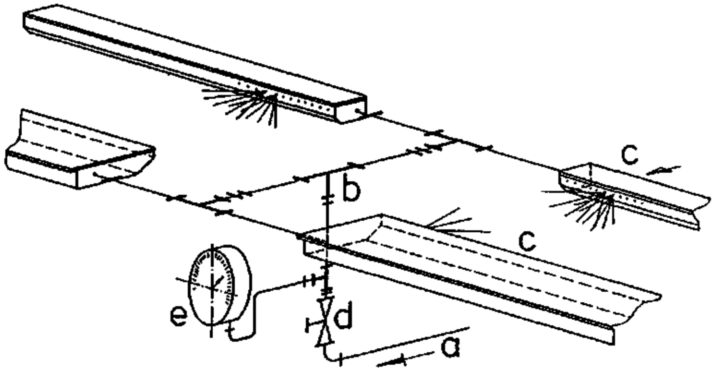


Figure 4.180 Spinneret blanketing (protective gas) attachment, electrically heated, for retro-fitting [24]
a) Saturated steam line for 2 spinning positions
b) Steam distributor
c) Electrical steam super heating and blanketing device
d) Shut-off valve
e) Pressure gage
→ flow direction

the steam delivery pipe through the spinning beam (Fig. 4.164, pos. 3) or by electrical heating, as shown for 2 spinning positions in Fig. 4.180. Live steam (a) is pressure-reduced at (d) to give the required steam flow rate, which is approximately 20...30% of the throughput rate. The steam is then superheated by electrical resistance heating rods at (c), after which it streams out from both sides of the spin pack parallel to the spinneret faces, uniformly across the spin pack length.

There is no demonstrable advantage for steam blanketing when spinning PA6. For other polymers, particularly those which are very oxidation-prone, it may be necessary to use the above-described apparatus with pure nitrogen instead of steam.

4.7.5.3 Hot Shrouds (Collars)

For highly viscous polymers, e.g., for tirecord, a 100...300 mm long, dry shroud, electrically heated to spinning temperature is fitted immediately below the spinneret to retard or delay the cooling of the filaments. Figure 4.181 shows an example of such a hot shroud (post-heater, after-heater) in cross-section. The interior of the heater is made from rust-free stainless steel, and outside it is electrically heated and temperature-controlled. The shroud sits below a round spinneret (a) for spinning PET tirecord using $[\eta] = 1.0$ and a spinning temperature of 310 °C. The front side of the heater should be openable upwards for servicing the spinneret, particularly in the case of rectangular spinnerets or rows of spinnerets.

A hot shroud can be beneficial for spinning many new, special polymers and spinnable liquid crystals.

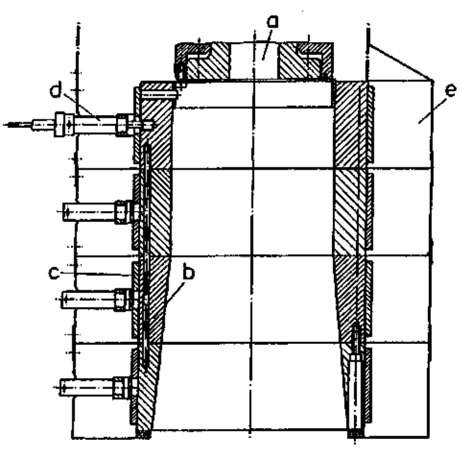


Figure 4.181
Hot shroud (heated collar)
a) Spinneret
b) Stainless steel body
c) Electric heating bands, with
d) Temperature sensor
e) Insulation

4.7.5.4 Waste Disposal

A simple method of preventing the spun waste from falling down the interfloor tube is to hang a waste chute in the quench. With the quench doors opened, the waste chute protrudes out above a waste wagon; extruded polymer and spun waste slide down the chute into the waste container (Fig. 4.182). Using a separating flap on the chute (c) solid waste (polymer blocks) can be separated from spun waste ("wool"). To minimize weight, the chute is made from $AlMg_3$.

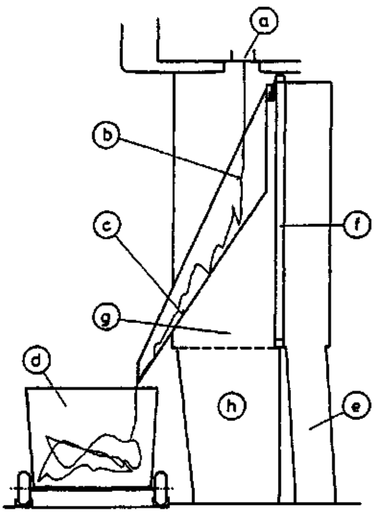


Figure 4.182
Spinning start-up waste chute
a) Spinneret
b) Filaments
c) Waste chute
d) Wagon for waste yarn
e) Quench air inlet
f) Quench air rectifier
g) Quench chamber
h) Interfloor tube

Spun waste can also be taken away by compressed air aspirators of large cross-section, located below the air rectifier, into waste containers. When stringing up onto the winder, the yarn is cut out of the aspirator, the aspirator is switched off and the yarn is thrown down, to be caught by the suction gun.

4.7.5.5 Interfloor Tubes

Interfloor tubes are used to protect the yarn against unwanted environmental interference between the bottom of the quench chamber and the take up machine by enveloping all threadlines from one spinning position. They are mostly made by welding $AlMg_3$ sheets together; the insides must be smooth to prevent yarn snagging. In multi-storey spinning towers, the types (A) and (B) shown in Fig. 4.183 are used; they isolate the yarn in the tube from the different floor pressures. The penetration holes in the floors or decks are usually sealed with polyurethane foam. Interfloor tubes for single yarns can be round, those for multiple yarns or rectangular spinnerets are rectangular. The latter can—like quench cabinets—be separated by separator plates; their depth in the quench direction should be not less than 300 mm. Interfloor tubes are sealed at the outlet ends by openable flaps, which have a slit to allow the yarn to pass through them.

In compact spinning plants having an open grille floor and a short distance between the quench and the take-up machine or winder, the interfloor tubes are left open at both ends (Fig. 4.183C) since there is no pressure difference between the spinning room and the winding room.

When closed interfloor tubes (A, B) are used, it is necessary to have pressure control between the air conditioning units serving the quench floor room and the winding room. The overpressure on the quench floor should be set such that, with the flaps closed, the exit air velocity in the yarn exit slit is ca. 2 m/s downwards.

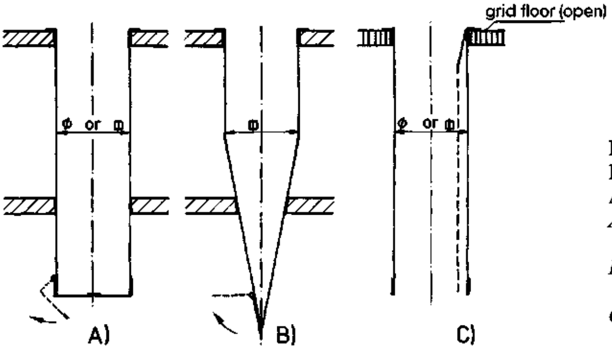


Figure 4.183
Interfloor tubes (made from Al 99.5 or AlMg3)
A) Round or rectangular, with lower closure flap and slit for yarn passage
B) Rectangular/conical, with lower closure flap and slit for yarn passage
C) Open, round or rectangular, for compact plant in a single room

When spinning PA66 LOY or MOY, the interfloor tube is also used to steam-condition the yarn. Figure 4.184 shows a steam conditioner in use since 1938 [144, 162]. A single multifilament yarn (13) is conditioned by 100 °C saturated steam at atmospheric pressure in the interior tube, while the jacket (54) acts as a steam heater to prevent condensation on the inner wall of the interior tube, which would result in a dyeing fault where the yarn runs against the condensate. These steam conditioning tubes can also be angled sideways to give the correct yarn path to the winder. Whether steam conditioners are required when spinning PA66 POY is open to debate.

A steam conditioner, based on the same construction principles, but made for 16 parallel fine titer multifilament yarns (13) is shown in Fig. 4.185, including the steam injection (2) and the jacket heating (54). The flaps (51, 52) are internally steam heated to prevent condensation. Together with the cover (53), (52) can be opened frontwards to facilitate yarn throwdown. A condensate collection tray, with condensate return, runs around the bottom of the inner tube (50). Right at the top of the tube, vapor is sucked out and condensed externally.

The "tube spinning system" (Fig. 4.186) was developed from the single end steam conditioner. Using one compressed air injector per multifilament threadline, each yarn is blown down its own guide tube. After yarn throw-down using high presssure, the pressure is reduced until optimum yarn tension above the winder is attained. This system results in an exact yarn guidance and prevents cascade breaks when one threadline breaks [163].

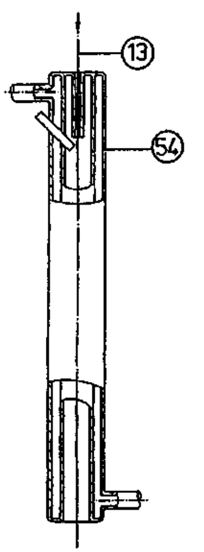


Figure 4.184
Steam conditioning tube with jacket heating, single end [75, 24]

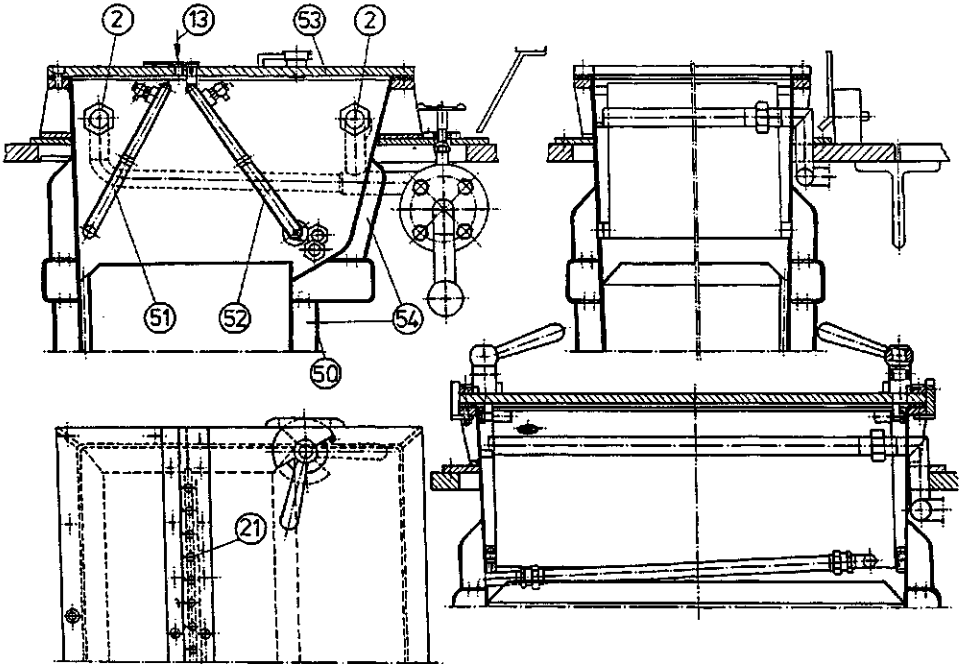


Figure 4.185 Steam conditioning tube for 16 PA66 yarns: upper section [24]

2 Steam injection tubes
51 Fixed, heated flap
52 Openable, heated flap
53 Hinged cover
54 Heating jacket
13 Yarns
50 Internal pipe

4.7.5.6 Quench Air Supply Ducts

In very tall spinning towers, the mezzanine between the quench chamber floor and the winding room floor is used as a buffer pressure chamber for the conditioned quench air supply, in order to be able to supply all quench chambers from one large volume at constant pressure. To this end, the room pressure must be held constant, and the supply air from the air conditioning plant must enter the quench chamber connecting flange without disturbance. By additional subdivision of these rooms, the spinning room can be supplied with comfort air and the winding room with correctly-conditioned air.

The development of more compact spinning machines has led to the use of exactly-dimensioned quench air supply ducts, which supply exactly the correct flowrate and pressure at the quench chamber inlet. In order to simplify manufacture, the quench supply duct has a constant cross-section over its entire length; the resistance of each quench inlet must then be adjusted to make the flow rates up all quench riser ducts the same.

It is, however, better to make the quench air supply manifold as shown in Fig. 4.187, using either conical- or rectangular step sections in such a way that the flow rate Q_n up each riser duct is the same. The air velocity in the manifold should be in the range of 6...10 m/s; above 8 m/s the duct becomes noisy. The duct walls should not pulsate, and the air flow in the manifold should not come into resonance. As individual quenches can be shut off during production, one builds in overpressure louvre by-pass flaps at the ends of the ducts; these must have a very short response time, as the electrical regulation of the fan (or fans) of the air conditioning plant respond with considerable inertia.

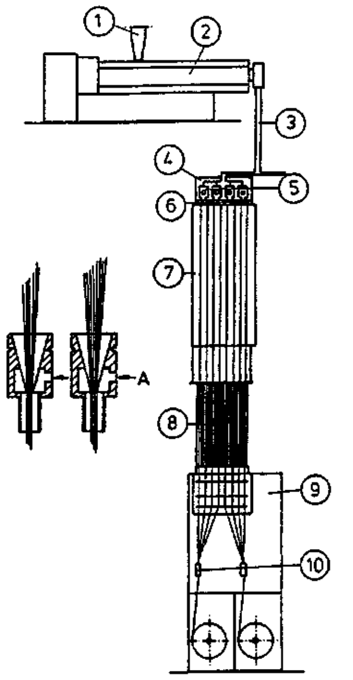


Figure 4.186
The Lurgi Tube Spinning System [163]
1 Granulate inlet
2 Spinning extruder
3 Polymer melt distributor pipe
4 Spinning beam
5 Spinning pump
6 8 spinnerets
7 Quench chamber
8 Take-up and interfloor tubes, with compressed air inlet (*A*)
9 POY take-up machine, with spin finish applicator, yarn cutter and aspirator
10 Yarn separation and intermingling (tangling)

4.7.5.7 Air Flow Restriction in the Quench Chamber

In cooling yarn bundles, each containing many filaments, it is beneficial to force the quench air to flow through—and not around—the filaments. Figure 4.188 demonstrates the advantage of placing a flow restrictor plate (fairing) close to the outer filaments of a filament bundle in terms of the uniformity of filament displacement by the quench and its corresponding effect on the isotherms in the displaced bundle. The non-uniformity of the temperature lines in the left half (at large distance between the sidewalls and the outer filaments) results in a lower and less uniform drawability than the right hand side, which has a very small distance to the quench sidewall [153].

In practice, such flow restrictor plates should follow the outer filament bundles all the way through the quench zone; the plates should be slightly convergent, so as to equalize the air resistance of the converging bundle. To reduce air consumption, one can incorporate corresponding flow restrictor masking plates of ca. 200 mm length on the inlet side of the air rectifier.

The flow restrictor plate in the quench chamber can be held in position by fixed distance pieces, by swivel end screws or pneumatically, with retraction, in order to avoid the filaments snagging against the inclined plates at yarn throwdown [24].

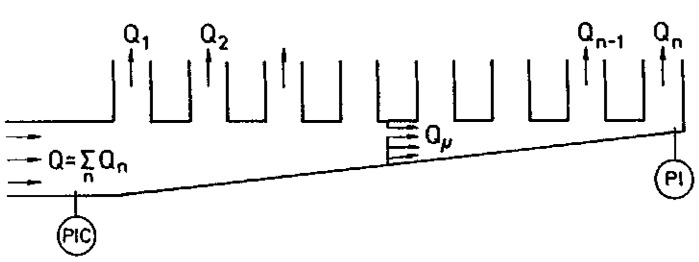


Figure 4.187
Dimensioning of a quench air supply duct
$Q = \Sigma\, Q_{BSn}$
$Q_n = \text{constant}$
$Q_\mu = Q - \Sigma\, Q_n$
$= Q - n\, Q_{BS}$
$v \approx 6$ m/s (< 8 m/s)

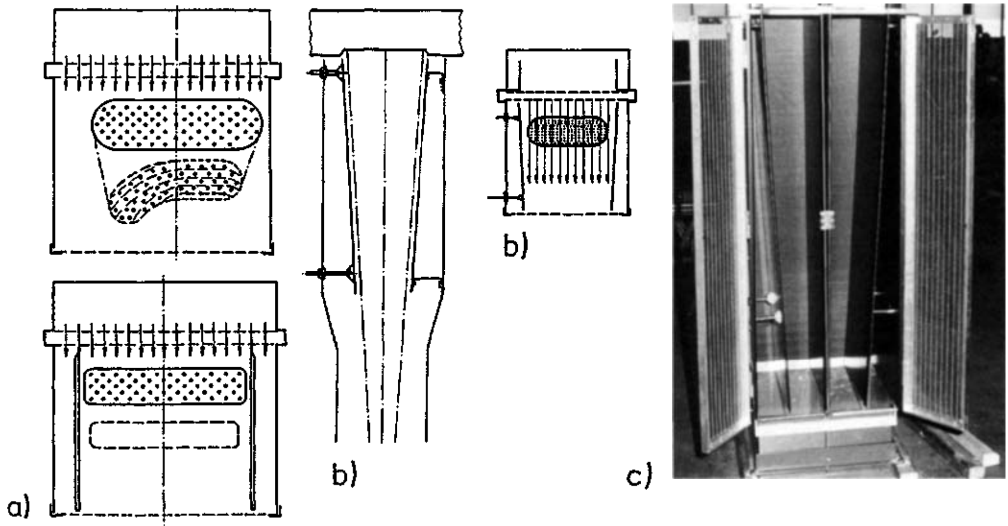


Figure 4.188 *a*) The effect of the flow-limiting plates in the quench chamber; above: without; below: with plates
b) Flow-limiting plates in the quench chamber, adjustable to within ca. 10 mm of outer filaments [24]
c) Double quench chamber with flow-limiting plates [24]

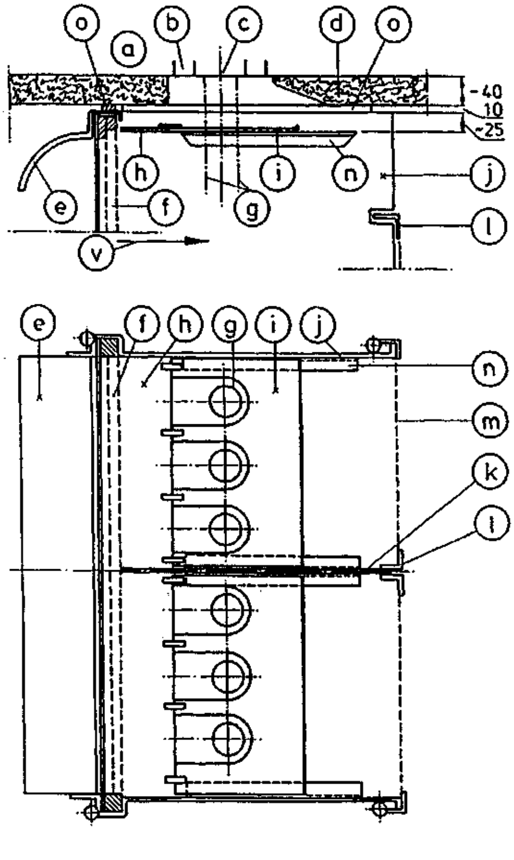


Figure 4.189
Spinneret protective plate to shield spinneret from quench (Example is for 6-fold spinning [24])
a) Spinning beam
b) Spin pack
c) Spinneret
d) Insulation
e) Quench inlet plenum
f) Quench air rectifier (interior stepped above)
g) Filaments
h) Fixed plate
i) Movable plate with fixing screws
j) Quench chamber sidewall
k) Internal quench chamber separator plate
l) Front door, with
m) Quench door grille
n) Angled supporting bracket
o) Seal between quench and spinning beam
v) Quench airflow direction

When there are many yarns being cooled in a quench chamber, it is recommended that air vanes (= separator plates) be placed between the yarns, with a separation of 20...25 mm between the outer filaments and the plates. For ease of handling, these separator plates should either be easily removable or should retract when the chimney door is opened.

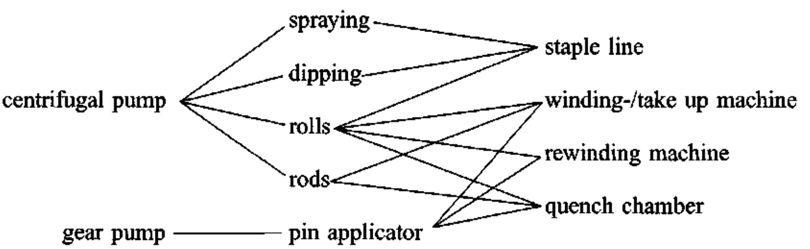
It is often worthwhile—particularly for fine titer—to shield the spinnerets against the quench flow, as is shown in Fig. 4.189. The upper air deflector plate is fixed normal to the front of the air rectifier and is extended in the flow direction by a slideable plate, which has sections cut out to allow passage of the filament bundles during spinning. These restrictor plates function as a very weak heated shroud, as the air between the plates and the spinneret is stagnant. This can also result in an improved Uster value.

4.8 Spin Finish Application Systems

Spin finish application is necessary to make the yarn more pliable, antistatic and more moist. For the downstream processing of tirecord, the yarn must also be made more receptive to rubber adhesion by treatment with resorcinol formaldehyde. In addition, there is the possibility of reducing the air friction component of yarn tension by converging the filaments as close to the spinneret as possible (compare Section 3.3.2). If the spin finish applied at spinning is not sufficiently durable, finish is again applied once or twice more during further processing, possibly after washing off the original spin finish. The tendency is, however, to make the spin finish suitable and stable for all further processing stages. In the case of PET POY for drawtexturizing, e.g., the finish must be able to withstand temperatures up to 240 °C, must not decompose and must remain on the yarn in sufficient quantity. For this reason, possibly more finish must be applied at spinning than remains in the end product.

For continuous filaments, the oil on yarn level should preferably lie between 0.8 and 1.5 w/w%, based on dry yarn, while staple tow requires up to 4% if washing occurs downstream. Spin finish is applied as a 10...25% solution or emulsion in distilled water. Layering of the spin finish or component separation can be avoided by stirring or by circulation. Finish damaged by oxidation cannot be re-used.

There are five different methods of applying finish at four different production positions:



The level of finish applied at spinning must be sufficiently high to achieve the 0.6...0.8% level required for further processing, taking into account losses during intermediate processing:

- when the yarn contacts the finish (particularly in POY spinning), one observes that the finish is explosively atomized and is taken up by the room air as an aerosol. This finish-contaminated air must be cleaned by washing and/or catalytic combustion.
- losses during hot drawing of yarn or tow by evaporation, decomposition or washing.
- drying out losses.

As more finish is again applied at further processing, the spin finish material balance, from beginning up to finished goods, is fairly complicated, and is not evident to the spinner. One should therefore limit oneself to optimizing the spin finish level up to the winding stage, and possibly the next processing stage.

4.8.1 Roll Application

This is the oldest finish application system, and is still used today particularly for wide tows and for speeds below ca. 1800 m/min. Roll application can be fitted at the inlet to the take-up machine, at the bottom of the quench chamber or at tow processing.

The sintered corundum lick (kiss) rolls [146] have a diameter of 120...180 mm and a width which is given by: max. tow width $+\geq 50$ mm. The roll drive is continuously adjustable within a range of 3...20—preferably 5...9 r/min, the roll running in the same direction as the yarn. For very wide rolls, stainless steel cylinders, plasma-coated with coarse Al_2O_3, then ground, are also used.

The bottom of the rotating roll dips into a shallow tray, which has an inlet in one corner and an adjustable-level overflow in the opposite corner. When built into a spinning machine, a yarn guide (10...20 mm) and the tip of the spin finish tray protrude beyond the face of the machine.

When built into the quench chamber, the upper part of the roll is protected against yarn waste by an openable cover (Fig. 4.190). The spin finish supply can be held in a sufficiently large machine tank. Finish is pumped from the tank to the tray by a submersible centrifugal pump via polyethylene tubing, the excess finish returning via similar tubing of larger diameter to the tank, where it is filtered. When built into the front wall of a spinning machine, all rolls can be driven by a continuous shaft, either directly or via a chain drive.

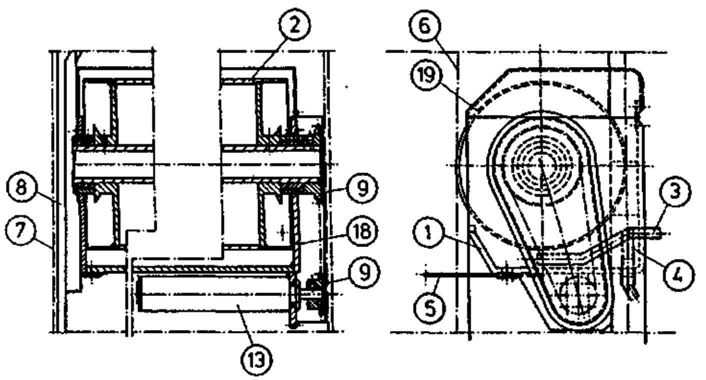


Figure 4.190
Spin finish lick roll for installation in the quench chamber [24]
1 Spin finish trough
2 Spin finish roll
3 Spin finish inlet pipe
4 Adjustable overflow
5 Yarn-retaining guide
6 Yarn warp (band)
7 Quench chamber sidewall
8 Support rods
9 Chain drive
13 Drive motor
18 Bearing housing = side wall to (1)
19 Hinged cover

The uniformity of finish application is only ±40%. One spin finish roll per spinning position, both for wetting and for finish application, sufficies when spinning long campaigns of the same product. For more frequent changes of titer, batch or product, two finish rolls in series are recommended, the first (upper) roll for wetting and the second (lower) roll for finish application. To change the ratio of moisture to finish then requires only changing one or the other of the roll speeds, and not the spin finish concentration.

4.8.2 Rod (Bar) Application

The rod applicator (Fig. 4.191) is, in principle, a corundum plasma-coated stainless steel tube of the same length as a lick roll width, having a row of closely spaced bores for the spin finish outlet above the point where the filament sheet contacts the rod. Any finish not removed by the yarn is collected in a slot at the bottom of the rod and led away. The spin finish supply system is the same as for roll application [24].

For use with radial quench, the tube can be bent semi-circular or U-shaped.

4.8.3 Spray Application

In spray application, the finish is sprayed onto a running tow from above by atomizing jets. It is seldom used alone, but is often used above a finish roll when the latter cannot transfer sufficient finish, as, e.g., before staple tow take up in cans. Normally a centrifugal pump delivers the finish to the spray jets.

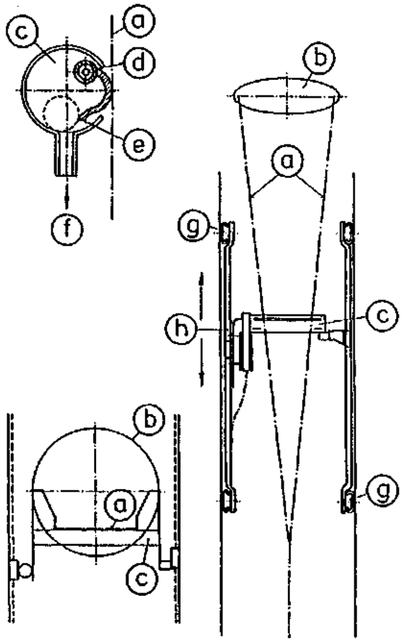


Figure 4.191
Spin finish applicator rod
a) Yarn path
b) Spinneret
c) Spin finish applicator rod
d) Spin finish applicator delivery pipe having slits or drilled holes
e) Spin finish overflow collector
f) Overflow pipe
g) Slide rails (for height adjustment)
h) Carrier rods
Comment: The spin finish applicator tube (*c* to *e*) can also be curved, e.g., round

4.8.4 Dipping Bath Application

Dipping baths can either have 2 or 3 silicone rubber coated calender rolls running in a heated finish trough or 1 to 5 dipping rolls running in a finish pan, both followed by nips to squeeze out excessive finish (see Section 4.13.5).

4.8.5 Pin Application (Metered Spin Finish)

Each threadline is dosed the required quantity of spin finish and water by an individual spin finish applicator (pin), this quantity being supplied by a single chamber of a toothed gear pump. Spin finish losses (spray-off) can be compensated by a slightly increased pump speed to give the finish level required for the given yarn. The spin finish applicators are placed either in the quench cabinet (after the yarn has cooled to below the glass transition temperature) or at the top of the take up machine. The dosage rate can be fairly accurately calculated, and needs only minor subsequent corrections.

A sample calculation, using metered spin finish, is given for a 6-fold PET POY yarn of 83.3...167 dtex final titer (125...250 dtex spin titer), spin at 3500 m/min and dressed with 1% finish oil on yarn using a 20% aqueous emulsion:

$$\text{Spun titer} \times \text{m/min} \times \text{\% oil on yarn/concentration} = \text{g/min emulsion pick up}$$

$$\text{Spin finish pump size, cm}^3/\text{r} = \text{g/min emulsion pick up at } 8\ldots65 \text{ r/min} \qquad (4.33)$$

This gives $2.19\ldots4.38$ g/min $\approx 27.4\ldots54.8$ r/min for a 0.08 cm^3/r pump. A 6-chamber pump is required.

Figure 4.192 shows the detailed construction of a metered spin finish system. Each finish applicator (2), tiltable through the angle (3) to optimize its contact with the running yarn, is supplied by an individual finish inlet pipe (1). The finish emerges in the applicator shortly before the yarn/applicator contact point (4). In the event of a yarn break, the surplus finish runs down the pipe (6) in the mounting block (5) into an overflow collector (7). Because of the low throughput (ca. 50 mm^3/s in the example

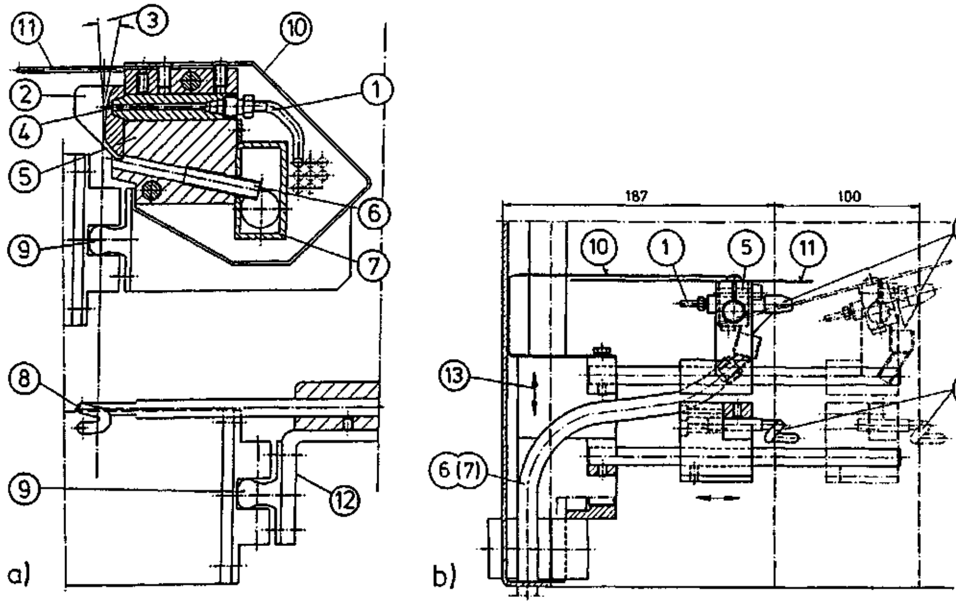


Figure 4.192 Metered spin finish application [24]
a) Closed execution, *b*) Open execution [33]
1 Dosed spin finish
2 Ceramic applicator ("oiler")
3 Adjustable angle of inclination
4 Oiler rentention pin
5 Retention block
6 Spin finish overflow
7 Spin finish overflow collector
8 Adjustable yarn guide
9 Locking latch for carrier assembly
10 Protective covering
11 Yarn guide cover plate
12 Carrier rod
13 Vertical carrier rod

above) and the corresponding danger of oxidation, re-use of the overflow finish is not possible. Waste finish from all applicators is collected in a common waste tank. A yarn guide (8) is positioned about 100...200 mm below the finish applicator. The yarn guide both pulls the yarn into the applicator from above and facilitates the threadline path from oiler to winder. There is no agreement on whether the finish applicator should point into—or away from—the quench air flow stream. Pointing it away from the quench has the advantage that the threadline can be seen; about 85% of spinning positions have this configuration.

As the spin finish cover is an important factor in yarn quality and uniform runnability, the flow rate to each applicator is often monitored and displayed on a scanner. The applicator carriage (5) has a quick-latching device (9) to enable it to be swung aside or moved out of position when throwing down at the start of spinning.

Metered spin finish has a uniformity of around ± 7%. The distance between the oiler and the spinneret must be adjustable, as a short free length of yarn above the convergence point is favorable for good Uster values, as well as conferring low yarn tension. In PET POY spinning, a convergence distance of 400 mm suffices for 0.5 dtex final dpf, 600...800 mm for 1.5...2.5 dpf, 1200...1300 mm for 5 dpf and 1700 mm for 10 dpf.

Figure 4.193 shows a double-sided applicator [24], used for microfilaments of high count and for thick multifilament bundles. Threading up through the applicators is facilitated by a matt hardchromed wire guide.

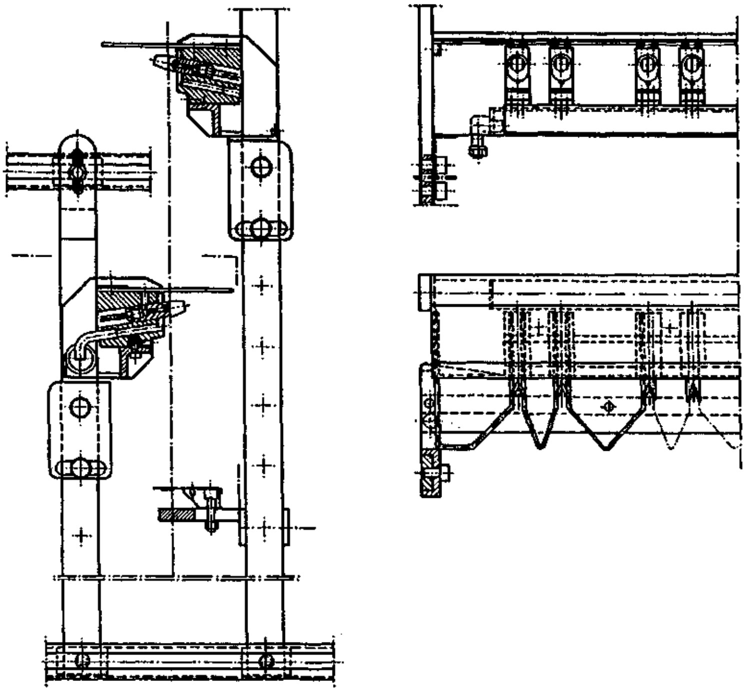


Figure 4.193 Double-sided metered spin finish application in the quench chamber. This is used particularly for large yarn bundles and for microfilament yarns, and is adjustable in height. It is fitted with yarn guides and thread-up guides [24]

Similar applicators with individual inlets can also be fitted at the yarn inlet to take up machines (see Section 4.9).

Figure 4.194 shows a spin finish pump assembly, together with drive. The 2 to 12 chamber pump is bolted onto the housing and joined, via a flexible coupling, to a reluctance geared motor bolted on from the other side of the housing; the system runs at 10...80 r/min and has a maximum power of ca. 60 W. A static frequency inverter powers all the finish pumps in a spinning machine. The earlier, often used

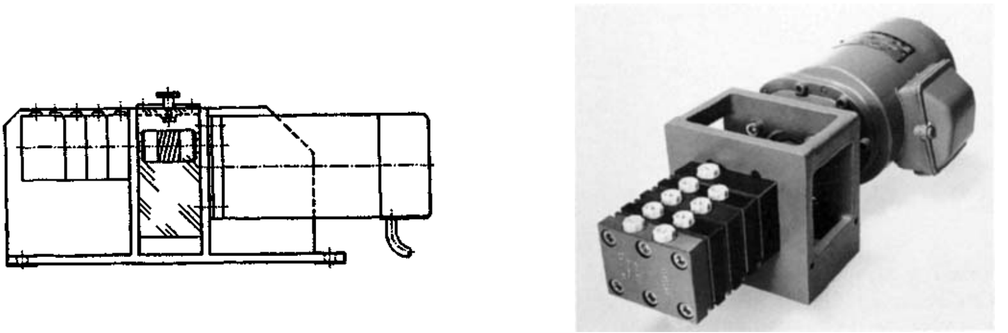


Figure 4.194 Spin finish pump assembly for many yarn ends, fitted with gear tooth pumps as per Figure 4.114 and a small, geared reluctance motor of 40...60 W to give 8...60 rev/min [24, 87, 106, 107]

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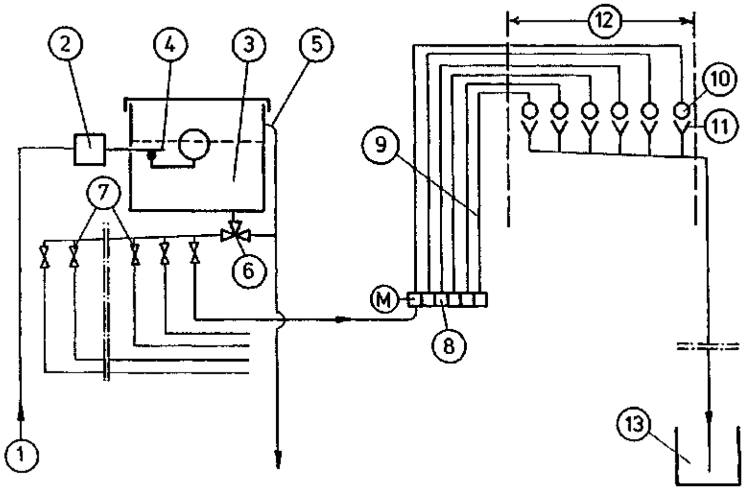


Figure 4.195 Metered spin finish application system, from spin finish mixing tank (*1*) through machine spin finish tank (*3*) to spin finish applicators (*10*, *11*) [24]

1 from vessel (*8*, *11*) Figure 6.30
2 Filter ≤5 μm
4 Float valve (in 6.31)
5 Overflow = return flow to (*5*) in Figure 6.30
6 Three-way valve for drainage, and for
7 Inlet to individual spin finish pumps
8 Spin finish pumps (Figure 4.194), one per spinning position
9 PE tubing
12 Spin finish applicator block (e.g., Figure 4.192)
11 Spin finish return (after a yarn break; not re-usable)
13 Spin finish waste collector drum

system of having the driven gear, attached to the pump, driven by a pivoted drive gear (similar to that used in wet spinning), stresses the pump driveshafts too much and leads to early leakage at the pump shaft.

Finish is provided for the individual pumps from a machine-based spin finish tank (Fig. 4.195). Finish, supplied from the central spin finish storage tank, is filtered by a 5 μm filter before entering the machine tank, where its inlet is controlled by a float valve and a level sensor, which switches the supply pump at finish make-up on and off. In addition, an overflow pipe on the side returns excess finish to the central supply tank. On the underside of the machine tank, a two-way ball valve permits either drainage of the finish or supply to a header pipe, from which individual outlets, each having a shut-off valve, lead to the spin finish pumps via individual PE tubes. PE tubing is also used to connect individual finish pump chambers to individual spin finish applicators.

4.9 Spinning Take-Up Machines

Spinning take-up machines incorporate all the necessary devices to take up, to handle and to wind the yarn emerging from the interfloor tubes. All take-up machines—except those for godetless POY—should nowadays be equipped with yarn guides, yarn cutters and aspirators, cold and/or heated godets or duos, yarn presence sensors and winders. Heated godets or duos and high speed winders for above 5000 m/min are encapsulated. Also encapsulated are intermingling (tangling) jets, air jet texturing devices for BCF yarns, etc. Figure 4.196 [33] shows photographs (to same scale) of the extrusion floor of a double-deck godetless POY spinning machine (above) and the take-up section (below). The upper deck contains the spinning beam, the pump drive, the quench cabinets and the spin finish application (behind the glass doors). Similar details can be seen in Figs. 4.60 [33], 4.62 [22] and other previous figures.

4.9.1 The Various Types of Take-Up Machines

Table 4.31 presents take-up machines suited to various intermediate or end products and having differences in construction and/or components to this end. These are presented in Figs. 4.197A–N. Figure (A) shows the principle of the earliest of these take-up machines, where the axes of the spun packages were parallel to the machine face and to the axis of the spinning machine. As the spun package size was limited by the machine pitch, construction of such machines ended around 1962, and was replaced by the construction shown in Fig. (B) [167], where the total package weight is limited only by the weight the package spindle can carry, and the diameter by the machine pitch. This principle is still in use today, and is being further developed.

Figure 4.197B2 shows an intermediate solution, where the threadlines from the spin packs are turned through 90 ° by godets to enable 2. . .8 packages per side to be wound up as per (B). This system was also abandoned after a few years, as the turning of the yarn sheet between the row of spin finish applicators in the quench chamber and the traverse guide arm above the winder results in a small deviation angle and therefore less ability to change the yarn tension.

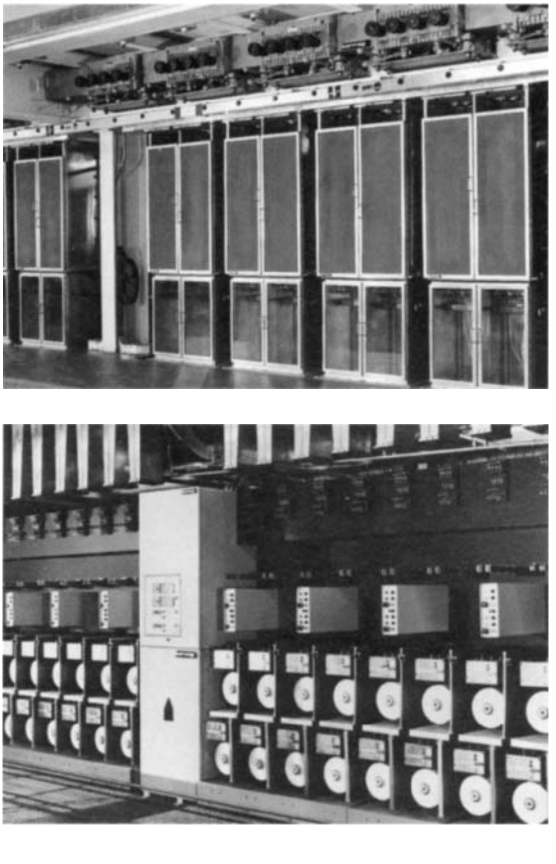


Figure 4.196
POY melt spinning plant [33], with (from top to bottom) spinning beam plus spinning pump drives, quench chambers and spin finish application, intermediate floor, interfloor tubes, yarn sensor assembly and double deck high speed winder bank

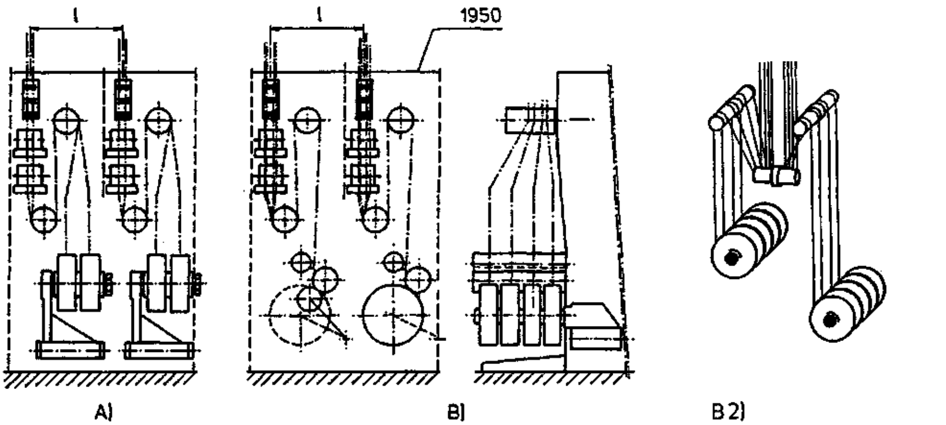


Figure 4.197 Spinning take-up machines: front views; yarn paths

A) Early generation machines having long friction drive rolls and package chucks parallel to machine front; built until ca. 1963; $v \leq 1500$ m/min.

B) As per *A*), but with individually-driven friction winders; since 1963 for $v \leq 2000$ m/min; from 1972: $v \leq 5000$ m/min; from 1980: up to 6000 m/min; from 1992: up to 8000 m/min.

B2) As per *B*), but with the yarn plane turned through 90° by means of mutually-perpendicular godets; ca. 1972 to 1984.

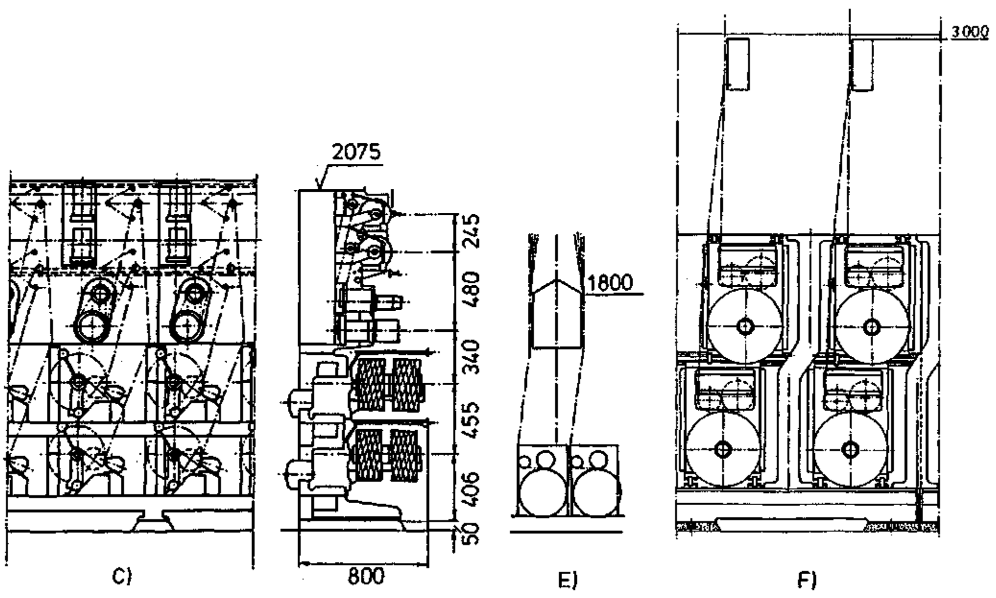


Figure 4.197 (*Continued*) Spinning take-up machines: front views; yarn paths

C) As per *B*), but with tension-controlled precision winders; $v \leq 3200$ m/min; yarn tension ≥ 5 g (Leesona [73]), otherwise ≥ 40 g.

E) POY machine without godets, single deck winders [33]

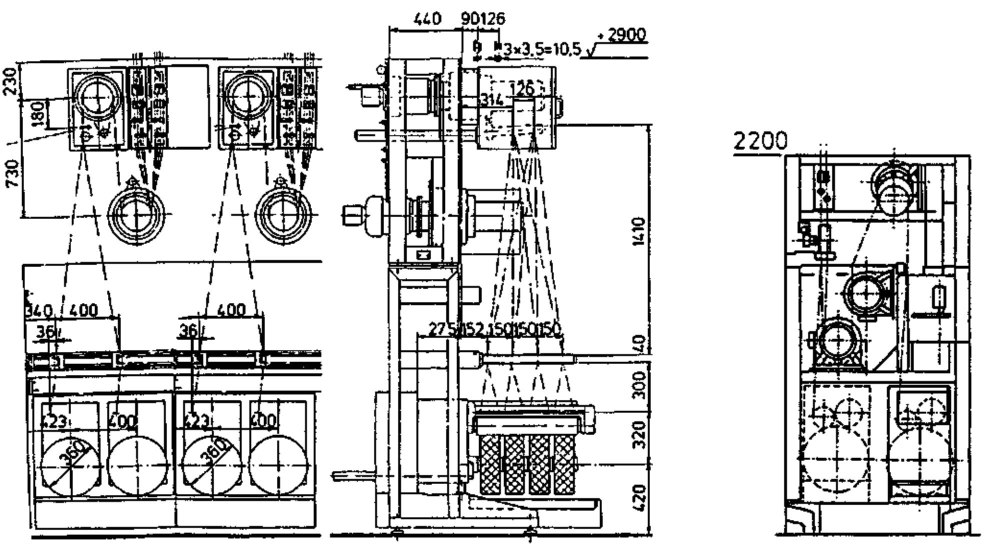
F) POY machine without godets, double deck winders [33]

(*Continued on the following page*)

Table 4.31 Take-Up Machines: Additional Information to Figs. 4.197 A–N

Fig.	Main titer range (final dtex)	Winder speed range m/min	Year of construction up to/from	Winder type	Godets/duos	Yarn ends per position	Application area
A	10...300...3000	250...1500	1962	Fr	cold	1...4	textile and technical
A2	10...30...300	250...1500	1970	Fr	cold, turned 90°	4...16	textile
B	10...30...3000	400...2500	1960	Fr	cold	1...4	textile and technical
C	100...3000	300...2500	1975	YT	cold	1...4	textile and technical
D	10...300	300...2000	1975	Fr	cold	2...4	textile POY
E	20...300	1000...4000	1970		–	4...8	textile POY
F	20...300	3000...6000	1980	Fr	–	8...16	textile POY
H	20...300	3000...6000	1981	Fr	cold for POY	4...12	textile
J	20...300...1700	2000...4000	1980	Fr	hot for ROY	4...8	textile and technical ROY
		...6000	1985	Fr	–for POY	4...16	technical ROY
M	500...2000	2000...4000	1985	Fr	1 G + 4 duo	2(4)	technical, tirecord, ROY
N	500...3000	2000...4000	1985	Fr	2 duos, etc.	2...4	BCF
H	30...300	3000...8000	1992	SD	cold	2...6	textile, FOY

Fr: Friction drive YT: yarn tension-controlled (dancer arm) SD: Spindle driven (surface speed-controlled)



H) J)

Figure 4.197 (*Continued*) Spinning take-up machines: front views; yarn paths
H) Spin draw take-up machine with two heated godets and two air-bearing separator rolls [33]
J) Spin draw take-up machine with 2 or 3 heated godets having air-bearing separator rolls and a high speed winder. By displacing the winders sidewards [33], the machine can be converted to a spin POY take-up machine without godets

(*Continued on the following page*)

Because yarn tension is crucial in good geometrical package formation (Fig. 3.50), spinning machines were built incorporating tension-controlled winders (Fig. 4.197C) [33]. It was soon established that dancer arm tension control was only satisfactory for tensions above 30...50 g, which thus limited the spun titer to above 300 dtex and ruled out these take up machines for textile titers. An exception here is the tension-controlled winder made by Leesona [180], which functions well at tensions as low as 2 × 5 g.

Once spinning speeds increased, these take up machines became obsolete, as the maximum speed of the tension-controlled winder is about 2500 m/min. On the other hand, it was fairly easy to attain speeds of above 4000 m/min using take up machines of type Fig. 4.197B. These latter machines succeeded because the two godets in Fig. 4.197B separate the higher tension below the spinneret satisfactorily from the optimum, lower yarn tension required for winding. Godets also damp the tension impulses arising from the yarn traverse motion, thereby reducing titer non-uniformity and improving the Uster values (Fig. 3.49).

Barmag [33] succeeded around 1970 in separating these two tensions sufficiently in their SW4 high speed winder range by the use of a winder-integrated grooved overfeed roll. In take up machines using these winders, the godets can be omitted (Fig. 4.197E). This can also be demonstrated from formula 3.17. To increase the throughput per spinning position, the winders were increased in size and arranged in a double deck configuration (Figs. 4.196 and 4.197F). A simultaneous increase in the length of the package spindle (chuck) enabled up to 8 packages per winder to be wound. With configuration F, up to 32 threadlines per spinning position can be spun.

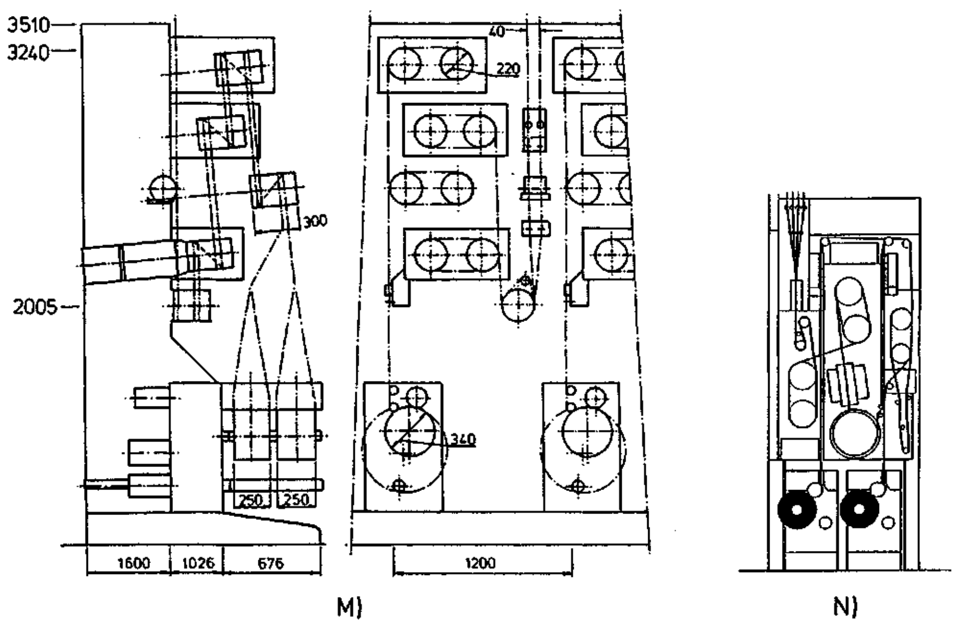


Figure 4.197 (*Continued*) Spinning take-up machines: front views; yarn paths

M) Tirecord spin draw take-up machine with 4 stage drawing for 2 × 1680 dtex × up to 4000 (6000) m/min, 2 ends/position

N) Principle of a carpet yarn spin draw texturizing machine for BCF yarns [170], 4 ends with 2 revolver winders

(*Continued on the following page*)

In order to produce fully drawn yarn in a continuous spin-draw-wind process, the two godets in Fig. 4.197B are fitted with separator rolls, enabling the yarn to be wrapped many times around the godets, and to be drawn between the lower- and upper godets. The second godet must run faster than the first one, the difference depending, inter alia, on the polymer type. The first godet must also be heated to the optimal drawing temperature. For various polymers, it is advantageous to replace single-stage drawing by two-stage drawing using 3 pairs of godets and separator rolls (Fig. 4.197J).

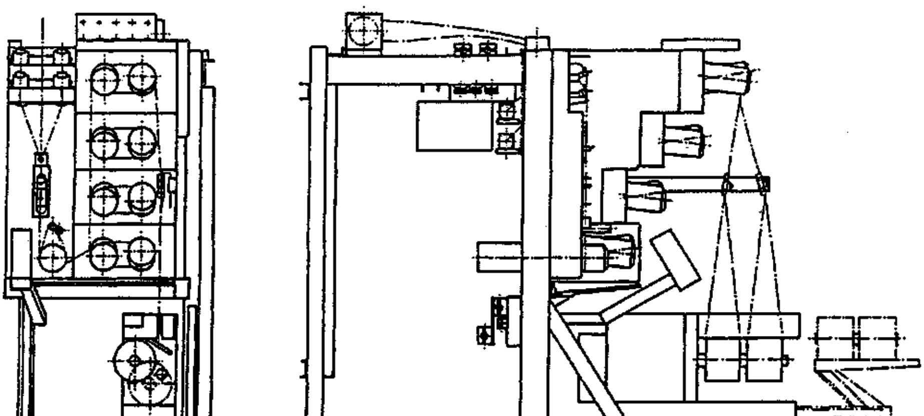
By extending the number of godets further, one arrives at the tirecord spin draw machine, shown in Fig. 4.197M; this machine has a cold first godet (+separator roll), 3 heated duos, 1 cold duo and a 2 cop high speed turret winder. Depending on yarn titer, it is possible to produce 4 ends on one winder or 4 ends on two 2-cop winders.

A special development later led to the continuous spin-draw-texturize-wind process for 2 or 4 ends per position (Fig. 4.197N). The yarns are pre-tensioned by two small rolls before being stretched between two heated duos, after which they are texturized by hot air, cooled, relaxed between 2 godets and then wound up.

Further increases in spinning- and winding speeds up to 6000...8000 m/min today, with a tendency towards 10 000 m/min, and—on the other hand—the spinning of microfilaments has resulted in increased spinning tensions and a move once again back to separating the spinning and winding tensions, i.e. a return to the configuration in Fig. 4.197B, in which the spinning and winding tensions can be separated without problems by the insertion of two godets. Even the Barmag SW4 to SW8 [33] winders need godets in this speed range.

POY and ROY take-up machines have a height of about 1800 mm, BCF machines of up to 2500 mm and tirecord machines of up to 2700 mm. In addition a working width of 1500...2000 mm behind the machine is necessary and at least 3000 mm in front of the machine; the latter increases to a minimum of 4000 mm for two opposed, mirror image machines. Using this information, the distance below the quench interfloor tubes, the quench cabinet height and the height of the granulate silo, the spinning building can be planned. For the required electrical supply and frequency inverters, see Section 7.1. Compressed air requirements are given in Section 6.5, and air conditioning is specified in Section 6.2.

A seldomly-built spinning/spin draw machine is shown in Fig. 4.197K for take-up with tension-reducing godets and in Fig. 4.197L for integrated spin draw. Here the spinning beam is at the ca. 8 m level and the godet service platform at the ca. 3 m level, below which are found the high speed winders in double deck configuration.



M2)

Figure 4.197 (*Continued*) Spinning take-up machines: front views; yarn paths
M2) Tirecord spin draw take-up machine, 2 ends, up to 4000 m/min [170]

(*Continued on the following page*)

Stable welded construction and sheet metal cladding (with noise abatement coating on the inside) suffice for LOY machines. The faster the godets and the winders must run (i.e., for POY and higher speeds), the higher the quality of the construction materials must be, i.e., gray cast iron GG40, or even GG48. The winders are mounted on rails or fixture plates to enable rapid winder change. For this reason, electrical- and pneumatic connections have plugs or sockets.

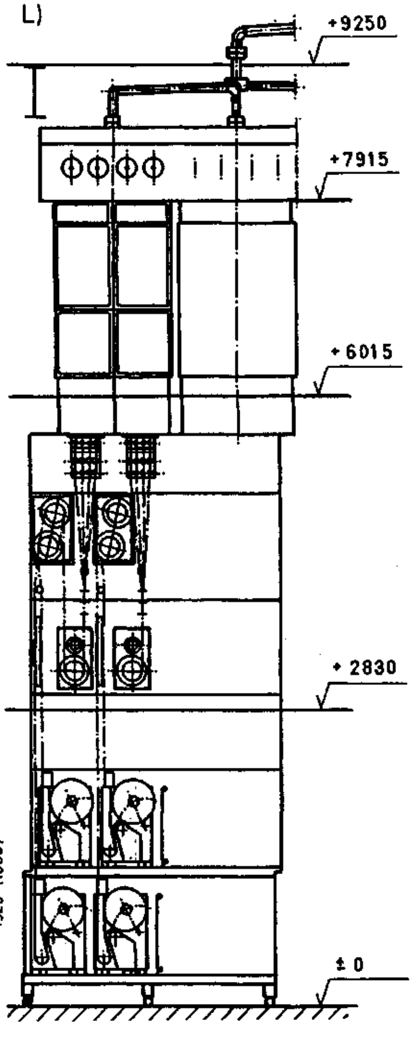
4.9.2 Yarn Inlet Zone

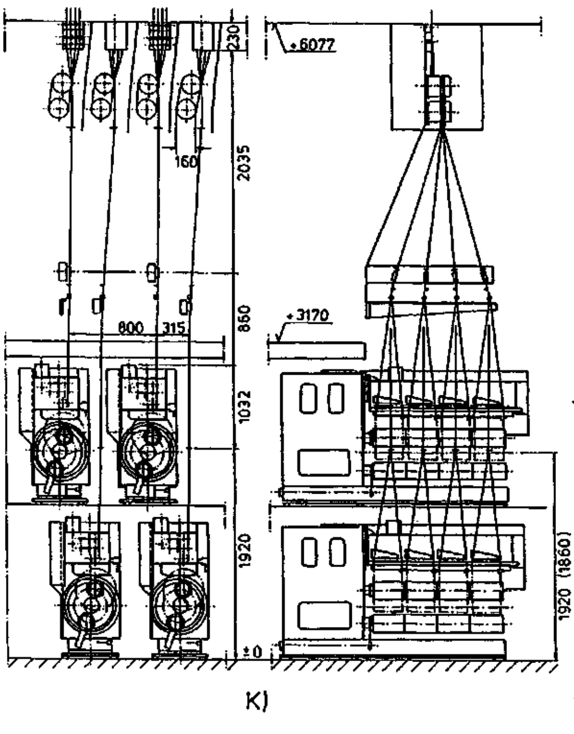
Modern take-up machines have a yarn sensing system for each threadline. At a yarn break, all winder ends are cut, aspirated and pneumatically transported to a waste container. This sensing system, in the direction of yarn travel, comprises (per threadline):

- inlet yarn guide
- yarn aspirator
- yarn cutter
- yarn oiler (if not in quench cabinet)
- yarn guide
- intermingling jet
- yarn sensor
- yarn guide

Figure 4.197 (*Continued*) Spinning take-up machines: front views; yarn paths
K) Multi-storey POY plant with godets and double deck (Toray) revolver winders [22]
L) Similar to *K*, but with a single stage draw using godets for FDY

L)





K)

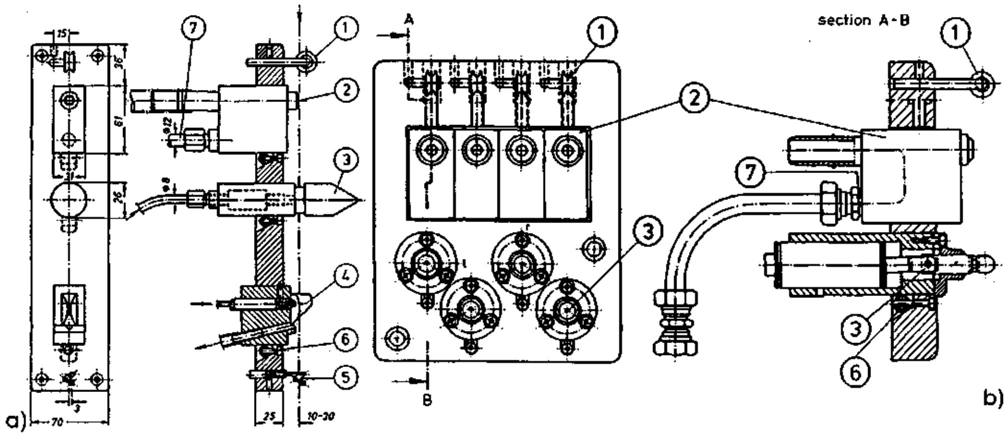


Figure 4.198 Yarn inlet and yarn presence sensing for a spinning machine
a) Single end, to be combined with other units [24]

1 Yarn guide
2 Yarn aspiration
3 Yarn cutter
4 Yarn oiler
5 Yarn guide
6 Pinch rolls for depth adjustment
7 Compressed air connection

b) 4-end version. Explanation as per a) [24]

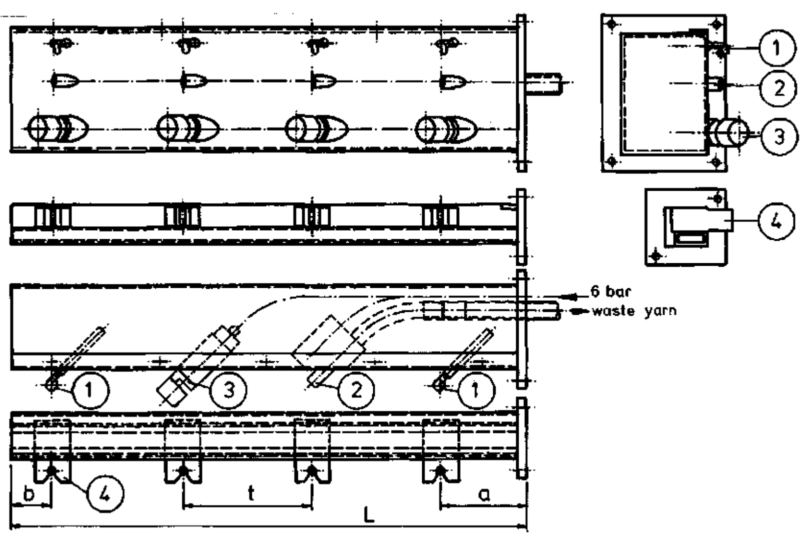


Figure 4.199 Yarn separation and sensing unit – parallel to winder axis:
$L = (n - 1) \times t + a + b$.$t$, a, b according to winder dimensions, t = yarn package pitch

1 Inlet yarn guide
2 Yarn aspirator
3 Yarn cutter
4 Yarn sensor

The yarn sensor (or an additional yarn guide located below the sensor) should be $\geq 3.5 \times$ the traverse stroke length above the center of each yarn package [24]

If the yarn sheets runs parallel to the machine face, the above elements, up to and including the guide after the oiler, are located on the machine face; the remaining elements are positioned above the winder (Fig. 4.198). The above elements should be adjustable in depth in order to match the yarn path.

In godetless POY spinning, the winder axes are at right angles to the axis of the spinning beam, and therefore so also is the sensor/cutter system (Fig. 4.199). The separation of the elements is the same as the package to package pitch. Connected to each aspirator, an aluminum pipe transports the aspirated yarn into a waste collector at the back of the machine. In all cases, the last yarn guide or element must be centered 3.5 to 4 times the traverse stroke length above the winder traverse guide.

The yarn aspirator and cutter (one per threadline) are activated by a common magnetic valve, operating at 6...7 bar compressed air pressure.

For spinning speeds of ≤ 2000 m/min, spin finish rolls having troughs are used, as per Fig. 4.190. The roll cover can be omitted, as this part of the roll lies behind the machine face. The lick rolls can be driven by a long, continuous driveshaft running the length of the machine. The lick rolls are made from sintered corundum (p. 368), have 140...180 mm diameter and are about 40...50 mm wider than the maximum yarn width at this position. The exact contact length between the yarn and the roll surface is adjusted by means of a yarn guide attached to a micrometer screw.

In Germany it is common to use 2 finish rolls, one above the other. The upper roll wets the yarn and the lower one applies spin finish. In the USA, one roll suffices for both functions.

4.9.3 Rolls, Godets, Draw Rolls

Godets are rotating rolls which transport, stretch or thermally treat yarns, tows or warps. They are classified according to size and usage:

	Diameter mm	Surface speed m/min	Comments	Section
Separator rolls	12...60	≤ 1200 ≤ 6000	ball bearing* air bearing**	4.9
Godets (draw roll, small)	75...300	≤ 8000	(almost always) driven	4.9
Draw rolls (large, for draw frame)	200...1000	≤ 400 (special cases: ≤ 1000)	driven	

* = not driven; ** or possibly turbine

4.9.3.1 Godets (Small Draw Rolls)

As godets are mostly mass produced, the purchaser should select from a range of standard dimensions and specifications. The overview in Table 4.32 should be consulted, as well as the suggestions given here:

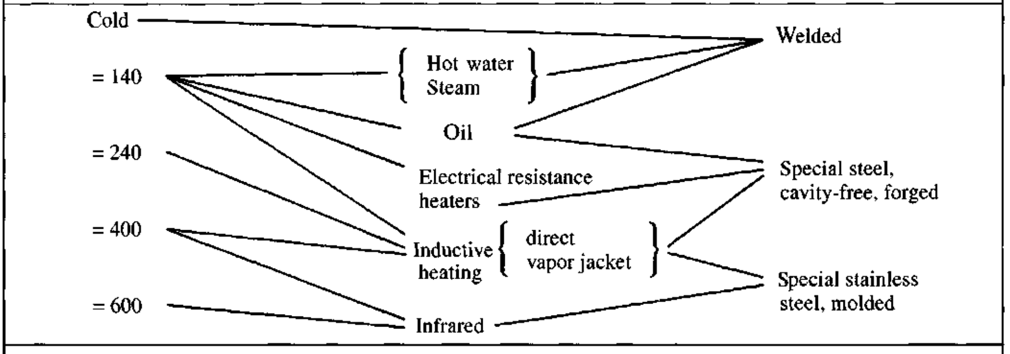
- For surface temperatures below 260...280 °C, a hard-chromed surface of 25 ± 2 μm thickness is adequeate. Tractive godets are smooth and bright, having $R_t \leq 0.5$ μm; they are possibly ground. Godets used for reducing yarn tension are matt hard-chromed to give $R_t = 1 \ldots 2$ μm. Draw rolls used to deliver yarn at low tension after drawing can have a bright inlet- and a matt outlet surface.
- For temperatures > 240 °C, plasma-coated godets are used. The coating can be, e.g., Al_2O_3 plus admixtures. The surface is either ground to $R_t \leq 0.5$ μm or is finished as "orange peel".
- Manufacturing accuracy should be better than k8. Dynamic balancing over the application speed range is absolutely necessary.
- Motor drives of > 200 Hz, corresponding to 10 000 r/min for 2-pole motors, should be avoided. For higher frequencies, the synchronous motor armature stampings must be made from special steel having low eddy current loss.
- Common speed ranges for cold godets are 400, 700...1800, 3000...4000 and 5400...6000 or to 8000 m/min.

Table 4.32 Commonly-Available Godets (Rolls, Draw Rolls)

Dimensions						
Cold or induction heated			With vapor jacket			max. drawing force
Diameter mm	Length mm	Working width mm	Diameter mm	Length mm	Working width mm	kg
80	40	20				0.5
100	40...50	20				1
120	60	30				2
150	160	90	160	160	100	3
160	160	90				6
180	180	100	190	180	120	10
190	180	100				10
220	200...250	140...170	220	250	180	15
250	250...350	190...260	220	250	180	25
300	300	(L-80)	220	250	180	40

Temperature range and type of heating

Surface temperature [°C] Heating method Construction, materials



Diameter (mm)	≤100	150	180	220	300
Circumferential speed (m/min)					
for filament	≤2000	4000	6000	8000	
for staple			1000	800	400

The possible number of godet types is very large; only a few types can therefore be described below.

- Cold godets, similar to Fig. 4.200A, where the godet is clamped directly to the motor shaft or as per Fig. 4.200B, where the godet has its own shaft. These godets have a flange or collar at the rear end to prevent yarn wraps running onto the drive shaft and a taper cone of 2...3° by 15...20 mm long in front to facilitate the removal of yarn wraps manually using a plastic knife.

  The bore taper is either 1 : 20 or MK3, with seating only at the front and back. The tightening nut must be counter-threaded and have a locking washer to prevent accidental loosening. The moment of inertia of godets of 150 mm diameter × 150 mm length is $GD^2 \approx 0.1$ kgm^2.

  The godets in Fig. 4.200 can also be driven by gears or a chain drive.
- Heated godets having a stationary, internal resistance heater (Fig. 4.200B). These consist of a stainless steel tube cast in aluminum or gray cast iron having internal heating spirals and cold,

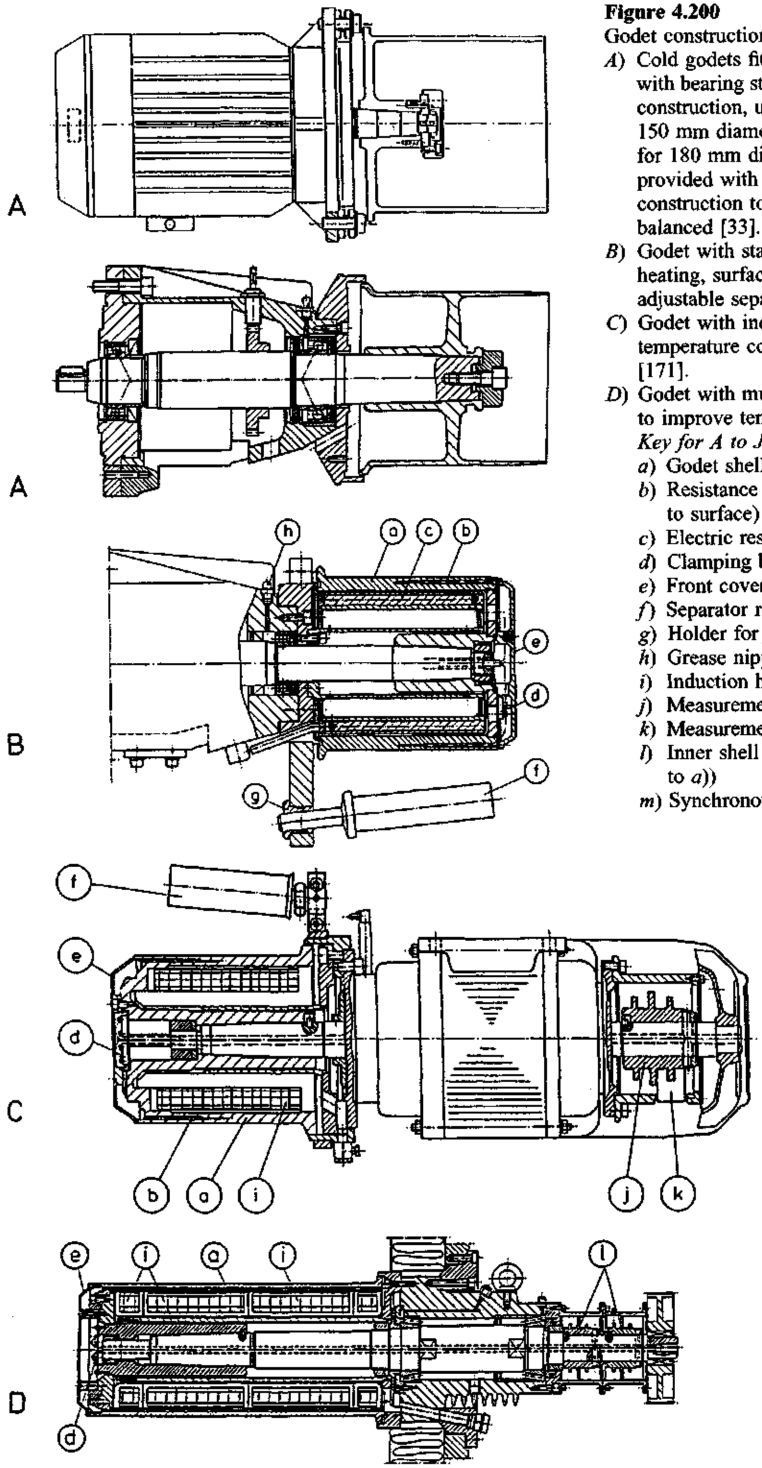


Figure 4.200
Godet constructions

A) Cold godets fitted to the motor shaft or with bearing stock. Depending on detailed construction, up to 6000 m/min for 150 mm diameter or up to 8000 m/min for 180 mm diameter. Shaft bearings provided with angular ball bearings; construction tolerance k8, dynamically balanced [33].

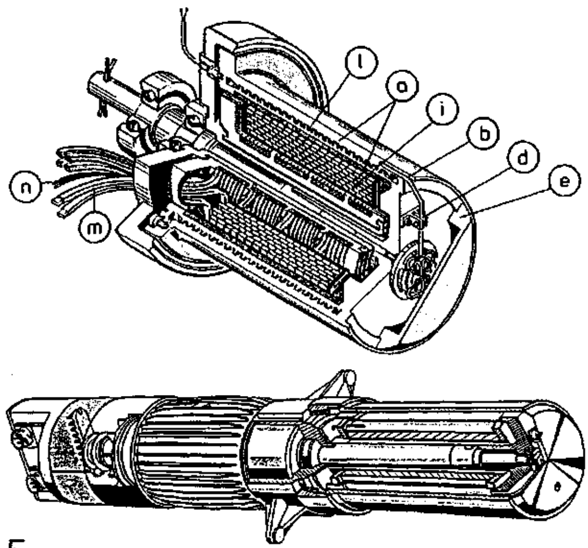
B) Godet with stationary electric resistance heating, surface temperature control and adjustable separator roll [24].

C) Godet with induction heating, surface temperature control and remote sensing [171].

D) Godet with multi-zone induction heating to improve temperature uniformity [171]

Key for A to J

- *a*) Godet shell
- *b*) Resistance thermometer Pt100 (close to surface)
- *c*) Electric resistance heater
- *d*) Clamping block
- *e*) Front cover plate
- *f*) Separator roll
- *g*) Holder for *f*), with angle adjustment
- *h*) Grease nipple (for special grease)
- *i*) Induction heater
- *j*) Measurement transmitter, rotating
- *k*) Measurement transducer, stationary
- *l*) Inner shell with vapor space (belongs to *a*))
- *m*) Synchronous motor



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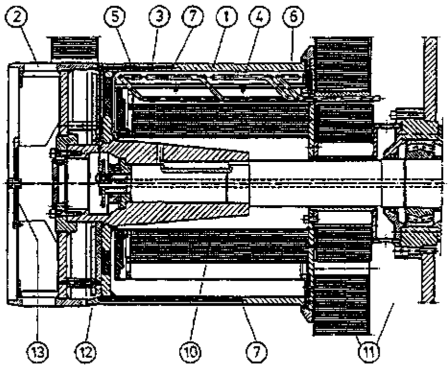

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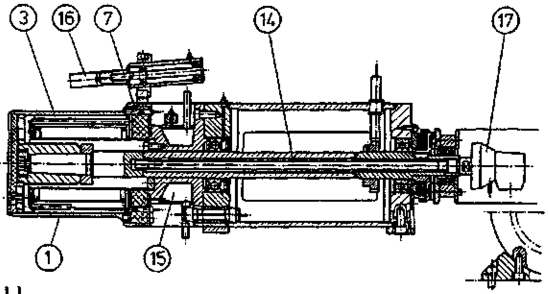

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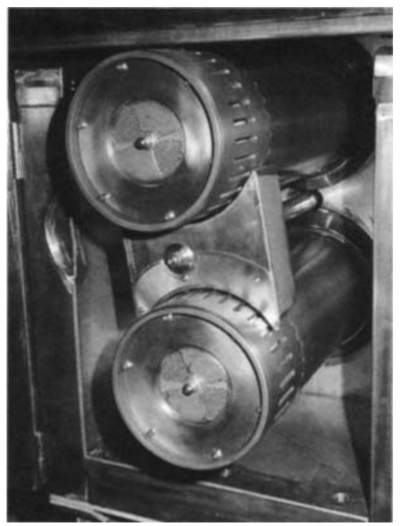


Figure 4.200

E) Godet with (water) vapor jacket and induction heater [33, 170]. Control as per C)

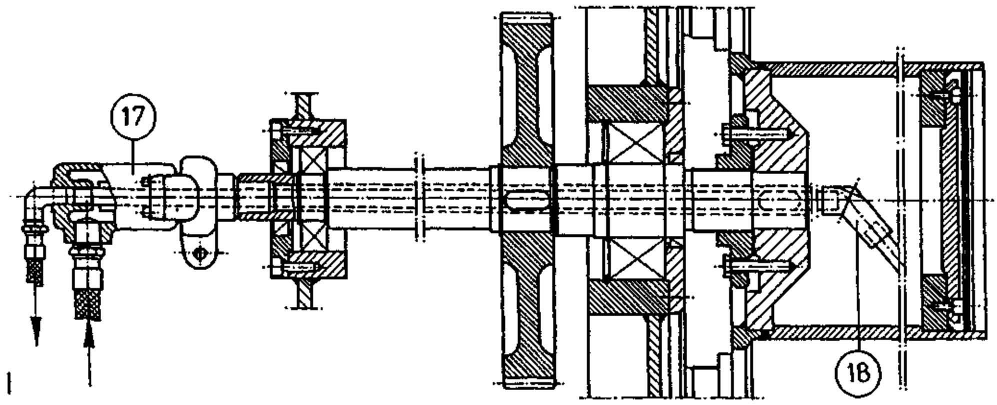
F) Infrared radiation-heated godet [24] with 3-zone temperature control system for up to 500°C surface temperature.

- *1* Godet shell
- *2* Cold nose for threading up (< 60°C to $T_G \approx 500$°C)
- *3* to *6*. Infrared (< 700°C) heating circuits (*4*)
- *7* Pt100 resistance thermometer for temperature control
- *10* Insulation
- *11* Air insulation
- *12* Nose for yarn run in
- *13* Cooling air flow rate adjustment

G) Godet duo with infrared heating as per F, but with cooling of the front part and insulation housing, for speeds up to 1000 m/min and string-up without opening the insulation housing [24].

H) Infrared radiation-heated godet with bright emitter for temperatures up to 700°C [24]

- *3* Bright radiator (in quartz tubes, up to 1000°C)
- *7* Thermocouple in collar
- *14* Shaft cooling
- *15* Bearing cooling
- *16* Separator roll
- *17* Sliding ring gland



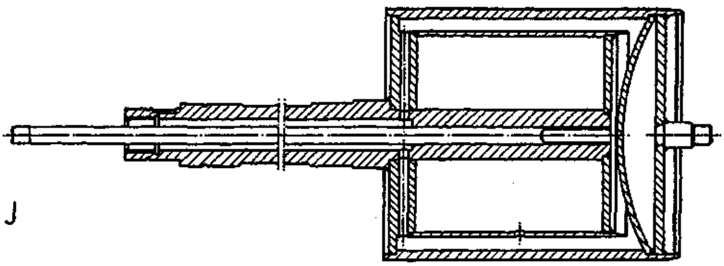


Figure 4.200
I) Vapor heated godet with condensate return (*18*) by means of a double sliding ring gland (*17*) [24]
J) Principle of a liquid-heated godet

protruding ends. The gap between the internal diameter of the godet shell and the heated surface should be as small as possible (≤ 0.5 mm for 150 mm diameter). This system is very sluggish, both in heating up and in controlling.

- Godets, similar to Fig. 4.200C, having induction heaters. The electrical current induced in the specially profiled brass rings, centrifugally spun onto the inside of the godet shell, determines the axial temperature profile (Figs. 4.201a and b); this profile is made slightly more uniform by many yarn wraps of sufficient heat capacity. The godet may alternatively be provided with a number of induction heaters, one after the other (Fig. 4.200D). Each heater induces its own maximum temperature on the godet surface, resulting in a smaller temperature deviation than when a single induction heater is used (Fig. 4.201B).

  An induction heating system is characterized by fast heating up times and low control inertia.
- Godets having a vapor heated jacket, similar to Fig. 4.200E. A high pressure steam jacket is incorporated between the rotating short-circuit ring and the outside of the godet shell. This vapor space is filled with a precise amount of water and is then evacuated and sealed gas-tight. Heat conducted from the rotating short-circuit ring vaporizes the water, which condenses on the inner surface of the godet shell, heating it uniformly. The surface temperature profile, measured between ca. 15 mm from the godet flange and 25…30 mm from the front of the godet, is better than ± 1 °C (Fig. 4.201a). The high heat of vaporization ensures a sufficient supply of heat.

  Manufacturers have developed various vapor space profiles to provide greater heat transfer surfaces, while at the same time containing the very high internal pressures (50 to ca. 200 bar overpressure is permissible) and large centrifugal forces. In the case of vapor-heated godets which (because of their construction) cannot contain excessively high pressures, safety elements, such as bursting disks, must be incorporated. These disks rupture once a critical pressure or temperature has been exceeded, as could, e.g., happen if the maximum temperature cut-out were to fail.

  Figure 4.202 shows three important jacket constructions. In (A), two concentric pipes (1, 3) and the short-circuit ring (4) form the vapor space (2). This construction is suitable for temperatures up to ca. 245 °C and vapor pressures up to ca. 50 bar. In (B), the inner surface of the jacket pipe has a

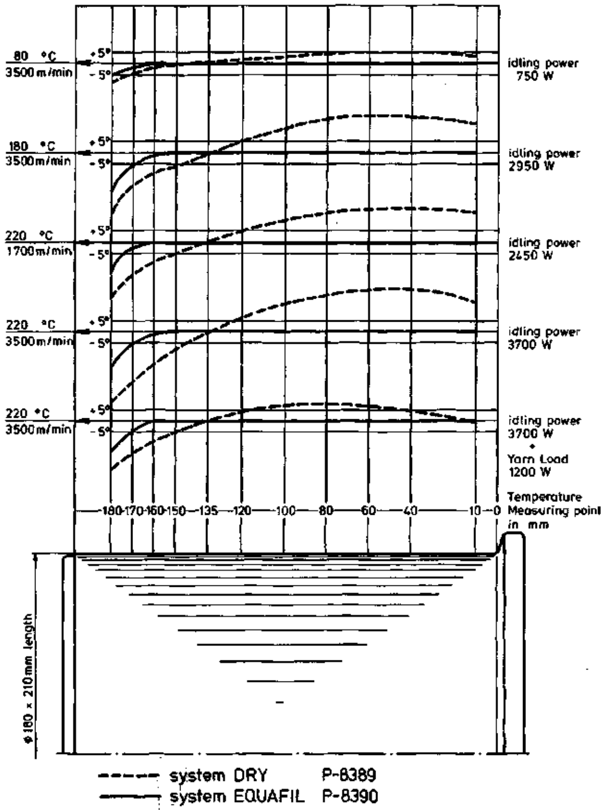


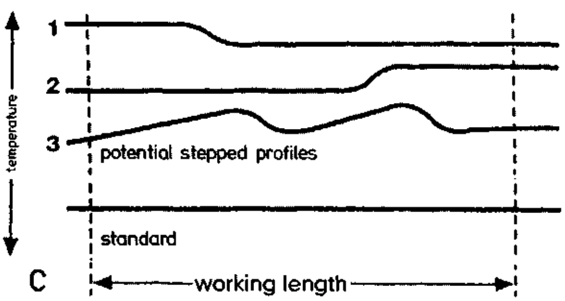
Figure 4.201
Temperature profile of an induction-heated godet (*A*) fitted with an additional vapor jacket (*B*) [172] and 1 to 4 induction heaters [24]. Godet with induction heaters

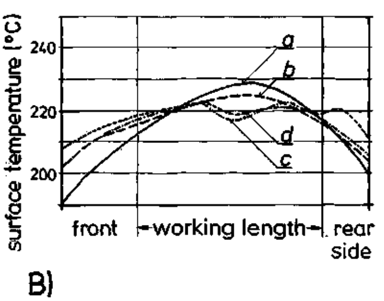
a) 1
b) 1 (corrected induction ring)
c) 2
d) 4

Max. temperature difference over working width in °C

a) 18...21
b) 10...13
c) 6...8
d) 4...6

C) Barmag [33] or Neumag [167] multi-zone induction heating system using 2500 Hz





serrated body and a short-circuit ring (4). The longitudinal slots (2) are connected at either end by rings. In this way, heat is brought closer to the outer jacket. Depending on the connection between the jacket and the inner ring, this construction is suitable for up to ca. 265 °C and 50...80 bar overpressure. Construction (C) comprises a thick-walled stainless steel jacket tube (5) containing longitudinal bores (2) parallel to the godet axis and an induction ring (4). It is suitable for temperatures up to 374 °C (maximum) at 225 bar overpressure. Figure 4.202D gives a schematic for calculating centrifugal forces and the force balance. After long usage, water vapor jacketed, induction heated godets exhibit temperature deviations caused by a mixture of air and degradation products in the vapor space. If this happens, the godet shell steel is not sufficiently corrosion-resistant to the high steam temperatures, and the porosity of the shell is too high for the high vacuum which arises when the godet is switched off and allowed to cool down. Repair can only be effected by the time-consuming evacuation and re-sealing of the vapor jacket. It was mainly for this reason that the induction heating principle in Fig. 4.201B was further developed into a multi-zone, multi-control system, either with *n* equal heating zone lengths [33] or with unequal length heating zones [154, 155]. Each heating zone is controlled by its own Pt100; there is, however, only one temperature transmitter, which transmits measurements sequentially. Heating is carried out with a higher frequency in [33]; this enables the short-circuit ring to be eliminated. The temperature constancy achievable at 150 °C is ± 1.5 °C [33]. It is also possible to set an axial temperature profile (Fig. 4.201C). This system is particularly suitable for fine titer, while the vapor induction heater still has compelling advantages for high total titer.

- Godet heating using dark infrared radiation, for surface temperatures of up to ca. 500 °C, can be achieved by the construction shown in Fig. 4.200F. Immediately below the jacket, radiation heaters are uniformly distributed across the surface, their cold ends protruding rearwards out of the godet or its thermal insulation. In the multi-zone version, the front and rear zones should have a slightly higher heating power, and should be separately controlled. In this way, an uniformity of ± 10 °C at a surface temperature of 500 °C can be achieved over the working length of the godet [24]. The photograph 4.200G shows an execution with godets of 250 mm diameter; this is a particularly small construction for this type of godet.
- For surface temperatures of between 500 and 600 °C, a construction using electric wire in quartz bright radiation is suitable (Fig. 4.200H). When in operation, the front godet bearing and the shaft in this region must be cooled by water or oil.

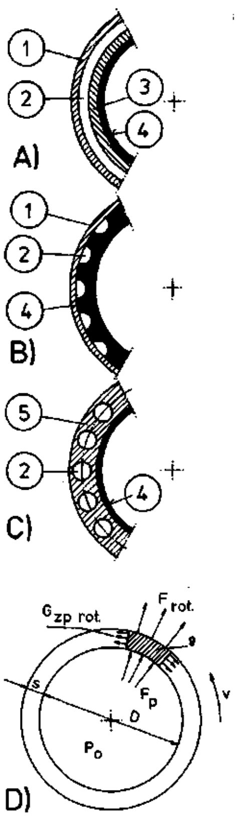


Figure 4.202
The forces in a vapor-heated double shell godet: explanations and descriptions:
A) The liquid/vapor space is formed by an outer hollow cylinder (*1*) and an inner shell (*3*), together with a short-circuit ring (*4*). Total heat is transferred through the vapor (*2*) to the surface [33]: $p_i \leq 50$ bar; $T_o \leq 245$°C.
B) The vapor/liquid space (2) is formed from semi-circular grooves, distributed uniformly along the godet circumference. The radial heat transport is predominantly by heat conduction to the surface, and is supplemented by the vapor condensation in (*2*), which improves the temperature profile [153]: $p_i \leq 50$ bar; $T_o \leq 265$°C.
C) The liquid/vapor space (2) comprises axial bores in the godet shell (5). The heat generated in (4) is conducted to the godet surface; the condensing vapor improves the surface temperature profile [154]: $p_i \leq 225$ bar; $T_o \leq 374$°C
a: Load due to pressure:

$$G = \frac{\varrho \cdot D}{2\,s} \qquad F_p = 0.5\,p_i \cdot D \cdot L \qquad (4.34)$$

b: Centrifugal force due to rotation

$$G_{rot} = \varrho \cdot v^2 \qquad F_{rot} = \rho \cdot v^2 \cdot s \cdot L \qquad (4.35)$$

At circumferential speeds of ≤ 1000 m/min, G_{Rot} is negligibly small.
D Godet inside diameter
s Wall thickness of godet shell
L Godet length
δ Density of godet construction material
v Surface circumferential speed
P_i Pressure of liquid/vapor system
F_p Radial force due to pressure
F_{Rot} Centrifugal force due to rotation
G Tensile stress induced by F_p and F_{Rot}

Figure 4.200I shows a steam heated godet with condensate return. Steam inlet and return is by means of a double sliding ring gland (17) at the rear end of the shaft. Steam flows through the outer pipe and condensate returns via the inner pipe, the front end of which is jointed (18) to facilitate complete condensate removal from the godet.

The godet construction must conform to the rules for pressure vessels (Fig. 4.4). The temperature distribution is particularly uniform.

The roller- or ball bearings should be to specification c3 or c4, depending on their working temperature. Similarly, the lubricants must be matched to the working temperature.

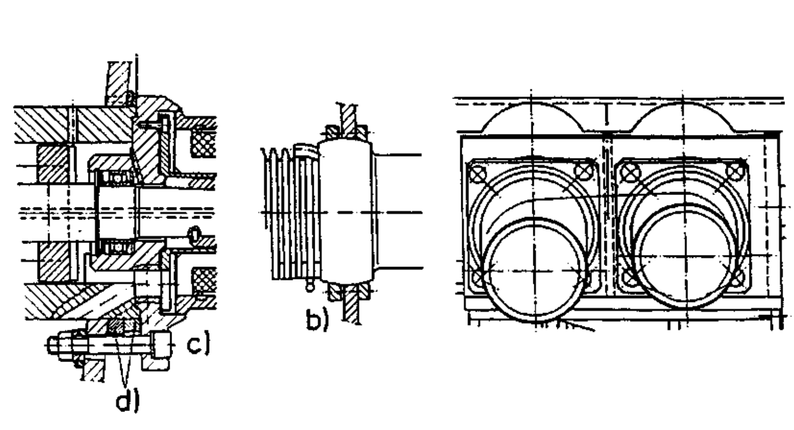
A liquid heated godet is shown in principle in Fig. 4.200J. The liquid entry and exit is the same as that of the steam-heated godet, and here too the construction must conform to the pressure vessel codes. The internal volume of the godet is reduced by means of a displacer to ensure that the heated liquid velocity close to the godet shell is high enough to achieve good heat transfer coefficients. The displacer should have at least two pressure equalization bores. It is unimportant that the displacer will then be filled by heating fluid during the heating up phase. The temperature decreases slightly in the axial direction, depending on flow rate and heat extraction, but is still considered to be uniform at high liquid flow velocities.

4.9.3.2 Duos (Godet Pairs)

To obtain multiple yarn wraps on two godets (Fig. 3.56a), it is necessary to tilt their axes, i.e., to have a small angle between the 2 godets (Section 7.6). The second (fed) godet has its axis perpendicular to the machine face, while the first (feeding) godet has its axis inclined to the second. The angle between the axes should be $\leq 3°$; on no account should $5°$ be exceeded. The inclination of the axes can be done in the following ways [171]:

- The second godet has its flange tilted through the desired angle relative to the first godet, and is then bolted to the back wall (Fig. 4.203).

Figure 4.203
Godet duo (= double godet): one godet is fixed, the second can be angled within a cone of angle $\leq 5°$ ($\leq 7°$); in Germany, according to UVV regulations, the clearance between godets should be ≥ 120 mm [171]
b) with universal ball joint and 2 clamping flanges
c) with adjusting screws
d) with 2 slightly skew rings, which are counter-twisted and clamped in position



- The godet and its motor have a universal joint, which can be slightly twisted in the retainer plate, then fastened with two locking rings (b). In the case of heavy godets with drive motors, a flange—normal to the godet axis and located behind the universal joint—permits the positioning of the godet axis by means of 3 or 4 pressure screws. The two locking rings are tightened afterwards.
- In (c), two slightly conical disks (d) are positioned between the godet flange and the tightening plate. These can be twisted relative to one another by means of a sickle spanner manually inserted from outside. At 2.5 ° inclination of both disks, any angle between the godet axis and the clamping surface between 0 and 5 ° can be set.

4.9.3.3 Accessories for Godets

- Temperature measurement and control
  In old machines having godets, one still frequently finds the so-called "collar" method of measuring temperature. (Fig. 4.204). Here, in a slot in the rear of the godet flange (collar), a temperature sensor (1) measures the temperature of the rotating godet. This is a rather poor indicator of the actual godet surface temperature, as the distance from the sensor through the godet shell to the surface is rather large, and, secondly, the convective heat transfer from slit to temperature sensor is dependent on the speed and load of the godet. The deviation in temperature can easily exceed 10 °C.

  The preferred temperature measuring system for all heating and control circuits consists of 2 Pt100 resistance thermometers in deep bores just under the surface of the godet shell (Figs. 4.200B–D, F). Because of the sensor's location close to the godet surface the deviation from the true temperature is less than 0.5 °C.

  The sensors are connected to the temperature transmitters, which consist of stationary and rotating parts by means of wires running through the driveshafts. The temperature transmitters supply the Pt100 with current and transmit their signals, as per Fig. 4.205, to the control cabinet, which holds both measured values and set points [171]. The control accuracy of such systems is nowadays within $\pm 1\,°C$ when the sensors are correctly located. Using high frequency, time-sequenced switching, up to 8 adjacent heating circuits can be monitored by one measurement transducer [33, 171, 172].
- Insulation boxes for heated godets are required to protect the workers, as well as to maintain uniform godet temperatures. Figure 4.206 shows an insulation box for a duo. The box must be openable to the front and must have inlet and outlet slits for the yarn. In addition, a small, measured air flow must ventilate the godets of vaporized spin finish, etc.

  Figure 4.207 shows a large insulation box for the 2 godets shown in Fig. 4.200F or G. The box can be opened to the front, and has 2 observation windows and inside overhead illumination. A particular feature of this construction is that the yarn can be threaded up over the godets without opening the insulation box, and that the protruding front ends of the godets do not exceed 60 °C, even when the godet and interior temperature is at 500 °C. Because of the interlocking slit (12), the rear high temperature is not conducted to the front cold head. Conversely, the cold head does not influence the interior temperature.

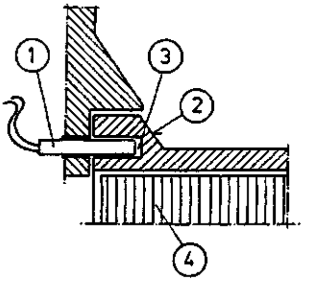


Figure 4.204
Godet flange temperature measurement [336]
1 Temperature sensor
2 Godet flange
3 Circumferential slit
4 Heater (stationary)

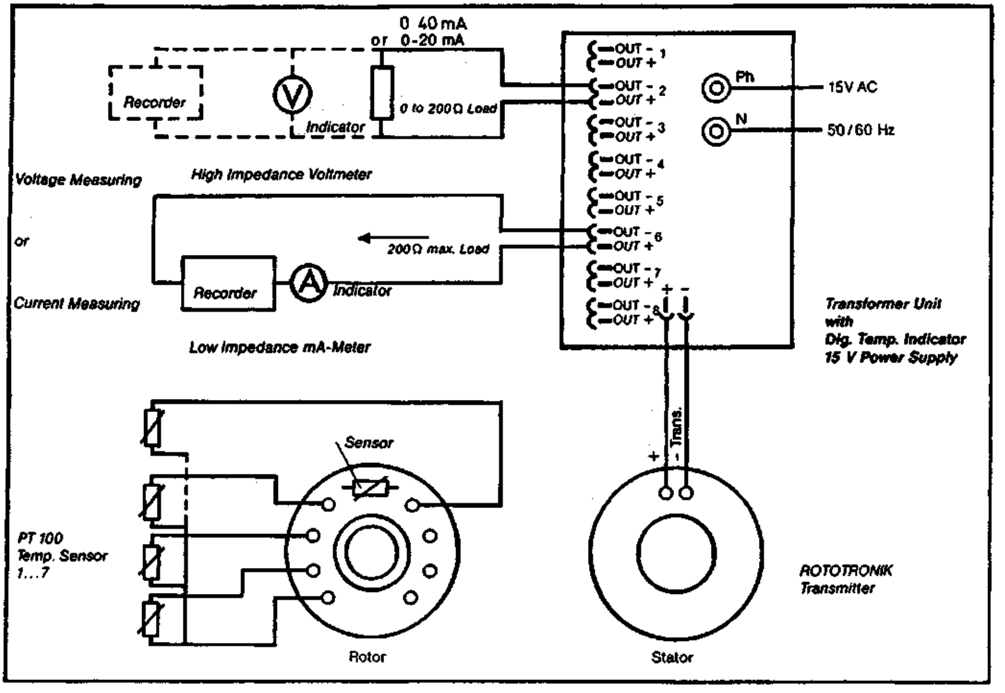


Figure 4.205 Principle of contactless godet temperature control [171,172]. Installation of the two temperature measuring elements and connection to signal transmitter (rotating) as, e.g., per Figure 4.200 *C*

4.9.3.4 Operating Data for Godets and Duos

When used in the multiple wrap mode, individual yarn wraps on the godet must not run into one another, i.e., the wrap separation must be greater than the yarn wrap width on the surface. Low titer yarns run onto the godet with a wrap width of b. Evaluations similar to that in Fig. 3.57 give:

for filament counts of	$f_r = 1 \ldots 18$	$> 18 \ldots < 500$	
the number of filaments			(4.36)
in the height	$n_H = 1$	$n_H = 0.712 + 0.01515 f_r$	
in the width (on surface)	$n_W = f_r$	$n_W = 28 + 0.2 f_r$	

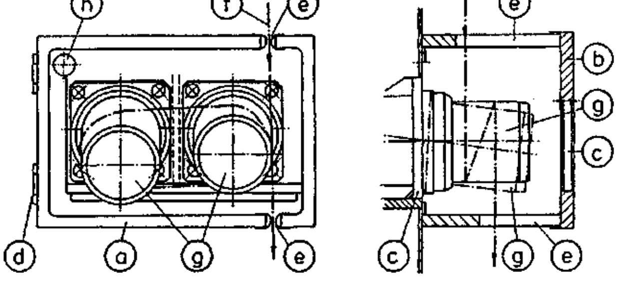


Figure 4.206
Openable heat insulation cover box for a godet duo (*g*)
a) Insulation box
b) Front door, with
c) Window, and
d) Hinges
e) Slits for yarn entry and exit (polished)
f) Running yarn
h) Aspiration aperture

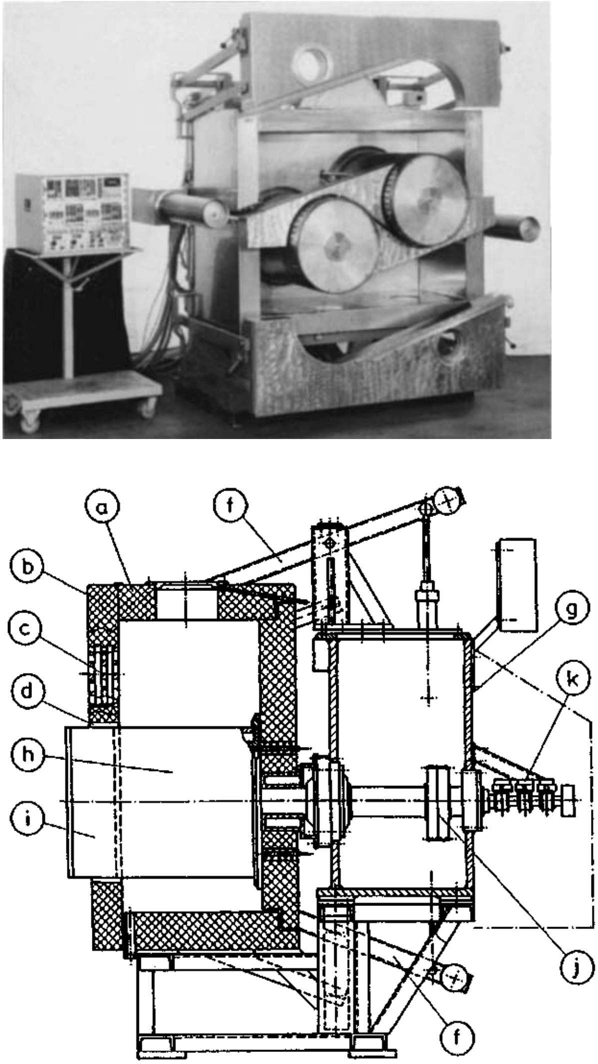


Figure 4.207
Insulation box for a multiplicity of godets as per Figure 4.200 *F* or *G*, which permits cold string up of the yarns from outside; the yarns then automatically run in their correct positions in the (unopened) heated section [24].
a) Insulation box
b) Front door, in 2 parts
c) Insulated window
d) String-up slit, in yarn warp plane
f) Door mounting (above and below)
g) Bearing housing
h) Heated godet
i) Cold head (Figure 4.200 *F*)
j) Connecting toothed gears
k) Contactless temperature measurement transmitter

The height and width in mm are obtained by multiplying the above number by the single filament diameter (for PP, PA, PET $\approx 0.011\sqrt{\text{dpf[dtex]}}$) or width (for non-circular filaments). If the number of vertical filament layers (n_H) is >2, it is better to use 0.9 × filament diameter, owing to the filament packing effect (compare Fig. 3.57). For 10 500 dtex f420, the above rules give b = 6.3 and $h_{max} = 0.031$ mm, and for 20 dtex f7, b = 0.38 mm and $h_{max} = 0.05$ mm. For safety reasons, a minimum wrap separation of 5 mm is used. For tow widths see Table 3.11.

Using 180° wraps, each godet can alter the yarn tension by, at most, $e^{\mu n \alpha}$. If, however, Z_1 is the inlet yarn tension, Z_n the yarn exit tension and n = the number of wraps, then the maximum tension (force) on each godet is given by:

$$Q = \frac{n}{2}(Z_1 + Z_n). \tag{4.37}$$

As an example, 4 ends × 167 dtex × 6 wraps, having an inlet tension of 100 g/end and an outlet tension of 330 g exerts a force of ca. 2.6 kg on each godet.

The required godet drive power is determined from the sum of the power required to overcome air resistance, bearing resistance and yarn tension, and is given by:

$$N = \frac{1}{\eta}\left(0.102 \times b \times d \times v^{1.125} + \frac{s \times v}{102}\right)[\text{kW}] \quad (4.38)$$

(see also Section 7.5; all above dimensions in m, kg, s).

Examples:

(I) 4 ends × 167 dtex are hot-drawn. The drawing force is 2 g/dtex at 5400 m/min (=90 m/s), and the godet dimensions are $b = d = 180$ mm. η, including bearing friction, is assumed to be 0.7. Thus:

$$N = \frac{1}{0.7}(0.522 + 1.179) = 2.43 \text{ kW} \quad \text{at} \quad 159.2 \text{ Hz.}$$

The 2-pole synchronous motor must therefore have ≥ 0.763 kW at 50 Hz.

(II) 2 ends × 2300 dtex are hot-drawn. The drawing force is 2 g/dtex at 2400 m/min (=40 m/s), the godet dimensions are $b = d = 190$ mm, and η is again assumed to be 0.7.

$$N = \frac{1}{0.7}(0.234 + 3.608) = 5.49 \text{ kW} \quad \text{at} \quad 201 \text{ Hz/6-pole} = 1.37 \text{ kW/50 Hz}$$

It follows from both examples that the air resistance component cannot be ignored for high speeds and low titers, whereas it only contributes less than 10% for speeds less than 3000 m/min and heavy titers.

The required heating power of a godet arises from the sum of the power required to heat the yarn and the power lost to the environmental air. The heat transfer coefficient of a rotating cylinder in air can be approximated by:

$$\alpha = d^{-0.2}[1.1(T_G - T_L)^{0.25} + 3.6u^{0.8}] \text{ kcal/m}^2\text{h.}$$

Here one can ignore the first term for $\Delta T \leq 230\,°$C, as it is only ca. 4% of the second term for rotating godets. The heat given up to the surrounding air then becomes:

$$Q_L \approx 4.2 \times 10^{-3} \times u^{0.8}(T_G - T_L)d^{0.8} \times L \times \pi \text{ [kW],} \quad (4.39)$$

Table 4.33 gives guide values for a godet temperature $T_G = 240\,°$C and an ambient temperature $T_L = 40\,°$C. The power to heat the yarn is given by:

$$Q_F \approx 7 \times 10^{-9} \times \text{dtex} \times u \times c(T_e - T_a) \text{ [kW]} \quad (4.40)$$

where c = specific heat [kcal/kg K], T_a = yarn inlet temperature and T_e = yarn exit temperature [°C]. Guide values are again given in Table 4.33.

From formula (4.39) it can be seen that the energy required by the godet decreases as the difference between the final yarn temperature and the environment temperature decreases. This stresses the need for a good insulation box around the godet (Fig. 4.206).

4.9.4 Separator Rolls

Separator rolls—normally without a drive—serve to change the direction of travel of the yarn or, when used in combination with a godet, to displace the travelling yarn to form many parallel wraps on the godet of a few mm separation, which can be increased or decreased by adjusting the angle between the separator roll and the godet axis (see Chapter 7). In operation, they have the same circumferential speed as the godets, but reach a maximum speed at ca. 1500 m/min in the case of ball bearing separator rolls, this limit being given by the maximum rotational speed of a ball bearing. Above 1200, and up to 6000 m/min, air bearing separator rolls must be used.

The surface of the separator roll is matt hardchromed, with a roughness of $R_t \approx 1$ µm. For lubrication of ball bearings, only non-adhesive special grease or a small amount of spindle oil must be used. The inclination to the godet axis is achieved by drilling a 3 to 5°-inclined bore in the shaft bush (Fig. 4.200B), which—as a hexagonal screw head—can be rotated from behind the flange holding the separator roll.

Table 4.33 Required godet heating power

Circumferential speed u m/min	Dimensions ∅ × l mm	α kcal/m^{2}hK	Power Q for 240...40 °C kW
1000	100 × 92	20	0.12 (for 85...20 °C)
4000	150 × 150	151.4	2.49
2000	190 × 190	87	2.29
4000	190 × 190	144.4	3.81
6000	190 × 190	199.8	5.27
	190 × 190		

Drawn titer dtex	Material	u m/min	T_2 °C	Q_{yarn} kW
167	PET	1000	85	0.027
4 × 167	PET	3600	200	1.29
2 × 1680	PET	3000	200	4.43
2 × 2400	PA6	2400	160	4.5
Examples		Drawing force g/dtex		$Q_{drawing}$ kW
1680	PET cord	7		0.68
167	PET textile	2		0.007

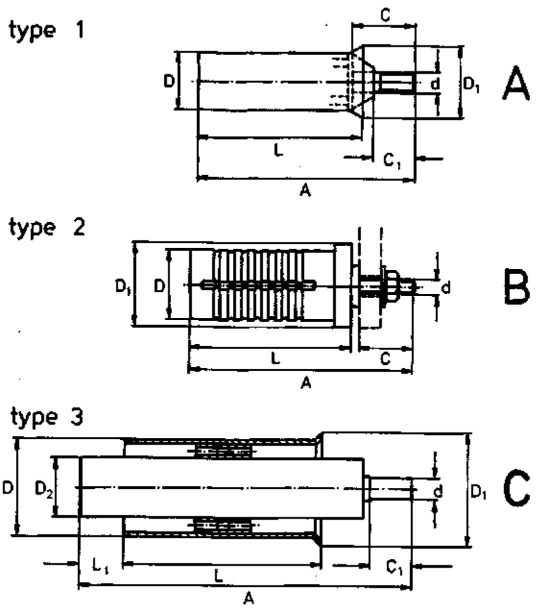
Figure 4.208 shows executions of the two separator roll types discussed above. Standard ball bearing separator rolls are either of diameter 21.2 mm × 47...77 mm long or of a diameter 26, 36 and 50 mm × 70, 110 and 200 mm long. Air bearing separator rolls are of diameter 1/2 or 1" × 0.5...3.5" long or [33] of 26.5 or 33.5 mm diameter × 135...170 mm long. To facilitate start up, air bearing separator rolls are sometimes fitted with a turbine at the rear end.

Figure 4.208D explains the internal construction of an air bearing separator roll capable of speeds up to 6000 m/min [24]. Exhaust holes for the compressed air are drilled in the bearing shaft at an angle to the rotational direction in such a way that in addition to the sleeve carrying force—a circumferential rotational component is generated. The rotational direction can be reversed by reversing the bearing shaft. To make start up easy, the sleeve of the air bearing separator roll should be as thin and light as possible. During operation compressed air is exhausted from both ends of the separator roll; the yarn must either be protected from this or be led away from this region. Air consumption is approximately given by (diameter in cm) Nm^3/h. In the case of small rolls the load can be ca. 1 kg, while the largest rolls can take loads of up to 10 kg.

4.9.5 Winders

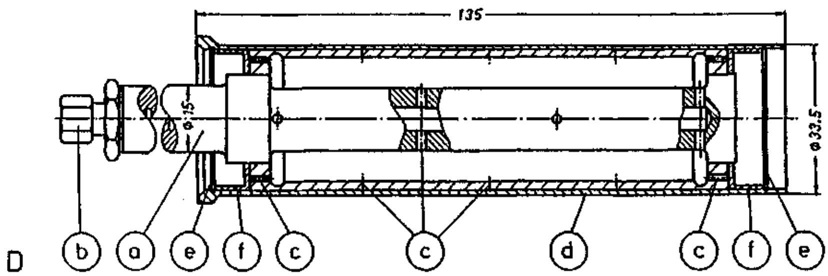
The yarn package is the most important way of collecting yarn; this also applies to storage, further processing and dispatch. The only exceptions are the cops from (draw) twist machines and—in a few special cases—balls and hanks of very coarse yarn. At the production plant, the packages must be doffed without any damage and then be transported for further processing. From this, the following requirements arise:

- good transportability and durability
- good storage properties
- good yarn take off properties
- no effect on yarn properties (see also Section 3.7)



◀ **Figure 4.208**
Separator rolls with ball bearings [176]

▼ **Figure 4.208D**
Air-bearing separator rolls for up to 60 000 r/min (6000 m/min) [24].
a) Bearing neck (journal)
b) Compressed air connection
c) Bearing housing with holes for compressed air
d) Roller tube (good running fit on the inside)
e) Wire clamping rings
f) Axial bearings



To produce such packages, the required winders must meet the conditions A to G, and—at the same time—(1) to (n) in Table 4.34. Fiber producers, in general, prefer the following combinations:

- for carbon fibers, amongst others: A1–B1–C1–D2–E2–F1–G1
- for monofils, tapes and draw frames: A1–B1–C1–D4–E2–G2
- for winding LOY, MOY: A3–B3–C2–D2 or D4–D1 or E2–F1–4–G4
- for winding technical yarns and BCF, amongst others: A3 or A2–B3–C2–D3–E1–F2–G4 or G5
- for spin take-up POY or FDY: A3 or A2–B3 or B1–C2 or C1–D4 or D3–E2–F1–8–G5 or G6.

In addition, there are conical- and biconical winders for rewinding the yarn. While such packages have good take-off properties, the winders do not, to date, run at constant winding speed. Examples are pineapple cone machines or biconical friction drive winders of types A3–B3, suitable for speeds up to ca. 1400 m/min, and used on drawtexturizing machines.

There is a tendency to increase spinning and take-up speeds to 8000 m/min [33, 178] and even up to 10 000 m/min [33]. In the case of PET, one motivation is improvement in dyeability and other yarn physical properties. Machine construction, however, is reaching its limit at these speeds. The improvements required in polymer quality have also not yet (1992) been clarified.

Table 4.34 Winder Types

Winding type A	Bobbin drive B	Control C	Chuck (Package spindle) D	Traverse E	Packages/chuck kg yarn/package F	Speed range m/min G
Precision winding (1)	Spindle drive (1)	Yarn tension-controlled (1)	2 chucks 1 chuck (1) (mobile) (2)	Stationary (1)	1...4 (30...60) (10...25)	<30 (1) <400 (600) (2)
Step-precision winding (2)	Mixed drive (2)	Speed-controlled (2)	Revolver (3) Stationary (4)	Mobile (2)	1...8 (30...60) (5...15)	<1200 (3) <3000 (4) 1000...4000 (5) 2000...6000 (6)
Random winding (3)	Friction drive (3)					3000...8000 (7)

The most widely used winder drive, the friction drive, reaches its limit between 5000 and 6000 m/min, depending on polymer, titer and spin finish. The heat generated by frictional transmission and the non-uniform axial temperature distribution due to the external rotor synchronous motor result in unacceptably high local surface temperatures which lead to bad package builds, and even to sintering of the surface yarn. For this reason, yarn tension-controlled winders (without dancer arm) or surface speed-controlled winders are used for speeds above 6000 m/min. More than 95% of winders for speeds > 6000 m/min are of these 2 types.

4.9.5.1 Package Drives

Unlike in normal winding of textile yarns, winders used for spinning require an exact and uniform package circumferential speed: it must be better than ±0.01%, as every deviation manifests itself as a titer deviation. Even at temperatures below the glass transition temperature—which is absolutely necessary—and/or directly after spindrawing, imposed changes have a negative effect on the yarn uniformity because of the relatively long storage times.

Table 4.34 gives the following drive combinations:

- In the friction drive (B3), a friction roll, usually of 150...180 mm diameter, is driven at constant circumferential speed. Here one can either use a self-starting, external rotor synchronous motor (Fig. 4.209, [175]) or an external motor flanged to the friction roll shaft, in both cases for a maximum speed of 5000...6000 m/min.

  At both ends, the friction drive roll has start-up rings, which have a diameter of 0.5 mm greater than the roll diameter. The function of these start-up rings is to make the empty paper tube speed ca. 0.3% faster than the friction roll circumferential speed, with a view to catching the yarn from the suction gun or from the other spindle on a turret (revolver) winder more securely, and winding it. Only after a number of wraps on the paper tube (n) does the yarn layer become sufficiently thick for the yarn to touch the drive roll body and assume its linear speed.

  The surface of the friction roll is matt hardchromed, and has a roughness of ca. 1 μm. Because of its high rotational speed, it must be dynamically balanced to the highest precision.

  The drive power required for the friction drive roll, both without and with packages running, can be calculated (see Section 7.5) as the sum of the power to overcome bearing friction, air resistance and yarn tension for a given roll speed, diameter and length.
- In spindle drive, the package spindle (chuck) is driven and its surface speed is regulated. As the package diameter increases, the spindle rotational speed and drive frequency decrease. To this end, one can measure the package diameter through the displacement of the bail roll or directly using a light beam or an ultrasonic transducer. The spindle and the above-described friction roll can both be separately driven by two static inverters. In this case the friction roll runs with constant rotational

speed (frequency), while the spindle runs with a rotational speed (frequency) which diminishes according to the increasing distance of the spindle axis from the friction roll.

In another system, the yarn inlet tension to the winder is measured and held at a constant value by changing the spindle speed. A higher yarn tension implies too high a spindle speed, which must be reduced, and conversely. Yarn tension measurements can be done as follows: either using a dancer arm with its accompanying strong changes of yarn direction, which limits the winding speed to 1000...3000 m/min [33, 170, 180] or measuring the practically straight running yarn [33, 171]. For the latter, two methods are presently known. In the first, the excursion force is measured by a small pin rotating at the yarn speed, while in the second method a very fine compressed air jet is used. Both methods can be used without problems for high winder speeds.

Table 4.34a Example of a Winder Selection Table [33] Covering Speed Ranges, Spindle Lengths, Number of Packages per Spindle and Package Dimensions

Winders for textile yarns										
V	Spindle length	Type	Traverse system	Width without package	Tube inner Ø	Package Ø	Package volume (dm^3)/Stroke (mm)			
m/min	mm			mm	mm	mm	4 ends	6 ends	8 ends	10 ends
2500–4000	920	CW4 T	camshaft	555 611	94 94	420 460	24.7/190 29.9/190	15.6/120 18.9/120	– –	– –
	1200	CW4 T	camshaft	555 611	94 94	420 440	32.5/250 35.8/250	22.1/170 24.4/170	15.6/120 17.2/120	– –
	920	CW6 T	birotor	555 611	94 94	420 460	24.7/190 29.9/190	15.6/120 18.9/120	10.9/84 13.2/84	– –
	1200	CW6 T	birotor	555 611	94 94	420 440	32.5/250 35.8/250	22.1/170 24.4/170	15.6/120 17.2/120	– –
	1500	CW6 T	birotor	611	110	420	–	30.0/220	19.9/157	16.4/120
2500–6000	920	CW6 T	birotor	555 611	94 94	420 460	24.7/190 29.9/190	15.6/120 18.9/120	10.9/84 13.2/84	– –
	1200	CW6 T	birotor	555 611	110 110	400 440	28.5/250 35.1/250	19.4/170 23.9/170	13.7/120 16.9/120	– –
2500–7000	920	CW7 T	birotor	611	110	440	26.7/190	16.9/120	11.8/84	–
	1200	CW7 T	birotor	611	110	440	35.1/250	23.9/170	16.9/120	–
2500–8000	920	CW8 T	birotor	611	125	425	24.6/190	15.3/120	10.9/84	–
	1200	CW8 T	birotor	611	125	425	31.7/250	21.6/170	15.2/120	–

Table 4.34a *(continued)*

V m/min	Spindle length mm	Type	Traverse system	Width without package mm	Tube inner ∅ mm	Package ∅ mm	Package volume (dm³)/Stroke (mm): 2 ends	3 ends	4 ends	6 ends	8 ends
Winders for industrial yarns											
2500–4000	920 (900)	CW6 I	birotor	555 611	94 94	400 440	– –	29.3/250 35.8/250	22.3/190 27.2/190	14.0/120 17.2/120	– –
	1200	CW6 I	birotor	555 611	94 94	400 440	– –	– –	29.6/250 35.8/250	19.9/170 24.4/170	14.0/120 17.2/120
2500–6000	600	CW6 I	birotor	555 611	94 94	400 440	29.3/250 35.8/250	– –	– –	– –	– –
	700	CW6 I	birotor	555 611	94 94	400 440	35.7/305 43.7/305	– –	– –	– –	– –
	920 (900)	CW6 I	birotor	555 611	94 94	400 440	– –	29.3/250 35.8/250	22.3/190 27.2/190	14.0/120 17.2/120	– –
	1200	CW6 I	birotor	555 611	110 110	380 420	– –	– –	25.4/250 31.7/250	17.3/170 21.5/170	12.2/120 15.2/120
2500–7000	600	CW7 I	birotor	611	110	420	31.7/250	–	–	–	–
	700	CW7 I	birotor	611	110	420	38.6/305	–	–	–	–
	920 (900)	CW7 I	birotor	611	110	420	–	31.7/250	24.1/190	15.2/120	–
	1200	CW7 I	birotor	611	110	420	–	–	31.7/250	21.5/170	15.2/120
2500–8000	600	CW8 I	birotor	611	110	420	31.7/250	–	–	–	–
Winders for carpet yarns											
1800–5000	600 900	CW5 C CW5 C	birotor birotor	555 555	73 73	400 400	30.0/250 –	– 30.0/250	– –	– –	– –

The rotating magnetic field motor [181] is in principle a poor squirrel cage induction motor; its torque reduces almost linearly with increasing rotational speed up to its frequency-dependent slip speed. It is only suitable for high yarn tensions and low speeds (≈50 g, ca. 2800 r/min) and is therefore only used for thick monofils, tapes, etc. This also applies to a displacement-rotor motor, where the rotor is displaced axially relative to the stator by the dancer arm acting via a steep worm gear. The torque available changes according to the rotor insertion depth.

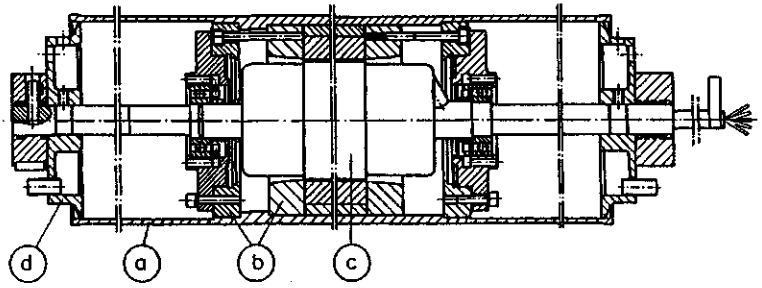


Figure 4.209
Friction drive roll for winders up to ca. 12 700 r/min [175]
a) Casing (hard chromed, matt)
b) End shield or plate
c) External rotor motor
d) Internal stator

4.9.5.2 Yarn Traverse Systems

In order to achieve good package build, the yarn is traversed backwards and forwards across the rotating package during winding. This is achieved by yarn traverse guide devices, which are either traversed sideways or rotate. The disadvantage of reciprocating traverse guides is that they rapidly change their direction at the edge of the stroke on reversal. This results in very large acceleration forces and consequent rapid wear. Rotary systems can traverse the yarn more rapidly, but can stress the yarn strongly at the reversal point.

The maximum linear speed of reciprocating traverse guides is 10...12 m/s, possibly even 13 m/s. Traverse guide reversal must occur within 0.001 s, which equates to a reversal force of 2000 × g. It is therefore important to make the traverse guide light and strong: weights of less than 150 mg are sometimes used. The expected liftetime of a traverse guide running at the speed corresponding to a winder speed of 3600 m/min is 6 weeks; this reduces to less than one week at higher speeds.

Figure 4.210 shows views of the traverse cam and its housing, including the guide rails for the traverse guide linear motion. PA6 or PA66 injection moldings are widely used for the guide shoe; the sintered Al_2O_3 slit guide is inserted into the molding. The guide has angled arms of unequal length to make it self-threading at string up.

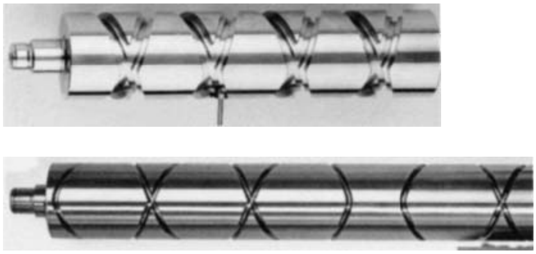
While the traverse guide shoe runs without tilting between the traverse cam groove and the trapezoidal guide plate in the housing, at reversal the guide is tilted at an angle which is twice the crossing angle. In this way, yarn helix angles of ca. 8.5° can be obtained at winding speeds of up to ca. 4000 m/min.

While previously many traverse cams were made using trapezoidal-shaped grooves (Fig. 4.210a), simple grooves (Fig. 4.210b) are preferred for today's higher winding speeds. The reversal in the cam must have a special shape to enable the traverse guide to tilt. The guide shoe must be long enough to run straight in the groove.

Various other measures are necessary to obtain a good package build: In random winding, it is important to avoid so-called mirrors or patterns, where successive windings lie parallel to one another on the package for a short time, as these mirror regions have less grip relative to the friction roll. Such mirrors can be largely avoided by "wobbling" the traverse speed, i.e., by allowing it to increase and decrease continuously by a few percent (Fig. 3.46).

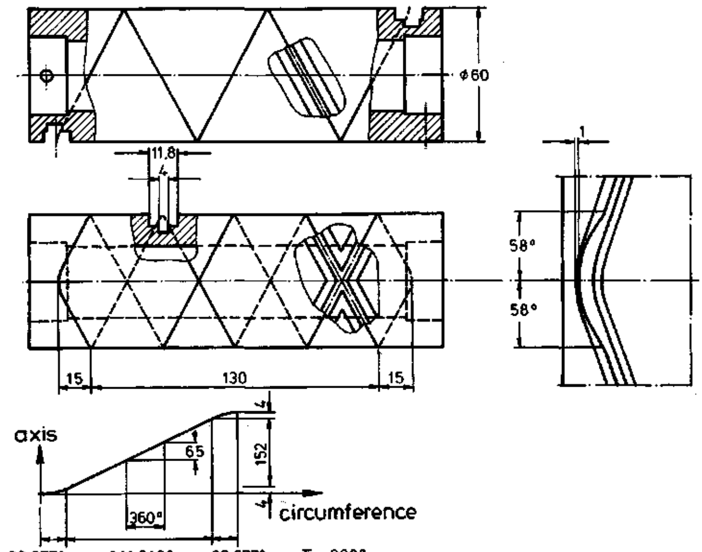
As the yarn reversal at the edge of the package produces a small radius in the yarn lay, more material is deposited here than across the width of the package between reversals. A slight axial displacement of both reversals and/or a special acceleration causing the traverse guide to tilt at reversal [169] avoids hard- and excessively high edges on the packages.

Either the traverse guide itself or an additional yarn hook per package enables a yarn waste bunch (reserve) to be formed at package string up before the yarn is traversed normally. The traverse guide can be stopped for a short time, then started again after a pre-set delay, but this is too slow for high speed winding. Alternatively, at package start up the yarn can be held to the side by a hook, then released to be automatically caught by the running traverse guide after a pre-set delay. The spiral winding after the waste bunch is used to knot the free end of a new package to the tail of a package about to run out on a transfer creel, thus avoiding re-threading at further processing.

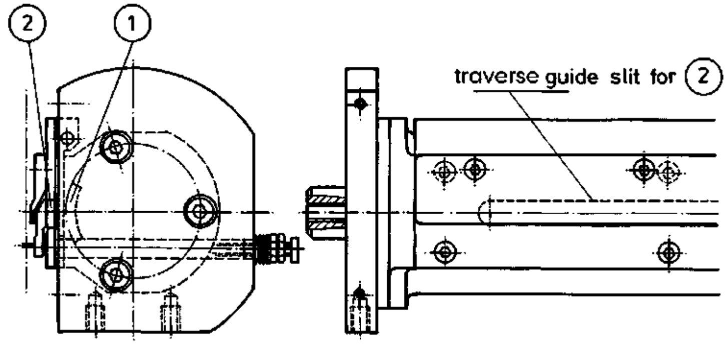


a)

Figure 4.210
Traverse cams
a) Photograph: single revolution per traverse stroke and many revolutions per traverse stroke
b) Contruction data (for many revolutions per stroke)
c) Bearing housing with (*1*) traverse guide and (*2*) slot plate to constrain traverse guide to horizontal displacement only



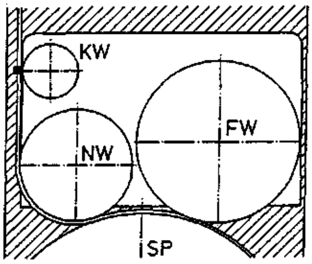
b)

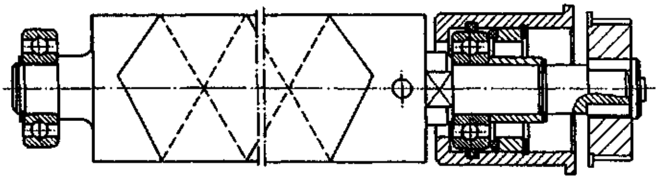


c)

To obtain a good package build, the helix angle of a flat yarn should be ≥7°. This gives the relationship between linear traverse speed v_{Ch} and yarn speed v_F: $v_{Ch} = \sin 7°$, i.e., 12 m/s linear traverse speed permits a maximum winding speed of 5908 m/min.

One possible way of making the traverse guide reversal in the traverse cam "soft", but ensuring that the yarn is traversed quickly through the reversal, is given by the double traverse using an additional grooved roll [33]; this is shown in Fig. 4.211. Here the yarn runs through the traverse guide in the traverse





a)

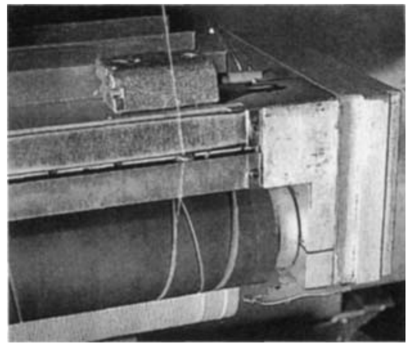


Figure 4.211
Traverse- and friction roll drive of the high speed winder series *SW* 4... [333, 334]
KW Traverse cam
FW Friction roll
NW Grooved roll
SP Yarn package (spindle bearing is stationary)
b) Grooved roll with bearing and timing belt gear
c) Photograph showing yarn running in grooved roll

b)

cam (KW) and into a groove in the grooved roll (NW), after which it passes over the friction roll (FW) and onto the package (SP). As it moves the yarn only, the reversal groove can be sharp-sided and therefore reverse the yarn more exactly than a cam and guide traverse. The grooved roll is constructed as an external rotor motor and drives the traverse cam via a toothed timing belt.

Further advantages of the grooved roll are the possibility of reducing the yarn tension to the winder by taking advantage of the 90° angle of wrap around the roll to overfeed by up to ca. 30%, and the possibility of equalizing the yarn tension between reversal and the middle of the package by cutting the groove to different depths. In this way, a post metered spin finish applicator yarn tension can be reduced from 60 g to 30 g, and even to 23 g when using the grooved roll with 6% overfeed. If the groove depth is uniform, the yarn tension varies by $\pm(3\ldots4)$ g, while if the groove is made deeper at the reversals, the tension varies by only ±1 g. By means of the "Redutens" system [169], an even stronger reduction of winder inlet tension is possible. In Fig. 4.212, the yarn coming from the spinneret runs through the first traverse guide (2), the overfeed roll (3) and finally a second traverse guide (4), placed half a cam (5) groove pitch from the first guide, and lagging it. On leaving the second guide, the yarn is taken up by the friction roll (6) and delivered to the package (7). As the yarn lies on the overfeed roll (3) without relative movement, the possible reduction in tension is greater than with the previously-described grooved roll, as static friction is involved.

Figure 4.213 shows how a double traverse guide system (Twin traverse system [182]) can reduce the acceleration of the traverse guide. There are 2 counter-running traverse guides which transfer the yarn from one to the other: the first guide (before reversing) passes the yarn to the second guide (after reversal). In this way, the guide reversal (without yarn) can be made more gentle ("soft" reversal).

With the rotary traverse system, traverse linear speeds of > 20 m/s can be attained, as the rotor runs in one direction only. This system has been known since 1965 [183, 184] and used in Japan since 1968 [168] and in Europe since 1984 [185] for winders for man-made fibers. The principle of the system is elucidated in Fig. 4.214. The yarn is pushed along the straight line or curve K by rotor B from F_1 to F_2. As soon as the furthermost point of rotor B disappears beneath the line K, the counter-rotating rotor A takes over the yarn at F_2 and pushes it back across to F_1. When the rotor arm A disappears below line K, rotor B again takes over the yarn, the above procedure continuing. For the yarn transfer from A to B to be carried out at the correct moment, the Toray system [185] needs 2 rotor wings, the Barmag system [186] 3 (Fig. 4.215). To equalize the sine wave form velocity along line K, this is made a curve. In Germany there are more than 30 patents covering this [186]. Figure 4.216 shows an example of the special layout

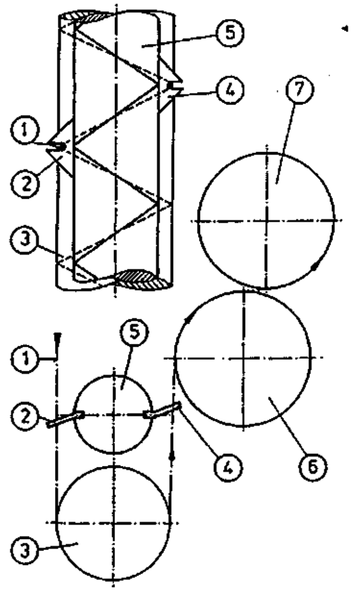


Figure 4.212
"Redutens" system with double traverse guides [169]
1 Yarn
2 and *4* Traverse guides
3 Overfeed roll
5 Traverse cam
6 Friction roll
7 Cross-wound yarn package

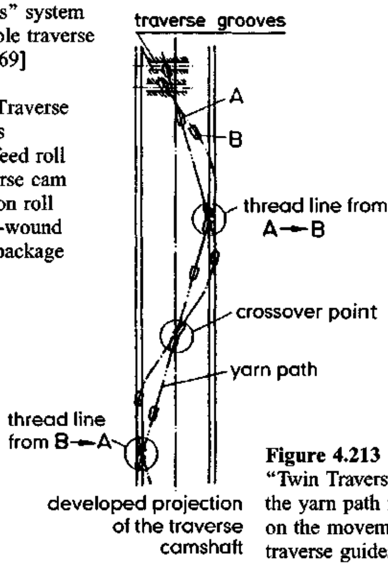
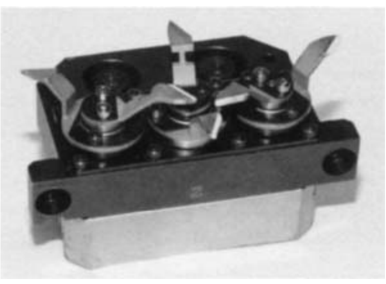


Figure 4.213
"Twin Traverse System" [182]; the yarn path is superimposed on the movement of the 2 traverse guides

of the two counter-rotating rotors, which have displaced centers, and Fig. 4.217 is a section through a winder with a tension-equalizing hoop (76), grooved roll (11) and friction roll (50) for the package (6) drive. Here, too, one can drive the roll (50) and the package (6) separately to reach higher winding speeds of up to 8000 m/min (1992).

Another traverse system using a grooved roll (Fig. 4.218) was taken over from staple tow spinning, but was later abandoned because of excessive yarn friction for speeds above 3000 m/min [57, 187, 203].

A special traverse mechanism enables the formation of a conical, cross-wound package on a cylindrical tube, or a pineapple cone on a conical tube (Fig. 4.219). The traverse guide sits in the guide shoe (a) containing the traverse guide slot (b); the inclination of the shoe is altered by slotted brackets acting on a signal from the bail roll (c). When the guide shoe (a) has a small angle, the traverse stroke is long. Conversely, a large angle results in a short stroke. The quality of the package faces



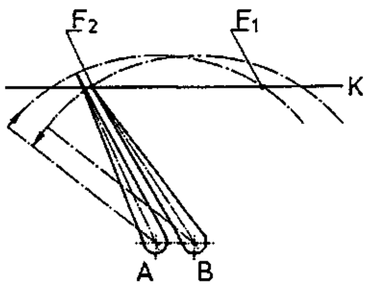
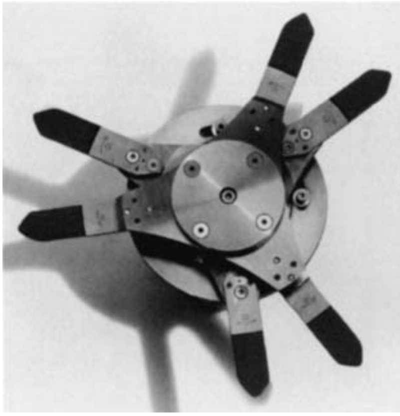


Figure 4.214 Explanation of the "Rotor" yarn laying system. The rotor arm *A* (rotating to the right) takes over the yarn from rotor arm *B* (rotating to the left) at point *F2*. Rotor arm *B* then disappears below the line of the tak-up roll *K* and then reverses.
Designs: Toray [185] $n \times 2$ wings; Barmag [33] 3 wings



◀ **Figure 4.215**
Three-winged rotor fitted to the Barmag *SW*... winders ("Birotor" [33])

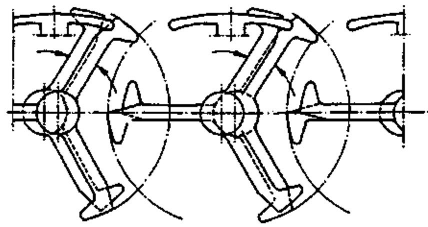


Figure 4.216
Rotor construction and yarn path restriction in the Birotor system [33]

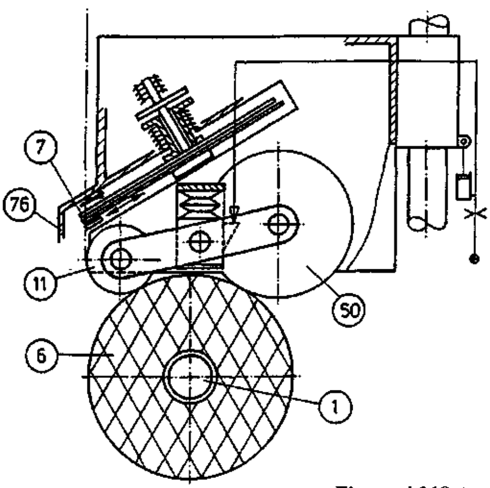


Figure 4.217
Pendulum suspension of grooved roll (*11*) and friction roll (*50*) in the yarn path of a rotary traverse having yarn restrictor plates on both sides (*76*).
The system also works with a spindle drive for the bobbin (*6*) without a friction roll (*50*) [33]

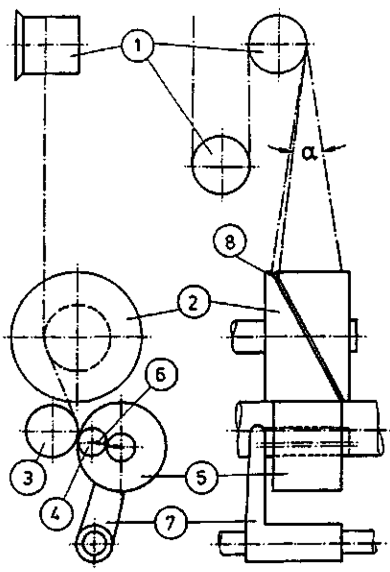


Figure 4.218 ▶
Grooved drum traverse
1 Godet
2 Grooved drum
3 Friction roll
4 Empty yarn tube
5 Full package
6 Yarn path to
7 Package holder
8 Instantaneous yarn run-in
α Traverse triangle

depends on the precision of the winder components. This winding system is, however, only suitable for winding speeds of up to 1200...1500 m/min. In addition, when using conical tubes, the winding speed is not constant. Pineapple cones have the best unwinding characteristics at further processing.

4.9.5.3 Package Spindles (Chucks) and Holders

The first requirement of the spindle is to seat the empty yarn container or tube, to clamp it against slipping when running and to receive the yarn winding. The spindle must run true, must be balanced and must protrude about ≥ 10...20 mm beyond the yarn package(s) at both ends. In its simplest form—and

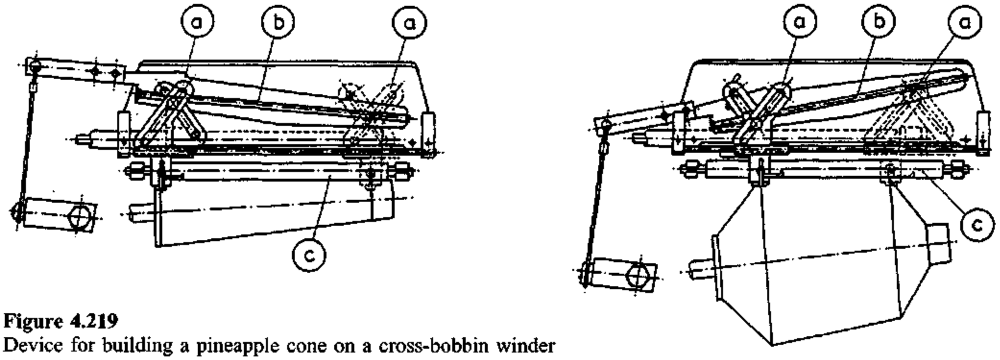


Figure 4.219
Device for building a pineapple cone on a cross-bobbin winder
a) Guide shoe *c*) Yarn guiding roll
b) Guide notch

suitable only for low speeds—a spindle has a bearing at one end or a bearing at each end and a spring system to clamp the tubes. A rubber ring, pushed into a groove on the inside of the tube and tensioned by a spring in the slightly larger diameter chuck, works for up to a few hundred m/min.

For speeds up to about 1200 m/min, the tubes can be clamped between two cones. The first cone sits on the transverse carrying arm, onto which it is fitted by light twisting, while the second cone is a part of the carrier handle, which can be folded sideways to fit the tube. Most false twist texturizing machines use this system (Fig. 4.224).

For take-up speeds up to ca. 1500 m/min and package weights up to ca. 20 kg, dynamically-balanced phenolic resin paper tubes of internal diameter 140...180 mm are mainly used. These are fitted to the chuck as shown in Fig. 4.220. In execution (a), pulling out the left hand lever separates the two cones slightly, whereby the inner cones move outwards, dropping the slotted collar ring slightly. The tubes are then slid over the chuck, the lever is released and the tubes are clamped as the cones move inwards. In execution (b), turning the knurled knob on the right clockwise or counterclockwise tensions or compresses the tension spring, thereby clamping or releasing the package. In this example, the chuck runs on longitudinal ball bearings on the hardened steel shafts [188].

For higher winding speeds, the spindles shown in Fig. 4.221 have been developed. Types (A) and (N) are capable of 6000 m/min, type (B) more than 8000 m/min. Each of the paper tubes needs its own clamping device. In (B) a self-clamping device [189] is used. On turning the spindle to the left, a free-standing ball bearing is displaced onto an inner surface, thereby clamping the paper tube from the inside. At the end of the doff, the stationary spindle is turned ca. 45° to the left to release the clamping (Fig. 4.222). Spindle working lengths of 900 mm × 94 mm tube diameter are able to carry, e.g., 100 kg of yarn (or 8 packages × 9 kg each) at up to 6000 m/min. This corresponds to a rotational speed of 20 000 r/min at start-up and 4200 r/min at full package weight. Automation makes heavy demands on the spindle.

Another spindle for 6 packages is shown in Fig. 4.221A [174]. Here the clamping levers are actuated by compressed air to clamp the paper tubes from the inside.

A further example is shown in Fig. 4.221N [167]. The tube clamps are held in position by spring-loaded spindles. On mounting empty paper tubes and twisting them to the left, the clamps engage the tubes.

These four high speed, clamping spindles are suitable for automatic take-off and doffing, and can also be driven by a motor from the rear.

4.9.5.4 Relative Movement Between Package and Roll, Including Turret Motion

The earlier, commonly-used system of having the package spindles, mounted on swing arms, parallel to the machine and driven by a continuous friction roll the length of the spinning machine, together with godets parallel to, or at right angles to the friction roll (Fig. 4.223), has long since been abandoned. In modern machines, the axes of the spindle and the friction roll are always at right angles to the machine

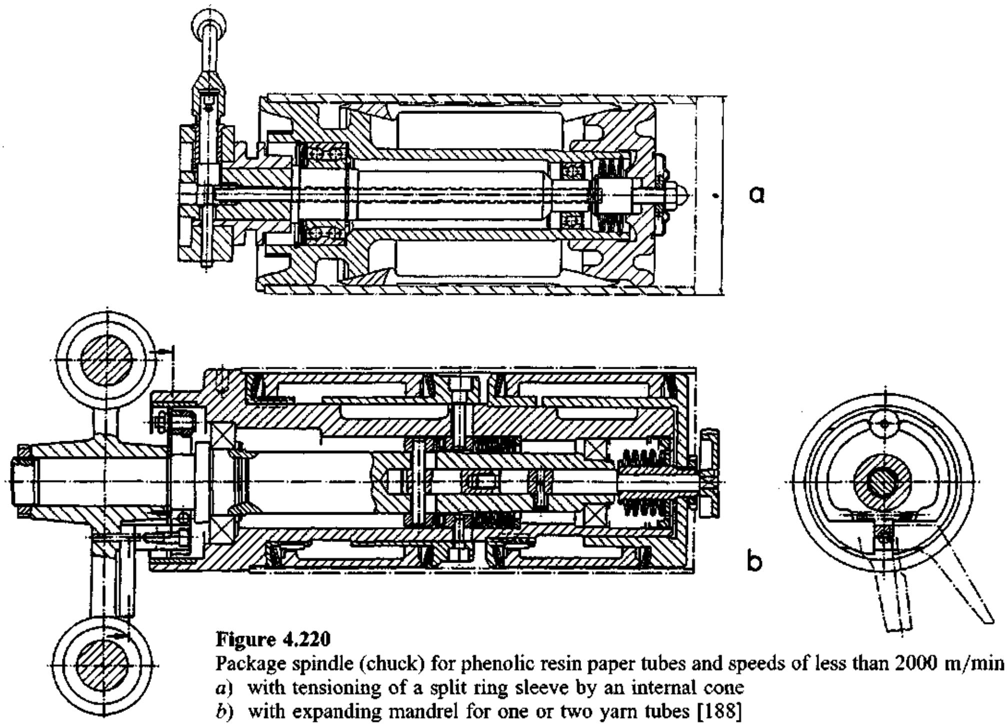


Figure 4.220
Package spindle (chuck) for phenolic resin paper tubes and speeds of less than 2000 m/min
a) with tensioning of a split ring sleeve by an internal cone
b) with expanding mandrel for one or two yarn tubes [188]

face. Winders having stationary friction rolls and pivoted spindles are currently built by only two firms [190, 197]. Such winders require a pneumatic chuck force compensation system to equalize the force component due to the package weight increasing during the running time; the compensation force also depends on the yarn- and package density. This system is also sensitive to more mirrors (wind ratios) than its fixed-spindle counterpart. In the latter, the traverse and the friction roll (if still required) are grouped in a housing, which moves vertically upwards relative to the spindle as the package diameter increases. This so-called traverse carriage (housing) has a constant weight, and so a constant package contact force can easily be maintained pneumatically. The traverse carriage moves upwards or downwards on two rods within the winder frame.

It is only in relatively slowly running winders (< 1500 m/min) that pivoted package holders are used. Figure 4.224 shows an example of a multi-tiered application in a drawtexturizing machine. Here both cylindrical cross-wound packages and (after a simple arm adjustment) biconical cross-wound packages up to 12 l volume can be made. Figure 4.225 shows a winder used in converting drawtwisters to draw-winders. Using a thick paper tube and two horizontal slides, the package holder and package are pushed away from the machine as the package grows. This method gives better package builds for flat yarns than the pivoted package holder system.

As the manual stringing up of one or more threadlines onto empty tubes requires skilled workers and also generates 1 . . . 3 min of waste (depending on the number of threadlines and titer), automatic package changing from the full package to the empty tube without process interruption is economically advantageous and a necessary component of full automation. For this to happen, the spindle carrying the empty tubes must be accelerated to at least the circumferential speed of the full packages, the latter spindle must be moved—in the yarn running direction—out of position and the spindle carrying the empty tubes must be brought into the former's position. The threadline run in tangents must become equal, the yarn must be broken or cut from the full packages without braking them and must be taken over by the empty tubes. The spindle carrying the full packages is braked and moved into the exact position required by the doffer, the packages are doffed and replaced by empty tubes. This process is

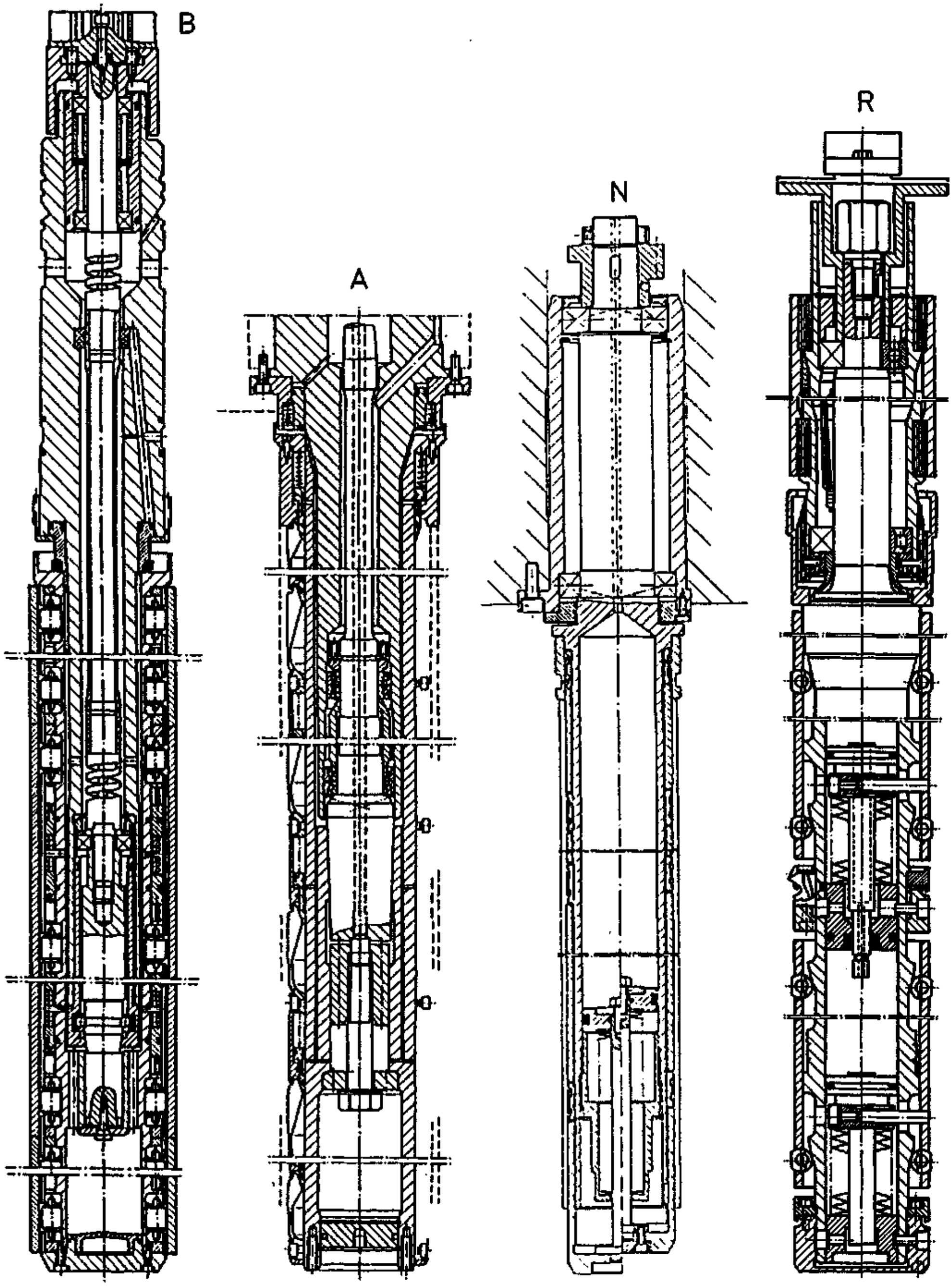


Figure 4.221 Package spindles (chucks) for high speed winders
B) Self-clamping, according to the free-running bearing principle of Barmag [33]
A) With compressed air actuation. (Here for 6 paper tubes = 6 yarn packages) [190, 179]
N) Self-clamping, with spring-loaded mandrels (Neumag [167])
R) Self-clamping, with flattened cylinders boosted by cones (Rieter [170])
A, *N* and *R* are suitable for use up to 6000 m/min, *B* can be used up to 8000 m/min

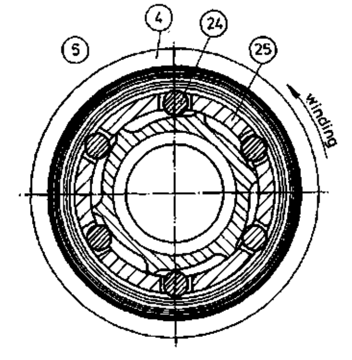


Figure 4.222
The free-running clamping principle of Figure 4.221 *B* [33]
24 Free-running rollers *4* Paper tube
25 Cage *5* Yarn package

explained in Fig. 4.226. The spindle carrying the empty tubes (10) moves anti-clockwise as the winding packages increase in size and move to (10′), when the new empty spindle reaches (10). The threadlines can either be clamped and cut on the spindle (37) or can be caught and broken off by slits in the paper tubes (38) so that they will wind onto the empty tubes. Both spindles are bolted to a turret. Each spindle is driven either by two timing belts, which are separated from one another by the turret axis, and from where they again drive the spindle, or—preferably—by individual drive motors. As the turret rotates in one direction only, the motor current direction must be continually changed by means of slip rings [182]. Patents covering this are given in [189–202].

The yarn reserve/waste bunch and the transfer of the yarn to the traverse guide must be fine-tuned.

4.9.5.5 Number of Packages and Package Size

For modern LOY, POY and ROY winders, wound paper tubes of 75–94–125 and 143 mm internal diameter are used to carry the yarn. The tube length is the same as the traverse guide pitch; the yarn stroke is 30...50 mm shorter. Today winders have typically 2...8 ends, depending on titer and desired package weight. Although winders made by different manufacturers differ slightly in stroke, a table from

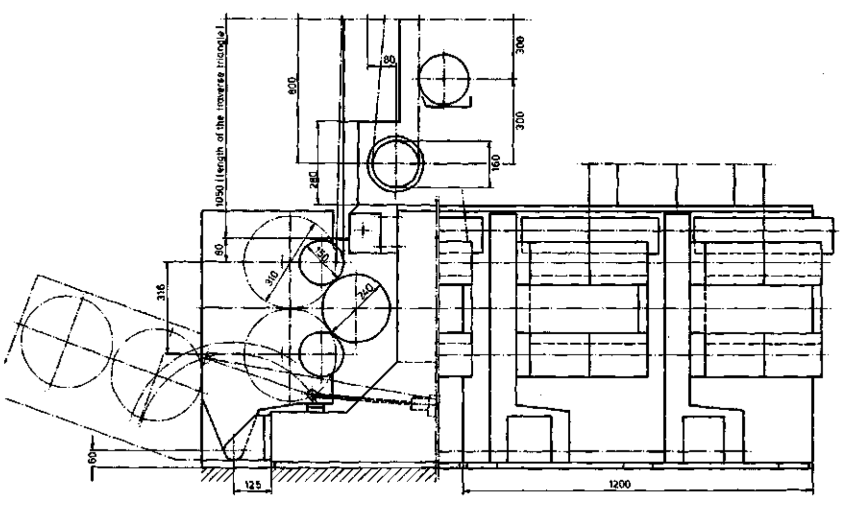


Figure 4.223 Package holding device and friction drive roll in earlier spinning take-up machines winding system shown in Figure 4.197 *A* (IWKA [166])

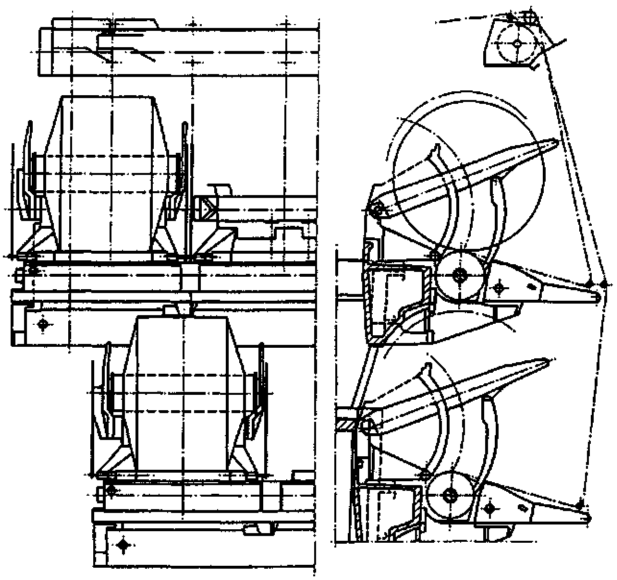


Figure 4.224
Friction-driven winding head for speeds up to 1200 m/min [33], used in draw-texturizing machines and to convert drawtwisters to draw-winders. The package weight is ca. 10 kg, and there is a choice of cylindrical or biconical package shape

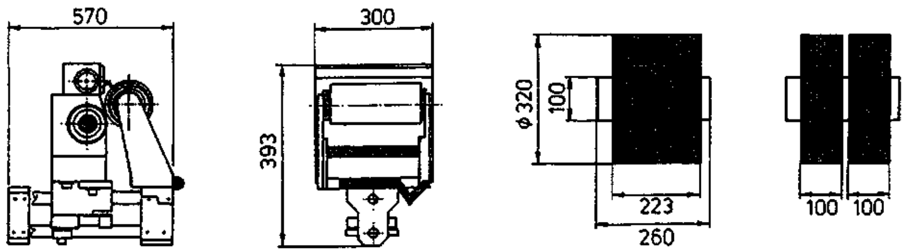


Figure 4.225 Friction winder for speeds up to 2000 m/min (Comoli [191]) having parallel displacement of the winder

Barmag [33] has been used as being typical of the relationship between traverse stroke and chuck length for various winders running at 2500...8000 m/min using different traverse systems (Table 4.34). Single end high speed winders are no longer mass-produced.

Package bulk densities are: PET ≈ 0.75 kg/dm^3, PA ≈ 0.7 and PP ≈ 0.65; soft-wound BCF has a bulk density of ≈ 0.4 kg/dm^3.

4.9.5.6 Special and Optional Equipment

In addition to the essential winder elements described above, special and/or optional features are available:

- the PCC system (precision controlled contact pressure system) [33]. Here the friction roll is bedded in a rocker and the spindle in a sliding carriage; both can be pneumatically regulated. The contact pressure can be more accurately controlled than for a fixed position spindle. This can be particularly important for sensitive yarns requiring low contact pressure.
- acceleration or start-up motor for the spindle. This is essential for a turret (revolver) winder in order to accelerate the spindle carrying the empty tubes. It is also useful on friction roll drives in preventing

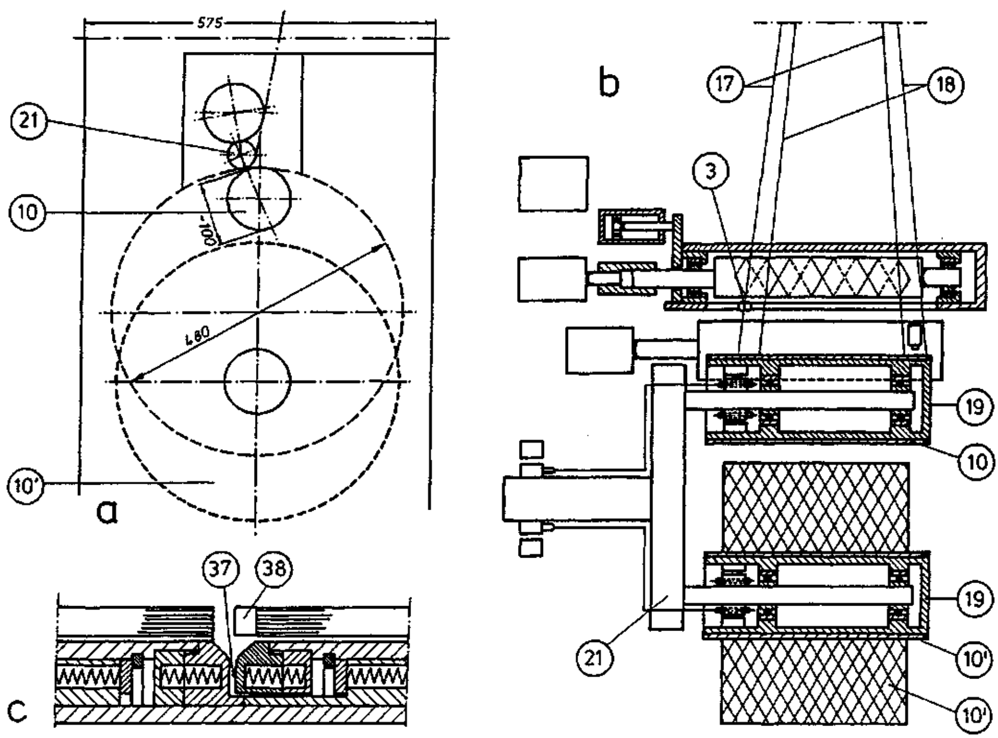


Figure 4.226 Principle of an automatic-doffing revolver (turret) winder

a) Side view (developed)
b) Front view
c) Yarn clamping
3 Yarn traverse guide
10 Empty paper tube
10' Full yarn package
17 Yarn traverse triangle during winding
18 Yarn traverse triangle at string-up
19 Package spindle (chuck)
21 Turret fitted with 2 chucks
37 Yarn catching slot in chuck, or
38 Yarn catching slit in paper tube

paper tube frictional damage during acceleration. The drive can be an asynchronous motor or a compressed air turbine. When an acceleration motor is used, the friction roll has only to compensate for the difference in speeds at the moment of contact.

- step-precision winding achieves a ribbon-free winding process: a computer-controlled traverse speed system combines the advantages of random winding and precision winding (Fig. 4.227) [33]. The procedure entails winding at a constant wind ratio (K_1, K_2, etc. in (a)), then decreasing the traverse speed practically instantaneously and winding at another wind ratio, and so on, during the package formation. At each wind ratio, the traverse speed is constant. In this way, no mirror windings occur, and the transport stability of the wound package is improved.

  An alternative to the above is ribbon-free random winding (b), which is also computer controlled. Here the traverse speed is changed shortly before entering a mirror pattern (which does not then occur), then changed back again to its previous value after the mirror region. Each traverse requires its own inverter, as well as its own controller [33].
- Automatic parallelization between the yarn packages on the spindle and the friction roll. Very long spindles carrying a large package weight bend slightly; this deviation from the parallel to the friction roll must be taken into account, preferably pneumatically. This system ensures that the contact pressure between the roll and the 4...8 packages is made more uniform [182].

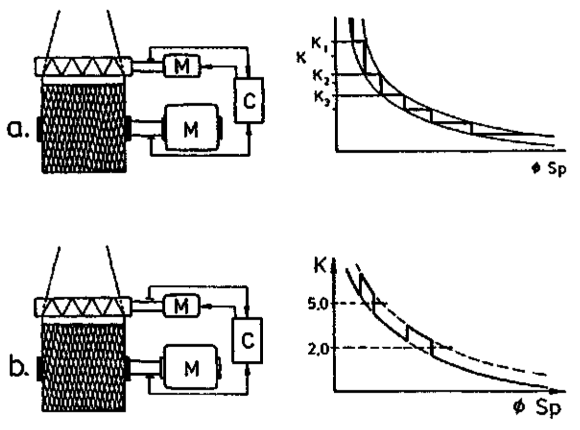


Figure 4.227
Improved traverse speed disturbance system [33] (Compare Figs. 3.45 and 3.46), = mirror disturbance, for large package diameters, -weights, -speeds and fine titer yarns.
a) Step-precision winding
b) Ribbon-free random winding (RFR)
–) Core bicone winding (CBC). Used to avoid crossed threads and package bulging in turret winders. At the start of package formation, a longer stroke is used; this is then progressively made smaller as the package builds (only possible with single inverters) [33]

- The facility for changing the winder, in order to avoid long down times and loss of production. The winder can be, e.g., mounted on a ground plate or a vertical wall, and be equipped with quick-change connectors for electricity, services and control. The winder is removed using a trolley or a lift.

4.9.5.7 Winders for Spinning and Further Processing

A winder essentially comprises a housing containing the prescribed elements. An example of a winder is shown in Fig. 4.228 [33]. The winder housing (a) carries the traverse- and friction roll housing (b) on vertical slide rods, the latter—with pneumatic assistance—being forced upwards as the package diameter increases. The four (in this case) yarn packages are wound on the spindle (c). At package start, the string up swing arm (d) swings across the spindle, causing the yarn to be caught in the paper tube slit and to build the waste bunch, after which the yarn moves into the traverse (h), which—here—consists of 4 traverse guides (h) in a 4 revolutions/stroke cam (i) and a grooved roll. (f) is the electrical terminal box and (g) is for compressed air and lubrication; both are located at the rear and connected by plugs.

Figure 4.229 shows a similar high speed winder [148] for winding two packages, but with automatic package changing (revolver), recognizable by the two empty paper tubes on the second spindle on the common turret.

Figure 4.230 shows another type of winder, where the friction- and traverse housing slides horizontally outwards on roller bearings as the package increases in size.

Reference [186] lists the most important technical details of high speed winders on the market in 1991. A summarized version is to be found in Table 4.35, and front views of these winders, to the same scale, are given in Fig. 4.231. Here the difference in size and height between manual- and turret winders is evident. Spindle driven winders for up to 8000 m/min require higher drive power than friction roll winders designed for less than 6000 m/min. Winders can be grouped according to their operating speed:

- for LLOY, i.e., mainly for wet spinning, carbon fibers and others, either winders similar to that shown in Fig. 4.224 or dancer arm, tension-controlled winders are used (Section 4.9, 5.8), as they are for
- LOY yarns, for which winders similar to those in Figs. 4.225 and 4.230 [191] are used, as well as simplified MOY winders as in Fig. 4.231A or B.

  The most important applications are in conventional melt spinning (ca. 500...1700 m/min) and in dry spinning of elastane (Spandex) yarns [191]. In all cases, two godets are used in an S-configuration. The same is true for
- MOY winders, with or without turrets, which are used mainly for carpet (BCF) yarns (which require soft winding), technical yarns, etc.
- Winders for POY yarns, i.e., for speeds between ca. 3000 and 6000 m/min. The winders shown in Fig. 4.231C, D and I have either an overfeed roll or a grooved roll, and can therefore be used without godets; all other winders require 2 godets in an S-wrap configuration.

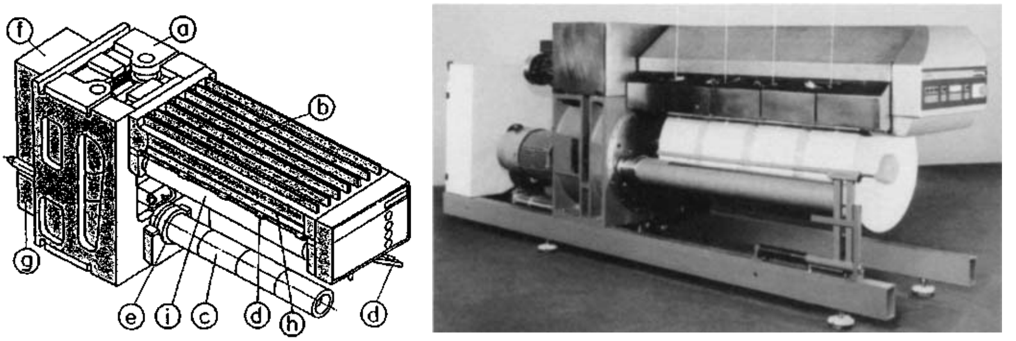


Figure 4.228 High speed winders: Barmag SW... series [33]

- SW4 (since ca. 1970) for 1 to 4 yarn packages and 1000 to 4000 m/min
- SW4.6 (since ca. 1975) for 2 to 8 yarn packages and 2000 to 6000 m/min
  - *a*) Housing with saddle
  - *b*) Housing containing friction roll, grooved roll and traverse cam
  - *c*) Package spindle with paper tubes
  - *d*) Yarn bunch mechanism
  - *e*) Package press-off mechanism
  - *f*) Pneumatic control
  - *g*) Electrical control
  - *h*) Traverse guide slot
  - *i*) grooved roll
- SW8 ("Craft winder") (since 1992) for 3 to 8 yarn packages and 3000 to 8000 m/min with
  - Birotor traverse
  - fully-automatic package and tube doffing
  - integration into a process automatisation system possible
  - single drives for chuck, bail roll, traverse and turret (running in the same direction)

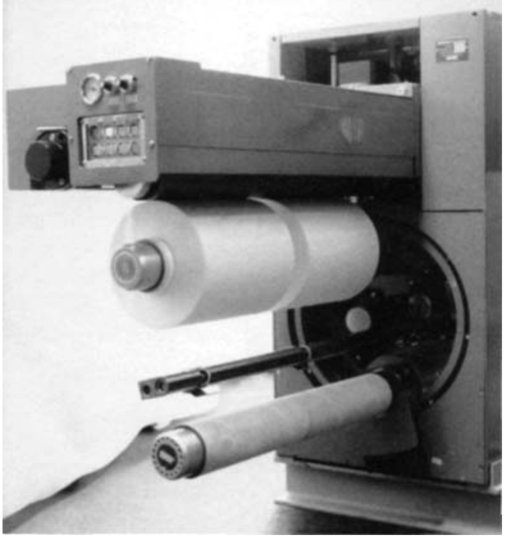


Figure 4.229
Revolver (turret) winder RK4000 with friction drive, for winding speeds up to 4000 m/min [167]

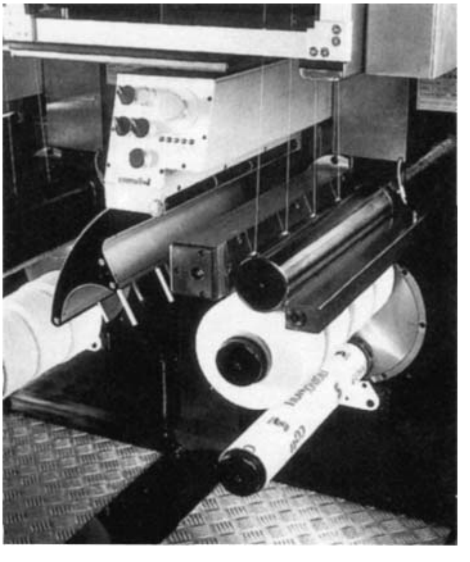


Figure 4.230
Revolver winder for speeds up to 2000 m/min [191], particularly for elastic yarns

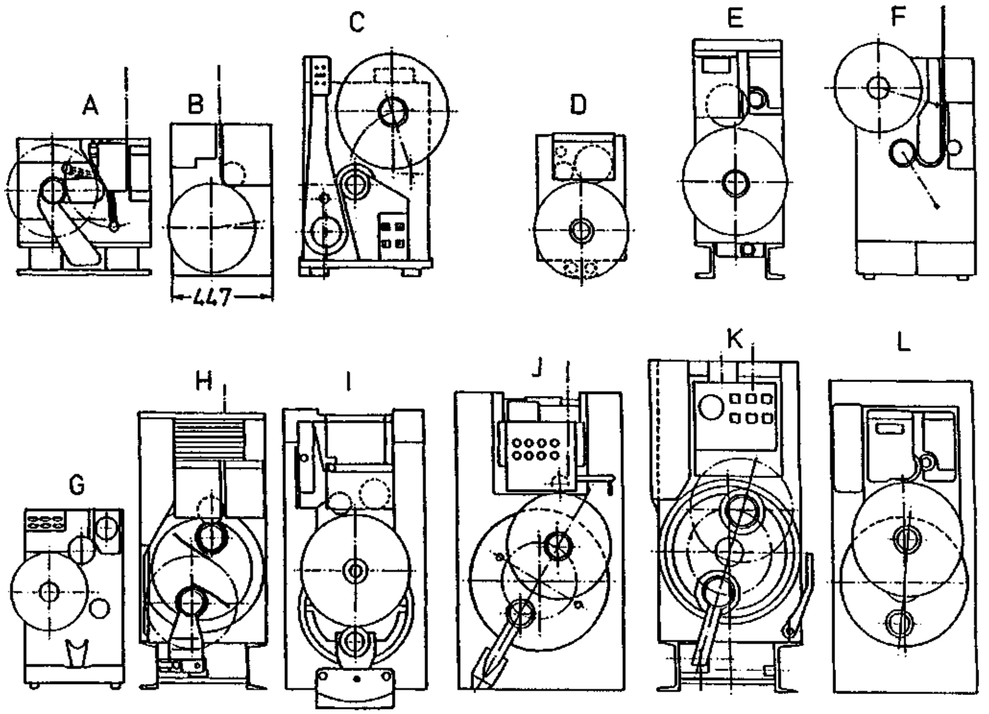


Figure 4.231 Front views of high speed winders commercially available in 1990/91 (to the same scale). For technical details, see Table 4.35

- ROY winders, such as, e.g., the Barmag SW8-... or the Toray high speed winders, capable of 6000...8000 m/min or even 10 000 m/min, require 2 godets in an S-configuration.

The following similarities and differences can be seen in the above high speed winders:

- Seen from the front, the yarn inlet is mainly between the center of the winder and ca. 150 mm from the right; there are 2 exceptions [33, 190] where the yarn entry is on the left. All winders can be used in double deck configuration.
- Only a few have a winder width of <500 mm [33, 190], permitting a winder pitch of ≤500 mm.
- Only one model without turret is 550 mm high [33], another (also turretless) [190] is 770 mm; all others are ≥1000 mm high.
- Only in 2 winders [33, 174] is the winding tension independent of the spinning tension. A special winder configuration [178] has an additional godet ca. 500 mm below the spindle.
- All winders have friction drives.
- Spindle drives for fine titer are made only by [33, 178], and for coarse titer by [33, 148, 170, 178] using yarn tension control.
- Single package high speed winders are no longer built. Winders having chuck lengths of 600–800–900 mm are built for 2...4 packages; winders having chuck lengths of 900 and 1200 mm are available for 3, 6 and 8 packages.
- Package diameters: without turret: 420...450 mm
  with turret: 360...420 mm (the latter by [178]).
- Traverse: All manufacturers offer a traverse cam system. Additional grooved rolls or incorporated godets are only supplied by [33, 174]. Rotor traverse is, to date, only provided by [178, 33].

Table 4.35 High Speed Winders (corresponds to Fig. 4.231)

Manufacturer	Teijin	Sahm (Alucolor)	Automatik Wicklerbau	Barmag	Barmag	Barmag	Barmag
Fig.	A	B	C	D	I	I	I
Type	MW 808	(DSG 4000)	DSG 6000L	SW4 series	SW 4 IR/600	SW 4 IR/600	SW 4.6-IS 900
Titer range (dtex)	50...300	15...1500	15...300	15...300	BCF	technical yarns	textile
Year of construction: up to/since		(1985) 1991	up to 1991	developed continuously since 1970	since 1984	since 1987	since 1988
Speed range (m/min)	2500...4500	100...4500	1000...5500	1000...4000 ...6000	1500...4000	2000...6000	2000...6000
Total chuck working length × $\varnothing_i/\varnothing_{full}$	820 × 89/360	600 × 94/360	900 × 94/420	400 × 52/360	600 × 75/420	600 × 94/420	900 × 94/550
No. of packages	4	1...4	2...8	(1)...4	2	2	3...8
Package drive	Friction	Friction	Friction	Friction	Friction	Friction	Friction
Traverse v_{max} (m/min) Stroke (mm) × DS/min_{max}	cam 600 190 × 1570	cam 400 112 × 1800 250 × 900	cam 500 112 × 2350 250 × 900	cam + grooved roll 400	cam + grooved roll 600 250 × 1500	Birotor 900	cam + grooved roll 900...760 250 × 1800
Doffing expected waste (%)	pneum. 3...4	pneum. 3	pneum. 3	manual initially; later pneum.	manual initially; later pneum. =revolver	manual initially; later pneum. +revolver	revolver, pneum.
Electric motor Spindle (kW/50 Hz) Traverse (kW/50 Hz)	0.45 S 0.125 AC	0.2 S 0.1 AC	1.25 S 0.5 AC		0.75 S 0.225 AC	0.75 S 0.225 AC	0.95 S 0.225 AC
Installed winder pitch (mm) single/(double) deck	600	500	600	500			600

Table 4.35 (continued)

Manufacturer	Barmag	Rieter	Rieter	Neumag	Neumag	Toray Eng.	Toray Eng.
Fig.	I	F	G	I	L	J	K
Type	SW 8.2 S–600	J7/A3	32/A6-096	NS 8000	NS 5000 W	TW562 RA	TW 602/7000
Titer range (dtex) textile	textile	500...4000	15...3000	2000...6000	600	40...300	textile
Year of construction: up to/since	since 1991		1989				
Speed range (m/min)	2000...8000	500...4000	6000	2000...6000	2000...5000	3000...6000	8000
Total chuck working length × $\varnothing_i/\varnothing_{full}$	600 × 143/460	600 × 75/300	900 × 94/420		920 × 94/435	800 × 120/460	800 × 120/460
No. of packages	2 or 4	2 or 4	6	4...8	3...8	4...8	4...8
Package drive	Spindle	Friction	Spindle	Spindle	Spindle	Spindle	Spindle
Traverse v_{max} (m/min) Stroke (mm) × DS/min_{max}	Birotor 1200 250 × 2400 120 × 5000	cam 800 250/1600 120/3300	cam 800 115/3200	cam 730 200/ 450...2150	cam 715 200/ 450...2000	rotor 162 × 2500	rotor 252 × 1600
Doffing expected waste (%)	Rev. pneum.	1 + res. sp. < 0.02	1 + res. sp. < 0.02	rev. < 0.02	rev. < 0.02	rev. pneum. < 0.02	rev. pneum. < 0.02
Electric motors Spindle (kW/50 Hz) Traverse (kW/50 Hz)	4.35 S 0.11 AC 6 kW AC-C	6 kW AC-C	• AC	2.6 AC-C 0.35 AC	3.7 AC-C 0.18 AC		0.4 AC
Installed winder pitch, min. (mm) single/(double) deck		450	600		600	660	675

rev.: revolver Other winders made by Teijin Eng. (H), Murata (L), Savio

- Auto-doff winders are supplied by all manufacturers except [190]. One model is provided by [153].
- The maximum winding speed for [179] is 4500 m/min. All others can reach 6000 m/min. Only [33, 161] can run at up to 8000 m/min.
- Lubrication: Periodic oil droplet or oil mist injection is recommended for ≥4500 m/min, while special grease or grease/oil emulsions can be used as lubricants at all low speed winders.
- Winder encapsulation and noise abatement are only provided, to date, by [33, 196], while [190] provides partial encapsulation. Such encapsulation can also be used to improve the air environment of the winder.

When it comes to the selection of a winder for a particular spinning line, the following criteria must be addressed after considering what has already been presented above:

- Number of yarn packages and their size per winder and per spinning position, and the type of winder drive,
- speed and yarn tension range. The actual winding tension must be of the order of 0.1 g/dtex, and the traverse-induced tension fluctuations must not run upwards to the spinneret. Table 4.36 gives an overview of the possibilities of combining various winder elements.

Table 4.36 Possible Winder Combinations

Winding type	Package drive	Control	Chuck (package spindle)	Traverse	Packages/chuck kg yarn/package	Speed range m/min
Precision winding	Spindle drive	tension-controlled	2 chucks 1 chuck (mobile)	stationary	1...4 (30...66) (10...25)	<30 400 (600)
Step-precision winding	Mixed drive	speed controlled	revolver	mobile	1...8 (30...60) (5...15)	1200 3000
Random winding	Friction drive		stationary			1000...4000 2000...6000 3000...8000

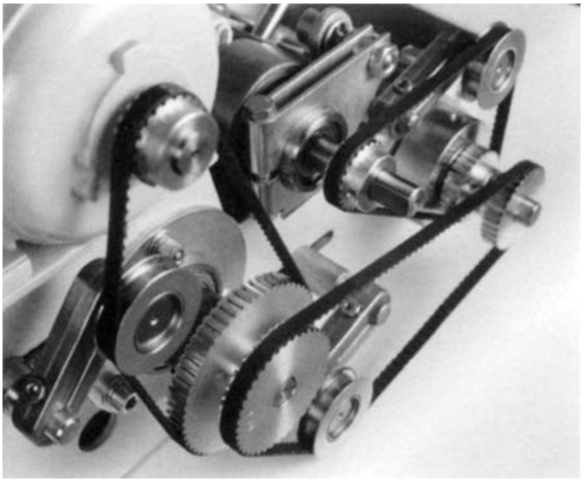


Figure 4.232
Drive of a yarn tension-controlled precision winder (Bandomat 300 E [179]) for 300...10 000 dtex, ≤500 m/min, 1 or 2 yarn package(s) per spindle, yarn tension controllable between 20 and 1200 cN, up to 25 kg/spindle package weight

Table 4.37 Dancer-Arm, Tension-Controlled Yarn Winders

Important application for		Carbon fiber	Tape Extrusion	Spinning	Spin draw	Large packages
Speed range	m/min	0...(15...30)	<400...600	<1200	<2500	200 (300)
Titer range	dtex	500...30000	300...5000	100...2000	300...3500	<4000
Yarn tension	cN	100...1200	15...400	10...200		
Package volume	1	10...13	15...80	3...10	30...80	30...140
Diameter × stroke. e.g.	mm	270 × 250	350 × 300	250 × 200	480 × 416	400 × 600
Dimensions:						
width	mm	500	525			1010
height	mm	320	402			1800
Manufacturers		Ba, Sa, Le	Ba, DS, Sa	Ba, Sa, Le	Sa, Le	DS, Sa

Ba = Barmag, Sa = Georg Sahm, Le = Leessona, DS = Dietze + Schell

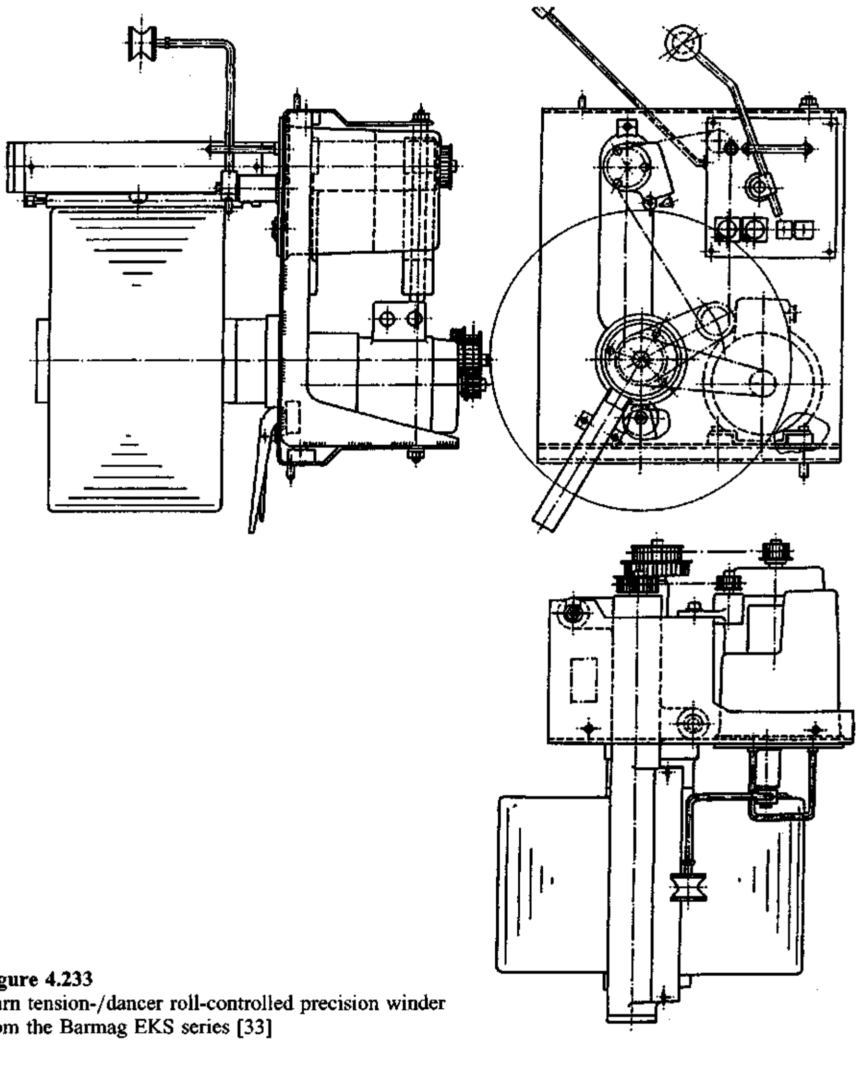


Figure 4.233
Yarn tension-/dancer roll-controlled precision winder from the Barmag EKS series [33]

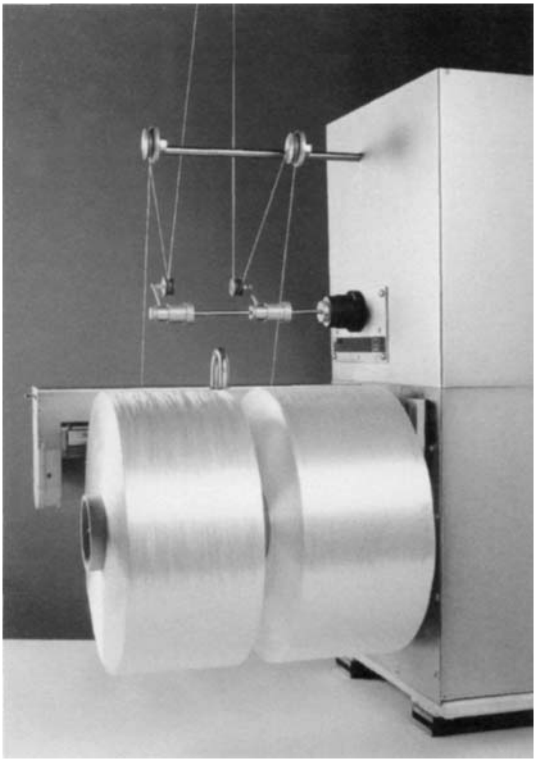


Figure 4.234
Yarn tension-/dancer roll-controlled precision winder SAHM 3002 [162] for up to 2 yarn packages, 3000 m/min and 2 × 33 kg yarn packages (Previously Alucolor DSG3000p [179])

4.9.5.8 Winders with Spindle Drive and Dancer Arm Tension Control

Such winders are normally designed for precision winding, but can also be controlled for random or mixed winding. The spindle drive can be by:

- Displacement armature motor or 3-phase motor with a displacement electromagnetic clutch. The dancer arm mechanically moves the rotor in the axial direction, the torque generated then depending on the displacement into the stator.
- DC motor, which is controlled by a non-contact potentiometer turned by the dancer arm. Brushes and collectors require permanent inspection and maintenance. It is known that only one manufacturer [180] is able to control the yarn tension down to below 5 g.
- Standard-dimensioned 3-phase motors (which are robust and maintenance-free). Here the dancer arm turns a non-contact potentiometer, which—acting through a single-board microprocessor—alters the frequency of an inverter to drive the spindle motor.

The yarn tension can be set on the dancer arm, usually by means of a spring or weight and damping. Typical minimum yarn tensions lie between 20 and 40 g, and the working range is as for friction winders up to 3200 m/min. Predominantly single end winders are produced, although it is possible to obtain such winders for 2 to 4 ends. In order to minimize yarn waste at the doff, an extra winder per row is fitted. At the doff, the running threadline from the full package is taken across to the empty winder, wrapped around the paper tube a few times, the yarn is cut at the full package, and the full package is removed. The procedure is repeated for all winders in the row or bank.

In precision winding, the traverse- and spindle rotational speeds must be fixed in the ratio of an irrational number (Section 3.7). This is achieved by the use of a fixed gearing and timing belts, as shown in Fig. 2.232 [166], or by a pair of precision-frequency motors.

Next Page

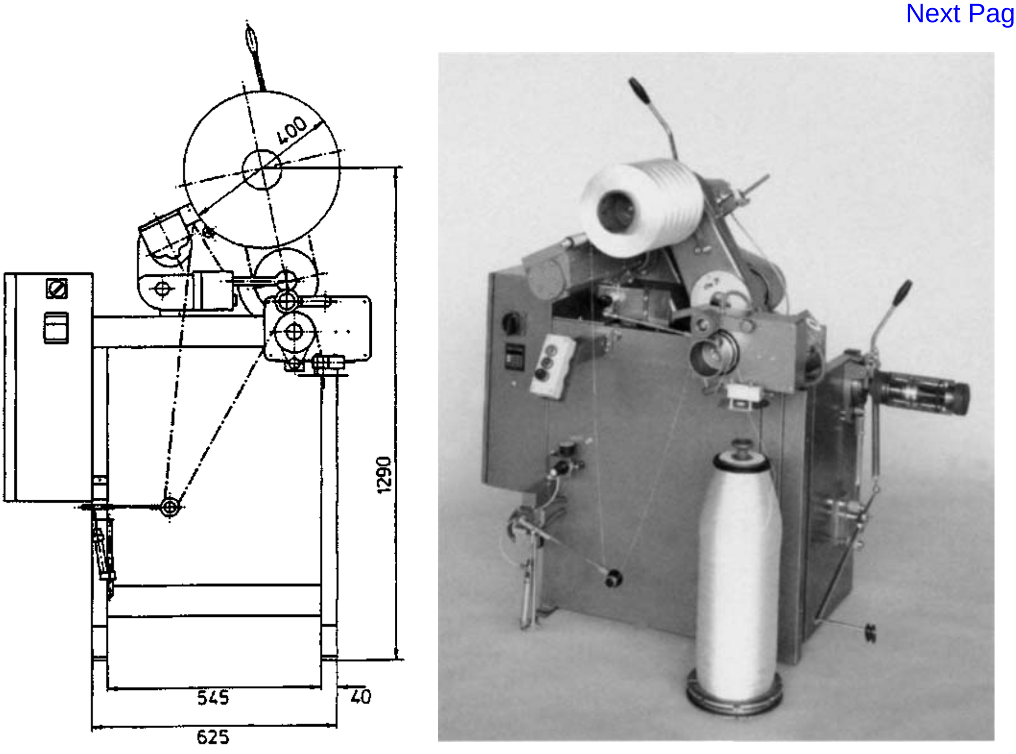


Figure 4.235 Yarn tension-/dancer roll-controlled precision winder for coarse yarns up to 70 000 dtex, 400 or 600 m/min and 50 l yarn volume (Dietze & Schell [253])

Table 4.37 gives technical details and operating ranges of currently-available dancer arm, tension-controlled winders, and Figs. 4.233 and 4.234 illustrate two executions. Figure 4.235 shows a winder [253] capable of winding particularly coarse counts of up to 70 000 dtex at (the typically-used) speeds up to a maximum of 400, or even 600 m/min. The stroke is 150...300 mm, and the maximum diameter is 420 mm, giving a package volume of up to 50 l. By incorporating a godet and separator roll, this winder can be used for both spun and drawn yarns.

The use of winder banks containing dancer arm, tension-controlled winders in vertical columns and horizontal rows is discussed in Section 5.7: carbon fibers.

4.10 Drawtwisting and Draw-Winding Machines

Up to ca. 1960, all continuous synthetic filaments were drawtwisted in order to obtain the required tenacity, the low elongation associated with elastic behavior and a certain degree of protective twist. The use of drawtwisters has since declined for many applications, but there now seems to be a slight revival in their usage again. The use of intermingling in the recently introduced draw-winding and warp-drawing processes has resulted in protective twist becoming less important. Figure 4.236 shows process routes used in converting melt spun fibers to flat yarns on packages, cops or beams. Drawtexturizing and BCF are discussed in separate sections.

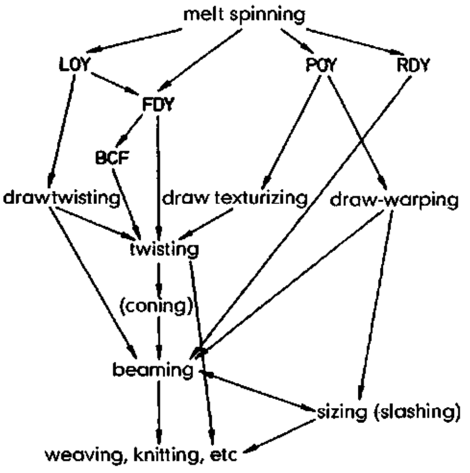


Figure 4.236
Yarn process flow diagram, from melt spinning to finished goods

Flat yarns produced on drawtwisters still have the best characteristics, and this is still an economical route for fine titer drawn yarn. Only 8 end spin-draw-winding per spinning position achieves the same cost of production as drawtwisting. In addition, conventional LOY spinning at 600...1700 m/min, followed by drawtwisting or draw-winding, is still the most risk-free way to produce flat yarns.

4.10.1 Drawtwisting Machines (Drawtwisters)

Drawtwisters were developed from ring twisting machines by adding one or more cold- or heated drawing zones, as demanded by the polymer, titer and yarn properties. Figure 4.237 shows a schematic drawtwister position: (A) is for PA6; for drawing PA66, an additional cold draw pin is added (see Fig. 2.34). For drawing PET (B), two heated godets (4) and possibly a heated plate (6) in the main drawing zone are required. By using a third cold godet (4) and possibly an additional hot plate (6), PET and bicomponent yarns can be drawn and heat set to reduce shrinkage (C). Configurations (B) and (C) are also suitable for polypropylene. The yarn inlet (1, 2, 3) and twisting sections (7 to 13) are the same for all configurations.

The undrawn or partly drawn yarn is taken off over-end from the supply package (1). A polyformaldehyde ring (e.g., Delrin®) prevents snagging of the last yarn layers by the edge of the tube. The yarn is taken through a guide (2) and pretensioned by wrapping it a few times around a double rod yarn brake before being wrapped at least four times around the silicone rubber-coated feed roll (cot) and grooved traversing guide, after which it runs off the continuous delivery roll (3) into the first drawing zone and over the godets, separator rolls and hot plates (4, 5, 6) already described. The yarn finally runs through the balloon guide (7) (which traverses up and down with the ring rail) into the yarn balloon, through the ring traveller (8) and is wound up on the spindle tube or cop (9, 10). The traversing of the ring rail (to which individual ring holders (8) are locked by means of an individual latch (11)) is governed by a (common) program, which determines the package (cop) shape. Each spindle can be stopped independently (12), and the ring tray (8) can be dropped by means of the latch (11)). The draw point, which is only a few mm long, should be located on the feed roll or drawing pin. Hot plates and draw pins are wearing parts and must be regularly checked; the use of heated godets only is therefore advantageous. Typical adjustable draw ratios for the various zones and the installed power are given for drawtwisters in Tables 4.38 and 4.39. The most important technical details of two commercially-available drawtwisters and one draw-winding machine are given in Table 4.40; machine cross-sections are shown in Fig. 4.238. Instead of line driveshafts running the length of the machine, single synchronous motor drives are being

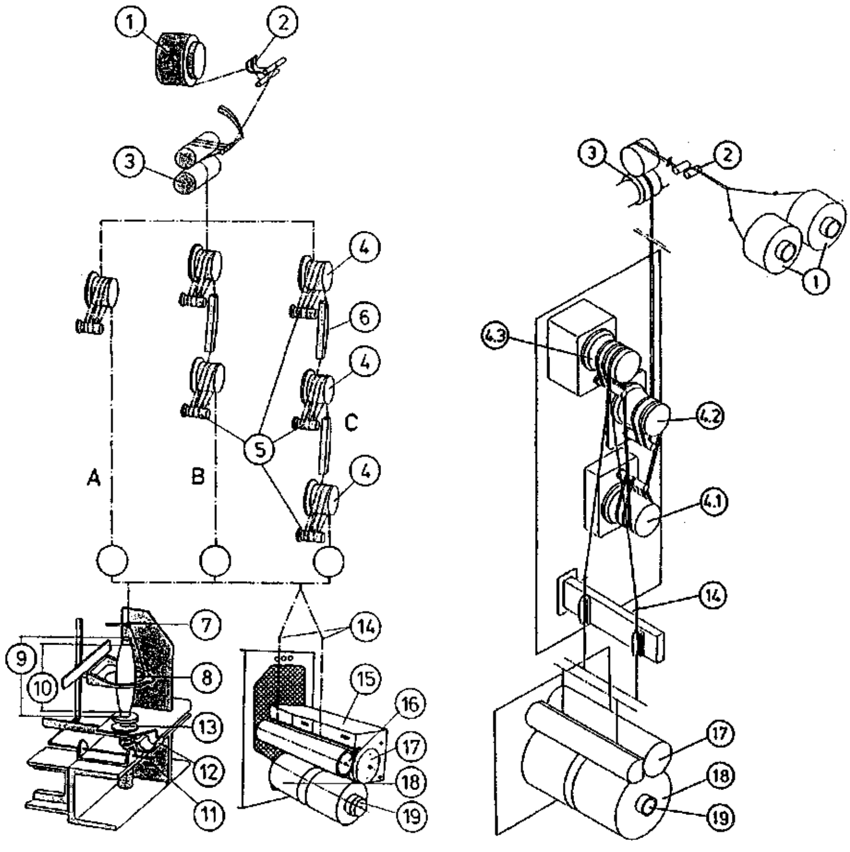


Figure 4.237 Schematic of a single-stage (left), two-stage and three-stage (right) drawtwisting/draw-winding position

1 Spin bobbin
2 Yarn tensioner
3 Feed roll with yarn traverse and cot roll
– draw ratio, single stage: 1 : (2.5 ... 9.5) three stage: as before and: 1 : (1 ... 2)
4 Godets (draw rolls), hot or cold, max. speed: 1200 ... 1800 m/min
5 Separator rolls
6 Hot drawing plates or -pins
– total draw ratio: up to 1 : 12
– lowest godet: cold
7 Balloon guide
8 Drawtwist ring, self-lubricating
– diameter = 130 ... 150 mm, with traveller
9 Drawtwist bobbin (tube, pirn), length 380 ... 520 mm for textile yarns, 500 mm for technical yarns
10 Package length = tube length - (40 ... 60) mm
11 Single ring tray disengagement
12 Spindle brake
13 Spindle drive whorl
– Spindle speed: max. 16000 (textile) ... 7500 (technical) r/min
– Ring rail double strokes: 2 ... 12/min
– Ring rail speed: 0.6 ... .4.2 m/min
– Ring rail acceleration: 3 times
– Titer range: 10 ... 330 dtex (textile); 100 ... 1200 dtex (technical)
14 to *19*. Draw-winder, 2-ends
14 Two yarns from a common godet (draw roll)
15 Friction roll housing
16 Traverse mechanism, 2-fold
17 Friction roll
18 Two drawn yarn packages

Table 4.38 Draw Ratio Ranges

Drawtwister with	1	2	3 draw zones	
Feed roll		cold. 100...600		m/min
1st zone	1:2...12	1:1...1.2	1:1...1.2	
		1:2...12	1:1...6	
1st draw roll	cold	<140	<140	°C
		200...1500		m/min
2nd zone	–	1:2...12	1:2...12	
2nd draw roll	–	<240	<240	°C
		200...1500		m/min
3rd zone	–	–	1:08...1.4	
3rd draw roll			<240	°C
			200...1500	m/min

Table 4.39 Installed Power of Drawtwisters

80, 144 or 156 spindles	For textile titer	1 kW	2 kW	3 kW	Max. drawing speed, m/min	Max. titer dtex	Source
	Drive, total	25...40	25...40	36...50	1200	380	[33]
	1 motor drive	25...33			1300	330	[205]
	2 motor drive	54			1300	330	[205]
	Spindle drive	24			15000 r/min	235HT	[33]
	Draw drive	18			1600	235HT	[33]
	for cord yarn		30...48		6000 r/min	3000	[57. 190]
					700		

Comments:
per draw roll (resistance) heater: 0.3 kW
per hot plate 200 mm long: 0.12 kW; 300 long: 0.21 kW; 400 long: 0.3 kW
per hot pin: 80 W

increasingly used. Spindles are driven either by belt drives, in groups of 4 spindles, from drum drive shafts running the length of the machine, or by single synchronous motors. In the above example, the draw-winder has 2 winders per 4 ends, while the example shown in Fig. 4.225 has 2 winders per 2 ends.

Drawtwisters and draw-winders are usually constructed from heavy castings and have a drive casing at one end containing the drive gears, draw gears and exchange gear sets, as well as—if used—the mechanical ring rail motion drive. There is a vertical cast frame for every set of 12 spindles. The godet boxes lie between these frames and have continuous driveshafts with helical bevel gears to drive the godets. The yarn creel and take-off guides are fixed to the top of the machine frame. Figure 4.239 shows a side view of such a drawtwister.

4.10.2 Construction Elements for Drawtwisters

- The spun yarn creel is located on the top of the machine (Fig. 4.240) in the case of old PA6 drawtwisters. The yarn is taken off over-end from the supply package (1) and passes downwards through a pretensioning yarn guide (2). If multiple drawing zones are used, another creel arrangement is preferable, because of otherwise excessive machine heights—either a transportable creel standing

Table 4.40 Drawtwisting and Draw-Winding Machines – Examples

Manufacturer		Zinser	Spinnzwirn/ Erdmann	Zinser Erdmann
Type		Drawtwister	Draw-winder	Draw-winder
Model		SZ 517/1	DM 24.5	SW 547
Suitable for		PA6, PA66	PA, PP, PET	PA, PP, PET
Drawn titer range	dtex	17...460	2 × (17...460) or 1 × (55...660)	⩽ 460
Drawing speed (max)	m/min	⩽ 1800	⩽ 2000	⩽ 1200
Max. spindle speed	rev/min	⩽ 16000	n/a	n/a
Cop/package weight	kg	⩽ 3.5	⩽ 2 × 14	⩽ 12
Drawing positions (max.)		144 or 156	108 for 2 ends = 216 threadlines	144
Draw roll pitch	mm	190	380	2 × 190
No. of drawing zones		1	2 or 3	2
Drawing zone length	mm	400	474/327/600	275/635
Ring diameter	inches	6 1/8″	n/a	n/a
Package diameter or cop length	mm	× 400	360 × 170	275 × 135
Stroke length	mm	⩽ 410	–	–
Tube/cops length	mm	⩽ 450	210 × 75/85	320
Machine length	mm	17185	20520*	15670
Machine width[2)]	mm	1085	1560	1900
Machine height[2)]	mm		3080	2650

*for 216 ends
[2)]without creel

on an extra floor above the drawtwister or a side creel standing on the floor, both as shown in Fig. 4.241. Figure 4.242 shows the detailed construction of a take-off thread guide, which is carried on a rod or arm (4) and which can be swiveled to the vertical for operation or to the horizontal for a supply package change, by using the cross-slotted swivel head (5). The guides (1) and (3) maintain the inlet and outlet position of the yarn, which is pretensioned by the multiple wraps over the braking rod (2) before running onto the feed roll (3) in Fig. 4.243.

- Figure 4.243 shows the yarn feed system (g, Fig. 4.241), which includes the rubberized inlet- and pressure roll or cot (1) and the traverse guide (2), which is oscillated a few mm sideways with a period of 3...6 min by a small geared motor. After at least 4 wraps around (1) and (2), the yarn runs off the bright, hardchromed delivery roll (4) into the first drawing zone and then onto the godet (4) in Fig. 4.237. The diameter of the delivery roll is reduced between threadlines to facilitate cutting and removing yarn wraps during running; the length of this section is about 80...100 mm.
- The godets used on drawtwisters are, in principle, similar to those shown in Figs. 4.200A for cold godets and 4.200C for inductive heated godets, but have diameters of only 80 or 100 mm and lengths of 45...80 mm (Fig. 4.244). The separator rolls correspond to those shown in Fig. 4.208a.
- Hot plates similar to that in Fig. 4.245 [33, 171] have a matt hardchromed or hard metal covered plate, which is heated from behind and is usually exchangeable. The plates are wear parts; in the case of semi-dull PET, the working surface (7) needs to be recoated after 1...2 working months. Hard material, plasma-coated running surfaces are therefore better, particularly when combined with yarn traversing. The required installed heating power is given by: $N = (T/3 - 10) \times L/200$ [W]; (T[°C] = hot plate working temperature and L = length [mm]). During operation the insulation cover (3) should be closed and the vapor aspiration (2) switched on.
- Hot draw pins (Fig. 4.246) are either directly electrically heated (d) by resistance elements or by liquid Dowtherm (Diphyl) (B), which enters and exits through (d). Another version has a central

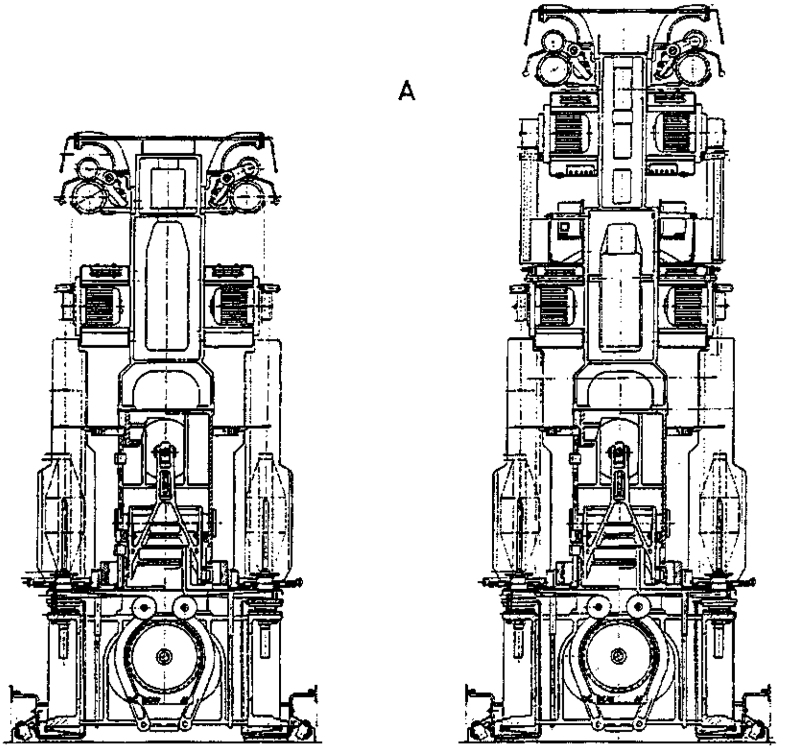
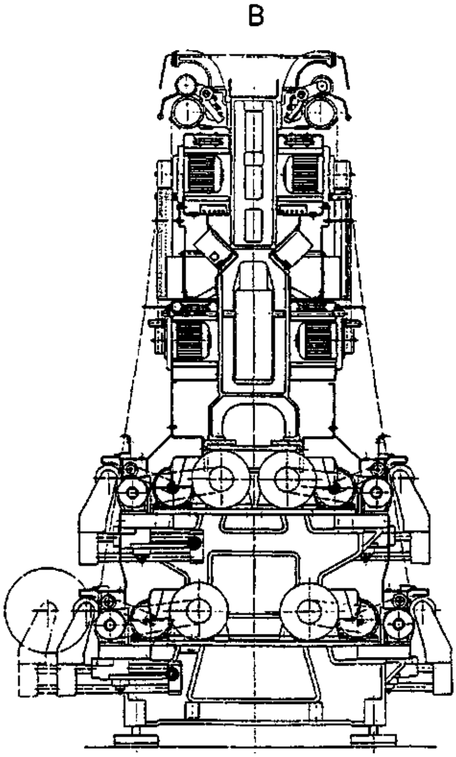
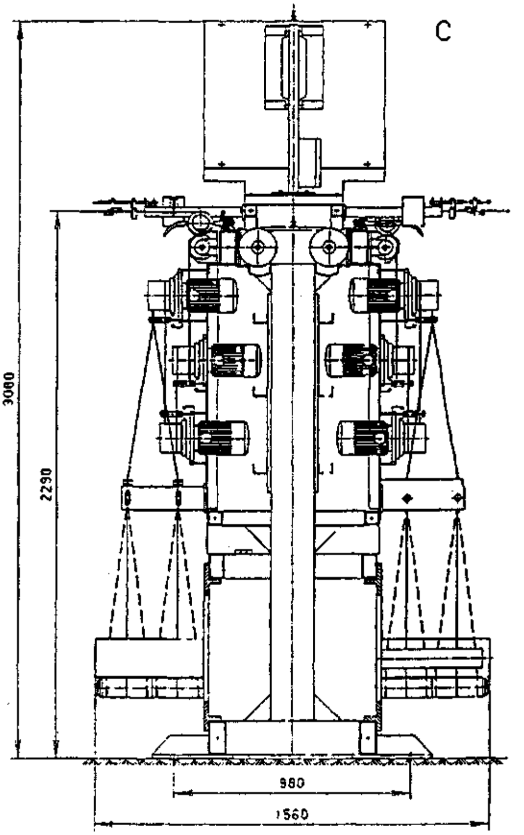


Figure 4.238 Drawtwister and draw-winder sections:
A) Drawtwisters with heated drawing zones from Barmag-Spinnzwirn [33] and Erdmann [171]. These machines have a continuous delivery roll, single-drive draw rolls and 4 spindles driven by one belt

electrical heater (d in C) and circumferentially distributed air cooling channels (h). All have an aluminum core for heat distribution and an exchangeable plasma-coated wear shell (a). The inclination of the draw pin can be adjusted by means of a pivot (A), an inclined bracket (B) or a rotatable mounting plate (C). The pin is inclined to avoid contact between the pre-drawn and post-drawn yarn.

- The spindles used are normal roller-bearing twist spindles suitable for heavy weights and speeds up to 14 000... 16 000 r/min. The spindles must have two seats for spring-loaded spherical caps, which press against the inside surface of the drawtwister tube to hold it in place. The traveller rings are of normal type, with wicks for oil lubrication, and are shaped to take C- or ear travellers. The spindles have a whorl for the belt drive and a braking surface for manual- or knee-activated stopping by a brake lever.
- Unless single motor spindle drives and a common inverter are used, the normal spindle drive is the so-called 4 spindle belt drive. For relatively light spindles, an endless hot-welded belt can be used, as in Fig. 4.249a, while for heavier spindles, the drive in (b) is used. Mostly the drive in (b) is used nowadays. Often, on braking, it is necessary to lift the drive belt from the spindle. The continuous drive can either consist of a long continuous drum drive or of a continuous shaft incorporating a drive drum at every (separate) belt wrap.
- Traveller rings and travellers are polished smooth and have a lubrication system: either a ring oil wick is used or the ring itself is sintered. For textile titers, HZ type C-travellers are mainly used (Fig. 4.247), while for technical- and coarser counts, NSC rings and -travellers are also used, the latter





▲ **Figure 4.238**

B) Zinser draw-winding machine [205]. Machine execution is as per *A*), but winders as per Figure 4.225 are fitted in the place of the spindles.

C) Draw-winders of Barmag-Spinnzwirn [33] and Zinser [205].

(For technical details, see Table 4.40)

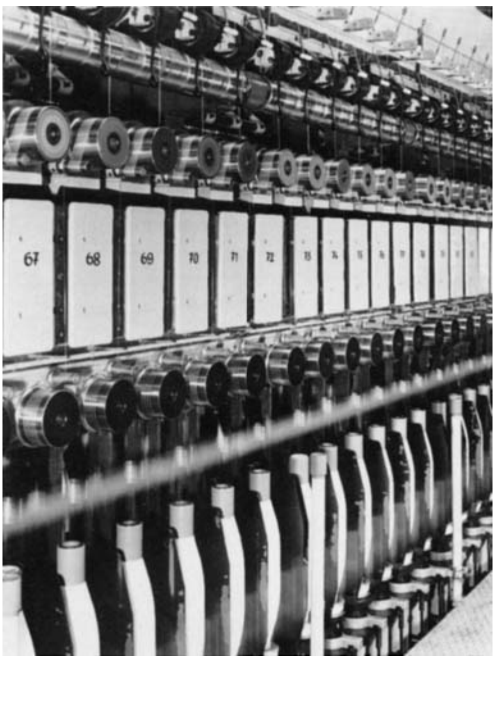


Figure 4.239
Side view of the drawtwister in Figure 4.238 A [33]

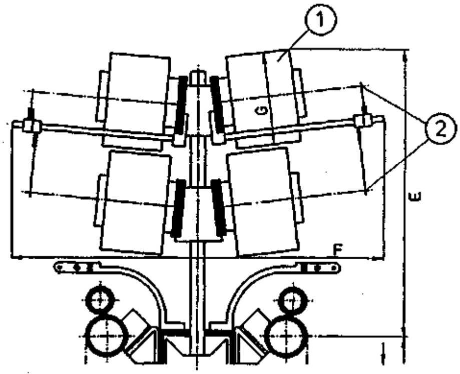


Figure 4.240
Spun yarn bobbin creel above a drawtwister. Alternatively, the creel may be placed on a platform above the drawtwister
1 Supply package
2 Pretensioning yarn guide

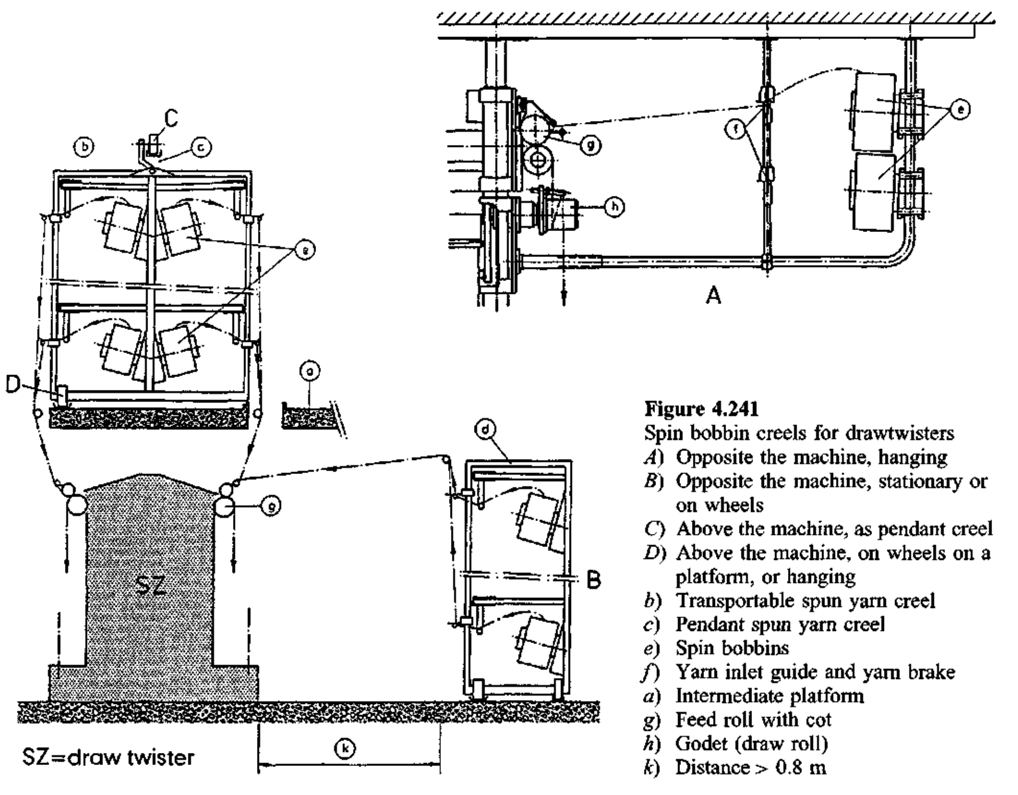


Figure 4.241
Spin bobbin creels for drawtwisters
A) Opposite the machine, hanging
B) Opposite the machine, stationary or on wheels
C) Above the machine, as pendant creel
D) Above the machine, on wheels on a platform, or hanging
b) Transportable spun yarn creel
c) Pendant spun yarn creel
e) Spin bobbins
f) Yarn inlet guide and yarn brake
a) Intermediate platform
g) Feed roll with cot
h) Godet (draw roll)
k) Distance > 0.8 m

having a nylon foot running on the inside of the ring. Table 4.41 can be used to match the traveller number to the drawn titer [248].

- The ring rail package build control system, on starting, first forms the waste bunch and transfer tail at the bottom of the drawtwist tube, then builds up the yarn layers (Fig. 4.250). The way in which the yarn windings are laid is important for yarn take-off and the tension variations associated therewith (Fig. 3.55). A simple switch-over system must suffice. This then actuates a 4-thread spindle system

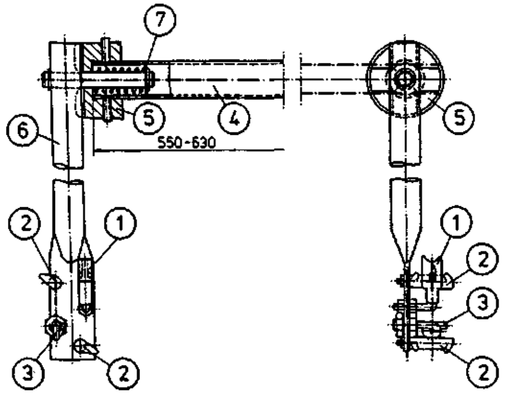


Figure 4.242
Yarn take-off device for a spin bobbin creel. The arm bearing the yarn guide can be swung out of the way for doffing or donning spun packages
1 Inlet yarn guide
2 Yarn brake guide
3 Pigtail guide for yarn take-off
4 Support arm
5 Swivel head with cross nut
6 Swivel arm, with
7 Spring-loaded bolt

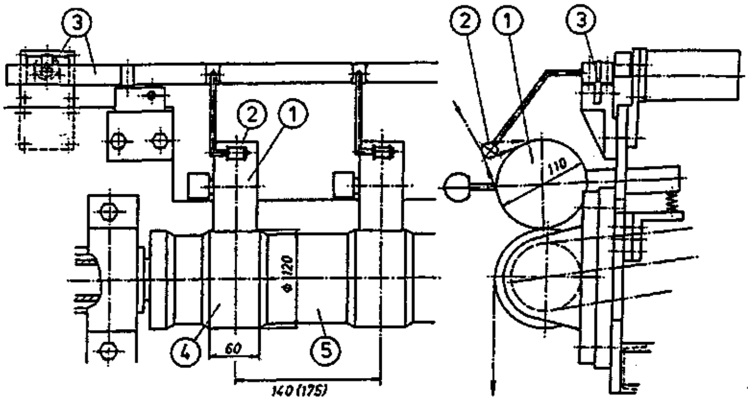


Figure 4.243
Feed roll of a drawtwister
1 Pressure roll (cot), rubberized, with swivel arm
2 Traversing guide, possibly with 5 grooves
3 Traverse bar, with drive (ca. 4...7 mm reciprocation)
4 Feed roll, with
5 Smaller diameter for yarn wrap removal

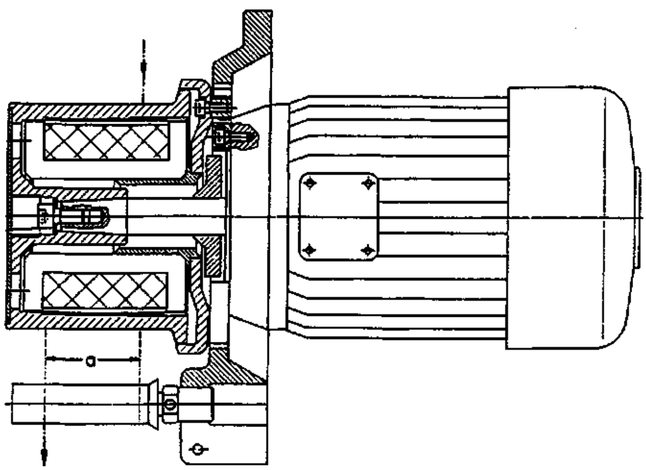
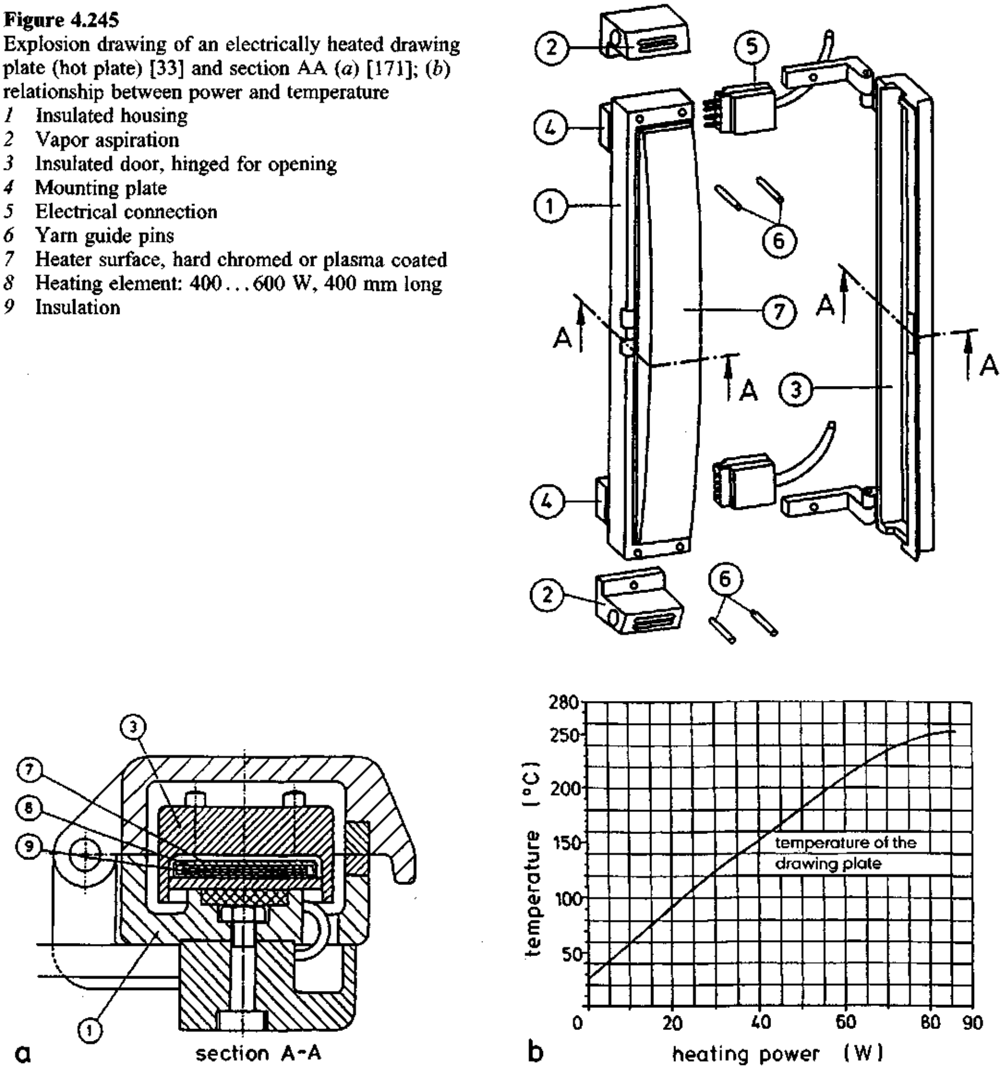


Figure 4.244
Draw godet for a drawtwister, induction heated, with single synchronous motor drive [171] and Thermicon® temperature control (without temperature sensor, using voltage and current measurement)
a) maximum working width (ca. 48 mm)

Figure 4.245
Explosion drawing of an electrically heated drawing plate (hot plate) [33] and section AA (*a*) [171]; (*b*) relationship between power and temperature
1 Insulated housing
2 Vapor aspiration
3 Insulated door, hinged for opening
4 Mounting plate
5 Electrical connection
6 Yarn guide pins
7 Heater surface, hard chromed or plasma coated
8 Heating element: 400...600 W, 400 mm long
9 Insulation



having a clutch, gears and end switches. Alternatively, a microprocessor system and hydraulics can be used. A hydraulic cylinder operates chain drives running the length of the machine; these chains raise and lower the ring rail.

- Programmable starting allows the threaded-up spindles to accelerate gently in order to avoid start-up yarn breaks. This system can also be used to reduce the tension differences between the top and bottom of the ring rail stroke.
- Cops doffers [205, 249] automate the doffing process. They remove the full packages (cops), place them on a transport wagon and refit empty tubes onto the spindle shafts (Fig. 4.251). The total doffing time is ca. 5 min per drawtwister. A robot can serve up to 8 machines. Threading up of the yarn through the traveller and onto the spindle must still, however, be done manually.

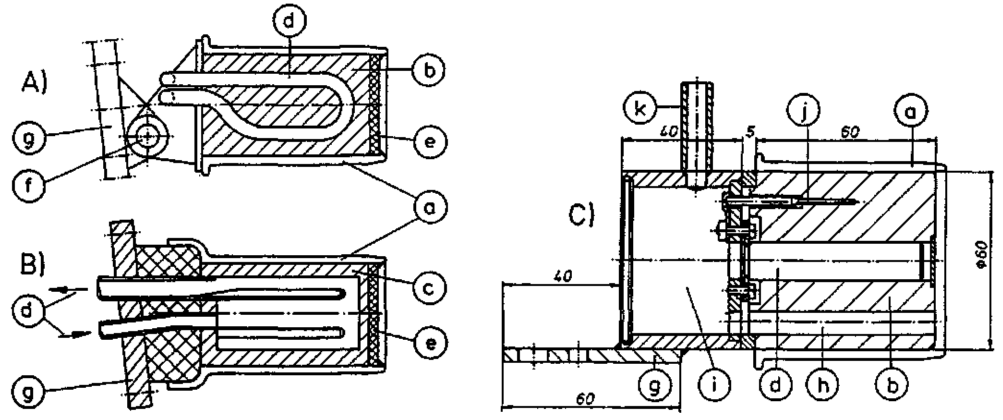


Figure 4.246 Hot draw pins [171]
A) Inclinable, with electrical heating
B) With fixed inclination, for liquid heating
C) With air cooling and electrical heating; swivels horizontally
a) Sheath, coated, exchangeable
b) Aluminium core
c) Steel core
d) Heating rod or tube
e) Front insulation
f) Swivel bolt
g) Fixing plate
h) Bores for cooling
i) Cooling air distributor
j) Temperature sensor
k) Cooling air connection

Table 4.41 Ear travellers for textile titers – traveller number and weight [248]

Drawn titer dtex	Traveller HZ number	Weight mg/each
11	30...32	21...16
17	32...34	24...21
22	30...32	29...24
44	28...30	39...29
67	26...28	60...39
100	25...27	75...48
167	21...23	150...110
220	19...21	255...150

The construction of heavy drawtwisters for technical and tire yarn has been terminated in favor of integrated spin draw machines and warp draw machines (Barmag SZ8 [33]).

The stepped draw roll (Fig. 4.252) and the multi-step godet, which was developed from the former for incremental drawing, have not found acceptance in practice, as the required draw ratios of up to 5 : 1 imply roll diameters which are too great to fit within a spindle pitch of ca. 175 mm.

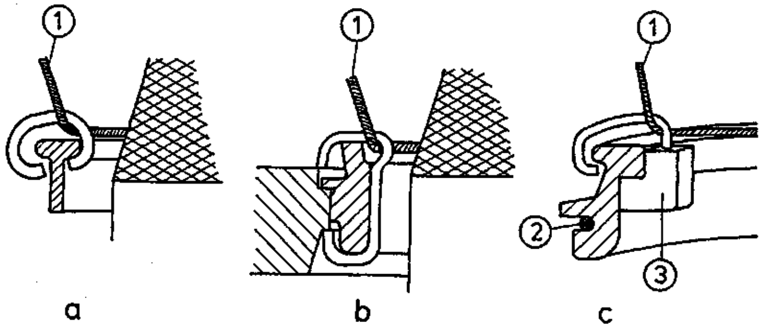


Figure 4.247
Traveller ring cross-sections and travellers [248]
a) C-traveller
b) Ear traveller
c) NSC traveller and -ring
1 Yarn
2 Oiling wick
3 Nylon shoe

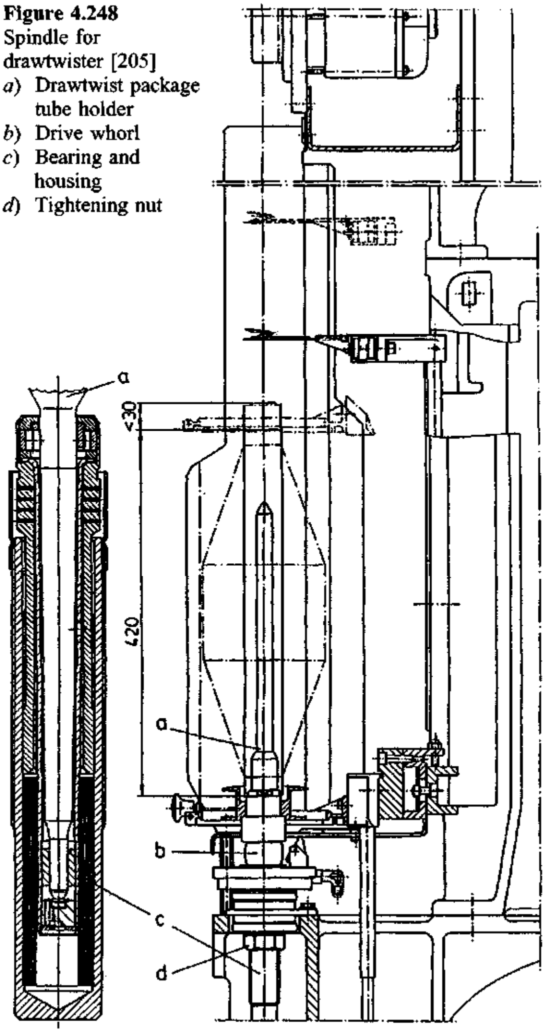
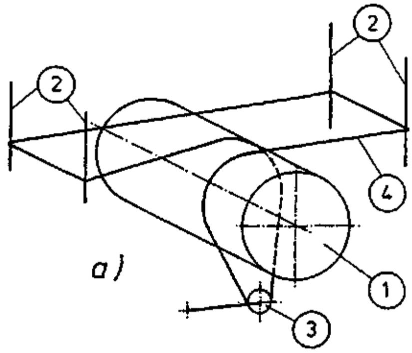


Figure 4.248
Spindle for drawtwister [205]
a) Drawtwist package tube holder
b) Drive whorl
c) Bearing and housing
d) Tightening nut



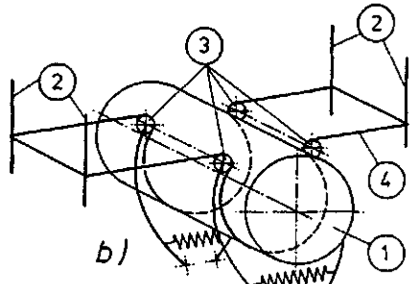


Figure 4.249
Four-spindle belt drive
a) for light and *b*) for heavy spindles and yarn packages (cops) (≥ 2 kg)
1 Drive drum
2 Spindles
3 Belt tensioner
4 Drive belt

Spindle settings for textile titers
Spindle speed: ≤ 16000 r/min
Tube length: ≤ 420 mm
Yarn stroke: ≤ 380 mm
Ring diameter: 130 ... 155 mm
Ring rail double strokes: 2 ... 12/min
– Speed: 0.6 ... 4.2 m/min
– End of stroke acceleration: ≤ 3 times
Yarn guide stroke: $\frac{1}{3} \times$ ring rail stroke

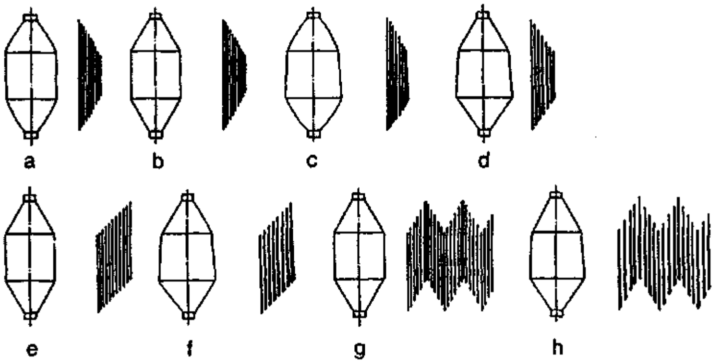
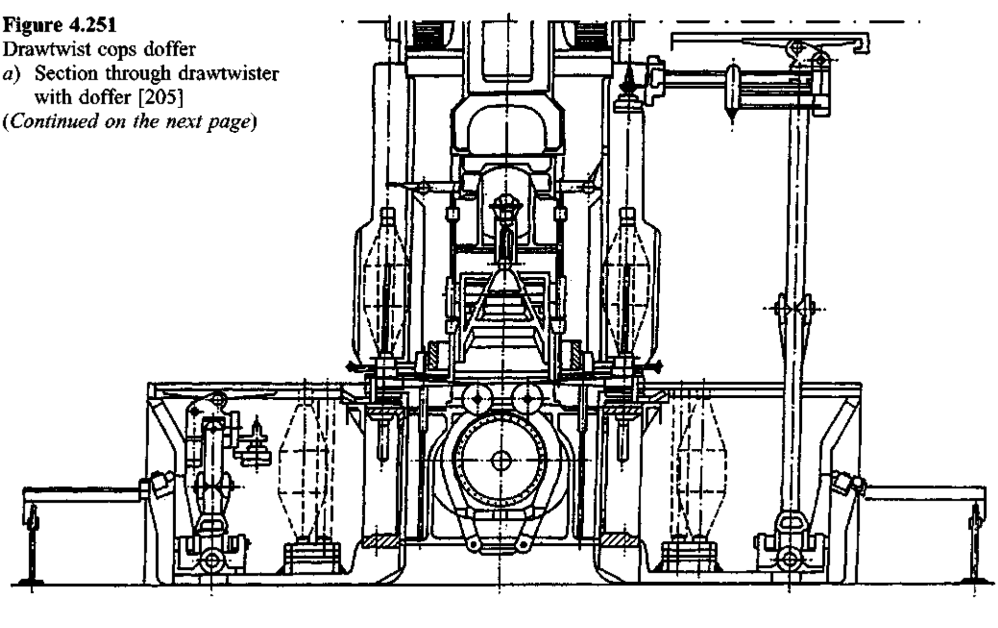


Figure 4.250 Possible winding modes and cops shapes achievable on a drawtwister [205]
a) Parallel winding with stroke reduction with time, and constant ring rail speed.
b) Parallel winding with stroke reduction with time: number of ring rail strokes/min = constant
c) As per *a*), but with downward stroke continuously decelerated and upward stroke continuously accelerated.
d) As per *b*), but with downward stroke continuously retarded and upward stroke continuously accelerated
e) Parallel winding, with slower stroke length displacement upwards
f) As per *e*), but with downward stroke continuously retarded and upward stroke continuously accelerated
g) Combined winding
h) As per *g*), but with downward stroke continuously retarded and upward stroke continuously accelerated

Figure 4.251
Drawtwist cops doffer
a) Section through drawtwister with doffer [205]
(*Continued on the next page*)



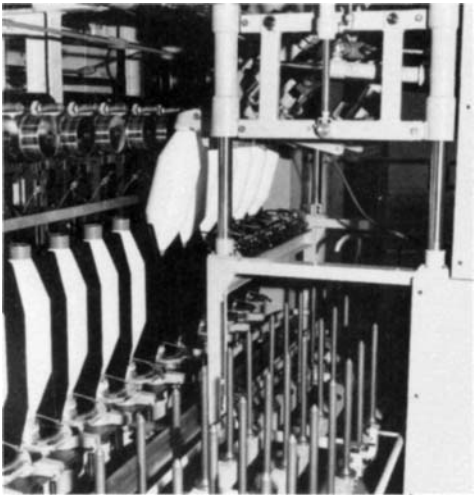


Figure 4.251
b) Doffer in operation [57]

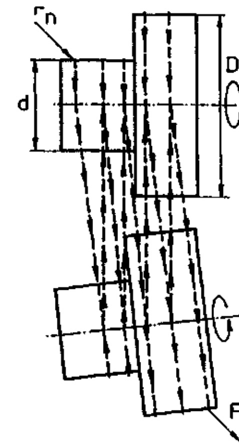


Figure 4.252
Stepped draw roll. Draw ratio $i = d/D$ (for yarn lateral displacement, see Section 7.6)

4.11 Warp Drawing, Warp Sizing and Slashing

To avoid the costly processing of single ends of flat yarn between the spin bobbin and warp beam, warp drawing (also termed draw-warping) is used. Here the spun yarn packages are housed on creels, from which the ends are taken to form a flat sheet of closely-spaced yarns, known as a warp. The warp is drawn by a series of drawstands (heated and/or cooled, as required), between which heating ovens are located. If the drawn warp is taken up as single ends on a bank of dancer arm, tension-controlled winders, the process is known as warp-draw-winding. If the drawn warp is wound up as a warp sheet on warping or hosiery beams, the process [207] is termed warp-draw-beaming, usually simplified to "warp drawing". For technical yarns, the drawing speed lies between 400 and 1200 m/min.

This process is applied to textile titer flat yarns, especially using POY as the supply yarn, on warp drawing and warp-draw-sizing machines to produce, in one step, hosiery or warping beams ready for use in warp knitting or weaving. The twist which would have been inserted at drawtwisting is replaced by intermingling the POY to > 10 nodes/m. Using such POY, it is possible to achieve < 2 yarn breaks/1000 kg in warp drawing. If the POY intermingling is reduced to 5 nodes/m, the break rate can easily increase to 5/1000 kg. The processing speed is between 500 and 800 m/min. The quality of these yarns and beams is excellent, both because of the POY quality and because all threadlines are given the same drawing treatment at the same time.

The capacity of a warp draw line is given by:

$$3.74 \times 10^{-5}\ \text{kg/shift} \times \text{no. of threadlines} \times \text{dtex/end} \times \text{m/min}\ [207] \tag{4.41}$$

Using 1200 ends of 76 drawn dtex per beam and working 64 shifts/month, production rates of 120...150 t/month/line are easily achieved. LOY supply yarn also achieves good results, but one must reckon on 20...30 slubs/1000 kg yarn and 70...80% of the above capacity.

Figure 4.253 shows a warp draw line [33, 209] integrated into a POY spinning plant. After doffing, the POY spun packages are taken by the doffer (1) and loaded onto the transport buggies, which form the creel (2). Yarn tensioners ensure uniform threadline tensions at the reed (3), which leads the warp into the drawing zone (4). After drawing, the warp enters the tangling reed (5), is relaxed in the relaxation zone (6), is warp-oiled by the oiler (7), passes through the warp accumulator (8) (which can store up to 16 m of yarn) and is finally taken up on beam by the beaming machine (9). The full beams are then transported to the weaving machine (10) or to the warp knitting machine (11). Drawing takes place between a 200 mm diameter trio and a second, water-cooled trio in (3). For PA, the first trio has unheated rolls, while for PET the second and third rolls are heated, and a heated plate is located between the two trios. The draw ratio can be continuously adjusted up to 1 : 5 by thyristor-controlled DC motors. Rubberized pressure nip rolls

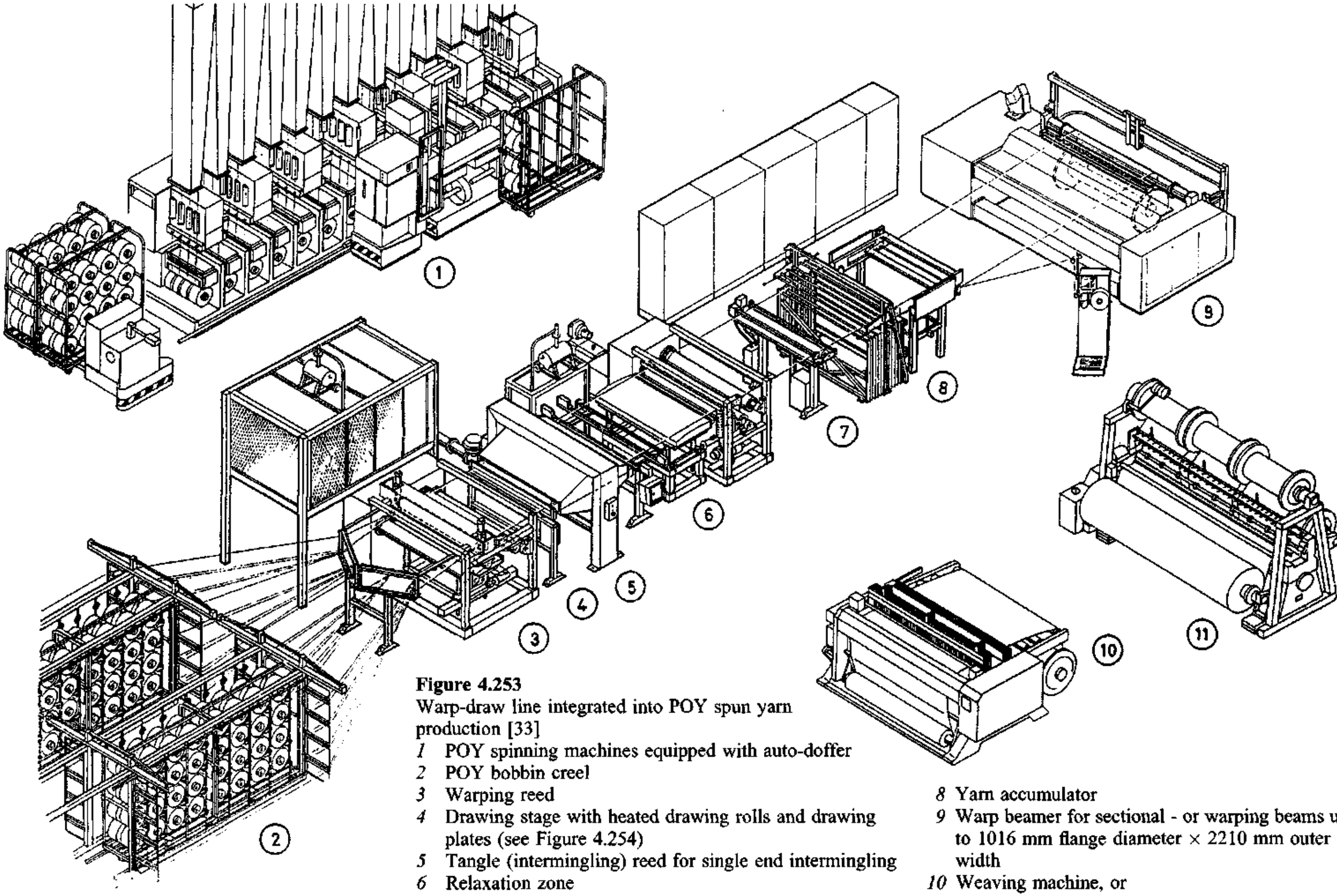


Figure 4.253
Warp-draw line integrated into POY spun yarn production [33]

1 POY spinning machines equipped with auto-doffer
2 POY bobbin creel
3 Warping reed
4 Drawing stage with heated drawing rolls and drawing plates (see Figure 4.254)
5 Tangle (intermingling) reed for single end intermingling
6 Relaxation zone
7 Warp reed and oiling
8 Yarn accumulator
9 Warp beamer for sectional - or warping beams up to 1016 mm flange diameter × 2210 mm outer width
10 Weaving machine, or
11 Warp knitting machine

control the warp inlet to, and outlet from, the draw stands. The machine size (without working space) is ca. 20 m × 5 m. A waste yarn winder allows a broken end to be replaced and/or can be used for quality control.

The yarn transport buggies and creels are those typically used in the textile industry, and the draw rolls (including bearings and drives) are similar to those used for drawing wide staple tows. The photograph, Fig. 4.254 [33], shows details of the drawing zone, including the pneumatically-driven presser rolls described above. The heated drawing plate lies between the rolls, and can be pneumatically depressed to avoid contact with the warp sheet, which is done at a line stoppage. The beamer is the same as that used in warping.

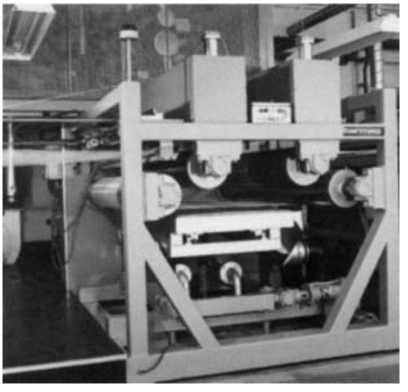


Figure 4.254
Drawing section of the draw-warping line shown in Figure 4.253 [33]

A warp-sizing (slashing)- and drying unit can be integrated into such a warp draw line. It is, however, advisable to work with a greater threadline separation to avoid sized ends sticking together, and to use the smaller hosiery beams [194]. Twelve such hosiery beams are then assembled onto one (larger) weaving beam. After sizing (slashing), the warp sheet is dried in a 2 × 5 m long air drying oven, followed by contact drying on a 5 roll hot calender. The line is designed for standard warping beams of 765 or 1016 mm flange diameter. After drawing, the yarn is entangled before entering the sizing (slashing) bath.

Warp draw lines manufactured by [208] have a working width of 1600...1900 mm, an installed power of 130 kVA and a drawing force of 2500 N; the line previously described [33] is designed for a working width of 1600 mm and a drawing force of 4000 N. A warp draw line which has the drawframe gearboxes in the center and the draw rolls protruding both to the left and right, is provided by [210]; here there are two half-sheets, one on either side of the central gearbox. For PA66, a 2-stage drawing zone is recommended, and a single zone for PET. The drawing rolls are heated 5...20 °C above the glass transition temperature of the polymer. A further system [24] employs wet drawing, intermingling, sizing (slashing), high frequency drying followed by 5-roll hot calender contact drying and beaming. These machines are particularly well-suited for microfilament yarns.

4.12 Texturizing and Drawtexturizing

Texturizing (or texturing) aims to convert the “synthetic” appearence of flat yarns to a more acceptable textile aesthetic and to confer on these yarns the properties associated with natural yarns such as wool and cotton, which have an inherent crimp or bulk. Further effects, such as high voluminosity or high elasticity, are also taken advantage of, but are often largely cancelled out in a further processing stage, as, e.g., in double heater, set yarns.

The first torsion crimping processes were developed by Heberlein [212] and Bemberg [213], but because hydrated cellulose yarns are not stable when wet, the process was not implemented before 1940. The first machine for the continuous crimping of horse hair-like yarn of 1100 dpf in bundles of ca. $(1 \ldots 2.5) \times 10^6$ denier, followed by decrimping, was built by Fourné [214]. Stabilization was achieved by using formaldehyde derivatives. Heberlein [212] licensed Helanca® [215], a polyamide, world-wide. In 1952 Fourné converted doublers to produce highly elastic PA6 bulked yarns [216, 217], first using the real twist process and—after 1954—using the false twist process. In 1952 texturizing throughput was 100...300 kg/1000 spindles per month; today it is 100...600 t/1000 spindles per month, depending on titer. World production of textured yarns reached 1.8×10^6 t/a in 1977 and 15×10^6 t/a in 1988.

Table 4.42, derived from [219, 220], gives an overview of known texturizing processes. The real twist process [217, 218], the Agilon® process [221] and chemically-induced texturizing are currently not of commercial interest. The twist separation process, knit-de-knit and gear crimping [222] do not contribute significantly to total world production.

4.12.1 Comparison of Texturizing Processes

The following overview gives a short description of the various texturizing processes and the most important characteristics concerning the texturizing aggregates, including the yarn properties thereby achieved. The overview is arranged according to:

- the classical process [217]
- the effects on yarn elongation:
  with spindle twist, preferably using magnetic bearings, or with 3 spindle friction disk aggregates, or with crossed belts, or with disks
- yarn drawing: without drawing (i.e., ex draw twist pin), or with sequential drawing, or with simultaneous drawing.

Today the simultaneous drawtexturizing process (i.e., twisting and drawing in one stage) is almost exclusively used for apparel titers. In contrast, BCF is only produced via the sequential process. The

Table 4.42 Texturizing Processes—Overview

Process				Examples
Mechanical		Air jet process (cold)		Taslan®
Mechanical/thermal	Torsion process	Real twist process		Texturized yarn
	Torsion process	False twist process	single heater	<1960
			double heater	>1957 set yarn
	Torsion process	Twist/detwist process		
	Torsion process	Twist separation process		
		Stuffer box crimping		Banlon®, Staple
		BCF gas jet process		BCF
		Knit-de-knit process		
		Edge crimping process		Agilon®
		Gear crimping process		
Chemical/thermal		Bicomponent		
Chemical		Salt solution baths		<1950

mechanical stuffer box is no longer used for textile yarns and has limited application for BCF yarns, but is absolutely dominant for the crimping of wide tow to staple fibers. Knit-de-knit is also becoming less important.

- The real twist process [213, 217] is shown in Fig. 4.255A. Here the yarn is highly twisted on an uptwister, is heat setted on aluminum foil-wrapped paper tubes which allow shrinkage, is detwisted (i.e., back-twisted to achieve zero net twist), and is then doubled (S and Z) to achieve zero torque yarn.

  The disadvantages of this process were the very low throughput rates and the somewhat "sharp" or spikey appearance of the yarn and/or finished goods, unless the process parameters were maintained exactly constant (Fig. 9.8).

Under the effects on yarn elongation (Fig. 4.255B), we distinguish between:

- HE (highly elastic) and set (i.e., double heater) yarns. Both of these yarns are produced in a continuous process involving twisting, heat setting, cooling and de-twisting. Twist is inserted by a false-twist generating aggregate: the twist runs from the aggregate back towards the first delivery roll, is set in, and is then de-twisted between the aggregate and the second delivery roll. If the texturized yarn is then wound up at low tension, HE yarn is obtained. If, instead of winding up, the textured yarn is relaxed through a second heater, allowed to cool and is then wound up at low tension, so-called set yarn is obtained. The first (primary) heater is a contact heater, and the second (secondary, setting) heater is a convective heater; both are Dowtherm (Diphyl) vapor-heated. The cooling plate after the primary heater is also of the contact type.

  Approximate throughput at various titers is:

Titer (den)	30	60	90	120	150
Throughput at 1000 m/min ($\eta \approx 0.9$) [kg/pos/24 h]	3.89	7.78	11.66	15.5	19.4

  Figure 4.256a shows typical longitudinal views of the above three textured yarn types.

In terms of the drawing mode (Fig. 4.255C), we distinguish between:

- Sequential- and simultaneous drawtexturizing. LOY yarn should be drawn in one stage and be continuously texturized in a second, following stage (sequential drawtexturizing). Although POY yarn can also be processed as above, it is advantageous to draw and texturize POY in one step (simultaneous drawtexturizing). The yarn appearance and physical properties of HE and set yarns processed by the sequential and simultaneous routes do not differ significantly, provided that both are friction-textured.

The type of twist insertion aggregate also differentiates the various false-twist machines:

- Magnetic pin twist spindles (diabolos) (Fig. 4.257A) rotate in the gap formed by two pairs of rotating disks and are held in position magnetically. They impart a positive twist to the incoming yarn: one revolution of the spindle imparts one turn in the yarn. If pre-twisted yarns are texturized, the pre-twist remains. The maximum spindle rotational speed (1990) is 800 000 r/min, which results in a maximum yarn speed of 250…350 m/min. Pin twist is therefore used mainly for very high or very low twist levels, as well as, e.g., for profiled special yarns. The appearance of the textured yarn is similar to that shown in Fig. 4.256a (A).
- Three spindle, disk friction false-twist aggregates (Fig. 4.257B) generate twist by friction between the disk and the yarn. The twist inserted depends on the so-called D/Y ratio, the ratio of the disk circumferential speed to the yarn speed; the D/Y ratio is typically 2.0. Disk rotational speeds are of the order of 18 000 r/min. The friction aggregate shown in Fig. 4.257B is the most widely used today. Further details can be found in Section 4.12.2.2. The textured yarns produced by this system can be seen in Fig. 4.256a (B1, B2).
- The nip twister (NCV = nip controlled vector drive, Fig. 4.257C) achieves an almost slip-free friction twist at the point where the two belts, pressing against one another, cross. The yarn twist is determined by the yarn speed and the belt speed vector (corresponds to the D/Y ratio), and is variable. For a single yarn, 8 mm wide belts are used; for double yarns, the belt width is 14 mm.
- The disk false-twisting unit (Ringtex = NCV drive, Fig. 4.257D) achieves a practically slip-free

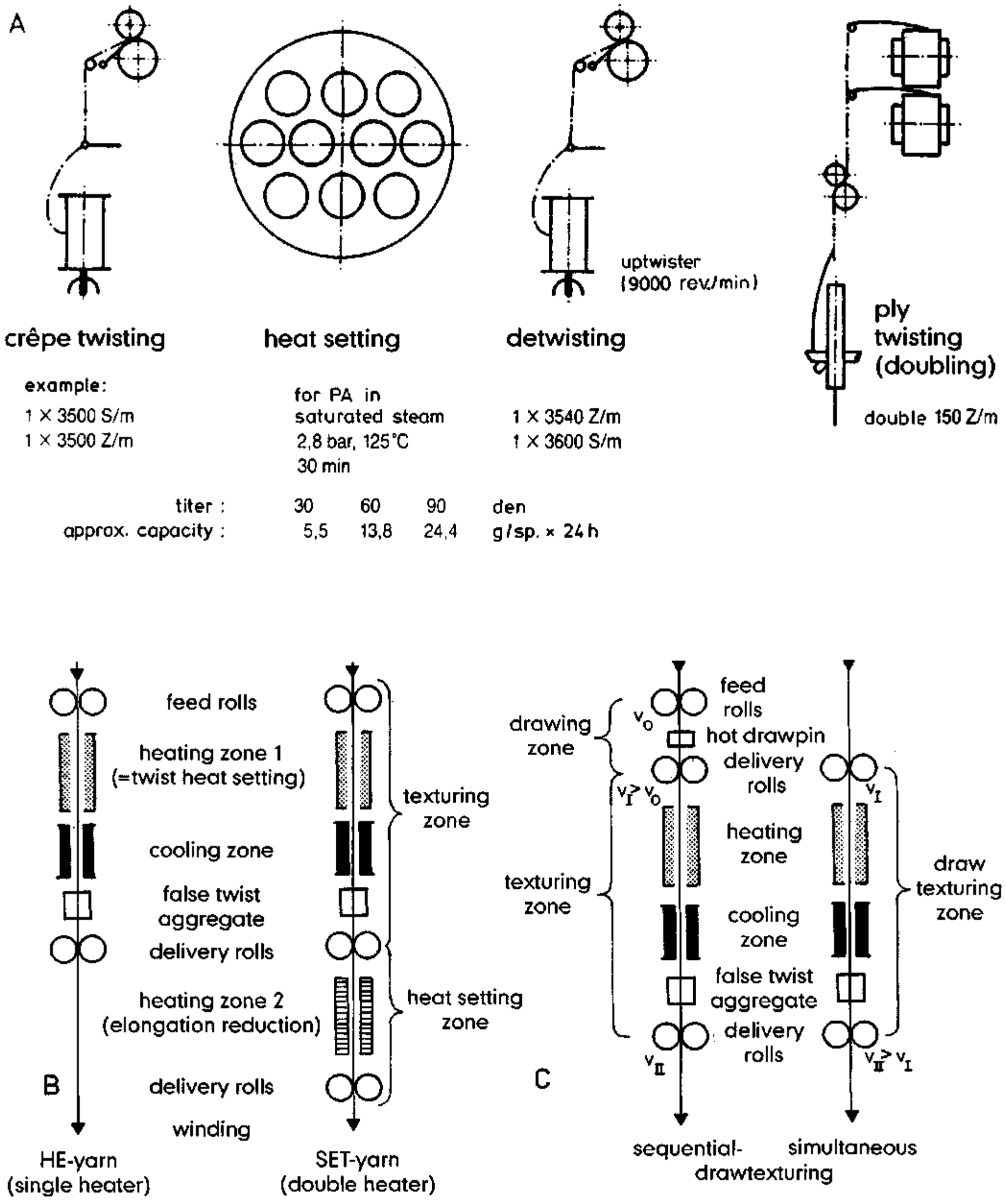


Figure 4.255 Torsional texturizing processes

A) Real twist process

B) Different processes for influencing yarn twist: highly elastic (HE, single heater) yarns and heat set yarns (double heater)

C) Different methods of yarn drawing: sequential (= separate drawing and texturizing zone) and simultaneous drawtexturizing (= drawing and texturizing in one zone)

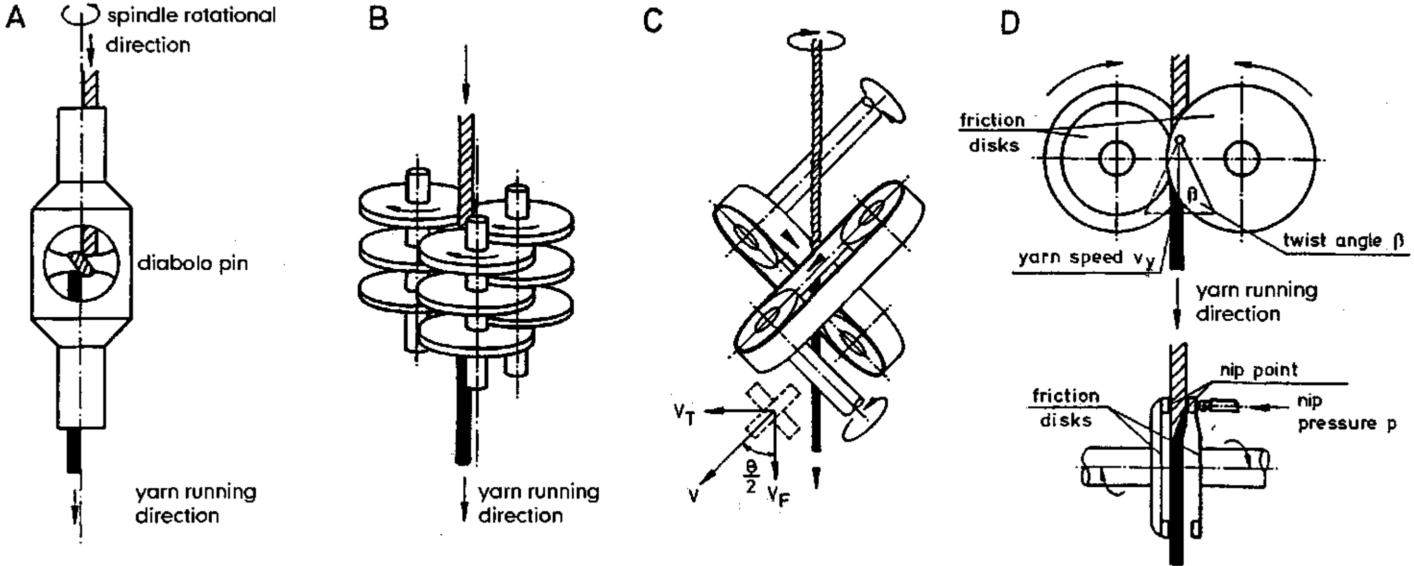


Figure 4.257
The most important aggregates or processing elements for the various texturizing processes
A) False twist magnetic spindle, inserted in the gap between two pairs of double, rotating drive disks
B) False twist friction disks
C) False twist double belt system (nip twister)
D) False twist double flat disk system (Ringtex)
(*Continued on page 437*)

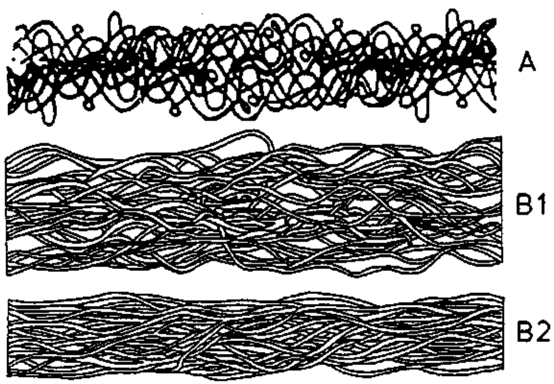


Figure 4.256a
Microscopic views of yarns processed as per Figure 4.255B
A) According to the real twist process (mainly known as Helanca®)
B1) HE (single heater) yarn } continuous processes
B2) Heat set yarn (double heater) } continuous processes

friction twist insertion at the contact point between two rotating circular friction surfaces. At least one disk is pressed against the other by a compressed air piston to form the contact point. The ratio of disk circumferential speed to yarn speed at the contact point (r/y ratio) and the twist angle β determine the yarn twist. r/y is typically 1.4, and the maximum yarn speed is around 1000 m/min. The appearance of the NCV textured yarn is similar to that shown in Fig. 4.256a (B1, B2).

- In the twist separation process (Fig. 4.257E), two multi- or monofilaments are separately led into the twist unit, are twisted together, heated and cooled together, and finally separated by means of a special aggregate (e.g., "Twisttex"). Twist stopper rollers are necessary in the inlet zone. Two compensation rollers having approximately the same yarn speed run in the twist separator aggregate; no other rotating parts are required for separating the two yarns. The construction is simple, the energy requirement is low and the unit does not generate much noise. Threading up requires an auxiliary twist unit.

  The Twisttex aggregate of Retech AG [336] is self-regulating and requires no drive. For fine titers, the maximum yarn speed lies between 600 and 1000 m/min. The twist level achievable is limited. The textured yarns have average to high stretchability and elasticity, large-loop texture and exhibit, to some extent, torque-liveliness. The two yarns sometimes also exhibit differences in texture, depending on process conditions (Fig. 4.256b).
- Air jet texturizing (Fig. 4.257F) is particularly suited to PET POY, which is first drawn on a heated draw pin in the first zone. The yarn is overfed into the texturing zone. Texturing is carried out either in a Venturi jet with an impact plate at the end or in a smooth bore tube having asymmetric compressed air inlet jets which blow the yarn at an angle against an impact sphere. Yarn uniformity is improved by wetting the yarn before entry into the texturizing jet. In the heat-setting zone, the yarn shrinks and is compacted and stabilized. Yarns with protruding single filaments and other effect yarns can be produced by the process. For yarn titers of 100...3000 dtex running at ca. 500 m/min and using compressed air at 8...10 bar pressure, the air consumption is ca. 8...15 Nm^3/h per jet. The air jet texturing process is suitable for processing PA, PP, viscose, acetate and glass fiber yarns.
- Stuffer box texturing (crimping) using a mechanical stuffer box chamber (see Fig. 4.308) requires fully drawn yarns or tow. The yarn or tow is forced into the stuffer box by two opposed delivery rolls acting in a pinching mode. The stuffer box can be heated or cold or can have steam injection at the inlet. Steam injection improves crimp, crimp uniformity and dye uptake regularity. While continuous filament yarns are seldom processed using this system (compare Fig. 4.270), the mechanical stuffer box is predominant in the crimping of staple fiber tows. For crimp character, see Figs. 3.60 and 9.8.
- The gas-dynamic stuffer box texturing process (see Figs. 4.281 to 4.286) can be used in a separate texturing process, independently of spinning (i.e., using drawn yarn feedstock), as well as—and especially—in an integrated spin-draw-texture-wind process; such latter machines are described in Section 4.12.6. Here the spun yarn travelling down from the quench chamber is first drawn between two heated godets and/or duos, is then aspirated at full yarn speed into the texturing jet using heated compressed air, and is practically brought to a halt by impact with the yarn plug in the section where the gas is separated from the yarn, the gas exiting the chamber sideways, while the filament bundle opens and the tangled yarn is continuously folded on the upper surface of the yarn plug. The yarn plug exits the end of the texturing jet and falls onto a rotating cooling drum. Here the loose plug is pulled against the cooling drum and cooled by the inspiration of room air through the drum. The cooled yarn is taken from the drum, and—after passing the relax rolls—is wound up as a package by the winder. The yarn bulk can be influenced by the hot air temperature and pressure, as well as by the individual speeds of the machine rolls. The bulked yarn is voluminous to very voluminous, has a soft or fleecy handle, a low elongation and low elasticity. The appearance of the yarn is as in Fig. 4.256c (A).
- The knit-de-knit (crinkle) process is a relatively cumbersome method which gives a specific crimp structure (Fig. 4.256c (B)). Before bulk development, the yarn is highly stretchable and has a marked wavy crimp structure, derived from the knitting stitch. After bulk development, the crimp has a wavy, two-dimensional, overlapping structure. The yarn is produced by knitting a sleeve from drawn yarn on a circular knitting machine. The knitted sleeve is then beamed and either heat set in saturated steam or dyed at high temperature, after which the sleeve is unravelled to give single yarns. Polyamide yarns of from 11 to a few thousand dtex are the preferred feedstock. Polyester does not give sufficient crimp stability.

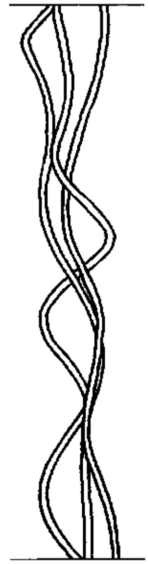


Figure 4.256b ▶
Twist-separation crimped yarn

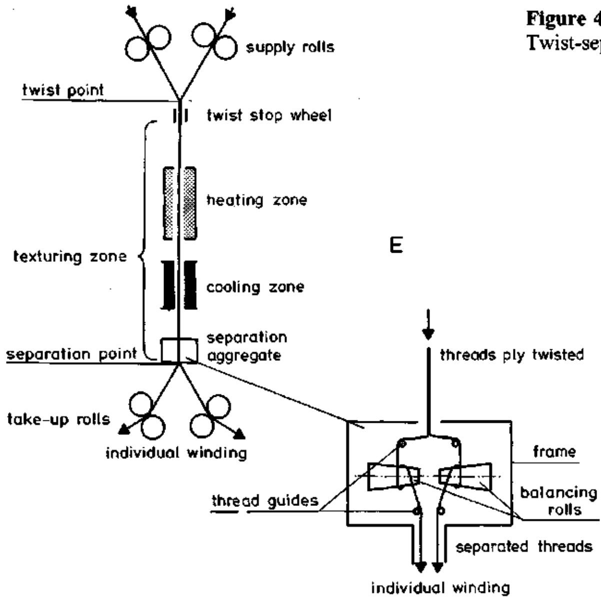


Figure 4.257
E) Twist-separation texturizing process

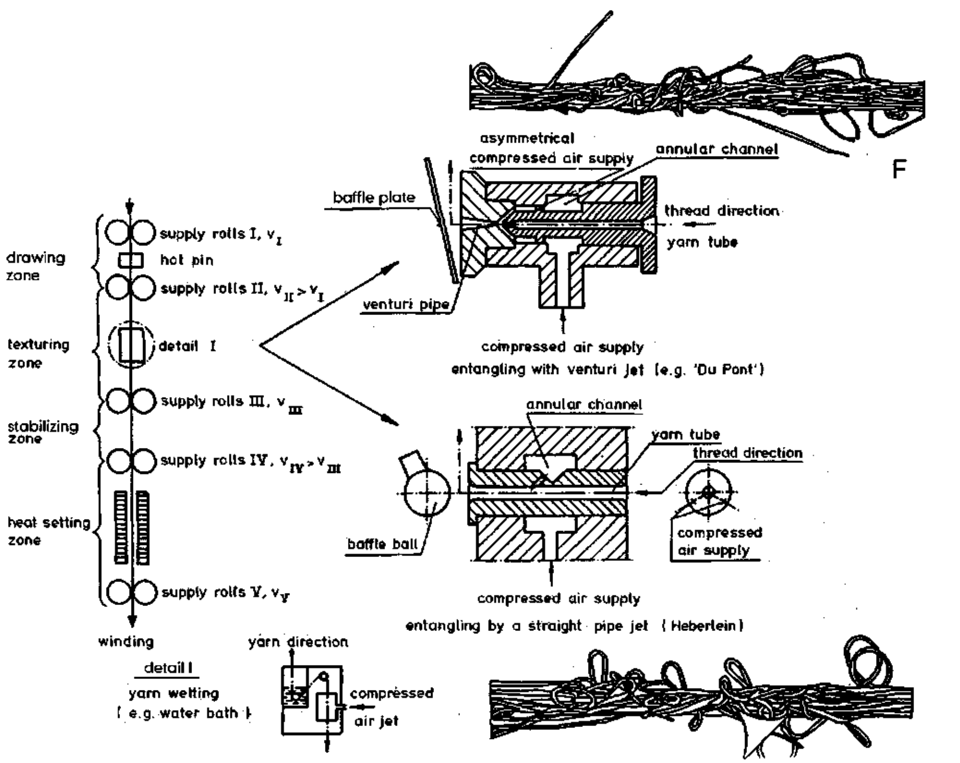


Figure 4.257
F) Air jet texturizing jet using cold, compressed air. Above: Du Pont; below: Heberlein (*Continued on page 439*)

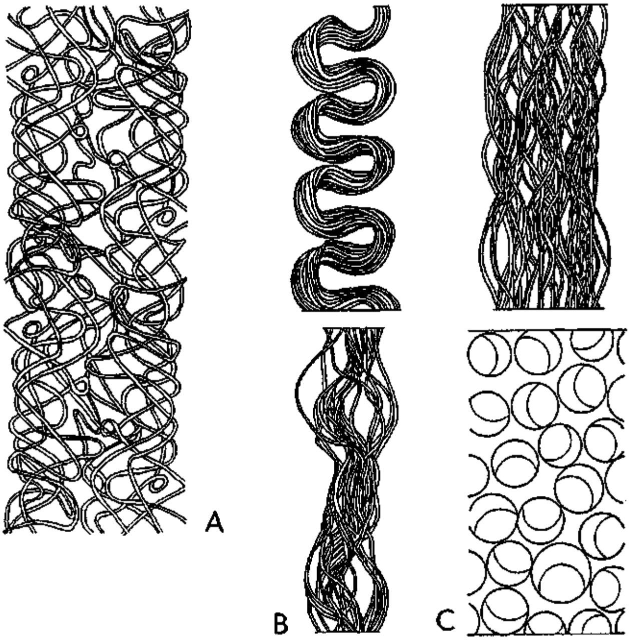


Figure 4.256c
(*Continued from page 437*)
Microscopic view and cross-sections of yarns texturized by various processes

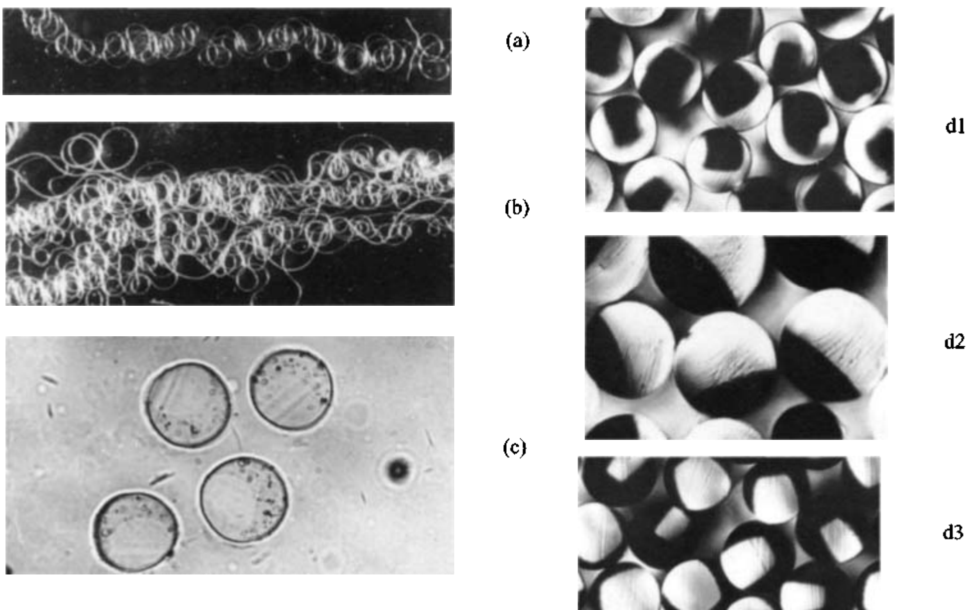


Figure 4.256d
Bicomponent spinning processes: factors affecting bicomponent S/S yarn [150]

a) Longitudinal view of 2 PA66/Co-PA66 monofilament yarns

b) Longitudinal view of PA6 multifilament yarn (HE, single heater)

c) Microscopic cross-section with η_{rel}	PA6 bright $=3.2$	PA6 semi-dull $=2.7$
d) Microscopic cross-section	PET (clear)	PET (black), both having $[\eta]=0.67$
1 Spinning temperature	305°C	280°C
2 Spinning temperature	290°C	287°C
3 Spinning temperature	280°C	305°C

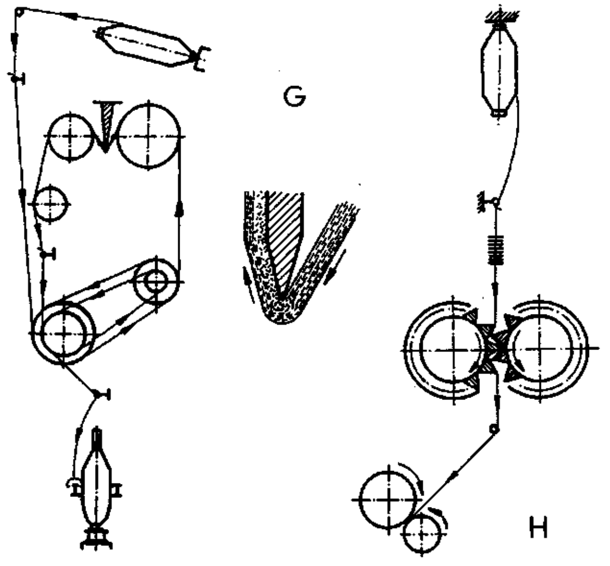


Figure 4.256c
G) Edge crimping process (known as "Agilon", this process is no longer used because of its poor crimp stability)
H) Heated intermeshing gear crimping process; the gear teeth are specially profiled

- Bicomponent texturing is described in detail in Section 5.2. Bicomponent fibers, made from polymers of different shrinkage, only develop bulk when the two components are eccentric to each other, functioning best when side-by side configuration is used (= S/S type, Fig. 4.256c (C) and 4.256d). After drawing, bicomponents develop bulk either directly or after a shrinkage treatment.
  Bulked bicomponent yarns have a poorer crimp stability than mechanical/thermally-crimped yarns, and are therefore not at present suitable for use as carpet yarns. Fine titer bicomponent lingerie made from polypropylene has also not achieved the required shape retention.

4.12.2 False Twist Texturizing Machines

4.12.2.1 Construction and Components

By far the greater amount of textile apparel yarns is texturized, predominantly on false twist machines. The best-known false twist texturizing machines are shown in Figs. 4.258 [33] and 4.259 [226]. Both of these machines are supplied as single heater and double heater machines. Figure 3.39 shows possible yarn paths and heater configurations. Components bearing the same numbers in Figs. 4.258 and 4.259 have the same function, even if they differ somewhat in constructional details:

- The bobbin creel always has two bobbins per threadline to enable the free end of the reserve bobbin to be knotted in or spliced to the transfer tail of the running bobbin (transfer creel).
  Figure 4.260a shows a simple creel of this type. The creel on the left is for four running threadlines = two false twist heaters. In (b) it is shown how the creel peg swings outwards to facilitate bobbin changing. A carrousel creel (Fig. 4.260c) also facilitates rapid bobbin changing, particularly for large POY bobbins.
- The yarn supply system can be like that on a drawtwister (Fig. 4.243), with one or many wraps around the feed roll, or it can comprise a rubberized presser roll exerting its weight on the delivery roll as the supply yarn makes a 3/4 wrap around the latter. (See Fig. 4.261b, [226]). The delivery system using rolls and rubber belts (apron feed, Fig. 4.261a [33]) has also proved successful. To thread up, the apron is disengaged from the roll. After re-engagement, the apron automatically runs over two tensioners fitted with ball bearings, which clamp the yarn, thus ensuring slip-free delivery.
- Heaters: In sequential drawtexturizing, the same hot draw pins (Fig. 4.246) and/or plate heaters (Fig. 4.245) are used as for drawtwisting. In many cases, centrally-heated thermal oil is used.

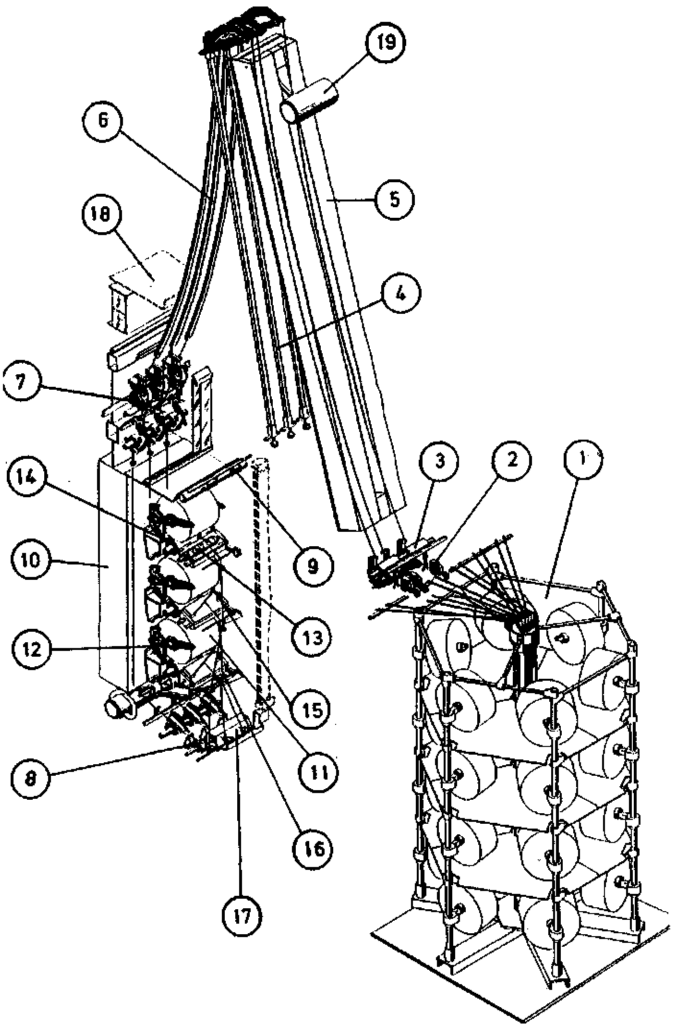


Figure 4.258
Barmag Type FK6 M80 [33] false twist drawtexturizing machine. Yarn path is no. 2 in Figure 3.39

1 Spun yarn creel
2 Yarn cutter
3 Feed roll
4 Heater string-up device
5 Primary heater
6 Cooling plate
7 Texturizing aggregate
8 Yarn sensor
9 Yarn sucking
10 Secondary heater
11 Bobbin winding
12 Bobbin holder
13 Traverse cam
14 Friction drive roll
15 Traverse guide
16 Yarn guide bar
17 Spin finish application
18 Possible operating platform
19 Aspiration

Up to about 1980, electrically-heated twin track primary heaters were used; these have now been abandoned because of poor temperature uniformity [33].

For the normal temperature range of 160...ca. 240 °C, Dowtherm (Diphyl) vapor heating is used exclusively, both for primary and for secondary heaters. According to the schematic in Fig. 4.262, a liquid sump (a) is located at the bottom of the Dowtherm vapor-heated body of the heater. An electric resistance heater in the sump vaporizes the liquid Dowtherm, which then heats the yarn contact surface (d) or the tubes (f) (from the outside) [33, 226, 172]. The condensate drains back into the sump.

Temperature sensors (c) and (g) must indicate the same temperature. Since this system operates under a vacuum, the liquid- and vapor volumes must be absolutely gas-tight. While the twin-track primary heater transfers heat to the rapidly twisting yarn through contact, the tubular secondary heater must heat the almost tensionless, bulked single filaments by convection. The tube of the secondary heater is sealed at the top and bottom by Al_2O_3 eyelet guides, both to prevent yarn contact with the tube and to minimize heat loss.

For yarn speeds of 1000 m/min, the primary heater should be 2.50 m long, the secondary heater 1.60 m. Primary heaters (twin track) have an installed power of 330 W, secondary heaters of 100 W

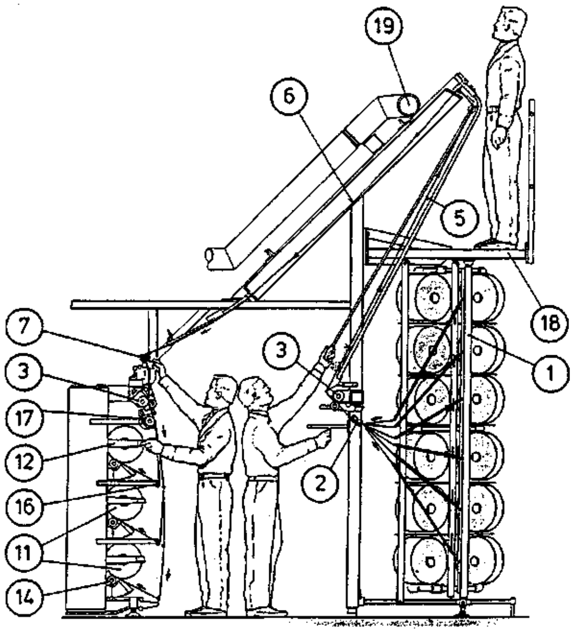
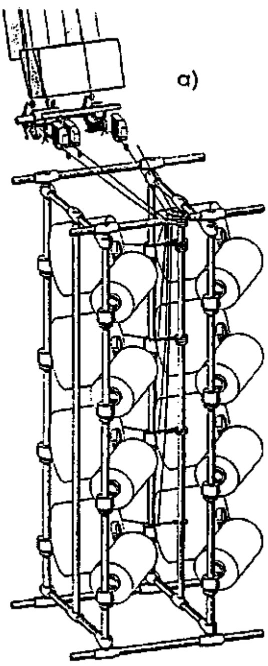


Figure 4.259
Rieter-Scragg Type SDS1200A false twist drawtexturizing machine [226]. Yarn path (modified) is no. 5 in Figure 3.39. Heater length: 2 m; Cooling plate contact length: 1.5 m. Recommended for multifilaments of ≤40 dtex. Single heater machine. (For *1* to *19*, see Figure 4.258)



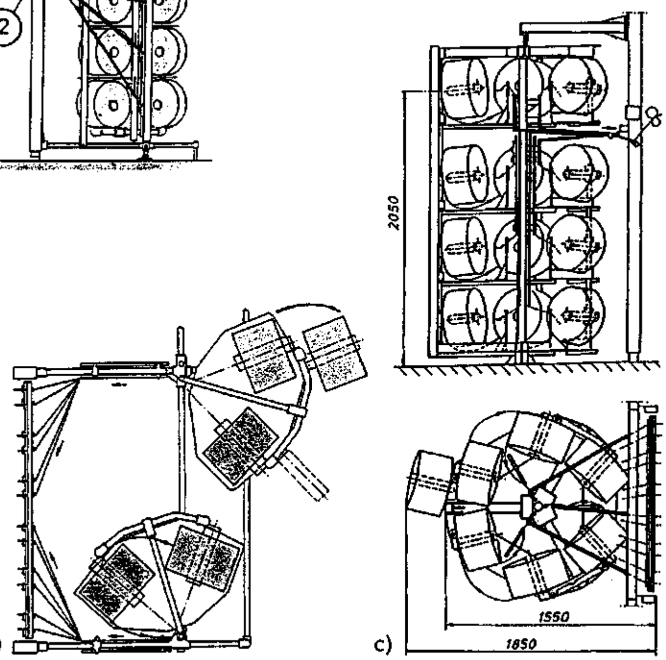


Figure 4.260
Creels for false twist texturizing machines
a) Simple creel for 2 × 4 running ends, with reserve package for knotting in [33]
b) Swivel creel for 2 × 6 running ends, having additional swivel function for individual packages and for reserve package knotting in (transfer) [226]
c) Carousel creel, with reserve package knotting in (transfer), for 2 × 6 running ends [226]

per tube. Actual power consumed is ca. 55...70% of the installed power. Care must be taken to insulate the primary heater well, including the openable door.

Depending on detailed design, the minimum heat flux required for hot draw-plates is 1.1...1.3 W/cm^2, while the maximum flux—even for hot plates of a few m length—is ca. 2.8 W/cm^2. The temperature uniformity of these hot plates is at best ±4 °C at 200...240 °C for a 400 mm

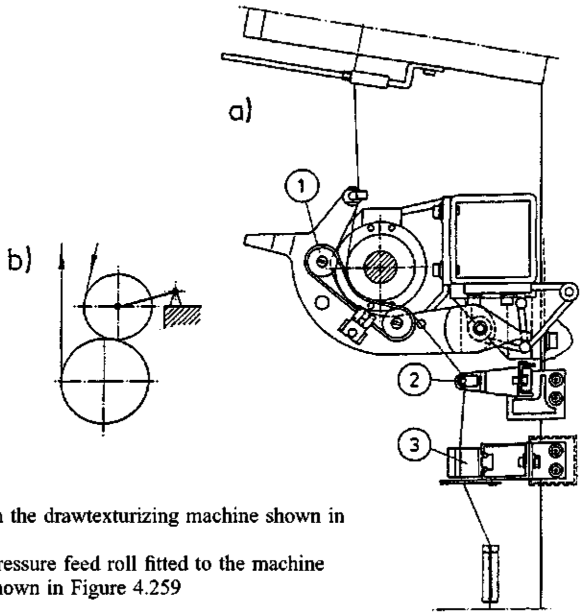


Figure 4.261
Yarn input roll with apron feed [33], from the drawtexturizing machine shown in Figure 4.258

a) *1* Apron feed
2 Yarn sensor
3 Yarn cutter

b) Pressure feed roll fitted to the machine shown in Figure 4.259

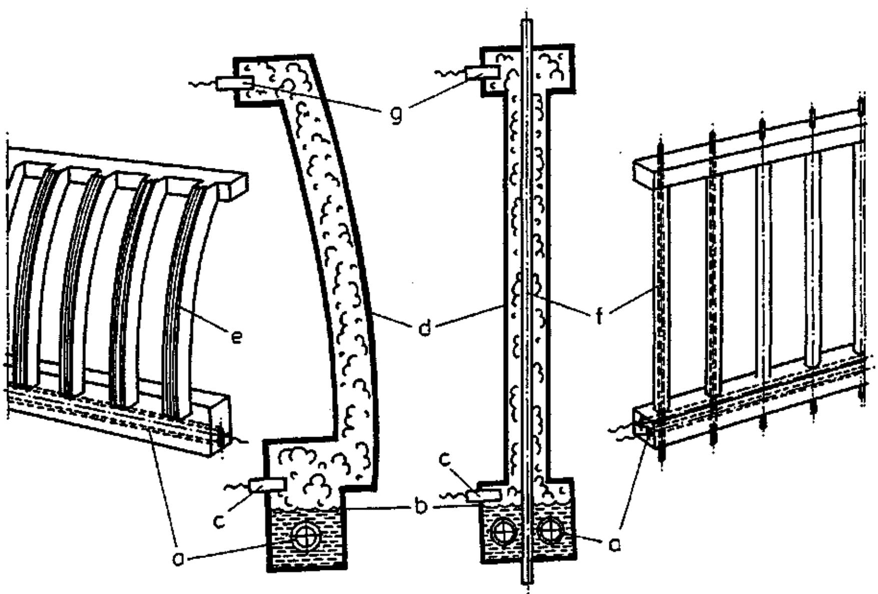


Figure 4.262
Electrical Diphyl (Dowtherm) vapor heating systems for primary heaters (grooved) and secondary heaters (heated tube) in drawtexturizing machines [172]

a) Electric heater in liquid Diphyl sump
b) Diphyl liquid level
c) Lower temperature sensor
d) Diphyl vapor volume
e) Double grooves in heater
f) Secondary heater tubes
g) Upper temperature sensor

long plates, and ± 8 °C for 1600 mm hot plates, both deviations being measured over the working length of the heater. In contrast, the Dowtherm vapor-heated tracks, tubes and pins achieve a temperature uniformity of ± 1 °C over their working dimensions.

The present generation (1992) of false-twist texturizing machines is reaching its limit of operation because the lengths of the heaters and cooling plates rule out an increase in processing speed. For higher speeds new shorter heaters, operating at higher temperature differences, are required. Such heaters are convective and only ca. 0.6 m long when operating at 500 °C.

- Coning oil applicators: Part of the spin finish is vaporized on the primary heater. To compensate for this, as well as for later coning, coning oil is applied by rolls before take-up. The plasma-coated lick rolls run in small, stainless steel troughs, which are held at constant liquid level. The lick rolls are driven at ca. 4...12 r/min by a continuous driveshaft running the length of the machine.
- Take-up: The take-up shown in Fig. 4.224 [224], among others, is suitable for up to ca. 1200 m/min. It must be possible to make either straight-edged or biconical cross-bobbins, depending on customer requirements. For retrofitting, take-ups similar to those in Fig. 4.224 are used.

In order to keep a large number of complicated machines, mostly with 216 positions, in continuous operation throughput the year, various auxiliary devices are required, and maintenance and cleaning must be done from time to time:

- A large percentage of the spin finish vaporizes and cokes in the tracks of the primary heaters. These fumes must be uniformly aspirated from all primary heaters into a common fume duct, which is connected to a high pressure suction fan. The exhaust air is expelled to atmosphere, preferably through a washer (scrubber).
- Yarn aspiration tubes are located just above the take-up winders. Their apertures can be opened or closed by means of a threaded sleeve. From these tubes, the yarn is aspirated into a waste collector held at negative pressure by a high pressure fan; the high pressure side of the fan expells the exhaust air above the roof of the building.
- Yarn sensors—mostly without contact—are placed between the coning oil applicator and the winder. The yarn cutter, activated by the sensor at a yarn break, is located between the creel and the yarn feed roll.
- Threading-up aids: The present high processing speeds and the height of the machines (4 to 6 m) dictate that string-up aids must be used, so that a man, standing on the ground, can thread the yarn up over the heater and cooling plate. The primary heater string up tool [33] has a yarn guide at its extremity. The guide is pulled down, the yarn is put into the yarn guide, and the guide is then pushed upwards into the operating postion. Similar tools are required for other two-storey operations.
- Depending on the height of the texturizing units above floor level, a service platform trolley having a number of steps may be required. The trolley, having its guard rail on the creel side, runs between the texturing aggregates and the creel. On receiving the weight of a man, the trolley automatically locks in position.
- Noise protection: As the noise level, comprising unpleasantly high frequencies, is usually > 90 dB, it is recommended that the texturizing aggregates be encapsulated with noise-protection material. In addition, workers should be equipped with ear protectors.
- Housekeeping (cleaning): Despite the aspiration of finish fumes, a mixture of spin finish, monomer and dust deposits on some machine parts. Depending on plant experience, these contaminated areas must be regularly cleaned according to a laid-down cycle. Particularly vulnerable to these deposits are yarn guides and the primary heater inlet and exit sections, as well as machine parts above the latter.
- Spare texturizing units should be available in sufficient quantity to avoid time-consuming repair work on the machine.

4.12.2.2 Texturizing Aggregates

The most important difference between false-twist texturizing machines lies in the false-twist aggregates. The pin twist aggregate (Fig. 4.257A) has a limited range of application nowadays and is used practically only for speciality yarns. Most aggregates in use today are of the friction disk type, particularly for PET set yarns and for fine titer high bulk PA yarns.

- Magnetic spindle false-twist aggregates
  Magnetic spindles are designed for up to 800 000 r/min, possibly for even up to 10^6 r/min. Their development began in 1952 [229] with a spindle rotor for a maximum speed of 90 000 r/min. In 1954/55 Fourné used a disk driven spindle reaching ca. 50 000 r/min, and Richter [230] attained 64 000 twists/min with a duo double threadline false-twist spindle. The currently-used system is shown in Fig. 4.263. The spindle has an internal diameter of 0.65 mm for up to 56 dtex, 1.0 mm for up to 167 dtex and 1.3 mm for up to 220 dtex. The spindle is forced to run in the gap between two rotating disk pairs by a magnet; the drive transmission ratio is 17 : 1. This gives a spindle speed of 600 000 r/min when using a magnetic spindle of 2 mm outside diameter and a drive belt speed of 25.87 m/s. The frictional heat generated is removed by a centrifugal air flow of 1.2 Nm^3/h. The yarn (F) is wrapped around the sapphire pin (S), ensuring that the yarn is twisted by the spindle. Because the yarn runs through the spindle in the axial direction, the yarn balloon is small. Figure 4.264 shows the construction of such an aggregate: top view, left for S-twist, and right for Z-twist. The twist direction can be altered by having the belt run in front of or behind the drive spindle. Figure 4.265 gives the drive power of such an aggregate and Table 4.43 machine settings for a pintwist PET set (double heater) yarn process [229].
- Friction disk false-twist aggregates
  Around 1960, hollow spindle friction aggregates were built. The spindle had rounded internal edges, and the yarn made 90° angles with the friction tube at both inlet and exit. Because of threading up difficulties, this system was abandoned [231]. It was only with the use of friction disks, the most widely-used twist aggregate today, that it became possible to thread the yarn through the twist aggregate using a yarn aspirator (suction gun). Friction aggregates for 22...220 dtex PET and PA POY are available as single aggregates (Fig. 4.266 [176]), as well as double aggregates, for belt-driven speeds of 12 000...20 000 r/min. The friction disks—which are exchangeble—can be selected from Table 4.44 as a function of disk material and yarn titer.

  Polyurethane disks are particularly suited to fine PA yarns; the other disk materials are suitable for PET. Many disks (up to a maximum) improve the twist generation and its uniformity, depending—of course—on the material and speed. More than the optimum number of disks can, however, cause

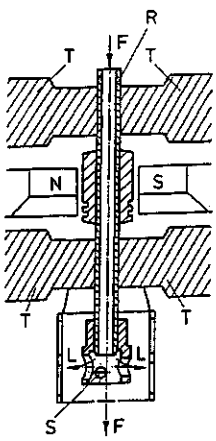


Figure 4.263
Principle of a false twist magnetic spindle
R) Twist insertion tube
S) Twist pin
L) Air outlet
T) Drive disks
N, S) Permanent magnet
F) Yarn

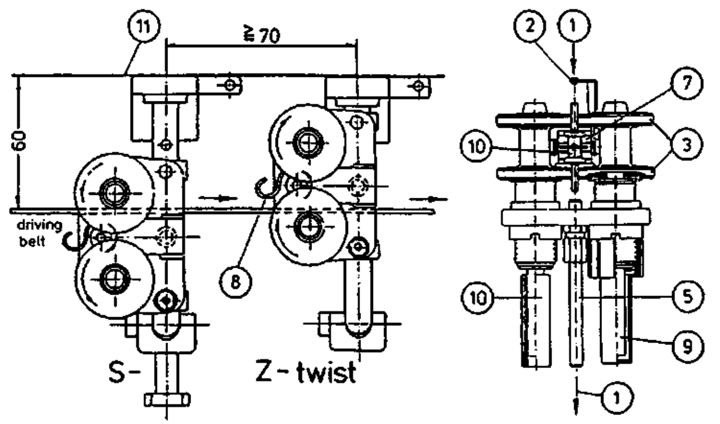


Figure 4.264
Example for mounting for a FAG false twist magnetic spindle for S- and Z twist [176]
1 Yarn inlet
2 Yarn inlet guide
3 Drive (and supporting) disk
5 Yarn guide tube
7 Magnet system
8 Safety hook
9 Roll journal
10 Whorl
11 Existing machine bracket

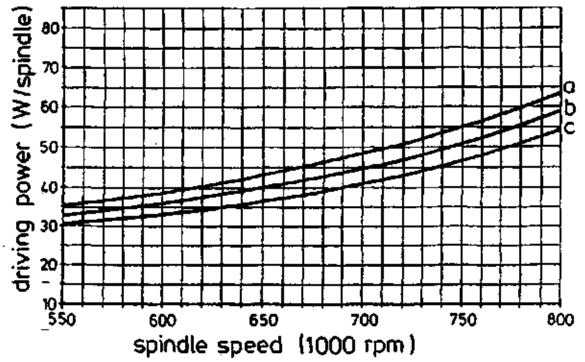


Figure 4.265
Power requirement of FAG false twist spindle [176] (After 20 h running-in-time, belt tension 1700 g, MFD 800, $i = 1:24$) [159]
a) 1/1 duty for a single aggregate with counter disk (S- or Z twist)
b) $\frac{1}{2}$ duty for a double aggregate with counter disk (SS- or ZZ twist)
c) $\frac{1}{2}$ duty for a double aggregate without counter disk (S- and Z twist)

Table 4.43 Machine Settings for a Magnetic Spindle, False Twist Draw-Texturizing Process [229]

Machine type	Heberlein "Unitex" FZ 42/1
Spindles	Double roller, magnetic spindles FBU 808
Yarn (undrawn)	PET POY
Spin titer	300 dtex f30
Final titer	167 dtex f30
Spindle speed	800 000 rev/min
Twist level	2518 t/m
Draw roll speed, roll 2	317.7 m/min
Draw ratio, roll 2: roll 1	1.74
Second heater overfeed, roll 2: roll 3	14.8% (=1.148)
Package take up overfeed, roll 2: winding roll	8.7%
Temperature 1st heater	200 °C
2nd heater	205 °C
Test results	
Titer	182.7 dtex
Tenacity	3.9 cN/dtex
Elongation	33.9%
Crimp contraction	18.4%
Crimp stability	47.8%

processing problems. The stepwise generation of twist in the travelling yarn, from inlet to exit, is illustrated in Fig. 4.267 [230]. The twist transfer from the disks to the fully-twisted inlet yarn (T_1 in Fig. 4.267) can only be approximately estimated. The smallest yarn cross-section is given by: $F = k^2 \times \text{dtex} \times 0.866 \times \cos\beta$, with $\tan\beta = 1000/\underline{[\text{t/m}]} \times d \times n$, where β = twist angle. In false-twist, $\beta \approx 35°$, which makes $d_{\text{twist}} \approx 1.21 \times k \times \sqrt{\text{dtex}}$ [μm]. Accordingly, $i = A_{\text{disk}}/d_{\text{twist}}$ = about 510...580 for 30 dtex and = ca. 220...250 for 167 dtex. At 18 000 r/min disk speed therefore, about $(10.4\ldots4) \times 10^6$ twists/min would be imparted to the yarn. The yarn, however, crosses the disks at less than 45 °, so that only $100 \times \cos 45° \approx 70\%$ of this is converted to yarn twist, corresponding to ca. $(5.2\ldots2) \times 10^6$ turns/min or 5700...2200 turns/m. As—in the case of 30 dtex—only 3540...4170 t/m are required for false-twist, the disk speed must be correspondingly reduced and use be made of slip to attain the correct twist. This can only be more accurately determined by trials.

Figure 4.266a (left) shows the aggregate opened up for threading, and (b) the aggregate in the running position, with the lever closed and the yarn in the twisting position [229].

Ceramic disks are mainly used for PET [233]; for fine titer PA, plasma-coated disks are also used. Nickel and diamond-coated disks are seldom used. Hardened polyurethane disks [176] give better

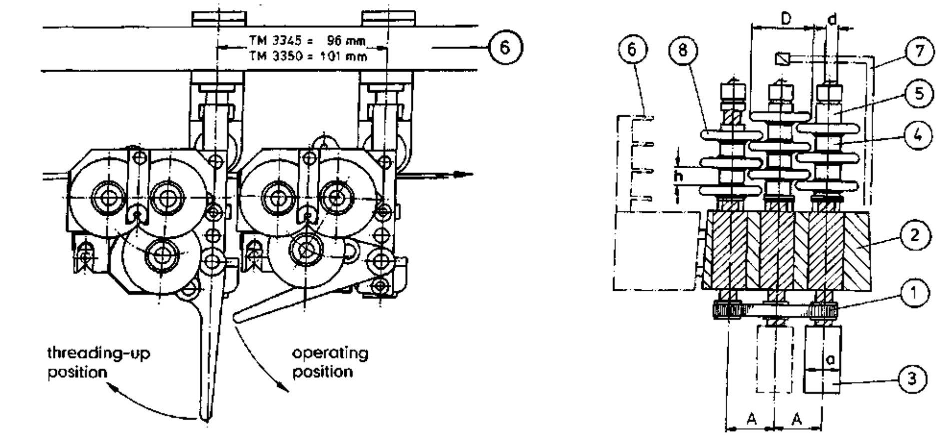


Figure 4.266 *a*) Friction texturizing disk assembly [176]

2 Bearing
1 Timing belt
4, *5* Spacing bushes
3 Whorl
6 Machine mounting bracket
7 Protective cover (to reduce noise and fouling) and yarn guide
8 Friction disks

FAG type	FTS 471	FT4717
A	33.7	38.5 mm
d	12	12 mm
D	45	50 mm
d_l	26	26 mm
u (10 000 r/min)	1413.7	1570.7 m/min
$\approx n_{yarn}$ 100 dtex PET slip-free	4.016	$4.462 \cdot 10^6$ turns/min

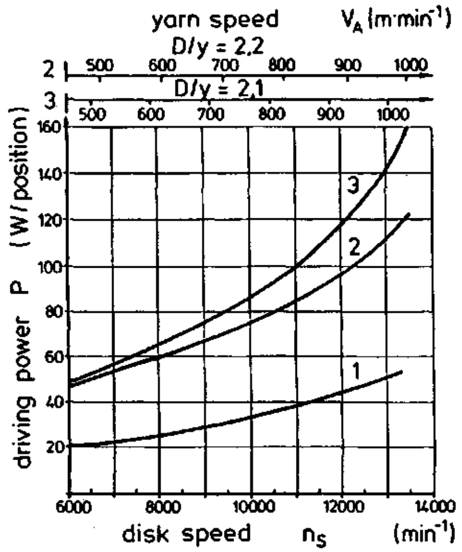


Figure 4.266
b) Power requirement *P* as a function of the friction disk rotational speed *n* and the yarn take-up speed V_A [176]
1 Friction disk without yarn
– Polyurethane disks (combination 1/7/1) or ceramic disks (combination 1/10/1)
2 Friction disk with yarn
– PET dtex 167f30, draw ratio = 1.73, $D/y = 2.2$
– Ceramic disks (combination 1/10/1)
3 Friction disk with yarn
– PET dtex 167f30, draw ratio = 1.73, $D/y = 2.1$
– Polyurethane disks (combination 1/7/1) (measured on the drive whorl ($D = 28$ mm) for the FTS52R disks and on the motor shaft for the FTS52M disks)

Table 4.44 Recommended Friction Disk Combinations for 6 mm Thick Disks [176]

Disk material			Titer range dtex
Polyurethane	Diamond coated	All ceramic	
3/3/1	2/4/1	–	11...78
–	–	1/4/1	11...55
3/4/1	2/6/1	1/6/1	44...150
3/5/1	2/7/1	1/7/1	78...330

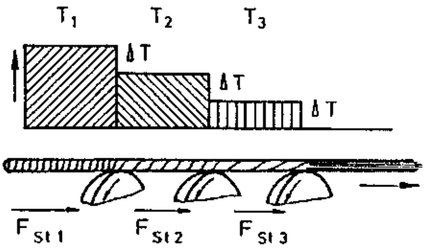


Figure 4.267
Schematic representation of twist distribution in a multi-disk friction aggregate [232]

yarn handling. All disks can be driven at up to 18 000 r/min, corresponding to 1900...2170 m/min circumferential speed. Typical d/y (disk speed to yarn speed) ratios lie between 1.8 and 2.1, i.e., the disks are suitable for yarn speeds of up to 900...1200 m/min, when correctly selected.

- Crossed belt false-twist aggregates (e.g., Murata's NIP system [223], Fig. 4.257C) work with two crossed, rotating belts. In the nip region, the belts twist the yarn with practically no slip, while the v_y speed component transports the yarn. The yarn tensions in the highly-twisted inlet zone (T_1) and the outlet zone (T_2) can be set by means of the yarn speed and the twist angle. Figure 4.268 shows the relationship between turns/m and the d/y ratio for two polyester titers, done in the same plant trial.
- The Ringtex friction texturizing aggregate [234] works with two rotating friction disks, pressed against one another, which meet at a cross-over point, nipping the yarn between the disks. The vector

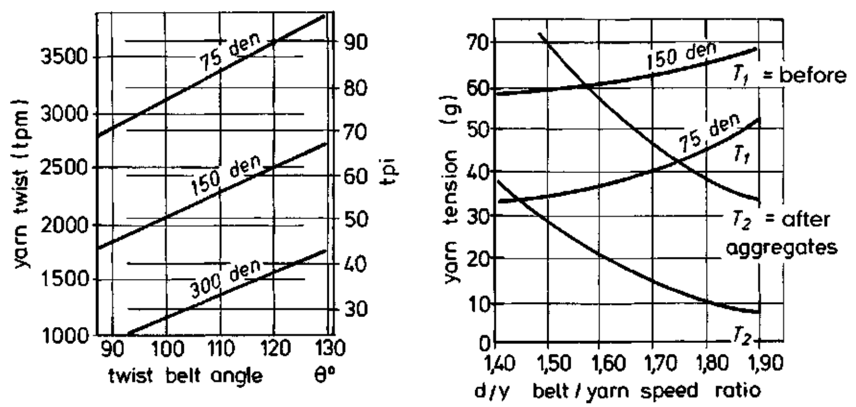


Figure 4.268 Relationship between twist/m (or twist/inch), twist angle and titer, as well as yarn tension [g], both before and after the friction disk, as a function of the d/y ratio for 2 titers [223]

V_y transports the yarn forward, while the other vector twists the yarn with a twist angle of α. These aggregates also twist the yarn with practically no slip, achieving an r/y ratio of ca. 1.4 [235]. According to the manufacturer, this system produces textured yarn having a 10% higher elongation and tenacity, as well improved bulk in high bulk yarns.

4.12.2.3 Drives for (Draw-) Texturizing Machines

As texturizing machines have their origin in the textile machinery construction industry, their drives (up to now) are the same as those used for textile machines, with long continuous driveshafts for delivery-, friction- and traverse drives running the entire length of the machine. These driveshafts are connected by change gears or timing belts in the machine headstock. In many cases everything is driven by a single common motor (Fig. 4.269). In some constructions the twist aggregates are driven by a dedicated, vertical motor. Here, too, the belt drive runs the length of the machine. In the case of a 216 position machine, the length of the stretched belt is ca. 27 m. These specially-made belts (e.g., [237]) have their free ends spliced and welded in a special device, enabling them to run as endless belts without any jarring. On the motor side, there is a slightly convex belt pulley and two edge pulleys, while on the far side there is the same belt pulley, but running in a longitudinal bearing, and tensioned by weights (or a hydraulic system) to give a fixed belt tension to compensate for belt stretching (jockey pulley system).

For the texturizing unit belt drive, a thryistor- or frequency-controlled electric motor of 30...50 kW is required; it runs at 50...60% of full load. To obtain a friction disk speed of 10 000 r/min when using a whorl diameter of 26 mm requires a slip-free belt speed of 13.614 m/s. The leather/plastic combination woven belt is capable of running at 30 m/s [237].

The drives for texturizing and draw texturizing machines differ only in the region of the primary heater, i.e., delivery rolls I and II, where the draw ratio has to be taken into account:

Zone	Operating as a ... using as feedstock...	Texturizing machine FDY	Draw texturizing machine LOY/MOY	POY
Primary heater	1st roll : 2nd roll	(1.1 ... 1) : 1 (overfeed)	(2.5 ... 4) : 1	(1.1 ... 2) : 1
Secondary heater	2nd roll : 3rd roll	1 : (0.8 ... 1)	1 : (0.8 ... 1)	
Winding	3rd roll : friction	1 : (0.9 ... 1)	1 : (0.9 ... 1)	

In the other zones (and also in the primary heater zone of texturizing machines), the speed differences are so small and so constant ($< \pm 1\%$ of the differences) that change gears or timing belt gearwheels are an ideal solution. In Fig. 4.269 [226], the spindle drive is taken from the main drive motor over pulleys at 90° in order to achieve a constant ratio of twist to yarn speed. This machine has a 45 kW AC main drive motor for 216 threadlines.

Precision-frequency drives of better than $\pm 0.01\%$ also permit the various horizontal shafts to be individually driven; this is also possible for the friction aggregates. Using this system, the traverse wobbling is simplified.

4.12.3 Stuffer Box Crimping Machines for Filament Yarns

Stuffer box crimping of textile titers is described in many patents [217], even though it had been used for a long time previously for crimping synthetic tow. Since 1960 Ban-Lon® [239] has been produced using a stuffer box crimping head similar to the one shown in Fig. 4.270. The drawn feedstock is forced into a heated crimping chamber [241] by two nip rolls and is removed from the chamber by a de-looping yarn brake at around 250 m/min. After 1970 attempts were made to increase the process speed to ca. 1000 m/min [179]. The contemporaneous development of air jet texturizing at ca. 2000 m/min resulted in a loss of interest in the stuffer box route.

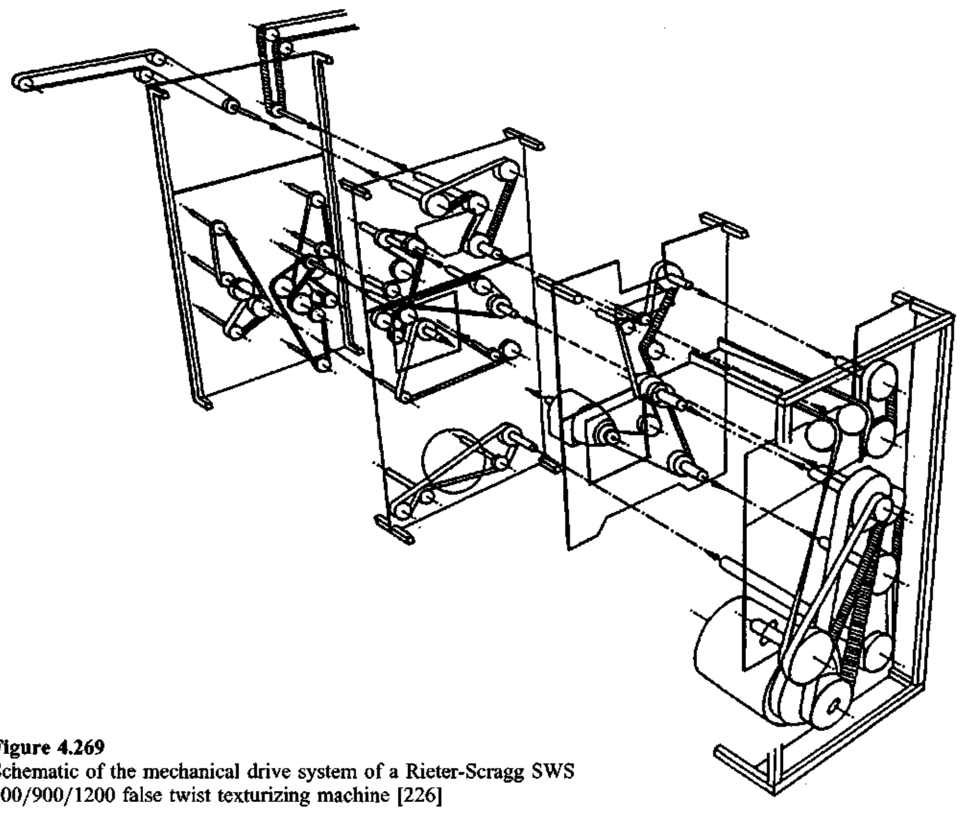


Figure 4.269
Schematic of the mechanical drive system of a Rieter-Scragg SWS 700/900/1200 false twist texturizing machine [226]

Independently of the above, a stuffer box crimper for carpet yarns [206] was produced in small numbers in 1964. This crimper could operate at ca. 500 m/min with PA, but only at up to 200 m/min with PP, because of the frictional heat generated.

Production of both of the above machines stopped long ago. To date, a stuffer box crimping machine for 300...4000 dtex and speeds of 100...500 m/min, depending on the material [24], is still being built for laboratory work, particularly for producing color samples. Also still being produced is a draw-stuffer box crimping machine for carpet yarn, capable of 470...890 m/min (Fig. 4.271, [242]). Drawn yarn coming from the last godet of the drawing zone is pressed into the U-shaped, rectangular stuffing box by a pair of nip rolls, where it is heat set by steam. The stuffer box back-pressure can be set by adding weights to the flap on the right hand outlet of the J-box. Because of limited throughput and because carpet yarn producers prefer a voluminous bulk, this machine, too, was not able to survive the advent of air jet texturizing.

4.12.4 Air Jet Texturizing; for Loop- and Entangled Yarn

In air jet texturizing machines, multifilament yarns are aerodynamically so entangled that loopy yarn, resembling natural fiber, is produced. The nature of the loops and their frequency can be determined by the process conditions. The process steps required here are: the flat, non-twisted feedstock yarn is opened up by overfeeding before the individual filaments are entangled to form loops in a jet. High overfeed results in more loops. The stability of the loop structure increases with the co-entanglement of neighboring filaments. The jet must have a turbulent, asymmetrical flow at a speed above the speed of

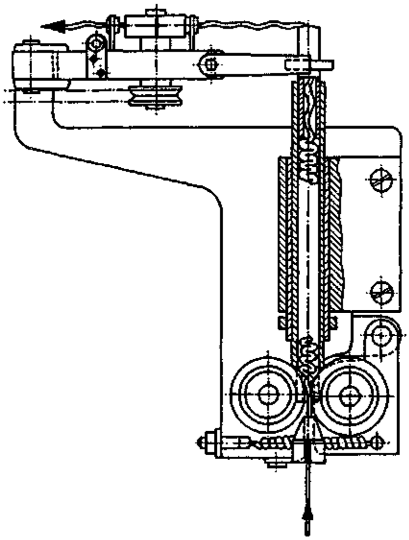
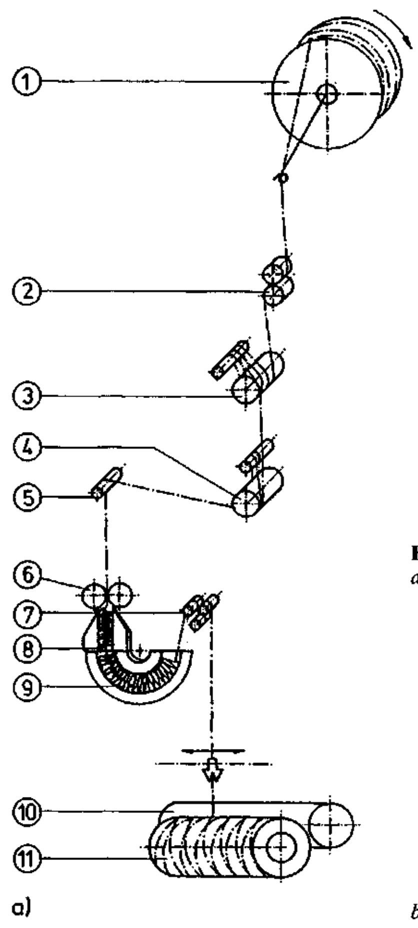


Figure 4.270
Ban-Lon stuffer box for textile yarns [239]



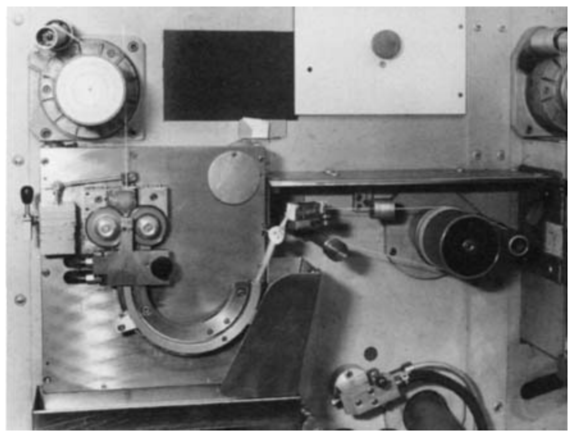


Figure 4.271
a) Schematic of a Textima PA6 carpet yarn draw-crimping machine [242]
1 Spin bobbin
2 Feed roll
3 Hot draw godet
4 Drawn yarn take-up godet
5 Yarn deflection roll
6 Stuffer box crimping inlet rolls
7 Stuffer box crimping chamber
8 Steam injection for heat setting
9 Heat setting chamber
(on right) Take-up rolls and yarn traverse
10 Friction drive roll
11 Soft-wound bobbin
b) Photograph of a stuffer box crimping position [242]

sound in air. As a result of the 90° deflection at the jet exit, many loops protrude strongly from the opened yarn. Shortly after the deflection plate, at the edge of the air flow stream, a plaited zone forms, which anchors the loops and binds the filaments together.

Figure 4.257 shows schematically the two most widely-used air jet texturing jets:

- In the Hema Jet® [229], the compressed air jet is at 45° to the yarn path through the body of the jet. The compressed air forces the yarn at high speed against the impact sphere, from where it is taken up at right angles to the jet body.
- In the Du Pont Jet [228], the yarn is forced through a venturi jet by compressed air symmetrically disposed within the jet. The yarn is forced out of the jet at high speed against an impact cylinder or plate, from where it is again taken up at right angles to the jet body. Many patents cover the shape and nature of the impact plate [245].
- In the Taslan Jet® [246], which can be fitted to any air jet texturing machine, loopy yarn is likewise produced. Loop formation takes place in the internal texturing zone (Fig. 4.272 [247]). Using this jet, even yarn pretwisted to 160...450 turns/m can be "Taslanized". A PET yarn of 89 dtex f68–400 Z/m, Taslanized using 20% overfeed, results in, e.g., a processed titer of 107 dtex having ca. 32 loops/cm. The original 4.7 g/dtex tenacity and 26% elongation is transformed by the Taslan process to 2.7 g/dtex and 15% respectively. Similar Taslan processing of a PA6 multifilament of 5.0 g/dtex and 26% elongation yielded 2.7 g/dtex tenacity and 20% elongation, with the titer increasing by 18...20% and the yarn volume by 50...150%. Further special jets are described in [243].

The operation of an air jet texturizing machine sourced from POY feedstock is shown in Fig. 4.273. Since drawing and loop formation cannot be combined, the POY yarn is "sequentially" drawn (Fig. 4.255C). A texturizing zone is then added, comprising an inlet and outlet roll, between which one of the previously-described texturing jets is located. The textured yarn can either be wound up directly or can be heat-relaxed onto a further roll before being wound up.

A yarn wetting device, located before the texturizing jet, amplifies the texturing effect and permits a ca. 20% higher yarn speed. Figure 4.274 shows a slotted yarn guide which locates the yarn while it is sprayed with water mist. The water consumption is 0.6...1.5 kg/h per yarn when using a compressed air pressure of more than 2.5 bar to generate the aerosol.

Figure 4.275 shows an air jet texturizing machine for drawn yarn feedstock (a), having a combination device for wetting and for compressed air (c). Similar machines, for the use of POY feedstock or for doubling or for core/effect yarns, are produced by a number of manufacturers [252]. One manufacturer [253] produces machines for very heavy titers. This process can also be used with

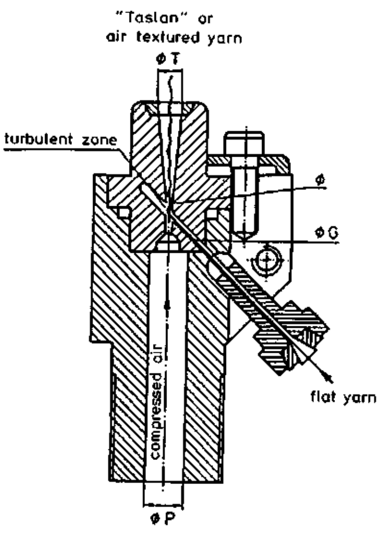


Figure 4.272
Section through an air jet texturizing jet [246] used in the "Taslan" process
ϕ = 16 mm ϕ = 3.96 mm
ϕ G = 1.575 mm ϕ T = 5.56 mm

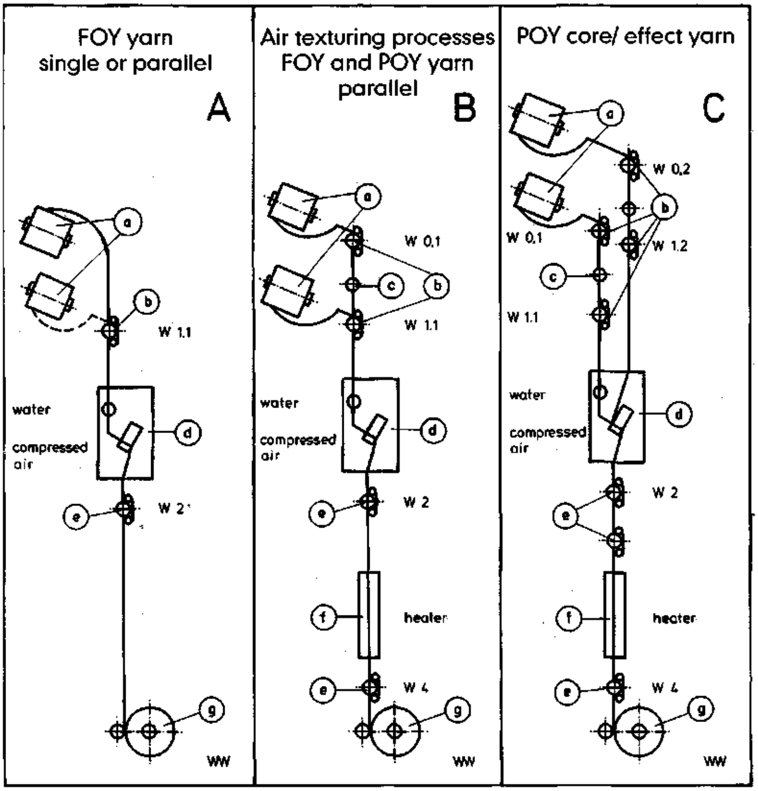


Figure 4.273
Various methods of producing air-textured yarns [229]
A) FOY yarn, single or parallel
B) FOY and POY yarn, parallel
C) POY yarn, core/effect
a) Take-off bobbin
b) Feed and/or draw rolls
c) Hot draw pin
d) "Hema" moistening and air-texturing jet
e) Take-up or post-drawing rolls
f) Heat setting heater
g) Take-up

continuous filament glass fiber [253], as well as with natural or synthetic ceramic yarns. A machine for processing POY, having components based on a false-twist texturizing machine, and a second machine capable of producing many yarn variations [224], can process titers of 100...5000 dtex, 500 dtex at 500 m/min and 5000 dtex at 250 m/min. Views of sample yarns (some magnified) are shown in Fig. 4.276; the variation in bulk is particularly noticeable. The measured and installed power of air jet texturizing machines is given in Table 4.45, together with data from manufacturers' catalogs and the literature. These values should only be regarded as guide values.

4.12.5 Air Consumption and Yarn Tensions of Texturizing and Aspirating Jets

Since aspirator jets, operating with super sonic air speed, permit no back-flow or -reaction, the air consumption is largely dependent on the jet diameter and the effective pressure in the inlet

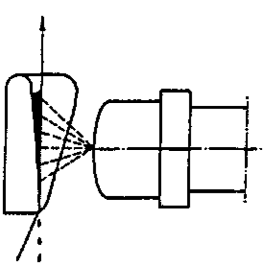


Figure 4.274
Principle of a yarn moistening device. *Left*: yarn running through a grooved yarn guide; *right*: spray jet

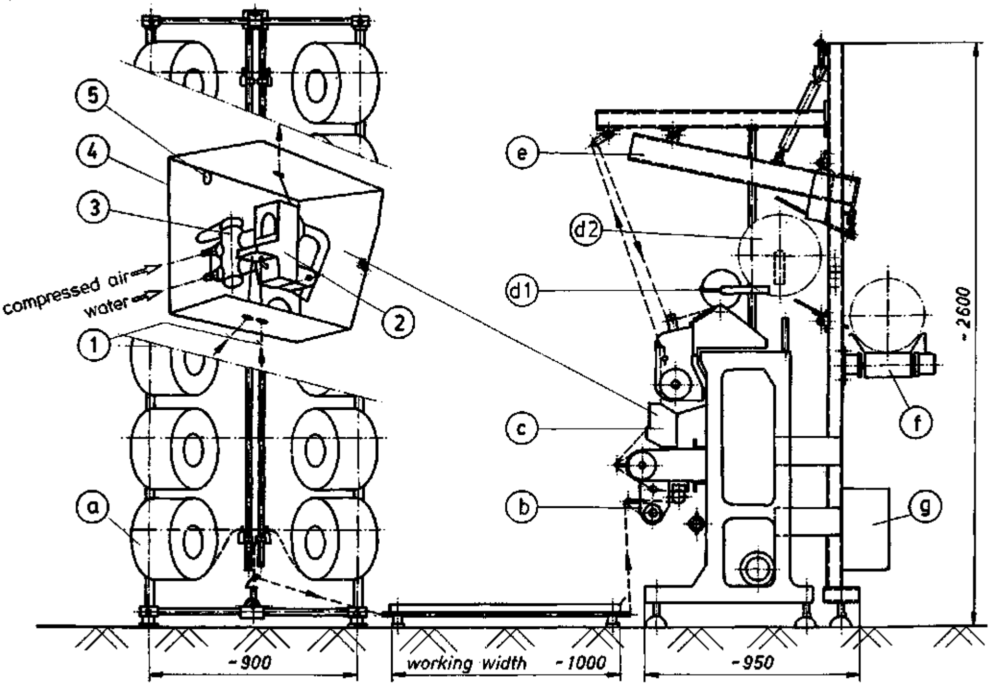


Figure 4.275 Schematic of an air jet texturing machine [251]

a) FOY feed bobbins
b) Feed rolls
c) Moistening and texturizing chamber
1 Entry of 2 yarns
2 Moistening
3 Air texturizing
4 Insulated housing
5 Texturized yarn
d_1 Take-up bobbin
d_2 Full bobbin being ejected
e) Doffing automat
f) Package reception and lateral transport
g) Switch box

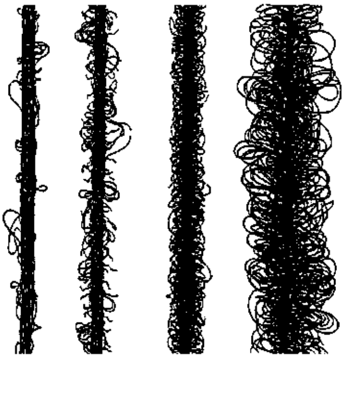


Figure 4.276
Loop-textured yarns from a Barmag air jet texturizing machine of type AM4 [224]

Table 4.45 Energy Consumption of a Barmag FK6 T90 Air Jet Texturizing Machine [33]

	Installed power W/position	Utilization %
Drive, single draw	443/yarn	≈41
double draw	693/yarn	≈37
Heating power per heated draw pin	300/pin	≈12
per 1600 mm long setting heater	100/yarn	≈50
Auxiliary drives and aspiration	306/yarn	≈66
Air consumption (depends on jet selected)		
for Heberlein jets	T321	
compressed air	8.9 Nm³/h/unit ±5% tolerance ±5% for leakage 10±0.1 bar (adjustable 5 ··· 10 bar) compressor: 12 bar, 16.7 Nm³/h/unit; utilization: ca. 54%	
compressed air specification:		
dew point +4 °C		
dirt content 0% for ≥0.1 µm		
technically oil-free, i.e., 0.1 ppm		
temperature 20 ··· 30 °C		

chamber, which differs only very slightly from the connected chamber pressure. The flow rate Q_N of standard air ($p_N = 1.0132$ bar, $\gamma_N = 1.276$ kg/m^3, $T_N = 288$ °K, $\chi = 1.405$) through a Laval jet of diameter d [mm] is given by [243]:

$$p_{OW} = \left[\frac{Q_{NL}\sqrt{T_D}}{14.932\sqrt{\frac{\chi}{\chi+1}}\cdot {p_o}^{n-1/(2n)}\cdot\frac{d^2\pi}{4}}\right]^{2n/(n+1)} \tag{4.42}$$

where the index "O" denotes outlet conditions and "W" the jet throat; the equation is valid for $p_{environment}/p_o \approx 0.528$, i.e., for $p_o \approx 1.9$ bar. In practice, the working pressure p_o is >3 bar (always). A simpler calculation uses an interpolation formula derived from the measurements of Bock [243], where:

$$Q = 0.191 \times (p_W + 1) \times d^3 + 4 \quad [\text{Nm}^3/\text{h}] \tag{4.42a}$$

Although the opening of the yarn increases with increasing jet diameter, the jet having a 1.78 mm diameter shows the best air texturing effect; the yarn, however, must run asymmetrically relative to the Laval jet axis. Comparative measured results are found in Fig. 4.277.

Both the yarn tension and the yarn opening increase with increasing vessel pressure p_o (Fig. 4.278) or flow rate. This is, however, only valid for over-critical jets (flow velocity ≥ speed of sound in air). Figure 4.279 shows an over-critical jet (3 mm orifice) and a sub-critical jet (7.35 mm orifice). In the latter, the yarn tension reaches a maximum at 1.5 ... 1.7 bar, then decreases with increasing pressure. The yarn tension can be derived from Formula (4.42) [243]:

$$F_2 = k_F \times 0.634 \times \frac{2\chi}{\chi+1}\left[\frac{Q_{NL}\sqrt{T_O}}{14.932\frac{\chi}{\chi+1}\cdot {p_o}^{n-1/(2n)}\cdot d}\right]^{2n/(n+1)} \tag{4.43}$$

(Dimensions are: Q_{NL} [m^3/h], T_O [K], p_o [bar], d [mm]). A prerequisite for the validity of this formula is that the force transferred to the yarn only occurs within the jet, and that the yarn opening (K_F) does not change in this region.

Figure 4.280 illustrates the effect of air pressure on yarn properties at two different yarn speeds: while at 250 m/min stable yarn properties are achieved at 5 bar, at 500 m/min stability is only achieved at 8 ... 9 bar.

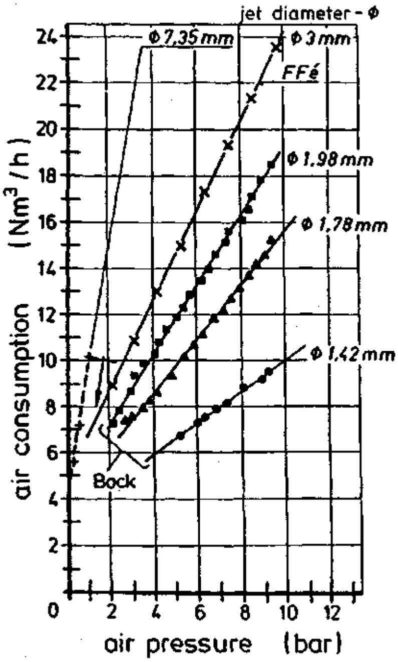


Figure 4.277
Air consumption of texturizing and take-up jets as a function of chamber pressure and jet diameter [233]

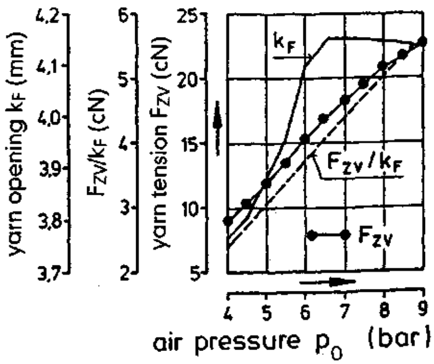


Figure 4.278
Yarn tension before the jet and opening of the yarn k_F as a function of air vessel pressure p_o [243]

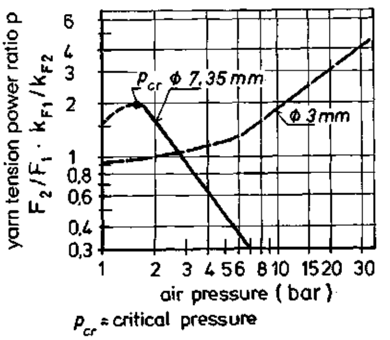


Figure 4.279
Relationship between the yarn tension ratio and air pressure for an over-critical ($D = 3$ mm) and an under-critical ($D = 7.35$ mm) jet. (p_{cr} is the critical point)

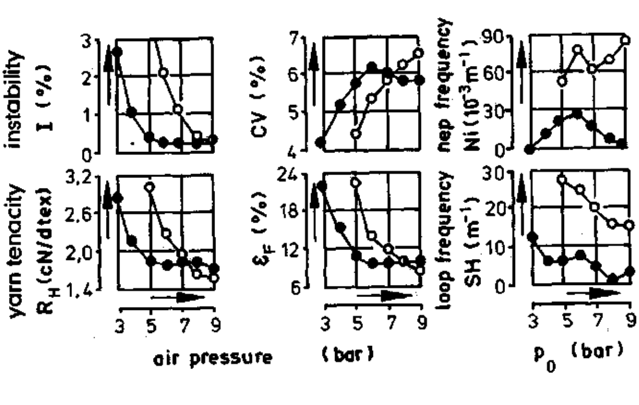


Figure 4.280
Textured yarn physical properties as a function of air pressure p_o and texturizing speed v_3 [243]

I	Instability
SH	Loop frequency
ε_F	Elongation at maximum load
CV	Coefficient of mass variation
Ni	Nep/slub frequency
R_H	Tenacity at maximum load
●	$v_r = 250$ m/min
○	$v_3 = 500$ m/min

4.12.6 BCF (Bulked Continuous Filament) Texturizing

This gas-dynamic texturizing process employing heated compressed air has been used since ca. 1975 for carpet yarns, and—less frequently—for staple tows, and has practically driven out all other processes for texturizing carpet yarns. The BCF process produces a good textured effect and matches the spinning speed optimally (ca. 600...700; recently up to 1000 m/min). Using a draw ratio of (3.2...3.4), texturizing speeds of 1800...3400 m/min can be achieved for typical carpet yarn titers and dpf's. The current texturing process is basically the same as that first patented (Fig. 4.281, [254]). Figure 4.281 also shows modern, closed texturizing jets [255–269].

Hot compressed air enters the jet at (14), flows up the channel (7) and enters the yarn channel (5) at (1), thereby aspirating the yarn into the injector jet (4) and transporting it downwards at high speed into the expansion chamber (10) containing lamellae, where the yarn—heated to plastification temperature—strikes the slowly-moving plug, causing the yarn to fold continuously as it is laid on top of the yarn plug. The hot air then escapes through the gaps between the lamellae (10), the plug moves slowly downwards and is pulled out of the stuffing box.

Recent developments include an openable ("split jet") texturizing chamber. Here the chamber can be opened and threaded up using a yarn aspirator gun; up to four threadlines can be processed in a 4-jet chamber (Fig. 4.282). The hot compressed air enters from the side at (c), passes through the dosing jet (d), entangles the yarn, which strikes the yarn plug at (g), after which the air passes through the gaps between the lamellae (g) and exhausts at (e).

A continuous spin-draw-texturize-winding (BCF) machine was shown and described in Fig. 4.197N, together with its constructional elements. In addition to these, other components are required for BCF processing and for improving the texturizing effect. Excluding the texturizing jet itself, these are:

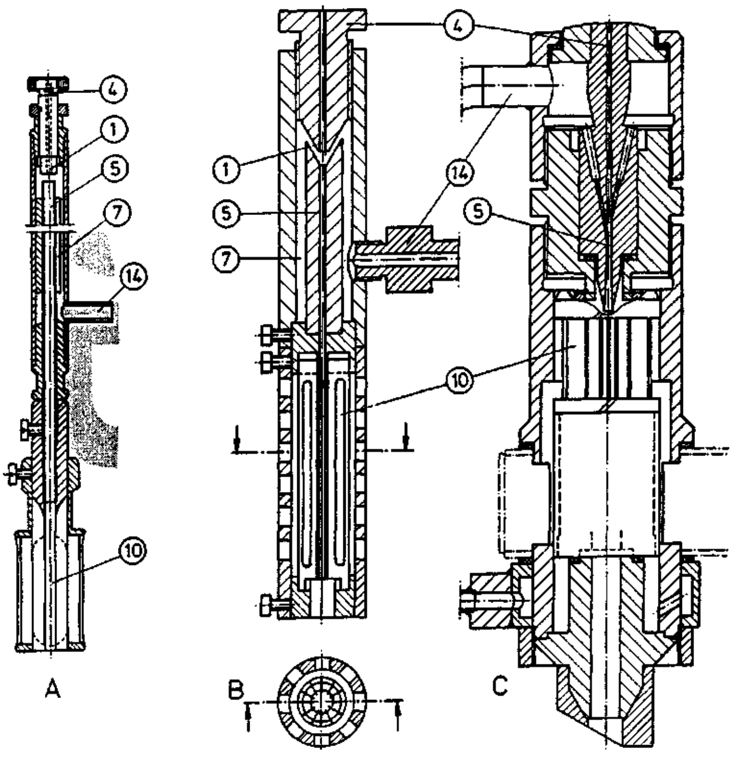
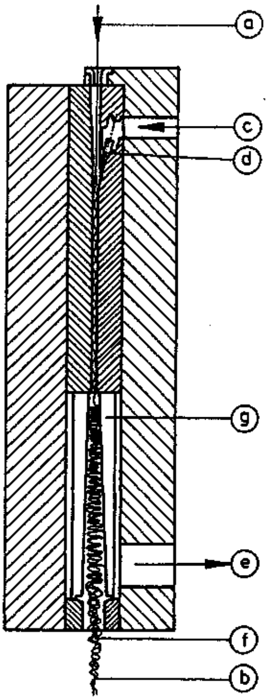


Figure 4.281
BCF texturizing jets
A) From patent document 1975, and *B*) from 1990
B) For up to 2000 dtex
C) For up to 6000 dtex



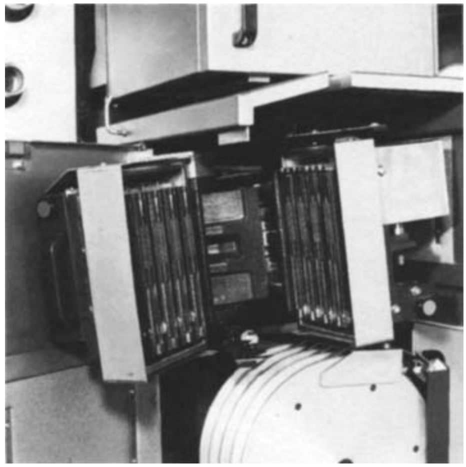


Figure 4.282
Four-fold BCF air texturizing jet with 4-groove cooling drum ([170], Rieter AG); openable jet (split jet). Principle and photograph.
a) Yarn entry (smooth)
b) Texturized yarn
c) Hot gas inlet
d) Dosing jet
e) Texturizing gas outlet
f) Parting plane
g) Lamellae around expansion chamber

- A heater for the texturizing compressed air, which should be heated to the optimum heat setting temperature for each polymer. Figure 4.283 shows a proven construction [171] for such a heater. Cold compressed air (a) flows through the outer jacket, reverses direction and is pre-heated while flowing through the inner cylinder, after which it flows through the spiral tube wrapped around the electrical heater (d), where it is brought to the final processing temperature before it flows out through (b) into the texturing jet. The temperature sensor (c) should be as close to the texturing jet as possible.
- A cooling drum to cool the plug from the texturizing jet to below the glass transition temperature. The plug is deposited on a 150...180 mm diameter perforated vacuum drum. After every revolution, the plug is displaced sideways to make space for new yarn emerging from the stuffer box [224]. After 3...4 wraps around the vacuum drum (Fig. 4.284), the plug has cooled to such an extent that the internal temperature of the plug lies below the glass transition temperature. The yarn is then taken off the suction drum, at which point the plug is unravelled.

A suction cooling drum of 320 mm diameter having only one perforated track per yarn through which room air is aspirated [270], is sufficient to cool the yarn down after a wrap of only 300...330°.

Figure 4.285 shows the spatial arrangement of these heating and cooling aggregates in relation to the texturing jet. The distance between the compressed air heater and the texturizing jet should be as short as possible. The circumferential speed of the cooling drum V_{cd} can be calculated from $V_{cd}/V_{yarn} = 1.28 \times 10^4 \times \text{dtex}/P \times \rho \times D^2$, where ρ = yarn density [kg/dm^3], (D = texturizing jet diameter [mm] and P = relative packing density of the yarn plug).

The texturized yarn is removed from the cooling drum at a lower speed than that of the flat yarn entering the texturizing jet. In addition, the plug must be unravelled. The possibilities here are:

- a step-roll duo [170], similar to that shown in Fig. 4.197N. The yarn is first taken to the smaller diameter, wrapped a few times, then taken to the larger diameter, after which it needs a fairly long length for relaxation before being taken up by a winder and soft-wound. Preferably, there is a dancer tension-compensator above the winder (Fig. 4.252).

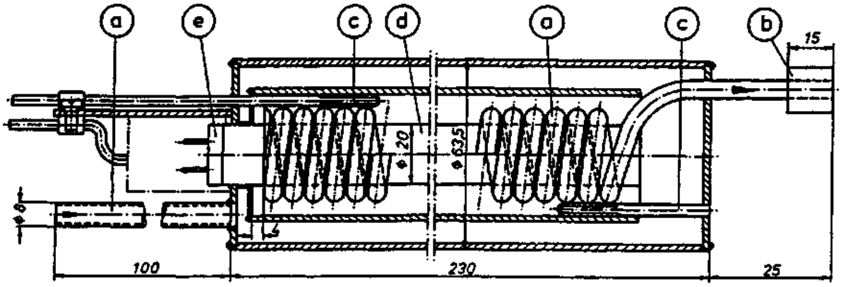


Figure 4.283 Compressed air heating chamber for BCF jets ([171], *Erdmann*)
a) Connection for cold compressed air
b) Exit for heated compressed air (as near to the texturizing jet as possible)
c) Temperature sensor
d) Electric heating rod: 0.8 ... 3 kW
e) Electrical plug

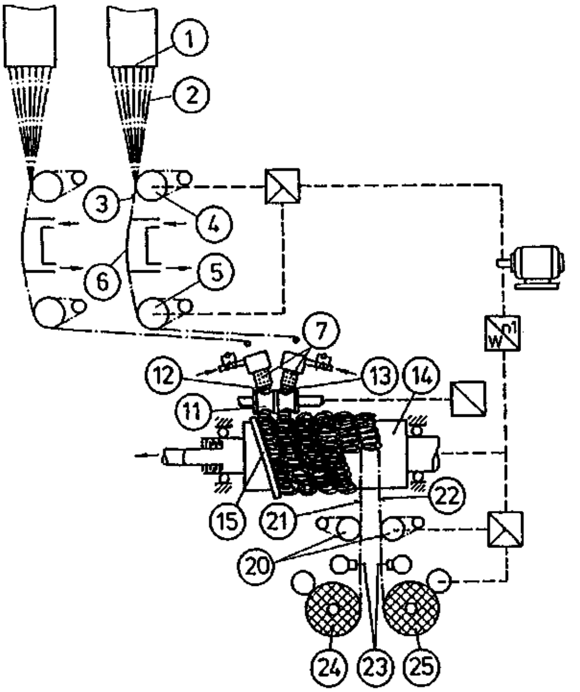
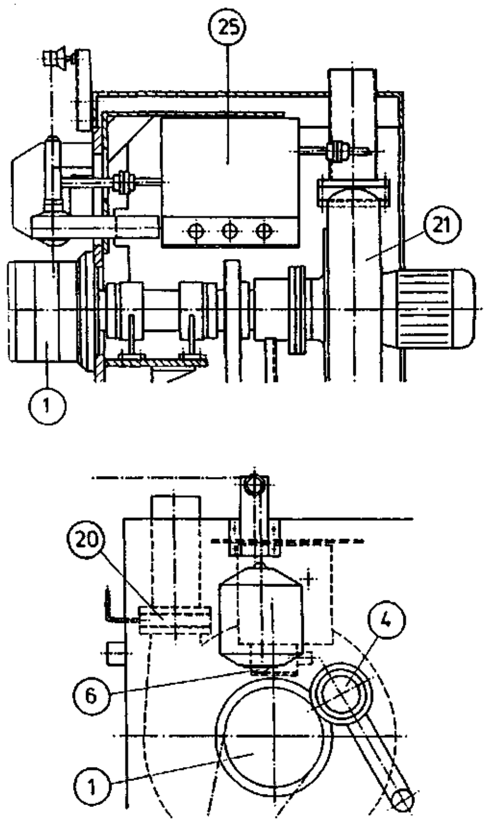


Figure 4.284
Principle of BCF spin-draw-texturizing process, 2-fold, having a multi-wrap cooling drum (DBP2 632 082 of 13.5.1983, Barmag [33])
1 Spinneret
2 Filament quenching
3 Yarn path
4,5 Hot draw rolls
6 Hot drawing plate
7 Air texturizing jet
11 Yarn take-out (and braking) rolls
12, 13 Texturized yarn plugs
14 Suction cooling drum
15 Yarn plug laying shoe
21, 22 Texturized yarns
20 Take-off godets
23 Yarn sensor
24, 25 Friction winders

- two separately-driven godets with separator rolls, of which the second runs slightly faster than the first. This system has the same function as the step-duo, but has the advantage that the relax ratios are continuously variable [33].

Figure 4.286 [148] shows a gas-dynamic texturizing jet for a filament tow of up to 30 000 dtex× < 2000 m/min. The operating principle of this jet is the same as those previously described, the differences being only the correspondingly larger jet dimensions, the higher air usage and the thickness of the yarn bundle. For staple fibers, the preferred crimping route is the mechanical stuffer box, although a mixture of both types has advantages in certain end-uses (e.g., fill fiber). A few



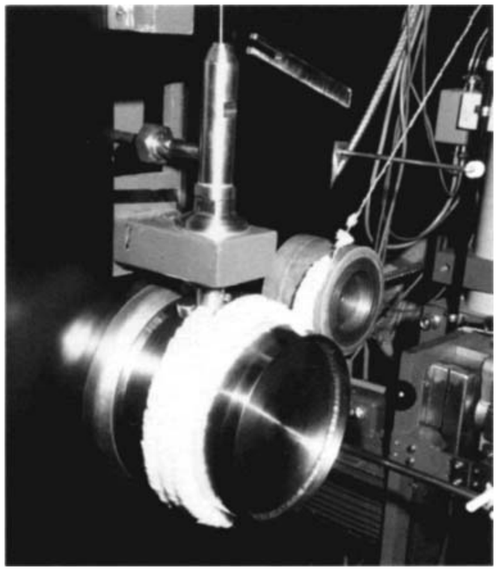


Figure 4.285
Schematic of a BCF texturizing jet (*6*) having a compressed air heater (*25*) and a multi-wrap cooling drum (*1*), as well as a take-off roll (*4*) with a suction fan (*21*) and throttle (*20*). Photograph [24]

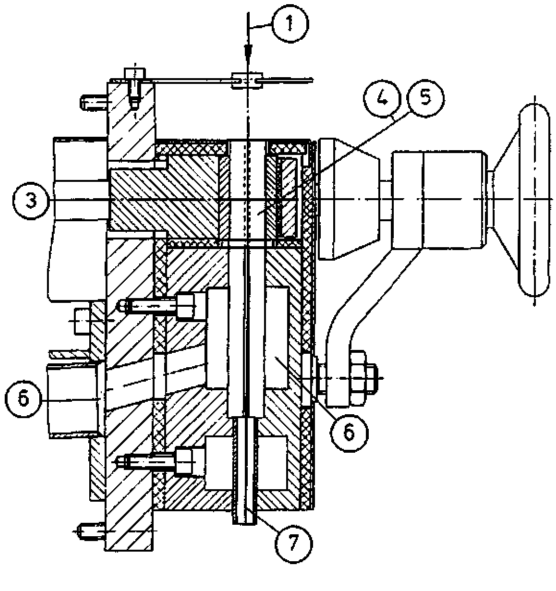


Figure 4.286
Air texturizing jet for a spun-drawn staple fiber tow of up to ca. 50 000 dtex ([167]; Neumag)

1 Drawn tow
3 Hot compressed air
4, 5 Suction jet, openable (split jet)
6 Exhaust air chamber, and -flow
7 Yarn plug, texturized

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details concerning the design of a gas-dynamic texturizing jet are: in Fig. 4.281, the internal diameter of the expansion (stuffing) jet is 14 mm. It is surrounded, on the outside, by 0.8 mm thick lamellae 1...1.5 mm apart, to permit the air to exhaust sideways. The stuffer box is slightly conical, its internal diameter increasing from 14 to 16 mm lower down, to ease movement of the yarn plug. The texturizing jet is inclined at 30...45° to the vertical to facilitate the change of direction from jet to cooling drum. The jet air consumption can be calculated as per Section 4.12.5.

4.13 Staple Fiber Plants

Staple fiber is first spun as continuous filament, then stretched, crimped and cut to staple length. The cut staple is suitable for blending with other synthetic, chemical or natural fibers, for (secondary) spinning into yarns and for use in non-wovens. Typical single filament titers are 0.5 and 1.0 dtex for fine fibers, 1.25 and 3 dtex for cotton-type (C), 3...8 dtex for wool-type (W), 10...ca. 25 dtex for carpet yarn type and up to 330 dtex for coarse fibers for, e.g., needle felt. The staple length for cotton type is between 28 and 60 mm, for wool type for carded yarn between 60 and 90 mm or for worsted yarn between 120 and 150 mm and for carpet yarn mainly between 150 and 160 mm, but also up to 220 mm. High tenacity (HT) fibers have tenacities of >7 g/dtex, and high modulus (HM) fibers an elastic modulus of >70 g/dtex.

Stuffer box crimped fibers, hot air jet textured fibers (in small quantities) and (the attractive) side-by-side bicomponent stuffer box crimped fibers are in common usage.

Flock fibers, of ca. 2 mm length, are almost exclusively cut in the so-called “guillotine” process.

Staple fibers can also be directly spun, e.g., by the melt-blowing process, where fibers of a few mm length to many dm can be produced. Another such method is flash spinning (high pressure, thin film extrusion into a liquid cooling bath). Staple fiber can also be produced from tow by stretch-break or cutting conversion. Yarn waste, spun or drawn, can also be processed into staple fiber.

4.13.1 Overview

The principle of a conventional staple fiber line is shown in Fig. 4.287, together with variations required for producing staple fiber, tow or sliver.

a) The melt is either delivered by a continuous polymerizer (since 1988, with a capacity of up to 250 t/24 h—in the meantime up to 500 t/24 h)—which is commonly the case for polyamide and polyester—or from a spinning extruder, which can have a maximum screw diameter of 300 mm and deliver up to 94 t/24 h of PET melt, 65 t/24 h of PA6 melt or 48 t/24 h of PA66 or PP melt, preferably through a large area non-stop filter.
b) Spinning beams having a capacity of up to 4000 kg/24 h per position when spinning 1.25 dtex PET (drawn), which corresponds to 24 positions for ca. 100 t/24 h— or, in back-to-back configuration— 2×32 positions for ca. 250 t/24 h, using spinning pumps of 100 cm^3/rev per position and spinnerets having up to ca. 3500 holes per plate.
c) Quenching the filaments in radial quench chambers using ca. 2500 Nm^3/h air or in rectangular quench chambers using ca. 3700 Nm^3/h, and a quench length of about 1200 mm for PET or up to 1900 mm for PP. It may be necessary to provide monomer aspiration over the first 120...150 mm below the spinneret.
d) Take-up of the yarn bundle over one (or two) spin finish lick roll(s) and a direction-changing pin or godet, for a total spun titer of 17 500 dtex per spinneret, and then plying the tows from each spinning position horizontally.
e) Additional spin finish application using rolls and/or a spray device.
f) Take-up of the complete spun tow by a quintet or septet, at 1000...2000 m/min for fine titers (mainly at 1500...1700 m/min for cotton type), or at 400...1200 m/min for carpet yarn (mainly at 500...700 m/min).

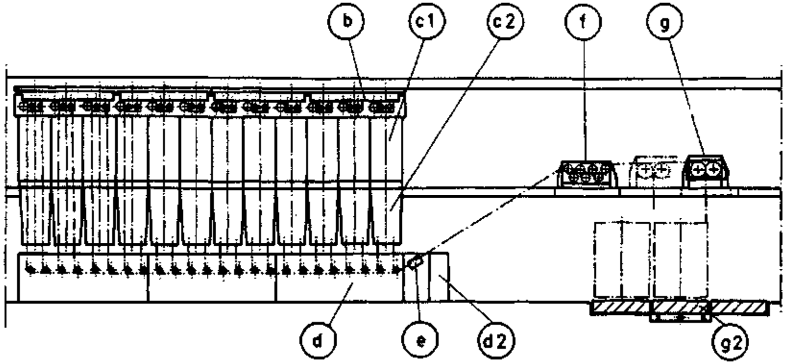
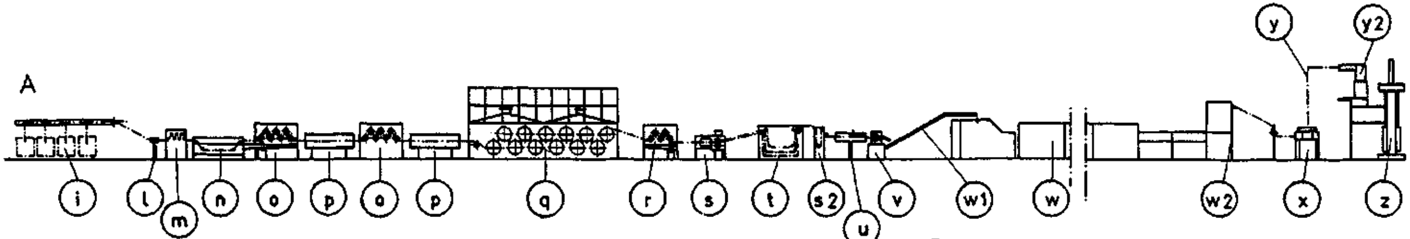
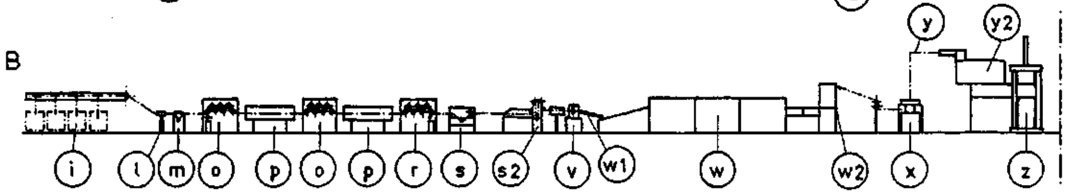


Figure 4.287
Staple fiber melt spin and drawing line [295]

- – continuous polymerization or spin extruder
- *b*) Spin beam with spin pump drive
- *c1*) Quench cabinets
- *c2*) Interfloor tubes
- *d*) Yarn take-up wall
- *d2*) Control box
- *e*) Additional spin finish application
- *f*) Take-up rolls
- *g*) Sunflower
- *g2*) Can traversing table
- *e*) Can creel
- *l*) Tow reed
- *m*) Tension controller
- *n*) Drawing and dipping bath
- *o*) Drawing septet, heated
- *p*) Hot air oven
- *q*) Heat setting calender
- *r*) Drawing septet, cold
- *s*) Spin finish applicator or -bath
- *t*) Tow plying
- *u*) Steam oven
- *s2*) Tension control
- *v*) Stuffer box crimper
- *w1*) Tow distribution into
- *w*) Drier and heat setting oven
- *w2*) Tow take-off
- *x*) Staple cutter
- *y*) Pneumatic staple transport
- *y2*) Condenser
- *z*) Bale press





A) Staple line for PET
B) Staple line for PP and PA

g) Deposition in round or rectangular cans, and
h) Can transport to
i) Can creel as the beginning of the
j) Fiber draw line, which, e.g., in the case of 2 drawing stages, comprises:
k) Cans in the can creel.
l) Tow reed to adjust the tow width.
m) Tow pre-tensioner, usually braked rolls or combined with
n) Dipping bath with immersed rolls, or dipping and squeezing-off calender.
o) (Two) delivery and drawing frames with partly heated, partly cooled rolls.
p) Heated drawing ovens, using hot air or superheated steam. In many processes hot water draw baths are included, especially in the first drawing zone.
q) Heat-setting at constant length between rolls, especially for cotton type.
r) Tow cooler, especially for high tenacity and high modulus types.
s) Tow finish application.
t) Tow spreader and folder.
u) Continuous steamer for moistening and heating tow.
v) Stuffer box crimper(s).
w) Dryer and heat-setter, using conveyor belt or suction drum.
x) Staple cutter(s), with tow pretensioner.
y) Pneumatic opener and staple transport.
z) Baling press.

In this complex sequence, in which some of the above-described components or units can be repeated, careful co-ordination and fine-tuning are absolutely essential, particularly the component sequence, the speeds, the temperatures and the tow width. In addition, reserve or replacement machines or buffers must be on stand-by to ensure continuous, breakdown-free, production. A machine stoppage on such a line results in about 20...30 kg/min waste per 1×10^6 dtex. A stoppage of the line while in production results in ca. (30...90) kg/min × tow dtex of yarn with different physical properties relative to normal production; such yarn is of a lower quality. The feed rolls before the draw rolls are particularly vulnerable to wraps arising from filament breaks. The stuffer box and the staple cutter are other vulnerable areas, owing to wear of rolls, lips and knives. Microprocessor control and continuous data logging are important in continuous production, as well as for tracing off-standard batches.

Further-processing lines for solution spun fiber contain partly the same or similar components; these are described in Section 4.15.3.

Staple fiber lines (e.g., Fig. 4.287) have a space requirement per line of 10...15 m width × ca. 60 to more than 100 m length × ca. 5 m height above the drawline, increasing to at least 7.50 m height at the baling press (Fig. 1.17).

4.13.2 Melt Spinning Lines for Staple Fibers

These spinning lines differ only from those used to produce yarns (Section 4.6.5–4.6.11) in the sizes of the spinnerets and spinning pumps. Before 1970, 1...4 round spinnerets of 160...190 mm diameter having 600...900 holes each were almost exclusively used [276]. Later these spinnerets were replaced by rectangular spinnerets of up to ca. 500 × 100 mm, having up to 3000 holes per plate. For a few years now, more and more round spinnerets of 200...300 mm diameter having up to 3500 holes in annular configuration have become evident. The advantages of this configuration, particularly concerning spinning throughput and fiber quality, are illustrated by Fig. 3.12 [277]. The main disadvantage of the older, smaller circular spinnerets was that the different numbers of holes behind one another led to large temperature differences between the filaments [154]. In rectangular spinerets, these temperature differences are smaller and more uniform, allowing a higher and more uniform drawability of the entire yarn bundle.

Parallel to such improvements and owing to the optimization of the quench chambers (Section 4.7), the spinning speed of PET cotton type staple was increased from 1000...1200 m/min in 1965 to 1700...1800 m/min in 1990. This resulted in an increase in throughput from ca. 25 kg/h/spinneret to ca. 125...150 kg/h/spinneret in the case of 1.75 dpf final titer.

If one compares staple fiber compact spinning (Section 5.1), which has up to 80 000 capillaries per spinneret and a throughput of ca. 80 kg/h/spinneret when spinning 1.75 dtex filaments at 120 m/min (after drawing) or up to 3600 capillaries/spinneret at 120 kg/h/spinneret, one readily sees the superior throughput of modern conventional staple fiber spinning, particularly for large lines. In contrast, compact lines can produce only 10...30 t/day. The distance between the spinning beam and the melt source must not be too large, or else the time-dependent depolymerization can become too large. As melt velocities in large manifolds should not exceed 6...8 cm/s, a 10 m long manifold will have an average residence time of 3 min and a residence time of more than 30 min at the wall (Section 4.6.5 and Fig. 4.87). To this must be added the residence time in the large area product filter (if fitted) of 2...3 min (average), as well as up to 20 min residence time for areas of poor or stagnant flow. Because of the residence time differences between the pipe axis and the wall, static mixers should be fitted before every pipe branch in the manifold.

The conditions given in Fig. 4.85 must be strictly observed, and the entire system must be heated by Dowtherm (Diphyl) vapor in order to achieve as little temperature variation as possible.

Even with large circular spinnerets, the (dry) temperature gradient of a few degrees from outside to center is no cause for alarm, as the high melt throughput will heat up the spinneret uniformly after a short running time, as long as the spinning beam heating—without melt flow—is acceptably good and uniform.

The spinneret hole-to-hole distances should be 3...max. 4 mm for cotton-type titers. For other dpf's, the rules given in Section 4.6.9 should be observed.

The quench chamber rectifier should protrude only ca. 20...25 mm on either side of the filament bundle. The quenching length and air quantity should be determined according to the rules given in Sections 3.3 and 4.7. There is still no agreement whether (roll) spin finish application should take place at the foot of the quench chamber or on the tow take up machine. Attempts over many years to spin staple at POY speeds have been abandoned for various reasons [279].

4.13.3 Spinning Take-Up Walls and Can Take-Up

Up until the 1960's, conventional LOY package take-up winder walls were often used, the spun packages being plied from creels in front of the drawstand. These take-ups are now completely obsolete, except for a few special cases. Can take-ups are able to combine the tows from 24...36 spinning positions, laying a single large tow of up to 500 000 spun dtex in one can. A drawing line producing a final titer of, e.g., 6×10^6 dtex requires a can creel holding only ca. 48 cans, whereas—if spun packages are used—the creel would have to hold more than 1200 bobbins.

A typical, double-sided spinning wall and can take-up for round cans is presented in Fig. 4.288. The multifilament tow coming down from the quench is first wrapped around a waste godet, then taken over one or two finish rolls and wrapped 90° around a deviation pin to deflect the tow in the horizontal direction. The assembled tows are then once again dressed with a large quantity of spin finish, are taken up as a single tow by a sextet and deposited in a rotating and traversing can by two special gear wheels which are resistant to filament wraps (sunflowers). The tow deposition in the can is epicycloidal, but the crinkle of the fast-running tow soon covers this (Fig. 4.289). By slightly adjusting the traverse relative to the can movement, uniform filling of the can is achieved.

Figure 4.290 shows a side view of a modern staple take-up having 48 positions. Each position has a spin finish roll, a yarn presence sensor, -cutter, -aspirator and yarn guide. The deflection of the yarn bundle to the horizontal is done by means of a toothed godet, driven by a synchronous motor. Further on, the tow is generously moistened, taken up by a sextet and fed onto a godet vertically above the two special gearwheels, from which the tow is deposited in rectangular cans (Fig. 4.291). Here the pair of sunflower wheels is traversed forth and back along the internal width of the rectangular can, while the can itself is traversed at right angles to the sunflower movement, with ca. 1/10 of the sunflower traverse speed. At a full can change, the left hand can of two empty cans is moved one can pitch to the right, whereby the full can is also jerked one pitch to the right, pushing the full can standing there onto the room floor. Tow laying in the new can is in a meandering pattern, due to the bi-axial speed relationship, which is again overlaid by the crinkle of the fast-running tow.

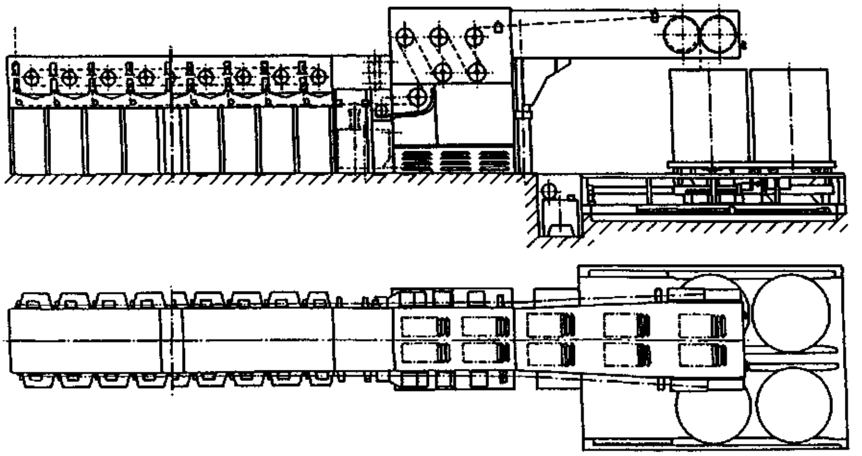


Figure 4.288 Double-sided staple tow take-up section with round cans (licenced by IWKA from *Fourné* [24]). Can rotational speed: 1...4 r/min, preferably 2.5...3.5 r/min; double strokes/min: ca. 0.1...0.4; to avoid twist insertion: incomplete rotation, i.e., 350° clockwise, then 350° counter-clockwise, etc

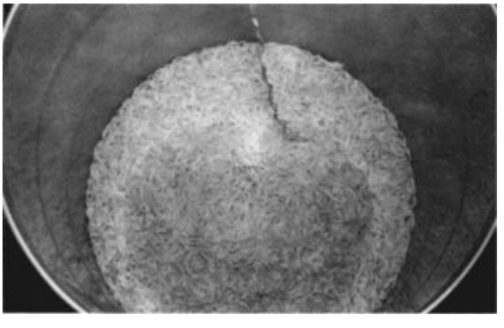


Figure 4.289 View into a half full round can [276]

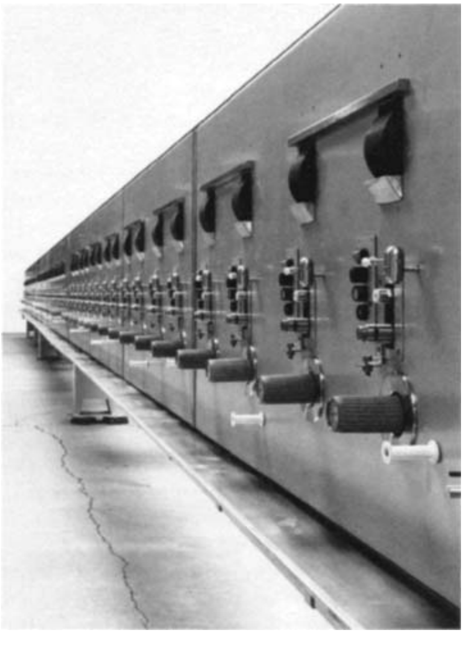


Figure 4.290
Staple take-up section with roll-applied spin finish, yarn guides, yarn aspiration-cutters and -sensors, deflection godets and tow guide rolls [174] (Fleissner)

Equal tow length in all cans is important for good process economics. After a pre-set doff time, the tow running into the full can is automatically cut, and the running end is transferred to the new, empty can. The free, cut ends can be spliced to other tows in the creel.

Nowadays round cans are supplied with ca. 1.6 m diameter × 2 m height (≈4 m^3) and rectangular cans have equal external dimensions, yielding a volume of ca. 5.1 m^3. The ca. 24% greater volume of

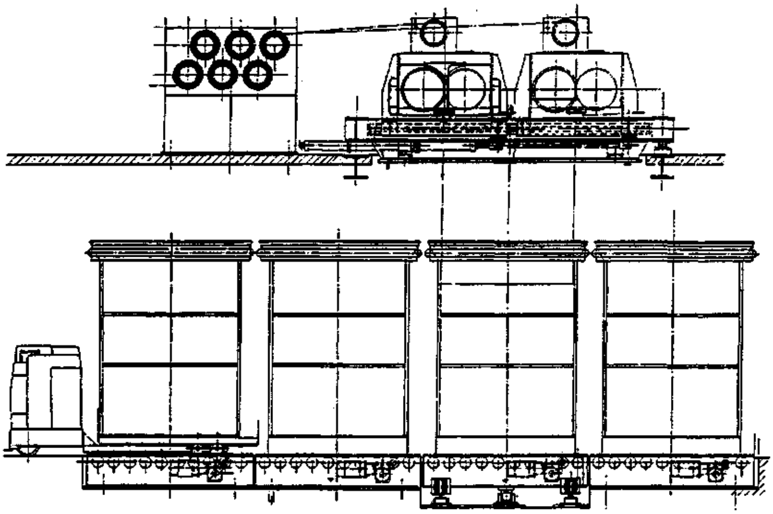


Figure 4.291
Staple tow take-up (sextet) with can take-up for rectangular cans [167] (Neumag)

rectangular cans gives them an advantage over round cans; the same argument applies at the creel, as the tow running time increases by this percentage, with a consequent reduction in labor time.

As the tow is deposited without tension, wraps must be avoided. Up to about 1200 m/min, the two sunflower wheels can be made from nylon of modulus 12; the tooth crowns are slightly rounded. For up to 1800...1900 m/min, special "combing" gears, as shown in Fig. 4.292, are used. By means of adjustable front apertures (6), air is sucked in. This air is blown out after every second tooth to prevent broken filaments wrapping. The slightly combing and contact-free running teeth (8) of both wheels have hard metal, plasma-coated, exchangeable crowns, as the gear wheels run 10...20% faster than the tow. In addition, one of the gear wheels must have a horizontally-floating bearing in order to cope with knots, thick sections and wraps. POY can take-up, which would be necessary at speeds above 2000 m/min, is based on taking up the tow in or around a cylinder, the tow then sliding downwards in or around the cylinder in a continuous spiral at a descending speed of as low as 100...300 m/min onto the bottom of the can [278–280]. Although the advantages of increased spinning throughput per position, increased storage life before drawing and possibly one less drawing zone are promising, high speed can laying has not been implemented. Firstly, tow laying at POY speeds is much more critical than at 1700...1800 m/min, and secondly, the tow is taken out of the can so fast at drawing (because of the reduced draw ratio required) that the tow tangles easily, preventing trouble-free running.

Can take-up and can creels in large production plants and/or for large transport volumes are integrated into automatic supply systems (Fig. 4.293). Using such an automatic system, many can creels can be supplied from an unequal number of spinning lines. To achieve this, the routes to the creels must be kept free.

4.13.4 Creels

The creel's function is to combine multifilament yarns or tows from spinning into thicker tows or warps. We differentiate between the following types of creels:

	for round cans		
can creels	for rectangular cans	with plying reeds	
bobbin creels	over-head take-off		
	rolling take-off	of spindles	single end warp

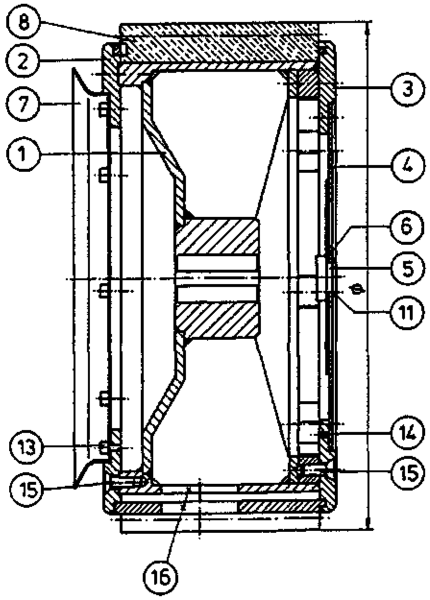


Figure 4.292
Fiber tow-laying wheel (sunflower) [24] (Fourné KG)

1	Wheel disk	Sunflower- or gear rim
2	Rear cover disk	diameter:
3	Front cover disk	1200 m/min: 180 mm
4	Ventilation slit disk	1500 m/min: 320 mm
5	Centering	1800 m/min: 520 mm
6	Slit sealing disk	Sunflower wheel tooth
7	Tow string up ring	width = tow width + ca.
8	Tooth profile	2 × 70 mm
11	Locking ring	
13, 14, 15	Connecting screws	
16	Outlet slits	

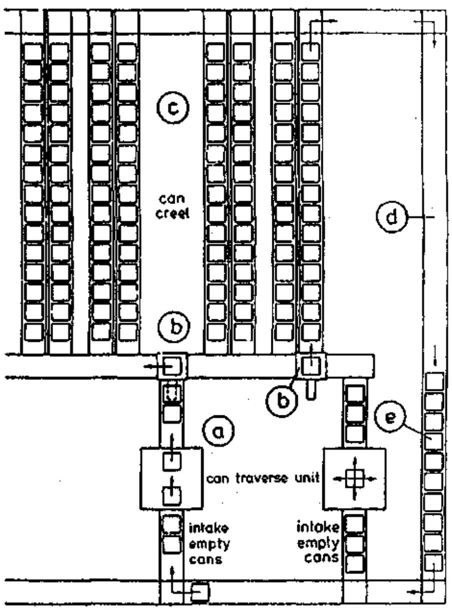


Figure 4.293
Automatic can creel supply system [295]
a) Can traverse unit below sunflowers
b) Can transport and distribution in the
c) Can creels
d) Recovery of empty cans
e) Supply of empty cans

The yarns or tow must run loop-free and with equal tension into the comb or reed and must exit with the desired width and pitch.

- A double can creel for round cans, having the take-out yarn guides about 2 m above the top of the cans, is shown in Fig. 4.294. For threading up, the tow guide support can be electrically lowered to the level of the cans. The tow from each can is then hung in this large eyelet guide and, after about 4 can pitches, it runs through a stationary yarn guide on the triangular holder, after which it runs into the tiltable warp sheet yarn guide on the right. The tow width can be adjusted by angling the comb guide, which is fitted with fused corundum guide pins. At process start, the tow guide support is again raised. The free length between the tow surface in the can and these raised yarn guides is sufficient for untangling at take-off speeds of between ca. 30 and 70 m/min. The second creel is charged with full cans while the first is in operation.

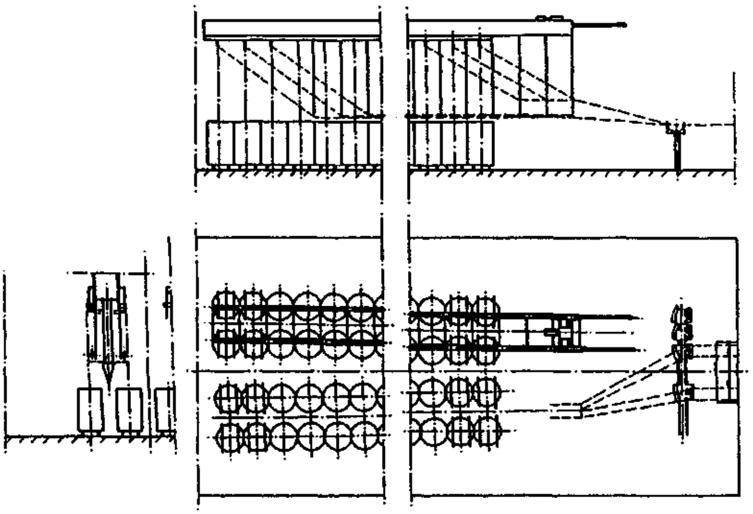
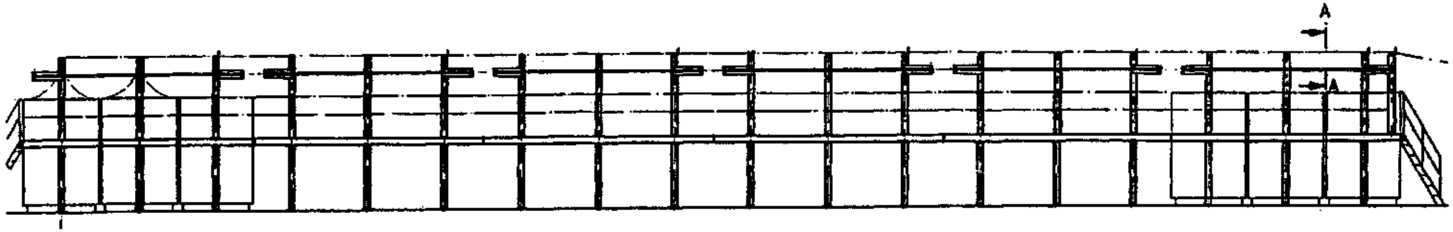


Figure 4.294
Two parallel can creels, one in operation, the other awating re-supply; double-sided; for round cans; with yarn guides which can be vertically raised ([24], *F. Fourné*)

- A creel for rectangular cans having fixed overhead yarn guides above the cans, is shown in Fig. 4.295. The tow take-out guides are about 0.5…8 m above the cans, and consist of disentangling pins in a weak zig-zag configuration. The straightened tows are then taken through a comb guide to the drawing line.
  The cans, whether round or rectangular, are made from AlSi or $AlMg_3$; they have a stable, round bead at the rim to prevent filaments snagging, reinforcing beading along their height and a stable base to enable them to be moved. The base may also have feet for lifting by a forklift truck or steerable wheels. The can weight is the weight of the empty can plus ca. (0.2…0.25) kg/dm^3 for the tow. Holes are drilled in the base of the can to prevent excess spin finish and water from forming pools there.
  The run-out time of a can can be calculated as in the following example: A 24 position spinning line producing 1.5 dtex (final) dpf × 3.4 (draw ratio) and 2767 holes per spinneret supplies a 338 680 dtex tow to the can at a throughput ($\eta = 1$) of ca. 73 150 kg/24 h. At a spinning speed of 1500 m/min and using cans having a volume of 1 m^3 (corresponding to ca. 250 kg of tow), the time to fill a can = can changing time = 4.92 min. The time to empty a can in the creel when drawing at 180 m/min (= 180/3.4, based on undrawn tow) is 139.45 min. The can creel must contain 28.3/($\eta = 0.9$) = 32 cans.
- Bobbin creel for over-head take off. Each bobbin is provided with a yarn pretensioner and guide, as in Fig. 4.242. The bobbins are then held on spindles on a single or double-sided frame, as shown in Fig. 4.296. Comb guides are fitted, on either side, outside the frame to guide the tows to the front of the creel, where they are assembled by a comb or reed guide. Single end sensors can be fitted to the comb.
  Over-head take-off of the undrawn filaments functions well up to above 400 m/min. For very low take-off speeds, it is recommended that end-caps be fitted to the spin bobbins. In over-head take-off, the yarn automatically obtains one twist per yarn wrap around the bobbin.



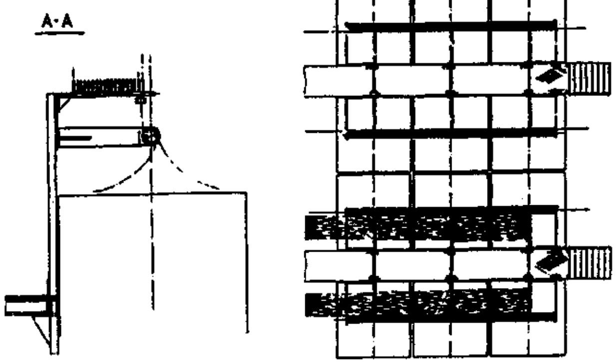


Figure 4.295 Can creel for large rectangular cans, with service platform ([291], Neumag). Left: tow cans

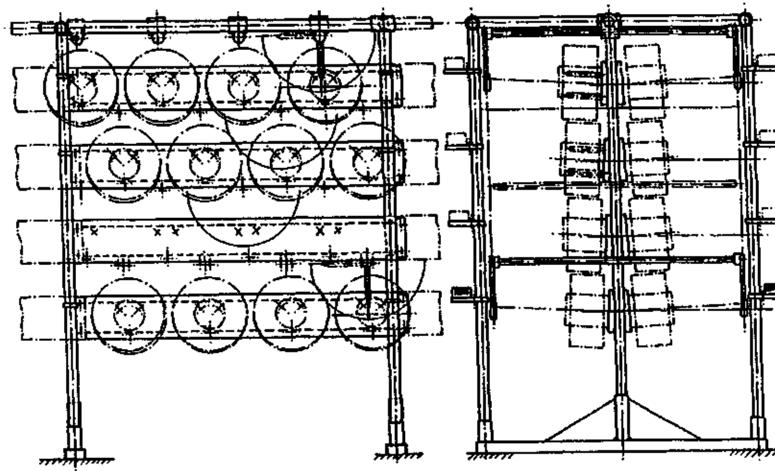
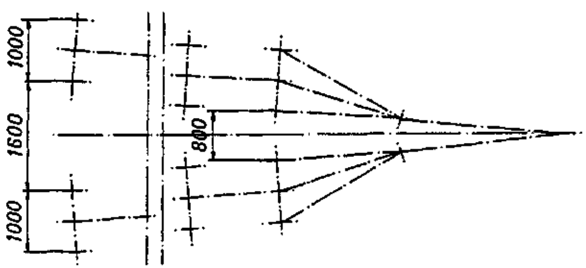


Figure 4.296 *a*) Package creel for over-end take-off, double-sided ([24], *F. Fourné*)



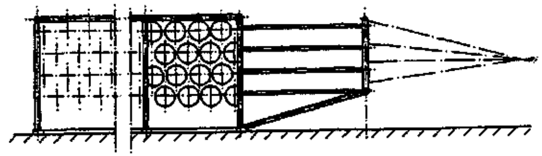


Figure 4.296
b) Installation of two double-sided bobbin creels for a total of 320 spin bobbins

- A rolling take-off bobbin creel avoids the above twist generation, unless—of course—the spun yarn already contains twist. As shown in Fig. 4.297, the yarn or tow is taken off tangentially from the rolling bobbin. Because of the spindle bearing resistance, the yarn is taken off under tension. In the case of 10...20 kg bobbins, the take-off tension varies from ca. 200 g at full bobbin to about 50...100 g just before bobbin run-out. Using belt brakes, tensioned by weights or springs, the take-off tension can be increased and therefore made more uniform. Figure 4.297 also shows a rolling take-off spindle with its bearing and a bobbin tensioner suitable for use with spinning tubes of different sizes.

 For a tensionless take-off, there are two possibilities: a DC spindle drive or air bearing spindles (Fig. 4.208D), with or without start-up turbines.

 After rolling take-off, the yarns pass through a comb guide in front of the creel (as in Fig. 4.296b) before forming the warp. Electronic yarn sensing can again be fitted, as previously.

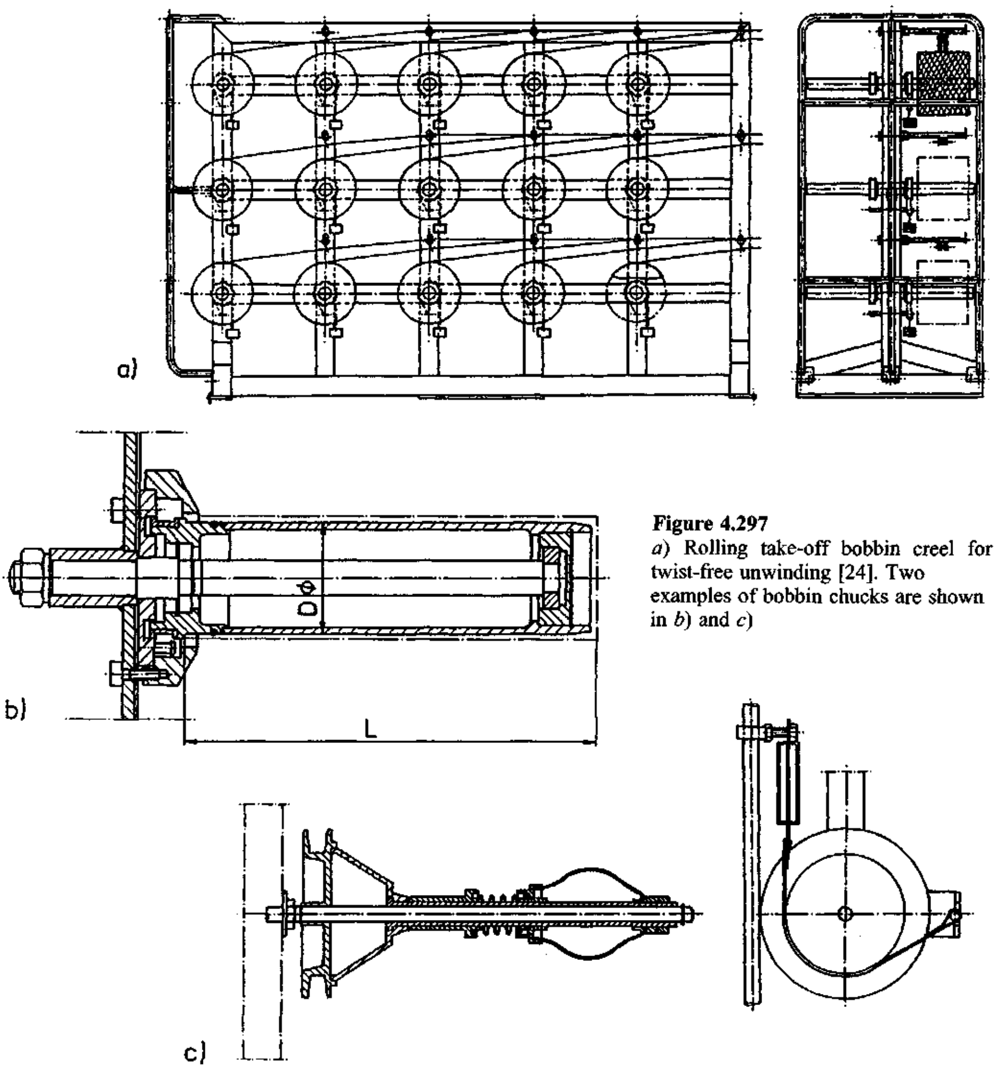


Figure 4.297
a) Rolling take-off bobbin creel for twist-free unwinding [24]. Two examples of bobbin chucks are shown in *b*) and *c*)

4.13.5 Tension Compensation and Dipping Bath

The yarns or tows coming from the creel should have a uniform tension, and—if wet processing is involved—a uniform moisture content.

For thin tow resp. multifilament sizes, the normal tensioners, consisting of two rows of combs, can be used. Using a counterweight to adjust the pin meshing achieves good uniformity of tension in the tow. This system can be used up to a maximum titer of ca. 60 000 dtex.

In larger lines, many rolls of relatively small diameters (80 ... 150 mm, Al_2O_3 plasma-coated) are arranged in a zig-zag configuration (Fig. 4.298a). For wet processing, the rolls are immersed in a bath which may contain spin finish. On emerging from the dipping bath, the tow is squeezed or nipped uniformly to remove excess fluid.

A 3-roll calender, which has the lowest roll dipping into the bath (Fig. 4.298b), is suitable for this application too. The tow led over the bottom or middle roll is pneumatically squeezed between the two upper rolls before proceeding further. To this end, the two upper rolls are silicone rubber-coated.

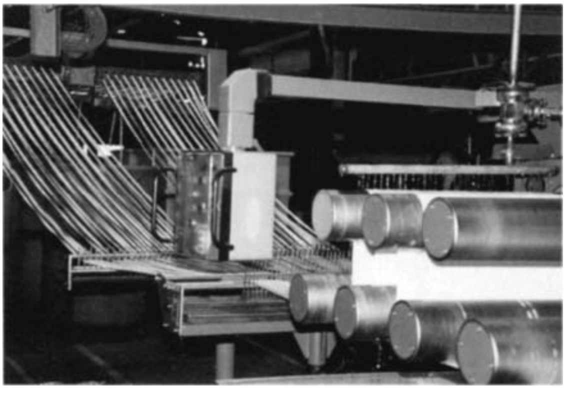
The dipping bath is made from stainless steel and is usually heated.

4.13.6 Drawing Frames

(Also see Sections 3.9, 3.10 and 4.9.3.1).

Drawstands containing rolls are used to feed, draw, dry and heat set synthetic yarns, tow, film and fiber. They consist of (rarely) 1 or 2 rolls, usually of 5 or more sequential rolls for transport of yarn or tow, for avoidance of slip through coefficient of friction and angle of wrap, for increasing or decreasing yarn tension, for thermal treatment, etc. Figure 4.299 shows typical roll configurations and gives guide values for the total angle of wrap of each configuration.

In Germany the UVV safety regulations [283] stipulate a clearance of ≥ 120 mm between rolls to avoid injury to hands when operating the drawstands. For staple production, the configurations "quintet H" and "septet" are preferred, together with a long, septet-like array of up to 24 or more large rolls for drying and—particularly—for heat setting. Coefficients of friction are given in Chapter 2 Sections 6.7 and 7.2 for various polymers and fiber types. The drawstand drive power required can be calculated from formula (3.28). For large drawing lines, a thryristor-controlled single DC motor drive per drawstand is



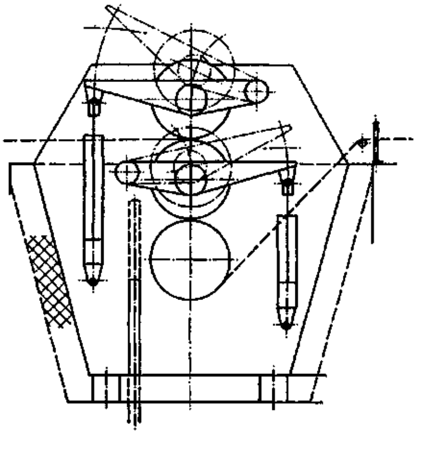


Figure 4.298 Tension-regulating calender
a) Yarn comb guide (reed) and free-running, individually-braked godet septet [167]
b) Spin finish application in a bath containing a calender

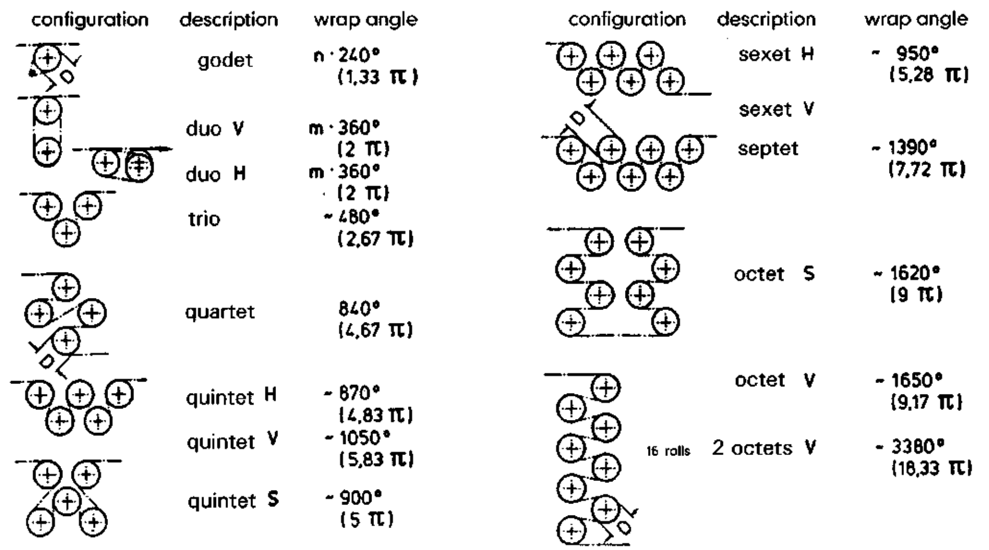


Figure 4.299 Drawstand roll configurations and approximate wrap angles (V = vertical; H = horizontal)

preferred, although the higher power requirements constantly arising tend to favor AC motors driven by static inverters (1990: ca. 50...70 kW). For large drives especially, the motor efficiency must be carefully calculated. As a starting point the following guide values can be used:

Motor power range kW	Approx. efficiency Drive system	gearboxes	Total
500...200	0.9	0.9	0.81
200...40	0.7	0.9	0.63
40...10	0.5	0.85	0.43
10	0.4	0.8	0.32

The power requirements are, e.g.:

$N \geq 0.051$ kW for 1 g/dtex × 1000 m/min × 100 dtex
$N \geq 30$ kW for 1 g/dtex × 100 m/min × 10^6 dtex, and for large, single drawstands:
$N \geq 435$ kW for 2 g/dtex × 180 m/min × 6 × 10^6 dtex.

The torque and radial forces acting on the rolls and drive aggregates up to the motor must be calculated. Here it must also be taken into account that each roll has an inlet and outlet tension, as does the drawstand as a whole. Since the tow acts as a belt running over the rolls, there can be an idling torque and regenerated power to be taken into account. This is handled by the braking power of the 4-quadrant thryristor. The acceleration- and braking power (from $G \times D^2$) must also be taken into account.

The individual drives must be carefully matched, considering the above criteria. It must also be taken into account that many lines utilize a crawl speed (ca. 30 m/min, after drawing) for stringing up and starting.

In older and smaller drawing lines, the speed control can be achieved by using infinitely variable PIV gearboxes (Fig. 4.300), joined to one another by universal driveshafts. They have one main drive motor located on the main draw stand. This is an energy-saving solution, as the relative drawing forces on either side of the drawstand are compensated by the driveshafts which run the length of the machine.

An advantage of these PIV drives is that the torque increases by about 250% as the speed is reduced when the draw ratio is about 6 : 1, whereas the torque of an electric motor remains constant over a wide range.

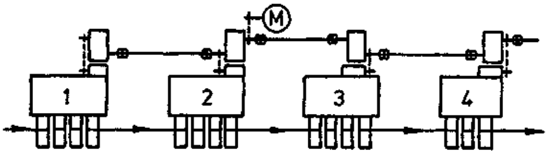


Figure 4.300
Drawstands, controlled by mechanical PIV gearboxes and connected by universal-jointed drive shafts

Multi-roll calenders for drying, heat-setting and cooling are mostly fluid or vapor heated, or are water cooled. They have large rolls, mainly of diameter 500...900 mm. The tow is alternately heated on one side, then on the other, which is advantegeous in obtaining a through-tow temperature of ≤ ± 1 °C after heat-setting. PA6 tows must reach a temperature of 180...190 °C, and PET tows 190...230 °C. Subsequent tow cooling must also achieve such uniformity in cooling the tow down to below the glass transition temperature.

For the best temperature uniformity between 100 and ca. 220 °C, roll heating is done by steam, with condensate removal, as shown in Fig. 4.200I. Liquid heating or cooling of rolls is done as per Figs. 4.200J or 4.301. The hot water or thermal oil inlet and outlet is done at the rear end of the roll by means of a rotating double slide ring gland (Fig. 4.302) [284, 285], which is held stationary by a torque converter bearing. Two flexible hoses connect the fluid inlet and outlet to the fluid heater. The roll shown in Fig. 4.200I has a self-bending siphon within the roll shell for removing condensate. The double ring gland needs constant checking and maintenance, as sealing disk wear and eccentricity between the roll shaft and shell can lead to leakage.

To allow for possible roll bending, a double row of swivel joint (or spherical) roller bearings should be used, as in Fig. 4.301; allowance must be made for the maximum roll temperature. Up to ca. 150 °C, grease or oil circulation lubrication systems can be used. Higher temperatures require special high temperature grease, appropriate for the temperature class. In all cases, the shaft bearings are heated from the inside. Self-regreasing bearing bushes are often advantageous.

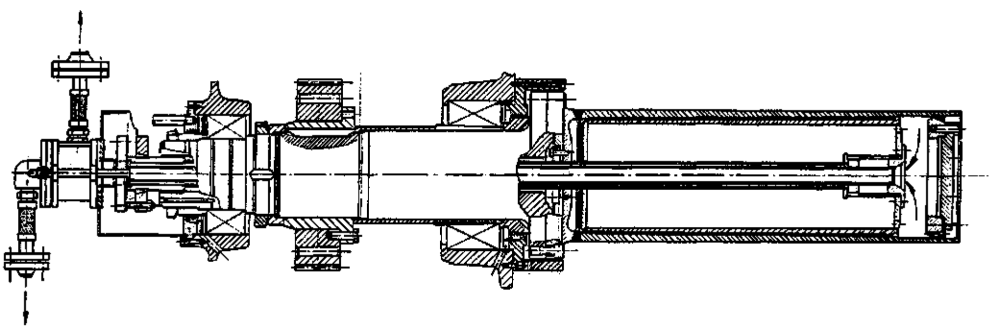


Figure 4.301 Drawstand-mounted liquid-heated draw roll with shaft, gear and double sliding ring gland connection [167, 295]

The rolls or shafts of a drawing frame are connected by helical gear wheels or gears having staggered teeth—taking into account the direction of rotation. These gears can be clamped to the shafts or fixed thereto by two opposing wedges.

Drawing and heat-setting units which operate at high temperature are usually equipped with suction hoods. The whole unit may be enclosed, with access only via doors and windows. In the case of large lines, it is advantageous to install automatic wrap removers on the rolls where filament wraps occur.

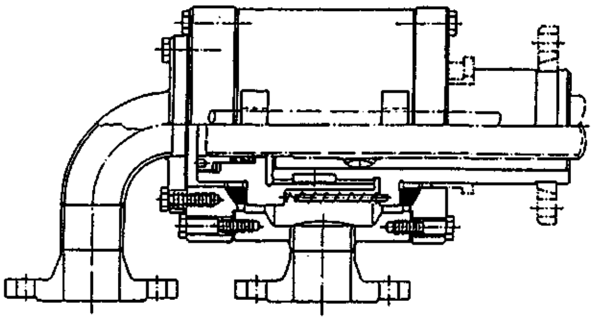


Figure 4.302
Rotating double sliding ring gland [284] (Maier)

These comprise either brushes running the length of the rolls or pins made from a soft metal (e.g., Ms) which traverse the roll length, running in weakly-spiral grooves in the roll.

4.13.7 Hot Drawing Ovens

Hot drawing ovens are used to thermally treat the tow between drawstands. Their working medium is either hot air or steam superheated up to ca. 250 °C; their function is to heat the tow or to hold it at a given temperature. The widely-used hot liquid drawing baths are discussed in Section 4.15.2.1. One differentiates between:

- Hot air ovens. Hot air ovens have working widths equal to the tow width +ca. 100 mm; in practice this means working widths of 350 to 1450 mm. They are usually 2500...4000 mm long, and can be opened for threading up (see Fig. 4.303). There are two hot air circuits, one above and one below. Each hot air circuit is fitted with a circulation fan, an air heater and a thermometer, enabling adjustable, linear air velocities in the tow direction of up to 25 m/s to be obtained. Typical fan and heater powers can be found in Table 4.46. The air temperature uniformity in the working area should

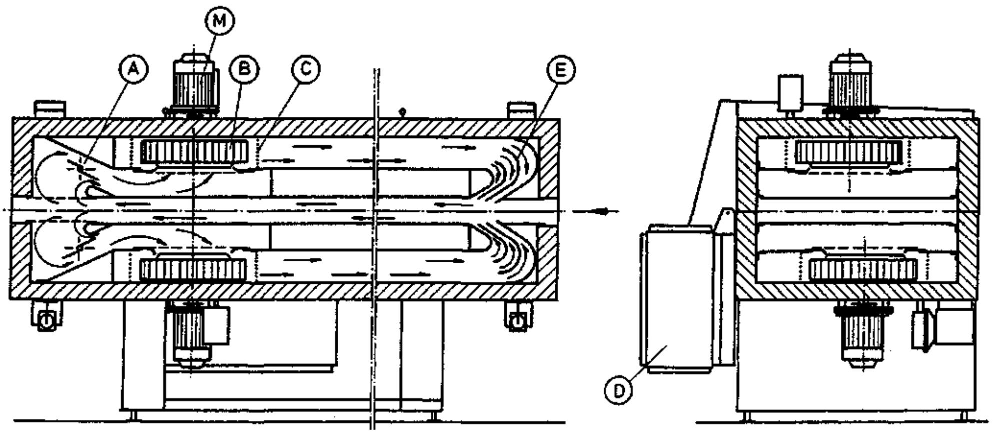


Figure 4.303 Schematic of a hot air drawing oven. The oven can be pneumatically opened ca. 25 mm for tow insertion at string up and ca. 400 mm for cleaning. Working temperature is up to ca. 250°C
A) Air flow control flaps
B) Radial fan
C) Blow-out cage and electric heater
D) Electrical connection and control
E) Air flow direction reversal (hot air to tow)

Table 4.46 Electric Heater Power and Fan Motor Power of Hot Air Drawing Ovens

Inner width mm	Length mm	Fan motor kW	Air heater kW
350	2500	2 × 1.5	15
900		2 × 3	36
1450		4 × 3	52
350	4000	2 × 1.5	18
900		2 × 3	40
1450		4 × 3	58

be $\leq \pm 1.5\,°C$, and the air velocity constancy should be $\leq \pm 0.1$ m/s (or $\leq 1\%$ for air velocities > 10 m/s). The internal duct material should be 1.4301 stainless steel, and the heating can be either electrical or by steam.

- Drawing ovens using superheated steam. The internal dimensions correspond to those of hot air ovens. Dry saturated steam, free of water droplets, led into the oven by piping and spray jets, is blasted against the inside of the cover and the bottom of the oven, which both hold cast Al heating plates, screwed onto the cover plates from the outside. The heating plates are temperature-controlled and have over-temperature protection (Fig. 4.304). The superheated steam passes through perforated plates, enters the channel through which the tow passes and heats the tow. To seal the oven, the tow inlet and outlet sections have labyrinth seals, with a smallest gap of only a few mm. The steam must be automatically switched off when the ovens are opened to prevent the workers being scalded by the steam. The required heating power corresponds to the sum of the fan and heater power given for hot air ovens in Table 4.46.

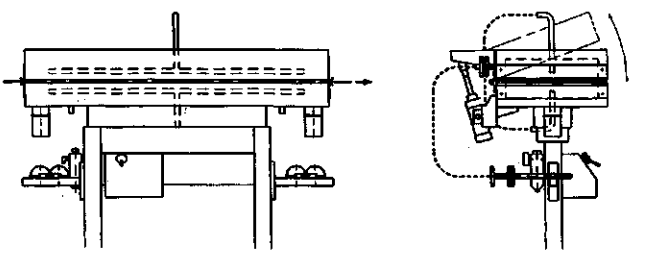


Figure 4.304
Hot air drawing oven for drawing in superheated steam. Saturated inlet steam is passed over electrically-heated superheating plates (*E*) [24]

- Saturated steam ovens are used mainly to "soften" the tow or yarn, e.g., before stuffer box crimping in order to improve the crimp. The tow is treated with 100 °C saturated steam at atmospheric pressure. In order to avoid condensed water droplets, the jacket of the oven is heated with the same steam supply (Fig. 4.305). The internal dimensions are the same as those of the ovens already described. The length should be ca. $= (0.8 \times$ tow m/s)m, i.e., ≥ 1.6 m long for a tow speed of 200 m/min. Water droplets must be removed from the steam (e.g., by a centrifugal separator) before entry into the oven.

4.13.8 Tow Spreading and Plying

While the tow should run through the drawing and heat-setting zones as thin and as wide as possible, the tow must be assembled into a narrower and thicker band for the stuffer box crimper, in order to match the dimensions of the stuffer box. During this latter operation, various sub-tows are overlaid and mixed.

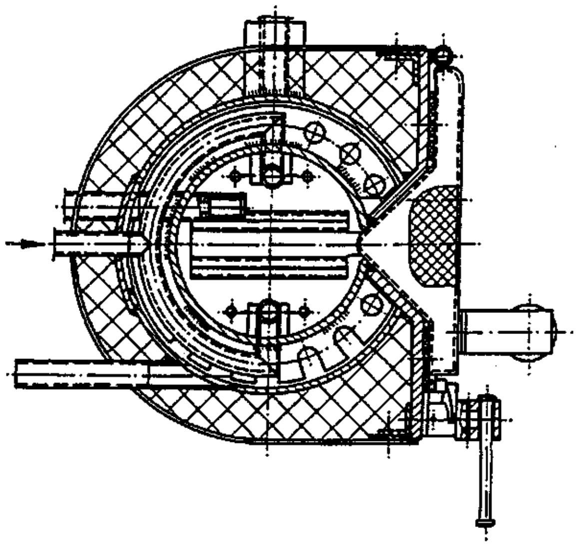


Figure 4.305
Saturated steam heating and moistening oven [24], with steam spray injection and heated jacket, for sideways tow guiding

If the change in the tow width required is small, the tow can be led over a series of consecutive arc-shaped rods, suitably coated so as to be wear-resistant, having their chords held parallel to one another in a frame. The curved rods are then angled in such a way that the tow, running over the rods in a zig-zag path, achieves the desired width: making the rods concave narrows the tow, while making the rods convex widens the tow. As this action can increase the tow tension considerably, not more than 6 to 7 consecutive rods should be used, and the change in tow width should not exceed ca. 30%.

To achieve large fractional changes in tow width, a roll stand (tow stacker) as in Fig. 4.306 can be used. Both stands contain free-running, fixed top rollers and free-running, inclinable lower rollers, which can be angled so that the part-tows run normally onto the roll axis and on exit produce the desired (almost) rectangular tow package.

In the case of very thick tows, a mirror image tow stacker is mounted above the tow stacker shown in Fig. 4.306. The half-tows, from above and below, are then plied.

To control the tow tension and/or the speed of the following machine, dancer- or pivot rolls, shown in Fig. 4.307, can be employed. If the middle (dancer) roll or the pivot roll dips, limit switches can be activated to change the speed of the following machine, either in small steps or continuously.

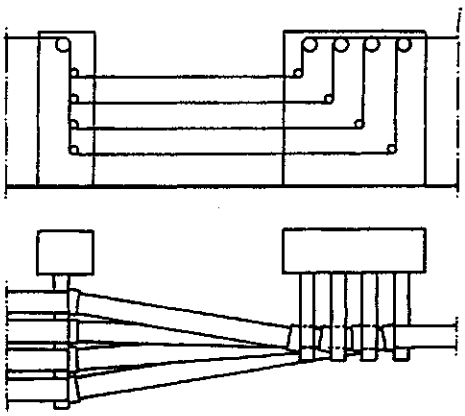


Figure 4.306
Tow stacker

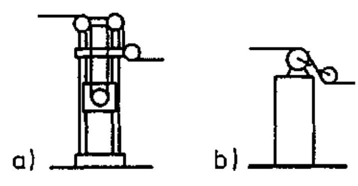


Figure 4.307
Tow tension control by means of dancer roll
a) with floating roll
b) with pivoted roll

The system in Fig. 4.307a (or a series of consecutive systems) can be used as a tow accumulator. The accumulated length of the system is then twice the distance between the upper and lower rolls. Frictional or pneumatic damping must be included to inhibit the dancer rolls from oscillating.

4.13.9 Stuffer Box Crimpers

Stuffer box crimpers are currently built for continuous filament yarns of a few hundred to a few thousand dtex, as well as for staple fiber tows of up to 3 million dtex. They are suitable for single filament titers from ca. 0.8...100 dtex and for speeds up to 300...500, or even up to 2000 m/min. Thicker single filaments make it more difficult to crimp the filaments (Section 3.11). Too high a fiber elastic modulus and pre-crimping temperatures ≥ crimping temperature in the stuffer box affect the end product properties and crimp. Since rotating and stationary parts work together in the crimping machine, two constructional principles are possible:

- The gaps between the rotating and stationary parts are made so small that no filament is carried along with the rotating part. For a 1 dpf filament, the gap would have to be < 10 μm. At up to 8 m/s gliding speed and with a temperature increase of from 20 °C to up to ca. 200 °C, this is very difficult, particularly when the gap(s) and the clearance of the cheek plates must be set by the cam (e, Fig. 4.308) and shims, or
- all gaps are made much larger, but no single filaments can enter these gaps, neither at the inlet nor at the cheek plates, nor between the compression rolls and the lip of the chamber plates. With this construction, speeds of from > 8 m/s up to, at present, < ca. 33 m/s can be attained [167] with PP, and 60 m/s with PA.

The crimping rolls are normally made from hardened and ground tool steel (e.g., St 1.2080 = X 210 Cr12), the cheek plates and stripper lips (both wearing parts) from oil-impregnated, forged bronze (e.g. Caro bronze). The cam, made from hardened steel (e), is approximately 0.2 mm eccentric. The cheek plates are allowed to rotate slowly, so that their inner sides remain flat.

The crimping roll shafts are internally water cooled and equalized in temperature. They therefore have a large diameter and relatively thin, slightly conical tires. External diameters of 200 mm and lengths of up to 500 mm for the rolls and crimping chamber are typical. One can reckon on $(1.5\ldots2) \times 10^5$ dtex/inch crimping chamber width. The tow is moistened and heated with 100 °C saturated steam, and spin finish is applied before the tow enters the stuffer box. Additional steam can also be injected into the stuffer box via angled bores in the side plates. The tow plug in the stuffer box is warmed up by both frictional heating and the kinking of the tow (see Section 3.11).

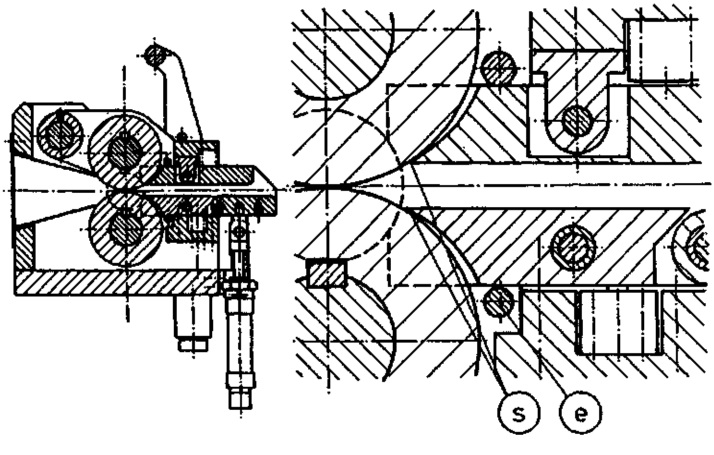


Figure 4.308
Stuffer box crimper, with gap width(s) adjustable by means of the stripper plate cam (*e*) [24]

In older stuffer box crimpers (for up to ca. 300 000 dtex), the tow entered the stuffer box vertically [148, 24], and the stuffer box could easily be opened to the front, allowing the tow to be inserted from the side. The pinch rolls were made strongly conical across their width. The chamber pressure was adjusted using a micrometer screw via a Belleville spring washer acting on a front swivel plate. The maximum processing speed was ca. 200 m/min. When more than 500 000 dtex was crimped, the shaft bent, resulting in the cantilevered crimping roll having a larger gap at the outside of the roll than inside; the crimp on the outside was consequently weaker.

The already-described modern, high capacity stuffer box crimper has a horizontal chamber and a pair of crimping rolls with bearings at either roll end. The rolls are driven by a pair of universal-jointed shafts (Fig. 4.309) and have an installed drive power of ca. 10 kW/10^6 dtex/100 m/min. Crimp values of 10 crimps per 10 mm are easily achievable (Figs. 4.310 and 3.60). The upper section is openable for easy maintenance.

New developments have led to a stuffer box crimper capable of up to 2000 m/min tow speed. The maximum tow width is 10...20 mm and the maximum dtex 75 000 [148]; the tow enters vertically. It would be suitable for use on a compact staple fiber spinning machine [167]. As stuffer box crimpers in continuous production are subject to breakdowns, it is sensible to have a standby machine available. At a crimper breakdown, the tow is then quickly diverted to the standby crimper.

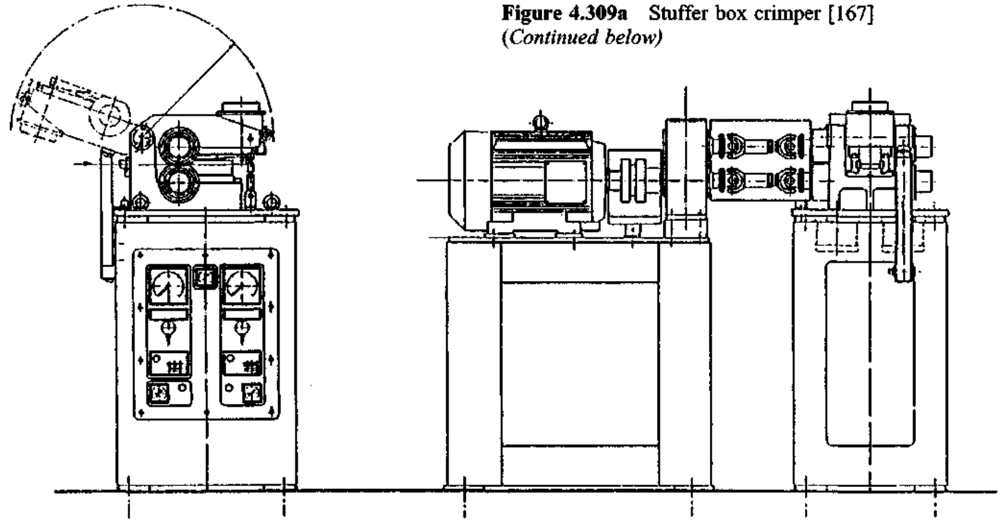


Figure 4.309a Stuffer box crimper [167]
(*Continued below*)

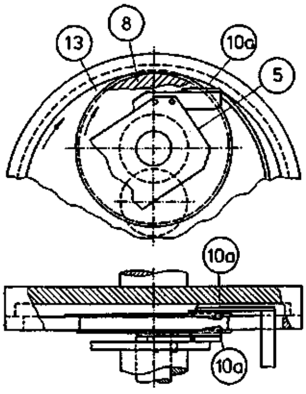
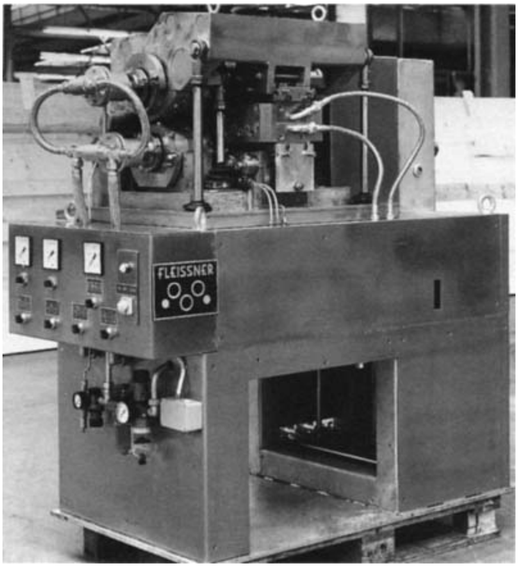


Figure 4.309b
Principle of a high speed stuffer box crimper. The tow is crimped in the space between the inner wheel, the outer wheel and the co-rotating side cover plate

5 Support for
8 Internal crimping roll
10a Counter pressure plate
13 Tow inlet



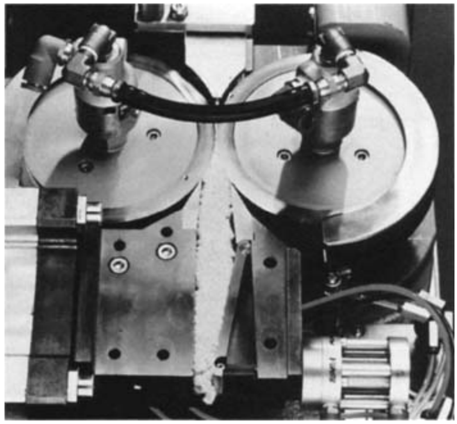


Figure 4.310
Stuffer box crimper for a wide tow (up to ca. 2.5 × 10^6 dtex × 400 m/min) [295]. (*a*): Fleissner crimper; (*b*): Barmag crimper [33], showing crimped tow outlet

According to a Japanese patent [339], the generation of frictional warming during stuffer box crimping can be avoided by giving the tow and all stuffer box components the same speed. To this end (Fig. 4.309b), the tow is squeezed between the inner surface of a rotating hollow cylinder (13) and a crimping roll (8), which has its bearing in an oscillating crank (5), and is pressed from inside onto (13). The clamped wide tow runs an adjustable distance beyond the clamping point and then against the flap (10a), and is crimped by the increasing resistance. The crimped yarn is taken out by the next machine in the sequence.

4.13.10 Dryers and Heat-Setting Machines

In drying and heat-setting, the tow moisture content and shrinkage are reduced, the crimp is set and the tow or yarn is allowed to shrink until the residual shrinkage is only ≈0.5%. There are essentially 3 machine types for 3 different product treatments:

- Rolls ——— Tow (straight) ——— under tension (adjustable)
- Suction drum ——— Tow (meandering) ——— for shrinking
- Conveyor belt ——— Fiber (flock) ——— for shrinking

The tow or fiber must be distributed with uniform areal density over the dryer width. To allow the tow or yarn to shrink easily, it is laid on the conveyor belt before entry into the dryer in a meandering form, by traversing the tow or yarn at right angles to the direction of travel of the belt. It is possible that consecutive, single lays overlap one another, causing potential problems at take-off. This can be overcome by having either a slowly-oscillating chute or a narrow slide (trunk) which traverses across the entire width, fitted before the stuffer box.

The tow or fiber is first dried in order to obtain a uniform moisture content. Should there be wet or moist islands present in the tow when it is heat set, these wet areas will have a shorter heat setting time than the drier areas, as the excess moisture needs time to evaporate. This results in variable heat-setting effects, particularly concerning shrinkage and dye uptake. A cooling zone must come after the heat-setting zone in order to stabilize the heat-setting effect. When heat setting using hot air recirculation, it suffices to use normal room air which has been passed through a water-cooled, ribbed tube heat exchanger. Here—as in drying—attention must be paid to the ratio of fresh-to recirculated air.

At the dryer or heat-setting machine outlet, the tow is taken upwards through an untangling zone and a large tow guide, after which it is pulled into the next machine. The tow is taken out over a pivoting roll of the same width as the conveyor; the height of this roll (and/or an optical signal) drives the speed of the following machine. Because of the effects of shrinkage and crimping, the take-out speed is lower than the inlet speed to the dryer.

- The roll heat-setting machine (see also Section 4.13.6) is mainly used for heat-setting the tow under high tension. If the correct temperature is set, the shrinkage can be reduced to $\geq 1\%$ (see Section 2.3.6.4). The speeds can be varied from roll to roll or from roll group to roll group, depending on process know-how. Since, however, runnability over the rolls requires a certain minimum tow tension, shrinkages of $\leq 3\%$ are not easily achievable. The minimum tension requirement also applies to the suction drum system.
- In the conveyor belt heat-setting process to reduce shrinkage, the tow or yarn is spread uniformly and without tension across the width of the conveyor belt. It is also possible to lay two or more meandering tows side by side. There should be no gaps in the lay, otherwise the hot air will flow preferentially through these gaps, resulting in non-uniformity across the width.

  In the suction drum dryer (Fig. 4.311), the tow is taken up by rolls (a) and deposited onto the feed conveyor (c) in 2 parallel meanders by a slide or trunk (b). The conveyor tranfers the 2 meandering tows to the suction drum (e) at (d). The suction of the fan (f) holds the tows on the surface of the suction drum, even when the tows run on the undersides of the suction drums (second, fourth drum, etc.). After the last suction drum the 2 meandering tows are transferred to the take-out conveyor (g), are taken up by the rolls (h) and are baled (j) from the traversing chute (i). The section of the suction drum which does not bear tow is blocked off from the inside by stationary plates to prevent air flowing through these non-working surfaces.

  Normal perforated plate—or woven wire mesh drums have a free area of from 30 to 45%. Special suction drums [286], which have diameters of up to 3500 mm and lengths of up to 7000 mm, are made with up to 90% free area, yet are still uniform. The movement of the tow over the arcs made by the drums results in a worthwhile saving in machine (and building) length.
- Conveyor dryers and/or heat-setters are used particularly when it is difficult to hold the tow on the underside of a suction drum, when a particularly long residence time is required, and when the tow is very thick and/or has a particularly low bulk density. The conveyor belt comprises either a special corrugated rod weave, or—mostly—a belt made from perforated plates. The latter is made from many perforated stainless steel folded and overlapping platelets, fastened on both sides to an endless chain. The open area should be as large as possible.

  Figure 4.312 shows a schematic of such a conveyor dryer and heat setter [167]. The tow is taken up by feed rolls (a) and laid on the conveyor belt (b), which traverses at its outlet end, and from where the tow drops into the gap (c) between the drum and the conveyor belt of the dryer. The tow is then taken through a drying, heat-setting, cooling (d) and conditioning zone (e), after which it is taken up over a tow guide and brake (f). In each dryer compartment, a fan (g) recirculates the air via a heater (or cooler) (h) through the tow on the conveyor belt, the air flowing from above the tow to below. The fan (i) exhausts a certain proportion of the drying air to atmosphere. Fresh make-up air is aspirated at another position. A 22 t/24 h drying and heat-setting line would have a length of 19.2 m, from tow inlet to outlet.

  Conveyor belt dryers can have very varied constructions, such as having the feed belt close to the floor, or—to shorten the machine length—having a three storey configuration. In the latter, the tow is fed from the uppermost storey and exits the dryer on the ground floor.

  Figure 4.313 shows the moisture content and temperature of a tow as a function of length in a dryer/heat setter. The diagram is valid both for belt dryers and suction drum dryers when the air flow conditions are the same.

  The rate of drying when using a penetrative air velocity of 1 m/s is 10 times faster than when an air velocity of 5 m/s is blown parallel to the tow surface or air of the same speed is blown through slits [295].

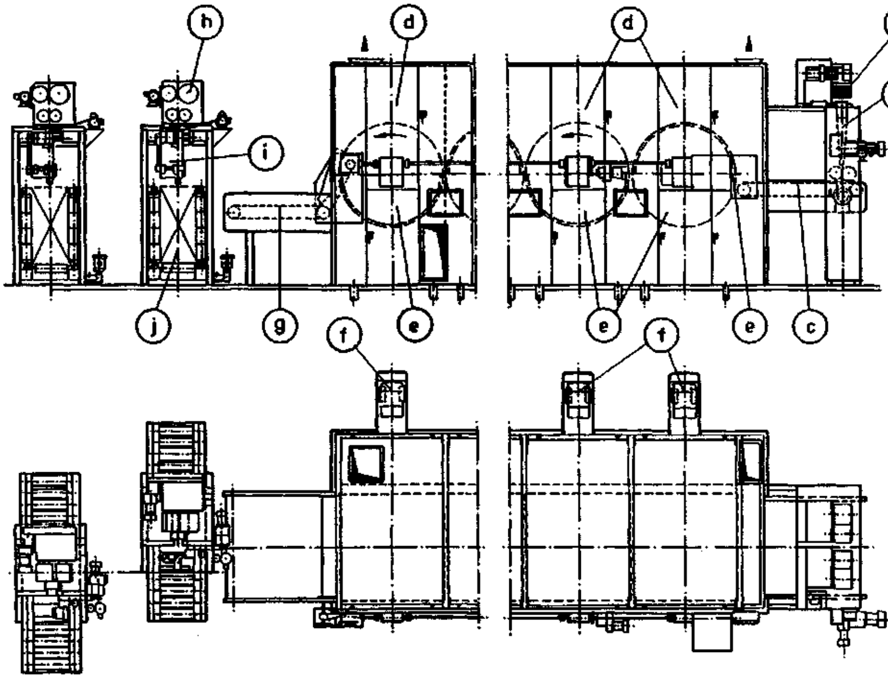


Figure 4.311 Perforated cylinder drier and heat setter [295] (Fleissner)

a) Tow inlet, double
b) Two tow spreaders
c) Inlet conveyor belt
d) Heating or cooling chambers
e) Perforated cylinders, 50% open area
f) Fan and drum drives
g) Outlet chute and take-away conveyor belt
h) Enclosed take-out rolls
i) Tow laying chute
j) Baling

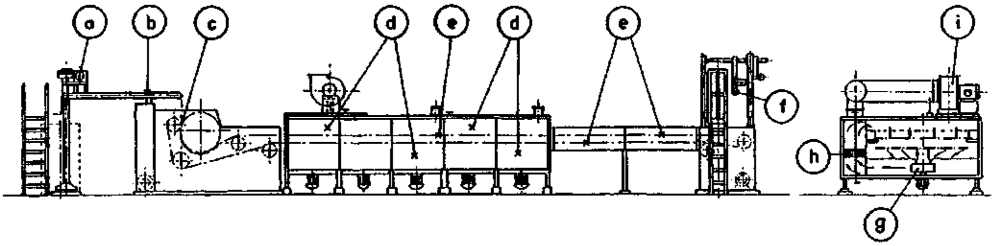


Figure 4.312 Belt drier and heat setter [167] (Neumag)

a) Tow inlet
b) Tow laying chute
c) Tow deposit
d) Heating and cooling chamber
e) Tow transport conveyor belt
f) Tow take-out
g) Recirculation fan
h) Heat exchanger
i) Exhaust air fan

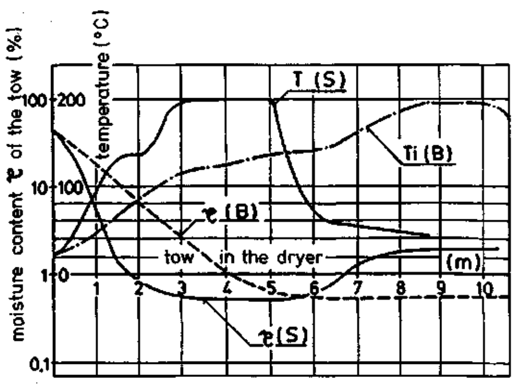


Figure 4.313
Tow temperature T and moisture content as a function of the length in the dryer (at constant tow width inside dryer) for a perforated cylinder (suction) dryer/heat setter (S) and a belt dryer/heat setter (B). The required external dryer/heat setter insulation housing length is ca. 2 m for (S) and ca. 5 m for (B) per field.

4.13.11 Tow Packaging

If endless tow is to be despatched for use off-site, cardboard cartons or large woven bags having a plastic coating (or liners) can be used. These containers are secured by a steel strapping band. Bale weights vary between 100 and ca. 300 kg and fiber densities between 0.35 kg/l (PP) and 0.45 kg/l (PET).

Figure 4.314 shows a schematic of a tow bale packing machine. The tow is taken up by inlet rolls (a) and an open sunflower wheel (b), which delivers the tow to a traversing laying chute (c), which then lays the tow in the cardboard carton. The carton slowly traverses at right angles to the movement of the chute in order to obtain a meandering tow lay. During the filling of the carton, the laying chute continuously moves upwards, so that there is always a gap of 300...500 mm between the tip of the chute and the tow surface in the carton. On reaching the maximum height for later compaction (which is here given by extending the carton top cover flaps upwards), the carton is moved by the conveyor belt (e) to the compaction station (f). At the same time an empty carton is moved into the filling position. At the compaction station, the carton is temporarily reinforced on 5 sides by pivoted, solid walls (g) and the

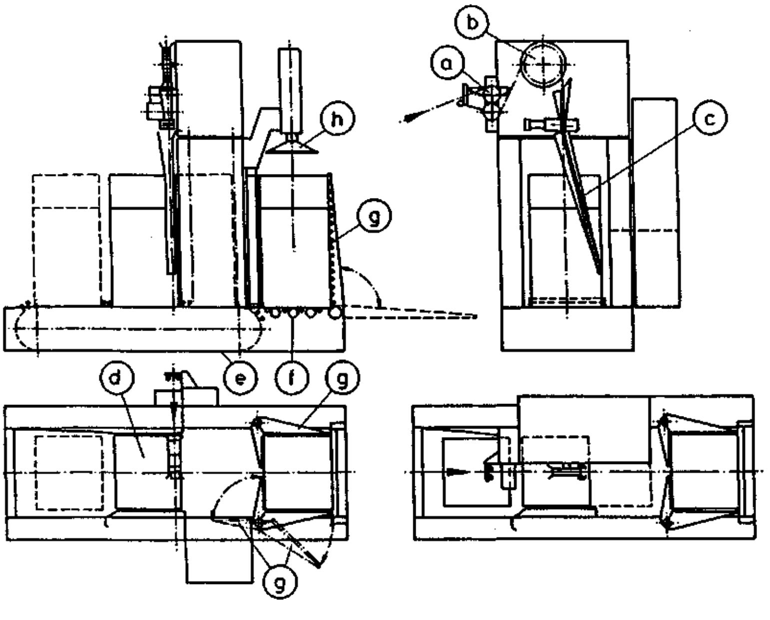


Figure 4.314
Tow baler (Tamper; see also Figure 4.311*j*)
a) Tow inlet
b) Sunflower wheel
c) Tow laying chute
d) Carton (box)
e) Traverse table
f) Carriage rollers
g) Flap for removing full carton
h) Pressure ram

contents are compressed by a hydraulic ram (h). After strapping, the reinforcing sides (g) are lowered and the bale is removed. At a carton change, the tow is automatically cut in such a way that both the end from the full carton and the end going into the new carton hang over the tops of the respective cartons. Instead of cartons large coated bags can be used. The laying chute can be set to traverse between 15 and 100 double strokes/min and the carton to traverse between 1 and 4 double strokes/min. The deposition speed of the tow in the carton is the same as the tow delivery speed of the dryer or heat-setter. The tow should be laid in the carton in straight, meandering lines with very little loopiness.

4.13.12 Staple Cutters

Staple cutting machines cut the continuous—and almost always crimped—filament tow to the staple length (=effective length) desired for secondary spinning. Although natural fibers have a broad distribution of lengths, man-made staple fibers are expected to have a narrow length distribution, which depends on the type and quality of fiber. Over-length fibers (0...10%) and under-length fibers (0...10%) should each constitute less than 10% w/w. An overview of staple cutters up to 1967 is given by [288]. Excepting for the "Gru-Gru" cutter [289], none of these is currently used for man-made fibers. Of the later developments, only the "Lummus cutter" [290] and the Neumag staple cutter [291] achieved dominant, world-wide application (i.e., excepting special cutters for high tenacity and flock).

- "Gru-Gru" *cutter* [291, 292]
  In the "Gru-Gru" cutter in Fig. 4.315, the tow enters from above and is pinched by the opposed, rubber teeth of the counter-rotating slotted wheels. One blade of the rotating knife passes between the two gaps near the pinch point and cuts the tow. A rather complicated special gearbox is required, both for driving the slotted wheels and for driving the knife. A large number of change gears is needed, as well as a large number of slotted wheels of different pitch for different staple lengths. The slots require a special flank geometry, and the knife must be inclined at a particular angle (Fig. 4.316, [292, 293]). Such cutters are suitable for up to 1 100 000 dtex dry and up to 700 000 dtex wet at 300 m/min. In an alternative version [288], twice the above titer can be cut. The lifetime of the knives is only a few hours, depending on the material and delustering agent level. A continuously operating line must therefore be equipped with a standby cutter. As the tow clamping by the rubberized teeth cannot be perfect, a few filaments are always pulled or stretched by the impact of the knife during cutting, resulting in under-length and over-length staples (Fig. 4.317). As soon as the 10% limits are exceeded or double-length staple is produced, the slotted wheels and/or the knives must be changed. A "Gru-Gru" staple cutter [292], together with its components, is presented in Fig. 4.318. The brake roll (a) must tension the crimped tow sufficiently to pull out the crimp before the "flat" tow is nipped by the slotted wheels (b), and cut between the gaps in the teeth by the knives in the knife head (c), which is driven by a spiral-toothed, bevel gear pair (d). The change gearbox (e) drives the two slotted wheels (b) and is connected to the knife head (c) drive. The left-hand slotted wheel (b_2) can be pressed against the right-hand one by means of a spring washer (f) to compensate for changes in tow thickness, such as knots. An advantage of this cutter over the cutter next described, is that it is possible to change the staple length immediately by gear changes (on the standby machine).
- "Lummus Cutter" [290, 295]
  The principle of the Lummus cutter is very simple and is explained in Fig. 4.319. The tension of the entering tow (a) is increased to pull out the crimp by the difference in speed between the braking roll (b) and the cutting wheel (c). The cutting wheel rim (d) has knives protruding outwards, onto which the tow (a) is wrapped. The pressure roll (e) is adjusted so that the gap between itself and the tips of the knives is only a few mm, with the result that, after a few wraps around the cutting drum, the tow is pressed so forcefully against the knives that the inner layer of the tow is cut and pressed out between the knives to the inside of the cutting wheel at one position. The staple length diagram is very uniform and remains so until the first knife becomes blunt or ragged, when single filaments pull neighboring filaments with them and the dreaded multi-length staples (crackers) arise. The fiber ends in the cross-section can become so hot that they fuse. It is also important to ensure that the tow width is the same as the knife width. An electronic knife cutting edge monitor [290] can be used to signal when a cutting wheel change is necessary.

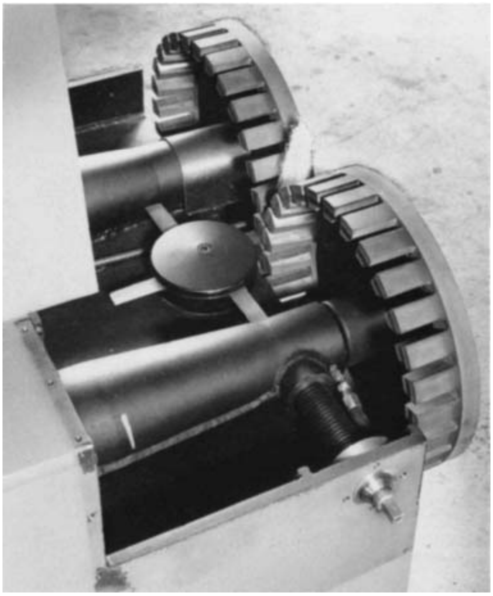


Figure 4.315
"Gru-Gru" staple cutter, opened. Photograph showing principle [24].

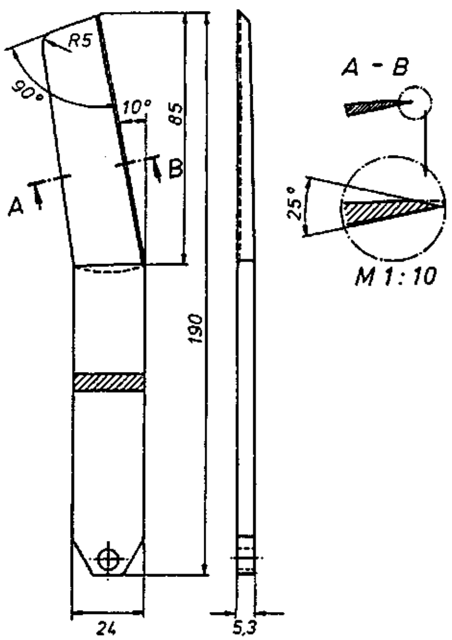


Figure 4.316 Special knife for "Gru-Gru" staple cutter [293]. (Material: 85Cr1 or similar, =1.2004, possibly carbide coated)

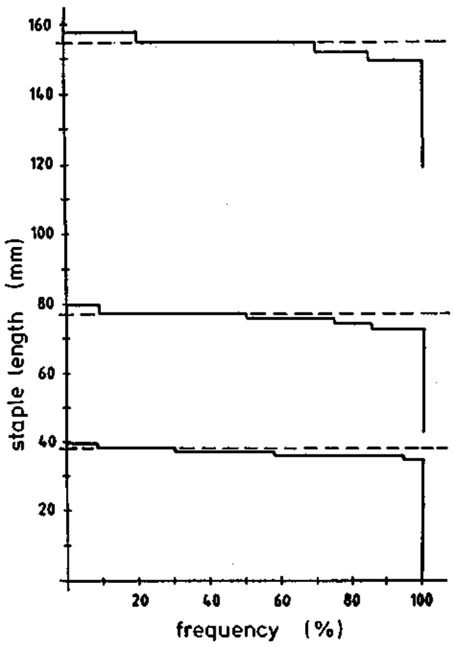


Figure 4.317 Staple cut length/frequency diagram for PET staple fiber cut on the Neumag staple cutter Type NMC ("Gru-Gru") [167]
[— represents the theoretical cut length of 40-80-154 mm (=knife spacing)]

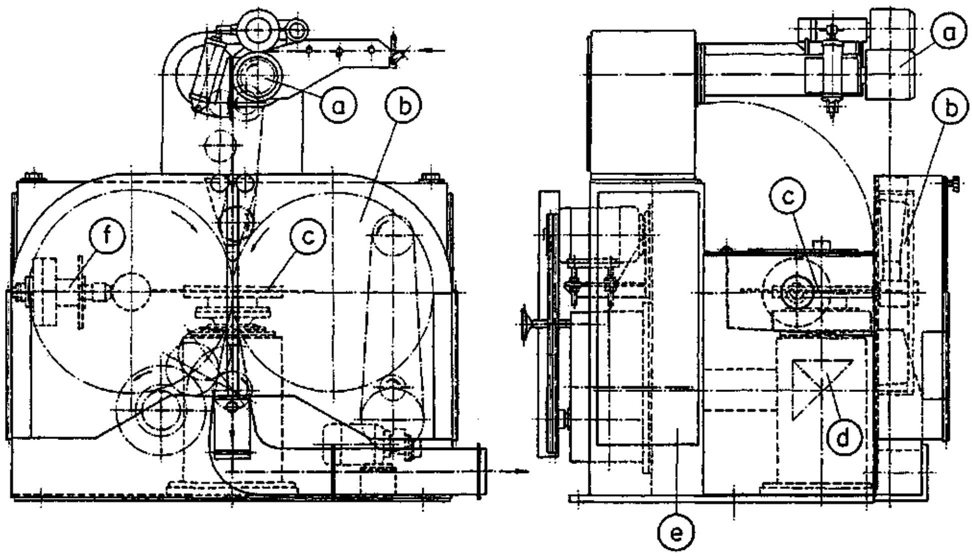


Figure 4.318 Schematic of a "Gru-Gru" staple cutting machine [258, 24]
a) Inlet rolls
b) Slotted rolls
c) Knife head
d) Knife head drive
e) Gear housing
f) Pneumatic contact pressure

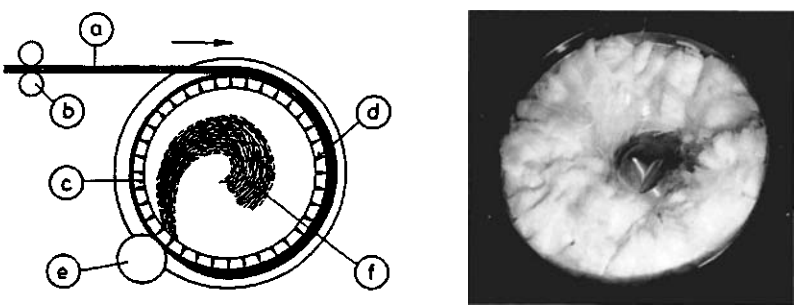


Figure 4.319 Cutting principle of the Lummus cutter ([232] in the USA; [279] in Germany). License holder: Eastman Kodak)
a) Tow
b) Tow tensioner
c) Cutting wheel
d) Knife
e) Pressure roll
f) Cut staple fiber
Photograph: Cut staple fiber emerging from the cutting wheel outlet

To avoid the "pinching cut" effect, machines similar in principle, but using traversing knives [296, 291] or a scissors-action cutting [297] or rotating cutting disks [299] have been developed. Because of their complexity, however, the above developments have not been commercialized. In a further development [279, 300], the tow is wound onto a slotted drum and is cut, against the tow tension, by a slightly inclined rotary knife having its axis at right angles to the axis of the drum.

- Neumag staple cutter [167]
  As shown in principle in Fig. 4.320, the tow is fed into the entry gap (a) between the rotating knife head (b) and an inclined, free-running pressure disk (c), which is dragged along by the tow friction.

After travelling 180°, the pressure plate (c) presses the tow against the radially-aligned knives, cutting the tow. The cut tow is forced through the gaps between the knives and falls out below as cut staple, as shown in the photograph. The cutting speed is about 3...5% of the tow speed. The maximum tow thickness is given as a function of cutting speed for two machine types in Fig. 4.321. The most commonly-used staple cut lengths are ca. 30...50 mm for cotton-type, 70...100 mm for worsted spinning, 120...160 mm for carded spinning and 130...200 mm for carpet staple. The staple cut length can be adjusted in small steps in the following ranges: Gru-Gru: 28 to 240 mm (depending on size); Lummus and Neumag: ≥6 to 240 mm (depending on size); the cutter using a slotted drum: ≥2 mm; guillotine cutter (for very short fibers): down to ca. 0.5 mm. The specific motor drive power of the first three cutters can be found in Fig. 4.322 or can be calculated from:

$$kW_{Motor} \approx 5 \times 10^{-6} \times m/min \times g/dtex \times \sqrt{dtex_{tow}} \tag{4.44}$$

Maximum allowable tow thicknesses are ca. 2.2×10^6 dtex (dry) for the Gru-Gru cutter, ca. 4×10^6 dtex for the Lummus cutter and ca. 3×10^6 dtex for the Neumag cutter. In the guillotine cutter, compressed tows of up to a few 10^7 dtex can be cut, but only up to a maximum cutting rate of ca. 200 cuts/min.

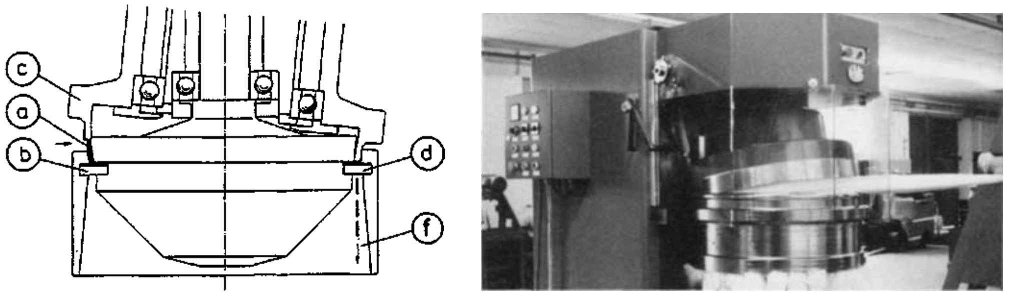


Figure 4.320
Working principle (*above*) of the Neumag staple fiber cutter [285]
a) Cutting rotor with tow and radial knives (*d*)
b) Pressure plate (loose, travelling)
c) Rotating pressure excenter
f) Cut staple fiber (falling down)
and photograph of the machine working (*right*), showing tow inlet, and cut staple being discharged under gravity

- Staple cutters for hard fibers (e.g., polyaramid, glass fiber, carbon fiber, etc.) operate on a principle similar to that shown in Fig. 4.323. In (a), used for glass fiber, the tow is pinch-cut between a rotary knife roll and a hardened pressure roll, while in (b), used for polyaramid, the tow is cut by the shearing blades on one roll intermeshing with wide slots on the counter roll. When using normal staple cutting knives, these become blunt and ragged within a few minutes. These special cutters work better at high tow tensions.

4.13.13 Staple Fiber Transport

The clumps of cut staple which fall from the staple cutter stick together because of the crimp and the spin finish. These clumps must be opened and transported to the condenser in front of the baling press by the transport air. This can be achieved by using special fans having open smooth blades on one side. The filaments, however, can be over-stressed on colliding with the fan blades, and it is preferable to use a suction conveyor system.

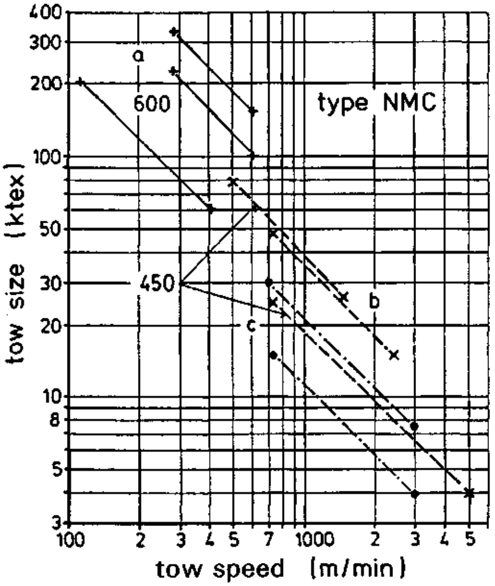


Figure 4.321
Cutting capacity of the Neumag staple cutter type NMC600 (*a*) and NMC 450 (*b*, *c*) [301]

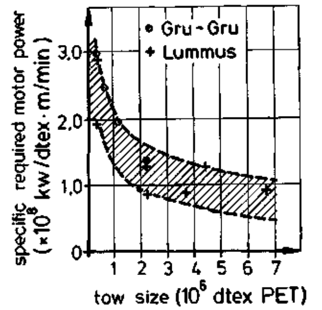


Figure 4.322
Required drive power of staple fiber cutters

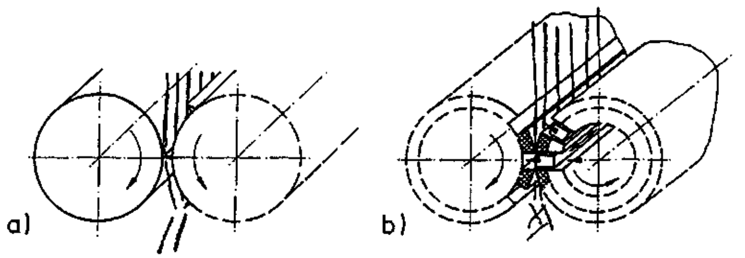


Figure 4.323
Staple cutter (in principle) for hard fibers (*a*), such as glass or polyaramid, and for polyester (*b*) [302]. (Enka)

During transport, the staple has a bulk density of between 0.1 and 0.5—preferably 0.35 kg staple/m^3 of transport air. The staple is blown or sucked at ca. 20 m/s in smoothly bent, round aluminum pipes having large bend radii ($R \geq 10D$) (compare Section 4.2.4). The suction system has the additional advantage that the filaments are not twisted and do not form plaits. The staple enters the condenser (Fig. 4.324) by means of a bifurcated pipe, alternately from one side, then the other, in order to fill the condenser uniformly. The exhaust air, after filtration, can be returned to the spinning room, exhausted above the roof or—in the case of large staple lines—returned to the fan.

4.13.14 Balers

In order to make the storage and transport of staple fiber economic, it is compressed (like cotton and wool) into standard bales of 200...500 kg weight, which are wrapped in plastic foil, covered by woven cloth and secured by steel straps.

While cut staple is continuously delivered by the cutter, the baling is a batch process, requiring a certain time to compress and pack the bale. A buffer is therefore required, and the fiber must also be separated from the transport air in a condenser, as shown in Fig. 4.325 [303]. The press is hydraulically

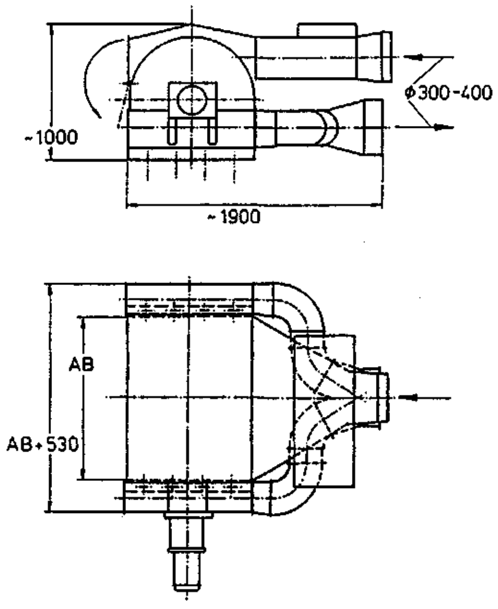


Figure 4.324
Staple condenser with double-sided staple entry in order to achieve uniform filling of the condenser [303] (Autefa)

driven. Packaging material supply should be automated, especially on large lines. Table 4.47 lists the throughput of a series of balers of average capacity [303]. As an example, 5 PET staple bales/h can be compressed using a force of 70 t to give a bulk density of 0.4 kg/l.

If one considers that a 70 t/24 h staple line produces a ca. 300 kg bale every 6 min and a 250 t/24 h line a bale every ca. 100 s, then the need for automation is self-evident. To this end, the tow or staple is deposited into boxes, which—when full—are transported to the baler on a rolling conveyor, where they are hydraulically positioned for compression and wrapping, preferably automatically. The completed bales are then pushed out onto a roller conveyor for transport to the store, while the empty boxes are returned for re-filling (Fig. 4.326).

Figure 4.327 shows the layout plan of a carousel press [303]. The staple is conveyed from (1) into the condenser (2), where it is uniformly distributed across the working area, is separated from the transport air and falls through the filling shaft (3) onto the floor. The filling volume per charge is monitored by

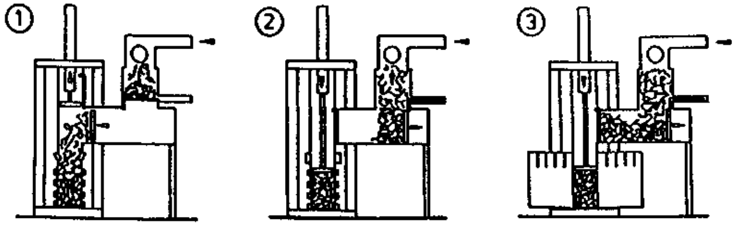


Figure 4.325 Working principle of a baler

1 The material to be compressed is separated from the transport air in the condenser, is dumped into the charging chamber and then pushed into the compression zone batchwise.

2 The charging chamber is refilled while the fiber in the compression zone is compressed.

3 While the compressed bale is being wrapped and strapped, newly-arrived staple is stored and pre-compressed in the charging chamber

Table 4.47 Capacities of Two Balers [287]

Type	Press area m × m	Bale density kg/m³ 10	15	20
			capacity kg/h	
400	1.1 × 0.64	350	400	450
	1.37 × 0.64	430	500	550
1200	1.1 × 0.64	950	1200	1950
	1.7 × 0.64	1200	1500	1605

Staple fiber bale weights

Press force t	Press area m × m	Bale weight kg
25	1.1 × 0.64	170...220
	1.37 × 0.64	200...260
70	1.1 × 0.64	200...260
	1.37 × 0.64	240...310

photocells, after which a push blade presses this part-charge in the pre-pressing box. During this operation, the continuously arriving material is pre-stored in the filling shaft. After each pre-compression a new part-charge is supplied, until the desired bale weight (set by means of the hydraulic pressure) is reached.

The carousel device then rotates the box containing the pre-compressed material under the main press, simultaneously supplying the pre-press with an empty box. While the pre-press repeats the above procedure, the main press (5) completes the final compression and raises the compression box hydraulically. The free-standing bale is then wrapped and strapped manually before being sent for weighing and dispatch.

Should a large amount of second grade staple arise over time, this can be separately transported from the cutter to a special storage bin, from where it can be periodically transported in separate ducting to the (empty) bale press to produce a second grade merge (lot).

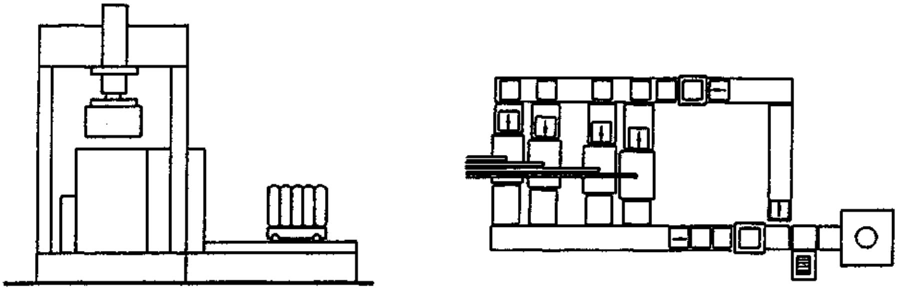


Figure 4.326 Fully automatic tow balers for 4 parallel-running tows [303]

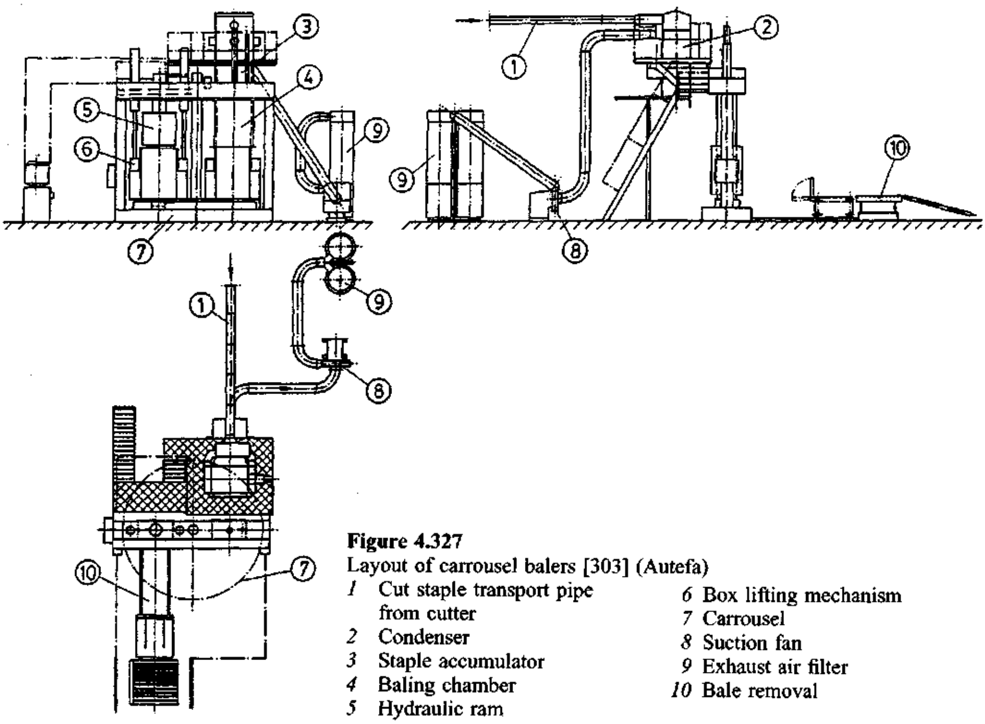


Figure 4.327
Layout of carrousel balers [303] (Autefa)
1 Cut staple transport pipe from cutter
2 Condenser
3 Staple accumulator
4 Baling chamber
5 Hydraulic ram
6 Box lifting mechanism
7 Carrousel
8 Suction fan
9 Exhaust air filter
10 Bale removal

4.14 Dry-Spinning Plants

The first rayon—Chardonnet's "artificial silk"—was spun by a solution dry-spinning process in 1904. This was followed, between 1920 and 1923, by cellulose acetate, produced by Celanese, Rhodiaceta and the Tennessee Eastman Corporation. Between 1935 and 1941, various PVC fibers were produced by the Carbide & Carbon Corp. (Vinyon), IG-Farbenindustrie (PeCe fiber) and Rhodiaceta (Rhovyl). In 1946 Du Pont started the production of PAN (Orlon), as did Casella, which was later acquired by Bayer AG (Dralon). Dry-spinning is also commercially practiced today for PVA, PAN copolymers, PUR and aromatic polyamides, amongst others. It has recently been used to spin water-soluble SAP, water glass and others.

4.14.1 Principle of Dry-Spinning

A heated solution of polymer in solvent is extruded into a hot stream of gas (which may be continuously heated during its passage). The solvent evaporates, and the fiber reacts to the loss of solvent by passing through a gel to a solid state. Since the fiber surface hardens first, while solvent is still diffusing out from the interior, a cylinder under external over-pressure is formed. The internal pressure decreases with increasing distance from the spinneret, and the surface suddenly collapses [304], giving rise to a round, oval or serrated, deformed cross-section, depending on the polymer [305]. Acetate is usually puckered lobate, while PAN is dumbbell-shaped, with the core having a lower density than the sheath [309]. Since they are freed of solvent in the interior of the sheath, the molecular chains become pre-oriented in the direction of the filament axis in dry-spinning. The exact spinning conditions (concentration, viscosity, temperature, spinning gas flow rate, etc.) are polymer-and solvent specific. Falkai [307] (Table 4.48) shows how spinning conditions influence the technological properties in dry-spinning.

Table 4.48 Dependence of the Properties of Dry-Spun Chemical Fibers on Selected Spinning Parameters (Increasing a Parameter in the First Column Changes the Properties in that Row as Shown [307]

Spinning parameter	Property	Solution viscosity	Spinn-ability	Residual solvent content of fiber	Spin-stretch-ability	Cross-sectional form **	Luster	Mechanical properties tenacity	Mechanical properties elongation
Solvent	boiling point	✕	↷	↗	↷	G→R	↗	↘	↗
	density	↗	↘	–	↘	–	–	↘	↗
	insoluble content	↶	↷	–	↘	–	↘	↘	↘
Concentration		↗	↷	↘	↘	F→G	↗	↗	↘
Solution viscosity (0.2···2 kg/m × s at 40°C)		✕	↷	–	↷	F→G	↗	↗	↘
Degree of Polymerization		↗	↷	–	↷	–	–	↗	↘
Spinneret hole	number	✕	↘		↗	–	–	↘	–
	diameter	✕	↷	–	↘	–	↗	↗	↘
	capillary length	✕	↘	–	↘	–	↗	↗	↘
Temp.	spinneret	↘	↘	↘	↘	F→G→H	↘	↘	–
	spinning tube	✕	↷	↘	↘	G→H	–	↷	↘
	quench air	✕	↷	↘	↘	G→H	↘	↷	↘
Spinning tube	length	✕	↷	↘	–	–	↗	↗	↘
	diameter	✕	↷	–	–	–	–	↗	↘
Air speed	countercurrent	✕	↘	↘	↘	G→H	↗	↗	↘
	co-current	✕	↷	↶	–	G→F	↘	↘	↗
Spinning speed		✕	↘	↗	↘	–	↗	↗	↘
Spin-draw ratio (in spinning tube)		✕	↘	–	↗	–	↗	↗	↘

↗ improvement in properties
↘ deterioration in properties
↷ property reaches a maximum
↶ property reaches a minimum
✕ no classification possible
– no relationship

** cross-sectional form
F = flat
G = curved
H = hollow
R = round

To operate dry-spinning economically, the recovery of the solvent is absolutely essential, and recovery of the spinning gas may be advisable. According to the polymer, the amount of solvent required may be 3 to 10 times that of the polymer flow rate. When dry-spinning a 24% solution of PAN in DMF, 9.5% of the polymer and 3% of the solvent are lost when the solvent recovery rate is 97%. These high losses are attributable firstly to the fact that the high spinning gas temperature of 300 °C leads to the formation of acetaldehydes, and secondly to losses occurring in the recovery process and in the exhaust gas. The PAN fiber must retain ca. 9% DMF when it leaves the spinning tube, otherwise it becomes too brittle.

This DMF retained in the fiber is extracted at further processing; the first draw- and washing bath can extract up to 5...8% of the DMF into the water. The bath water is concentrated, then distilled, returning re-usable DMF solvent. Table 4.49 lists further solvents for dry-spinning. As most solvents (or their

Table 4.49 The Most Important Solvents in Dry Spinning

Solvent	Used for	Boiling point °C	Heat of evaporation kcal/kg	Explosion limits vol%	Explosion limits g/m³	Flame point °C	Typical solids conc. range %	Solution spinning temperature °C
Acetone CH_3COCH_3	2-acetate modacryl	55…56	125	2…13	50…310	−18	20…27	56…59
+ CS_2	PVC						30	70
+ alcohol + CH_2CH_2OH								
	2-acetate							
Carbon disulfide CS_2								
Dimethylformamide								
$HCON(CH_3)_2$								
(DMF)	PAN	159	116	3…11	50…200	57	22…26	120…145
	PUR							
Dimethylsulfoxide								
(DMSO)								
Tetrahydrofuran	Vinylidene chloride	66		2…12	50…290	21		
	Copolymers							
Water	waterglass	100	540	–	–	–	40…60	
	SAP					70…80	20…50	
	PVA					30…45	130…160	
Dimethylacetamide	PAR	166.1	118.9	1.8…8.6	30…158	63	20…30	60…

vapors) are potentially explosive, it is necessary in such cases to employ protective gas (which also can keep the fibers whiter). When spinning PAN/DMF, the spinning gas has a temperature of 300...350 °C before reaching the face of the spinneret; this drops to 100...150 °C in the first 30...40 cm below the spinneret due to heat exchange with the filaments, indicating that after-heating of the gas is required. The protective gas is usually nitrogen, but purified CO_2 and other gases can also be used. As the lower explosion limits of the solvents given in Table 4.49 are around 2%, it is safe to use a spinning gas containing less than 2% of O_2. If the temperature of this <2% O_2 spinning gas is too high, more yellowing results than with purified nitrogen.

When extracting the solvent from the spinning gas using, e.g., 17...20 °C cooling water, about 40 g/m^3 of DMF is retained by the gas. After being heated and entering the spinning tube, the concentration of DMF in the spinning gas increases very quickly to an over-critical value, reaching up to 300 g/m^3. At this concentration and at about 160 °C, this mixture is aspirated from the bottom end of the spinning tube (Section 8.7).

4.14.2 The Dry-Spinning Tube (Shaft, Duct)

Three dry-spinning tubes are compared in Fig. 4.328. Tube A, an (old) acetate-spinning tube, is an example of a very simple dry-spinning process [309]. For spinning secondary cellulose acetate (2-acetate) the shaft is heated with water at 50...70 °C at atmospheric pressure. Spinning speeds of 200...600 m/min are attainable. Tube B shows a closed loop gas circuit for dry-spinning of PAN fibers [318]. The spinning gas (c) is heated in the heating zone (e) and rises because its density decreases. It then falls down the right-hand side as its temperature decreases, despite the heater at (e), and contacts the filaments emerging from (g). The solvent condenses out in the lower bend and is drained at (f). Tube C is a modern dry-spinning tube for PAN tow. The protective gas, heated to ca. 350 °C, enters the tube at the top, flows downwards with the filaments and is extracted at the bottom of the tube at a temperature of ca. 160 °C. When spinning PAN between 200 and 600 m/min using an annular spinneret containing 2600 capillaries, a throughput of ca. 600 kg/24 h/tube can be achieved.

The spinning tube size is determined primarily by the spinneret size and its throughput. Table 4.50 gives the most important technical details for 3 typical spinning tube sizes. For constructional reasons, the spin pack outside diameter is about 40 mm larger than the spinneret. There must also be place for the spinning gas to pass through, i.e., the gas must have at least the same cross-sectional area as the spinning tube: $D_T^2 = D_i^2 + D_{Pa}^2 - D_{Pi}^2$. A plate spinneret of 120 mm diameter has $D_{Pa} = 160$ mm and $D_{Pi} = 86$ mm. For a tube having $D_i = 250$ mm, $D_T = 284$ mm, but—taking a standard size—$D_T = 318$ mm would be selected. On aerodynamic grounds, a total cone angle of 7° would be used (Fig. 4.329), thereby making $L_K = (D_T - D_i)/2 \times \tan 3.5° = 556$ mm. Table 4.50 shows, however, that for spinning 480 kg/24 h $D_i = 320$ mm would be better. This changes D_T to $D_T = 347$ mm, or—using standard sheet metal—$D_T = 1250/\pi = 398$ mm, making $L_K = 638$ mm.

The upper cone is also important: its function is to keep the laminar gas flow from the upper filter pack laminar for as long as possible, despite the high Reynolds number. When combined with a highly-polished tube inner wall, the transition to turbulence can be delayed to a point far down the tube, thereby improving the titer CV%. At the lower end of the spinning tube (Fig. 4.328), the filaments and the spinning gas are separated, the gas being aspirated circumferentially through a sieve concentric with the spinning tube into an annular channel on the outside of the tube (n in Fig. 4.331).

To begin spinning, the service hatch is opened (Fig. 4.330 or (b) in Figs. 4.331 or 4.332) or the filaments, saturated with solvent, are spun into a spongy ball, which is then thrown down the tube, exiting at the lower service flap (j). The tow is then threaded through the yarn guides and taken to the winder.

There are 2 basic forms for the upper cone:

- As per Fig. 4.331, for spinning staple fiber [24]. After the spinning gas distribution at the top of the tube, the gas is heated by a Dowtherm (Diphyl) vapor-heated spiral (k) and filtered by a multilayer gas filter pack (l) (which must be easily exchangeable). A spinneret pack (as shown in Fig. 4.157) is hung in the shaft, clamped by the device that holds the solution inlet pipe (d). The internal area around the service hatch (d) is fitted with a smooth, shaped filling piece, and the gas-tight cover (b) is closed.

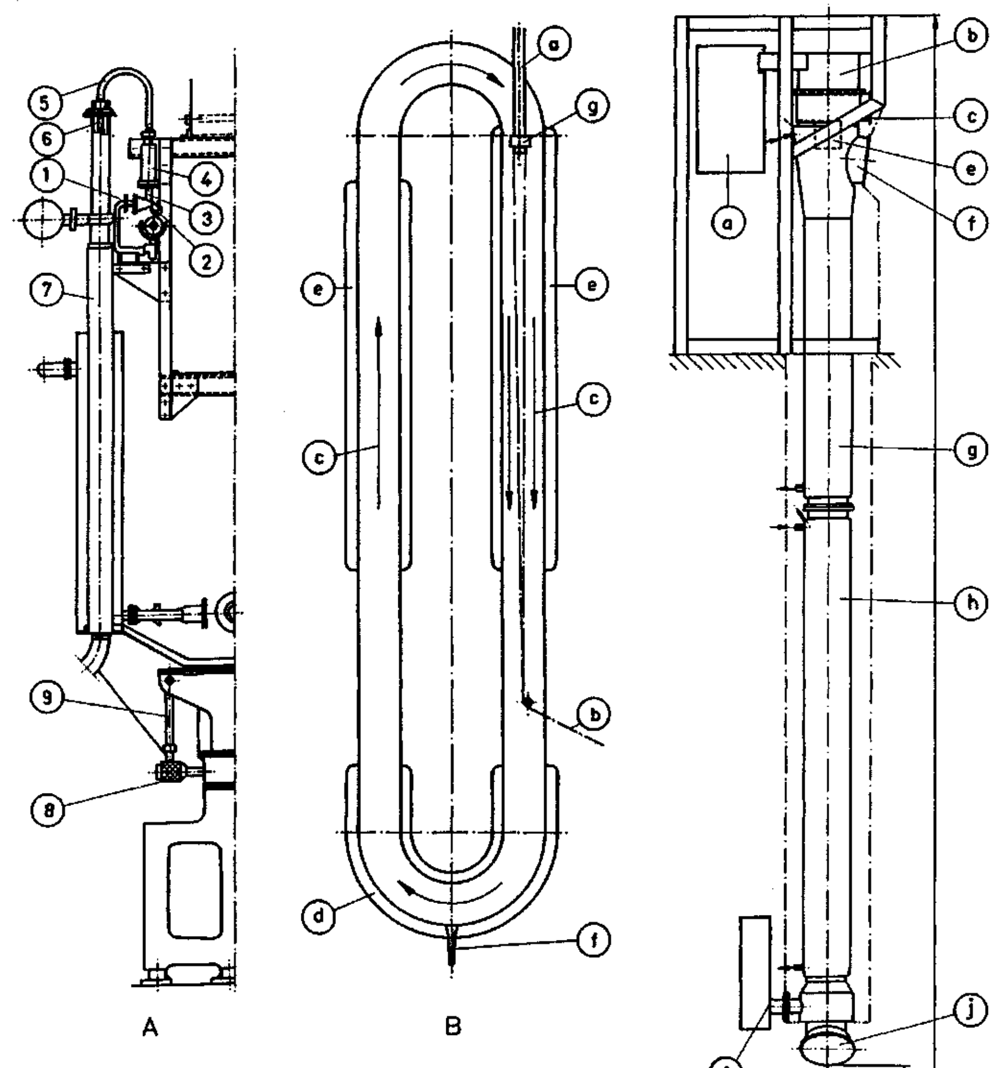


Figure 4.328
Dry spinning tubes (for measurements, see Table 4.50)
A) (*left*) Schematic of a dry spinning machine for acetate, PVC and other polymers

1 Pipe	*5* Spinning support	*8* Spin bobbin
2 Spinning pump	*6* Spinneret	*9* Traverse guide
3 Connecting pipe	*7* Spinning tube	
4 Filter candle		

B) (middle) Schematic of a convection dry spinning tube for PAN multifilament (Rhône-Poulenc Textiles)

a) Solution	*c*) Spinning gas	*e*) Tube heating	g) Spinneret
b) Yarn	*d*) Tube cooling	*f*) Condensate	

C) (right) Dry spinning tube for PAN staple (for measurements, see Table 4.50) [24]

a) Pre-heated spinning gas	*e*) Spinneret	*i*) Spin gas take-up and return to gas recovery
b) Spinning gas after-heating	*f*) Service flap	
c) Spinning pump;	*g*) Tube heating	*j*) Service flap
d) Heat exchanger	*h*) Tube heating	*k*) Spun tow

n-multiflament dry spinning tube (shaft): see Figs. 4.330 and 4.392

Table 4.50 Dry Spinning Tubes

Spinning tube inside diameter (cylindrical part)	250	318		400	mm
Cross-section	0.0491	0.0794		0.1256	m^2
Inlet zone					
for laminar flow [299] (Tu < 1%)	115	115	125	118	m
for turbulent flow [299]	8.15	13.35	12.24	20.2	m
Boundary layer thickness after 8 m wall length	11.4	12.46	14	18	mm
Spinneret dimensions D_o/D_i	205/161	205/161		197/100	mm
surface area	21 918	21 918		22 626	mm^2
number of holes (pitch 3.76 mm)	1550	1550		1600	
PAN ($c > 0.24$) in DMF ($c > 0.76$):					
1.5 $dtex_{final} = 6\ dtex_{spin}$					
for $i = 4$ and $v = 350$ m/min	19.53	19.53		20.16	kg/h
Rate of evaporation of DMF					
($c = 0.76 \rightarrow 0.09$ w/w%)	54.52	54.52		56.28	kg/h
at an outlet concentration of 200 g/m^3					
and an inlet concentration of 40 g/m^3					
corresponding to a spinning gas throughput of	340.75	340.75		351.75	m^3/h
corresponding spinning gas velocity of	1.928	1.177	1.284	0.778	m/s
Re (170 °C. γ air, $N_2 \hat{=} 31.43 \times 10^{-6}\ m^2/s$)	15 336	11 983	13 073	0001	
for cylindrical tube		$> 2300 = Rc_{krit}$			
therefore: inlet cone, stabilized laminar inlet					

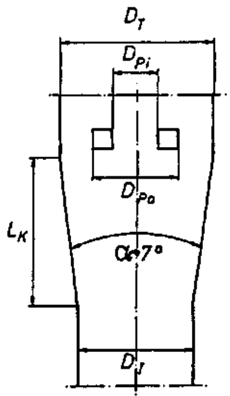
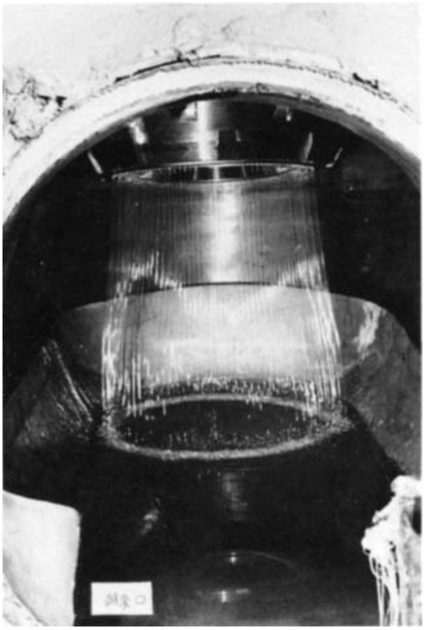


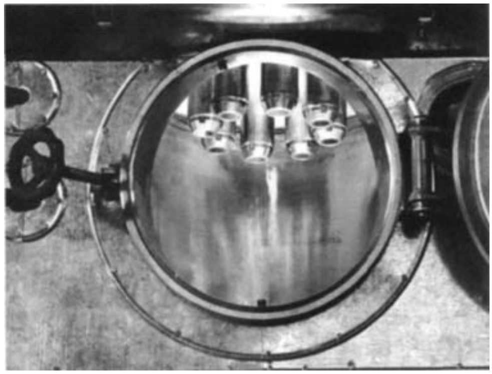
Figure 4.329
Upper inlet cone and ring spinneret of a staple dry spinning tube

- For spinning multifilament yarns (e.g., PUR elastane (Spandex)), 4 . . . 16 filter and spin packs as per Fig. 4.155B are inserted from above into the spinning tube shown in Fig. 4.332 [24]. The spin packs which protrude through the spinning gas filter, are supplied with solution by 2 to 8-fold spinning pumps.

  The temperature uniformity from tube to tube is particularly important. The tube wall temperature can be slightly regulated by having 2 or 3 liquid-heated (e.g, using Marlotherm [313]) zones, with the



(a)



(b)

Figure 4.330
a) Dry spinning shaft [24]—inside view of the spinning chamber showing an annular spinneret for PAN staple fiber in the process of spinning
b) Inside view of a spinning chamber having 8 individual spinnerets for elastane (Spandex) yarns. See also Figs. 4.332 and 2.108 pos. *a*)

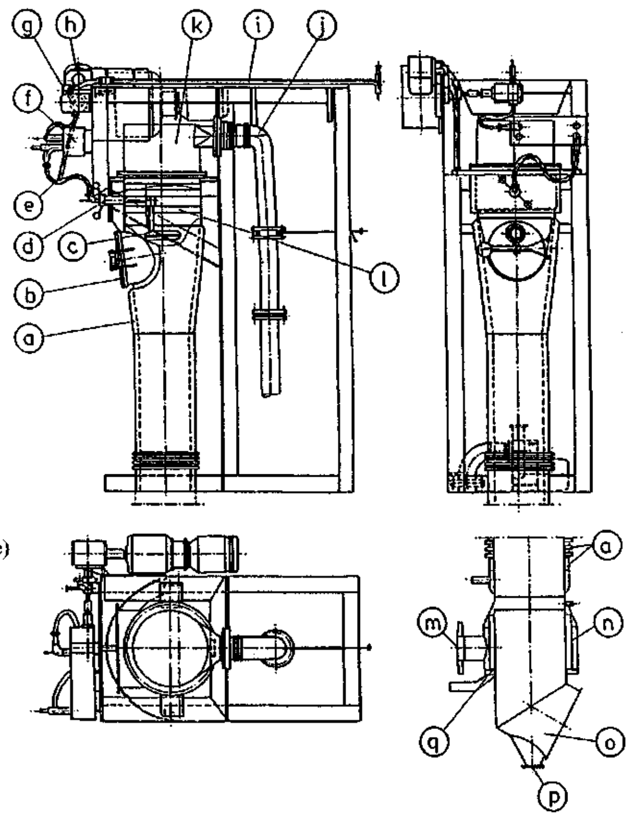


Figure 4.331
Dry spinning tube for staple fibers [24]
a) Spinning tube with heating jacket
b) Service flap for spinneret access
c) Ring spin pack (see Figure 4.430)
d) Spin pack locking
e) Solution delivery pipe
f) Thin film heater (e.g., Alfa Laval type)
g) Spinning pump swivel, mounted to
h) Spinning pump drive
i) Solution delivery pipe
j) Spinning gas supply
k) Head gas re-heater
l) Sieve packet for spin gas
m) Spinning gas aspiration
n) Cylinder sieve
o) Lower service flap
p) Yarn exit
q) Condensate return

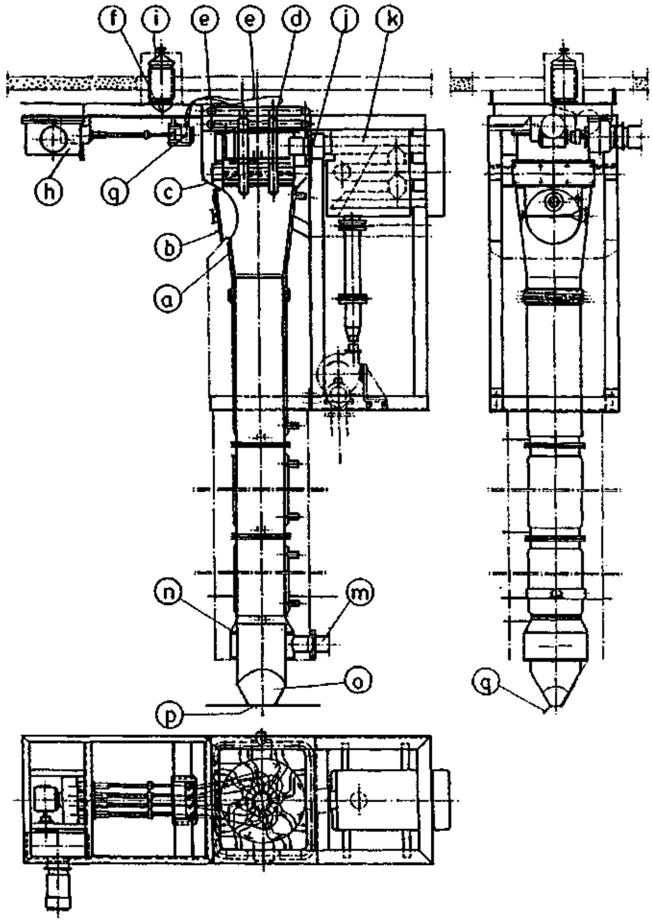


Figure 4.332
Single dry spinning tube for elastane (Spandex) yarns with 8 spinnerets [24]
Description as per Figure 4.331, but additionally
c) eight spin packs with solution inlet pipes similar to that in Figure 4.155B
p) eight yarn guide outlets

temperature decreasing downwards. The spinning gas temperature, coming from a central heater, will certainly be different at the start and end of the main gas ring in the case of long spinning machines. The gas must therefore be re-heated in every spinning tube, preferably to the condensation temperature of a Dowtherm (Diphyl) vapor-heating system.

Typical spinning tube lengths, from spinneret to yarn exit, are 5...7 m; these lengths can be adjusted for existing floor levels in available buildings. The upper (spinneret) service hatch should be 1.50...1.70 m above the (local) floor.

Spinnerets, spinneret bolting and spin packs have been described in Figs. 4.155 and 4.157.

4.14.3 Staple Fiber Dry-Spinning Lines

A complete, double-sided staple fiber dry-spinning line is presented in Fig. 4.333 [24]. The spinning ducts (a) are supplied with fresh hot gas by the gas ring main (b). The spent gas is exhausted at the bottom of the duct into the gas return ring main (c), from where it goes to a gas recovery unit (e, in Section 8.7). Part of the recovered gas is bled off and replaced by fresh gas, after which the gas is returned to the gas ring main for re-use. An effective spinning duct height of 6...7 m permits spinning of a tow comprising

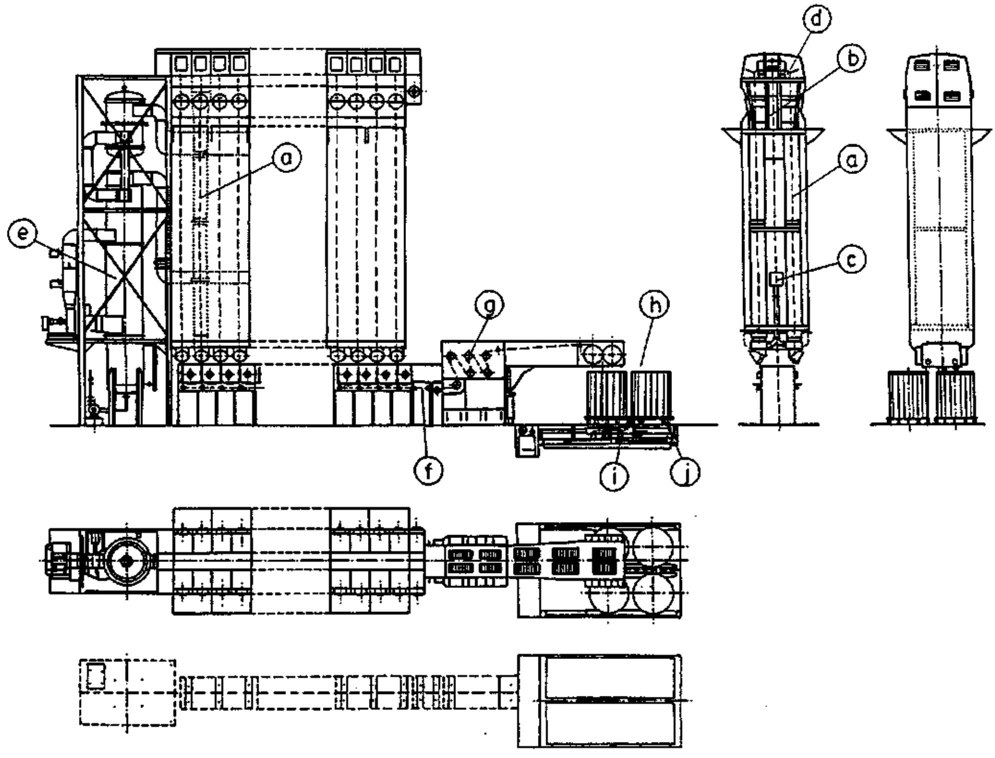


Figure 4.333 PAN staple fiber dry spinning plant [24] (*F. Fourné*, for Mitsubishi Rayon Co. Ltd.)
a) Dry spinning tubes
b) Hot spinning gas inlet
c) Spinning gas return
d) Solution inlet pipe
e) Spinning gas preparation (see Figs. 8.13 and 8.13a)
f) Tow take-up wall with additional spin finish application
g) Take-up sextet
h) Can take-up (see Figure 4.288)
i) Can rotating—and exchange table
j) Spinning cans

1.5…1.75 dtex single filaments at a throughput of 500…600 kg/24 h per tube when using ring spinnerets as per Fig. 4.157. The spun tow is plied horizontally at (f) and deposited in spinning cans (h), ready for transfer to further processing.

The further-processing line corresponds to that of a solution wet-spinning machine (Section 4.15), except that the spinning section and the coagulation bath are replaced by a can creel. Single filament titers (final) between 1.2 and ca. 13…14 dtex can easily be spun using the dry-spinning systems previously described; higher dpf's should be wet-spun.

In the dry-spinning of multifilaments, the lower service port has as many yarn guides and outlets as there are spinnerets in the tube (or spun yarn packages). For most solution-spun polymers, the take-up speed lies between 400 and 1200 m/min. The calculation of the amount of solvent in the gas is exactly the same as for the case of spinning staple fiber tow.

4.15 Solution Wet-Spinning Plants

Cupro-cellulose filaments were first produced in 1900 by precipitation in a water bath. The wet-spinning of viscose (=hydrated cellulose), in which sodium cellulose xanthogenate is precipitated in a bath containing water plus ammonium sulfate, assumed great importance [316]. A large amount of rayon continuous filament and staple suddenly appeared on the world market, particularly after 1933 [309, 316]. These references discuss in detail the technology, both physical and chemical, including machine construction.

In 1964 the wet-spun proportion of world man-made fiber production was as high as 75%. This decreased to ca. 41% in 1978 and further to only 23% in 1987. Recently, however, there has been a revival in viscose wet-spinning, and many, new "high tech" yarns and staples are wet-spun, or can only be wet-spun.

4.15.1 Wet-Spinning Process

After the preparation of a homogeneous solution (or after solution polymerization), the most important factor in successful wet-spinning is good filtration—often multiple filtration—to remove gels and substances solvated by the solvent, and to de-gas the solution. Unlike viscose, solutions of synthetic polymers do not require a time-dependent "ripening". One should, however, ensure that the age of the solution reaching the spinnerets is about the same. The pipes taking solution to the spinnerets should also be free of dead spots and stagnant areas, where the residence time of the solution may be indefinite.

Figure 4.334 shows a number of arrangements for the relative positioning of the spinneret and the spinning (coagulation) bath. The configuration to be selected depends on the requirements of polymer, solvent, concentration, spinning bath path and—particularly important—ease of handling.

a) Spinning in a flat bath. Here the front face of the spinneret is almost vertical, and the filaments are taken up almost horizontally through the bath. Baths of length 0.4...ca. 5 m are known in the literature. A worker should be able to stand within 0.6 m (=arm's length) of each point to be serviced.
b) When spinning from a deep bath, the submerged spinneret face is practically horizontal, and the filaments are taken up either vertically or at a slight angle through, and out of, the bath. If the spinning pipe must be swung upwards out of the bath at the start of spinning—or to change a spinneret, the swivel radius R must not be tangent to any side of the bath. For this reason, the typical maximum depth of the spinneret below the liquid level is 0.6...0.8 m. For spinning PAN solutions into naphtha or petroleum, spinneret depths of ca. 3 m have been used [337].
c) Cone (funnel) spin process. In most cases, the yarn and the liquid travel co-currently in order either to pre-stretch the yarn using the fluid friction or to obtain smaller speed differences between the filaments and the liquid, as, e.g., in Cuoxam spinning in water. PVA is spun upwards through an inverted funnel (see Section 2.7.2). Horizontal funnel spinning using baths (a) or (e) is known for wet-spinning of PUR.
d) Air gap spinning. The spinneret face is parallel to, and above, the bath liquid surface. On exiting the spinneret, the filaments first pass through a gap—either of air or a protective gas—of a few mm to up to ca. 1 m length before travelling vertically downwards into the coagulation bath. After penetrating about 0.8 m, the direction of travel of the filaments is reversed, and they leave the bath at a small angle to the vertical. If protective gas is used, the gap between the spinneret and the bath should be encapsulated in such a way that the filaments remain visible and easily reachable. Air gap spinning with a funnel and/or submerged spinning (similar to b) is used in the wet-spinning of polyaramids, amongst others (Section 2.11.2).
e) Spinning using many spinnerets per bath. This is similar to (a), but many spinnerets are used; the filaments can either be wound up parallel to one another or can converge onto a winding roll. If these filaments are later to be processed as single ends, the yarn separation should be 4...10 mm, depending on titer. Separator plates can be inserted in the bath to prevent cascade breaks when one yarn breaks.

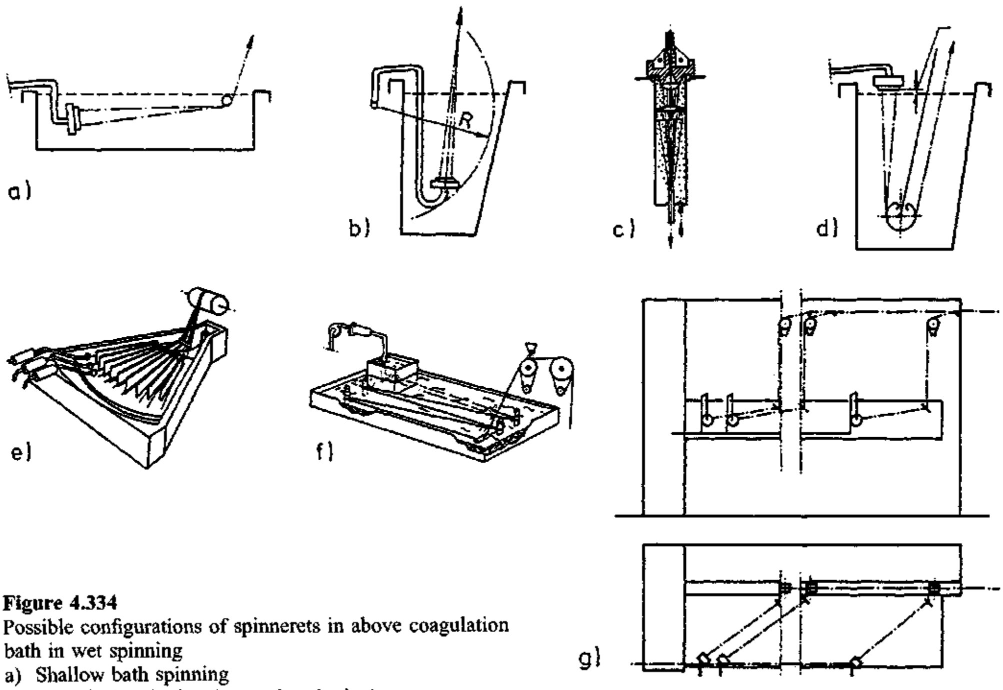


Figure 4.334
Possible configurations of spinnerets in above coagulation bath in wet spinning
a) Shallow bath spinning
b) Deep bath spinning (upwards spinning)
c) Funnel spinning
d) Air gap spinning
e) Shallow bath spinning, with convergence of filament bundles from many spinnerets to form a tow
f) Increasing the length in the coagulation bath during shallow bath spinning
g) Deep bath spinning, with parallel guidance of the filaments to increase the length in the bath and to converge the filaments to form a tow

f) Spinning bath with extended effective length. If the filaments reach a certain minimum tenacity after a pass of one bath length, the filament direction can be reversed by pins or guides, and the filament can be zig-zagged through the bath.
g) Spinning bath extension by means of many parallel spinnerets inclined to the bath surface, is possible for baths up to ca. 500 mm wide. After travelling at an angle to the bath, the filaments are taken vertically upwards by godets. Here the spinning pipes and spinnerets must be individually swivellable in the same direction.
h) Double pass through the coagulation bath or single passes through two baths. Here the filaments are taken up as per (b) or (g), and then, after the first godet, either diverted back into the spinning bath or are diverted into a parallel bath above the first bath, after which the filaments are taken up by a second godet, possibly with stretching.
i) "Extreme" spinning bath extension, absolutely necessary for certain special filaments, is described in Section 4.15.2.1.

The above is by no means an exhaustive treatment of spinning bath configurations. If one cannot, from experience, find an appropriate configuration for a new development, recourse must be had to experimentation to find the optimum geometry and operating conditions, as the osmotic- and diffusion processes for fiber coagulation have not been theoretically investigated to the point where calculations can be made. The coagulation time of currently-known polymers varies between 1 s and 12...15 min.

The coagulation of the filament occurs by diffusion of the solvent out of the filament into the spinning bath, this process taking place under osmotic pressure. The filament surface coagulates first, forming a gel hose under external over-pressure, which collapses with simultaneous stretching in all 3 dimensions [304, 305]. Depending on polymer and conditions, the filament cross-sections can vary from slipper-shaped through dumbbell-shaped, etc., to octolobal.

Table 4.51 lists the most important solvents and coagulation agents for the wet-spinning of various polymers. For a detailed discussion of work done on PAN, see Hunyar [320, 321], inter alia.

Table 4.51 Gear Dosing Pumps for Spinning Solutions (fixed mounting [107]) (see also Figs. 4.339 and 4.340b)

Available pump sizes 33		$0.2\ldots60\,cm^3/rev$
Number of pump streams		1
Rotational speed range		ca. 10...80 rev/min
Inlet pressure		1...20 bar
Counter pressure		up to ca. 25 bar
Working temperature		40...120°C
Viscosity		0.01...500 P
Dimensions of a medium-sized pump	Weight	1.5 kg
	Width B	105 mm
	Height H	75 mm
	Length L_1	100 mm
	Total length L	135 mm

4.15.2 Constructional Details of Wet Spinning Lines

Here the first consideration must be corrosion resistance of all parts coming into contact with the solution and the bath coagulating agent, as these liquids are often extremely aggressive. Polyaramid, e.g., is dissolved in n-H_2SO_4 and spun into a bath containing water and H_2SO_4, a particularly corrosive combination. Often 1.4571 stainless steel can be used, sometimes plastic-coated. Hastelloy-(C = NiCr17FeW) and Nickelalloy (2.4360) combinations can also be used, but are very expensive. An additional problem is that the bath vapors can sometimes be explosive in air or cause health problems. In such cases, extraction hoods are fitted above the bath surface. The antimony-free pure lead sheets previously used in viscose spinning with a strong sulfuric acid coagulating bath (the "Müller" bath, [309]) are nowadays replaced by 1.4571 stainless steel, PVC plates or metal plates having 6 to 10 layers of plastic coating. In addition, gearboxes and bearing housings must be sealed against the bath vapors, as a small amount of vapor in the air can cause corrosion.

4.15.2.1 Spinning Baths

The wide variety of spinnerets in use was shown in Fig. 4.334. In the simplest execution, the spinnerets are welded using corrosion-resistant stainless steel. If resistance to hydrochloric acid gas, amongst others, is required, recourse must be had to appropriate coating processes. Figure 4.335 gives construction details for spinning pumps, either long and flat or short and deep, as well as the positioning of the spinning pipe. In Fig. 4.336, the liquid enters the spinning bath at (d) and flows laminarly across the width. After flowing through the bath volume, the liquid exits via an adjustable weir at the yarn oulet side. The following overflow tank has a quick-change sieve at its exit.

The spinning bath tank can, if required, be fitted with either a jacket for heating or cooling, or an immersible coiled pipe. Tow processing speeds of more than 100 m/min are critical, as at speeds of 120...140 m/min the bath is quickly emptied by the liquid dragged out by the tow. At speeds above 80 m/min, stripper brushes and liquid return systems must be provided. Baths which generate gas or vapors must have removable or openable cover lids provided with drop run-off edges.

Table 4.52 Wet Spinning Solutions and Coagulation Baths

Fiber type	Solvent	Conc. %	Conc. w/w %	*T* °C	Coagulation bath	Conc. %	*T* °C	Examples
Polyacrylonitrile	dimethylformamide	100	17...25	20...40	DMF	40...60		Dolan
					water	60...40	5...25	
	dimethylacetamide	100	20		DMAC	40...65		Acrilan
					water	60...35	20...30	
	dimethylsulfoxide	100	20		DMSO	50		
					water	50	10...40	
	dimethylformamide	100			heavy benzene (naphtha)	100		
	ethylene carbonate	85				> 70		
	-water	15						
	zinc chloride-water	60:40			$ZnCl_2$	15	85	Beslon
	zinc chloride+	54			$ZnCl_5$	14		
	sodium chloride	4	10		NaCl	1	25	Beslon
	-water	42			water	85		
	sodium rhodanide	50			NaSCN	10	0...20	Courtelle
	-water	50	10...15		water	90		
	nitric acid/water	65...80	10...13		$HNO_3(H_2O)$	30 (70)	3 25...10	Kash-milon
	sulfuric acid/water	70...75	15		H_2SO_4/H_2O	50...55	5	
	ethylene glycol	90...85				20...40		
	carbonate/water	10...15	15...20			50...60	40...90	
Modacrylic	acetonitrile				water/ acetonitrile			
	acetone				water			
Polyvinyl-chloride	cyclohexanone				water + capropyl alcohol + cyclohexanone			
Polymetaphenylene isophthalamide	dimethylacetamide + (1...3) % calcium chloride				water + DMAC + calcium rhodanide			
Polyurethane elastomer	dimethylformamide	100	20...30	60	water + DMF	≈90%	20...27	

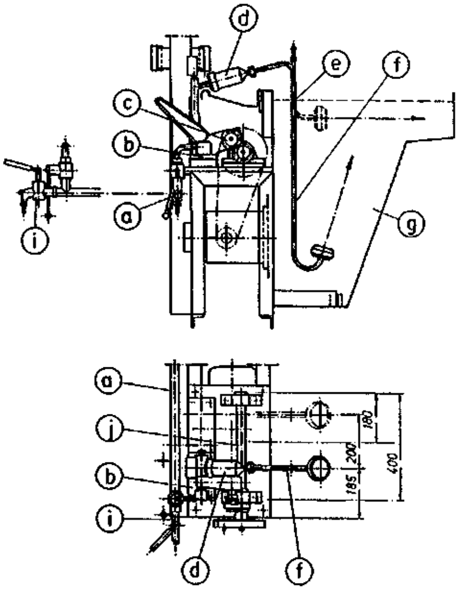


Figure 4.335
Wet spinning position with spinning pump, spinning pump drive and spinning nozzle. The apparatus can be tilted for either shallow bath spinning or upwards (deep bath) spinning.
a) Solution inlet
b) Pivot bracket
c) Spinning pump on pivot arm and spinning nozzle
f) Spinning nozzle for upwards-spinning
g) Spinning bath
i) Tap for solution sampling
j) Spinning pump drive shaft

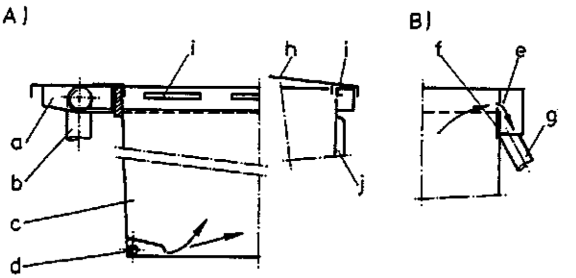


Figure 4.336
Design details of a spinning bath
a) Gutter for spinning start up
b) Water discharge
c) Spinning bath
d) Bath inlet and distribution
e) Overflow, with
f) Bath level regulator (overflow weir)
g) Spinning bath discharge
h) Cover plate
i) Aspiration slit (for gases)
j) Heating/cooling jacket
A) Spinning side
B) Yarn exit side

Underwater pins or rollers are used to locate the tow exit point; their lower ends should dip at least 50 mm into the liquid.

Figure 4.337 shows a schematic section of a large spinning bath for a staple tow having 8...16 parallel spinnerets, each for up to 200 000 final dtex, fed by spinning pumps (a) and having a service passage from which the spinning pipes and spinnerets (b) can be pivoted upwards. It is also fitted with liquid strippers (c), a bath liquid return (e) and an overflow tank (d) [302]. The total lengths is ca. 9.3 m. For wet-spinning very thick tows, two baths can be opposed, with the tows running to the center between them and being taken up vertically together as a single tow.

Spinning pumps and spinning pipes are generally mounted in such a way that they can be swivelled out of the bath. This simplifies shutting down one position, the changing of spin packs and starting to

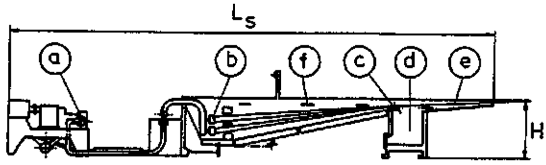


Figure 4.337
Bath for shallow spinning of PAN [318] (ARCT [318])
a) Spinning pump and -drive
b) Spinneret (offset)
c) Liquid-stripping comb
d) Discharge channel
e) Recirculation trough
f) Aspiration slits

spin, where the solution can initially be spun onto the start-up gutter (a in Fig. 4.336) before being taken by hand through the bath.

4.15.2.2 Spinning Pumps, Spinning Pipes and Spinnerets

In addition to the gear pumps used for melt spinning (described in Section 4.15.2.1, [57]), pivotable or flange-mounted pumps used in viscose spinning can be used, provided that the corrosive properties of the solution are taken into account (Fig. 4.338). Additionally, Fig. 4.339 shows a pivot lever, which can be used to make pumps which have their driveshafts running through the lever, or melt spinning pumps, pivotable. The solution passes through the pivot axis into the lever, flows down into the pump chamber, and is then pumped out through the opposite side of the lever. The seal, made from a hardened cone having a hardened spherical cap plug on the other side (in Fig. 4.340), remains tight both during pivoting and when in position. The required base plate is shown in Fig. 4.340. The solution flows in at (f), passes into the pump (a) fixed to the lever and leaves via the pivot holder (c) into the spinning pipe connection (b). The pressure sealing screw (e) is sufficiently tightened so that the three seals (d) remain tight and pivotable.

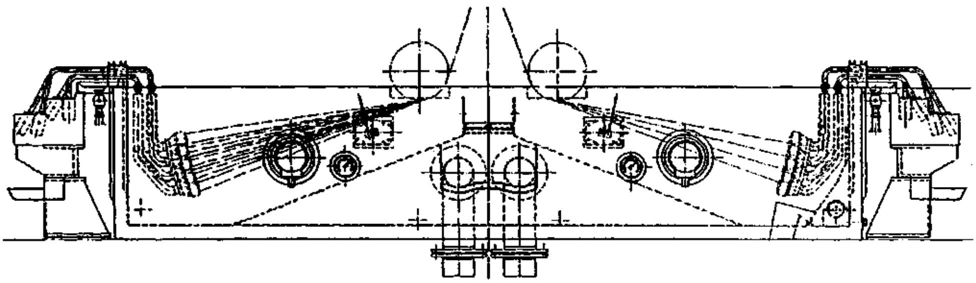


Figure 4.338 Two opposed, wet spinning baths having a common, central tow take-off, in order to achieve constant length in the bath for all spinning positions [167] (Neumag). The spin pumps and spinning nozzles are pivoted

Fixed-mounted solution spinning pumps (Fig. 4.340b [33]) have a driveshaft mounted in bearings and fitted with a gland located in the cast mounting bracket, and are usually driven as shown in Fig. 4.341.

The pivoted intermediate gear (d) serves to engage or disengage the pump from the fixed driveshaft (b). Solution spinning pumps are not heated, as the solution temperatures are usually below 60 °C, and are generally designed for viscose spinning (in terms of construction materials). Should melt spinning pumps

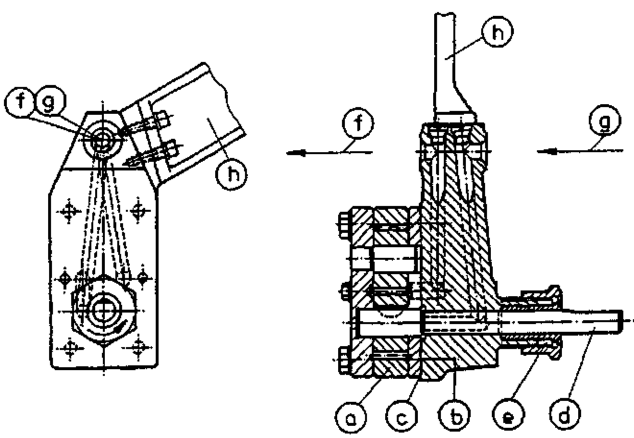


Figure 4.339
Pivotable pump mounting with spinning pump for wet spinning machines [33]
a) Toothed gear pump
b) Pump mounting, with
c) Lapped mounting face
d) Pump drive shaft
e) Gland
f) Solution inlet
g) Solution oulet (pressurized)
h) Pivot handle

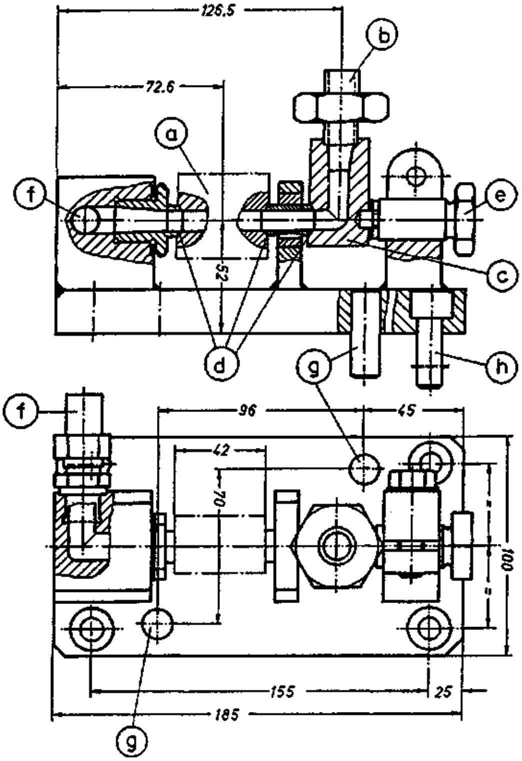


Figure 4.340
Mounting plate for a pivoted spinning pump (*a*) and a pivoted spinning nozzle (*b*) [168]
c) Spinning nozzle holder
d) Universal joint in conical seal
e) Contact pressure screw
f) Solution inlet pipe
g) Plate centering pin
h) Securing bolts

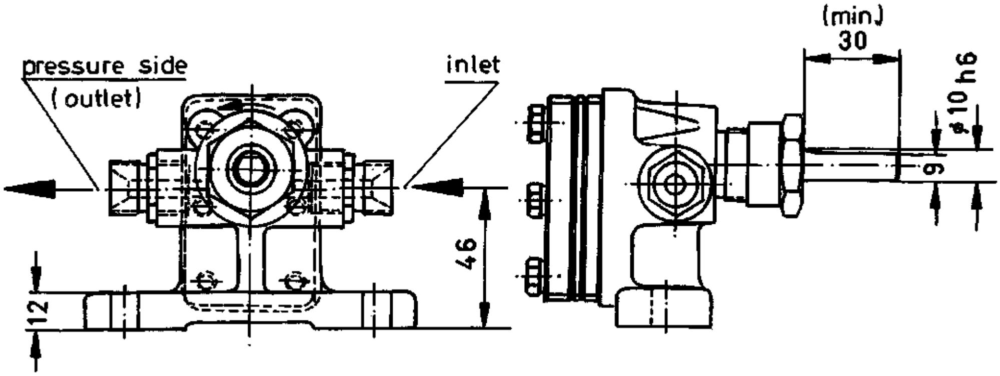
be used, their suitability for the solution must be checked. The spinning pumps are generally driven by a common driveshaft for the whole machine, onto which are fitted individual gears for each pump. The gear engagement given in Fig. 4.341 must be observed, so that the gears are self-locking when running—which facilitates operation.

Figure 4.342 shows a spinning nozzle with the connecting nut (B) located in position (b) in Fig. 4.340. The solution then flows through a candle filter (f) to the spinneret holder (g). The latter can also be made as per Fig. 4.155a. A manometer and a temperature sensor can be built into each filter and spinning nozzle (just before the spinneret), respectively. The appropriate spinnerets and their bolting are described in Sections 4.6.10.2 and 4.6.10.5, and shown in Figs. 4.138ff and 4.155a. The spinneret capillary diameters lie mostly between 60 and 150 μm, and the hole spacing is of the order of 0.5 mm. The spinning filter has a fineness of 5...10 μm.

4.15.2.3 Drawing and Extraction Baths

The materials of construction and constructional details are the same as those pertaining to Fig. 4.336. The bath liquid must flow in the same direction as the yarn or tow travel. The drawing and washing (extraction) baths differ only in the manner of the tow immersion (Fig. 4.343):

A) The tow from the last delivery roll (a) is either hydraulically depressed vertically by two rolls (c) or by two rolls on pivot arms (d). In operation, the resultant tow forces on the inlet and outlet roll must point past the pivot points (as shown in the diagram) to make the system self-locking.
B) The last draw roll (a) and the corresponding pulling roll (e) are both submerged in the bath. (B2) and (B3) show configurations for one and two drawing stages.
C) In a new process, the tow runs between the delivery roll and the pulling roll(e), practically touching



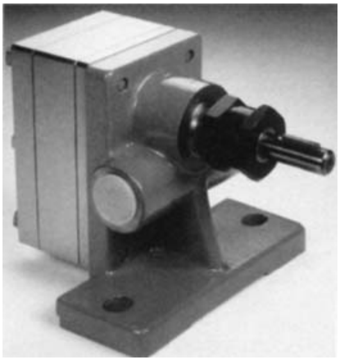


Figure 4.340 b
Solution spinning pump for fixed mounting, with molded mounting bracket [33]

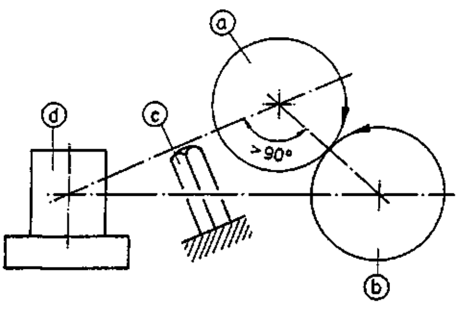


Figure 4.341
Pivoted spinning pump drive—principle
a) Spinning pump drive gear
b) Gear wheel mounted on continuous machine driveshaft
c) Position stop (limiter), adjustable
d) Connection block (Figure 4.340)

the rim of the drawing bath. Immersion of the tow is achieved by having the liquid recirculation pump (i) deliver at an extremely high throughput, so that the liquid level (c) is always a few mm to cm higher than the tow, the excess liquid overflowing the bath at (g) being caught in the overflow tanks (h) and returned to the pump (i). To prevent too strong a surge of water in drawing bath, an impact plate (or similar) (j) can be fitted above the pump outlet.

While the above-mentioned baths are suitable for both wet drawing and extraction (the processes differing only in the tow tension applied), the baths below can only be used for extraction or washing.

- Figure 4.344a shows the principle of a frequently-used tow washer. Successive washing tanks are raised in the direction of the tow travel, so that they overflow counter-currently to the tow travel. The

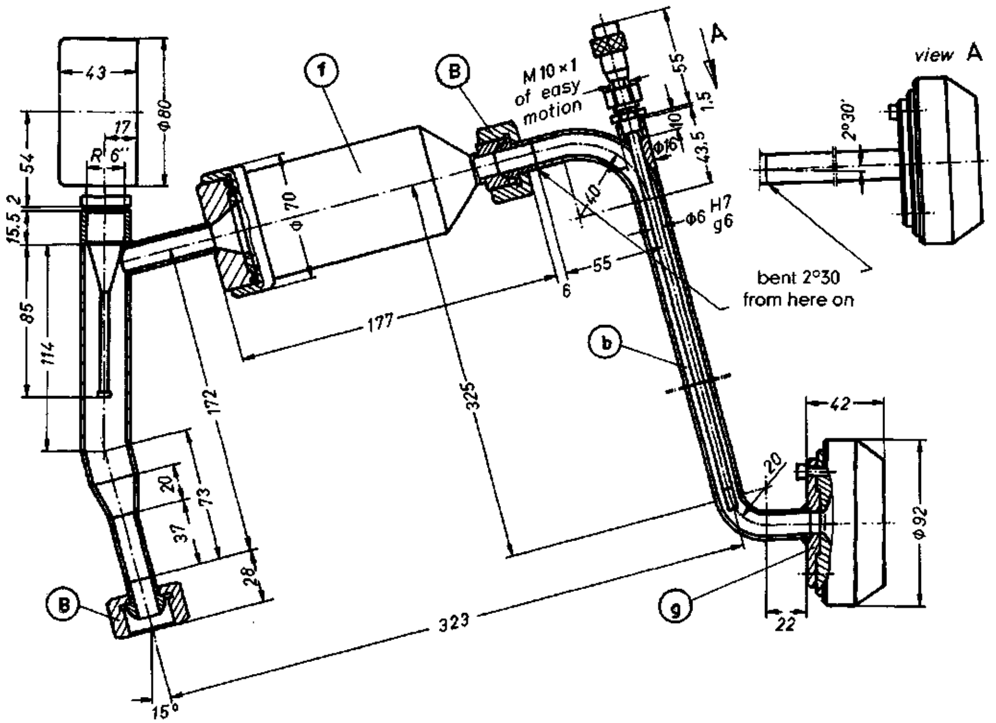


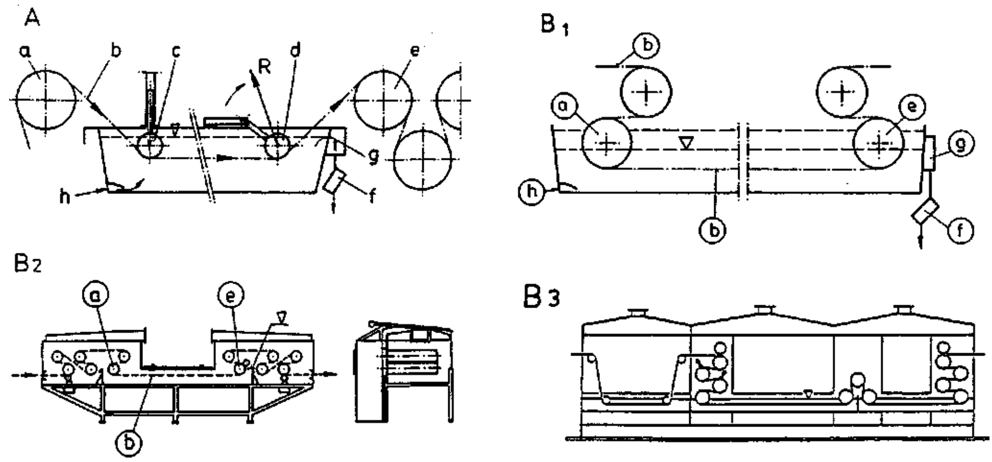
Figure 4.342 Spinning nozzle with quick-fit screw connection (*B*), candle filter (*f*) and spinning pipe and spin pack (*b*); spinning nozzle configuration is for either shallow- or deep bath spinning [24]

tow is squeezed to remove excessive water on leaving each washing tank. When clean washing water is added to the last (i.e., tow outlet) tank, the solvent accumulates in the first (tow inlet) tank, from where it can either be sent back to the spinning bath or to solvent recovery.

- Figure 4.344b shows how tow can be extracted by running through a washing bath located between two squeeze rolls (wringers). The bath water flow is as per Fig. 4.344a.
- Figure 4.344c illustrates a tow washer employing a suction drum. The washing water is sucked into the drum through the tow, from where the water flows into the recirculation pump and back into the bath. The tow can also be sprayed above the suction drum.
- Figure 4.344d shows a spray washer, used particularly for thin tows. The tow runs over a series of parallel upper and lower rolls, and is sprayed with water from above.
- Figure 4.345 shows a combination machine which simultaneously draws and extracts the tow. At the exit of the coagulation bath of the wet spinning machine, a washer having 10 or more compartments is added. The speed of the rolls (and wringers) is progressively increased in steps from beginning to end (incremental drawing). For normal tow sizes, the lower rolls are free-running. Drawing increases the wringing effect, and the simultaneous washing and drawing process is said to be particularly effective.

4.15.2.4 High Throughput Wet-Spinning Machines

These large spinning machines are used for spinning Acrilan® (PAN in DMAC) [323], Dolan® (PAN in DMF) [326], Courtelle® [324], Beslon® (PAN in $ZnCl_2$/water) [325] and Kashmilon® (PAN in HNO_3) [327]. Polyaramids, such as, e.g., Kevlar® and Twaron®, are wet-spun as solutions (n-H_2SO_4) and further processed as above.



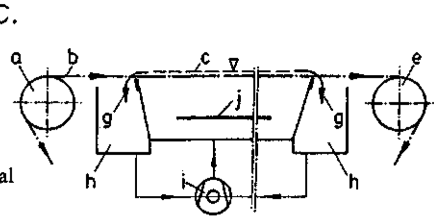


Figure 4.343
Tow path through drawing baths—principles

A) Immersion bath with immersed transport rollers
B1) Immersion bath with underwater feed and draw rolls
B2, B3) As per *B1*, but with sextets for drawing
C) Overflow drawing bath

a) Feed roll for
b) Tow (beneath *c*))
c) Immersion roller or
d) Pivoted immersion roller
e) Take-off roll
f) Filter
g) Overflow
h) Bath supply
i) (strong) centrifugal pump
∇) Bath level
R) Resultant force (self-locking)
j) ∓ flow deflector plate

In the schematic wet-spinning and further-processing line shown in Fig. 4.346, the coagulation bath (A) is followed by one or two drawing baths (B and C), which are followed by a series of extraction/washing baths (G, H, etc.). After application of spin finish, drying and stuffer box crimping, the tow is (mostly frequently) packed for later processing on a converter or (less frequently) shrunk by heat-setting, cut to staple length and baled. If the required number of consecutive baths (G, H, etc.) becomes too large, and the following washing and extraction stages consequently take up too much space, the baths can be folded into a 3-storey arrangement (Fig. 4.347). The tow emerging from the drawing baths on the ground floor is diverted towards the spinning machine on the first floor, after which it is again diverted to the next floor and emerges from the last washing bath running in the original direction.

Unless contradicted in this section (4.15), the individual further processing stages are the same as those used in melt spun staple fiber production. Figure 4.348 shows such a line having four spinning positions, the individual tows from which are plied and drawn in three stages, extracted using a suction drum washer, post-stretched and then dried at constant length on a tension-controlled calender. After two double-sided spin finish applicators, there are 6 steamers and 6 stuffer box crimpers (because of the extremely thick tow), after which the tows are transported to 6 tow packers. If the drum dryer were to be replaced by a suction drum or conveyor dryer with meandering lay, the tow residual shrinkage would be very low. Similarly, the tow packing line can be substituted by staple cutters and bale presses.

In this case, the contact dryer/calender rolls each have a diameter of ca. 900 mm; a suction drum dryer would have rolls of diameter 1400 mm. Typical drying temperatures lie between 130 and 150 °C. The speed of the dried (uncrimped) tow is generally 45...55 m/min.

High bulk PAN yarns are made by intimately mixing 40...60% fully-shrunk PAN staple with 60...40% high shrinkage PAN staple at secondary spinning. Such yarns are mainly used for knitting.

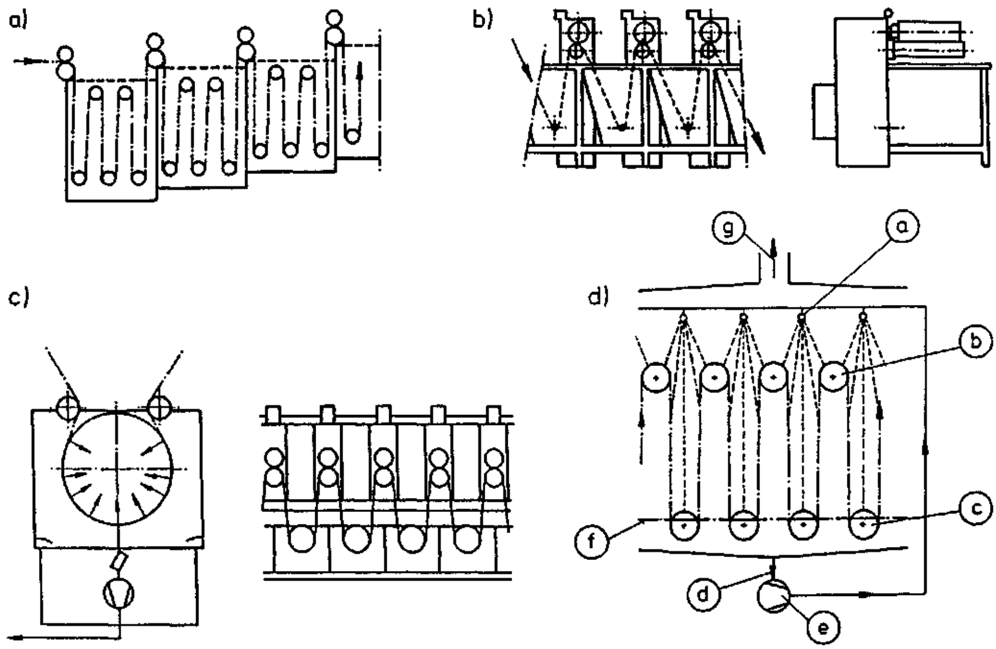


Figure 4.344 Tow path through extraction or washing baths (which are also suitable for spin finish application)—principles—simple dipping bath as in Figure 4.343A
a) Deep washing baths, with gravimetric fluid flow from right to left; tow passage is from left to right.
b) Simple immersion washing with squeezing rolls between baths [318] Roll length for 1.5×10^6 dtex: 400 mm; for 3×10^6dtex: 750 mm; drive power: ca. 0.5 kW/10^6 dtex
c) Suction drum washing, with spraying and squeezing [295]
d) Spray washing with partial immersion of the lower rolls
a Spraying system
b Upper rolls (driven)
c Lower rolls (idling)
d Sump discharge
e Pump
f Bath level (adjustable)
g Vapor venting

The high bulk is developed by heat-setting the secondary spun yarn, when the high-shrinkage component shrinks, causing the pre-shrunk filaments to form (over-length) loops.

4.15.3 Aftertreatment Lines for Dry-Spun Tow

The same further-processing lines are used as for wet-spun tow, except that the coagulation bath is replaced by a can creel, as dry-spun yarns are mostly deposited in cans (Section 4.13.4).

Undrawn dry-spun PAN in the can still contains ca. 9% DMF. As in melt- and wet-spinning, the tows are plied to form a broad sheet, which then passes through drawing, extraction, drying, crimping, heat-setting, etc., and is finally packed as tow or baled as staple. The tow speed is not, however, limited by the wet-spinning process. After drawing, speeds of up to ca. 120 m/min are possible, but most processes run at only 80...90 m/min, limited by the speed through the processing baths. The draw ratio required for a dry-spun tow can often be larger than 1 : 4; this must be taken into consideration in machine design.

The high DMF content of 7...15% in the undrawn tow can only be reduced to ca. 4...7% after passing through the first drawing/washing bath. It therefore becomes expensive to recover DMF from subsequent baths by evaporation. As fine filaments (down to a final single titer of 0.5 dtex) can be

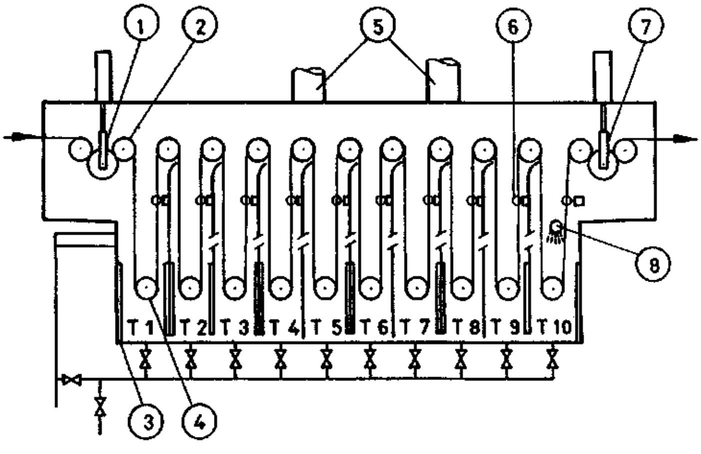


Figure 4.345
Combined drawing/washing machine for PAN tow (incremental drawing)

1, 7 Squeezing rolls (pneumatically pressed)
2 Driven rolls
3 Heater
4 Driven rolls
5 Vapor vent connection
6 Tow guides
8 Direct steam injection

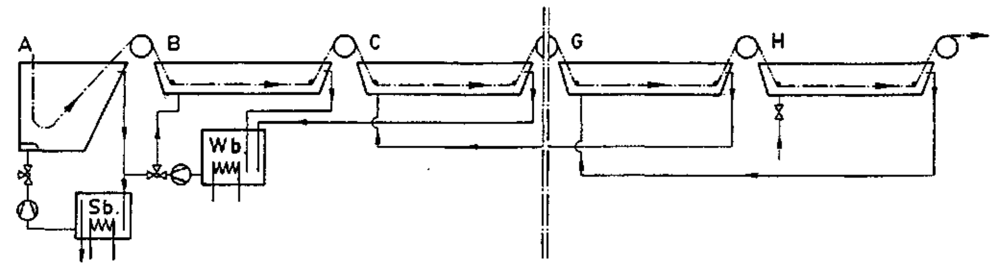


Figure 4.346 Configuration, yarn path, bath flow direction and required piping [24]

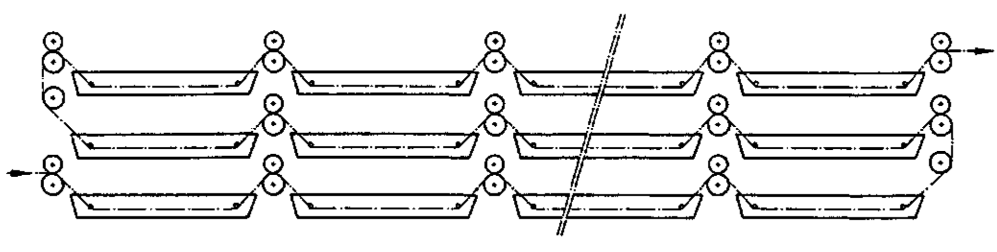


Figure 4.347 *Three deck arrangement of further-processing baths*

produced by dry-spinning, the post-drawing stage sometimes used in wet-spinning to produce fine filaments, can be omitted. Dry spun filaments, even without thermal treatment, are bulkier than wet-spun filaments; this must be taken into consideration at take up in cans, fiber transport and baling.

4.15.4 Solution Wet-Spinning of Multi- and Monofilaments

Wet-spinning of continuous filaments requires special designs in order to achieve economic throughputs at small machine size. The excessively long further-processing stages need to be converted to something more manageable. The spinning pumps, spinning pipes and spinnerets shown in Figs. 4.339 and 4.342

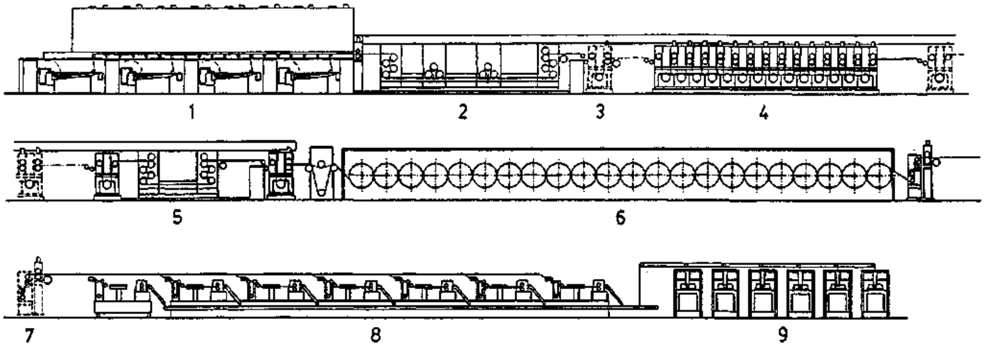


Figure 4.348 Wet spinning—and further-processing line for PAN tow [295]
Space requirement: ca. 170 m × 10 m × ca. 5 m high

1 Four wet spinning machines
2 Three stage drawing
3 Tension and speed control
4 Tow washing (see Figure 4.344c)
5 After-drawing
6 Tow drying
7 Spin finish, double sided
8 Steaming and stuffer box crimping machine
9 Tow packing machine

can be used here. Even if the pumps and spinnerets are staggered, the threadline pitch remains ca. 100 mm.

As the spinneret hole-to-hole separation in multifilament spinning needs to be only 0.5...1 mm, much smaller spinnerets can be used. A spinneret plate of 10...14 mm diameter permits up to 80...100 capillaries. Here the usage of the spinning pump and spinneret assembly shown in Fig. 4.349 is recommended; this employs one 4-fold pump and has a spinneret pitch of 30 mm. If the spinning pipe heating and the feeding of a second solution component is omitted, the spinneret pitch can be reduced to ca. 24 mm. The spinning pipes can be individually pivoted upwards, but individual solution flows cannot be switched off. For this reason, the coagulation bath should have a spinning start-up trough (as in Fig. 4.336).

If the threadline-to-threadline pitch is too large for further processing, the filaments can be taken out of the coagulation bath, either by using a grooved roll having the groove pitch equal to the desired threadline pitch, or a form of tow stacker can be used, as shown in Fig. 4.306. In this way, monofilament warps of 4 to 6 mm yarn pitch or 120 dtex multifilaments of 8...10 mm pitch can be assembled for further processing.

An example of a washer for a parallel warp is shown in Fig. 4.350; here all rolls must be aligned parallel to one another. If, however, each vertical pair of rolls is inclined towards the other, up to 4 parallel filaments per roll pair can be handled independently of the others. By using a number of wraps around the rolls, the filaments can run onto the rolls at the rear, traverse across the roll width, and exit the roll front as a group.

If the drawing- and yarn tension behavior during processing is not known, a free-running roller system (Fig. 4.351) can be employed. Each filament, however, must be able to withstand the yarn tensions arising. One or two filaments are wrapped around the grooves in the upper- and lower free-running rolls; they advance one pitch sideways after every wrap and are taken up. Nelson rolls, well-known in viscose spinning, can be used in treating single yarns (Fig. 4.352). The yarn is spun from the spinneret (1) and taken over the rolls (2) onto the inclined rolls (3), where the small angle of inclination causes the wraps to advance along the axis of the rolls. The yarn passes through the funnel (11) and is taken up in the centrifugal spinning pot (12), from where it is later rewound. In the extraction bath (4), pumps spray the yarn from above the upper rolls. The water runs down the filaments, with an intensive washing action occurring on the washing boards (5). If the longitudinal rolls are provided with axial slits (Fig. 4.200F), each zone can be treated as a separate bath, and a drying head can be fitted at the end of the shaft.

Using rolls of 150 mm diameter 800 mm apart and inclined at 3 °/0.3 °, a yarn path of 170 m per 1 m roll length can be obtained.

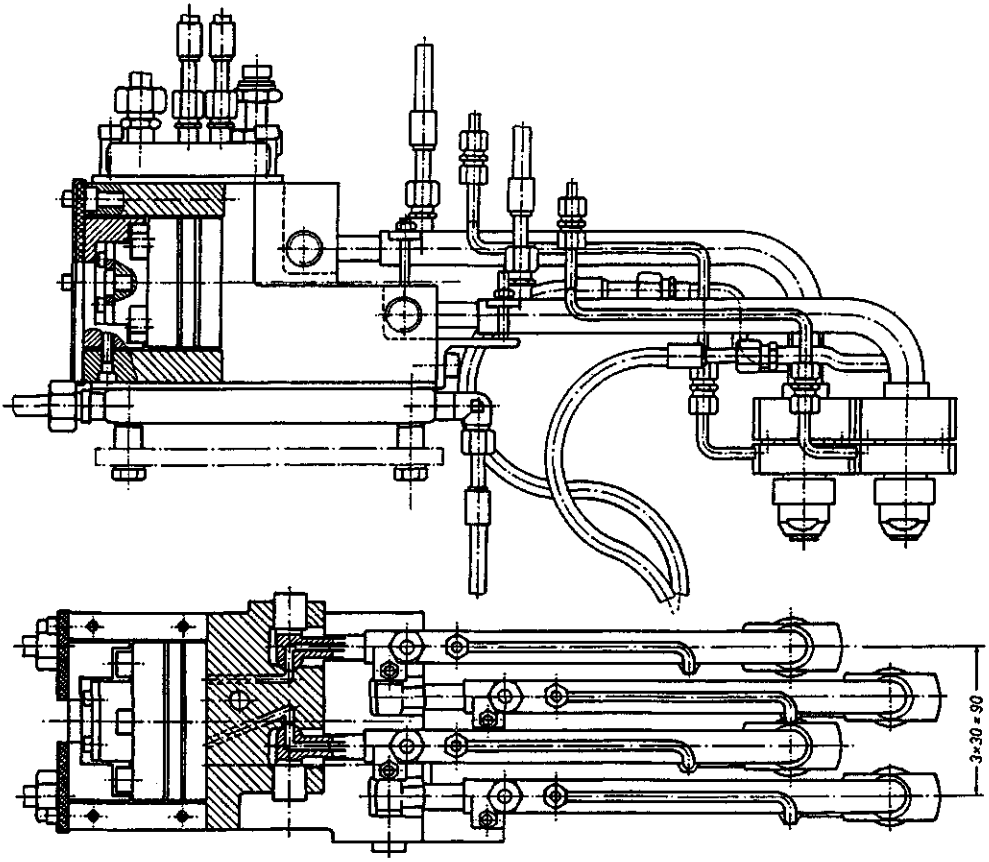
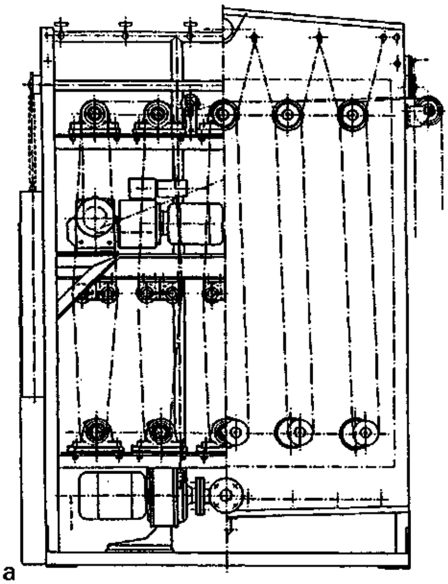


Figure 4.349 Pump and 4 spinning nozzle aggregate for the wet spinning of multifilaments or, here especially, hollow fibers (with additional core fluid-dosing according to the bicomponent C/S process; spinneret diameter 16 mm; 4-fold spinning pump; with jacket heating of the spinning nozzles [24]) (Fourné Maschinenbau)

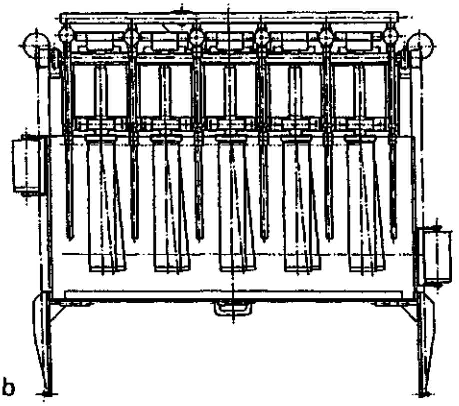
If the filaments suffer a length change during processing, only a parallel roll system containing many rolls can be used for the washing and drying unit. The roll speeds must be finely adjustable, either singly or in groups (see Fig. 4.344d).

Figure 4.353 [313] shows another possible method of transporting the filament wraps sideways. Two cage rolls, inclined to one another, mesh in such a way that the lands on opposite sides of the two rolls protrude, pushing the filament wraps towards the front of the roll, from where the yarn is taken up onto another roll to be dried or wound up. This system has not, however, been used since ca. 1970.

Figure 4.354 shows a layout for spinning 16 hollow filament yarns from polyethersulfone. A solution of the polymer in DMAC is introduced at (a) and stored in (b). The solution is extruded from four 4-aggregate spinnerets (e) through a ca. 400 mm long inert gas zone into the coagulation bath (c), which is topped up with coagulant from (d). On emerging from the bath, the filaments are brought closer together by a grooved roll (f), are taken up by the trio (g) and are drawn approximately 1 : 2 in the liquid drawing bath by a second trio (i). The filaments are washed in (j) and dried as a warp in the hot air recirculating oven (k) before running over a tension-regulating trio (l) to be wound up on a hank winder (m). The take-up speed is between 10 and 13 m/min at (g) and 20...25 m/min at the trio (l). The coagulation bath (c) consists of a 50 : 50 mixture of DMAC and water.

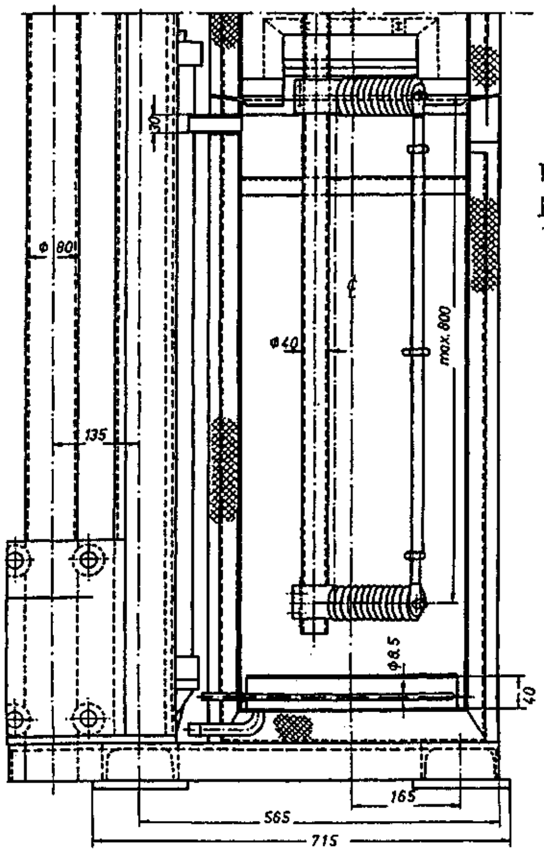


a



b

Figure 4.350
Yarn washing machine with yarn warp spraying from above [24]
a) with parallel upper and lower rolls for one warp
b) with lower rolls angled relative to the upper rolls, for 1 to 4 parallel tows per roll pair



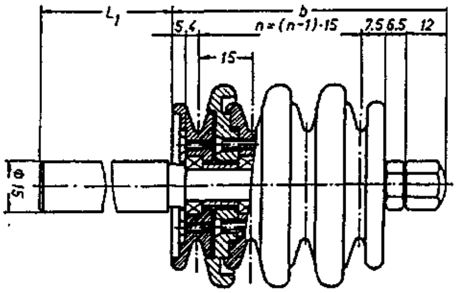


Figure 4.351
Free-running yarn roller reel for extremely long yarn paths [24]
left: reel configuration
right: constructional details of yarn roller

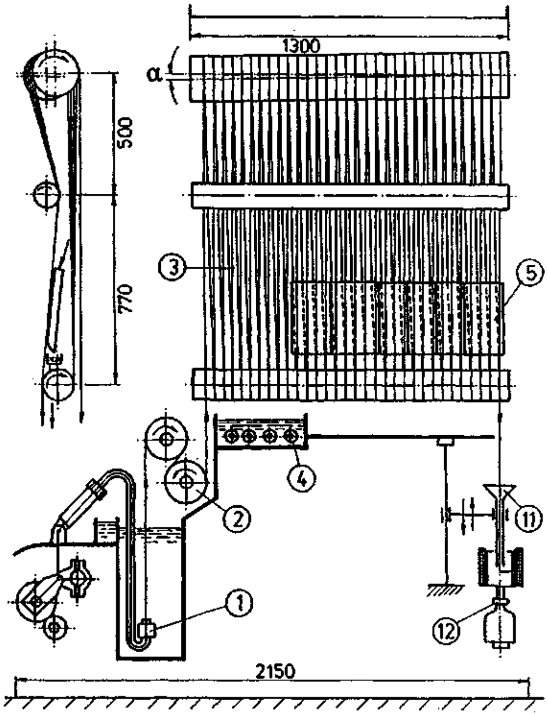


Figure 4.352
Continuous aftertreatment of 1 (or 2) yarn(s) according to the "Nelson" principle
1 Spinneret
2 Take-off rolls
3 Inclined rolls with yarn displacement
4 Washing bath plus heater
5 Washing board in yarn path
11 Yarn funnel
12 Centrifugal winding pot with drive

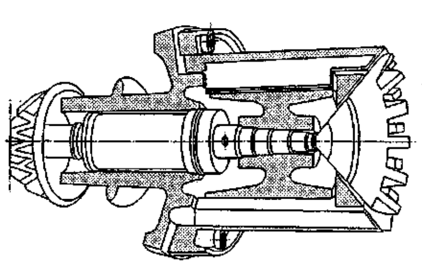


Figure 4.353
Sideways yarn wrap transport on two mutually inclined reeling rolls (Industrial Rayon Corp.)

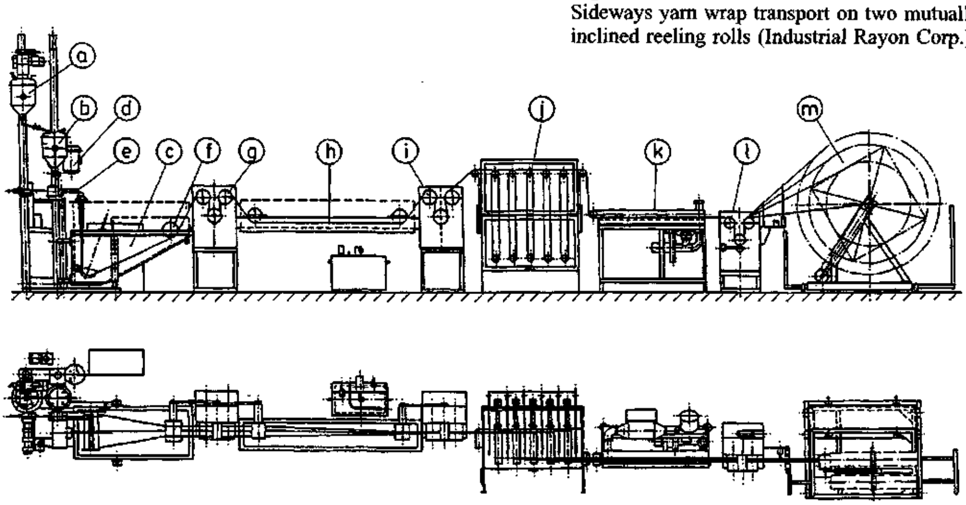


Figure 4.354 Solution spinning machine for hollow filaments ([24]; Fourné Maschinenbau)
a) Solution preparation tank and air separator
b) Solution storage tank
c) Spinning bath
d) Core fluid storage tank and dosing
e) Spinning pump and spinneret packs (16 spinnerets in a width of 600 mm)
f) Collection take-up
g) Take-up stand
h) Hardening bath
i) Drawstand
j) Washer
k) Recirculation air drier
l) Tension control
m) Hank winder (for modules)

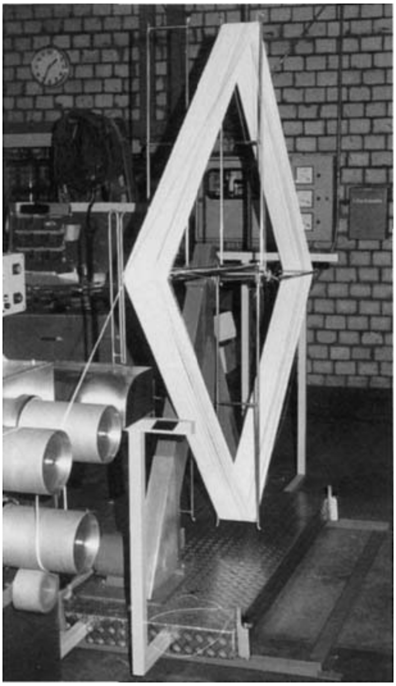


Figure 4.355 Hank winder [24]

A hank winder should ideally be driven by a soft-torque motor to even out the differences in speed between the center and edges of the hank; it also needs a long, vertical slotted yarn guide (Fig. 4.355, [24]).

4.16 Piston (Rod) Spinning Units

Piston spinning is used when the melt or solution cannot withstand shear forces, when spinning is done by the sinter-extrusion process or when only very small sample quantities are available for spinning.

4.16.1 Spinning of Very Small Quantities

Filaments can be spun from even small quantities of polymer produced in laboratory syntheses. From 10 g of polymer, ca. 800...900 m of undrawn 100 dtex yarn (or ca. 3000 m of drawn 30 dtex yarn) can be produced. This length of yarn can be knitted into a ca. 5 m long sock on a circular knitting machine for dye uptake- and textile testing. Even the smallest extruder spinning head must first be filled before any extrusion can be performed; this small filling quantity remains in the head after extrusion (Table 4.52). The smallest available rod spinning device, however, retains only ca. 1 cm^3 of melt or solution at the end of extrusion, and operates practically without shear or mixing. Available sizes vary from ca. 150 cm^3 to 2 dm^3. They can be heated up to 350...500 °C and operate at maximum pressures of 100, 400 or even up to 1000 bar. As shown in Fig. 4.356, a reluctance motor drives, via a worm drive, a spindle having a motion thread (taper or trapezoidal threads). Attached to the spindle is a tight-sealing piston, which is driven down the heated cylindrical bore to contact the molten polymer or solution. Above the spinneret filter there are sensors for melt temperature and pressure. Molten polymer or solution below the piston is extruded through the spinneret to form filaments, which are cooled or coagulated, etc., as required. The extrusion rate Ex is given by:

$$\text{Ex (g/min)} = \text{Spindle feed [cm/min]} \times d^2_{\text{cylinder}} \times \pi/4 \times \varphi_{\text{melt}}\ [\text{g/cm}^3].$$

The throughput must be checked by weighing, as the granulate (bulk density ~ 0.7 g/cm^3) is compressed during melting. These spinning devices can obviously only be operated batch-wise.

Table 4.52 Minimum Volume to Fill Extruder Spinning System(=waste) [338]

Extruder screw diameter mm	Spinning pump cm^3/rev	Spinneret diameter mm	Minimum volume to fill system cm^3 (ca.)
10	0.6	32	34
13	1.2	42	44
18	1.8	52	75
22	2.4	52	96
25	3.3	64	130
30	4.5	80	180

This process can also be used for spinning hollow filaments, bicomponents and multicomponents (see Fig. 4.357); in this case, the "dead" volume is somewhat larger. The advantage here, though, is that no abraded metal—not even traces—comes into the melt; this is, e.g., important for optical fibers.

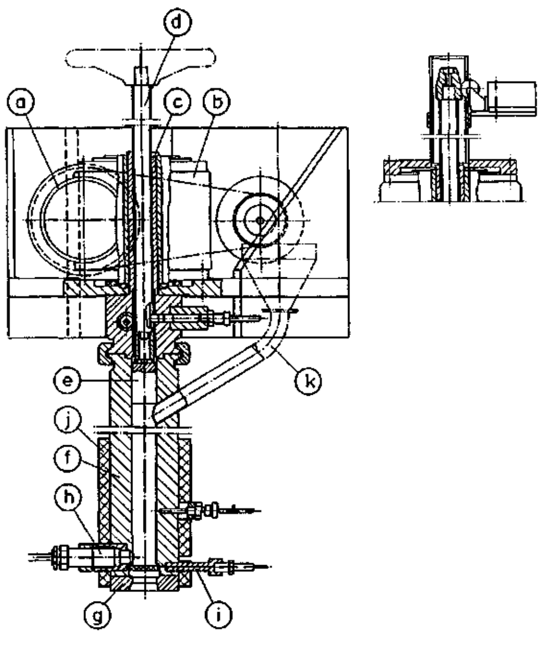


Figure 4.356
Piston spinning apparatus for spinning extremely small quantities of material (Polymer or solution, ≥ 10 g up to max. 2 l) (Fourné Maschinenbau [24])
a) Reluctance motor
b) Hollow shaft worm drive
c) Spindle nut
d) Spindle
e) Piston (plunger)
f) Spinning cylinder
g) Spinneret
h) Melt pressure transducer
i) Melt temperature sensor
j) Heating collars
k) Filling funnel (removable)

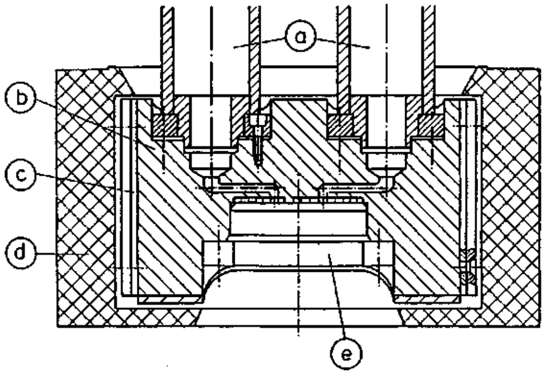


Figure 4.357
Bicomponentspinning head for two piston spinning devices [24]
a) Piston spinning device
b) Distributor head
c) Electrical heating
d) Insulated housing
e) Bicomponent spin pack

4.16.2 Ram Extrusion [330]

Ram extrusion is, in principle, the same as piston extrusion, but the devices are larger, having extrusion volumes of up to 30 l per 1 m cylinder length. They are used particularly for the extrusion of PTFE, gel solutions, pitch and—in smaller amounts—PA. Depending on melt viscosity, pressures of up to 800 bar may be required, e.g., for PTFE sinter-extrusion, where the viscosity can reach 10^{10} Pa × s.

In Germany, two ram extrusion machine types are produced, one having a vertical [331] and the other a horizontal cylinder [332]. The internal diameters are ca. 200 mm and the stroke lengths ca. 2000 mm. Both are hydraulically driven. For reasons of wear and corrosion, 1.4550 steel (=AISI 347) or St52 (internally hardchromed or—better still—chemically nickeled) are recommended. The piston, mainly made from gunmetal (red bronze) or, better, from forged sinter bronze, has a play of ca. 0.1 mm for small diameters and up to 0.3 mm for large diameters.

For temperatures up to ca. 220 °C, the cylinder is heated either electrically or by thermal oil. Electrical resistance heating cuffs are used up to 340 °C, and for temperatures up to ca. 600 °C, electrical resistance heating rods are cast into special brass. If, in the case of large ram extruders, the same polymer is always used, one need not be so concerned about complete extrusion of the total volume. Instead, a flow distributor (displacement body) should be fitted close to the spinneret to improve the melt temperature uniformity.

References

1. *Fourné, F.*: Synthetische Fasern, Wissenschaftl. Verlagsges. mbH, Stuttgart, 1964, p. 31
2. Zimmer AG, Frankfurt/Main, Germany, for continuous polycondensation
3. Karl Fischer Industrieanlagen GmbH, Berlin, Germany
4. Ems-Chemie AG, Domat/Ems, Switzerland
5. In the FRD: AD-Merkblätter, Ausgabe 1988, Carl-Heymanns-Verlag KG, Cologne
   In den USA: ASME Boiler and Pressure Vessel Code; particularly Section VIII, Dir. I; Section IX; Section II; The American Society of American Engineers, New York/N.Y.
   In the Netherlands Rules for Pressure Vessels, SDU Publishers, The Hague
   In Sweden: Swedish Pressure Vessel Code, The Swedish Pressure Vessel Commission, Stockholm 1974
   In France: CODAP; Syndicat National de la Chaudronnerie, de la Tolerie et de la Tuyauterie Industrielle, Paris
6. TÜV = Verband der technischen Überwachungsvereine, Essen, Germany
7. Lloyd's = Deutscher Lloyd Versicherungen, Munich, Germany
8. Condux-Werk Herbert A. Merges GmbH + Co. KQ, Hanau, Germany
9. Ekato Rühr- und Mischtechnik GmbH, Schopfheim et al., Germany
10. *Adolphi, G.*; et al.: Lehrbuch der Chem. Verfahrenstechnik, Deutscher Verlag für Grundstoffindustrie, Leipzig, 1969

11. *Perry, J. H.:* Chemical Engineers Handbook; McGraw-Hill Book Company, Inc., New York, 1950
12. Chemie-Ing.-Technik **42** (1970) 21, p. 1322
13. *Vusu, L. G.,* van de: Chem.-Ing.-Technik **31** (1959) S. 583 and Chem.-Eng. Sci. **4** (1955) p. 178, 209
14. VDI-Wärmeatlas, VDI-Verlag Düsseldorf
15. Hütte, Des Ingenieurs Taschenbuch, 28. Auflage, Verlag Wilhelm Ernst + Sohn, Berlin, 1955, and Physikhütte, Band I, Mechanik, 29. edition, Berlin, 1971
16. *Gatterstädt, J.:* VDI-Forschungsheft **265** (1924) p. 617 and VDI-Z, **68** (1924)
17. *Molerus, O.; Wellmann, P.:* Chem. Eng. Sci. **36** (1981) p. 623 and 1977
18. *Ottjes, J. A.:* Chem. Eng. Sci. **33** (1978) p. 783
19. *Herning, F.:* Stoffströme in Rohrleitungen, 4. Auflage, VDI-Verlag, Düsseldorf, 1966
20. Autefa Maschinenfabrik GmbH, Augsburg, Germany
21. According to *J. Keilert* in [22], modified by *F. Fourné*
22. Automatik, Apparate-Maschinenbau GmbH, Großostheim, Germany
23. C.F. Scheer + Cie. GmbH + Co., Stuttgart, Germany
24. Fourné Maschinenbau GmbH, Alfter, Germany
25. *Ludewig, H.:* Polyesterfasern, Akademie-Verlag, Berlin, 1975, p. 160
26. N.N.: Granulieren von thermoplastischen Kunststoffen, VDI-Verlag, Düsseldorf, 1974
27. H. Dreher GmbH + Co. KG, Aachen, Germany
28. *Pflüger, R.:* Verarbeitung (von PA), in *Vieweg, R.; Müller, A.:* Kunststoff-Handbuch, Bd. VI, Polyamide, Carl Hanser Verlag, Munich, 1966, p. 214
29. *Redecker, D.:* Die Analyse des Schneidvorganges bei weichen hochpolymeren Kunststoffen in [26], p. 75
30. *Hensen, F,; Knappe, W.; Potente, H.:* Handbuch der Kunststoff-Extrusionstechnik II, Extrusionsanlagen; Carl Hanser Verlag, Munich, 1986
31. Werner & Pfleiderer GmbH, Stuttgart, Germany
32. Maag-Zahnräder AG, Zürich, Switzerland
33. Barmag AG, Remscheid, Germany
34. *Felger, H. K.:* in *Becker/Braun:* Kunststoff-Handbuch, Polyvinylchlorid 2/1; Carl Hanser Verlag, Munich, 1985
35. Kurashiki Rayon Co., Ltd., Tamashima/Japan, construction: *Fourné, F.,* 1962–1964
36. Zeppelin Metallwerke GmbH, Friedrichshafen, Germany
37. Schmidding-Werke, Köln (Niehl), Germany
38. Vollmar Anlagentechnik, Königswinter, Germany
39. Waeschle Maschinenfabrik GmbH, Ravensburg, Germany
40. Umformtechnik Hausach GmbH, Hausachen/Baden, Germany
41. *Mitune, A.:* Studies on PET; IV. The Formation of PET in Solid Phase, J. Chem. Soc. Japan **65** (1962) p. 996
42. *Li Chen Shu:* Journ. Macromol. Sci. Phys. **1967,** p. 801
43. *Chut Vung Cha:* Amer. Chem. Soc., Div. Polymer Chem. **1965,** p. 84
44. *Zupiev, L. I.; Lyznik, Z. F.:* Polycondensation von PET in fester Masse, Plast. Massy **3** (1970) p. 14
45. *Bamford, C. H.; Wayne, R. P.:* Polymerization in the Solid Phase, Polymer [London] **1969,** p. 661
46. *Chang, T. M.:* Kinetics of Thermally Induced Solid State Polycondensation of PET; Polymer Eng. Sci. **1970,** p. 364
47. *Hirsch, M.:* Die Trockentechnik, Julius Springer-Verlag, Berlin, 1927
48. Bayer AG, Leverkusen: Molekularsieb-Adsorber; Firmenschriften and Anwendungsschaltbilder
49. Zeolithes are minerals composed of calcium, aluminium oxide silicates or alkali aluminium oxide silicates which can hold a large amount of water in their crystal lattice. The water can be recovered either by heating or altering the crystal structure.
50. Gebrüder Bühler AG, Uzwil/Schweiz, and Firma Bühler-Miag GmbH, Braunschweig, Germany
51. Karl Fischer Industrieanlagen GmbH, Berlin, Germany
52. SOMOS GmbH, Weiterstadt, Germany
53. *Mücke, W.:* Beschicken von Extrusionsanlagen, in *Hensen, Knappe, Potente:* Kunststoff-Extrusionstechnik II, p. 662, Carl Hanser Verlag, München, 1986
54. *Kerlinger, H.:* Institut für Textil- and Faserforschung, Stuttgart, Denkendorf, Germany
55. Simar Fördertechnik GmbH, Markgröningen, Germany
56. "Hoverdryer" der Firma Rosin Engineering Comp., Ltd., London/England
57. Emil Kammerer KG, Bergisch-Gladbach, Germany
58. W. C. Heraeus GmbH, Hanau am Main, Germany
59. *Fourné, H.; Fourné, F.:* Neue Entwicklungen auf dem Gebiet der synthetischen Fasern, Textil-Praxis **1958,** p. 1124 and 1205, **1959** p. 8

60. *Fourné, F.:* Schmelzspinnverfahren für synthetische Fasern and Fäden, Textil-Praxis, Dec. 1964, p. 1169
61. *Klare, H.; Fritsche, E.; Gröbe, V.:* Synthetische Fasern aus Polyamiden, Akademie-Verlag, Berlin, 1963
62. *Fourné, F.; Kucznier*; et al.: at Von Kohorn International Corp., White Plains, N.Y./USA, 1960
63. *Schenkel, G.:* Kunststoff-Extrudertechnik, Carl Hanser Verlag, Munich, 1963
64. *Falkai, B., v.:* Synthesefasern, Verlag Chemie, Weinheim, 1981
65. *Michailov, N. V.; Sarej, T. A.; Arsentev, A. N.:* Chim. Volokna **5** (1968) p. 3–10
66. *Kohlwey, J. F.:* Kunststoffe **44** (1954) p. 3; *Plunket, R.:* US-Pat. 2 230 654 (1941); also see [61]
67. J. Polymer Sci. **52** (1961) p. 245, also see viscose spinning, polyimide- and polymide acid spinning
68. *Schmidt, K.:* 18. Int. Chemiefasertagung Dornbirn, June 1979
69. Didier Engineering: John Brown Deutsche Engineering GmbH., Essen, Germany
70. *Klare, H.:* Geschichte der Chemiefaserforschung, Akademie-Verlag, Berlin, 1985, p. 175, Fig. 50; from 1938–1944 for PA6.
71. *Herprechtsmeier, P.:* Lichtwellenleiter (aus PMMA and PTFE nach Bikomponenten-Stabspinnverfahren), Funkschau **11** (1988) p. 46
72. So-called ram extrusion spinning apparatus for PTFE
73. Dynisco Inc., Norwood, Mass./USA
74. Nöldechen, A.: Strom kann man tropfenweise abzapfen; Die Welt, Nr. 258, 4. November 1989, p. 20 (finely crystallized yttrium-barium-copper oxide superconductor in sodium alginate gel, with the latter removed in an acidic bath. This gives fibers with a transition temperature of 85°K and a tensile strength of 19.6 kg/mm^2)
75. ICI FIBRES, Harrogate, North Yorkshire/England
76. H.J. Zimmer Verfahrenstechnik, 1950–1952, Offenbach/Main, now incorporated in [2]
77. Du Pont de Nemours & Co., INC., Wilmington, Del./USA
78. Xalloy der from Xalloy, New Brunswick, N.J./USA, and Herstal-Lez-Liège/Belgium
79. Reiloy from Reiloy Metall GmbH, Troisdorf-Sieglar, Germany
80. Brookes Ltd., GB-Oldbury, Warley/West Midlands, England
81. *Mayer, M.:* Faserextrusion, in *Hensen, F.:* Kunststoff-Extrusionstechnik II, p. 566, corrected, Carl Hanser Verlag, Munich, 1986
82. *Potente, H.:* Auslegen von Schneckenmaschinen-Baureihen, Modellgesetze and ihre Anwendung, Carl Hanser Verlag, Munich, 1981, and Handbuch der Kunststoff-Extrusionstechnik I, Carl Hanser Verlag, Munich, 1989
83. *Rauwendaal, Ch.:* Polymer Extrusion, Carl Hanser Verlag, Munich, 1985
84. *Hensen, F.; Knappe, W.; Potente, H.:* Handbuch der Kunststoff-Extrusionstechnik, I, Grandlagen, Carl Hanser Verlag, Munich, 1989
85. Davis-Standard, Pawcatuck/USA
86. Mitsubishi Heavy Industries Ltd., Tokyo/Japan
87. *Thiele, H.; Zettler, H. D.:* Auswahlkriterien für Reaktoren zum Herstellen von Polymeren, Kunststoffe **79** (1989) 8, p. 687
88. *Thiele, H.; Zettler, H. D.:* Bauformen von Reaktoren zum Herstellen von Polymeren, Kunststoffe **79** (1989) 9, p. 791
89. Hermann Berstorff Maschinenbau GmbH, Hannover, Germany
90. *Zielonkowski, W.:* Doppelschneckenextruder, Kunststoffe **58** (1968) 6, p. 394
91. *Janssen, L. P.; Pelgrom, J. J.; Smith, J. M.:* Druckaufbau and Ausstoßleistung eines Doppelschneckenextruders, Kunststoffe **66** (1976) 11, p. 724
92. *Werner, H.:* Entgasen von Kunststoffen in mehrwelligen Schneckenmaschinen, Kunststoffe **71** (1981) 1, p. 18
93. Werner & Pfleiderer, Stuttgart, Germany
94. N.N.: Vollrollige Zylinderrollenlager im stationären Getriebebau, VDI-Zeitschrift **122** (1980) 7, April, p. 282
95. Baker Perkins Chemical Machinery Ltd., Stoke-On-Trent/UK; in Germany: Köln-Gremberg
96. *Edie, D. D.:* Flow Peculiarities of Polypropylene, Fiber Producer, April 1980, p. 28
97. DE 233 176 4, Spinneinrichtung für das Spinnen von Hochpolymeren (Zimmer AG, 22. 6. 1973)
98. Indian (own) development
99. *Schlünder, E. U.:* Hochschulkurs Wärmeübergang I; March 1982, p. 167, Karlsruhe
100. *Forgues, L. V.:* Design Considerations in the Selection of Hot Polymer Valves, Fiber Producer, April 1978, p. 33
101. Kenics Mixer, Kenics Corp., Danvers, Mss./USA
102. Sulzer mixers, Gebr. Sulzer ACi, Winterthur/Switzerland
103. Toray High Mixers, Toray Engineering Co. Ltd.
104. *Pahl, M. H.; Muschelknautz, E.:* Statische Mischer and ihre Anwendung, Chemie-Ing.-Technik, **1980,** 4, p. 285
105. Process Developments Ltd., London NW 9
106. Feinprüf GmbH, Göttingen, Germany
107. Barmag AG, Spinning pump division, Remscheid, Germany

108. Zenith Div. Parker Hannifin, Waltham/USA
109. Kawasaki Heavy Ind. Ltd., Osaka/Japan
110. *King, C. p. W.:* Metered Finish as Applied to Melt Spun Fibers, Fiber Producer, October 1980, p. 17
111. *Fourné, F.:* Spinnschachtpräparation, Chemiefasern/Textilindustrie, Oktober 1979, p. 838
112. Maag-Zahnräder AG, Zürich/Switzerland
113. Gebr. Kufferath GmbH + Co.KG, Düren, Germany
114. Haver & Boecker, Oelde, Germany
115. Fluid Dynamics/Memcor Filtertechnik GmbH, Eschborn/Ts
116. Höganäs Metallurgy, Höganäs, Sweden; in Germany: Höganäs GmhH, Düsseldorf
117. Pressemetall Krebsöge GmbH, Radevormwald, Germany
118. Mott Metallurgical Corp., Farmington/USA
119. Fuji Filter Mfg. Co. Ltd. Tokyo/Japan
120. Brunswick Corp., see 'K5'
121. *Morland, C. D.; Gecosala, R. R.:* Proc. World Filtration Congress III, 1983, p. 409
122. *Morland, C. D.; Mitchell, B. D.:* Polymer-Filtrationssysteme zur Faserherstellung, Chemiefasern/Textilindustrie **39/91** (1989) p. 1171
123. *Fourné, F.:* developed in 1983/84
124. Ceccato SpA., Milan/Italy
125. Engelhard AG, Frick/Switzerland
126. ENKA Tecnica, Heinsberg, Germany
127. Günther Frey G.m.b.H. + Co. KG, Berlin, Germany
128. Heraeus GmbH, Hanau, Germany
129. Kasen Nozzle Mfg. Co. Ltd., Osaka/Japan
130. Nippon Nozzle Co. Ltd., Kobe/Japan
131. SIM spinnerets for glass spinning, made by DAGE LTD., Basel/Switzerland
132. Heating as a consequence of shear work in the gap: the pressure loss is given by: $\Delta p = 12 \cdot \eta \cdot G \cdot L/\varrho \cdot \mathrm{D} \cdot \pi s^3$ with, e.g., η [kg s/m^2] = 0.0098 P, G [kg/s], L, D, s [m] ς [kg/m^3]
133. *Fourné, F.:* Air Quenching—Rectangular vs Radial, Int. Fiber Journal, August 1988, p. 30
134. DOS 34 09 530 (NEUMAG; AD: 15. 3. 1984)
135. LURGI GmbH, Frankfurt/M., for "Docan" spun-bond plants having spin packs weighing up to ca. 100 kg
136. Evaluated and interpolated from information supplied by Barmag [33]
137. *Schneider, K.:* Zahnradpumpen für Polymerschmelzen and -lösungen, Kunststoffe **68** (1978) 4, p. 201
138. *Fourné, F.:* Einige Ursachen von Titer-, Dehnungs- and Färbeschwankungen, Chemiefaser/Textilindustrie, June 1984, p. 419
139. Desch Antriebstechnik GmbH + Co. KG, Arnsberg, Germany
140. Cyclo Getriebebau Lorenz Braren GmbH, Markt Inderdorf, Germany
141. A. Friedr. Flender AG, Bocholt, Germany
142. Lenze GmbH + Co. KG, Extertal, Germany
143. P.I.V.-Antrieb Werner Reimers GmbH + Co. KG, Bad Homburg v.d.H., Germany
144. USP. 2 273 105 [Du Pont (*Heckert*), AD: 9. August 1938 (equivalently: BP 533 304, FP 851 437 with additionally 50571)]
145. BP 541 238 (*Dreyfus, H.,* AD: 17. April 1940)
146. FP 927 334 [Du Pont (Hull), AD: 24. 5. 1946, with US priority 4. 6. 1941]
147. FP 980 574 [Soc. Rhodiaceta, AD: 9. 2. 1949, with US priority 26. 5. 1948, Du Pont (*Pohl, M. H.*)]
148. FP 991 912 (Elite Sdruzene Tovarny Puncoch, AD: 31. 5. 1949, with ČSSR priority of 6. l, 1948)
149. US-P. 2 289 860 [Du Pont (*Babcock*), AD: 9. August 1938 (equivalently: BP 533 303, FP 851 437 with additionally 50574, Dutch Pat. 54872, Ital. Pat. 378 902)]
150. *Fourné, F.:* Blasschächte — Stand der Technik; Chemiefasern/Textilindustrie **37** (1987) p. 542
151. *Fourné, F.:* Air Quenching of Melt Spun Filaments, Fiber World, September 1984, p. 78
152. *Lückert, H.; Stibal, W.:* Chemiefasern/Textilindustrie **36** (1986) p. 22, see also Ullmann's Encyclopedia of Industrial Chemistry: Fibers, 3. General Production Technology, p. 521, VCH Verlagsgesellschaft mbH, Weinheim, 1987 and *Fourné, F.:* Chemiefasern/Textilindustrie, April 1987, p. 320
153. DBP 3 414 602 (*Fourné, F.,* AD: 18. 4. 1984)
154. *Fourné, F.:* Fadenkühlung beim Schmelzspinnen; Chemiefasern/Textilindustrie (1977) **6** p. 526 and (1978) **4** p. 315
155. DBP 2 930 553 (*Fourné, F.,* AD: 27. 7. 1979)
156. Didier Engineering, Essen, Germany, and its customers
157. Zimmer AG, Frankfurt/Main, Germany, and its customers

158. DBP [Zimmer AG (*H. Koschinek*)]
159. DBPA [Allied Chemical Corp. (1968)]
160. DBP 3 318 096 [Automatik Apparate-Maschinenbau GmbH (*Schweitzer*), AD: 18. 5. 1983]
161. *Syben, N.:* Möglichkeit zur Dämpfung von Geschwindigkeitsschwankungen der Blasluft bei Synthesefaser-Spinnverfahren, Firma Krantz-Lufttechnik, Aachen, 1974
162. US-P. 2 289 860 (AD: 9. August 1938, Du Pont)
163. Lurgi, Frankfurt/Main, and Neumag, Neumünster, Germany
164. *Regenscheit, B.:* Ausblase- and Absaugekanäle lufttechnischer Anlagen, information from Krantz Lufttechnik, Aachen/VDI-Berichte, Bd. 34, 1959
165. Naxos-Union, Frankfurt/Main, Germany
166. IWKA, Karlsruhe, Germany
167. NEUMAG, Neumünster, Germany
168. Barmag, Remscheid: grooved roll
169. DBP 30 16 662 (AD: 30. 4. 1980; Automatik Wicklerbau, Hürth-Efferen)
170. Maschinenfabrik Rieter AG, Winterthur/Switzerland
171. Edmand Erdmann Elektrotechnik G.m.b.H. + Co. KG, Mülheim/Ruhr, Germany
172. Dienes Apparatebau G.m.b.H., Mühlheim/Main, Germany
173. *Fourné, F.:* Klimabedingungen für Synthesefaser-Anlagen, Chemiefasern/Textilindustrie, Sept. 1989, p. 9S6
174. Fleissner GmhH + Co. KG, Egelsbach, Germany
175. Siemens AG, Erlangen, Germany
176. FAG Kugelfischer KGaA, Hammelburg, Germany
177. New Departure Hyatt Bearings, Sandusky, Ohio/USA
178. Toray Engineering Co., Ltd., Osaka/Japan
179. Georg Sahm Gmbh + Co. KG, Eschwege, Germany
180. Leesona Corp., Burlington, NC./USA
181. "Alquist"-winder of Stahlkontor Weser, part of Lenze GmbH + Co. KG, Extertal, Germany
182. Murata Machinery Ltd., Kyoto/Japan
183. DPA 15 60 617 (Toshiba Machine Co., Tokyo, Japan, AD: 6. 4. 1965)
184. DPA 15 50 469 (Maschinenfabrik Schärer, Erlenbach/Switzerland, AD: 15. 9. 1966)
185. DBP 1 925 678 (Toray Industries, Inc., Tokyo/Japan, AD: 18. 12. 1969, with Japanese priority of 20. Mai 1968)
186. EP 011 4641, EP 011 4642, EP 012 0216 (Barmag, AD: 27. 1. 1984), EP 0166 292, AD: 11. 6. 1985, EPA 019 4648, AD: 11. 3. 1986 (Barmag and others)
187. W. Schlafhorst + Co., Mönchengladbach, Germany
188. Ringspann Albrecht Maurer KG, Bad Homburg v.d.H., Germany
189. DBP 2 106 493 (Barmag, AD: 11. 2. 1971)
190. Automatik Wicklerbau, Hürth-Efferen, Germany
191. Comoli Fermo e Figli, Peruzzaro (NO)/Italy
192. Asahi Kasei, Osaka/Japan: DBO 2 461 972, AD: 30. 12. 1974
193. Barnag, Remscheid, Germany: DBA 2 110 367, AD: 4. 3. 1971
194. ICI, London/England: DBA 2 523 771; AD; 28. 5. 1975
195. Mitsubishi Jukojyo K. K., Tokyo/Japan: DBP 2 459 990, AD: 18. 12. 74
196. Rieter AG, Winterthur/Switzerland: DBP 2 048 416, AD: 8. 4. 1971 with Swiss priority of 3. 10. 1969
197. Teijin Ltd., Osaka/Japan, DBP 2 524 415, AD: 3. June 1975 with Japanese priority of 6. June 1974
198. Torii Winding Machine Co. Ltd., Kyoto/Japan: DBA 2 035 543 and 2 065 767, both AD 17. July 1970
199. The Bouligny Company, Charlotte, N.C./USA
200. Savio S.p.A., Imola (Bo)/Italy
201. Teijin Seiki Co., Ltd., Osaka/Japan
202. International Fiber Journal, December 1988, High Speed Take-up Winder Chart
203. Textima VEB, Berlin (East) and VEB Erste Maschinenfabrik Karl-Marx-Stadt
204. Winders of the type KS19 and KS21 of Barmag, Remscheid, Germany
205. Zinser Textilmaschinen GmbH, Ebersbach/Fils, Germany
206. Dobson & Barlow Machinery Sales Ltd. (no longer existent), Bolton/England
207. *Bogucki-Land, B.:* Kett-Strecken; Melliand-Textilber., **1987** p. 164
208. Karl Mayer, Obertshausen, Germany
209. Liba-Maschinenfabrik GmbH, Naila, Germany
210. *Hagewood, J. F.; Monroe, N. C.:* Neues Streck-Schärsysiem von McCoy-Ellison; Chemiefasern/Textilindustrie, Sept. 1988, p. 784

211. Val Lesina, Italy, and Cora Engineering, Chur/Switzerland: Neue Entwicklungen beim Kettstrecken, Chemiefasern/Textilindustrie September 1988, p. 788
212. DRP 618 050 (Heberlein & Co. AG, Wattwil, Switzerland, AD: 11. March 1932)
213. DRP 830 183 (J. P. Bemberg AG, Wuppertal-Oberbarmen, Germany; AD: 7. January 1942)
214. DRPA, Vereinigte Glanzstoff-Fabriken AG, Wuppertal, Germany
215. "Helanca" is a registered trade name [196], jointly held with Billon of France
216. *Fourné, F.:* Kräuselmaterial; Melliand-Textilber. 1954, p. 492
217. *Fourné, F.:* Strech Yarn (Kräuselmaterial); including a patent review; I: Melliand-Textilber., **1956** p. 661, and II: Melliand-Textilber. **1958** p. 247 and 361
218. *Fourné, F.:* Filati Elasticizzati; Fibre Syntheticce; Nov. 1957, p. 1111
219. *Wegener, C. D.:* Chemiefasern/Textilindustrie, **1974**, p. 475
220. *Lünenschloß, J.; Farber, K.; Steinmetz, J.:* Textil-Praxis Aug. 1984, Beilage
221. Deering Milliken Res. Corp., Pendleton/USA
222. *Fourné, F.:* for BASF, 1951
223. Murata Machinery Ltd., Kyoto/Japan
224. Barmag [57], Texturizing machine dept., Remscheid, Germany
225. Lünenschloß, s. Texturierverfahren — Wandtafel des Textilinstituts der RWTH Aachen 1982
226. Rieter-Scragg Ltd., Langley, Macclesfield, Cheshire/England
227. RPR — Officine Meccaniche Riva S.r.l., (SO)/Italy
228. Giudici Davide + Figli, S.n.c., (CO)/Italy
229. Heberlein Maschinenfabrik AG, 9630 Wattwil/Switzerland
230. Primatex GmbH, Furth i. Wald — no longer existent
231. Hobourn Aero Components Ltd., Strood, Rochester/England
232. *Farber, K.:* Ein Beitrag zum Falschdrahttexturieren von schnell gesponnenen Filament-Garnen, Dissertation am Textiltechnischen Institut der RWTH Aachen, June 1986
233. *Lünenschloß, J.; Farber, K.:* Trends der technischen Entwicklung in der Textilindustrie nach der ITMA 1983 in Mailand — Falschdrahttexturieren, Inst. f. Textiltechnik der RWTH Aachen, 1984
234. Registered trade of Barmag [33]
235. Corresponds to D/Y ratio at disk texturizing
236. Maschinenfabrik Schweiter AG, Horgen/Switzerland
237. Siegling, Hannover, Germany
238. US-Pat. 2 575 781, 2 575 837, 2 575 838, 2 575 839
239. "Ban-Lon": Joseph Bancroft & Sons, Co., Wilmington, Del./USA
240. *Press, J. J.:* Man-made Textile Encyclopedia. Text. Book Publ., Inc., New York, 1959, p. 235
241. For PA66: 220°C; for PA6: 187°C yarn temperature in the chamber
242. Textima Model 1023
243. *Bock, G. D.:* Die Texturierung von Filamentgarnen im Luftstrom, Dissertation am Textiltechnischen Institut der RWTH Aachen, 1985
244. US Pat. 4 249 768
245. US Pat. 4 104 770; 3 835 510; 4 183 123; 4 148 116; 4 157 605; 3 881 231
246. US Pat. 2 783 609 (Du Pont, AD: 5. 3. 1957, and "Taslan": Textured Yarn; Bulletin X-32, May 1955)
247. *Rivers, J. T., jr,:* "Taslan" Textured Yarn. Textile Fiber Dept., Du Pont
248. Reiners + Fürst, Mönchengladbach, Germany
249. Barmag-Spinnzwirn GmbH, Chemnitz, Germany
250. Orlon Acrylic Fiber; Du Pont; Bulletin OR-90, May 1958
251. Eltex — Textilveredelungsmaschinen GmbH, Reutlingen, Germany
252. Among others: Barmag [208], Eltex [235], ICBT Intern., Caluire/France
253. Dietze + Schell Maschinenfabrik GmbH, Coburg, Germany
254. DBP 2 006 022 (device for producing texturized yarns, BASF, AD: 11. 2. 1970)
255. DAS 2 055 319 (Du Pont, AD: 10. 11, 1970)
256. DAS 2 631 393 (Bayer, AD: 13. 7. 1976)
257. DBGM 7 722 587 (Barmag, AD: 28. 7. 1977)
258. DOS 2 753 705 (Metallgesellschaft, AD: 2. 12. 1977)
259. DOS 2 807 490 (Bayer, AD: 22. 2. 1978)
260. DBP 2 828 306 (Bayer, AD: 28. 6. 1978)
261. DOS 2 844 391 (BASF, AD: 12. 10. 197S)
262. DOS 2 903 508 (Teijin, AD: 30. 1. 1979)
263. DOS 3 013 811 (BASF, AD: 10. 4. 1980)

264. DAS 2 206 064 (BASF, AD: 3. 1. 1972)
265. DAS 2 461 447 (Chevron Research, AD: 24. 12. 1974)
266. DOS 2 738 762 (Neumag, AD: 27. 8. 1977)
267. DOS 2 934 325 (Barmag, AD: 24. p. 1979)
268. DOS 3 026 934 (Du Pont, AD: 10. 7. 1980 with US priority of 18. 7. 1979)
269. Barmag [57], machine type Speetex STM 25
270. EPA 0 282 815 (Rieter AG, AD: 2. 3. 1988)
271. EPA 0 256 448 (Barmag, AD: 7. 8. 1987)
272. DRP 160 896 (Vienna, IG-Farbenindustrie AG, AD: 15. 2. 1937 and 7. 1. 1938)
273. *Bauer, R.; Koslowski, H.:* Chemiefaser-Lexikon; Deutscher Fachverlag, Frankfurt/M., 1993; 10. Edition
274. Heathcoat Textile Machinery Co. Ltd., Marsh Barton, Exeter, Devon/England
275. Mitsubishi Heavy Industries, Tokyo/Japan, ca. 1968
276. *Fourné, F.:* Ein neues Spinnsystem für Polyester-Stapelfasern, Textil-Praxis, Nov. 1964, p. 1073
277. *Lückert, H.; Stibal, W.:* Neuartige wirtschaftliche Technologien zur Produktion von PES-Fasern; CT1 36/88, January 1986, p. 24
278. *Fourné, F.:* Schnellspinnen and -schneiden von synthetischen Fasern; CTI, December 1976, p. 1098
279. DBP 2 633 477 (*Fourné, F.,* and *Fourné, U.;* AD: 26. 7. 1976 and DBP 2 823 532; *Fourné, F.;* and *Fourné, U.:* AD: 30. 5. 1978)
280. DOS 2 261 366 (yarn take-up AD: 15. 12. 1972, Barmag)
281. IWKA, Karlsruhe, Germany
282. Leichtmetallwerke Gmöhling GmbH + Co. KG, Fürth, Germany Firma Fleissner GmbH + Co., Egelsbach, Germany
283. Unfallverhütungsvorschriften der Deutschen Berufsgenossenschaften (UVV) (German safety instructions)
284. Meier GmbH, Heidenheim/Brenz, Germany
285. The Johnson Corporation, Three Rivers, MI/USA
286. Fleissner GmbH, Egelshach, Germany Prospekt: Siebtrommeln
287. Mohr Maschinen- and Anlagenbau GmbH + Co., Gerabronn, Germany
288. *Götze, K.:* Chemiefasern nach dem Viskoseverfahren, Springer Verlag, Berlin 1967, p. 878 (2. Vol.)
289. DRP 665 939, Gruschwitz Maschinenbau AG, Zittau, Germany
290. Lummus Industries, Inc., Columbus, Georgia/USA and [293]
291. Neumag GmbH, Neumünster, Germany
292. Kosik GmhH, Kelheim/Donau, Germany
293. Klingelnberg, Ferd. Söhne, Remscheid, Germany
294. DOS 1 660 286 (Eastman Kodak Co., Rochester, N.Y./USA; AD: 6. 9. 1967, and others
295. Fleissner GmbH + Co., Egelsbach, Germany
296. DBP 2 4S6 941 (*Fourné, F.,* and *Fourné, U.;* AD: 2. Dec. 1974)
297. Swiss Pat. 332 761 (Rhodiaceta AG., AD; 1. October 1956)
298. DOE 2 343 690 (AD: 30. August 1973)
299. *Lubitsch, W.:* Entwicklung eines Verfahrens zur Verarbeitung endloser Chemiefaserkabel in ein Stapelfaserband nach dem Konverterprinzip; CTI June 1975, p. S10, and July 1975, p. 590
300. US-Pat. 3 062 082 (Kieth; AD: 18. Mai 1959)
301. Neumag [167], Prospekt: Stapelfaserschneidmaschine NMC, 7.87
302. *Reichstein, H.;* u.a.: Industrie-Anzeiger, 18. 6. 1980, p. 21 DM + E Corporation: Prospekt "New Machinery for Fiber Cutting"/USA
303. Autefa Maschinenfabrik GmbH, Friedberg/Augsburg, Germany
304. Mises, v.: Z. des Vereins Deutscher Ingenieure; 1914, p. 750, Düsseldorf, Germany
305. Hütte: 28. Edition, p. 952
306. *Gröbe, V; Meyer, K.:* Faserforschung u. Textiltechnik 10 (1959) p. 14
307. *Falkay, B. v.:* Synthesefasern; Verlag Chemie, Weinheim, 1981
308. *Corbiere, J.:* in *Mark, H. F.;* et al.: Man-Made Fibers; Science and Technology; Vol. 1, Inter-science-Wiley; New York, 1967
309. *Rogovin, p. A.:* Chemiefasern; VEB Fachbuchverlag, Leipzig, 1960, p. 57
310. Rhone-Poulenc-Textile, Lyon/France
311. *Hoff, L.:* in *Geiger-Scheel:* Handbuch der Physik; Mechanik der flüssigen and gasförmigen Körper; Springer Verlag, Berlin, 1927, p. 153
312. Prandtl, L.; et al.: Führer durch die Strömungslehre; 8. Auflage; Vieweg and Sohn, Braunschweig 1964
313. "Marlotherm" of Hüls AG, Marl
314. *Fourné, F.,* for Mitsubishi Rayon Co., Ltd., American Celanese Inc., etc.
315. DRP 108 511 (*Stean, Ch. H.*)

316. *Götze, K.:* Chemiefasern nach dem Viskoseverfahren; 3rd Edition, Bd. II, Springer Verlag, Berlin, 1967
317. *Fourné, F.:* Labor- and Pilotanlagen für die Chemiefaserindustrie, CTI June 1980, p. 494
318. ARCT, Roanne/France
319. *Gröbe, V; Meyer, K.:* Untersuchungen über den Einfluß des Fällmittels auf die Fadenbildung beim Naßspinnen von Polyacrylnitril Faserforschung u. Textiltechnik **10** (1959) p. 214
320. *Hunyar, H.:* Die Rolle der polymerhomologen Verteilungsbreite bei der Herstellung synthetischer Fasern aus Polyacrylnitril, Faserforschung u. Textiltechnik **6** (1955) p. 300
321. *Hunyar, H.; Wiesner, E.:* Über Phasentrennung bei kolloiden Lösungen makromolekularer Gemische; J. Polymer Sci. XXX (1958) p. 645
322. Uddeholms AB: Korrosionshandbuch; Uddeholm/Sweden
323. Monsanto Comp. Pensacola, Florida/USA
324. Courtaulds Ltd., Coventry/England
325. Toho Rayon Co., Ltd., Tokyo/Japan
326. Hoechst AG, Frankfurt/M.-Hoechst, Germany
327. Asahi Chemical Industry Co., Ltd., Tokyo/Japan
328. Vereinigte Glanzstoff-Fabriken AG; In 1948/49, 17 washing/desulfurizing/bleaching zones were separated from 1 drying zone by a pair of rolls ca. 1700 mm long.
329. Industrial Rayon Corp. (IRC) (Brit. Pat. 539 200), *Offenländer* (US Pat. 2 107 451) and *Jentgen:* Kunstseide **21** (1939) p. 333
330. *Stamprecht, P.:* Ram-Extrusion von PTFE and UHMWPE, in *Hensen, Knappe, Potente:* Kunststoff-Extrusionstechnik II, p. 617, Carl Hanser Verlag, Munich, 1986
331. FAG Kugelfischer Georg Schäfer KGaA, Hammelburg, Germany
332. Plastik-Maschinenbau GmbH, Kelberg, Germany
333. DOS 2 040 479, AD: 14. 8. 1970: Schnellaufende Kreuzspulvorrichtung; Barmag, Wuppertal, Germany
334. DOS 2 345 898, AD: 12. 9. 1973; Kreuzspulvorrichtung; Barmag; Wuppertal, Germany
335. Lucas, Neumünster, Germany previously: Krenzler, Wuppertal, Germany also "Knit-de-knit-process" or "Crinkle-process"
336. Retech AG, Meisterschwandern/Switzerland
337. PAN/DMF solution spun into a hot, 3 m deep petroleum bath; Stockholm, Sweden, 1960
338. *Fourné, F.:* Labor- and Pilotanlagen für die Synthesefaser-Industrie, CTI June 1976, p. 525
339. DBO 38 36 646, AD: 27. 10. 1988, with Japanese priority of 31. 10. 1987; Kabushiki Kaisha Takehara Kikai Kenkyusho, Nagaokakyo, Kyoto, Japan