6
BCF processes and yarns

6.1 Introduction

It is still possible to buy and certainly to construct a draw-texturing machine for producing BCF yarns. It could even be an economical proposition for making carpet yarns from a readily available feedstock such as polypropylene or polyester POY.

However, the majority of BCF yarns are produced today in a vertical operation in which nylon or polypropylene granules are melted and spun, or polymer is fed directly from continuous polymerisation to spinning, and then both drawn and textured, all in one continuous sequence. This is partly a result of the development of the original stuffer-box texturing process to become what is now a jet-driven process. The process speeds achievable today are high enough to justify direct integration with spinning. The second factor is that comparatively large volumes or lot sizes are required to produce face yarns for carpets. This favours an integrated process with large packages that can be loaded directly into the creel of the tufting machine.

There is also a need for twisted and heat-set yarns in many carpet qualities. The size of the textured yarn package may have to be restricted to that which fits into a two-for-one twister. Modern direct-cabler twisters do accept large packages but there is still a difference between their capacity and that of the creel in the tufting machine, especially with regard to the maximum diameter of the yarn package.

Originally called stuffer-box texturing, the production of BCF yarns consists of the ‘stuffing’ of a single yarn into a constricted body, which is part of the machine. This produces a saw-toothed, two-dimensional structure in the yarn. The simultaneous or following application of heat fixes the yarn structure, since we are dealing with thermoplastic or deformable yarns. The resulting yarn has bulk but no torque. The bulk can be removed by the application of a light tension but returns on relaxing this tension. Being wound under a fairly high tension, the yarn in this state is referred to as having latent bulk properties.

During stuffer-box texturing the heat is applied either by means of heated input rolls or by heating the stuffer-box itself. The process suffered from its origin, which was the type of crimper used to produce staple fibres. These crimpers produced fibre with a given and acceptable variability but the subsequent blending of the fibres masked any slight irregularity in the crimp. For carpet yarns with no opportunity to blend, this variability meant that they could not be used in plain constructions without a rigorous testing and sorting of every package of textured yarn.

The breakthrough results from using a jet and an expanding hot fluid that consists of hot air or steam both to open up the filaments by the turbulence created, and to 'stuff' the now hot yarn against the slower moving plug which forms inside the jet. Cooling takes place after the jet by impinging the yarn on to a cooled, slow-moving surface. It is now the hot fluid and yarn plug rather than the stuffer-box that provide the bulk. It is easier to maintain an accurate control of the fluid temperature and this comes into direct contact with the yarn. Furthermore the bulk is characterised as being three-dimensional.

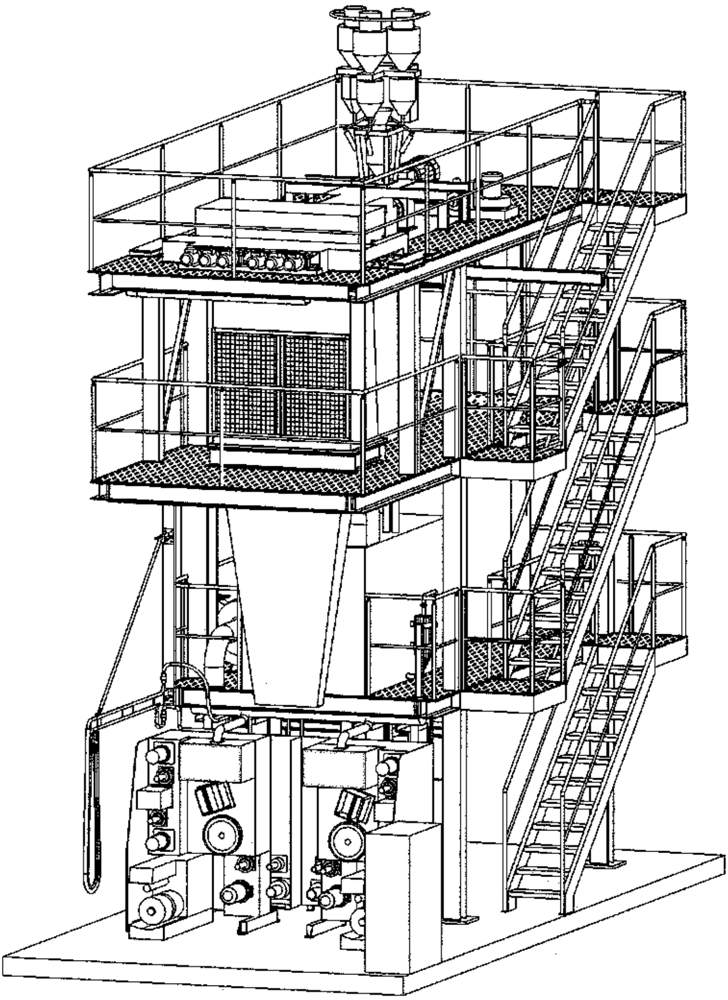
Sequential or predrawing has been a feature of the several generations of stuffer-box machine which were supplied from a creel with undrawn yarn. Even though the newer jet process has been integrated with spinning, it is still necessary to interpose a drawing stage. The heat for drawing is normally provided by heated rolls or godets.

6.2 BCF draw-texturing machine

6.2.1 Layout of the BCF machine

Unlike the false-twist texturing machine the integrated process does not have a yarn creel, since the starting material is polymer in the form of chips (also known as granulate). The polymer chips are normally washed and dried by the polymer supplier. In the spinning plant the chips are kept under an atmosphere of nitrogen to prevent moisture being reabsorbed by the polymer. The dry polymer chips are melted in an extruder and pumped through a spinneret. The number of holes in the spinneret determines the number of filaments in the yarn (or component of the final yarn, since several yarns may be combined at a later stage of the process). After quenching and application of spin finish the 'as-spun' yarn is ready to enter the draw-texturing section. Whereas the blending, extrusion, spinning and quenching take place on various floors of the plant, starting from the top, the draw-texturing machine is located on the ground (first) floor.

Since each position of the draw-texturing section, located as it is below its own spinning head, must be capable of being stopped and started and adjusted in synchronisation with the spinning head, there is no line-shaft drive as in a false-twist texturing machine. Each position consists of driven rolls (also known as godets), mostly being heated, as well as a texturing unit, a yarn entanglement or interlacing section and of course the winding or take-up head. All of these elements will be described below in the order that they occur in the process. The general layout of a typical spin-draw texturing plant for the production of BCF yarns is shown in Fig. 6.1.



6.1 Layout of BCF spin-draw texturing plant. Courtesy of Rieter Textile Systems.

6.2.2 Finish application

Before the freshly spun (extruded) filaments can be handled, i.e. touched in any way, they need to solidify and to be lubricated. The lubricant, which is known as a spin finish, is applied immediately below the quench, either by means of a lick roll or by a ceramic applicator.

Lick rolls comprise slowly rotating rolls with a sintered or porous surface, which both dip in a trough containing the lubricant and touch the passing yarn in order to apply a uniform quantity of spin finish to the filaments. The applicator comprises a metered system, since all of the lubricant applied remains on the yarn unless the level of application is set too high, in which case dripping will be visible. The advantages of the applicator method lie in the metering, which means that the quantity applied is known and that the applied finish is always fresh and not recirculated as with the lick roll.

Both methods rely on an even application to all the filaments. This is not always easy to achieve, especially if a high number of filaments is present. With carpet yarns the number can vary from 34 to 136 per thread-line. Special air-jets can be used which spread the finish evenly over all of the filaments. It should be noted that the filament cross-section also influences the quantity of finish that can be carried by a specific yarn.

6.2.3 Drawing

In common with other jet-texturing processes and in contrast with false-twist texturing, the drawing process must be completed before texturing commences. Nylon can be drawn cold, but in practice the draw forces are reduced considerably by the application of heat. Otherwise larger motors, shafts and bearings would be required and the power consumed by the inverter drives would increase. In any case, the yarn has to be heated as a prerequisite of bulk texturing. The heated rolls are fitted in pairs. They can be both driven and angled towards each other to facilitate the wrapping of the yarn or else one can be a driven heated roll and the other a separator roll, which is neither heated nor driven. The former pairing is often known as a ‘duo’. In both cases the objective is to wrap the yarn bundle around the heated roll with several wraps (up to ten), in order to allow time for the heat to penetrate the filaments uniformly. The wraps must not touch each other, in spite of an inevitable slight wandering. Quite obviously the temperature profile of the heated roll must be consistent, not only between rolls, but also along the working surface of each roll.

The drawing takes place in two stages. A roll, which is not usually heated, draws off the yarn from the spinneret, past the quench (cooling) and over the spin-finish applicator. As soon as the filaments start to solidify, the pull exerted by the surface speed of this roll draws the filaments. In other words the weight per unit length of each filament (its denier) is already lower when it reaches this draw-off roll compared with its state at the spinneret. A low stretch of 1–2% is applied between the draw-off roll and the first of the duos in the draw zone, in order to ensure a light but constant input tension.

The main drawing takes place between two duos, each of which consists of a pair of heated rolls. The first pair is heated to between 50 and 90°C. The second pair is heated to a higher temperature. The first application of heat is to assist drawing by locating the draw point where the filaments leave the first duo and by reducing the drawing tension. The stability of drawing is determined by the location of the draw point. The location is the result of a complex relationship between the friction between the now warm filaments and the roll surface and the draw tension exerted by the second duo.

The purpose of the second application of heat is to set the freshly drawn yarn and also to raise its temperature to something close to that of the texturing jet, which it is about to enter. This facilitates the bulking process in the jet, which takes place at a sustained, elevated temperature (see Section 6.2.4 below).

A draw ratio is applied between the two roll duos. This ratio (as well as the applied temperature) depends on the material being processed (see Section 6.4.2 below) but can vary between 1.5 and 4.0. By this means the filament denier is reduced to a level which is fairly close to that which obtains in the final product – the carpet pile or tuft.

Motors drive the rolls and in fact the rotating part of the roll is usually mounted directly on to an extension of the motor shaft. The individual motors are invariably inverter-driven and are of the reluctance type. This allows the speed of rotation and the ratios to be selected and varied with ease. The draw ratio is that between the first and second draw-roll pair or duo in the drawing zone. Too high a draw ratio can lead to filament breaks and sometimes to yarn breaks. These can have a disastrous effect on the efficiency of such a high-production, continuous process. If the draw ratio is too low the yarn physical properties will not be adequate for application in the carpet and may even prevent the bulking jet from performing correctly.

Under normal circumstances the second pair of heated rolls runs at the highest surface speed of any component during the continuous process. The demands both on the accurate control of the speed of rotation and of the temperature of the heater within each roll are high. Various heating methods are used by the machinery manufacturers including vapour phase, high-frequency and induction heating.

Vapour-phase heaters work on the same principle as the conventional contact heaters used in false-twist texturing (see Section 4.2.7). The roll is self-contained and the liquid inside is heated by an induction heater within the roll to produce the vapour. As heat is taken away from the roll surface by the yarn, which is initially colder than the roll, the vapour condenses on the inside surface of the roll to replace the heat loss. Since the temperature of the vapour is controlled very accurately, this system results in the heat being supplied to the roll surface precisely as demanded by the yarn. A very uniform operating temperature is the result.

Induction heaters provide an alternative and very efficient method of heating the roll surface and hence the yarn. This is because they can be so designed that the heat is induced mainly in the outer shell of the roll. For higher temperatures the induction heater core must be of a laminated design to reduce eddy current losses and to prevent an unwanted rise in the core temperature.

Radiant and resistance heaters are also used. The former method is more suitable for rolls of large diameter (>250 mm) and conversely the resistance heater only finds favour for rolls of diameter between 80 and 120 mm.

Depending on the process, the temperature sensors are either embedded in the roll shell or located in a slot at the rear of the roll. To preserve heat and to save energy, the heated roll pairs (duos) are usually housed in an insulated box with doors for access. The rolls used for BCF drawing and processing operate within the range 50–200°C.

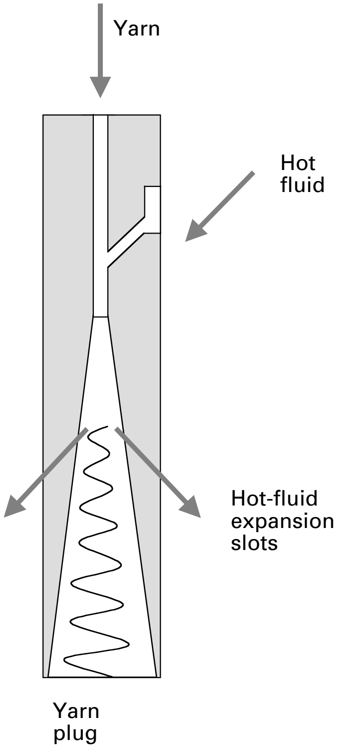
6.2.4 Texturing by hot-fluid jet

The texturing zone follows the drawing and comprises preheating, hot-fluid texturing and cooling sections. The preheating is carried out by means of the second roll duo described in the previous section.

6.2.4.1 Hot-fluid jets

Hot-fluid jets have been the subject of many patents since the early 1970s. These more often than not cover novel methods of generating a hot and turbulent fluid into which the yarn is fed. The jets are so designed that there is a forwarding action on the yarn to assist its passage through the jet. The turbulence within the jet does greatly improve the transfer of heat from the fluid to the yarn. Finally the expansion of the hot fluid within the jet and its escape is an important feature of successful jet design. The principles of a hot-fluid texturing jet are illustrated in Fig. 6.2.

It is the compression of the filaments and the formation into a yarn plug whilst hot which causes the properties of bulk to be imparted to the yarn. Since the yarn is hot, the deformation of the individual filaments results in the well-known, three-dimensional yarn crimp, which is the characteristic of a BCF yarn.

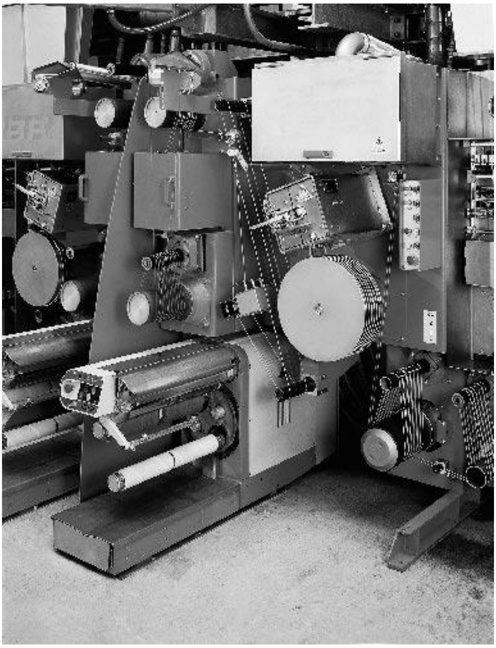


6.2 Principle of hot-fluid texturing jet. Courtesy of Rieter Textile Systems.

In the original stuffer-box it is fibre-to-metal friction and a restricted space which are the prime factors that produce the yarn plug formation. It is the expansion of hot air or steam, and the consequent reduction in its velocity, which slows down the progress of the filaments through the jet and forms the yarn plug in the hot-fluid jet.

When the hot fluid enters the jet its high pressure causes it to enter with a high velocity and degree of turbulence and to carry the filaments forward. However, the design of the jet enables the fluid to expand as it passes through the jet and therefore to slow down. This retards the forward movement of the yarn and causes a plug to form.

Modern jets must have an opening mechanism; otherwise the threading would be impossible in this, a continuous process. Furthermore the jets are usually supplied for two, three or four thread-lines. This is quite a challenge and the hot-fluid jet is a good example of modern precision engineering. It is also necessary to use corrosion-resistant and hardwearing materials. Hot air is commonly used for the jet but there are plants where steam is preferred (see Section 6.3.7).

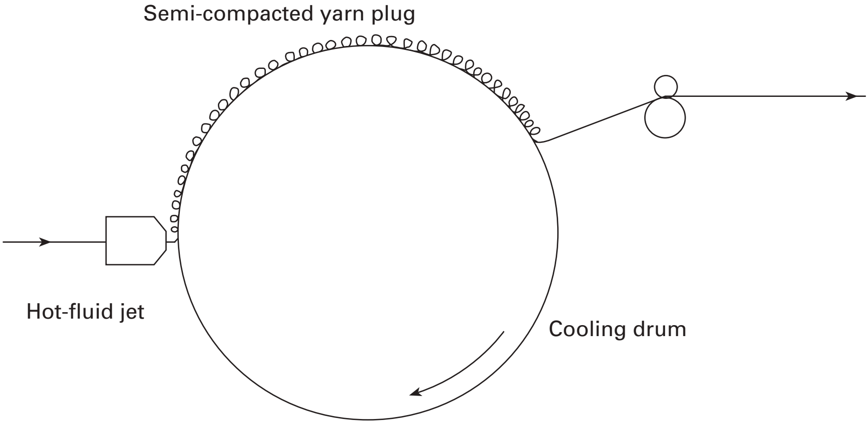


6.3 Close-up of BCF draw-texturing machine. Coutresy of Rieter Textile Systems.

6.2.4.2 Cooling zone

In contrast with cold-fluid or air-texturing jets, it is not the turbulence which causes the bulk formation but rather the constraint on the movement of the hot yarn during its passage through the jet. However, the bulk is not permanent unless it is retained whilst the yarn is cooled. The physical shape of the cooling device varies but most often it consists of a slow-moving, cooled surface on to which the hot yarn plug is impinged.

Figure 6.3 shows a typical cooling drum as well as a hot-fluid jet. Figure 6.4 shows the principle of the cooling drum. Typically it consists of a rotating drum with a mesh surface through which air is drawn. The ambient air passes through the bulked yarn, which is still in the form of a plug though less compressed, and this passage of air provides the required cooling. It is the combination of the flow of fluid in the jet, its regulated temperature, flow and pressure and the action of this cooling drum that determines the uniformity of texture in the yarn. A monomer extraction device may also be provided for fume removal.



6.4 Principle of yarn plug and cooling drum. Courtesy of University of Manchester Institute of Science and Technology.

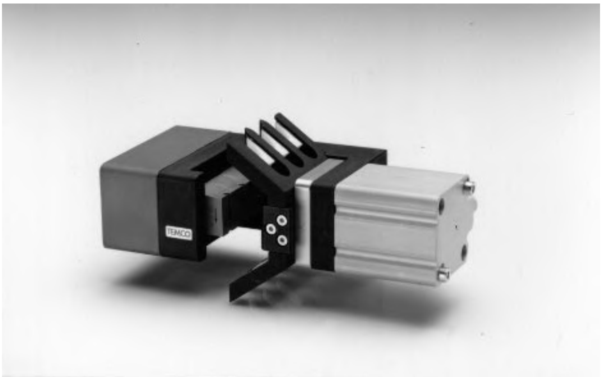
6.2.5 Relaxation and entanglement

A further pair of roll duos is provided after the texturing zone. This allows the freshly textured yarn to be relaxed and entanglement to take place. Entanglement by air-jet is important, especially for yarns which go directly to the tufting process. The jets work on the same principle as those used in the false-twist process (see Section 5.3.2.1). Only the size and therefore the air consumption are greater. For this reason the jets are normally housed in a sound-proof box and are located between the duo pair. The rolls are capable of introducing relaxation by having the first pair running faster than the second (the opposite of drawing). By this means the yarn tension in the jet can be optimised. Thus the efficiency of entanglement is improved with both more frequent and uniform interlacing and lower air consumption.

Figure 6.5 shows the intermingling jet produced by *Temco*. The jet has an opening mechanism to facilitate threading. The version shown is for three thread-lines and has plates designated LD 32 04. The guiding of the yarn through the jet is important especially when three components of different colours are being combined. Other jets for intermingling BCF yarns are produced by *Heberlein.*

6.2.6 Winding

Watching the operation of the automatic winding heads fitted to the *J0/10 Rietex* at work gives a fair indication of the advances in engineering that have taken place during the evolution of the texturing process. Automation



6.5 Entangling jet. Courtesy of Temco Textilmaschinenkomponenten GmbH & Co.

at this stage of the the process not only reduces the demands on labour but also ensures a consistent package build from the start of the package. Waste is reduced to a minimum and the package size is consistent. Furthermore the operators do not have to be present at the precise time of doffing. It is hardly surprising that automatic winding is used so widely in BCF production when production rates of 85–100 kg/head/hour are considered to be normal. The weight of each package is 5–15 kg and two (or even four) yarns are wound side-by-side. The doff-times for each package range from 20 minutes to as low as eight minutes for the smaller packages destined for cabling. Apart from the straight-sided package build and shorter doff-times, much of what has already been written in earlier chapters about package wind quality and variation applies also to BCF yarn production.

The winders are large in size, since they wind up to four packages of yarn on one spindle. They must be capable of up to 5000 m/min and the very high rates of traversing and the resulting high forces as the traverse guide reverses at the edge of the package have led to some unique designs. One of these is the *Birotor* fitted to the *Barmag* range of BCF machines. It consists of a purely rotary action of two vanes that produces the required traversing motion of the yarn from one end of the package to the other. Thus it is only the weight of the yarn and not that of the traversing guide mechanism that is being reversed.

6.3 Process variables

6.3.1 Polymer granulate

In a single-stage process there is considerable scope for influencing the end product before the draw-texturing stage is reached. Quite apart from the type of polymer granulate and the additives for delustring, reducing static and reducing the soiling, the type of spinneret used for extrusion determines the number of filaments and their cross-section. In addition the speed of the spinning pumps alters the as-spun yarn denier. The temperature at extrusion also influences the physical properties of the finished yarn. Some polymer chips, especially polyester, require extensive and controlled drying before reaching the melting stage in the extruder.

6.3.2 Spun-dyed yarns

Perhaps the greatest single variable at this stage is the choice and proportion of masterbatch consisting of pigmented polymer granules. Masterbatch is blended in with the natural polymer by means of dosage equipment and determines the final colour of the yarn. Undesirable variability in colour therefore depends on both the quality (uniformity) of the masterbatch and the accuracy and reliability of the dosing procedure. Natural and masterbatch polymer chips are metered by either volumetric or gravimetric means into the extruder.

Perhaps it seems strange for a process involving coloration to be so dependent on the skills of the masterbatch supplier. Colour matching is a special skill and it is understandable that many of the manufacturers of dyestuffs should also add to their skills by supplying pigmented polymer to match exactly the customers' requirements.

6.3.3 Extrusion (spinning)

The polymer chips having been melted and mixed in the extruder, the melt is distributed to the spinning packs containing the spinnerets via a spinning beam. The main purpose of the spinning beam is to maintain an absolutely uniform temperature of the molten polymer whilst distributing it to the spinning heads. The melt is fed into each spinning pack by a metering pump. The spinning pack contains both a filter and the spinneret. For this reason the spinning pack must be capable of being changed, since filters need replacing at predetermined or monitored intervals. This means that the spinning position must be stopped, however briefly, to allow the changeover to take place.

The pumps are inverter-driven and, together with the first rolls of the draw unit, determine the spun denier of the product. The extruder melts the polymer by means of barrel heaters, which are usually of the induction type. The extruder screw itself performs work on the molten polymer as well as providing a mixing function.

The spinning beam, pumps and spin packs are maintained at a uniform temperature and this is critical for good product quality. The temperature depends upon the polymer material. Nylon is spun at around 260–280°C whereas polypropylene, mostly spun-dyed, is usually extruded with a melt temperature within the range 230–240°C. The temperature uniformity is maintained using the same vapour phase principle as is used with contact heaters in the false-twist process (see Section 4.2.7.1). However, the large volume to be heated necessitates the use of a separate boiler and jacketed pipework.

For polypropylene it is possible to heat the spinning beam, pumps and packs using electrical heating. There is a considerable saving in capital cost but the maintenance of a uniform temperature throughout the process requires very skilful design to ensure even heat flow.

6.3.4 Three-colour spinning

An important development, which is unique to BCF yarn production, is the extrusion of three pigmented yarns in one machine. The three colours are spun from different masterbatch blends in three separate extruders. The spinning beams are so arranged that the spin packs of the three colours are situated side-by-side above the respective draw-texturing machine position. The principle of three-colour spinning machines is shown in Fig. 6.6.

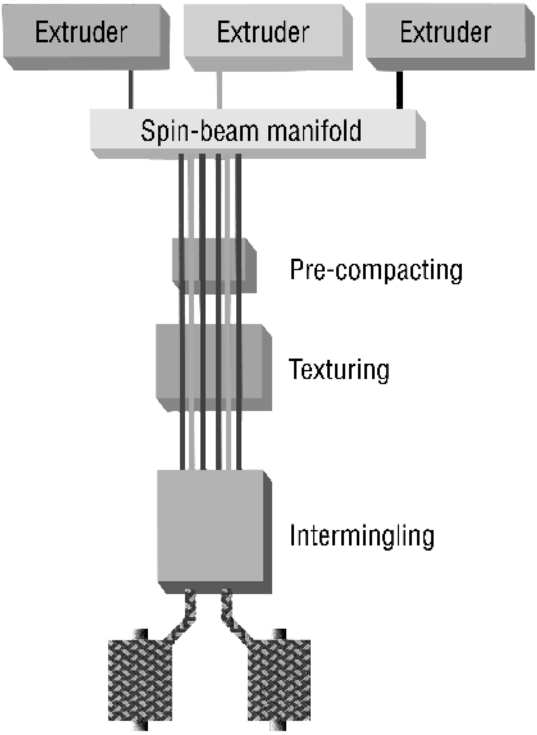
6.3.5 Hot drawing

The effect of increasing draw ratio should be obvious. It reduces the denier of the final product, as with all drawing processes. Although limited by the molecular structure of the as-spun yarn, the yarn strength will also increase and the elongation decrease.

Remembering that the yarn has been partly drawn between the spinneret and the draw-off roll, the temperature of the first duo is adjusted to suit the material being processed. Nylon (which can be drawn cold) is normally drawn with roll temperatures of 50–60°C. Polypropylene requires roll temperatures of 80–90°C.

The second duo is heated to match or come close to the hot fluid applied in the texturing jet. The resultant softening of the filaments reduces the energy required to heat and deform the yarn plug once it is inside the jet. It is also desirable for the yarn to experience a gradual rise in temperature, rather than for it to rise, fall and rise again before it reaches the cooling drum.

Adjustments to speed are made at an operating station using a keyboard with screen to indicate the settings made. The input to the inverter drive is digital. The speeds are given in metres/minute corresponding to the surface speed of the corresponding roll duo.



6.6 Three-colour BCF process. Courtesy of Rieter Textile Systems.

Similarly roll temperatures are set digitally at the keyboard and displayed on the screen. Alarm systems are incorporated to warn of divergences. They can be programmed to operate a visual and acoustic alarm signal and even to cut the yarn at the input to the draw-texturing machine. In this case the yarn is diverted to waste through a suction nozzle, in order to prevent faulty yarn from being wound. Many yarn producers regard this procedure as brutal and wasteful. For this reason on-line monitoring is likely to become the practice of the future. In a fully monitored process, the temperature control system software can 'flag' the yarn package so that it is automatically downgraded during the packing process.

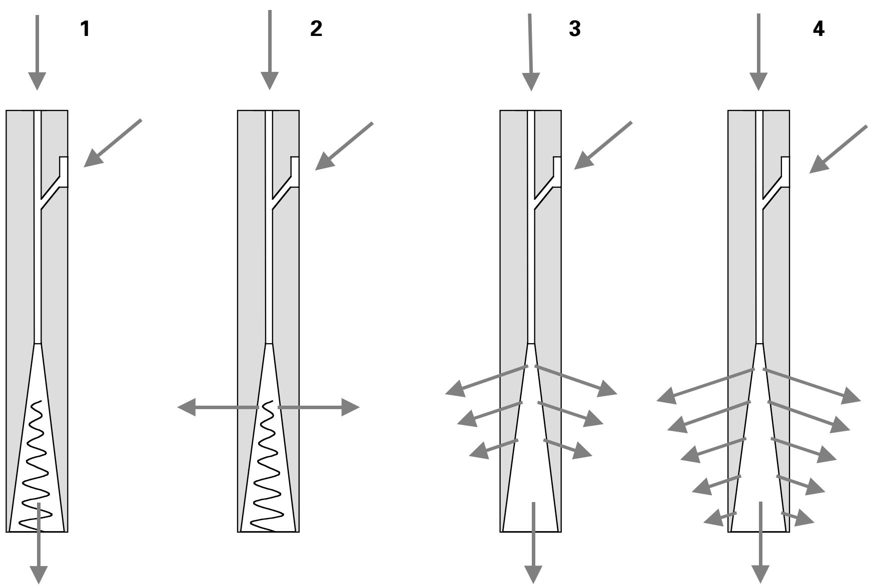
6.3.6 Hot-fluid texturing – Air

The major variable is the air temperature followed by the air pressure. For nylon (specifically nylon 66) temperatures range from 200–220°C whereas polypropylene requires a lower air temperature in the range 140–160°C. An in-line heater system, allowing rapid and accurate adjustment and control of the temperature, heats the air. There is both an indication and an alarm function built into the control software.

The second variable, namely the air pressure, affects the turbulence within the jet. This will influence the heat transfer from air to yarn, although its influence on yarn properties is secondary. The air pressure range is approximately 5–8 bar.

It is important to note that the final bulk in the yarn is influenced not only by the conditions within the jet but also by its whole temperature history from melt to final package ready for tufting or weaving. This applies to all thermoplastic yarns.

The third variable within the jet is the escape of the hot fluid (see Fig. 6.7). This is a design feature of most jets. Though not a process variable it does play an important part in determining the density of the yarn plug and thus influences the bulk characteristics of the yarn. Figure 6.7 shows clearly that a restricted escape of fluid as shown in 1 and 2 causes the formation of the yarn plug and with it the three-dimensional crimp, though this is not permanent at this stage. On the other hand unrestricted escape by the hot fluid as shown in 4 results in no yarn plug and no bulk.



6.7 Flow-controlled plug formation in jet. Courtesy of Rieter Textile Systems.

6.3.7 Hot-fluid texturing – Steam

The use of steam has advantages and disadvantages compared with a hot-air jet process. The infrastructure required to generate steam and to remove condensate is more complex and costly. This does not, however, apply in all cases. There are plants where steam is already available as a piped supply. Examples of the type of plant where steam is consumed include yarn-dyeing operations and also melt-spinning plants for nylon 66.

There is a close correlation between steam pressure and temperature. However, for fluid-texturing the steam is superheated using in-line heaters, in order to attain the elevated temperatures required for good bulking, without the necessity of designing a jet and manifold to operate at very high pressures. For example superheated steam supplied to the texturing jet at 195°C requires a manifold pressure of around 10 bar. Steam usage depends on many factors but a rough guide is that 1 kg of steam is required to process 1 kg of yarn.

6.3.8 Cooling zone

Both the cooling drum and the following duos are rotating at constant speeds. The rate at which fresh, processed yarn emerges from the jet is dependent on its bulk. The length of time that the yarn spends on the drum before it is drawn off is therefore a control measure of its bulk. Photoelectric or infrared sensors are used sometimes to monitor this. The information can be recorded and used to trigger alarms or it can be fed back to control a process variable such as the steam temperature. Closed-loop control is practised with some processes, notably those based on the *Fibre M* principle (see Section 6.3.11).

How often control feedback is applied in industry depends on the stability of the process. Quite clearly a stable process does not require this extra complication and therefore stability should be the prime target for any texturing operation.

The cooling is achieved by means of extraction or suction of air from the inside of the cooling drum, which has a perforated surface. The cooling should be just sufficient to the point where the subsequent handling of the yarn, i.e. relaxation, entanglement and winding, can take place without loss of bulk. The cooling does not have a direct influence upon the final yarn properties unless it is inadequately applied. However, it is only by cooling the yarn plug while it is still in a deformed state that permanent bulk can be imparted to a thermoplastic yarn.

The process variables in this part of the process consist of the surface speed of the cooling drum relative to the output of yarn from the bulking jet and the setting of the extraction fan to increase or decrease the rate of cooling. It should be noted that the yarn leaves the jet and is deposited on the cooling drum in a bulked and partly compacted form (see Fig. 6.3).

6.3.9 Entanglement and relaxation

As with all entanglement or intermingling processes, it is the design of the entanglement jet that has the greatest influence upon the yarn. This means that the yarn channel width and shape and the air inlet must be chosen to suit the yarn being processed. The jet specification must define both the orifice and the air inlet channel dimensions as well as the angle that the air inlet channel makes with the yarn channel.

The yarn channel must bear some relationship to the total yarn count, since jets do not work effectively if the channel is too big or if it is stuffed full of yarn. The air orifice size determines the amount of energy available for entangling from a given air manifold pressure. The formula for calculating the air consumption, q_{vn}, for a jet of known dimensions is as follows:

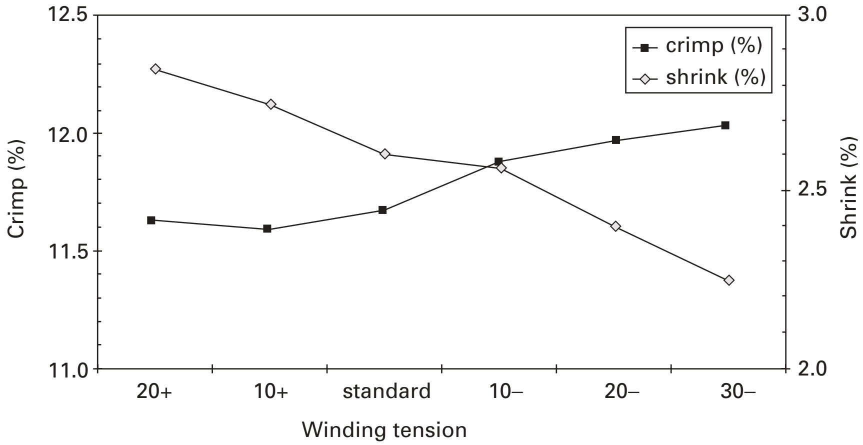
$$q_{\mathrm{vn}} = F(1+p_{\mathrm{e}})\,\mathrm{m}^3/\mathrm{hr} \qquad (\text{or } q_{\mathrm{vn}}/1.58 \text{ in cfm}) \qquad [6.1]$$

where F is a factor equal to $0.4648 \times d^2 \times n$, p_e is the pressure in bar (1 bar = 100 kPa), d is the diameter of each air hole in mm and n is the number of air holes.

If the jet is located between two independently driven rolls, the yarn tension through the jet can be optimised by adjusting the relative speed of the rolls. If the jets are mounted immediately before the winder some forwarding action from the airflow in the jet is desirable. This is especially helpful in maintaining yarn tension during doffing and thus in reducing yarn breaks or wraps at this point.

Most air-jets have a recommended range of air pressures. Within this range, the higher the pressure the more tightly locked are the knots. Too low a pressure can also lead to irregular knot formation. Some air-jets produce a higher knot frequency with higher air pressures. Others exhibit a flatter curve within the operating range (see Section 5.10). A typical entanglement jet used for BCF yarns was shown in Fig. 6.5. The jet is operated using air pressures in the range 4–10 bar (400–1000 kPa) and the air consumption lies between 20 and 70 m^3/hr per yarn.

If the yarn is destined for tufting without twisting and heat-setting, the entanglement is important for efficient processing of the textured yarn. This can be influenced by a further input of heat under relaxed conditions. In practice this means that one or both of the rolls between the cooling zone and the automatic winder can be heated as a process option. Since the relative speed or overfeed can also be adjusted to give a correspondingly low yarn tension between these relaxation rolls, it is possible to reduce the residual shrinkage of the textured yarn as well as to impart good entanglement



6.8 Influence of winding tension. Courtesy of CENTEXBEL.

properties. However, most carpet yarns are heat-set as part of a following process and not during draw-texturing.

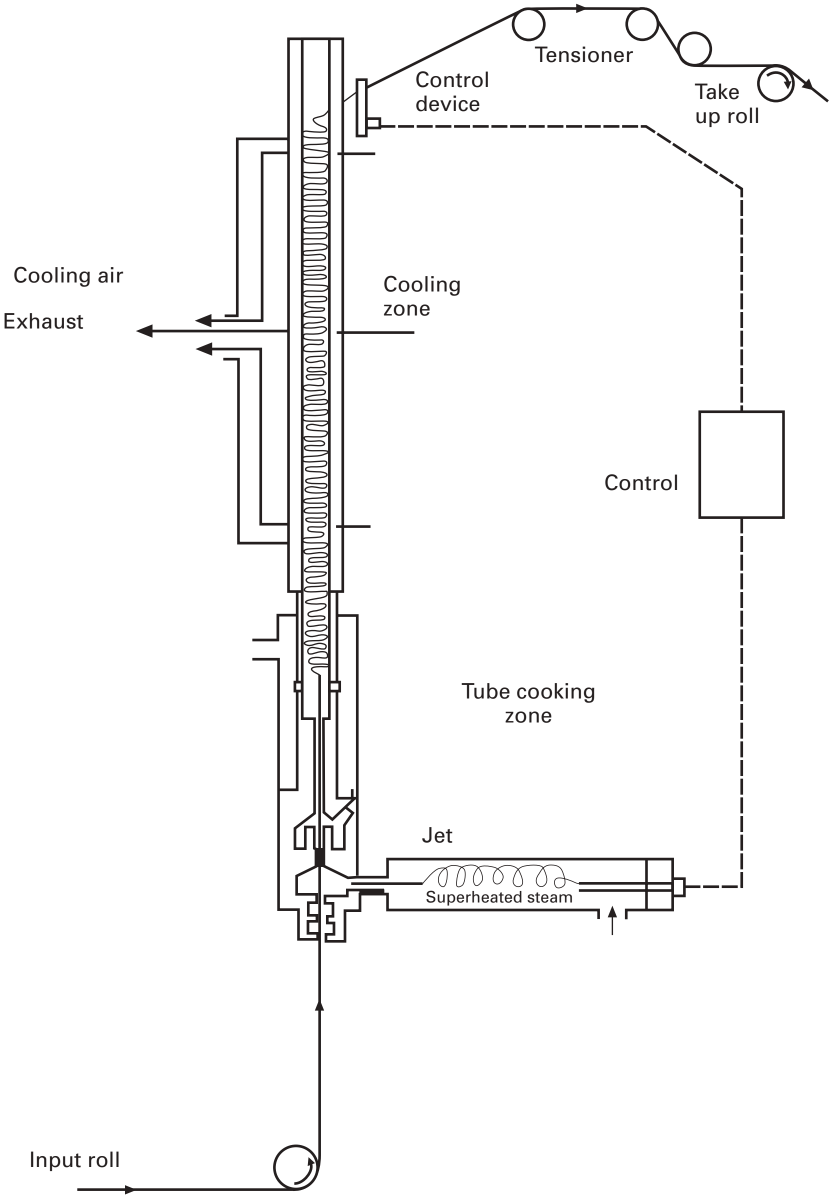
6.3.10 Winding

Although winding is not normally considered to be a process variable, the nature of the latent bulk in a BCF yarn means that winding tension does have some influence on yarn properties. Figure 6.8 shows that an increase in the winding tension will reduce the crimp in the textured yarn but will also result in an increased residual shrinkage. If not monitored closely it therefore follows that an incorrect winding tension can cause visible faults in the finished carpet.

6.3.11 Process control

As we have seen, the process must be very stable in order to produce first-quality carpet yarn. By measuring the yarn bulk and using the measured value as feedback to alter the bulking temperature, the stability of the process can be secured and in some cases improved.

The example shown in Fig. 6.9 demonstrates a principle that can be applied to all hot-fluid jet processes. In this case, it is a steam jet and the yarn plug forms vertically above the jet. Since the yarn enters the jet at a constant rate and is also drawn off with a different, but constant, velocity the height of the yarn plug is proportional to the yarn bulk. Thus the height of the plug is measured by photocell. In order to introduce a more elegant proportional control, four cells are in fact used. This system is used in



6.9 Fibre M process – control loop. Courtesy of UMIST.

production and it has been shown that a more uniform steam bulk results from its use. The level appearance of a carpet yarn is due both to the dye uptake and the uniform reflectance of light as a result of its controlled level of bulk. The same control principle can be applied to the deposition of the yarn plug on to the cooling drum and to the point at which it leaves the drum, remembering that it is being withdrawn at a constant rate.

6.4 BCF yarns

6.4.1 Yarn form

Since all the yarns described in this chapter are destined for furnishing fabrics, in most cases specifically for carpets, the final form of the yarn is the same or similar, whether the starting material is nylon, polypropylene or polyester. The requirements for woven and tufted carpets do differ. Tufting machines are fed usually from spacious creels. Large, textured yarn packages are needed to allow a maximum run time during tufting. The size is limited by the winder or by the size of the creel on the tufting machine.

Very few BCF yarns are dyed after texturing. Coloration is most commonly achieved either by using pigment dyes in the polymer in the form of masterbatch or by dyeing or printing the finished carpet. There is a process by which yarns are printed, which is known as space dyeing. In this process the BCF yarn is passed through a printing head with several colours. It is a package-to-package process.

The major factor which affects the choice of yarn package size is the requirement of many cut-pile carpet constructions that the BCF yarn is first twisted and heat-set. Since the twisting is often combined with plying, special machines have been developed. One of these, is a direct-cabling machine made by *Volkmann* of the *Saurer Group* and known as the *VTS-05 Carpet Cabler*, based on the two-for-one twisting principle with the additional feature of being able to twist and ply in one stage. However, the two-for-one spindle into which the BCF textured yarn package has to be placed imposes a size limitation. Typically direct-cabling machines can accept packages with an outside diameter of 285 mm compared with a maximum of 400 mm on many automatic package winders.

Following this the yarn is heat-set using steam or hot air. The fact that the yarn is heat-set after twisting affects the post-texturing conditions in the BCF draw-texturing machine. The principles by which heat-setting machines for carpet yarn operate do differ but they all allow heat to be applied to the yarn in a relaxed state. The time that the yarn is subjected to heat is also adjustable. After passing through the process the yarn is wound and is ready for tufting or weaving. *Superba* and *Suessen* make the most commonly used machines for heat-setting carpet yarns. The former employs pressurised steam heat and the latter dry heat.

The designation of BCF yarns is similar to that employed for false-twist textured yarns (see Section 5.2). An additional category is provided by the description of a twist-set yarn.

6.4.2 Fibre materials

6.4.2.1 Nylon

The most commonly used continuous-filament material for carpet-face yarns is polyamide, which is known as nylon (6 and 66) throughout most of the world. For pile applications the filaments are coarser than those used in other texturing processes, notably >10 dtex/filament, since tuft and loop resilience is an important property of the yarn in a carpet. The total range of yarns produced lies between 600 and 3000 denier (660–3300 dtex). The subsequent twisting and plying (cabling) process often used results in a carpet-pile yarn with up to three times the count of the as-textured product.

Filament cross-sections vary but trilobal is by far the most common. This is because a BCF yarn made from filaments having a trilobal cross-section has the desired light reflectance and soil-hiding properties. The trilobal-filament cross-section is chosen not only because of the light reflectance properties but also because the shape effectively increases the bulk of the yarn and hence the cover in the carpet. In addition a delustrant is usually added to the polymer.

Although spun-dyed nylon carpet yarns are growing in importance and have been available for a long time in one or two basic colours, mainly black, most nylon carpet yarn is still spun, drawn and textured as écru (undyed). The carpet is produced as a greige fabric before dyeing or printing to order.

Dyed carpets are not necessarily plain. Cross-dyed effects are common as a result of a combination of nylon filaments having different dye affinities or by using a spun-dyed combined with an écru yarn. There are also effective carpet printing processes. Printed carpets are often seen in airports and hotels, since the very large pattern areas that are possible with this process are highly visible and can be produced by this method.

Spun-dyed yarns in carpets offer several advantages. First, the achievable colours are brighter. The whole of the filament cross-section has a uniform colour whereas many dyestuffs only react with the skin of the filament surface. The trilobal cross-section enhances the colour, especially when the whole filament is coloured. Furthermore the colour-fastness including the resistance to bleaching is greater with a spun-dyed product.

The properties of carpet yarns made from BCF nylon are very good in terms of resistance to wear and tear in the carpet. Nylon carpet yarns have the outstanding property of high resilience, which is important for a carpet tuft. If suitably treated, carpets made from BCF nylon retain good anti-soiling characteristics and can be treated also to reduce static.

6.4.2.2 *Polypropylene*

One major difference between nylon and polypropylene is that the vast majority of polypropylene BCF carpet yarns are spun-dyed. That is to say masterbatches of polypropylene chips having a specific colour are blended accurately with the naturally-coloured chips before extrusion (see Section 6.3.2 above). There are, however, disperse-dyeable grades of polypropylene and new variants are appearing on the market all the time.

Polypropylene BCF is available in a wide range but most commonly from 600–5000 denier (660–5500 dtex). The filaments are similar in shape to those used in nylon carpet yarns with trilobal predominant and for the same reasons.

Because the application depends on the gauge of the tufting machine and resilience is a premium property, textured yarns made from polypropylene resemble those from nylon. The resilience of polypropylene BCF yarn being somewhat lower than nylon, it may be that a slightly thicker filament will be used, in order to achieve the desired carpet quality.

The carpet yarn produced from polypropylene is characterised by its chemical inert properties, its freedom from static and its volume, which arises from its low density. The yarns should cost less to produce as a result of the raw material price (the main raw material is propylene, which is a by-product of oil refining). Also the low density means that higher yields can be expected during the production of carpets.

Since temperatures applied for drawing and heat-relaxing polypropylene are lower than those required for nylon, the machines that are produced solely for processing this fibre may be simpler in concept and therefore supplied at lower cost than those that are capable of processing nylon as well as polypropylene. Processing speeds may also be lower, though the gap is narrowing.

Many machines are capable of producing carpet yarns from both the major fibres. But at least two machines, the *Rieter Pathfinder* and the *Austrofil BCF* by *SML*, have been introduced which are specifically designed for polypropylene fibre.

6.4.2.3 *Polyester*

Polyester BCF yarns are the ones least commonly found in the carpet business. The properties of polyester BCF are similar to those of polypropylene and it is of course a dyeable fibre. However, the main reason for its production is the existence of polyester variants with excellent flame-retardant properties. The range of yarns available is similar to the other two materials, though the total weight actually produced is quite small.

A different approach to the process technology can be made because polyester yarns are so widely available as POY. It is therefore common practice to operate the draw-texturing process in a second stage separated from spinning. There are no carpet yarn machines marketed in Europe which are designed specifically for producing polyester BCF yarns in a single stage. However, the specification of such a machine would not differ greatly from that designed for nylon. Temperatures and speeds would be similar to those used for nylon (nylon 66).

6.4.2.4 Starting materials

Since this book is dedicated to yarn texturing, the starting material for the process covered here is a freshly spun, quenched and lubricated yarn, which may in some cases be coloured. Alternatively three different coloured yarns may have been extruded and combined before, during or after texturing. The three coloured yarns are presented usually to the draw-texturing stage of the process side-by-side. The side-by-side layout is retained at least until after spin-finish application to ensure a more even application of finish to each yarn.

6.5 Modification of yarn properties during draw-texturing

6.5.1 Yarn denier

The denier of the finished yarn is determined by the requirements of carpet tufting or weaving. Furthermore the final denier may be reached by plying, either during spinning and texturing (two or three ends combined at the entanglement jet) or during twisting by cabling and plying.

A second important aspect is the number of ends that are processed through one fluid jet. Quite clearly it makes economic sense to process as much material as possible through a texturing jet up to its maximum capacity. Schellenberg (1984) was one of the first people to report that up to four ends can be processed when finer yarns are being produced. It is necessary to split the ends from the spinneret so that they both enter and leave the jet with separation.

The as-spun denier is a function of the speed of the metering pumps and the draw-off rolls, which in turn provide the input to the drawing section. Since the metering pump and draw-off roll speeds also affect the molecular orientation of the yarn, the relationship is complex and cannot be decided by a simple formula.

Whatever compromises have been made during spinning the relationship for calculating the draw ratio after spinning is simple, namely:

denier before texturing

$$= \text{as-spun denier} \times \frac{\text{output draw-roll surface speed (m/min)}}{\text{input draw roll surface speed (m/min)}} \qquad [6.2]$$

By and large the influence of this draw ratio on the yarn properties is the same as indicated in Section 5.3.1.

6.5.2 Yarn bulk

Miller and Southern (1991) have shown that both yarn bulk (also known as fibre crimp) and dyeability of the finished yarn can cause streaks in carpets, especially in the case of nylon 66. From this it is clear that the property of yarn bulk is very important. Since the tuft sits vertically in the carpet, yarn bulk is related directly to cover. If the yarn is too thin the light reflectance will change and a visible streak will be apparent.

This also means that the bulk must be entirely uniform for the carpet appearance to be acceptable. There are no blending stages after texturing, unless heat-setting is applied. Here Miller (1994) has shown that heat-setting, when skilfully applied, can level out some yarn bulk variation (see Section 6.4.1).

Translated into process variables, uniform bulk means impeccable control of temperatures, fluid flow (volume and pressure) and cooling conditions. The ability to control these parameters accurately lies firstly in the machine design but also in the plant discipline applied to this complex process, where only a few minutes out of control spills out large volumes of waste yarn.

The process know-how and conditions which lead to good-quality BCF yarn are the property of the large carpet fibre and yarn manufacturers. Here it is sufficient to state that yarn temperatures should be similar throughout the process from spinning to the hot-fluid jet and again during post-texturing treatment. One thing to avoid is subjecting the yarn to widely fluctuating temperatures during the successive process stages. It should also be remembered that thermoplastic yarns have a memory. If a nylon yarn is heated to a temperature that is higher than that during the previous process (stage) then its properties, including bulk and shrinkage, can change. This applies during subsequent processing, especially during heat-setting or when the carpet is being finished. In contrast to nylon, polypropylene and polyester respond to reheating, even if the temperature is lower than that experienced previously during processing.

Temperatures, air pressure, and cooling drum settings must be determined by experiment. This may not be as difficult as it sounds, since the suppliers of the polymer chips, the masterbatch and the machinery maker will be able to advise about the best starting point for these trials.

6.5.3 Entanglement

For single-end yarn destined for tufting without twisting, plying or heat-setting the specification of the air-entanglement jet is a most important factor. As we have seen (in Section 6.3.9) the air-jet size must be matched to the yarn, though each size of jet is capable of processing yarns in quite a wide range.

Entanglement jets for BCF yarns are provided for single-, two-, three- and four-ply yarns. When three yarns of different colours are being combined at the jet, the guiding arrangement before the jet is critical, since any imbalance in the yarn tensions can cause a variable appearance in the yarn. This is in the hands of both the machine and jet manufacturers.

Compared with these aspects, the possibility of variation in entanglement properties by changing air pressure and yarn tension is limited. It is sufficient to state that the yarn tension must be kept as low as possible, compatible with a stable thread-line. Too high a yarn tension will necessitate higher air pressures (i.e. consumption of air) and will ultimately lead to a situation where entanglement becomes impossible.

A well-entangled BCF carpet yarn does not exhibit the visible knots that are seen in an intermingled, false-twist textured yarn. In fact the structure of the entanglement knot is quite subtle and can be seen most easily when two or three spun-dyed yarns are combined and entangled in one jet.

6.5.4 Yarn shrinkage

Much of what has been written about false-twist textured yarns applies also to BCF yarns (see Section 5.3). Only here the temperatures used during spinning, drawing and texturing determine the bulk in the BCF process. Post-texturing heat treatment is usually a separate process after twisting, since the applied twist needs to be set into the yarn by the application of heat. Yarns for tufting only are not normally heat-set after texturing as part of the BCF process. That is to say, the last roll before the winder is unheated or, if a heater is provided, it is switched off.

As we have seen, both polyester and polypropylene respond in a direct way to the application of heat. The more that is applied, the lower is the residual shrinkage. The relationship is slightly more complex because the yarn tension that is present during the application of heat also influences the residual shrinkage. So does the time during which the heat is applied, especially if there follows a rapid cooling of the yarn. This means that the residual shrinkage of the final product is influenced directly by the processing conditions at all stages from extrusion to final heat-setting.

The relationship between the time of heat treatment and the yarn residual shrinkage is more complex in the case of nylon. One additional factor is the presence or otherwise of moisture. For this reason, the final heat-setting stage, after twisting and cabling, is the point at which the final shrinkage of a nylon BCF yarn can be influenced significantly. The use of steam means that nylon can be set at almost 100°C lower than when dry heat is applied (see Section 2.2.7).

Uniformity of treatment during spinning, drawing and texturing has a direct influence on the yarn shrinkage. If it is uneven, then the tuft height may be variable leading to a carpet with a poor appearance. Furthermore variable heat treatment can always cause differences in dye uptake with nylon yarns.

6.5.5 Yarn lubrication

If a BCF yarn is to be tufted without intermediate processing, the only opportunity to apply lubrication is between quenching and drawing. In other words, the conventional spin-finish application must be designed so that the yarn friction properties are suitable for texturing, winding and tufting. This is quite a tall order.

Modern plants use applicators for the addition of spin finish. Because BCF yarns have at least 30, and sometimes over 100, filaments the applicator must apply the finish evenly across all the filaments. The level of application varies from under 1% in the case of nylon yarns to between 1 and 5% for spun-dyed polypropylene yarns. It is adjusted by the metering of the finish to the applicator. One disadvantage of the old lick-roll system is that the correlation between lick-roll speed and the pick-up of spin finish is not so good. Changing the depth of lubricant in the lick-roll trough also has a marginal effect on the level of spin finish applied to the yarn. This is the reason why applicators rather than lick rolls are seen commonly in a modern BCF yarn texturing plant.

6.5.6 Yarn appearance

When a yarn is destined for a carpet there are many properties which determine its appearance. It is not the only concern of the yarn producer that the yarns dye evenly. Just as important are the properties of light reflectance. In fact, two yarns, which have been spun from the same polymer, may appear to have different shades in the carpet, because of an optical effect caused by bulk or other physical variations.

As we have seen previously (see Section 5.3.7) light reflectance is influenced by many properties, including fibre cross-section, the amount of delustrant applied to the polymer and the level and type of bulk. Two yarns may have the same overall level of bulk (see Section 8.3.3.2) but the first may have a finer crimp than the second. This will have a dramatic effect upon the appearance of the yarn in carpet.

The BCF process is therefore one in which control is vital at all stages. To repeat, the productivity of the process is so high that even a few minutes with the process out of control will result in a large quantity of downgraded product.