4

Filament yarn production

4.1   Introduction

Although most filament yarns used today are synthetic fibers that need texturing, there are some that need no modification in this way. Industrial filaments made from synthetic polymers constitute one case and natural filaments, such as silk, another.

This chapter will concentrate mostly on textured yarns but a brief discussion of silk throwing will be included for the sake of completeness, at the end of the chapter. Industrial filaments are so diverse that little discussion will be given. Suffice it to say that the majority of the successful processes exploit the exceptional strength that can be obtained with some drawn polymers.

During the period since 1975, manufacturing facilities have sprung up in countries such as China, Taiwan, Korea, Mexico, and Brazil. These countries operate to fill some of the demand of new markets. They also serve the established ones in the USA, Japan, Europe, and other developed areas. Such changes affect the price and distribution of the materials. The total consumption of textured yarn in the USA, Japan, and Europe has declined but there has been steady growth in industrial and carpet yarns. According to Wilson and Kollu [1], 51% of the textured yarn produced in 1983–4 was false twisted polyester filament, 22% was false twisted nylon, 18% was bulked continuous filament (nylon and polypropylene), and the remainder was made up of air-jet and other forms of textured yarns. Obviously, false twisting is very important in this field. However, the market has forced many filament yarn makers to move to products nearer to staple yarns in character and consequently the use of air-jet texturing has risen. Atkinson and Wheeler [2] state that air-jet textured yarns have maintained about 5% of the market for false twist textured yarns and most of that goes into automotive upholstery. Polyester has largely displaced nylon in that particular market.

4.2   Texturing filament yarns

4.2.1   Purposes of texturing

The prime purpose of texturing filament yarn is to create a bulky structure that is desirable for the following reasons:

1   The voids in the structure cause the material to have good insulation properties.
2   The voids in the structure change the density of the material (which makes possible a lightweight yarn with good covering properties).
3   The disorganized (or less organized) surface of the yarn gives dispersed light reflections, which, in turn, give a desirable matte appearance.
4   The sponge-like structure feels softer than a lean twisted 'flat' yarn.
5   The crimped or coiled filament structure gives a lower effective modulus of elasticity to the structure when compared with that of a flat yarn.

From this it will be realized that, in order to make yarns to these specifications, it is necessary to deform the individual filaments and set, or otherwise hold, them in the desired deformed condition. When deformed in this way, the filaments in the whole bundle are unable to lie side by side in close contact and the required voids are produced.

Furthermore, the non-straight, separated filaments are much more easily deformed than are those in a flat yarn, and one obtains a softer hand and greater 'stretch'. There are two general classes of textured yarns that relate respectively to thermoplastic yarns only and to those which can be more widely used.

In general, the first classification involves the stages of deforming, heating, cooling, and relaxing the filaments. The process is known as heat setting despite the fact that it is the cooling that does the setting. Theoretical filament structures are shown diagrammatically in Fig. 4.1.

In the second case, the texturing of non-thermoplastic materials, filaments are deformed and are held in their deformed state by frictional contact with the neighboring filaments. An example of the latter is the air-jet method that will be described later in this chapter. Meanwhile, we will continue with heat set yarns.

4.2.2   Physical basis of texturing

Before considering the methods of false twisting, let us review the mechanics involved. It will be recalled that the process phases in false twist texturing consist of:
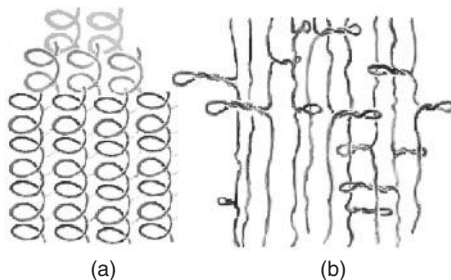

(a)   (b)

Fig. 4.1   Theoretical yarn structures

1   Deforming the filaments.
2   Applying heat to raise the filament temperature above the glass transition temperature, T_g.
3   Cooling the filaments to below T_g.
4   Rearranging the filaments under suitable tension.
5   Winding the textured yarn.

Theoretically, phases (1) and (2) can be interchanged or be coincident, provided the deformation persists until the filaments are cooled below T_g and the polymer becomes set. However, time is a factor in determining the degree of set achieved and, in high speed machinery, it is usual to apply heat as soon as possible in the process. If temperatures of some polymers are raised too high, they tend to yellow and this gives trouble with the end products, particularly those of light color shades. The deformation can be of any kind, but in false or real twisting, the primary modes of deformation are torsion and bending. Since the real twist process is simple, it will be used for explanation although it is no longer commercially important.
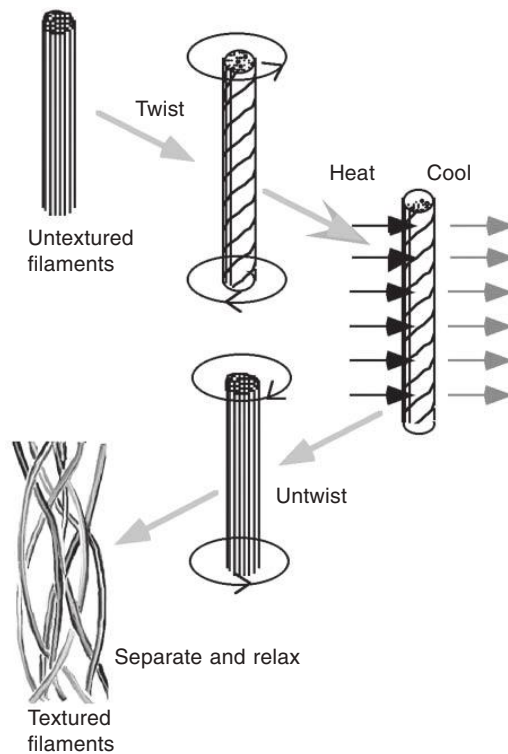
4.3   Real twist texturing

Explanations are a little easier if we consider the early types of discontinuous processes. Various forms of twister were used to induce the initial deformation. A batch of packages of yarn was then taken from the twister and placed in an autoclave.[1] The temperature of the yarn was raised above T_g (but below T_m), and then allowed to cool. The product taken from the autoclave was non-twist lively or 'dead' (see Fig. 3.4), but the fiber deformations were set into their newly twisted shapes. To develop the bulk, it was necessary to untwist the yarns until the filaments were approximately parallel and separated, and then relax them. It will be noted that filament separation in the phase (4) was necessary for the bulk to form without undue interference between neighboring filaments.

    In untwisting yarn from the set condition, a torque is applied to each filament. The sum of the individual torques is the total applied to the yarn. The torque places it in a state of stress, which is retained until the fibers are relaxed. Untwisting and relaxing the yarn allow the newly imposed stresses to be relieved by changes in the shape of the filaments as they move within the structure during the process of relaxation. This form of texturing is shown diagrammatically in Fig. 4.2. When relaxed, each filament seeks a minimum energy state, two of which are depicted in Fig. 4.1. If the structure is open enough, most of the filaments will achieve one of the minimum energy shapes, but a tight structure prevents full relaxation. In the latter case, not all the potential bulk is developed. A normal yarn structure will consist of shapes similar to those shown, or combinations of them if yarn is untwisted and the filaments are separated before release. Some methods of texturing produce alternating directions of coiling. The result is that the yarn produced has little or no twist liveliness because torques from the opposing filament coils cancel. This form of texturing is shown diagrammatically in Fig. 4.2.

    Consider extreme cases. The adjacent helical coils in Fig. 4.1(a) take up a great

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1   A vessel that uses high pressure steam to obtain the necessary temperatures. For the characteristics of steam, see Appendix 3.

Fig. 4.2   Principle of twist texturing

deal of space and we have a so-called 'bulky' yarn. The other model, Fig. 4.1(b), consumes relatively little space and we have a low bulk, high stretch yarn. As the yarn is extended, the intermittently snarled filaments are progressively converted to straight parallel filaments. There is a great deal of yarn stored in the snarls, and, consequently, there is a surprisingly large extension of the yarn before the snarls are fully converted to straight parallel filaments. Furthermore, the tension needed to pull out the snarls is relatively low, and thus the yarn behaves as a low modulus material (until all the snarls are removed). Of course, as the filaments change from the snarled to the straight condition, they are subjected to torsional and bending stresses, and energy is stored in the extended yarn. Once the tension is removed, the yarn attempts to return to a minimum energy state and contracts. Thus, the stretch yarn behaves rather like a rubber band and its principal characteristic is the enormous and almost elastic extension that becomes possible. A practical yarn is intermediate between the extremes. There are varying proportions of each kind of minimum energy shape according to the method and conditions of texturing. Also, there are modifying factors. Helical portions tend to intermesh, parallel portions tend to migrate (and become non-parallel), many filaments fail to reach their minimum energy state, and many filaments interfere with one another. Consequently, there is a wide range of combinations of bulk and stretch that can be achieved, but generally the higher the stretch capability, the lower the bulk. Of course, even the adjacent coil model provides a yarn with a moderate degree of stretch because the helices act as coil springs. In practice, the breaking elongation might vary from 10% for a bulked yarn to 500% for a stretch yarn.

4.4   False twist texturing

4.4.1   General comment

One of the most important types of yarn modification is false twist texturing. As mentioned in the last chapter, a running yarn twisted as shown in Fig. 4.3 causes false twist to be trapped between the feed system and the twister. The feed yarn has little or no twist, the yarn between A and B has false twist, and the yarn leaving B has the same twist as the input. If heat is applied in the zone AX and the yarn is cooled in zone XB, then the yarn approaching B will be heat set in the twisted condition. Overfeeding (not shown) and untwisting slackened filaments at B facilitates the necessary fiber rearrangement and separation. (An overfeed is where the input speed is slightly more than the output speed.) When the filaments relax, the uneven contraction of the filaments causes them to rearrange themselves laterally. If heat is applied in zone CD, the latent crimp can be developed to produce a bulked, set yarn in one continuous process.[2] In the particular case shown, a godet is used to grip and feed the input yarn; however, no twister is shown for reasons of clarity. All the phases mentioned in the previous section are embodied in this continuous process. The integration reduces costs of machinery and material transportation. The savings have been so large that false twist texturing has become a major system for yarn production. The
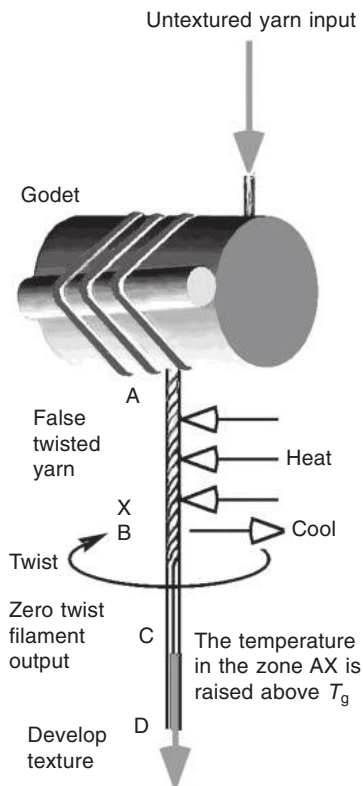
Untextured yarn input

Godet

A

False
twisted
yarn

Heat

X
B

Cool

Twist

Zero twist
filament
output

C   The temperature
in the zone AX is
raised above T_g

Develop   D
texture

Fig. 4.3   False twist texturing

2   Notice that care was taken to avoid saying that the output yarn had no twist.

means of twisting has changed and the systems will now be reviewed in a more or less historical sequence.

4.4.2 Pin twister type of false twist texturing machines

To heat set the twisted filaments and relax them afterwards to produce bulk, it is necessary to heat the running filaments at two places and so we have two-heater machines to produce the developed yarns. To produce yarns in which the filaments have not been relaxed only one heater is required. Examples of a two-heater machine are shown to a small scale in Fig. 4.4. It is necessary to use high twist levels to produce adequately textured yarns; for example, with a 70 denier yarn, one might well use some 80 tpi. (This would give a TM of about 10 on the cotton system.) To get high production, it is necessary to use very high twisting speeds, of around 500 000 r/min. This calls for special designs of twisting unit in which the mass and size of the rotating element are as small as practical (or the element is eliminated). It also calls for special bearings, or suspension systems. In the pin twister shown in
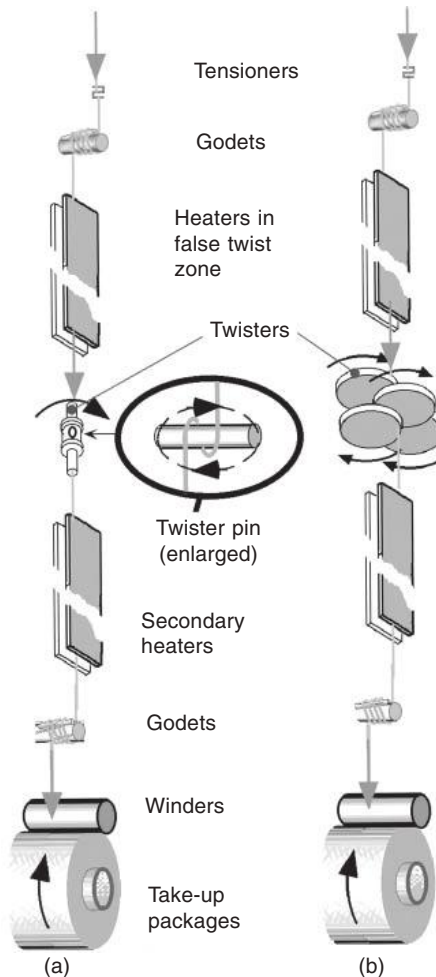

Fig. 4.4 Manufacture of false twist yarns

Fig. 4.4, the spindle is frequently less than 0.25 inch diameter × 1.5 inch long (approximately 6.4 mm diameter × 38 mm) and it is held against drive rollers by a magnetic field; this obviates the need for a direct bearing. The bearings of the drive rollers have to rotate at only a fraction of the speed of the spindle (typically 12–15%). It should be noted, however, that the spindle gets very hot because of air drag and magnetically induced eddy currents within the metal. Also, the false twist pin (shown inset) is usually made of ceramic or sapphire to withstand the abrasion caused by the yarn passing over it.

A given element of polymer must reside in the hot environment for a sufficient period to reach T_g because it takes time to soften the polymer. If, for example, the time is 0.5 second, the spindle speed is 500 000 r/min and the twist is 80 tpi, the heater length has to be at least 52 inches. Thus it can be seen that the heaters must be long.

It also takes a significant time for the yarn to cool sufficiently to freeze it into the twisted configuration. Thus, a certain distance is needed between the heater and the false twist pin. The needed heating and cooling lengths increase with spindle speed and this leads to increases in the threadline length. Not only do high production machines become very tall, but there is also increasing difficulty in handling the long, heated filaments. Frictional drag of the yarn over the heater plate is a significant factor. The frictional coefficient is modified by the fact that the yarn rotates at high speed about its axis as it passes over the heater plate. At very high speeds, the design of the heater becomes extremely important and it sometimes becomes necessary to use forced cooling of the yarn leaving the heater.

Where two heaters are used (to produce a set yarn), the threadline length is almost doubled, as shown in Fig. 4.5. If the threadline is vertical and the two heaters are immediately above one another, a two-story building becomes necessary for high
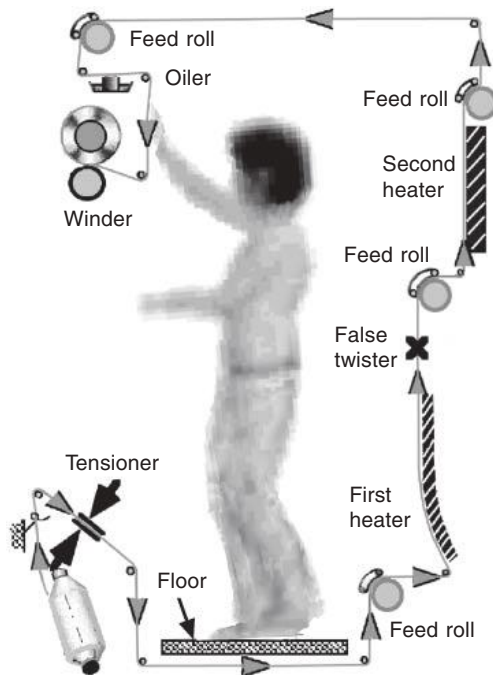

Fig. 4.5   Two-heater false twist machine

speed machines. Alternatively, a more complex threadline may be used; for example, the heaters might be inclined to the vertical. In all cases, the modern machines need a great deal of headroom. Threading up (or 'stringing up') needs skill because of difficulties in handling the hot, high speed yarns. It might be added that the use of air to piece and to thread godets, and other high speed elements, is very common in the filament industry.

To reiterate, the temperature of the polymer has to be raised to a level between T_g and T_m. Within these limits, the higher the temperature, the better the set, but as the temperature approaches T_m, the yarn strength deteriorates and excessive differences in dye affinity are likely to be created. Atmospheric conditions should be controlled because moisture affects the setting process and can lead to degradation of the polymer. Generally, an air temperature of $75 \pm 5°F$ ($24 \pm 3°C$) and an rh of $65 \pm 2\%$ are used, but the conditions might vary according to the yarn being textured. Excessive humidity causes yarn to drag over contact surfaces, which leads to erratic tensions in the yarn. This, in turn, leads to variations in the bulk developed. Insufficient humidity leads to the production of static electricity and, on all of these accounts, control is very important.

Tension in the yarn within the heater is controlled by the feed uptake rates. The feed rolls have to be adjusted to give an overfeed of 2 or 3% to take into account twist contraction and shrinkage. Insufficient overfeed leads to high tension, which causes unacceptably high end-breakage levels and low bulk. Too much overfeed leads to low tension, which results in the formation of tight spots (sometimes called 'voids'), poor set, and, again, deterioration in the end-breakage or filamentation rates. The tight spots are seen as apparently untextured (or lightly textured) segments in the yarn that show up as defects in the fabric. These tight spots are caused by twist slipping over the false twist pin in an erratic manner. Segments of yarn leave the twist pin containing real twist; a twisted segment of yarn is unable fully to develop bulk. Over-twisting the yarn can produce a similar result. The twist level determines the hand and appearance of the material; a high twist gives the fabric a soft, fine texture, whereas a low twist yields a rough, pebbly look. High twist gives a relatively high crimp contraction and therefore more stretch potential. It also causes more tight spots and weakens the yarn (up to 20–30% strength loss for nylon, but very little for polyester or acetate).

Fiber producers apply a finish to the surface of the filaments immediately after extrusion to help drawing and subsequent operations. The finish is intended to reduce static electrification and friction, but when it is heated in the texturing operation, any volatile fractions of the finish are driven off, giving rise to unwanted fumes. Heavier fractions can oxidize or otherwise deteriorate and cause problems with the deposit of solids in the heater zones. This is especially so if high heater temperatures are used (say 400°F, about 200°C). Loss of the fiber finish can also create a problem and it is often desirable to apply a lubricant after texturing. These so-called 'coning oils' replace the losses and facilitate winding and fabric manufacture. However, any such oil should be stable and capable of being scoured away without detriment to the color or performance of the yarn. A sufficiency of fiber finish or additive is important but excessive amounts of finish are to be avoided. Also, variations in the add-on levels of finish should be kept to a minimum.

Some fibers are dulled by the addition of titanium dioxide (TiO_2); this additive affects the wear rate of guides and pins. Such wear can adversely affect the quality of yarn being produced as well as the efficiency of the operation.

With a single-heater machine, it is necessary to soft-wind the yarn packages to
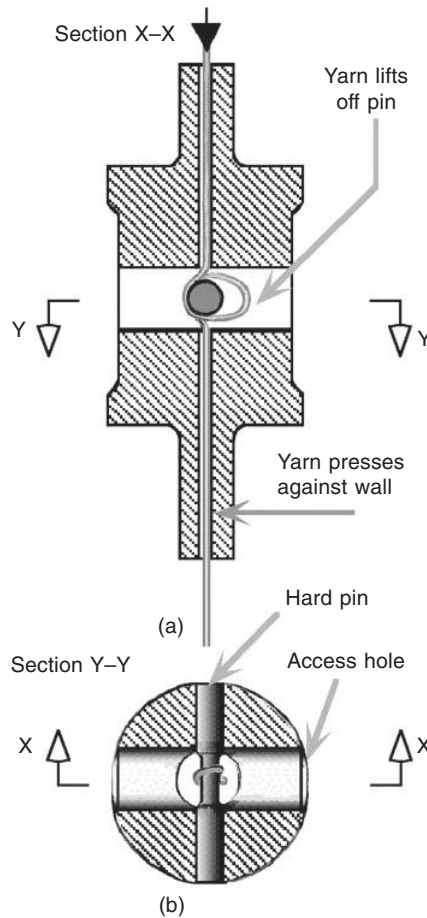
permit satisfactory subsequent autoclaving to produce set yarns. With two-heater machines, it is necessary to overfeed the yarn into the second heater to allow the crimp to develop. This overfeed level is normally about 4 to 5%. The single-heater machine used in conjunction with an autoclave is less efficient than a two-heater machine. With the batch process of autoclave setting, variations between batches are more likely and thus there is an increased risk of producing barré in the fabrics. This is because of the changes in bulk and dye affinity arising from non-constant heat treatment conditions. Whatever system is used, great effort has to be taken to strictly control all temperatures, tensions, and twist levels so that they are similar from spindle to spindle, from time to time, and from batch to batch. The consequence of a failure to control, in all these respects, is that streaks and barré will be produced in the dyed fabric. Modern machines are equipped with control devices; in addition, strict quality control is exercised by means of proper sampling and testing. However, the potential flaws are rarely visible in the yarn coming from the machines. Therefore, it is necessary to carry out tests on dyed yarn at a very early stage before large inventories are accumulated.

4.4.3   Limitations of the pin twister machine

The size of the false twist spindle dictates the maximum rotational speed that can be used. Remembering that the power absorbed by a spindle due to air drag alone is roughly proportional to D^4U^3 (where D is the diameter and U is the rotational speed), it will be readily realized that the spindle has to be kept as small as possible (see Fig. 4.6). However, there is a practical limit to smallness. It must be possible for a knot to pass through the spindle and this means that the diameter of the central hole in the spindle must be several times that of the yarn diameter. Thus, with 150 denier (167 dtex) yarn, the central hole must be of at least 1 mm ($\approx$ 0.04 inch) diameter; for heavier yarns, the hole must be larger. Requirements for the false twist pin and the need for sufficient space to permit the threading operation control the minimum size of the largest diameter of the spindle.

Centrifugal forces acting on the yarn, spindle and drive system can be very high. In the case of the spindle, it is necessary to ensure that it is dynamically balanced; otherwise, at high speeds, it will tend to 'tramp' like an unbalanced wheel on a car, and the drive tires might suffer considerable damage as a consequence. As well as encountering considerable centrifugal force, these tires are also subjected to high temperatures (due to frictional heating). The combination of the two can cause polymer creep, with a result that the tires sometimes grow in diameter during service. A change in diameter alters the forces acting on the surfaces. Growth usually signals impending failure of the tires. The surface of the tires can also suffer damage due to high shear stresses caused by the localized loading, and the damage shows up as a pitting of the surface. If the spindle is unbalanced, the loads are greatly increased and failure of the tire surface is hastened. There is usually a finite life for these tires and the units have to be replaced from time to time. Damage and imbalance cause an increase in noise level and faulty machines are difficult (if not impossible) to operate within the legal noise level limits of some countries.

The yarn is pressed against the wall of the axial hole inside the spindle by the centrifugal forces. This causes the yarn to drag, which can cause filament breaks, and since the drag is related to $\omega^2 d$ (where ω is the spindle speed and d is the hole diameter), it is obvious that a large central hole in a very high speed spindle is

Section X–X

Yarn lifts
off pin

Y

Y

Yarn presses
against wall

(a)

Hard pin

Section Y–Y

Access hole

X

X

(b)

Fig. 4.6   A pin twisting element

undesirable. This is especially important when producing fine yarns. Eccentricity can induce quite strong yarn ballooning in the heater zone. As will be realized, the variations in distance between the yarn and the heater surface can greatly affect the local heat transfer rate. Under certain circumstances, this can affect the set of yarn in a periodic fashion and produce patterning or barré in the final fabric.

Additionally, centrifugal force acts on the yarn wrapped around the pin inside the spindle. A portion of the yarn wrap sometimes moves away from the pin as shown in the enlarged sketch in Fig. 4.6(a). Eccentricity of the wrap causes it to pull away even more and the eventual restraint is from the walls of the access hole. The grip on the yarn by the pin is then reduced and twist slips over the pin. Intermittent slippage of this sort generates undesirable tight spots in the yarn. Twist is associated with tension and this is an unstable relationship, which can lead to surges that give operational problems as well as the undesirable periodic tight spots.

At the high linear speeds of yarn take-up associated with high speed operation, there is frictional heating of some of the outer filaments of the yarn. Such heating occurs (a) at the twist pin, (b) in the central hole of the spindle, (c) at various guides, and perhaps (d) at the heater surface (if the yarn is not properly controlled). At these 'hot' spots, there is likely to be filament damage or breakage. The undesirability of

breakage has already been mentioned. Apart from the problems of wild filaments (uncontrolled filaments not bound into the body of the yarn) and reduced yarn strength, the local overheating might cause segments of some filaments to fuse together. Furthermore, it might result in changed local yarn extension, or it might change dyeability at the local spots. Whichever combination of such faults is generated, it impairs both the efficiency of the operation and the quality of the product. In all these cases, the higher the speed, the worse the problems become. Consequently, there must be practical upper limits to speed and this, in turn, means that there are practical upper limits to the productivity of pin twisters. Improvements in the technology continue to raise the limits, but it becomes increasingly more difficult and costly to do so. In fact, the rise of friction twisting caused further machinery developments of pin twisters to show unsatisfactory returns on investment. Whether pin twisters will find a market in the future is uncertain.

4.4.4   Friction twisters

In the search for ever higher productivity, the false twist element has, over the years, become ever smaller. The ultimate stage was that the diameter of the high speed rotating element was reduced to that of the yarn itself. After that we had friction twisting with its enormous potential for increased speeds. An example of friction twisting is shown in Fig. 4.4(b) and two embodiments of the principle are shown in Fig. 4.7.

   In Fig. 4.7(a), friction between the bore of the rotating tube (bush) and the yarn causes twist to be inserted into the yarn. In Fig. 4.7(b), it is the friction between the outside surface of the disk and the yarn that gives the effect. In both cases, there is slippage and therefore it is not possible to calculate the twist insertion rate from the ratio of diameters (i.e. rotating element diameter/yarn diameter). It is better to consider the torque generated. From Fig. 4.7(a), it may be seen that the reaction F must balance components of yarn tensions T_{in} and T_{out} resolved in a direction perpendicular to the axis of the bush. For the present purpose we may ignore the components F_3 and F_4. In other words:

$$F = F_1 + F_2 \qquad\qquad [4.1]$$

where $F_1 = T_{in} \cos \gamma$
          $F_2 = T_{out} \cos \alpha$

   Since torque is (force) × (radius of action), and the relevant radius is that of the yarn under operating conditions, we may write:

$$\text{Torque} = \mu k F d/2 \qquad\qquad [4.2]$$

where d is the diameter of the yarn in the free state, and k is a factor that takes into account the local compression at the contact zone between it and the twister, as well as the end effects at the edges of the twister. The factor $k < 1$ and μ is the coefficient of friction. In the simple case shown in Fig. 4.7(a):

$$\text{Torque generated by the twister} = \mu\,(kd/2)(T_{in}\cos \gamma + T_{out}\cos \alpha) \qquad [4.3]$$

If n is the linear density of the yarn, the effective yarn radius is $K\sqrt{n}$, where the factor K includes $k/2$ used in equation (4.3) as well as the factor relating diameter to linear density:
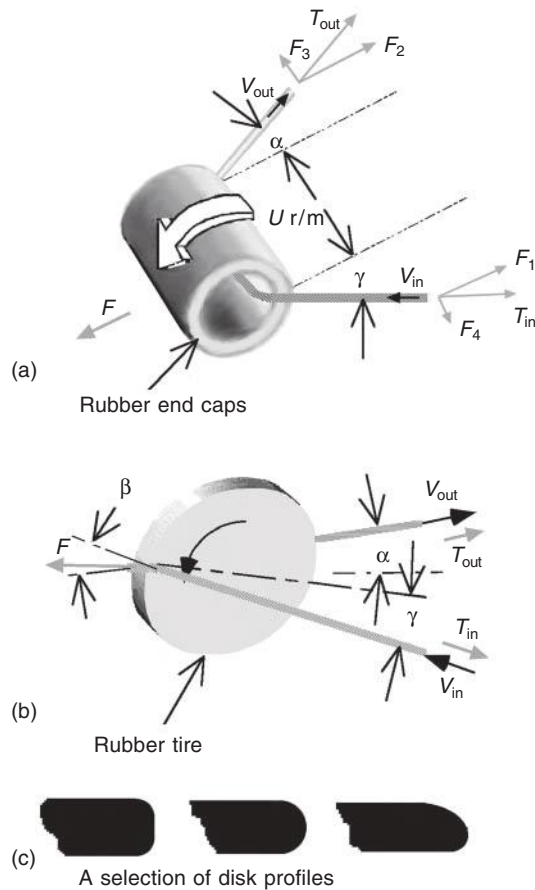
(a)

Rubber end caps

(b)

Rubber tire

(c)

A selection of disk profiles

Fig. 4.7   Friction twister elements

$$\text{Torque generated by the twister} = \mu K\sqrt{n}(T_{in}\cos\gamma + T_{out}\cos\alpha) \qquad [4.4]$$

In other words, the torque is influenced by the linear density of the yarn and its compressibility. It is also influenced by the coefficient of friction, the tensions applied as well as the angles taken up by the entering and departing yarns.

Similar logic can be applied to the disk twister, but in this case, K is further affected by the attitude of the yarn on the surface of the disk (the angle β shown in Fig. 4.7(b)), which is discussed in the following paragraphs. The disk type of machine is more widely used, therefore we shall restrict most further discussion of false twist machines in this chapter to that form.

There is a degree of self-adjustment in the angle β. However, under unstable conditions, there is surging and the angle fluctuates. At high speeds, torque and tension surges lead to difficulties and impose a limit on the speeds that can be achieved. A feedback mechanism involving the phase relationships between the tension and the rotational speed of the yarn leads to the surging.

Equation (4.4) shows that the degree of texturing is strongly affected by the coefficient of friction, the linear density of the yarn being textured, the applied yarn tension, and the yarn angles. The angles α and γ may not be the same, but for the purposes of explanation let them be typified by a single value, θ. The twist level is also a function

of the stiffness of the yarn, as well as the torque. For a given yarn, it is important to use high values of μ and θ. To give high values of μ, bushes or disk tires made of urethane or some other high friction material are used. It is difficult to get a high value of θ with a single disk ($<90°$) and stacked disk twisters such as those shown in the center of Fig. 4.4(b) are usually used to give high cumulative values of θ. With a simple bush, θ is limited and the amount of relative rubbing at the bush ends becomes a problem because the rubbing causes accelerated wear. The tensions must also be limited, otherwise there is likely to be individual filament breakage caused by the excessive friction.

Considering the stacked disk type of false twister, the outside surfaces of the disks are the drive surfaces. A high cumulative value of torque is obtained as the yarn follows a sinuous path through the stack of disks. The multiplicity of disks makes it possible to generate sufficient torque in the yarn to produce the desired texture in the material. But there can be a progressive increase in yarn tension, which (if allowed to get too high) can cause damage to both the yarn and drive rollers. Generally, the stacked disk type of machine can operate commercially between about 15 denier (17 dtex) and 150 denier (167 dtex), at threadline speeds (V) of the order of 500 m/min.

As was pointed out, the angles of the threadlines are important. The cumulative value of θ in a stacked disk arrangement is dependent on the depth of penetration of the disks. The angle β is also affected. Some designs use three sets of disks with equidistant centers; the distance apart of the sets of disks (i.e. the penetration) is adjusted by using various spacing bushes. Another design has one set of disks hinged so that penetration can be easily adjusted without having to 're-string' the system. The hinged stack system also makes stringing up much easier because one set of disks can be swung out of the way to allow insertion of the yarn. Some designs use a number of smooth surface guiding disks that serve to merely guide the yarn through the stack. These disks are adjusted to give the desired run-on and run-off angles at the working disks (i.e. the angles α and γ). The guiding disks supply little or no torque to the yarn. A variety of disk profiles can be used, and the driving disks have a variety of drive surfaces.

Because of the relatively high cumulative values of θ, it is possible to replace the rubber-like surfaces with a more durable, hard surface. The most successful of these hard surfaces to date seems to be aluminum oxide (Al_2O_3) but other possibilities include plasma coatings, various other oxides, glass, glass mixtures, ceramics, synthetic rubbers, and polyurethane. Also under development is the use of artificial diamond dust embedded in nickel. Always, the balance to be considered is between the coefficient of friction obtainable and the wear rates of both disks and yarn.

If the angle of the disks is changed so that a component of the frictional forces acts along the threadline, the disks tend to pump the yarn through the system without large increases in tension. Also, if the yarn can be encouraged to work at an angle β (Fig. 4.7(b)), a similar result is obtained. In practice, the yarn lies at the angle β quite naturally, and the value is affected by the disk penetration. Thus, there can be a degree of pumping even with parallel disks, and so most practical disk texturing systems are carefully designed to allow the yarn to pass through with moderate tensions. The accumulation of the angles of wrap through the stack causes the torque available to the yarn to increase without a corresponding increase in tension. Limiting the yarn tension improves efficiency, decreases filament breakage and reduces wear of the disk driving surfaces. However, if the yarn tension is allowed to drop too low, there can be a loss of control, which causes problems. The normal tension ratio between

input to the disk stack and output is 1.5. Also, the torque produced tends to drop over time, as the surfaces become worn and slick.

Another factor that requires special vigilance is the change in frictional characteristics of the disks. As the surfaces wear or become polluted with polymer or breakdown product, the frictional characteristics change. A good drive surface tends to wear clean but there is still a tendency for changes to occur even though they happen much more slowly. Soft surfaces, like polyurethane, can easily be damaged by inexpert handling; also a wrong setting causes very rapid deterioration. The hard surfaces are more durable and the damage is much more likely to occur to the yarn. In particular, filament breakages can be very troublesome. Variations in the torque can vary the hand and appearance of the fabrics made from the yarns.

As was mentioned earlier, there is some slip in friction twisting and the exact amount depends on the cumulative values of μ, β, θ, and T, as well as on the operating speed. Since μ and T are limited, the major variables are the operating speed and depth of disk penetration (which affect θ and β). Although variations in μ due to changes in humidity or fiber finish might be considered to be minor when compared with those of speed and penetration, they cannot be ignored because they directly affect the quality of the product. The fiber finish can be heavily modified, or even burned off, by overheating. In terms of quality control (rather than machine design), variation in μ is important. Some effects of variations in θ and speed are given in Fig. 4.8. For very high production rates, V must be high and the practical variable becomes θ. Too high a value of θ causes high end-breakage rates and unsatisfactory yarn, which is why the length of the bottom curve is so short. There is exceptionally high filamentation (i.e. breakage of filaments, where many of the filament ends appear as hairs on the surface of the yarn) under the latter conditions mentioned. Consequently there are upper limits to speed and torque. Productivity is very high but it is limited, despite the fact that the twist is applied directly to the yarn surface. The slip is roughly an exponential function of the twist density (tpi or twist/m); at high twist
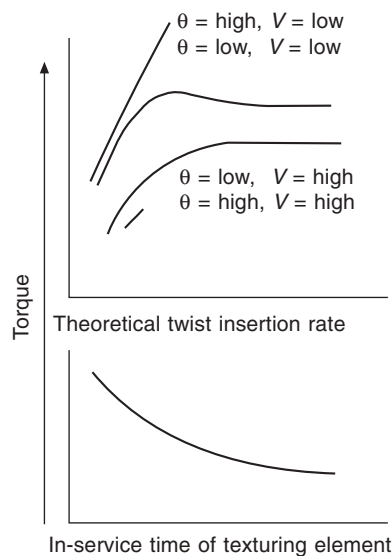
Fig. 4.8   Torque produced by a stacked disk twister

levels, the slip level may approach 50%. This not only causes wear but also raises the temperature of the yarn to dangerous levels.

One design variation is to use a grooved ball that meshes with one or more disks. The yarn torque accumulates in much the same way as already described. However, the larger surface area on the ball distributes the wear and allows the higher coefficient of friction associated with a softer material to be used. Another variant uses crossed belts to apply the twist. These keep good control of the filaments but belt wear can be a problem.

The input and output velocities V_{in} and V_{out} in Fig. 4.7 differ because of contraction and the feed and the take-up have to be adjusted to take this into account.

4.5   Draw-texturing

As texturing speeds rise, they approach the speeds used for filament drawing and it becomes possible to contemplate a merger between the two operations. This raises the question of whether the fiber producer or the throwster should do the whole operation. (The throwster is a person or organization that carries out only the texturing operation. It was derived from the silk trade.) It may be recalled that the freshly extruded filament is relatively weak and ages rapidly. However, at high extrusion speeds, the polymer does become partially oriented and filaments might be stable enough to ship to the throwster. If the feed yarn is partially oriented (draw ratio ≈ 1.7), ageing is a relatively minor problem. The use of partially oriented yarn (POY) as a feedstock for the throwster is quite practical provided proper care is exercised in inventory control and it is now a firmly established procedure. Databases are often used to ensure that the material is used in timely fashion and that none of the feed yarns remain after their shelf-life has expired. Once such logistical problems are solved, there are several benefits to the use of POY, as was discussed earlier.

There are two forms of draw-texturing; namely, (a) sequential, and (b) simultaneous. In the former, the drawing and texturing are separate phases within the same machine, whereas with simultaneous draw-texturing the drawing, heating, and twisting are carried out simultaneously (see Fig. 4.9). Simultaneous draw-texturing may be carried out on a conventional texturing machine by merely altering the feed and take-up roll speeds. Although it is cheaper to use simultaneous draw-texturing, the yarns are drawn in the twisted hot state in this process, which results in a variation in the draw from one filament to the next. There can be an inferior degree of setting and a poorer crimp-resilience; also, at high speeds it is difficult to get a sufficient draw in all filaments without excessive tension. As has been discussed, the high tensions cause filament breakage or even end-breakage and this not only impairs the quality of the product but also impairs the operating efficiency. However, the economics of the situation favor simultaneous draw-texturing.

One problem is due to flats that develop on the filaments and give the yarn a crisper hand than a pin twisted yarn, and a different optical effect. It is claimed that draw-textured yarns are less prone to barré and the picking, pilling, and snagging associated with knit goods, provided that there is good control over the age of the feeder yarn. It is also claimed that higher bulk can be achieved, and that more level and deeper shades of dyeing are possible. It will be noted that there are pros and cons, but the balance has swung in favor of friction twisting and draw-texturing. The combination has become an important texturing system. There are variations on the
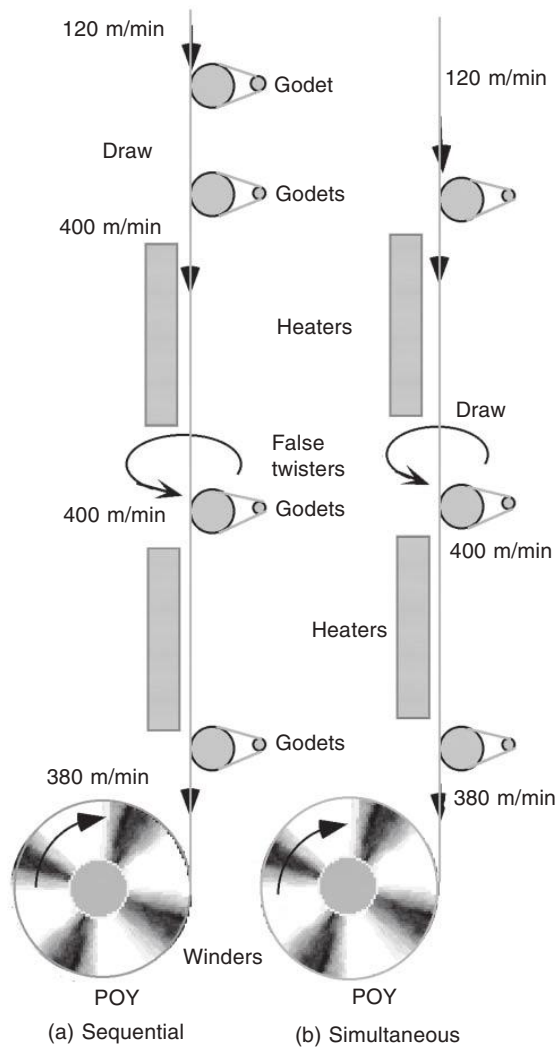
120 m/min

Godet

Draw

Godets

400 m/min

Heaters

False
twisters

400 m/min   Godets

Heaters

Godets

380 m/min

Winders

POY

(a) Sequential

120 m/min

Godets

Draw

Godets

400 m/min

Godets

380 m/min

POY

(b) Simultaneous

Fig. 4.9   Two forms of draw-texturing

theme, and very likely there will be more, but this book can only deal with the principle. However, it is interesting to note that a number of draw-texturing systems have run commercially above 450 m/min for some time, and this is equivalent to 0.4 lb/spindle hr (0.18 kg/spindle hr) when producing a 70 denier yarn. Speeds of over 1000 m/min have been reached in the laboratory.

At very high speeds, there can be surges of twist and tension, which adversely affect the quality of the yarn. Careful control of all the parameters is necessary to avoid these instabilities. Also, disturbances, such as knots, can provoke instability and there may be a considerable amount of faulty yarn processed following the passage of a damaged section of yarn, knot, etc. For this to happen, the machine has to be operating near the critical range of speeds, tensions, and twists. The higher the speed, the more difficult it is to avoid the problem.

4.6   Stuffer box texturing

4.6.1   Fiber buckling

The stuffer box has long been used to texture yarns and fibers, but modern technology has caused it to again become interesting outside its original usage. For this reason, it is desirable to explain the underlying principles. In essence, a yarn is overfed into a heated chamber and the overfeed causes the hot filaments to buckle. They become set in that configuration as they cool, perhaps before being removed from the stuffer box. It will be recognized that the phases of heating deformation and cooling have again appeared, except that now the deformation is a zigzag type of crimp rather than coils or snarls.

   In this new case, there is no need for twist and extremely high speeds become possible. However, to maintain quality, the size of the zigs and zags have to be controlled, otherwise the variance in crimp affects the appearance and hand of the product. The filaments in the stuffer box just before buckling behave as struts. Figure 4.10 shows a long, slender filament subject to end loading. A small load, F, causes a deflection, y, which causes a bending moment at the mid-point of the fiber. The deflection y increases uncontrollably when buckling occurs; ends move together to produce a crimp. The actual crimp amplitude and the crimp frequency are defined in the lower portion of Fig. 4.10 and the maximum amplitude is A. The system is unstable and the strut tries to collapse into parallel portions, each of length $l/2$. In a constrained situation, the filament collapses into a zigzag shape as shown in the bottom portion of the picture. The length, l, depends on the design of the machine and the size of the filament.

$$\text{Buckling length for round strut} > (\text{Cross-sectional area}) \times \sqrt{\pi E/F} \qquad [4.5]$$

This suggests that the crimp is dependent on three major factors, namely: the buckling force F, the modulus of elasticity E, and the geometry of the cross-section. The force F is principally determined by the degree of overfeed. The polymer and its heat treatment determine the modulus. The geometry of the cross-section is established during extrusion and is a function of the linear density of the filament. Thus the texture is seen to depend partly on the feed rates and the temperature within the stuffer box.
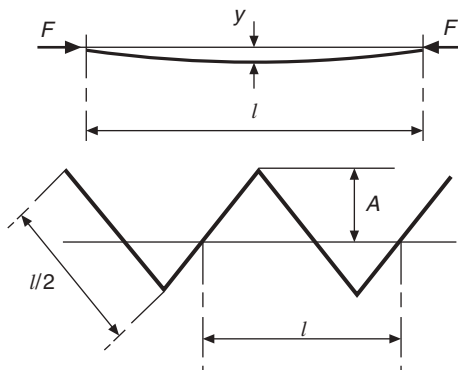

Fig. 4.10   Fiber collapse in a stuffer box

4.6.2   Stuffer box

Some modern systems depend on a controlled overfeed and a fiber transport system within the stuffer box such as is shown in Fig. 4.11. An overfeed is a condition where the input speed is greater than the speed further along the process flow line. The transport system is intended to improve the uniformity of the process at high speeds. Without it there can be a tendency to intermittently choke. Even partial chokes affect F and thus the crimp level. Hence, a smooth flow of fiber through the stuffer box is essential. Another difficulty at very high speeds lies in ensuring that each filament is heated to the same temperature. Not only is it necessary to raise the filaments above T_g, but all filaments should have identical temperature histories so that conditions are the same for all. Failure to provide such conditions leads to a variation in crimp level from filament to filament. Although it is not feasible, in practice, to transfer the heat equally to all filaments, at least the variation should be kept to a minimum.

Some fine stuffer box textured yarns are plied to give the material a resistance to snagging and filament breakage in the fabric during normal use. However, plying is expensive and there is a loss of bulk in the yarn (which was the purpose of texturing in the first place). Sometimes the bulk is not fully developed until the fabric has been finished and this means that some potential faults are not discovered until the fabric finishing process is completed. Omission of a heat setting stage, or the use of improper
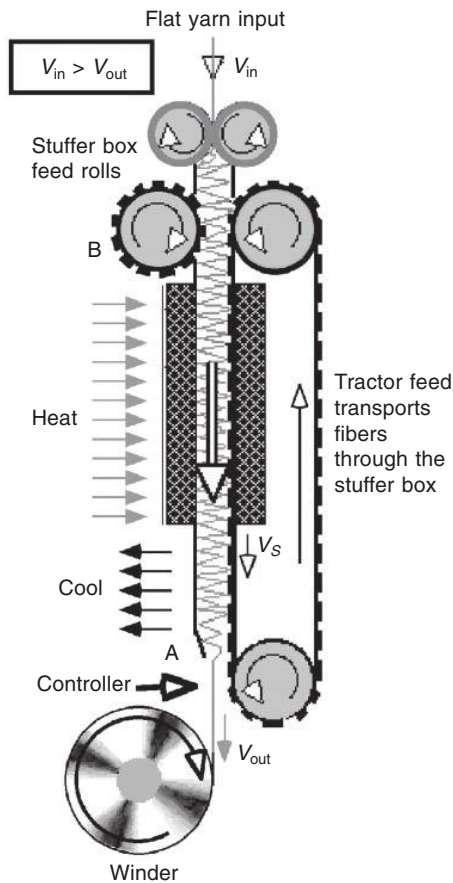

Fig. 4.11   Stuffer box texturing

processing temperatures, cause changes in bulk and dye affinity, both of which can lead to barré in the fabric. Thus it is necessary to test the product [3] for shrinkage and dye affinity at the yarn processing stage to avoid expensive claims from customers because of improper quality.

It has become possible to process yarns at up to 1200 m/min. This may be compared with the speeds obtainable for friction twisting. Unfortunately, the crimp stability and the uniformity of stuffer box yarns is not so good as with false twist textured yarns. Nevertheless, the system is capable of handling relatively heavy yarns so it has become quite important in carpet yarn manufacture [4]. A stuffer box takes up little space and can easily be placed in line with another process. Because of the high speed capability, it is often used for crimping tow. It would be very difficult to do this with other methods because of the large number of filaments involved.

Hot fluid texturing is a variant of stuffer box texturing, where the solid filaments in the stuffer box are replaced by jets of hot fluid polymer. As the material enters the nozzle in a plastic condition, the strands are looped or otherwise disturbed before they impinge on the plug of filaments in the stuffer chamber. The outgoing yarn is wrapped around a cooling drum to set the crimp. This is a form of bulked continuous filament (BCF) production, which spins and texturizes the filaments in one operation; it is used mostly to produce nylon and polypropylene yarns for floor coverings [1].

4.7   Air-jet texturing

4.7.1   Simple air-jet devices

All the foregoing methods of texturing require that the yarns be thermoplastic so that they can be heat set. This precludes the use of non-thermoplastic yarns like rayon. Air-jet texturing provides a means of creating texture in such materials. Further, it is a useful means of producing a yarn structure near to that associated with staple yarns. This is an important concession to the tastes of the ultimate consumer. False twist and air-jet texturing can be combined.

The major principle involved is the tangling effect given by highly turbulent airflow acting on filament feed yarns. Entanglements within the yarn structure are made, and are interlocked by inter-filament friction to form a stable yarn. In some ways, these air-textured yarns resemble staple yarns made by traditional spinning methods. To get the needed air turbulence, high pressure air is supplied to a nozzle and this produces supersonic airflow at the exit. Also, an obstruction or asymmetry is introduced in the airstream to cause a series of violent eddies; this is known as a von Karman vortex stream. The obstruction can be in the form of a hollow needle through which the feedstock is fed. Because the emerging airstream contains shock waves (like those seen in jet engine exhausts), there are some severe pressure gradients in the air discharge. A diagram of the divergent portion of a nozzle with a filament injection needle is shown in Fig. 4.12(a) where the swirling airflow (gray arrows) passes over an obstruction such as needle, creating turbulence downstream (shown in black). The attitude of the needle, and its rotational position about its own axis, are adjusted to maximize the quality of the textured yarn. Because the needle is hollow, it acts as an injector since the static air pressure in the throat of the nozzle is less than atmospheric pressure. Thus, a filament feed yarn can easily be inserted into the exit airstream (Fig. 4.12(b)). Separated filaments follow different flow paths and when the filaments are recombined at an integration point, there are lengthwise displacements of one
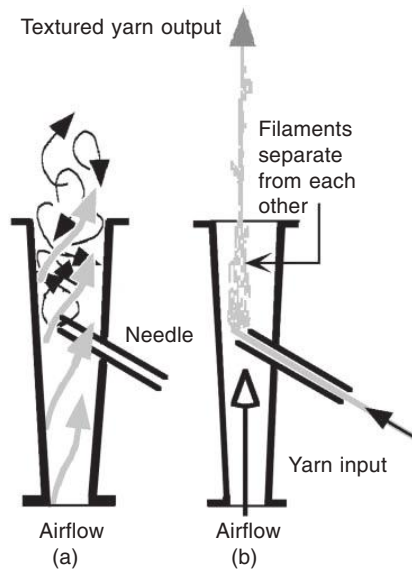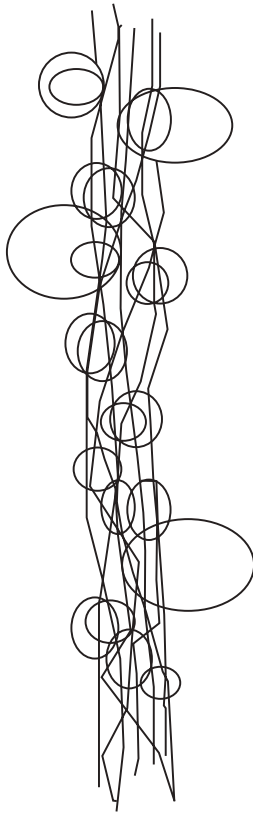
Fig. 4.12   Air-jet texturing

filament to another; some filaments are overfed and the result is that a structure with loops and bows is formed, as shown in Fig. 4.13. A bow in this context means a curved portion of filament that does not make a complete loop.

The needle causes the airstream, which is passing over it at high speed[3] to break up into eddies. These eddies can be superimposed on a general vortex motion tending to untwist the feed yarn. The untwisting allows separation. However, separated filaments possess torque because of the untwisting and, if overfed, the filaments tend to curl or snarl and occupy more space. Since the filaments are separated, different filaments are caught by the progression of eddies and there is a tangling effect as the snarls and loops become caught up in each other. Filament separation is an essential part of the texturing operation. The subsequent tension applied to the filaments after they recombine at the integration point causes the loops and tangles to interlock to give a moderately bulky yarn. The yarn has characteristics similar to staple yarn. Longitudinal migrations of portions of the filaments, caused by differing path lengths taken by the filaments between separation and integration, enhance the texture because some filaments are temporarily overfed with respect to their neighbors (in Fig. 4.14, filament *a* has been overfed with respect to *b* and *c*.) The excess lengths produce loops and bows. Compared to false twist textured yarns, air jet yarns are considerably less extensible.

In some operations, the entering filaments are moistened, which enhances the texturing operation because of better separation of filaments within the nozzle; control of the flowing filaments is also improved. This is referred to as the wetting process, where one or more yarns pass through a water bath before entering the air-jet. Care has to be taken to remove the debris or finish particles that accumulate, so that the jet nozzles do not become blocked. Alternatively, water applicators are used, which allow finer control of the water applied.

A baffle is sometimes used to divert the flow, to create extra turbulence and to

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3 The Reynolds Number must be above the critical value.

Fig. 4.13   Air-jet texturing yarn

Integration point

Bows

Filament
migration

c

Separation   *b*
of filaments

a

Nozzle
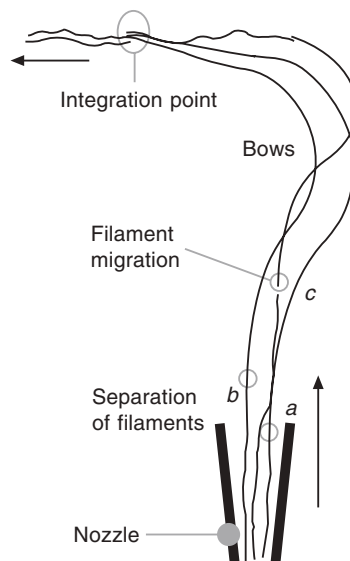
Fig. 4.14   Filament separation

lessen air consumption. Baffles can be used to limit the filament bow size and control the loopiness of the yarn. Bearing in mind that stability of the yarn depends on inter-filament friction, it might be realized that a drawing stage following the texturing can stabilize the structure by pulling the closely looped portions tighter. The drawing process in this case is like tightening a knot. A thermal process may follow the texturing [5] to achieve a reduction in loop size and to reduce shrinkage in boiling water.

4.7.2   Effect yarns

As a class, effect yarns are a speciality of interest to fabric designers looking for special effects in their products. Yarns with nubs, bouclé yarns with loops on the surface, and many more, are members of the class. It is beyond the range of this book to deal with them all, but a few processes will be mentioned in passing to give a flavor of a few possibilities.

There are special mechanical attachments that can be fitted to normal spinning machines to produce effects such as aperiodic nubs or loops. Some of these are based on a random speed varying device that affects the draft in staple spinning. However, these are not very useful when drawing a filament yarn because of the variation caused in the molecular structure. More likely one will find devices that raise loops or break them to produce the desired effects. There are also some treatments based on unequal shrinkage of components within the yarn structure to produce bulk, perhaps in a randomly induced fashion. Air-jet texturing is sometimes used in series with the basic yarn process. Some spin staple fibers to form a sheath around a core of filaments; these (together with those described later in this section) are called core yarns. Such core yarns are sometimes regarded as 'effect yarns' when they produce special effects rather than act as replacements for traditional yarns.

If the components within the combination of fibers or filaments can be induced to shrink differentially with respect to one another, then extra bulk can be produced, sometimes evenly and sometimes not. If some fibers are capable of being set and others are not, then a further set of possibilities arise.

Slitting or fibrillating thin polymer sheets may make flat filaments, like miniature ribbons, which can then be made into yarns. Fibrillation may be carried out by drawing a sheet of certain polymers such as polypropylene and concurrently applying lateral stress to produce a yarn of flat filaments without the need for slitting. These so-called flat filaments may be mixed with some of those already discussed to produce interesting visual effects arising from their differing optical properties. Combinations of various of the yarns described in the various sections bring the possibility of a wide range of effects.

The idea is extended by extruding different polymers through the same spinneret and combining them as a 'co-extruded yarn' (see Section 4.8.6). Alternatively different spinnerets are used for each polymer and the filaments are mingled together before taking-up prior to winding to produce a 'co-mingled yarn'. For example, it is possible to use a component to give strength in the core and a more aesthetically pleasing fiber as the sheath. The component delivered to the nozzles at the highest delivery speed is the 'effect' component, which goes mainly to the sheath, and the component fed at the lower speed becomes the core. (The more slowly moving filaments approaching a mingling point are under more tension than the faster ones, which produces a

migration similar to that described in Section 3.9.3.) It is possible to use POY as one of the components and to include a drawing stage in the process.

4.7.3   Modified false twist texturing

Air-jet texturing is now being used in conjunction with false twist texturing to produce filament yarns with staple-like characteristics [1]. Modifications to the structure involve surface loop control and/or the production of free fiber ends in the surface to simulate staple fiber yarns. Feeding two or more sets of filaments into the yarn at different rates can form loops, and also modifying the polymers can change yarn properties. The conditions in melt spinning can also be varied to alter the structure. The ability to extrude very fine filaments has also increased the range of possibilities.

The great number of alternatives not only makes the modern machines much more complex than formerly but the technology draws on a much wider base. The result is a wide range of product possibilities. Control of fiber speeds, tensions, and temperatures at all positions is an essential prerequisite for consistent and acceptable yarn quality. To get high productivity and adequate bulk, it is necessary to use expensive high pressure air. Also, to control bulk, it is essential to maintain the settings, which uses expensive labor. On the other hand, the air texturing produces no appreciable morphological changes in the polymer and at least one source of barré is removed. Productivity is very high.

4.8   Other texturing techniques

4.8.1   Bi-component yarns

The basic idea of a bi-component yarn is to use filaments that consist of two parallel components, each having different physical attributes (which affect their shrinking or swelling characteristics). A composite structure has the potential to curl if a filament consists of polymers A and B disposed side by side as shown in Fig. 4.15(a). The filament curls when polymer A is caused to shrink relative to polymer B. This is because of the forces generated by the shear due to shrinkage. If the differential in shrinkage is sufficient, and the ends of the filament are restrained, the curl develops into the reversing-coil helix sketched in Fig. 4.15(b). As with other textured yarns, this improves the bulk and lowers the effective modulus of the yarn. However, the result is obtained without mechanical texturing and therefore is not restricted in the same way. There is potential for very high speed production, but the method is often applicable only to very fine yarns.

One method of producing such a structure is to extrude compatible but different polymers through the same spinneret. It is important that the components mutually adhere. This rules out using polyester at the present. Usually two forms of nylon are
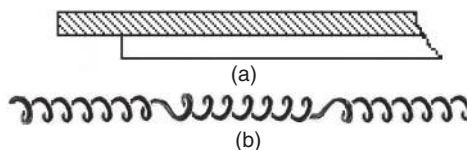

Fig. 4.15   Bi-component yarn

used. Another method is to combine two dissimilar strands from adjacent spinnerets in such a way that they adhere to produce a bi-component yarn. Again, it is very important to make certain that there is adequate bonding between the components. A considerable volume of such bi-component yarn is used for ladies' hosiery.

4.8.2   Edge-crimping

A product related to bi-component yarn, but not always regarded as such, is edge-crimped yarn. If a yarn under tension is run over an edge (Fig. 4.16), a lengthwise layer of polymer is disoriented and possesses different shrinkage characteristics from the rest of the yarn. The effect can be demonstrated by running a human hair over a finger nail and watching it curl. One of the problems with an edge-crimping process is the maintenance of the edge over which the yarn slides. Variations in conditions at the edge lead to variations in crimp and thus to quality control problems.

A further related idea is that of asymmetric quenching of the yarns at extrusion (or elsewhere). The rate of cooling affects the crystallinity and is associated with variations in density. In other words, asymmetric quenching can also produce a texturing effect. It is believed that similar effects could be produced chemically. In any of these cases, the bulk can be developed by heating, which can cause further differential shrinkage (or swelling) to augment the effect.

4.8.3   Twisting and folding of filament yarns

It should be explained that 'folding' in this context is jargon used in the filament trade; it has a similar meaning to the 'doubling' discussed earlier, inasmuch as strands are laid more or less side by side before they are integrated into the final yarn. The process is often a two-step operation with a forming twist being first applied to single ends and then cable twisting the composite to achieve the desired end result. The final product has a low or zero filament twist, but the ply twist is sufficient to control the surface of the yarn. Often two-for-one twisting or a variant of it is used for these operations. There is little or no need for the improvement in evenness that such doubling brings. Reasons for this operation include [6, 7]: (a) entrapment of wild fibers or broken filaments, (b) torque balancing of false twisted yarns, (c) improvement of load sharing between the filaments, (d) changing the load elongation characteristic of the yarn, and (e) changing the optical and tactile character of the yarn.
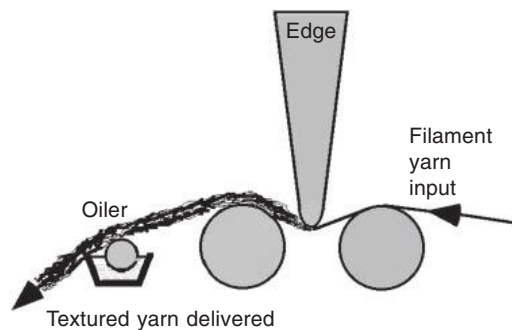

Fig. 4.16   Edge-crimp texturing

4.8.4   Knit-de-knit texturing

The fundamental idea of knit-de-knit texturing is simple. If a fabric is knitted, heated, and cooled and thermoplastic yarn is unraveled from the fabric structure, then the yarn is found to have a texture set into it. The newly unraveled yarn has repeating deformations, but these can be manipulated to redistribute the zigs and zags of individual filaments and create a textured yarn. It is used for certain specialty yarns. For example, where low bulk, lustrous fabrics are required using a fiber such as Quiana® (a high cost nylon used as a high fashion silk substitute), then the knit-de-knit process might be appropriate. In such specialty markets, it is aesthetic results that are more important than high productivity and low price.

4.8.5   Elastomeric yarns

Elastomeric fibers are characterized by very high elongations at break (up to 100%) and have a composition of at least 85% segmented polyurethane [8]. They owe their extensibility to the soft, elastic material used. Polyethers or polyesters are used as segments of block co-polymer chains, which are joined together by urethane groups but which are not cross-linked. The result is a polymeric structure capable of high 'power' yet which can be heat set into desired shapes. In this context, 'power' refers to the ability of the material to recover from elongation or other deformation. A large proportion of this material is used in foundation garments, swimwear, and hosiery. Sometimes an elastomeric core is sheathed with another type of fiber to give good aesthetic properties. Care has to be taken that the elastomeric core does not 'grin' through to give unsightly changes in color or reflection due to different dye behaviors.

4.8.6   Texturing by co-extrusion

Co-extrusion is where two or more polymer components are extruded through the same nozzle to produce a filament with stripes of different polymers (Fig. 4.17). It is difficult to manage more than two components; thus two component systems are likely to be most significant commercially. There are two distinct possibilities. The first is to have the stripes firmly bonded to each other in such a fashion that treatment will cause it to curl or otherwise texture in the manner of a bi-component yarn. The second is to make the stripes have little or no bonding, in which case the filament can be decomposed into a series of finer ones. Ultra fine filaments can be separated from the main body to make silky yarns and a variety of surface effects are possible by altering the cross-sections of the separated fibrils. Multi-lobed cross-sections diffuse
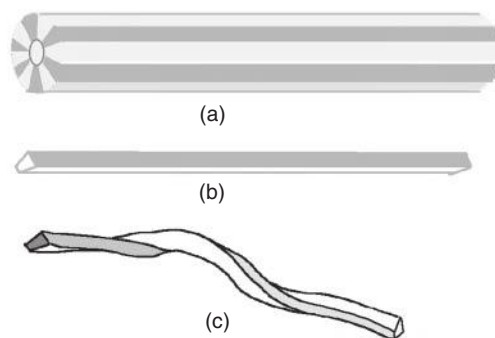
(a)

(b)

(c)

Fig. 4.17   Co-extruded filament yarn and components

reflected and refracted light to give a dull effect whereas flat cross-sections give a sparkle such as that associated with silk. The author has no details of the production of these materials.

4.9   Industrial filaments

Polypropylene (an olefin) is sometimes used for some non-apparel yarns but care has to be taken to protect the yarns from sunlight, which degrades them. The moisture absorbency is less than 1%, which is a serious disadvantage for apparel and some home uses. However, it does have good dimensional stability if the temperature is kept below about 120°C ($\approx$ 250°F). The main use is in industrial fabrics. For that reasons there is little need to consider texturing the yarns.

High tensile man-made filaments, such as those made from aramid polymers, are also used for many industrial applications, such as ropes and cables, because of their very high tenacities. Other common industrial filaments are those of polypropylene and similar polymers, which are used for carpet backings, bale wrappings, etc. Space precludes discussion of the technical aspects of ropes and cordage but the reader is referred to the work of Backer [9].

Other fibers are used because of their modest cost and/or their high strength. Glass and high modulus, high strength fibers, such as carbon, are increasingly used for reinforcement of composites but discussion of this important sector must be curtailed because it carries us beyond the production of yarn. When sheets of certain polymers are stretched, they split in the direction of stretch with a result that the sheet is transformed to a web of interconnected filaments. This process is called fibrillation and it was discussed briefly in Section 4.7.2. The use of chopped fibrillated material falls outside the range of our discussions although some fibrillated materials do end up as yarn, even if only in tape form.

Often these fibrillated filaments have a rectangular cross-section. Sometimes the position of the slits is precipitated by ridged roll surfaces, or the sheets are slit. According to Schuur and Gouw [10], it is a pity that water bath quenching is less suitable for making thin films because of draw resonance, which gives unacceptable thickness variations. In other words, it seems that it is not yet possible to make fine fibrillated filaments. The stretching of the film is carried out in ovens with forced-fed hot air. A stretching force of 1 to 2 g/den (i.e. 9 to 18 g/tex) is normally used. Sometimes bi-component structures are created by using laminated sheets of different polymers, e.g. polypropylene and polyethylene. This gives a structure that is easily textured to give bulk. If the sheets are slit into narrow strips, the result is a textured yarn. Untextured strips of polypropylene are used directly as yarns where more robust use is contemplated, as in the manufacture of sacking, bale coverings, carpet backings, and the like.

4.10 Silk filaments and staple yarns

Silk filaments are converted into yarn by a process known as throwing.[4] The filaments from the skeins arriving from reeling in the filature have to be plied. This requires a

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4   From the Anglo-Saxon 'thrawan', to twist.

twist of perhaps 4 or 5 tpi (0.1 t/m) to be added during the plying process. The plied yarns are then twisted to the level required for the end use. Twisting is sometimes carried out by ring frames similar to that shown in Fig. 7.3, but sometimes there is a twister included in the reeling equipment that produces hanks of silk yarn. In many of the silk producing areas of the world, silk goods are an encouraged cottage industry. In those areas, there is still a considerable amount of manual manipulation of silk filaments in the production of yarn. Staple yarns are often thrown using spinning wheels and mule spinning frames.

The plied silk yarn usually has considerable amounts of gum left on it, and it is quite normal to produce a warp yarn that needs no sizing for weaving. Most other staple yarns and some filament yarns need to be sized by the addition of a softened adhesive to withstand the rigors of weaving.

4.11   Morphology and dyeing

Dyes are color producing substances that can be permanently attached to or incorporated into the fiber. The affinity between the dye and the fiber depends on the physical and chemical properties of both. As has already been mentioned, the physical characteristics of the fiber depend upon its mechanical and thermal history. The morphology of a polymer changes as it is heated and cooled. It also changes as the fiber is drawn. The dye affinity of the material changes accordingly. Thus, the texturing operation can affect the dyeing operation materially. If there are periodic variations in polymer morphology arising from any of the manufacturing stages preceding the dyeing operation, there will be periodic changes in the color of the yarn along its length. If the wavelength of the error is small, the fault appears in the fabric as a moiré effect. If the wavelength of the error is large, the fault appears as barré. Such periodic errors could be caused by finish deposits on a feed or take-up roll in the texturing, or by faulty winding, or some other mechanical error. Many yarns are dyed in the form of relatively low density cones or cheeses and the winder on the texturing machine has to be configured accordingly. Staple yarns are sometimes dyed in hank form. Thus, if there is uneven dye penetration into the package, a range of error wavelengths may be found from this cause also. It is possible, and desirable, to determine these wavelengths by dyeing a knitted test sleeve, or by other means, to find the source of the problem. In addition, there can be more random types of variation arising from a variety of causes, such as spindle-to-spindle variations in the texturing conditions, mechanical or thermal instabilities in the texturing machines, faulty winding, etc. These variations tend to show up in the fabric as shading or streakiness.

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