4

False-twist process

4.1 Introduction

The fundamental principles behind the false-twist, draw-texturing process have been explained in previous chapters. Here, the way in which these principles are employed in a production environment will be examined. The process described is based on the production of polyester yarns, which account for the vast majority of false-twist textured yarn production in the world. However, it should be noted that these same principles could also be applied to the production of polyamide (nylon) and polyolefin yarns by the false-twist route.

In principle, enhanced textile properties, both tensile and tactile, are given to spun, continuous-filament POY by the simultaneous actions of drawing (stretching), heating and twisting the filament bundle. This subsequently is untwisted and then either:

1 collected directly on a bobbin after oil application (these yarns are variously referred to as 'high elastic' yarns or 'stretch' or 'single-heater' yarns); or
2 subsequently heated under controlled partial relaxation and wound on a bobbin (called a package) after oil application ('double-heater' or 'set' yarns).

The false-twist process can be broken down into three fundamental elements. It is the way in which these elements are employed and controlled that, when they are used in combination with each other, gives the resulting product its desired properties. These elements are the three Ts: tension, twist and temperature. By controlling these three fundamental variables a wide variety of different textured-yarn types can be made from one POY feedstock.

4.2 Draw-texturing machine

4.2.1 Machine profiles

Though coming in a wide variety of cross-sectional shapes, sometimes referred to as the machine profile, all draw-texturing machines consist of certain basic components. At this point the function of each of these components will be considered separately and its influence on the process described. These will be discussed in the order in which they would normally occur on the machine, i.e. the order in which they appear in the path or route of the yarn through the draw-texturing machine. Regardless of the manufacturer and the profile of the machine the basic principle is the same for all of them. The components consist of:

1 a creel for feed yarn storage;
2 two shafts, between which the yarn is heated, drawn, cooled and passed through a twist-insertion device;
3 two shafts between which the yarn can be subsequently heated under partial relaxation. Note that on some machines specifically designed for the production of nylon yarns, this heater may be omitted;
4 a device for the application of coning oil;
5 a yarn collection and winding system.

The profile of the machine was briefly referred to above. This is the designation given to the shape that the primary heaters and cooling plates make in profile. Commonly there are M, V, L and S profiles. All of these describe the cross-section of the machine, with the exception of S which simply stands for straight. Figure 4.1(a,b) shows line diagrams of M and V profiles. The profile of a machine has a definite influence on its performance with respect to capability for production speed and number of yarn breaks observed. The rule is that the lower the number of angles through which the yarn turns on its route (sometimes referred to as the thread-path or thread-line of the yarn) from the input shaft of the machine to the twist-insertion device, the lower the overall processing tensions. For this reason the V profile is preferred for high-speed machinery. The V profile is also preferred for the production of polypropylene yarns which have a high co-efficient of friction, even though process speeds are relatively low. Table 4.1 shows a comparison of M and V profiles.

4.2.2 Creels

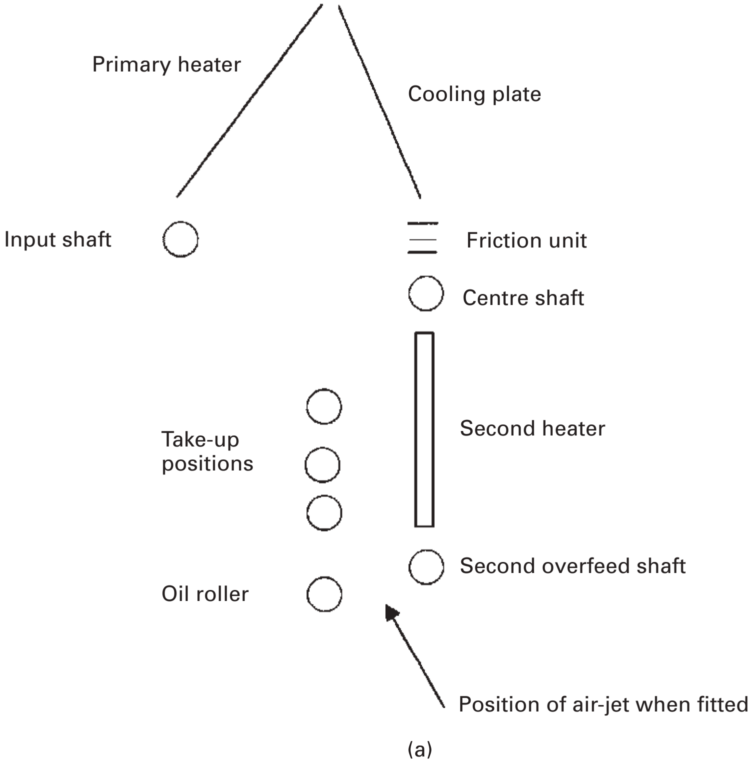
Often neglected, maintaining the creel in good repair with a high standard of cleanliness and good alignments is fundamental to an efficient process.

The creel itself should be of robust construction and be large enough to accommodate a variety of feed yarn package sizes; to be efficient, it should also be able to accommodate a reserve package, from which transfers can be made for a continuous process. To this end it is a decided advantage if the creel is of a rotary design so that POY can be loaded on to all arms within the creel from one position. This is far more efficient from the

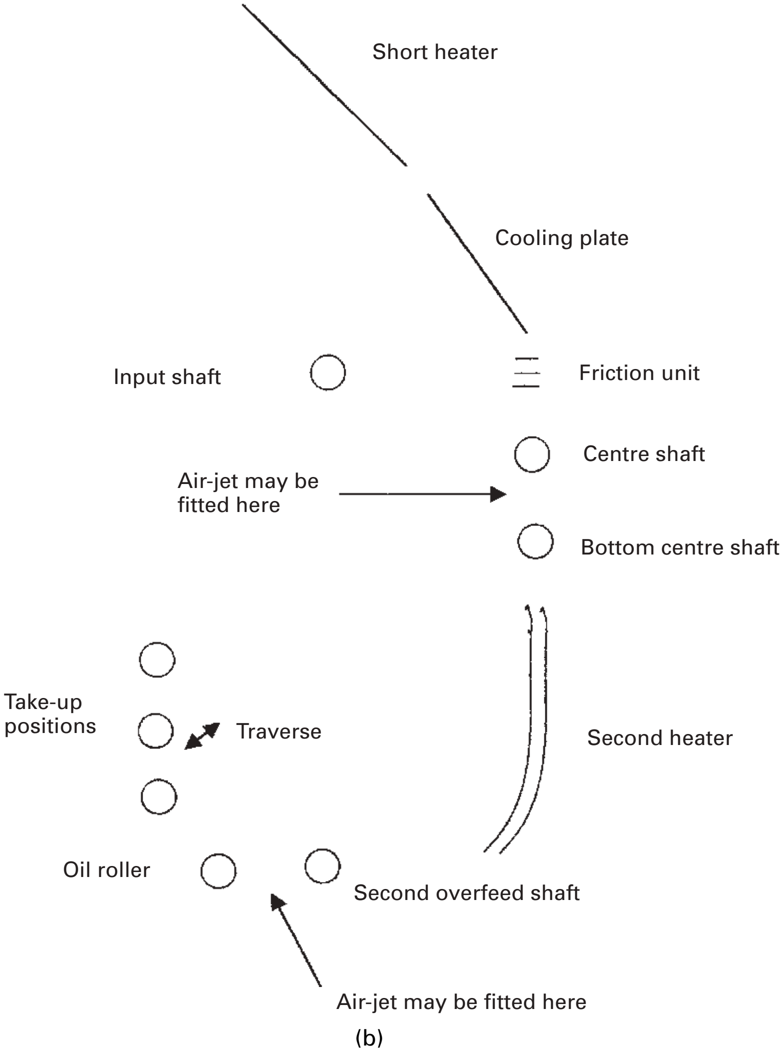
Table 4.1 Comparison of M and V profiles. Fibre 167 dtex (150 denier) 132 filament; draw ratio 1.665; machine speed 700 m/min; D/Y ratio 1.9

	M profile	V profile
Pre-draw tension (g)	40.2	24.8
Above-spindle tension (T_1)	74.0	63.5
Below-spindle tension (T_2)	65.0	58.7
Tension ratio (T_2/T_1)	0.88	0.76

Source: Courtesy of UNIFI.



4.1 (a) M profile machine. (b) V profile machine. Courtesy of Barmag-Saurer Group.



4.1 Continued.

standpoint of labour management and also reduces the risk of POY damage being incurred.

All ceramic surfaces within the creel should be in good condition and of a low friction surface. The support arm for the feed yarn package should be exactly centred on the guide in the central gathering strip in both the horizontal and vertical planes. There should also be sufficient room to allow the yarn to balloon freely off the feed yarn package.

The condition of the creel is of particular importance when processing nylon yarns, which commonly employ lower draw ratios than polyester yarns and are therefore susceptible to anything that may increase processing tensions within the creel.

4.2.3 Yarn cutter

At some point in the thread-line there will be a cutting device, usually situated between the creel and the first shaft of the machine. This device is designed to cut the yarn in case of an end break and so protect the machine from wraps, which occur when a free, broken end winds itself on to an opportune rotating shaft or roll. The cutters are usually fired by an electrical signal, which comes from a break sensor situated as close to the take-up device as possible. They are normally of robust construction and are generally trouble free requiring little maintenance apart from the replacement of worn components. In some cases the yarn cutter may be linked to an in-line monitoring device so that if an off-quality package is detected it may be automatically cut down. The cutter being activated by a signal generated by the monitoring system (see Section 8.3.1.2).

4.2.4 Yarn transport systems

The next component is the input shaft, which transports the yarn from the creel into the draw zone. Obviously all the shafts in the machine are usually of a similar type. The prime consideration is that the yarn is transported through the machine with no slippage. Normally the transport or feed unit will consist of a bright chrome metal surface and a rubber apron (sometimes referred to as a '*Casablanca apron*') or a nip roll.

Rubber aprons have the advantage of being cheap but they are easily damaged. Also if they have not been carefully manufactured, for instance if they have not been cut squarely or have some form of weight bias, they can cause problems. Nip rolls, though initially more expensive, have a much longer working life than aprons. However, these also have problems and great care must be taken to ensure that the running surface in contact with the yarn is perfectly round and parallel across its width. The life of the nip roll is significantly increased by periodically removing it from the machine and buffing to reveal a fresh running surface. If these rubber surfaces are not maintained in good condition, they can cause problems of dye faults, high yarn breaks and broken textured filaments.

4.2.5 Yarn displacement systems

Yarn displacement systems are considered here as they are an integral part of the transport systems described above. The yarn displacement prolongs the lifetime of the rubber components of the system by continuously traversing the yarn back and forth across its surface. The system commonly consists of a simple cam-driven bar, which runs the length of the machine with suitable guides attached. Should the displacement system fail, it is possible for the yarn to cut a groove in the rubber surface. This will lead to slippage and possibly damaging consequences including high yarn breaks or dye faults. Obviously the importance of having the rubber surfaces of the transport system in good condition is highlighted by this traversing action. If it is not of good and uniform surface it would be possible for the displacement system to traverse the yarn into and out of a faulty part of the surface, thus causing intermittent faults.

4.2.6 Twist stops

Some machines particularly those of V profile, or machines of any profile designed for the production of nylon yarns, may be equipped with a twist stop at the point where the yarn enters the primary (first) heater. The function of the twist stop is two-fold:

1 The twist stop prevents the twist, developed in the yarn by the twist-insertion device, running all the way back to the input shaft and hence causing yarn instability between the input shaft and the entrance to the primary heater and therefore increased yarn breaks.
2 The twist stop effectively traps all of the twist generated in the yarn between the top of the twist-insertion device and the entrance to the heater. This allows the twist to have maximum effect within the heater and hence to generate the maximum possible bulk in the textured yarn. An effective twist stop is particularly important in the production of yarn destined for ladies' hose.

The design of the twist stop, as well as the material from which it is constructed, can have a detrimental effect on the textured yarn. A poorly designed twist stop can result in increased break rate, loss of tenacity, loss of textured elongation and an increase in broken filament level. The twist stop is usually mounted on a small bearing to allow free rotation but in some instances it may be replaced by a stationary, high-friction, polished ceramic guide.

4.2.7 Primary or first heater

Until recently all first heaters were of the contact type. Now almost every major machine manufacturer will offer machines with short, non-contact, high-temperature first heaters. *Teijin Seiki* originally showed these at the

1990 ITMA and since that date development in the technology and efficiency of these heater types has been rapid.

4.2.7.1 Contact heaters

Contact heaters have been used for many years on texturing machines supplied by different manufacturers. They have the advantage of being reliable and cheap to operate but they have several disadvantages which make them unsuitable for use on high-speed machines. Primary contact heaters are usually liquid filled and work on the vapour phase principle. They have an electrical heating element in the base of the heater, controlled by a thermocouple or PT100 resistance thermometer, to regulate the temperature. The liquid is a eutectic or diphase mixture of two components, mixed in such a way that they produce vapour with a comparatively low pressure at the heater operating temperature.

The diphase liquid used in vapour phase heaters is often known as *Dowtherm*, which is one of the most common brand names. It is used in both the primary and secondary heaters. There are two types of *Dowtherm* in common use. One is *Dowtherm J*, which is most commonly found on machines making polypropylene yarns and has a guaranteed temperature range of 110–180°C. The other, standard *Dowtherm A*, comes with a guaranteed operating range of 180–235°C.

The heater is sealed and all air is exhausted so that a condition of vacuum applies internally. This allows the vapour to condense on the inside surface of the heater track once the heaters have brought the liquid to the operating temperature. The condensation causes the vapour to give up its latent heat and this enables the heater track to be held with an almost constant temperature profile within ±1°C of the set-point regardless of the yarn load.

Since vapour phase heaters operate at relatively low temperatures (110–235°C) they have a limited ability to transfer heat into the yarn. This means that the faster the machine speed the longer the heater is required to transfer sufficient heat into the yarn. At 900 m/min a heater of 2.5 m is the minimum length required, though a heater of 2.0 m length is sufficient at lower speeds. This puts pressure on the machine designer. The machine configuration becomes awkward and a greater amount of floor space and/or height is required for each machine. It will be appreciated that the larger the machine the more difficult it becomes to operate.

Contact heaters become dirty very quickly, since the spin finish from the POY accumulates on the surface of the heater. As the deposits of spin finish build up on the heater, the transfer of heat to the yarn becomes less efficient. There is also an increase in the number of yarn breaks on the machine.

The build-up of dirt on the heater also means that the machine has to be stopped frequently to clean off the deposits, leading to an increase in downtime and lost production.

Use of a contact heater brings with it an increase in T_1 tension before the spindle due to friction. This contributes approximately 4 g of tension for each increase of 100 m/min when producing a yarn of 167 dtex (150 denier). The contribution from friction also indicates that there is a natural resistance to inserting twist into the yarn which means that there is a limit to the amount of bulk that can be generated on a contact heater machine. All of the above factors combine to make contact heaters unsuitable for the production of yarn at high speed.

4.2.7.2 Short or high-temperature heaters

The first genuine short heater technology to make significant inroads into the textile machine market was from *Teijin Seiki*. The machine was previewed at the 1990 ITMA in Hanover. Since that time most of the major machine manufacturers have developed and supplied machines with short heaters, i.e. *Barmag, ICBT, Murata, RPR and Guidici*.

The advantages of short heaters that have pushed machine manufacturers in this direction are as follows: the short heater, by use of high temperatures, is capable of bringing the yarn to a working temperature in a much shorter space of time. From this simple statement it becomes obvious that the heater itself can be much shorter in length, usually 1.0 m, and the yarn can pass through the heater at a higher speed and maintain its working temperature.

Being what is termed non-contact (though there is minimal contact between the yarn and the guide surfaces within the heater) means that friction is dramatically reduced. This reduction in friction obviously assists in allowing the yarn to be processed at a much higher speed. Also, it has the benefit of allowing the twist, imparted by the friction unit, to transmit more effectively into the yarn leading to a higher bulk level being generated on short heater machines. Heater cleaning cycles can be dramatically lengthened leading to reduced downtime. Some extraordinary claims have been made about the running time achievable between heater cleans, but these should be treated with a degree of scepticism.

There is still much development work to be done in determining exactly what are the optimum temperatures for each yarn process. Obviously yarn type and machine speed and configuration are factors to be considered when optimising heater temperatures to give the best process. What is clear is that there is a narrow operating window for each yarn/process combination and if temperatures stray too far outside this window then process efficiency will decrease dramatically.

4.2.8 Fume exhaust

The main function of the fume exhaust is to help maintain the machine, and particularly the primary heaters, in a clean condition. Basically low-velocity air is drawn across the yarn path at the entrance and exit to the primary heater. It has to function at both points as, not only does the thermal effect cause fumes to be emitted at the highest point of the heater, but the speed of the yarn passing through the heater tends to drag fumes with it to the bottom. So fume exhaust is necessary at this point also. Note that this effect increases as the throughput speed of the yarn increases.

Though the main effect of the fume exhaust is to help maintain the machine in a clean condition, it can, on sensitive products, have an effect on the bulk of the textured yarn, producing variation around the machine. It is believed that this is caused by the effect of open and blocked fume exhaust ports, which change the amount of air drawn over the yarn, affecting the rate at which it cools. For this reason it is important that the fume exhaust systems are regularly cleared of any blockage.

4.2.9 Cooling plates

The cooling plate is situated between the exit of the first heater and the entrance to the twist-insertion device. It has two major functions:

1 It allows yarn bundle to cool, while still in a highly twisted state, between leaving the primary heater and entering the friction aggregate. Yarn temperature at the entry to the twist-insertion device is ideally in the range 86–90°C for polyester.
2 It gives stability to the highly twisted yarn bundle between exit from the primary heater and entry into the friction unit. This is very important since, if the cooling plate were not present, the yarn would be very unstable in this highly twisted state and have a tendency to balloon resulting in a high break rate.

The cooling plate is often neglected, but it plays an important part in ensuring that the yarn produced on the machine is of uniform good quality. If the cooling plate is out of alignment it can affect the yarn in the following ways:

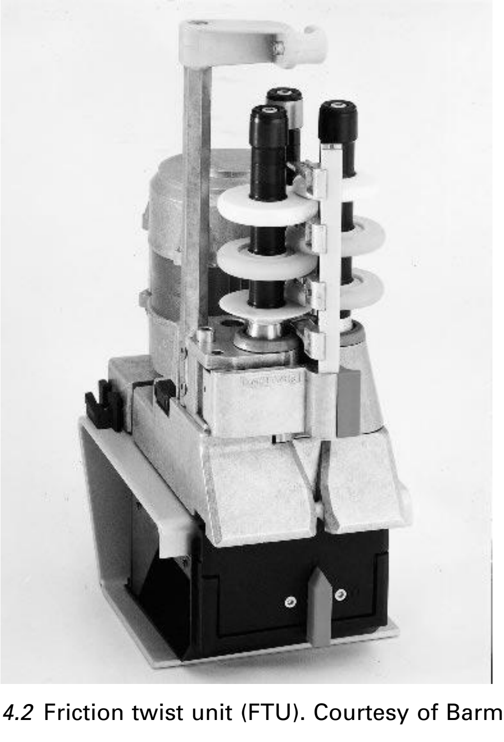
1 With too little contact, the yarn is unstable and tension surges can result, giving dye faults, or the yarn can become so unstable as to cause breaks.
2 With too much contact the plate can restrict the amount of twist generated in the yarn running back up into the heater, causing lean or low bulk ends.

The cooling plate is normally made from nitrided steel and has a curved profile. Though other surfaces and profiles have been employed by various machine manufacturers, this shape and surface is the one most commonly employed.

The length of the cooling plate is proportional to the design speed of the machine. This means that the faster the machine goes, the longer the length of the cooling zone. This is to ensure that the yarn is at the optimum temperature when it reaches the friction unit. In efforts to reduce the length of this zone several methods of forced cooling have been tried in the past but to date none have been commercially successful. Both forced air and water-cooling have been tried. The main problem is in ensuring uniformity of cooling around the machine, otherwise positional variation in bulk and dyeability may result.

4.2.9.1 Twist insertion

The heart of the draw-texturing process is the twist-insertion device sometimes referred to as the friction aggregate or FTU (see Fig. 4.2). The action of twisting the drawn-heated filaments and then subsequently de twisting



4.2 Friction twist unit (FTU). Courtesy of Barmag-Saurer Group.

them are what gives the crimp character and bulk to the yarn. The name false-twist texturing follows from this.

Over the years there have been many methods employed to give yarn crimp and texture. Those commonly used are:

1 bush crimping;
2 spindle or pin crimping;
3 ring crimping;
4 crossed-belt crimp;
5 stacked discs.

The most successful of these, and the one most commonly used across the world, is the method using stacked discs.

In principle the yarn is twisted at high speed by the discs of the friction unit. The twist is transmitted back up the yarn path on to the primary heater where, as the yarn has been 'softened' by the heater and cooled on the plate, it is set into its molecular structure or 'memory'. This is why the yarns that are processed by the false-twist texturing process must be thermoplastic in nature. It is also the reason why the process is sometimes described as a torsion-texturing process in scientific journals.

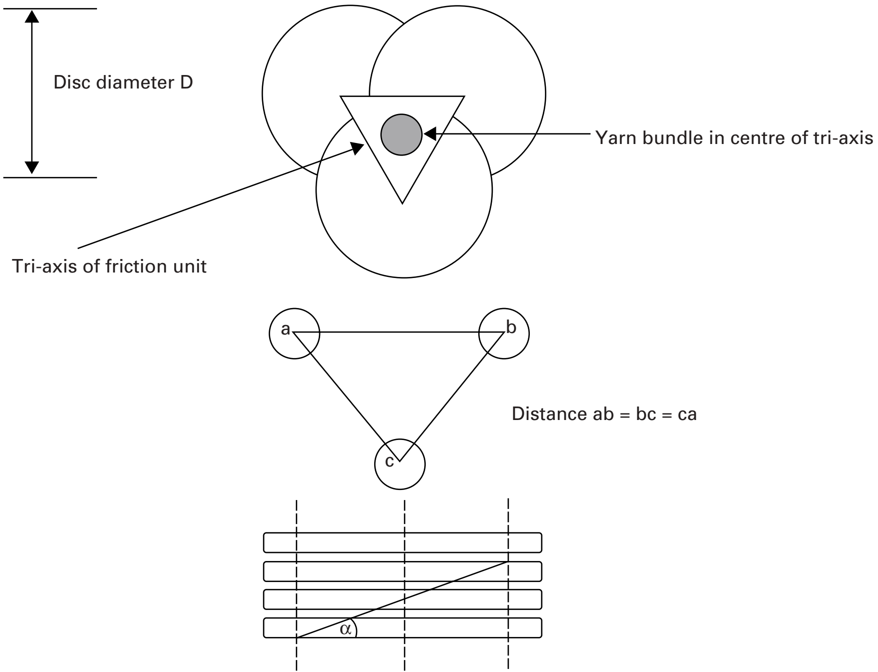
As the yarn exits the friction unit, it untwists in the opposite direction to that above the unit but, as the yarn is now cold, it does not affect the sense of twist or torsion set in the yarn's memory. The amount of twist inserted into the yarn is governed by two main factors:

1 the amount of contact between the yarn and the friction discs (angle of wrap);
2 the speed of the friction discs relative to the speed of the yarn, named the D/Y ratio (see Section 4.3.3).

To enlarge on these, the angle of wrap is defined by the total contact of the yarn with each disc in the friction unit. Thus the angle of wrap = $\Sigma(\alpha_1 \ldots \alpha_n)$ where α is the angle over each working surface and n is the number of discs. The angle of wrap can be varied by:

1 increasing or decreasing the diameter of the friction disc;
2 increasing or decreasing the horizontal distance between the friction discs;
3 increasing or decreasing the vertical distance between the friction discs;
4 increasing or decreasing the number of friction discs.

In practice, the most common methods of changing the angle of wrap are 3 and 4 above, with 4 being the preferred method (see Fig. 4.3). Dimensional set-ups for two typical friction units are shown in Table 4.2.



Where T = thickness of friction disc

S = inter disc spacing

A = axial spacing

Then yarn angle $\alpha = \frac{3T + 3S}{2\Pi P}$ Where $R = 2\Pi\left(\frac{D}{2} - \frac{A}{\sqrt{3}}\right)$

4.3 FTU geometry.

Table 4.2 Set-up of two typical tri-axis friction units

Unit type	Temco 471	Barmag type 8
Axial spacing (mm)	33.77	36.9
Disc overlap (mm)	11.23	15.2
Disc overlap area (mm^2)	41.9	101.6
Cylinder diameter (mm)	6.01	9.5
Triangle area (mm^2)	184	425.4
Yarn angle on disc (°)	45.9	43.7
Max bearing (rpm)	15 000	16 000
Whorl diameter (mm)	25	28
Disc dimensions		
Diameter (mm)	45.0	52.11
Thickness (mm)	6.0	9.0
Bore (mm)	12.0	12.0 or 14.45

Source: UNIFI.

4.2.9.2 Choice of friction material

Several types of materials have been used for the manufacture of friction discs, the most common ones being:

1. ceramic;
2. polyurethane;
3. nickel/diamond;
4. plasma-coated ceramic.

Of these the most common ones used commercially are ceramic and polyurethane. Their advantages and disadvantages are shown in Table 4.3.

Although both types have their individual strong points, polyurethane is usually the preferred choice. This is a soft, high-friction material that 'grips' the yarn better than ceramic, i.e. less slippage, therefore for a given D/Y ratio will impart more twist into the yarn, thus lowering the T_2 tension.

A new type of ceramic disc is now finding favour with some yarn manufacturers. This type is generally referred to as soft ceramic. The discs have many of the advantages of the standard type but are claimed to generate less snow. However, it must be stated that snow generation is still significantly

Table 4.3 Advantages and disadvantages of ceramic and polyurethane discs

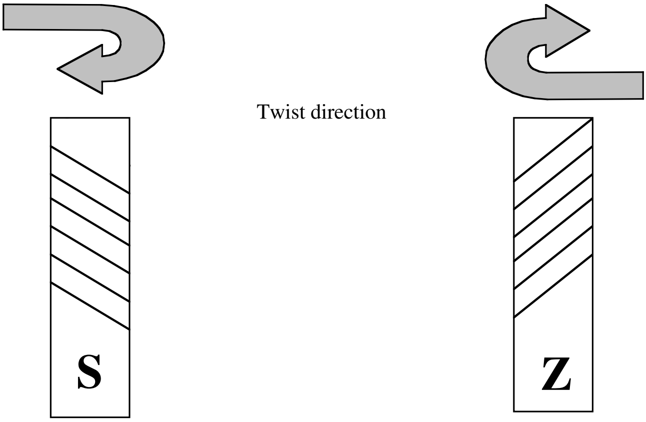
Ceramic discs	Polyurethane discs
Advantages	**Advantages**
Cheap (long-term)	Low snow* generation
Long life	Soft handle to fabric
Crisp handle to fabric	High bulk character to yarn
	Kinder to yarn
Disadvantages	**Disadvantages**
High snow* generation	Expensive
Low bulk character	Limited life
Mechanical damage to yarn	Easily damaged

*Snow is the term used to describe the white deposit that forms on the texturing machine, particularly around the twist-insertion device and cooling plates. This deposit consists of very low molecular weight polymers (oligomers) and spin finish deposits. These are formed by a combination of heat and the abrasive action of the surface of whatever twist-insertion device is employed on the surface of the yarn.

higher than that seen with polyurethane discs. The basic principle is that the yarn is passed through the centre of the overlaps of discs mounted on spindles, whose centres form the apexes of an equilateral triangle. Twist is inserted in the yarn in the direction of rotation of the discs (see Fig. 4.4).

As the yarn exits the friction unit, it untwists in the opposite direction to that in which the twist was inserted above the unit – hence the name false-twist texturing. The diameter and thickness of the disc, the spacing between the discs, the type of disc material and the speed of rotation all have an effect on the amount of twist that is inserted in the yarn.

The disc diameter and spacing between the discs influence the angle of wrap over each surface. The thickness of the discs affects the amount of contact between the yarn and the disc. The number of discs determines both the total angle of wrap and contact. The speed of the disc (D/Y ratio) affects the amount of twist put into the yarn at a given speed for a given disc configuration, i.e. as the disc speed increases twist increases. Some examples are given in Table 4.4. For calculation of disc speed see Appendix 2.



4.4 S and Z twist directions.

Table 4.4 Relationship between D/Y ratio, yarn and unit speeds

D/Y ratio	Yarn speed (m/min)	Unit speed (rpm) (52 mm disc)
1.6	800	7835
1.8	800	8815
2.0	800	9794

The twist inserted can be calculated to a theoretical value when considering other factors such as the yarn diameter, the twist contraction ratio and friction unit geometry. This value is of academic interest only as far as the day-to-day production of textured yarn is concerned.

4.2.9.3 Disc stacking

When it comes to choosing the correct disc stacking for a yarn, two things must be considered:

1 How much bulk (cover or crimp) is required in the product?
2 Will the disc stacking affect the break rate?

Two rules apply:

1 The higher the number of working discs used, the higher the resultant bulk will be.
2 The higher the number of working discs used, the higher the break rate will be.

To enlarge on these, as previously stated, the more discs that are used, the greater will be the angle of wrap between the yarn and the discs and the greater will be the total amount of contact between the discs and the yarn. Both of these factors increase the efficiency of twist insertion at a given D/Y ratio and hence more twist runs back up the yarn into the heater to develop the bulk in the yarn.

Regarding yarn break rates, polyester, along with other yarn types, is to a certain extent ‘lazy’, i.e. it does not like to be forced to do work. Increasing the number of angles the yarn is put through and increasing the amount of twist are both work as far as the yarn is concerned and, hence, there is a risk of increasing the break rate.

4.2.9.4 Guide discs

Why do we use a guide disc on the top and bottom of the friction unit stack? The guide discs are used to protect the polyurethane discs and increase their lifetime. They do this by effectively reducing the stress placed on the first and last polyurethane discs by reducing the angle of contact. The first guide disc also initiates the twist insertion in the yarn and so no longer leaves the first polyurethane disc to do all of the work. This increases the lifetime of the polyurethane disc significantly.

4.2.9.5 Disc size and diameter

As production speeds on texturing machines increased, more efficient means of transmitting twist into the yarn were required to maintain its required tensile and tactile qualities. As the speed of the friction unit is restricted by purely mechanical considerations such as bearing capability and vibration, both the thickness and diameter of the friction disc have been increased to insert more twist into the yarn. Increases in these two dimensions expose the yarn to a greater contact area between it and the working surface of the friction disc, enabling a more positive twist insertion to take place.

Friction discs now are available in a bewildering variety of sizes. However, some of the most frequently used are:

Diameter (mm)	Thickness (mm)
45	4*
45	6
50	6
52	6
52	9
53	9

* More commonly used on fine denier nylon hosiery yarns.

Friction discs are now being manufactured with a thickness of 12 mm. However, these have yet to find widespread acceptance.

4.2.9.6 Crossed-belt twisters

Of the five methods of twisting listed in Section 4.2.9.1, spindle and pin crimpers were rendered obsolete by the much greater twist-insertion rate of friction twisting by stacked discs, enabling much higher production speeds to be achieved. Although there were many trials of geometrical variants of ways of providing a normal force by means of a curved yarn path, none proved more acceptable than discs. The one alternative method that has been successful in commercial use is the crossed-belt twister, sometimes referred to as a nip twister, in which the normal force that generates friction is externally applied. The *Barmag Ringtex* twister, which is no longer produced, used the same basic principle. Belt twisters were pioneered by *Murata* and are used on their *Mach Crimper* machines, which are among the market leaders, particularly in Asia, with a reported installed productive capacity of around 30%. Nip twisters were introduced by *Murata* in 1979. Some early problems, concerned with life of belts, drive systems, inter-belt pressure and yarn cooling, were then solved in the first few years of industrial use (Isaacs, 1990). The claims for the *Mach Crimper* are superior yarn quality, high productivity, precision control of twist over a wide range, and versatility in control of yarn characteristics, including production of novelty and speciality yarns (Murata Machinery, 1993).

The units have two belts, between which the yarn passes, mounted at an angle, which may be varied (see Fig. 1.9). Rotation of the belts imparts both twist and a forwarding action to the yarn. This unit can itself be driven by a common tangential belt drive, which uses the same principle as conventional stacked discs. More recently individual units driven by inverter-controlled motors have been introduced. The twist-insertion rate is controlled by three factors: the angle of the belts to each other, the contact pressure applied to the belts and the velocity ratio (V/R), which is the equivalent of the D/Y ratio for stacked discs. It is possible to run two yarns with opposite twist through a single unit, and combine them at wind-up.

The widespread acceptance of this type of unit was hampered in the early days by problems with excessive belt wear and with belt supply. Concerns were also voiced about the length of time it took to ensure that all positions on a machine were making a uniform product. Small adjustments were required on individual units to both belt angle and contact pressure, either of which can dramatically affect the resulting tension and crimp level, in order to be assured of uniform position-to-position production. This was an obvious disadvantage for mass production compared to using stacked discs, where all parameters are fixed using discs of constant dimension and spacers of uniform settings between the discs, leaving little or no room for human error. Some problems occurred in obtaining consistent belt speeds and hence twist level on alternate S and Z twist positions on units driven by a tangential belt when producing two-ply yarns. There were also some within-spindle problems in maintaining constant belt speed, with slippage and the occasional tendency to surge being seen. Companies with extensive experience of disc twisters have therefore been reluctant to adopt belt twister machines.

The system did, however, offer advantages; it leant itself in particular to the production of high-tenacity yarns destined for use in sewing thread or similar end uses. The greater tenacity was attributed to the much gentler twisting action on the yarn than is seen with stacked discs, leading to less physical damage to the yarn bundle. This system was also capable of generating a yarn that showed more textured bulk than one produced by using stacked discs, due to its efficiency at inserting twist into the yarn. This high bulk generation in turn led to the development of special POY feed yarns for use on these machines, the measured textured denier of the yarn produced being higher than one made by other means. This was particularly important for sewing threads where the final product is sold by length and not by weight. The high twist insertion capability also leant itself to the production of heavy, i.e. greater than 300 denier, yarns, which at realistic production speeds are difficult to process with conventional stacked disc units due to the difficulty of gaining sufficient twist-insertion rates. There was also a cost advantage, as the wear rate on polyurethane discs with heavy denier yarns is excessive, leading to more frequent changes of discs being required.

Belt or nip twist units are, in more recent times, being used with some success in producing speciality or novel yarns where the high twist-insertion rate and high bulk character of the yarn produced can be exploited. This type of production is normally made on machinery where supplementary feed shafts and additional heating elements have been fitted (see Sections 4.5.3 and 5.6). This particular type of end use is now being actively marketed by *Murata* and may well lead to wider use of nip twister machines by companies that have so far exclusively used disc twisters.

A development that has been important in promoting the use of *Mach Crimpers* for regular production of textured yarn is a tension control system (TCS) to improve yarn quality and uniformity. The operation of the T_2 control consists in monitoring the tension T_2 in the yarn coming from the twister and using this tension as input to a feed back control, which acts on the air control valve for the pneumatic pressure applied to the belts. This adjusts the normal force N acting on the yarn, and hence the friction force μN, which provides the component that controls yarn tension. The control loop compensates for any variation in coefficient of friction μ between belts, over the period of belt use, or due to yarn finish, by keeping the value of μN within target limits. Although acting directly to maintain constant tension, the component of the friction force that generates yarn torque is also maintained constant, which controls the twist level. It is important, however, that the use of TCS should not mask problems in the POY feed-stock by automatically compensating for unsatisfactory quality, which would otherwise be detected as variations in tension T_2.

4.2.10 Secondary heater

After the yarn has passed through the centre shaft, it is passed through a heater tube usually between 1.0 and 1.3 m in length, where it is heated under controlled relaxation. The reason for subjecting the yarn to this is to reduce the amount of skein shrinkage or crimp and stretch left in it after exiting the twist-insertion device. If this is not done, i.e. no secondary heat is applied, it is known as either single-heater or high-extension yarn. Though suitable for certain end uses in this condition, particularly where a fabric of dense construction or stretch fabric is required, it is not suitable for many other applications.

To reduce the amount of crimp (or to modify) the yarn it is heated to temperatures usually between 150 and 235°C in a conventional, closed tube design. Non-contact, high-temperature heaters operate at significantly higher temperatures, the rule being the higher the temperature in the secondary heater the lower the amount of crimp left in the yarn. These are called double-heater or set yarns. They find use in all types of fabric manufacture and, because of their low shrink character, give a ‘crisper feel’ to the fabric and drape better than single-heater fabrics (see also Section 5.3.5).

The secondary heaters are usually of the vapour phase heated, enclosed tube design of approximately 1.0–1.3 m in length though there is now a trend towards electrically powered, high-temperature, non-contact secondary heaters. The principle of the vapour phase heater has been described in Section 4.2.7.

The non-contact type heaters have the advantage of being easy to thread by the operator, and indeed may be seen as a step toward a fully automatic, self-threading machine. They are normally in the region of 600 mm in length and operate at significantly higher temperature than vapour phase heaters. However, they have one major disadvantage which is that they are very prone to problems caused by static electricity in the yarn. This problem manifests itself as a tendency for the yarn to waver from its desired thread-path as it travels through the secondary heater. If the yarn wavers sufficiently away from the central path through the heater it can come into contact with the walls of the high-temperature heater itself. If this should happen, the walls of the heater are hot enough to cause those filaments that come into contact with it to melt. In the worst case this leads to dye flecks being apparent in the fabric and it may also cause the yarn to break.

4.2.11 Coning oil application

Coning oil is applied to the yarn to enable it to be processed more efficiently during knitting or weaving. It does this by reducing the friction present between the yarn and the metal components of either the knitting or weaving machine. It also helps reduce the friction caused by two ends of yarn rubbing against each other, particularly as part of a warp during shedding. The oils applied are usually mineral based, though in recent times, there has been a trend toward the use of synthetic, biodegradable oils. With both types significant amounts of emulsifier, corrosion inhibitor and anti-splash agent are added. The most common method of oil application is probably by roller and trough but more sophisticated methods are available, e.g. *Metoil* developed by *Rieter-Scragg*. The latter is a metered application system governed by the size of the orifice in the application head and the pressure head applied to the system.

The rate at which the oil is added to the yarn with a roller and trough system is governed by four factors:

1 the speed of the oil application rollers;
2 the area of contact between the yarn and the oil roller;
3 the viscosity of the oil;
4 the type of surface of the oil application roller.

The amount of oil applied to yarn depends upon its end use but values typically lie between 1 and 3%.

Note: A dyepack (a yarn package that is to be dyed) is an important exception. Oil applied to yarns destined for package dyeing would result in uneven dye pick-up and serious contamination of the dye vessel would follow (see Section 4.4).

4.2.12 Take-up/package build

It is impossible to separate the take-up system on texturing machines from its influence on the package build. All take-up systems consist of a package support, a drive for the package and a traversing system for laying the yarn on to the package. There will also be a mechanism where some controlled disturbance is employed on the traversing system to prevent the formation of pattern regions in the wound package (see Section 4.3.5). The influence of these factors, both mechanical and yarn-related, will be described in greater detail in Sections 4.3.5.1 to 4.3.5.11 inclusive.

4.3 Process variables

In this section the effect of the various parameters employed during the production of a textured yarn will be discussed, and their influence on the properties of the yarn examined. For an overview of the effects of changing process variables, see Appendix 1. For calculations relevant to changing these process parameters on the texturing machine see Appendix 2.

4.3.1 Draw ratio

The draw ratio is the amount the yarn stretched between the input shaft and the centre shaft, and is calculated as a ratio of the speeds of these two shafts (see Appendices 1 and 2), i.e.

$$\text{draw ratio} = \frac{\text{centre shaft speed (m/min)}}{\text{input shaft speed (m/min)}} \qquad [4.1]$$

The draw ratio determines:

1 the final textured yarn extension;
2 the denier of textured yarn;
3 the tenacity of the yarn, which is a value calculated from the yarn breaking strength and resultant denier.

Draw ratio also affects:

4 broken filament levels (too high a draw ratio, excess broken filaments);
5 yarn process stability (too low a draw ratio, yarn unstable, high break rate and surging);
6 dye uptake and uniformity: high draw ratio → low dye uptake; low draw ratio → high dye uptake.

Finally:

7 an effect in residual yarn shrinkage may also be seen (higher draw ratio increases the molecular orientation and hence reduces the residual shrinkage).

Draw ratios are normally set to give yarn extensions in the range 22–28%.

4.3.2 Primary heater temperature

Primary heat is applied to the yarn between the input and centre shafts. This assists the mechanical action of stretching and twisting the yarn by softening (making more malleable) the yarn bundle. Primary heater temperatures directly affect the following:

1 bulk (crimp generation);
2 dyeability;
3 broken filament levels;
4 yarn break-rate.

In general the effects of changes in primary heat can be summarised as shown below.

Increasing primary heat	Decreasing primary heat
Increases bulk	Decreases bulk
Increases filament breaks	Decreases filament breaks
Decreases dye uptake	Increases dye uptake

The chosen primary heater temperature is normally a compromise to allow both uniform dyeability and achievement of the required bulk level and the minimisation of broken filaments and yarn breaks. The temperature normally lies in the range 190–230°C for contact heaters.

It should be noted that there are some important exceptions when considering primary heater temperature. Modified polymers are by their nature more susceptible to filament damage. Those that have been modified to produce, for example, cationic dyeable yarns or have flame-retardant properties are usually run approximately 15–20°C cooler than normal disperse dyeable polyester in the primary heater to reduce this risk.

Bright yarns, i.e. those with low titanium dioxide content, are also run at lower primary heater temperatures. In this case the temperature is kept low in order to produce a leaner, less bulky yarn (note that the low primary heat may be used in conjunction with high second heater temperatures for both polyester and polypropylene yarns). The reason for this is that a lean yarn reflects more light back to the eye and therefore appears to be brighter and more lustrous. This is due to the lower crimp amplitude allowing more light to be reflected from the fibre rather than bouncing around within its wave-like structure (for a more detailed explanation see Section 5.7).

Also it should be noted that the nylon 6 products are processed at lower heater temperatures than either polyester or nylon 6.6 and polyolefin (polypropylene and polyethylene) fibres are processed at even lower temperatures.

4.3.3 Twist insertion or D/Y ratio

The most common method of changing the amount of twist inserted in the yarn is by changing the speed of the discs, keeping the number of discs and the spacing between them constant. This changes the ratio of speeds between the friction discs and the linear speed of the yarn. This is known as the D/Y ratio and is calculated as follows:

$$\text{D/Y ratio} = \frac{\text{circumferential speed of discs (m/min)}}{\text{throughput speed of yarn (m/min)}} \qquad [4.2]$$

The rotation of the friction unit or other twist-insertion device is commonly provided by one of two means. The most common is a motor-driven tangential belt system, which circles around the machine and transmits the drive to each spindle by pressure against a jockey pulley in the base of the friction unit. Alternatively, on more modern machinery, it is possible to have each individual friction unit driven by its own motor, which is linked to an inverter-controlled power supply.

In the case of a tangential drive, the rotational direction of the friction unit is set by placing the jockey pulley in the base of the friction unit either to the front or to the rear of the tangential belt thus imparting either ‘S’ or

'Z' twist. In the case of an individually motor-driven unit it is simply a matter of turning a switch to reverse the direction of the motor.

The yarn tension before the friction unit (T_1) and the yarn tension after the friction unit (T_2) govern the value of the D/Y ratio employed. When setting the D/Y ratio, the objective is to balance these tensions, to have a stable situation in the yarn either side of the friction unit, i.e.

$$\frac{\text{output tension } T_2}{\text{input tension } T_1} = 1.0 \quad \text{(referred to as the tension ratio)} \qquad [4.3]$$

What happens if the tension ratio is unbalanced?

1 Output tension T_2 lower than input tension T_1, i.e.

$$\frac{T_2}{T_1} < 1.0$$

This situation is caused by a high D/Y ratio; i.e. the friction discs are revolving too quickly. If you consider the friction unit to be not only a device to impart twist but also a yarn conveyor, it means that the yarn is literally being pushed through the friction discs by their forwarding action. In turn this means that the friction unit is trying to 'store' too much yarn between the entry and exit discs. This is an unstable situation and, if the tension ratio falls to below 0.8, non-uniform twist insertion may be seen in the yarn. This may take the form of:

(a) surges which cause long lengths of highly twisted yarn;
(b) tight spots which are very short lengths of highly twisted, untextured yarn (see sections 5.7.8 and 5.7.9).

Both of these lead to apparent fabric faults.

2 Output tension T_2 greater than input tension T_1, i.e.

$$\frac{T_2}{T_1} > 1.0$$

Here the friction discs are revolving too slowly; i.e. the D/Y ratio is too low. In this case the yarn is literally being pulled through the friction unit, i.e. the discs are revolving so slowly as to hinder the yarn as it is being pulled through the top half of the machine by the centre shaft. This is, of course, a highly stable situation within the friction unit, but gives rise to mechanical damage to the yarn, i.e. broken filaments and increased yarn breaks, and in the case of polyurethane discs, increased disc wear.

4.3.4 Second heater temperature and overfeed

The second heater temperature and overfeed must be considered as one relationship since the combination of temperature and overfeed has a pronounced effect on the resultant yarn shrinkage. Before the yarn enters the second heater it has a very high skein shrinkage; too high for many fabric end uses. To lower this shrinkage secondary heaters are employed, the conventional, enclosed-tube type at temperatures commonly between 150 and 240°C and the high-temperature, non-contact type at significantly higher temperatures up to 350°C, dependent upon the process. The higher the temperature in the second heater the lower will be the final yarn shrinkage. The secondary heater overfeed can enhance or reduce the effect of the temperature by altering the tension on yarn in the heater (see Section 5.3.5.2).

Normally the second heater overfeed is set as high as possible within the limits of yarn stability, usually in the range 3–12% dependent upon machine configuration and product requirements. If a high second heater overfeed is employed, the tension on the yarn in the heater tube is low allowing the heat available to have its maximum effect. If the second heater overfeed is low, yarn tension is higher restricting the effect of the heat. Note that if the overfeed is too high the yarn can wrap back on the centre shaft of the machine and cause breaks.

The choice of second heater overfeed may also be restricted where an intermingling jet is mounted either above or below the second heater. If the overfeed is too high the yarn tension can be so low as to allow the jet to blow the yarn out of the jet chamber physically, if the jet is of the open type. This is especially true in the case of detorque jets (see Section 5.3.4) which are always mounted below the second heater. With jets of an enclosed or forwarding type, whether mounted above or below the second heater, these restrictions of yarn tension do not apply to the same degree and the main consideration must be that of achieving uniformity of intermingling.

4.3.5 Package build

Building a good package, which means one that meets the manufacturers' standards and that satisfies the customers' needs with regard to off-winding performance, is of crucial importance in order to have a viable product that can compete in the market. There are many factors that have to be taken into account when specifying a yarn package; these will be explored in the following sections.

When winding a package the following factors have to be taken into account and the parameters for building the package adjusted accordingly:

1 the characteristics of the yarn regarding skein shrinkage and intermingling;
2 the end uses of the yarn – weaving warp, weaving weft, warp knitting, weft knitting and, very importantly, package dye.

Factors affecting the form of a package wound on the texturing machine are:

1. yarn skein shrinkage;
2. yarn denier;
3. intermingling level;
4. take-up overfeed;
5. wind angle (traverse speed);
6. cradle damping;
7. taper angle;
8. traverse stroke length;
9. stroke modification;
10. pattern breaking;
11. tree geometry;
12. density requirements – determined by end use (see Sections 4.4.1.1 and 4.4.2).

Each one of the above factors can have a strong influence on the way a package builds on the machine and, in the case of an automatic doffing machine, may influence its doffing performance. They will now be considered separately.

4.3.5.1 Yarn skein shrinkage (effect of setting on the machine)

Yarns with high skein-shrinkage values tend to build denser (harder) packages than yarns with low shrinkage. This is because the yarn tries to shrink while it is on the package particularly high shrinkage nylon yarns and hence tries to force its way both down into the tube and towards the centre of the traverse stroke. Yarns with low skein-shrinkage values tend to build packages where the reversal points are very hard but the package is soft in the middle. This is caused by there being so little shrinkage in the yarn that it tends to remain at the edge of the package where it is laid by the traverse guide and does not try to migrate toward the centre. These low-shrinkage yarns are usually built with a high degree of stroke modification to prevent prominent raised edges on the packages.

4.3.5.2 Yarn denier

The denier of a yarn can be related to its overall diameter or thickness. This has an important bearing on how the package winds. Consider the difference between winding a spool of cotton thread and winding a roll of string. The diameter affects how the layers of yarn on the package lie against each other. For this reason higher denier yarns, i.e. two, three and four plies, are wound at high wind angles, i.e. high traverse speeds. This gives a better opportunity for the yarn to lie side-by-side rather than on top of itself, which in turn can lead to erratic unwinding tensions or to it trapping and not coming off the package at all.

4.3.5.3 Intermingling level (mingle or interlace)

The level of intermingling in yarn has a profound effect on the way a package of yarn is built. Consider two yarns; one with no intermingling, the second with intermingling but in all other respects identical. The non-intermingled yarn winds onto the package like a ribbon due to the effect of the thread-line tension during winding (T_3). With an intermingled yarn, the thread-line tension is prevented from flattening out the yarn, since the intermingling points tend to impart to the yarn a more circular cross-section. The more a yarn is intermingled, the more this effect is apparent (see Section 5.3.3.4).

Where the yarn retains its more circular form, it has more of a tendency to roll over itself as it is being wound on the package. It is for this reason that intermingled yarns are more prone to webbing and overthrows (Section 4.3.6) than non-intermingled yarns. When the yarn is at the reversal points of the traverse, it is subjected to very high forces. The change in direction of the traverse guide puts such force on the yarn that its own momentum tends to throw it on to the outside of the package (hence the term overthrow). The part of the yarn that forms the overthrow is that which is immediately behind the traverse guide at the point at which it changes direction.

To overcome this, intermingled yarns are run when possible with high wind angles and high taper and with a stroke modification programme that is designed to give as hard an edge to the package as possible.

4.3.5.4 Take-up overfeed

The take-up overfeed is the speed of the take-up shaft relative to the centre shaft of the machine. Consequently this has a great effect on the hardness (density) of the package:

1 low take-up overfeed, i.e. 3%, leads to a hard package;
2 high take-up overfeed, i.e. 8%, leads to a soft package.

4.3.5.5 Wind angle (traverse speed)

Over the years, as an understanding of package build and its consequences has grown, the wind angle (or angle of wind) has assumed an increasing importance. Whereas at one time it was used merely to adjust the take-up tension (T_3) for reasons of package density, it is now the predominant factor in building a package of textured yarn.

The angle at which the yarn is laid on the package greatly affects the way the yarn 'packs' or in other words the manner in which successive layers of yarn lie against each other. This in turn has a great effect on the number of package build faults generated on the machine and, very importantly, on how the package will unwind at the customer's plant.

At this point it is worth examining the relationship between wind angle and crossing angle and how these translate to the appearance of specific patterns. Figure 4.5(a) shows these patterns, which are known as 'diamonds' on the surface of the package. It also shows how so-called ribbon phases or pattern points may be found to occur with specific wind angles and package diameters which result in the need for a pattern breaking mechanism as described in Section 4.3.5.10.

The wind angle is defined as half the crossing angle, which as such is determined by the speed of the traverse guide in cycles per minute and the length of the traverse stroke. If the wind angle = α, then:

$$\tan\alpha = \frac{2\times\text{traverse stroke length (m)}\times\text{traverse speed (cycles/min)}}{\text{speed of take-up shaft (m/min)}} \qquad [4.4]$$

e.g. for a process running with a take-up shaft speed of 760 m/min and a traverse speed of 430 cycles/min with a traverse stroke length of 250 mm the wind angle is calculated as:

$$\tan\alpha = \frac{2\times 0.25\times 430}{760} = 0.2829 = 15.8^\circ$$

From this it follows conversely that the traverse speed can be calculated as:

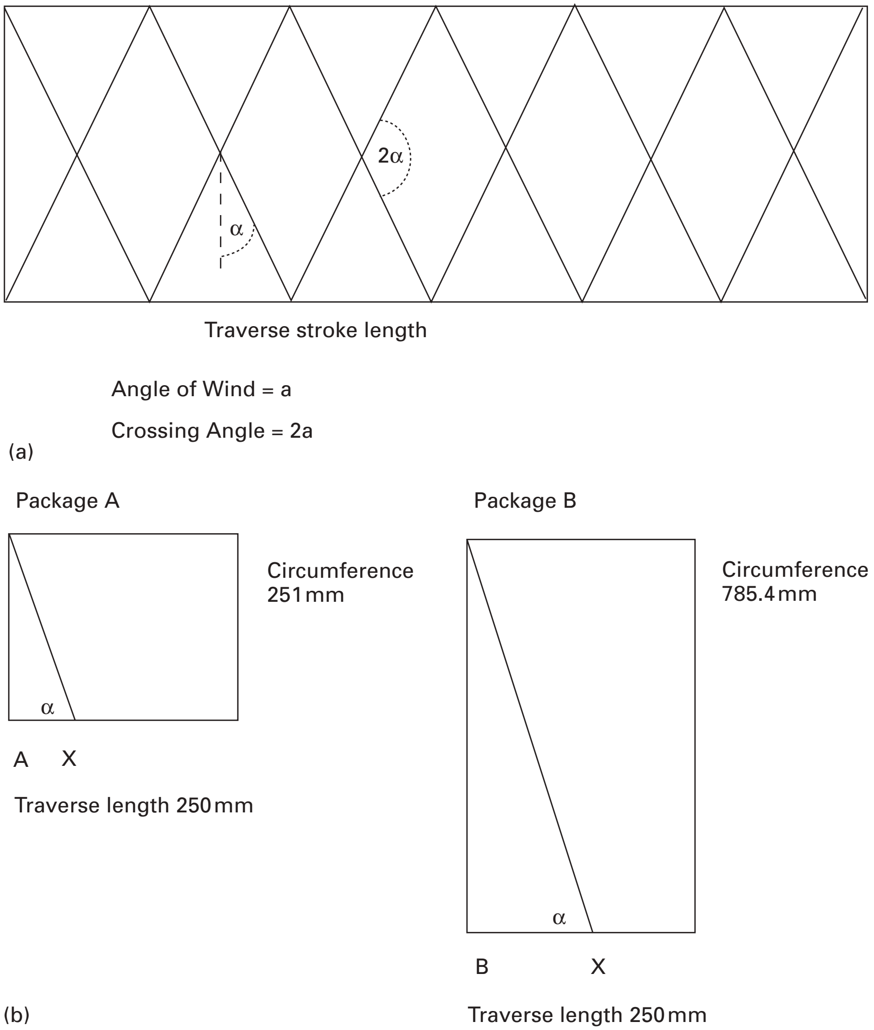
$$\text{traverse speed} = 2\times\tan\alpha\times\text{take-up bowl speed (m/min)} \qquad [4.5]$$

The relationship between α and package diameter will now be described.

As a package builds on the texturing machine a characteristic pattern of 'diamonds' can be seen on the outer surface of the package. The number of 'diamonds' apparent decreases as the diameter of the package increases (Fig. 4.5(b)). As α is fixed, determined by the take-up bowl speed and traverse rate both of which are constant, the number of 'diamonds' apparent is directly related to the circumference of the package. The relationship between these can be calculated as follows.

Consider two packages both built with identical winding specifications but one, package A, of diameter 80 mm and the second, package B, of diameter 250 mm, both using a wind angle of 16.0°. Then:

$$\text{circumference of package A} = \pi d = \pi\times 80 = 251\,\text{mm}$$



4.5 (a) Surface pattern diamonds. (b) Detail of traverse wind.

and

$$\text{circumference of package B} = \pi d = \pi \times 250 = 785.4\,\text{mm}$$

By opening this cylindrical form of the packages out to a rectangular shape, one side of which is fixed by the traverse stroke length, the distances AX and BX can be found by simple trigonometry (see Fig. 4.5(b)). With the wind angle α set at 16.0°:

$$\begin{aligned}\mathrm{AX} &= \tan 16.0° \times 0.5 \times \pi d\\ &= 0.2867 \times 125.5\\ &= 35.98\,\mathrm{mm}\end{aligned}$$

and

$$\begin{aligned}\mathrm{BX} &= \tan 16.0° \times 0.5 \times \pi d\\ &= 0.2867 \times 392.7\\ &= 112.59\,\mathrm{mm}\end{aligned}$$

$$\text{Therefore number of diamonds on package A} = \frac{2 \times \text{stroke length}}{\mathrm{AX}} = 13.89$$

and

$$\text{number of diamonds on package B} = \frac{2 \times \text{stroke length}}{\mathrm{BX}} = 4.44$$

Pattern regions may occur at various diameters throughout the package; these are sometimes known as ribbon phases. These are based on the relationship between the revolutions of the package and the number of complete traverse cycles made. A pattern will occur when this relationship resolves into a whole number integer, since fractional relationships do not result in pattern regions. The diameters at which pattern regions will occur can be calculated as follows.

Let α = the wind angle, N = the observed pattern ratio and D_N = the diameter at which patterning occurs where:

$$N = \frac{\text{take-up speed (m/min)}}{\pi \times D_N\,(\mathrm{m}) \times \text{traverse cycles/min}} \qquad [4.6]$$

It follows that:

$$D_N = \frac{\text{take-up speed (m/min)}}{\pi \times N \times \text{traverse cycles/min}} \qquad [4.7]$$

since D is also related to the winding angle α through:

$$\tan\alpha = \frac{2 \times \text{traverse length}}{\pi \times D} = \frac{\text{traverse cycles/min} \times 2 \times \text{traverse length}}{\text{take-up speed (m/min)}} \qquad [4.8]$$

From this it is apparent that a simple table can be calculated for values of N to determine where patterns are likely to occur (see values in Table 4.5).

Note that the calculated values of diameter for $N = 1$ are exceptionally large, in fact larger than most textured yarn packages will ever become, so that these values can be ignored. Also, some diameter values for $N = 9$ are

Table 4.5 Calculated pattern diameters

	Wind angle														
	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16	16.5	17	17.5	18
N	Diameter to nearest whole millimetre														
1	819	782	749	718	689	663	638	615	594	574	555	537	521	505	490
2	409	391	374	359	345	331	319	308	297	287	278	269	260	252	245
3	273	261	250	239	230	221	213	205	198	191	185	179	174	168	163
4	205	196	187	179	172	166	160	154	148	143	139	134	130	126	122
5	164	156	150	144	138	133	128	123	119	115	111	107	104	101	98
6	136	130	125	120	115	110	106	103	99	96	93	90	87	84	82
7	117	112	107	103	98	95	91	88	85	82	79	77	74	72	70
8	102	98	94	90	86	83	80	77	74	72	69	67	65	63	61
9	91	87	83	80	77	74	71	68	66	64	62	60	58	56	54

very small, smaller than most tube diameters, and therefore can also be ignored. If patterning is apparent it is usually found at diameter values corresponding to $N = 3$.

Some guiding principles for the choice of wind angle are as follows:

1. The smaller the angle, the faster the yarn is capable of unwinding from the package.

   Logic – with small wind angles, successive wraps of yarn around the package lie closer to one another. Thus, when unwinding the yarn tends to spring off the package rather than have to drag along its length.
2. The bigger the angle of wind the better the package build on highly intermingled yarns.

   Logic – because intermingled yarns tend to lie on the package more like a cord than a ribbon they are more prone to roll over layers of yarn already wound on the package. With a high wind angle more space is left between successive layers of yarn as it is wound on the package. This reduces the chance of successive layers being wound directly on top of each other, where they would be prone to roll, and instead gives a greater opportunity for the layers of yarn to lie against each other.

The use of high wind angles brings other factors into play, since the traverse speed and the forces on the yarn at the reversal points of the traverse stroke are very high. These forces have a tendency to try to throw the yarn over the edge of the package (overthrows or webbing). For this reason, when using very high wind angles, a stroke modification setting is used that puts a very hard edge on the package such that it resists the tendency to overthrow.

Some guidelines for wind angles for polyester are:

Process type	Wind angle
Weaving warp	15–17°
Weaving weft	12–16°
Weft knits	12–14°
Raschel	14–17°
Dye pack	16–19°

Hosiery yarns commonly employ smaller wind angles.

Note: Wind angle is of critical importance when building dye packs (see Section 4.4).

4.3.5.6 Cradle damping

Cradle damping is the force on the cradle employed to stabilise the package as it is building to full size. These forces are adjustable and may, dependent on the machine type, be either mechanical or pneumatic. In either case they perform the following functions:

1 Apply a downward force on the tube at the start of package winding:
    a high down force – more resistance to cradle rising, high density;
    b low down force – low resistance to cradle rising, low density.
2 As the package increases in size, i.e. weight, the damping system acts to compensate for the increasing weight of the package.

An additional force may be put on the cradle by the application of pressure at each side. This is a relatively weak force that is used purely to give stabilisation to the package and prevent unwanted vibration in the system while the package is building.

Note: Running package dye yarns requires great care in the choice of these forces; these will be mentioned in Section 4.4.1.

4.3.5.7 Taper angle

The taper angle of a package determines the rate at which the stroke length reduces and hence gives the package its final shape. This reduction in stroke length is caused by the taper mechanism controlling the rate at which the gauge screw extends from its set position for the initial stroke. The gauge screw acts through a lever on a cam inside the traverse box, which governs the movement of the sine bar. This in turn controls the movement of the traverse guide. The mechanism controlling the traverse guide is fairly complicated, but it does work.

The simple reason why a taper angle is put on a package of yarn is to improve its winding performance when it reaches the customer. The rule is that the higher the unwinding speed the greater the degree of taper that is put on the package, i.e. the more the package sides slope away from the vertical, as shown below:

Unwinding speed (m/min)	Taper angle (°)
500	90 or 85
1500	75

As a package increases in size the tension on the yarn in the take-up (T_3) area changes, i.e. at initial stroke (start of package) T_3 is at its highest, and at final stroke (at full size) it is at its lowest.

If the package builds at a 90° taper, i.e. straight sided, the wind angle changes as the package diameter increases. This is due to the diameter and hence the circumference of the package increasing. Since it is not possible to reduce the diameter of the package, the reduction in traverse stroke length caused by the taper cam helps maintain the wind angle as its circumference increases (see Section 4.3.5.3).

4.3.5.8 Traverse stroke length

The maximum stroke length that can be set on the machine will vary according to machine type. However, a maximum value of 250 mm is common. Setting the initial stroke length correctly is of importance since it has a fundamental influence on the quality of package build.

It has been found that as the wind angle increases, and therefore the speed of the traverse guide increases, hence the take-up tension (T_3) increases, and stroke length decreases and vice versa. This effect on yarn tension during winding is shown below:

1 high (T_3) – short stroke;
2 low (T_3) – long stroke.

It should be noted that incorrect setting of the stroke length, for example by having it longer than the machine manufacturer's recommendation, can lead to accelerated wear of the components within the winding mechanism and an increase in package build faults.

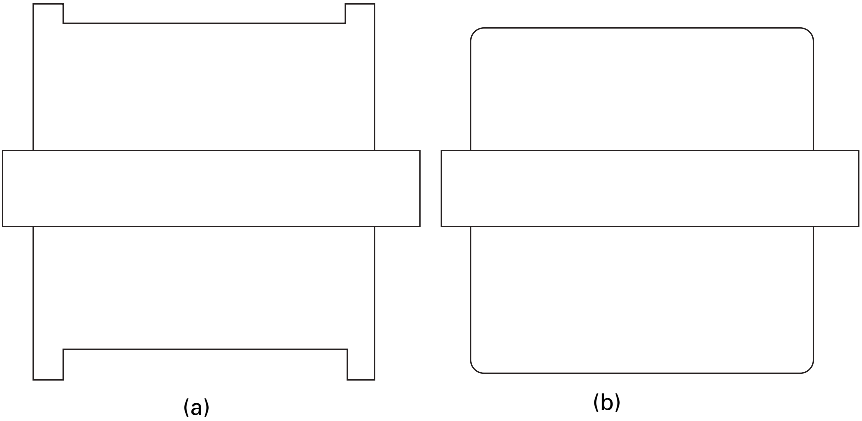
4.3.5.9 Stroke modification

Stroke modification is the name given to the mechanical action of continually varying the traverse stroke length during the formation of a package. This is commonly synchronised to work with variations in traverse speed as part of the cycle known as 'pattern breaking'. This variation in traverse speed is sometimes called the disturbance and is specified as amplitude of percentage variation away from a mean traverse speed (see Section 4.3.5.10).

The stroke modification bar is driven backwards and forwards along the length of each take-up deck by a rotating spindle, which is chain driven from the stroke modification gearbox. An electrical signal usually controls the motion of the spindles, which may be infinitely variable between fixed limits.

Consider the movement of the traverse guide back and forth across the length of the package. If there was no stroke modification, the stroke length would remain constant and hence twice as much yarn would be laid at the edges of the packages as in the centre, due to the length of time the traverse guide spends at the reversal point. The reversal point is the end of one stroke and the start of another. Hence the package would look as shown in Fig. 4.6(a).

To overcome this problem the traverse stroke length is continually varied. The amplitude of the stroke length variation and the speed and frequency at which it is varied have a significant effect on the overall look and shape of the package. More importantly, they affect the package significantly in terms of apparent faults and the unwinding performance. However, if the stroke modification were exaggerated, the package would look like that shown in Fig. 4.6(b). This is just as undesirable, since the edges



4.6 (a) Yarn package with no stroke modification. (b) Yarn package with excessive stroke modification.

of the package are very soft and prone to both yarn overthrows (see Section 4.3.6.3) and physical damage.

The stroke modification system consists usually of a mechanically driven action whereby the stroke modification chain, driven from a gearbox, drives a threaded spindle, which in turn oscillates the stroke modification bar longitudinally along the length of the machine. Note that there is usually one spindle and one bar for each take-up deck of the machine. In order for the stroke modification bar to perform its function correctly, it must be in exactly the correct position at its start or rest position.

As the stroke modification spindle drives the bar backwards and forwards along the length of the machine, it takes with it a small cam (usually nylon but may be of some other material) which is attached to the bar. This cam acts to move the angle of the lever that controls the movement of the sine bar; this in turn controls the stroke of the traverse guide across the length of the package. As the bar moves to the left it reduces the stroke length. As it moves to the right, it increases the stroke length. It is this variation in stroke length which determines how much yarn is laid by the traverse at the reversal points and hence how soft or hard is the edge of the package.

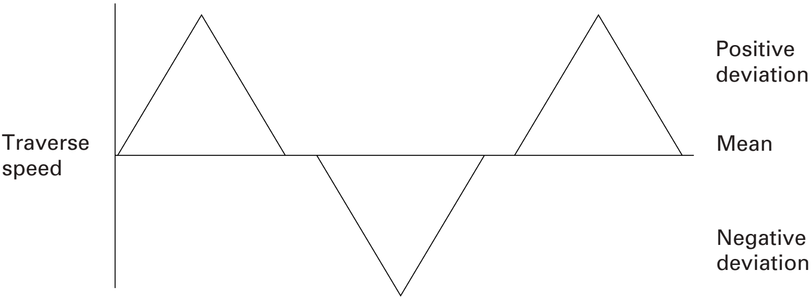
4.3.5.10 Pattern breaking (traverse disturbance)

Rise and fall is also known as traverse disturbance and is sometimes referred to as the pattern or ribbon breaking function on the machine. Usually this works in conjunction with the stroke modification system. The rise and fall feature continuously varies the speed of the traverse guide, within set limits.

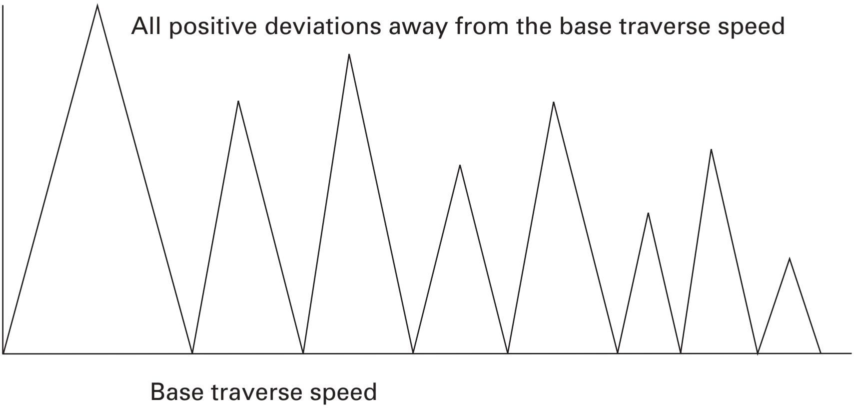
The system of varying the traverse speed is designed to prevent successive layers of yarn being laid upon each other, by continuously changing the traverse speed and thus the wind angle of the yarn. This is designed to prevent ribbon phasing or patterning (see Section 4.3.5.5 on wind angle above). The way in which this variation is generated may vary from machine to machine. On some this variation takes place either side of the average or mean traverse rate, e.g. 3% disturbance and a mean traverse speed of 300 double strokes per minute. A representation of this is shown in Fig. 4.7.

On other machines the traverse disturbance is all positive. In this case it rises from a base level to a maximum and then falls back to the base value (Fig. 4.8). Note that the maximum value of the disturbance may be infinitely varied within limits.

Modern stroke modification systems are often controlled by a microprocessor and are capable of producing a wide variety of disturbance patterns at the reversal points of the traverse stroke. Though complex in



4.7 Traverse disturbance equally distributed either side of the mean speed.



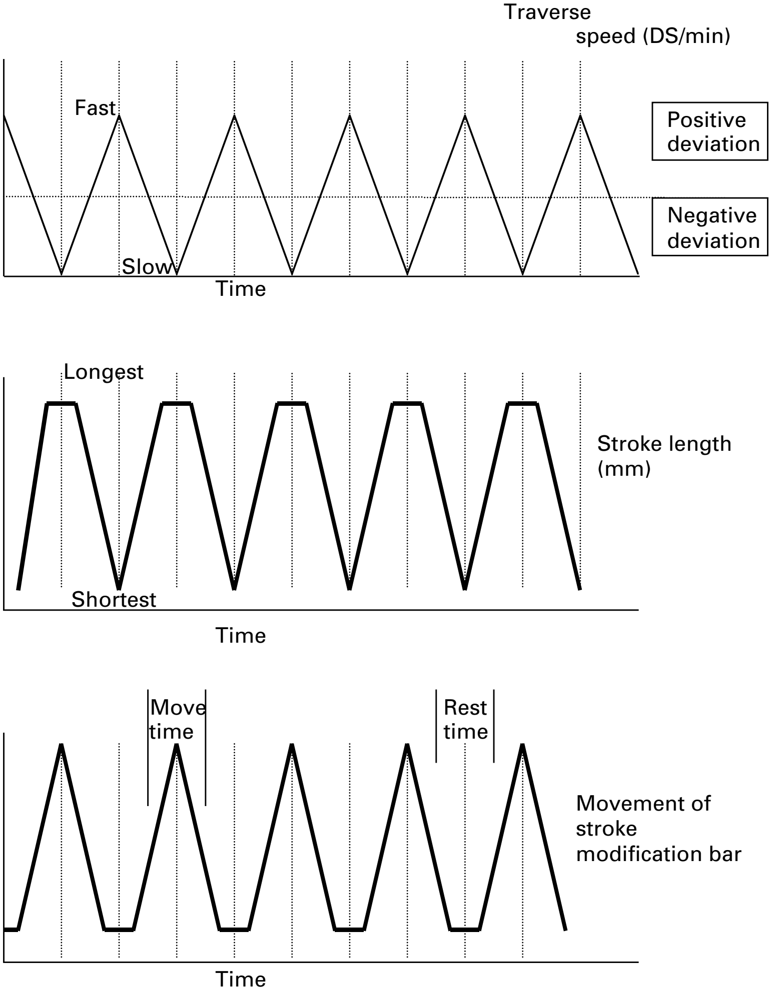
4.8 Traverse disturbance – all positive.

movement, sometimes comprising as many as 16 separate reductions or increases in stroke length to complete one cycle, these complex patterns can be extremely useful when dealing with different yarns, since some are very prone to produce overthrown ends because of their physical properties (see Section 4.3.6).

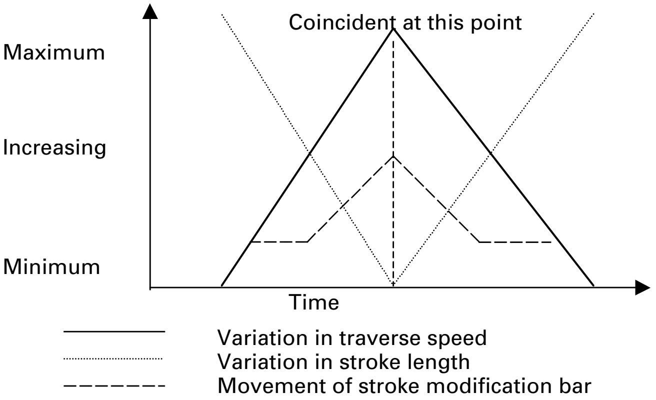
The time taken for the traverse to speed up and slow down must be precise and may be known as either the rise or fall time or ramp-up and ramp-down time. The rise and fall times and the rest and motion times of the stroke modification bar are synchronised. By this synchronisation, the maximum movement of the stroke modification bar occurs when the traverse speed is at its minimum. In other words the shortest stroke occurs when the scroll shaft revolutions are at their peak. The longest stroke coincides with the minimum revolutions of the scroll shaft.

The rest and motion times of the stroke modification are self-explanatory. The motion time is the time in seconds that the stroke modification bar is moving and the rest time is the time in seconds that the bar is stationary. The synchronisation of the traverse disturbance and stroke modification is represented in Fig. 4.9.

By superimposing these diagrams on top of each other it is possible to get a clearer understanding of how the traverse speed variation and the movement of the stroke modification system are synchronised to each other, as shown in Fig. 4.10.



4.9 Stroke modification function. Courtesy of Barmag-Saurer Group.

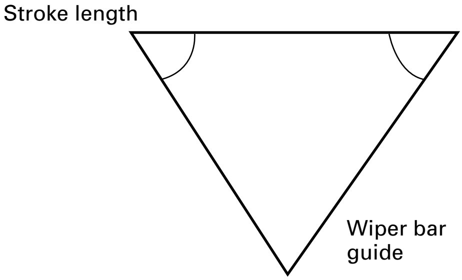


4.10 Stroke modification function superimposed on traverse disturbance.

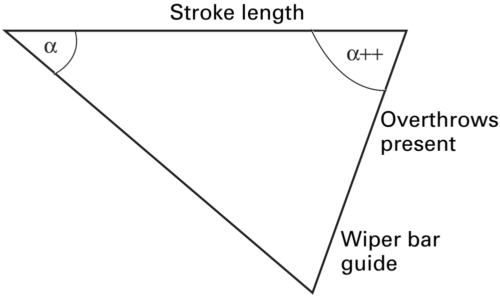
4.3.5.11 Tree geometry

Question: What have trees got to do with texturing machines?

The tree is the name given to the arrangement of the guides that lead the yarn from the oil application roller up to the package take-up roller. The important thing to remember when setting up the wiper bar guides, as they are sometimes known, is that the guides should be exactly centred on the package such that the guide forms the apex of an isosceles triangle of which the initial stroke length is the base (Figs 4.11 and 4.12). If this guide is not centred correctly on the textured yarn package, there will be a tendency for overthrows to be present on the side of the package to which the guide is offset.



4.11 Correct tree geometry.



4.12 Incorrect tree geometry.

4.3.6 Package build faults

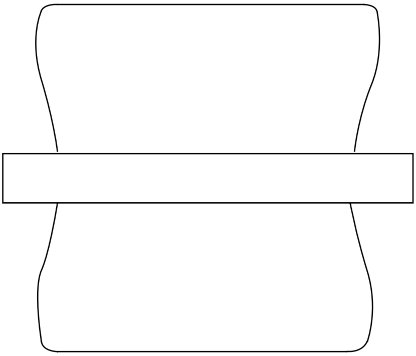
A brief description of some of the more common types of package build faults is included. Where relevant, line drawings of some of the more common types of package build fault are shown (see Figs 4.13–4.18).

4.3.6.1 Bulging

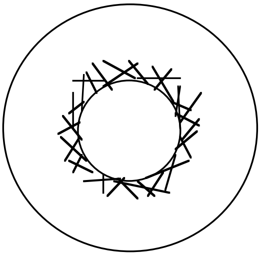
Employing small wind angles, usually of less than 13°, often causes bulging. Though this is sometimes counted as a package build fault, it may also be done as an intentional part of the specification. It helps the yarn to unwind off the package at high speeds and is particularly useful when producing yarns designed for high-speed weft insertion in weaving (see Fig. 4.13).

4.3.6.2 Webbing

Webbing is sometimes confused with overthrows and though some of the causes of this fault can be the same they should be treated differently. There



4.13 Package build – bulging.



4.14 Package build – webbing.

are many reasons why webbing can be apparent on a package some of them machine related and others specification related. These will be discussed separately below. Webbing is characterised by a distinctive 'birds nest' appearance to the package, particularly close to the tube, i.e. within the first half inch of the package (see Fig. 4.14). This not only looks unsightly but will also lead to unwinding problems for the customer.

Webbing is more usually seen with intermingled yarns, especially those, which are built with a high package density. Also to be kept in mind is that the machine design itself may be a factor, depending upon the take-up geometry.

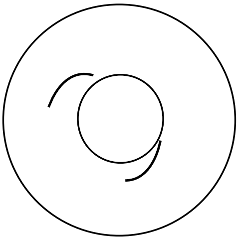
Webbing will occur especially on intermingled products if the wind angle is too small. For this reason intermingled yarns are generally run with wind angles greater than 15°. Webbing is also likely to occur, if the stroke modification programme chosen is one which causes a soft edge on the package at the reversal points.

Some other causes of webbing are poor alignments in the mechanical set up of the take-up system, worn components or even something as simple as a stiff bearing. Uneven damping settings may also result in packages with webbing. The overall density of the wound package is also a big factor. High-density packages produced with correspondingly high take-up tensions will result in webbing.

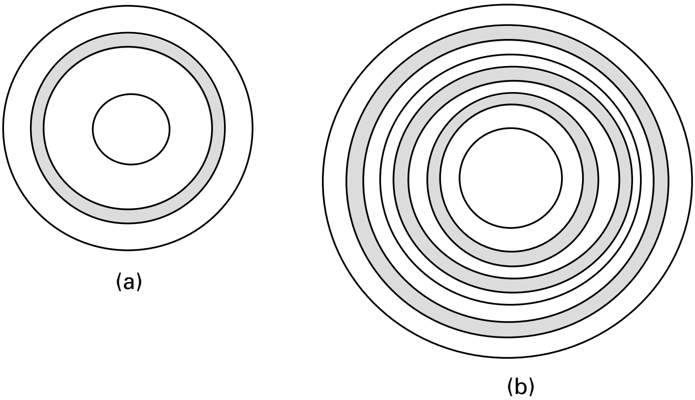
Note: With dye packages a special set of circumstances exists where the edge of the package at the reversal points has to be relatively soft to avoid problems with dye uptake in the dye vessel. When the package is compressed and if the edges are too hard it is not possible to get even dye penetration at the reversal points. Again these will be discussed separately in Section 4.4.

4.3.6.3 Overthrown ends

Overthrown ends or overthrows occur as single, long threads, which are usually observed on the side of tapered packages approximately one inch



4.15 Package build – overthrows.



4.16 Package build – (a) ridges, (b) concentric rings.

away from the tube wall (see Fig. 4.15). It is at this point in the package that the anti-bulge feature of the taper cam or other stroke-shortening feature comes into operation. This is designed to prevent the package from bulging too severely at low wind angles. Giving a rapid decrease in stroke length at this point prevents bulging. It is due to this rapid change in stroke that the overthrows are more prone to appear. In this case rapid is a relative term, the actual change in stroke taking place over approximately 15 mm of the package build. This is relatively fast when you take into consideration the overall doff-time.

4.3.6.4 Ridges

These are normally found to be due to incorrect setting of the taper mechanism, particularly when running taper angles of 85 or 90°. The ridge is normally apparent at the very outside of the package, usually within the final 8–10 mm (see Fig. 4.16(a)). It is caused by the taper cam losing contact with the gauge screw thus allowing the stroke to lengthen again and therefore resulting in an apparent ridge on the package. It can also happen that a ridge is seen on intermingled products when a temporary change in air pressure is observed.

The chosen wind angle can also have an effect on the formation of ridges. The exact mechanism of this is not known but it is more likely to happen on yarns with low filament denier. In these cases a wind angle of between 14 and 16° is preferred. It can also happen that ridges, in the form of concentric circles, can be seen on both shoulders of the textured package (see Fig. 4.16(b)). These have been demonstrated to be due either to faulty end caps on the cradle arms or non-concentric tubes, see Section 4.3.7.1. These types of ridges manifest themselves more clearly on high-density products.

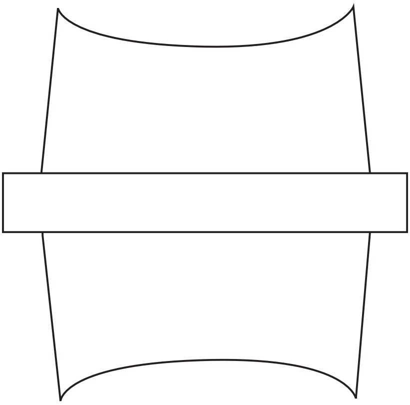
4.3.6.5 Saddling

Saddling is the name given to packages that show pronounced raised edges that are hard (see Fig. 4.17). When this occurs it will usually be seen on every position on the machine and rarely on just one deck. The causes may be:

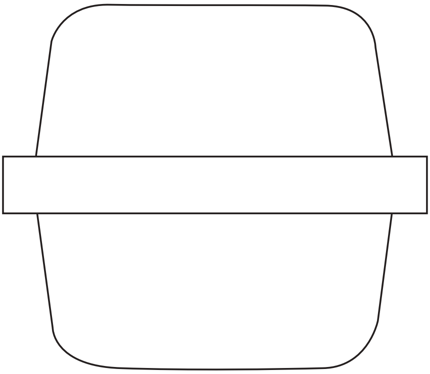
1 take-up tension is (T_3) too high, giving very hard dense packages, or
2 an incorrect setting of the stroke modification system resulting in too much yarn being laid at the extremes of the traverse stroke.

4.3.6.6 Shouldering

Shouldering is the reverse of saddling. It is manifested by the edges of the package being so soft that they have a sloping appearance. Often this will be accompanied by webbing (see Fig. 4.18).



4.17 Package build – saddling.



4.18 Package build – shouldering.

4.3.6.7 No-tail package

A no-tail package, i.e. a package of wound yarn on which there is no reserve of yarn left with which one package may be transferred to another, is sometimes classified as a package build fault. This yarn reserve or transfer tail is formed manually or in the case of automatic doffing machines automatically whenever a new tube is placed in the machine at doff.

4.3.7 Tube design (yarn carrier)

Though often ignored, the type and design of the tube on which the yarn is wound, the materials used and the method of its manufacture can play a very big part in the product behaviour. This may apply not only on the texturing machine, with respect to any package build problems, but also in downstream processing at the customer. Both cardboard and plastic dye tubes are affected but the dye tube is much more critical due to the nature of the process. Dye tubes will be discussed separately in Section 4.4.

4.3.7.1 Cardboard tubes

Cardboard tubes come in two basic designs. These are usually known respectively as either 'square cut' or 'bull-nosed' tubes, occasionally referred to as 'roll-nosed'. The difference is that the square cut tube has the same internal and external diameters at either end of the tube, whereas the bull-nosed tube has a smaller inside diameter at one end of the tube, the end opposite to where the transfer tail is placed. This end of the tube being turned in upon itself during the manufacturing process forms the smaller diameter. It is then burnished to form a smooth edge to the tube. This type of tube, though requiring different sizes of end cap at either end of the cradle, does offer the consumer improved unwinding capability since it reduces the incidence of the yarn snagging on the end of tube as it unwinds.

The tubes are made from compressed paper bound together with adhesive. The process of building up the thickness of the tube wall by successive layers is known as lamination and is what gives the tube its final strength. The two most important criteria for a cardboard tube are its concentricity and its 'squareness' at either end. Concentricity refers to how uniformly the circular cross-section is maintained along the length of the tube and by 'squareness' is meant how straight and level the ends of the tube are such that they fit securely and evenly on to the end caps in the cradle.

The final layer in the lamination process is the outer covering of paper, which will designate the tube colour. It is important that this layer is carefully applied to ensure that the overlaps on the wrapping are as smooth as possible. This is to prevent the possibility of yarn snagging and catching on the overlaps when unwinding at the customer. This may result in fabric faults or yarn breaks and is of particular importance on both hosiery yarns and yarns with low filament denier.

If the tube is not concentric this will lead to package build problems. What happens is that at high take-up speeds, i.e. with high tube revolutions, the tube will start to bounce in the end caps; in severe cases the cradle itself can be observed bouncing up and down. As a result of this, a package is built on which a series of concentric rings on the walls of the package can be plainly seen. A similar situation will arise if the ends of the tube are not cut squarely. These problems will manifest themselves more on packages that are built to a high package density than on ones built to a low density.

The crush strength of the tube is also an important consideration. This is particularly so in the case of very tightly wound packages such as those containing nylon yarns destined for use in ladies' hose and especially so-called torque yarns, i.e. yarns with very high twist and little residual shrinkage. If the crush strength of the tube is not sufficient then severe deformation of the tube will occur on the texturing machine leading to growth in the tube length on the machine due to the force exerted on the tube by the wound package. In extreme cases, the tube itself may collapse whilst still in the end caps and result in a forced machine stop.

It is also important to ensure that the tubes are uniform in weight, otherwise information recorded at the weigh scale regarding gross and net weights of yarn packed will be incorrect.

4.3.7.2 Plastic dye tubes

Commonly injection moulded tubes are used for package dye yarns using polypropylene as the base material. A small amount of coloured pigment may be injected into the polymer to give a range of colours available for use in product identification (see Section 9.1.1). Two types of polypropylene may be used, either a homopolymer or a copolymer. In recent times the use of copolymers has found favour; this is because they are more durable and can readily withstand the forces generated during subsequent tube compression in the dye process.

Two types of plastic dye tubes are routinely used for production in the texturing plants: the compressible dye tube and the rigid, non-compressible, perforated tube. Within the category of compressible tubes there are two types. The first compresses along the main axis of the tube. This type is known as an axially or longitudinally compressible tube, i.e. its overall length reduces under compression. The second type are those that allow compression directed towards the centre of the tube such that the diameter decreases. This is known as a radially compressible tube.

4.3.7.3 Axially compressible tubes

The major problem that is apparent with compressible dye tubes is that, as they are intentionally designed to be compressed, conversely they are also prone to expansion on the machine when yarn is being wound on them. This is due to both centrifugal forces and the effect of the increasing weight of yarn placed upon the tube. On a manually doffed machine this does not create a problem but on the automatic doffing machines such as the *Barmag AFK* it can cause a serious problem. Should the tube expand in overall length, then it will not roll out of the cradle properly and as such will result in high doffing failures. This increase in length can also, if great enough, lead to a situation where the tubes are so long that they will no longer fit the cartons for despatch to the customer.

The manufacturer can design different compression capabilities into the tube, in particular by changing the angle of the ribs supporting the length of the open area of the tube. The provision of any longitudinal reinforcement designed to restrict compression and the possible inclusion of stoppers placed between the ribs of the tube are again designed to restrict overall compression.

Plastic dye tubes are manufactured by a process of injection moulding and hence the uniformity of product should be excellent. However, it must be bore in mind when contemplating any changes to the design of a dye tube that this means that modifications (usually irreversible) have to be cut into the mould, a lengthy and expensive process.

4.3.7.4 Radially compressible tubes

The radially compressible tube can be treated in a similar manner to that of the rigid tube, as described in the next section. Tubes of this type are used where the benefits of excellent unwinding capability are required but the tube can absorb the shrinkage apparent in the yarn by a reduction in its diameter.

4.3.7.5 Rigid dye tubes

Rigid dye tubes are, as their name suggests, designed such that they cannot be compressed. This in turn means that they are not prone to the same degree of expansion on the texturing machine. Due to the tube's non-compressible nature the yarn can be wound onto a rigid tube at higher tension leading to higher package densities and increased package weights. To increase the strength and rigidity of these tubes it is common for a small amount of glass fibre to be added to the tube during the moulding process. The same considerations of weight, uniformity and concentricity apply equally to all types of tube for winding textured yarns.

4.3.7.6 Compressible steel springs

For some uses, particularly the production of nylon yarns for package dyeing, the plastic dye tube is eschewed in favour of a compressible steel spring. These steel springs have some advantages over the plastic design, since they are capable of more than one trip through the process, an important economic consideration. They also have a higher compression rate than the plastic tube. Nylon yarns are usually dyed at higher compression rates than polyester and will, due to their nature, shrink on the tube to a greater extent than a polyester product. The steel spring is more able to accommodate this high residual shrinkage than a plastic tube without sustaining physical damage. The greater shrinkage potential of nylon yarns means that the package produced on the texturing machine is wound at a much lower density than a polyester package (see Section 4.4.1.1).

These tubes must be carefully inspected after each journey through the process to ensure that they are free from damage. This is especially important from the points of view of both operator safety and product integrity, and inspection must be carried out before they are re-used on the texturing machine.

4.4 Package dye yarns

Package dye products must be viewed from a different standpoint from normal products wound on cardboard tubes. When building a dye pack it has to be remembered that the package being produced on the texturing machine must perform satisfactorily after it has been dyed, possibly compressed and generally after suffering a lot of abuse. There are certain rules that can be applied depending on whether a yarn is being produced on rigid or compressible tubes. These will be discussed separately below.

4.4.1 Compressible tubes

A compressible-tube product is the most challenging package that can be built on the texturing machine. Almost every rule that would normally apply to building a satisfactory package on cardboard tubes has to be broken when building this type of package. It must be remembered that when winding on to a compressible tube the yarn must unwind satisfactorily after it has been compressed by anything up to 30% within Europe and even more in the USA. This means that the following must be considered when deciding how to specify a dye pack on a compressible tube:

1. The package must be soft, i.e. of low density (see Sections 4.4.1.1 and 8.3.5.3). This is to ensure that when the package has been placed on the spindle in the dye vessel and compressed, it is not so hard or dense that the dye liquor will be prevented from penetrating evenly during the actual dye process.
2. The wind angle used must be large; this is so that the wind angle, which decreases under compression on the package, becomes small enough to enable the package to unwind satisfactorily.
3. A stroke modification setting must be chosen that does not produce a package with hard edges. If the edges of the package on the machine are hard, they will become even harder when the package is compressed and will give rise to uneven dye penetration, hence giving an uneven speckled appearance to the dyed yarn at the package edges.
4. Cradle forces must be chosen such that no undue pressure is put upon the tube, since this may cause distortion of the tube during the winding process.

Also to be bore in mind when producing a dye pack on an automatic doffing machines is how it doffs. Dye packs may be difficult to doff due to two main factors:

1. A very low take-up tension (T_3) is necessary because of the need to produce a soft package.
2. The fact that the tube is designed to compress means conversely that it is far more likely to expand. If the tubes on the machine start to expand

so that they approach the maximum opening length of the cradle, then problems with doffing may occur.

4.4.1.1 Density on compressible tubes

The density of a compressible dye pack must be low, as mentioned above, so that the density of the package after compression is suitable for the even penetration of the dye liquor. Also it has to be remembered that the dye process itself, normally carried out under pressure at 130°C, will also affect the package, since the yarn crimp contraction reduces dramatically during this process, leading to an increase in apparent density. The density to which the package should be wound is heavily dependent on the customer's dye equipment. Some examples of major dye machine manufacturers are *Obem, Krantz, Bellini* and *Longclose*; detail differences exist between the machines produced by these manufacturers.

The *Bellini* and *Longclose* machines are very similar, being what are known as vertical machines, i.e. the packages are stacked vertically in columns one on top of the other. The *Obem* manufactured machine is a horizontal machine, i.e. the packages are laid into the machine in horizontal columns each one of the columns being placed in separate torpedo-shaped tubes. The dye packages designed for use in each type of equipment should be optimised and will be different. However, this is not normally the case in a production environment because it leads to an overcomplexity of product range. As such an all-purpose package must be striven for, one that suits all types of dye machines.

Typical values for the package density on compressible-tube polyester products lie in the range 0.32–0.40 gm/cm^3 (320–400 gm/dl). Occasionally it is necessary to produce packages on a compressible tube to a density outside this range. In this case it would usually be to a lower density. Nylon yarns in particular are wound usually to a significantly lower density (0.13–0.18 gm/cm^3) due to their high shrinkage potential.

As will be appreciated, density is a relative measurement calculated from the overall volume of yarn on the package and its net weight (see Section 8.3.5.3). To ensure the maximum capability of the machine to maintain all packages within a specified density range it is essential that such factors as cradle forces, traverse stroke length and taper angle of the package are set with great care. Every effort should be made to ensure that the winding tension from position to position is as uniform as possible. This applies equally to the physical properties of the yarn, which may affect the way in which the yarn is taken up on to the package. Properties such as crimp level and level of intermingling, where applicable, must also be held within given tolerances.

Note: The lower the density the more difficult it is to build a satisfactory package with respect to overthrows.

4.4.1.2 Package build on compressible tubes

With rare exceptions all compressible-tube products are built with a taper angle of 85–90°, i.e. with a package edge as straight as possible. Why is this important?

When the packages are stacked on top of each other on the dye spindle, they must join together evenly with no gaps or air spaces between them when they are compressed. If there were gaps present it would be possible for the dye liquor to take the easy route when being pumped around the dye vessel system and pass through these gaps in preference to making its way through the coils of yarn on the packages. This fault condition is known as 'blow by' and when present leads to very uneven, streaky dye uptake and blotchy looking packages of yarn.

By making the packages with a straight edge, i.e. taper set at 90°, the top face of the bottom package mates securely with the bottom face of the package above it and so on up the whole length of the spindle. This secure mating of the packages in sequence up the height of the spindle is known as making a good yarn-to-yarn seal.

Normally the total height of the spindle would be equal to between six and eight packages of yarn but it may be more or less than these figures. This is of course dependent upon the type of equipment that the dyer has available, the type of pumping sequence and dye cycle being employed. These have to be chosen carefully by the dyer to ensure good shade uniformity from batch to batch and also to give the most economic use of the equipment.

Owing to the necessity of making a soft edge on the package, dye packs, particularly if interlaced, show a marked tendency towards overthrows. Though the use of high wind angles and low take-up tension help in overcoming this tendency it is always present and can occasionally cause problems.

4.4.2 Rigid (non-compressible) dye packs

Much of what has been written above regarding compressible-tube products can also be applied to a rigid-tube dye pack. However, there are some exceptions that must be noted:

1 It is usual for a rigid dye pack to be produced to a higher package density than a compressible-tube product, usually in the range 0.37–

$0.50\,\text{g/cm}^3$ (370–500 g/dl), which after dying closely equates to that of a dyed compressible-tube product. Again these values are chosen to suit the dyers' equipment and process.

2 It is much more common for rigid-tube products to be built with a taper angle of 75 or 80°. This again is to suit both the dyers' process and the unwinding capability of the package. In cases where the packages are produced with a taper, the dyer will use a spacer between each package on the dye spindle to support the packages during the dye process.

3 Owing to the fact that the tube is rigid and cannot be compressed it is possible to build the package in a manner that is much closer to that of a cardboard-tube product. This means winding somewhat harder edges to the package and a wider range of wind angles can be used without giving resulting problems in dyeing or unwinding.

4.5 Machine types and variations

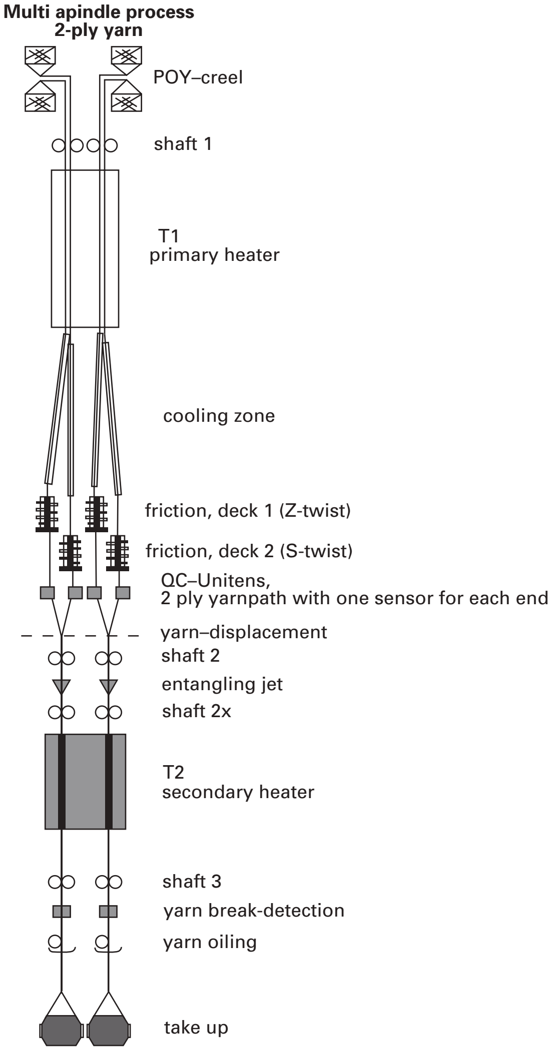
4.5.1 Introduction

At this point it is worth discussing the variety of texturing machines available, though some of these will be discussed in more detail later. Already, mention has been made of contact heater or conventional machines and non-contact or short heater machines. Within these two broad classifications many other variants exist. A standard texturing machine usually consists of individual positions with single thread-lines. This means that if two single ends are combined together to produce a two-ply yarn, effectively half the production capability of the machine is lost, since only half of the available take-up positions can be used. To overcome this, many machine manufacturers produce what are known as double-density machines.

4.5.2 Double-density machine

The double-density machine, shown in Fig. 4.19, is supplied with a doubling of components used to texture the yarn so that all take-up positions on the machine can be used in the manufacture of two-ply products. Thus, the machine is equipped with two creels, two string-up devices, two yarn cutters, two heater tracks, two cooling plates and two friction units (or a single specially manufactured double unit) per take-up position and, where applicable, two on-line sensors and two intermingling jets.

Although these machine types are expensive with regard to both the initial capital cost and the extra amount of floor space required, they can prove to be a sound investment, due to the increased productivity and



4.19 Double density machine. Courtesy of Barmag-Saurer Group.

reduced variable costs per unit weight of yarn produced. In addition to being ideally suited to maximise the production efficiency of the machines when running a two-fold (or two-ply) yarn, this arrangement of shafts opens up other possibilities such as the production of combination yarns. These will be discussed further in Chapter 5.

4.5.3 Multiple-input shaft machine

So-called multiple input shaft machines usually have one, or possibly two, additional feed shafts fitted in the input zone of the machine, though the additional shafts may also be situated at the centre or bottom of the machine dependent upon the type of process (see Section 5.6).

With this arrangement of shafts, each having individual speed control, the possibilities for the manufacture of yarns with properties far removed from those of standard, dyeable, textured yarn become greater than with a conventional machine. There is not only the opportunity to run fibres of different chemical composition side-by-side but also to generate tone-on-tone effects using the same fibre type or to explore the manufacture of core-and-effect-type products. Placing a hotpin or other heating element between the additional feed shafts can further expand the range of possibilities. The addition of these heating elements presents an opportunity to modify the molecular structure of the fibre before it enters the texturing zone. Also it is possible to place an intermingling jet or some other component between these shafts.

Alternative machine arrangements are now finding increased usage for manufacturing yarns which have modified characteristics regarding dye uptake, and both optical and physical effects in fabric. These products are sometimes referred to as novelty or speciality yarn products. Commercially the products have added value, for which a price premium is demanded. These yarn types will be discussed briefly in Chapter 5.

4.6 Plant environment and operating procedures

4.6.1 Plant air conditioning

Ideally both the texturing area and POY storage area should be air conditioned so that temperatures and humidity remain constant all year round. The temperature, and in particular the humidity, has a discernible effect on the efficiency of the texturing process with regard to yarn breaks. This is especially true in the case of nylon yarns, which are extremely sensitive to changes in humidity. Though opinions vary as to exactly what these values should be, those shown below would be typical for the temperature and humidity that the texturing area should be maintained at.

	Temperature (°C)	% Relative humidity
Polyester	21.5 ± 1	52 ± 2
Nylon	22.5 ± 1	58 ± 2

4.6.2 Lighting

Lighting should be maintained to high standards with sufficient light available to allow all operations to be carried out efficiently without the added strain of working in poor lighting. There is no substitute for natural daylight. However, in many instances this is not possible and all areas of the manufacturing plant in which operators are working should be well equipped with overhead lighting, both in the general area and particularly in the machine operating aisles. Operator functions such as splicing POY transfer tails and threading a texturing machine are more easily and successfully accomplished if the lighting is good.

4.6.3 Machine operation and maintenance

4.6.3.1 Machine operation

The operation of a texturing machine requires several different groups of human actions to produce a package of textured yarn:

1. the POY feeder yarn has to be loaded into the creel;
2. the transfer tails of the POY have to be spliced;
3. the yarn has to be threaded manually through the machine;
4. the full-sized textured yarn package has to be doffed.

The performance of these various tasks has to be considered in order to maintain an economic and cost-effective process. The question of whether it is preferred to have specialists for each function or to have each individual operator trained for multitasking needs to be addressed. The solution to this question will obviously differ from location to location dependent on the management philosophy of the operation.

However, no matter which scheme of operation is chosen, there should be a standardised procedure for each of these separate tasks. By having standardised procedures, which are regularly audited to ensure they are being observed, it is possible to maintain consistency from person to person and thus reduce the incidence of operator faults.

4.6.3.2 Machine maintenance

Like all machines, texturing machines will break down and require repair. Also as a matter of necessity they require a certain amount of routine maintenance to keep them in prime order. Again, the manner in which maintenance is planned for the texturing machine will vary from location to location. Dependent on the size of the operation, maintenance may be on an *ad hoc* (as needs) basis or a more formal structured approach may be applied.

It is usually the case that a machine is taken out of service at regular intervals to be cleaned and to receive routine maintenance to ensure maximum efficiency. The exact interval during which a machine is run between these cleaning and servicing procedures will depend not only upon the type of machine but also upon the nature of the product and process. It may be prudent to schedule a thorough maintenance program on the machines for replacement of wear items at longer intervals of possibly one to two years, again dependent on the philosophy of the operation.

As with any routine procedure, it is sensible to have clear standardised methods that are always followed. This not only applies to routine cleaning and servicing of the machine but to all maintenance undertakings ranging from the simple replacement of a fuse to a complete overhaul of the machine. In addition to having standardised methods for carrying out maintenance programs, accurate records should be kept of what work is carried out, the causes of any unplanned machine stops and of high usage of any particular spare parts. By maintaining such records, it is possible to isolate the causes of these stoppages and, armed with this information, to go back to the machine manufacturer or component supplier in order to seek redress or make improvements.

4.7 Safety

As with all machinery that employs high-speed rotating parts the operator working the machine must be made aware of the associated dangers. Unfortunately, owing to the nature of the process it is not always possible to shield these rotating parts adequately and thus ensure freedom from hazards. For this reason high standards of awareness of these dangers must be communicated to anyone working with these machines. Long hair should be safely secured under a hat, rings and other jewellery should be removed and loose clothing, particularly ties, should be avoided.

Many textile processes also involve the use of high temperatures. Here also awareness of the hazards involved should be clearly communicated to everyone involved and appropriate procedures adopted for the maintenance of a safe working environment.

Eye protection should be available for use when working on machines. This is particularly necessary when cleaning machines owing to the possibility of yarn fly and snow deposits being swept into the eyes. Safety shoes are also advisable.

Textile machinery has one other hazard present. It is a source of high-volume, high-frequency noise, especially if equipped with intermingling jets. For this reason ear protection should be mandatory in all textile plants.

Any motorised mobile equipment used should be fitted with both audible and visual warning devices. They should be routinely serviced to ensure maximum safety of the operators in the area.

Safety and the maintenance of an efficient and viable manufacturing plant should be treated as being equally important. Regular safety inspections of all aspects of the plant environment should be actively pursued and accurate records should be kept of any accident or incident. This is particularly relevant in case any litigation should arise.

Should any member of the workforce be found to be infringing safety procedures, no matter at what level, this should be treated as a serious matter and where necessary disciplinary action should be taken.

4.8 Product integrity

Good housekeeping and the maintenance of the manufacturing environment in a clean and well-ordered condition are a necessary part of any textile operation. Not only does it make a more pleasant working environment but also it greatly aids in ensuring that the yarn will reach the consumer in good condition and reduces the number of packages downgraded to a lower quality because of dirt or damage.

All items associated with the handling and transport of the textured yarn should be maintained to a high standard of cleanliness and kept in good repair. This is especially true of any mobile equipment that may be employed. There is no more disheartening sight than packages of yarn, which may have taken many hours to produce, being deposited upon the floor in total disarray, caused by a damaged wheel on a yarn truck. This same philosophy also extends to all kinds of yarn packaging employed (this will be expanded upon further in Chapter 9).