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The Woollen System — Development and Basic Principles

by

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THE WOOLLEN SYSTEM — DEVELOPMENT AND BASIC PRINCIPLES

by *J. P. VAN DER MERWE*

1.1 Introduction

Pure wool yarns may be produced on either the woollen or worsted system of manufacture. To the uninformed both will be described as woollen yarns. A distinction must, however, be made between end products produced from either woollen spun yarns or worsted spun yarns.

In the fourteenth century refugees who fled Europe to escape political and religious persecution settled in the town of Worstead in Norfolk, England. They brought with them the knowledge and expertise which enabled them to make cloths finer and superior in quality to those that had been made in Britain before. It is from the name of this town that the term 'worsted' was derived[1].

'Woollen' simply relates to something to do with wool. Woollen spun as well as worsted spun materials have a character of their own. In the case of worsted yarns the fibres are arranged parallel to the yarn axis giving a yarn of very clear and smooth appearance. In the case of a woollen yarn the fibres are arranged in a random manner, resulting in a hairy, lofty and bulky yarn. (See Fig. 1).

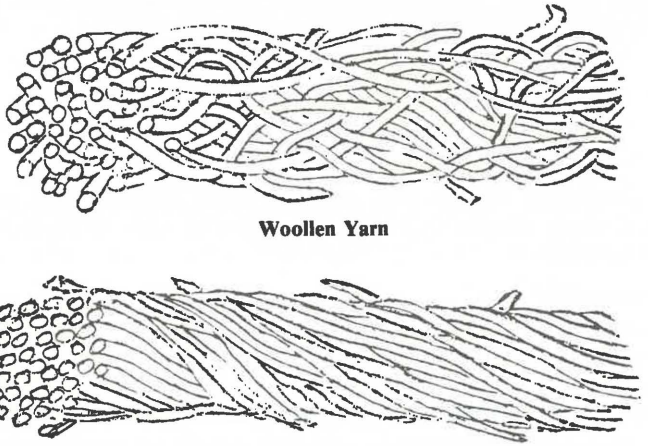


Fig. 1 — Diagram of a woollen and worsted yarn.

Lambswool and Shetland knitwear, knitted from woollen spun yarns have become household names. Woven fabrics from woollen spun yarns such as tweeds, Harris tweed, Cheviots, Saxonies and Welsh are equally well known.

Other articles produced on the woollen system are flannels, billiard cloths, blankets, meltons, beavers, felts, honeycomb quilts and tennis-ball covers.

1.2 Yarn Production Systems

A number of mechanical processes are required to produce a yarn from staple fibre. The main purpose of these mechanical processes is to rearrange fibres from their original rather random and discontinuous form into a coherent form, viz. a continuous strand or yarn, which can withstand the subsequent processes required to produce a fabric. Further requirements include the removal of impurities. Although a multitude of machines exist to achieve the purpose of producing a yarn from the original staple fibre, the fundamental operations are:

opening, cleaning and blending,
sliver formation,
drafting of the sliver,
twist insertion.

No matter what machines are being utilised in producing a yarn according to specification for blend composition, colour, linear density and twist, it must be the primary aim of every mill and every individual employee to produce a yarn as strong, as even and as economical as is practically possible.

Broadly speaking, the various ways of producing staple fibre yarns can be grouped into the following four main systems,

short staple or cotton,
long staple or worsted,
semi-worsted,
woollen.

The processing routine for woollen yarns differs from, and is much shorter and more simple than that for worsted yarn manufacture. This is illustrated in Table 1.

1.3 Raw Materials

In the worsted system long, virgin wool is used and a combing process is included in the processing sequence to remove short fibres and to help in aligning the fibres along the yarn axis. The woollen system uses virgin wool but it can, however, produce similar yarns which contain no new wool because the system is particularly suitable for the production of yarns from short fibre materials and it is said that the woollen spinner can spin any type of fibre, no matter how short it may be, as long as it has two ends.

It is for the latter reason that the woollen spinner can utilise a variety of fibrous raw materials of which the following are the most important:

(i) *shoddy* — obtained by tearing up of rags originating from old and new knitwear as well as loosely constructed woven fabrics.

(ii) *mungo* — obtained by tearing up of new or old hand-woven and milled cloth or felt.

(iii) *noils* — short fibres removed from the long fibres during worsted combing.

TABLE 1

Schematic presentation of the worsted and woollen systems of manufacture.

Worsted System	**Woollen System**
Sorting	Fibre Selection
↓	↓
Blending	Dusting
↓	↓
Dusting	Scouring
↓	↓
Scouring	Drying
↓	↓
Drying — oiling	Dyeing
↓	↓
Carding	Dusting
↓	↓
3 Gillings	Blending
↓	↓
Combing	Oiling
↓	↓
Gilling	Carding
↓	↓
Backwashing	Spinning
↓	
2 Gillings	
↓	
Drawing	
↓	
Spinning	

(iv) cotton, rayon and other synthetic fibres in staple form, and
(v) textile processing wastes.

The list of fibre types suitable for processing on the woollen system of manufacture is almost endless, while blends of the various fibre types are normal practice. Small amounts of cotton or nylon are added to very short wool blends to increase yarn strength.

For the purpose of this review the discussion will be limited to the woollen system of manufacture and to the processing of virgin wool into yarn, unless otherwise stated.

2. OPENING, CLEANING AND BLENDING

2.1 Opening

Wool is normally received at the mill in a press packed bale with a density of approximately 250 kg/m^3. The latest trend is to compact the bales to a density[3] of up to 570 kg/m^3 or higher. It is therefore essential that the bales be opened and that machines be employed to open the fibres to facilitate removal of part of the particulate impurities such as sand, dust and vegetable matter in a preliminary dusting process and to facilitate a better penetration of the scouring liquors during scouring.

For the dusting or shaking process a double-cylinder opening machine is often used, as shown in Figure 2. Sand, dirt and dust are removed by the rotating spiked beaters which beat the wool against the screens at the bottom of the machine.

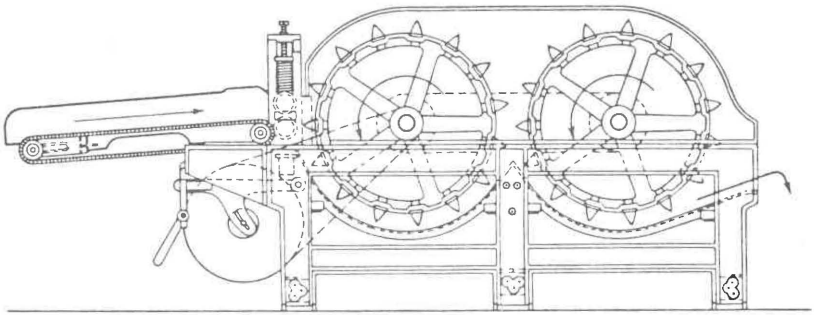


Fig. 2 — Double Cylinder Wool Opener[2]

Very dirty, long and coarse wools and hair fibres are often cleaned in a cone duster in which the wool is beaten by a spiked, cone-shaped revolving drum against a screen below.

2.2 Cleaning

2.2.1 Scouring

The next stage in the opening and cleaning sequence is scouring. Apart from particulate matter, wool also contains suint, grease and mineral impurities which have to be removed by scouring. Certain lower grade wools for carpets and blankets are not scoured but carded in greasy form to assist in lubricating the fibres during carding. In the latter case the grease and dirt are removed by hank scouring or by piece scouring.

Several scouring systems for the scouring of loose wool are available and some of these are listed below:

Emulsion scouring,
WRONZ Mini-Bowl[4],
CSIRO Lo-Flo, [5,6]
Solvent systems[7].

The most popular and widely used scouring system is the emulsion scouring system which will be briefly dealt with below and should more detail be required on scouring in general, it can be obtained from the literature[8].

A scouring plant for the scouring of wool, by means of the emulsion scouring method, consists of a series of at least 4 scouring bowls and one rinse bowl. The wool is transported through the bowl by harrow forks and is squeezed between a set of rollers before it moves to the next bowl. The scouring bowls are charged with soap or detergent and in some cases also an alkali.

The wool grease, consisting mainly of fatty alcohols and fatty acids with a melting point of about 45°C, is emulsified by the soap, and the fatty acids saponified by the alkali above the melting point. The suint, consisting of potassium salts of fatty acids, is soluble in the water and assists in emulsifying the grease. Most of the dirt and grease is suspended in the soap or detergent solution and is removed when the wool is squeezed at the end of the bowl. Heavy particles drop to the bottom of the bowl and are removed automatically. The dirty wash liquor removed from the wool by the squeeze-rollers is collected in a settling-tank, in which a partial separation of grease and dirt takes place, the liquor being returned to the bowl. The concentration of the scouring agents decreases as the wool proceeds through the bowls. The last bowl normally consists of clean water to rinse the wool.

2.2.2 Drying

After scouring, the wool is dried in a chamber by circulating hot air. When the wool leaves the last rinsing bowl it is squeezed to a moisture content of $\pm$ 40%. The wet wool is conveyed, either by aprons or on perforated drums, through the flow of hot air. A well known dryer of this type is the Fleissner suction drum dryer illustrated in Figure 3.

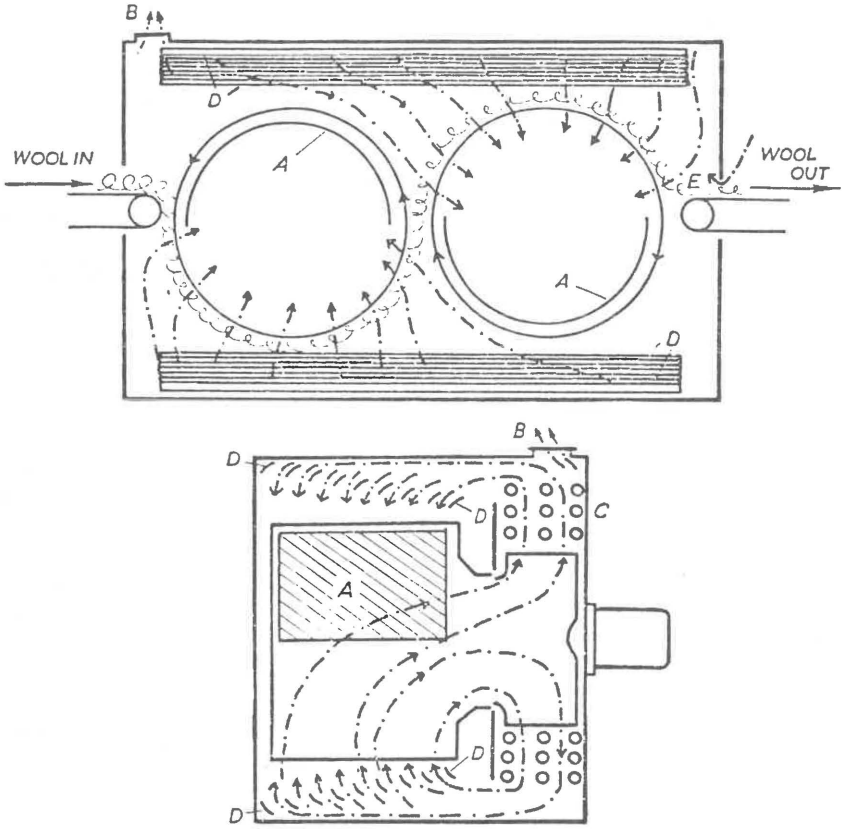


Fig. 3 — Longitudinal and Cross-sectional Views of a Suction dryer: A-Stationary baffle; B-Exhaust air; C-Heating pipes; D-Baffles to distribute air evenly across the width of the dryer; E-Air intake.

2.2.3. Removal of Vegetable Matter

Wool contains a certain amount of vegetable matter such as burr, leaves, twigs[9] etc. which must be removed either mechanically of chemically. The presence of vegetable matter[10] interferes with fibre movement during drafting, causes endbreakages during spinning and gives rise to slubs and irregularities. In the final fabric these impurities can lead to speckiness due to their dyeing behaviour differing from that of wool. They can also cause discomfort to the wearer.

Small amounts of vegetable matter are removed with relative ease by the card. If they are present in large amounts, however, they must be removed by an additional process, either by mechanical deburring or chemically by carbonising.

2.2.3.1 Burr-Picking Machines

These machines remove burrs from wool mechanically by subjecting the wool to a sequence of pin and beater treatments which knock the burrs out while the wool is held in the pins.

The multiplex machine[11] consists of four mechanical combinations. In the first step the wool is fed through cockspur feed rollers. The wool is then combed and opened by a rotating fine-lagged main cylinder. The wool is carried over a rack where the impurities are thrown off by centrifugal force. The second step is the removal of dust and light impurities by air currents which are directed through the machine.

The third cleaning is effected by the delivery of the wool from the main cylinder to the first burr cylinder which is covered with toothed wire. The wool fibres pass down between the wires leaving the burrs exposed on the surface, these being removed by rapidly moving guards. The fourth cleaning is effected by the second burr cylinder which strips the wool from the first cylinder thereby reversing the position of the wool in its relation to the cylinder and thus allowing the other ends of the wool to be cleaned by the revolving guards. The cleaned wool is finally removed from the cylinder by a brush.

2.2.3.2 Crushing

Most woollen cards are equipped with peralta rollers. In this system the web delivered by the scribbler doffer is passed through a pair of weighted plain steel rollers which crush the vegetable matter. The crushed vegetable matter is then dropped from the wool as it passes through the rest of the carding machine. The rollers, themselves, are kept clean by scraper blades.

2.2.3.3 Carbonising

Chemical removal of vegetable matter from wool or noils is carried out by wet carbonising with sulphuric acid. Rags, containing cellulosic materials, are usually dry carbonised by treatment with hydrochloric acid gas. The acid used in carbonising converts the cellulosic material to brittle hydrocellulose which is removed from the wool by crushing and subsequent dusting.

2.2.3.3.1 Wet carbonising

Wet carbonising[12,13] is normally carried out on scoured wool. In this process the wool is passed through a stainless steel bowl containing sulphuric acid at room temperature with a specific gravity of 1,02 to 1,04. The wool is then squeezed to a moisture content of approximately 40% and then dried in two stages. The first drying stage (71°C) is thermo-physical to dry the wool and the second or baking stage (93°C) thermo-chemical during which the cellulose is converted to hydrocellulose. After baking, the wool is passed through crushing rollers and a shaking machine to remove the cellulose. The wool is then passed through scouring bowls containing soda ash to neutralise the residual acid in the wool after which it is rinsed and finally dried.

A wet carbonising process utilising hydrochloric acid[14] instead of sulphuric acid offers certain advantages such as producing a softer, less stringy, less pilled, less flat and more resilient product.

There is also less danger of damage to the fibres when excessive acid concentrations and drying temperatures are employed. This fact can be taken advantage of in carbonising wool with cockle burrs. There is also less danger of damage due to wet ends after the acid treatment. To some extent this is due to the volatility of the hydrochloric acid and the tendency of excessive acid solution to form a constant boiling mixture in the dryer, the hydrochloric acid gas being removed constantly with the water evaporation.

The major disadvantage, however, is that plants made from special materials are required due to the corrosive action of hydrochloric acid.

2.2.3.3.2 Dry Carbonising

Dry carbonising[15] is carried out on rags containing blends of wool and cellulose. In this process, the rags are heated and then put into the rotating drum of the machine. The rags are lifted by hooks, set on the inside periphery of the drum, and dropped through hydrochloric acid gas. The gas is introduced into the centre of the rotating drum by a perforated pipe connected to a retort in which the gas is produced by dripping liquid hydrochloric acid onto a heated plate. The entire machine is heated and the rags tumbled for approximately three hours.

The rags are then removed, allowed to cool, shaken and then neutralised before tearing.

2.3 Blending

The primary object of blending of fibres intended for woollen yarn production is (i) to mix the fibres thoroughly and (ii) to blend fibres together to produce a yarn with characteristics that cannot be produced by using any one fibre type on its own[16-19].

Von Bergen[20] states that the most important reasons for blending are to achieve variations in aesthetics, performance and economics. The components of these are:

I. **Aesthetics**
   1. **Appearance**
      (a) Colour
      (b) Lustre
      (c) Surface texture
      (d) Cover
      (e) Drape

2. **Handle and touch**
   (a) Liveliness
   (b) Fullness
   (c) Firmness
   (d) Loft
   (e) Dryness
   (f) Smoothness
   (g) Softness

II **Performance**
1. Functional (end use)
   (a) Wrinkle resistance
   (b) Warmth and comfort
   (c) Durability
   (d) Fastness
2. Processing
   (a) Tailorability

III **Economics**
1. Fibre cost
   (a) blend composition
2. Processing
   (a) Spinnability and weavability
   (b) Dyeing and finishing

It is well known that, although the fibre physical properties, such as length and diameter of natural fibres may be the same, they vary considerably in their characteristics[21] due to changes in climatic conditions during their growth, areas of cultivation and certain genetic differences. To produce a uniform yarn or cloth it is therefore essential that the individual components of the blend be mixed thoroughly.

In the woollen trade, as a rule, dyeing is carried out on loose stock. Colour blends and particular shades can be produced by mixing fibres of different colours. Blending must, however, be thorough. On the other hand, fibres differing in dye uptake may be blended and then dyed in piece form to produce special effects.

Spinning and weaving performance may be increased by adding a small amount of synthetic fibre, e.g. 10% nylon to the blend. It has been found that the long and fine fibres in a blend tend to migrate to the yarn core, while the coarse and short fibres migrate to the surface of the yarn[21,22]. This phenomenon may be used to advantage to produce a yarn with good tensile properties by selection of strong fibres to form the core. Specific aesthetic properties may be obtained by incorporating fibres that will migrate to the

surface. Incorporating synthetic fibres with wool fibres may increase pleat and crease retention while minimising wrinkling[17].

Blending is also carried out for economic reasons. Substitution of one or more components by other raw materials may have considerable cost advantages either in that the fibre is cheaper or that the overall production efficiency in carding, spinning, winding and weaving or knitting is increased thereby lowering the production cost.

2.3.1 Blending Systems and Blending Equipment

While a considerable degree of blending takes place during preliminary cleaning and opening this is normally quite inadequate if a consistent product must be maintained from one hour to the next. A well planned blending system must be employed to ensure an evenly distributed blend continuously supplied to the card. A further important function of blending is to apply a lubricant to minimise fibre breakage, to reduce fly during carding and to assist the movement of the fibres during drafting in the spinning process[18].

In the days before blending machines were available and labour was still available at low cost, wool was blended on the floor[23] by spreading the various constituents of the blend in layers. Vertical cuts were then taken and fed to an opening picker or teaser. This process was carried out at least twice. Oil was added to the blend by sprinkling with a watering can to which a T-shaped perforated delivery pipe was fitted. Oil was applied to the individual components, layer by layer or after one or two passages through the picker.

The aforementioned blending method is mainly of historical interest. Today it is carried out only when small sample lots are to be blended and oiled. Modern blending machines have not changed much through the years but the use of blending bins for storage of fibre and the transfer of fibres by pneumatic means through ducting and spreaders have become the general practise. Oil is applied in the form of a fine spray after blending. The latter method of applying oil is more effective in distributing the oil evenly over the fibres and it is much cleaner because it is applied after blending. This has the added advantage in allowing longer runs between fettling of the cards.

Today blending is carried out on either the batch system or the continuous system. The batch system is used mainly for small lots where mixing of colours and fibre qualities are important. The continuous system generally is used for large blend lots as is required for the manufacture of carpets and blankets and therefore mainly for the processing of coarse fibre types.

2.3.1.1 Batch Blending[23-26]

Irrespective of blending system used, baled fibre must be "burst" and if the material is dusty it should be shaken and opened to get rid of most of the dirt. Where a very small quantity of fibre is to be added to the blend to produce either a special shade or perhaps a handle effect, it is essential that a premixing or "melling" of the small lot with part of the major component be

carried out. For example, when a blend consists of 98% black and 2% white fibres, the 2% white fibres are premixed with 20% black fibres. This mixture is then blended as one constituent of the blend with the remainder of the black part.

In batch blending, the weighed components of the blend are arranged round the trap of a suction duct, coupled to a fan. The components are fed into the trap in their relative proportions taking a double hand as the unit. The material is fed by ducting to a teaser or plucker i.e. a fearnaught or willey which opens, removes dust and dirt and slightly mixes the blend. The material is carried further by ducting to a blending bin in which the material is spread evenly over the floor of the bin by a rotary spreader. When the bin is full, or when all the fibres of a blend have been fed into the bin, the door is opened and the material fed into a trap in the ducting, by striking the pile vertically down. The fibre is transported to a second bin to effect further mixing. If the latter is not required the fibre is fed to a fearnaught to open the fibre further. Upon leaving the fearnaught, the airborne fibres are sprayed with an atomised oil/water emulsion and transported to storage bins in the carding room or sheeted for storage.

In another batch system the blend, after having been dusted and opened on a fearnaught, is fed into a revolving polygonal chamber built of sheet panels having doors and glazed sight holes around the circumference. The blend is fed into the bin by cyclone on the one side of the bin. The blend is compressed by rollers which are suspended by counterweights from a telescopic support and lifted by the material. A series of nozzles are arranged on the roller arm and oil is sprayed evenly onto the blend as the bin rotates. When the bin is full it is stopped and a panel removed and the blend struck vertically into a trap from which the oiled fibres are transported to the card storage bin, baling or sheeting machine or directly to the card hopper.

In the newer blending systems the fibres are layered horizontally in the bin by means of a telescopic cyclone while the bin is emptied in vertical layers by the bin emptier to produce a more homogeneous blend.

2.3.1.2 Continuous Blending

In batch blending, the full mass of blend is processed as a unit but in continuous blending the components enter the system at one end and emerge in a continuous stream of opened mixed and oiled blend at the other end[26]. Batch blending is normally carried out when a large number of components are to be blended together, as is generally the case in the hosiery trade, because it produces a more homogeneous blend. It does, however, require more labour than the continuous system of blending. Continuous blending is preferred to batch blending when coarse fibres are to be blended as is the case with the production of carpet yarns, blanket yarns and rug wools.

The unit method of hand feeding, used in batch blending is eliminated in

continuous blending systems and is replaced by some or other means of weighing and feeding of the blend components into the system.

Several systems for the continuous feeding of the component parts into the blending line exist. In one such a system the components are weighed in their proportions in a skip or box and this skip, containing a unit mixture of the blend, is then emptied into a special hopper feed, levelling out the intermittent feed of the skip, which levels out the flow for feeding the opening machine[26].

The modern trend is to place a series of weighing hoppers along a common feeding lattice. Each component of the blend is then weighed onto the lattice in the correct proportion by the individual weighing hoppers. The lattice then transports the blend to a hopper which feeds a picker, such as a willey, to open, blend and remove dust and dirt from the fibres. The material is then transported by a lattice to a hopper feeding a fearnaught for pre-carding and blending of the material. When the material leaves the fearnaught it is sprayed with oil through compressed air nozzles. Oiling at this stage is advantageous because dust and dirt have been removed and distribution of the oil is much better, due to the opened state of the fibres. This means that less frequent fettling of the card is required[26].

After oiling, the fibre is transported pneumatically to a blending bin. Several bin systems are available, the most popular being to deliver through a telescopic cyclone into a rectangular bin. While the blend is being fed into the bin, the cyclone moves forwards and backwards, layering the blend in thin sheets on top of each other. Once filled, the bin is emptied by a bin emptier in vertical layers, thus assuring a perfect blend[27]. The process of layering the blend horizontally and emptying vertically can be repeated as many times as required because the fibre length is not impaired due to the fact that the fibres are not mechanically processed but are pneumatically transported through ducting.

After proper blending, the blend is transferred from the blending bin to a bin at the back of the card or is fed directly to the card by chute feeding.

Savings in labour with a continuous system of blending are considerable because generally manual labour is required only to provide the hoppers with fibre. The entire plant is controlled by one operator selecting the various functions on an illuminated chart. The risk of error is very low because the machines and switches are electrically inter-controlled: if a component of a circuit is faulty, nothing will be started in this circuit[27].

In conclusion, it can be stated that the process of blending consists of

"bursting" of baled fibrous stock,
mixing of components,
opening and dusting of the blend on a picker e.g. a willey,
blending and pre-carding on a fearnaught,

oiling of the blend by spraying under pressure with an oil/water emulsion, and

further blending by horizontal layering in bins and by vertically emptying the bins.

The requirements of blending are the following[23]:

Blends containing relatively small amounts of a given component must be pre-mixed or "melled",

Dense, greasy material must be opened before mixing with lofty material,

Dirty, limy and sandy materials should be shaken separately from very greasy material,

Uniform blend composition can only be achieved by accurate weighing of the components.

Pneumatic conveying and cleaning can be combined.

3. OILING

The purpose of oil application to fibres is as follows[28-31]:

(i) to minimise fibre breakage during opening and carding by lubricating the fibres to allow them to slip past each other more easily;
(ii) to provide a stronger web if the lubricant has good cohesive properties;
(iii) to eliminate static electricity, thereby allowing a more regular sliver to be spun;
(iv) to assist in the drafting of the twisted slubbings to allow a yarn to be spun with low short-term variation. In this case the oil must have good lubricating as well as cohesive properties;
(v) to reduce fly.

For a fibre lubricant or, more correctly, a fibre processing aid, to meet these demands, it must ideally fulfil the following requirements[28-33]:

(i) It must have good lubricating properties to assist disentanglement during carding and allow regular drafting of the slubbing during drafting. It must therefore have lubricating and cohesive properties in order to control both static and dynamic friction, of the fibre assemblies.

Static cohesion and dynamic friction properties can be easily explained[33,34] by a stress/elongation curve for slubbing. (See Figure 4).

Maximum static fibre to fibre friction or cohesion is given by the point A in the stress/elongation curve. Therefore, fibre assemblies with a high value of A possess a high static cohesion and *vice versa.*

Dynamic friction is represented by the descending part of the stress/elongation curve. Frictional behaviour is determined by the slope of the curves AB and AC respectively. AB indicates a slubbing with high dynamic frictional properties and AC one with low frictional properties.

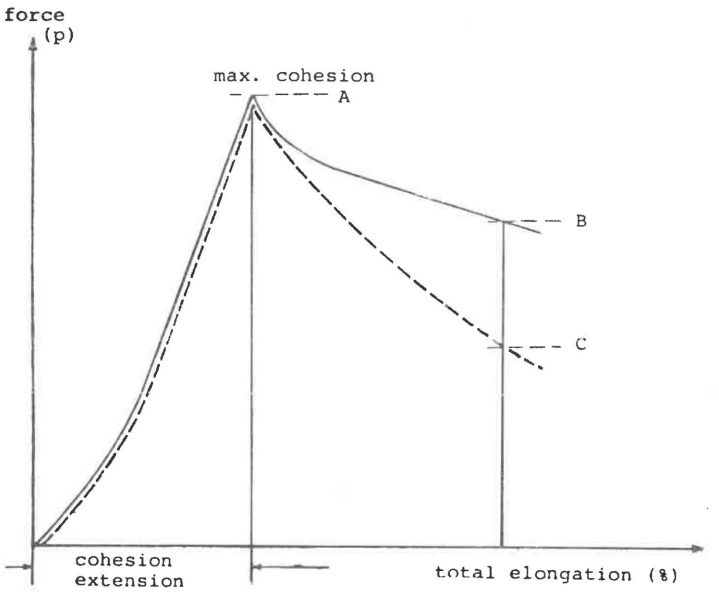


Fig. 4: Stress/elongation curve for slubbings treated with different lubricants[34]

Cohesion and dynamic friction properties of slubbings can be adjusted to suit the processing requirements by the addition of the correct lubricant; e.g. a sliver showing too high dynamic friction and too low static cohesion properties is sprayed with a lubricant to reduce dynamic fibre to fibre friction and to increase static fibre to fibre cohesion.

(ii) It must lower the fibre to metal friction.

(iii) It must control static. Wool in a dry state is a poor conductor of electricity and an electrical charge is developed when the fibres are separated as during carding. The static electricity charges lead to the formation of excessive amounts of 'fly' and a poor fibre/fibre cohesion. It is essential, therefore, that static must be controlled. Lubricants, however, are normally applied as emulsions in water, and the water in itself, being a good conductor of electricity, will assist in minimising static and help dispersion and spreading of the oil on the surface of the fibre.

(iv) It must be able to spread evenly over the surface of the fibre to effect good lubrication[35]. The spreading properties of a lubricant depend on its interfacial tension relative to the surface to which it is applied and on its

viscosity. Due to the variation in different types of wool the spreading is dependent mainly on viscosity. A thin oil with low viscosity will spread over fibres and penetrate more easily through a fibrous mass than a thick oil.

(v) The lubricant should be stable against transport and storage conditions and it must be stable against extreme temperatures.

(vi) Emulsions with water must be stable should there be a need to store them for a period of time i.e. they should not separate, change viscosity or change in colour.

(vii) It must form a stable emulsion with both soft and moderately hard water under various temperatures.

(viii) It must not undergo any change in nature while in contact with fibre. Fatty and mineral oils absorb oxygen from the air and become sticky, rancid and dark coloured. The oxidation process is rapid when the oil is spread in a thin film over the fibre and spontaneous combustion can occur due to the heat generated by the exothermic reaction.

(ix) The use of the lubricant should not be hazardous in respect of:
  (a) causing fires;
  (b) being toxic;
  (c) having a detrimental effect on metal, paint or rubbers and leathers fitted to cards and spinning frames.

(x) It must be removed easily from the fibre in finishing processes.

3.1 Lubricant types used in woollen processing

Several types of lubricants[31-33,35-37] are available on the market for the processing of fibres on the woollen system. These vary in properties and price and the type for a particular requirement can be obtained by selecting one from the main types listed hereunder:

3.1.1 Oleines

These were the first lubricants to be used for the lubrication of fibres and many are still being used today. They are liquid fatty acids based on oleic acid (9-octadecanoic acid) containing about 12% saturated acids, such as palmitic and stearic acid, and 8% linoleic acid (which is unsaturated)[35]. Oleines are derived from tallow and bone grease. The unsaturated acids can give rise to exothermic oxidation and can thus lead to spontaneous combustion. Inclusion of antioxidants in oleine blends is therefore essential.

The most widely used oleic type of lubricant consists of 70% oleic acid and 30% mineral oil[35]. During scouring of the woollen yarn or garments the oleine is saponified *in situ* in the wool by the soda ash present in the scouring liquor, forming a soap which assists scouring and milling. It is claimed that the residual saponified oleine plays an important role in the "woolly" handle of Shetland and Lambswool goods[32,33].

Application levels of oleines to wool vary between 6% and 8% on the mass of the wool. They are removed by scouring with soda ash. Excessive amounts of soda ash should not be used because the wool may be damaged. By controlling the pH between 9 and 9,5, damage can be kept to a minimum because the soda ash is converted to sodium bicarbonate during saponification[35].

3.1.2 Blended Oils (Semi-neutral oils)

These are blends of mineral oil, glycerides (non-drying oils) and oleines. Emulsifiers are added to render the oils emulsifiable with water. The addition of the fatty acids promotes better spreading of the oil, it prevents fly formation and improves scouring properties[35]. Mineral oil cheapens the blend. This type of oil, because of its low free fatty acid content, is mainly used in the production of knitting yarns and fine woollen yarns sold in the grease. When scouring a wool which has been lubricated with these oils it is necessary to add either soap or a detergent to the soda ash liquor.

3.1.3 Mineral Oils

These consist mainly of a blend of mineral oil and nonionic emulsifiers. They are stable to oxidation, allow cleaner working in carding and are almost odourless. Some can be scoured from wool by water alone provided the wool to which they are applied is clean of wool grease. They are, scoured mostly in mild alkaline liquors with an addition of detergent and salt.

3.1.4 Synthetic lubricants (Water scourable oils)

These are manufactured from polyalkene glycols, polyalkene oxides and phosphoric esters[36].

The synthetic oils find particular application in the production of wool yarns for Superwash treatment[33]. These lubricants are easily removed by scouring and no oil is left on the wool that may interfere with subsequent Superwash processing.

In comparison with conventional semi-neutral types it is claimed[34] that synthetic lubricants improve carding and spinning performance, slightly increase yarn tensile strength, hardly affect frictional properties and increase elasticity.

Manufacturing of synthetic lubricants can be controlled so that any desired combination of properties can be obtained in one lubricant[32]. They are more expensive than the conventional oils, but are applied at lower concentrations and in semi-worsted spinning, for example, small amounts of lubricating agent are added to the clean wool blend whereby scouring is eliminated.

In some instances, emulsifiable mineral oil and synthetic lubricants are blended to yield a product that combines the desirable properties of both lubricants at an acceptable price.

Two types of synthetic lubricants are available in the trade:

(i) Water soluble but grease immiscible types. They are removed during hank dyeing. They are applied to clean blends at a concentration of 1 – 3% o.m.f.

(ii) Water soluble and fully miscible with wool grease. This particular type has high solvency power for wool grease. This means that when the yarn is immersed in water both the lubricant and the wool grease are removed. Removal is effected by hank scouring.

3.2 Lubricant choice

A number of factors are involved when selecting a lubricant. Retention of adequate yarn strength and good elasticity, together with satisfactory yields and ease of removal of the lubricant during scouring, are of prime importance[33].

In the case of wool, the choice of a lubricant is influenced by the fibre physical properties, such as diameter, crimp and length. These also influence the quantity of lubricant to be used. The choice is also influenced by the method of processing, i.e. woollen, semi-worsted etc. and the actual end-use i.e. hosiery, apparel, carpet etc.

In general, it can be stated that yarns or fabrics to be scoured are normally sprayed with oleines or semi-neutral oil because the residual soap left in the fibre gives a fabric of a soft handle as is the case with Lambswool, Shetland types[32,33] and certain carpet blends. Mineral oil is also used in blends which are to be scoured for their lubricating and cost advantage properties. Wool grease miscible synthetic lubricants have a special field of application on carpet yarn qualities where greasy or clean and greasy wool blends are processed.

Where yarns and fabrics are not scoured and wools with a low residual grease content are used, water soluble synthetic lubricants must be used. Scouring is not carried out in the case of semi-worsted carpet yarns because they are dyed without scouring. Scouring, subsequent to spinning and twisting of tufted carpet yarns, is not required. The blends in this case are normally stock dyed and then oiled with water soluble synthetic lubricants after blending. This also requires the lubricant to be non-staining and non-soiling. These requirements are met by some synthetic lubricants with high antistatic properties or a purely antistatic product which gives little or no lubrication. Yields can, however, be reduced by such "dry" processing conditions and "fly" can be increased.

Pigmented fibres should be processed with lubricants which can be removed by a neutral scour because alkaline scouring often leads to cross staining of adjacent non-pigmented yarns due to pigment migrating from the wool. A lubricant which is removed by neutral scouring should be used.

3.3 Oiling Methods and Equipment

Lubricants are applied to the fibre blend either manually or by automatic spraying[38]. Oiling is done by hand with a sprinkling can, the oil being applied as uniformly as possible to each layer of stock after it has been laid. Vertical cuts of the oiled blend is then fed by hand through a mixing picker once or twice and allowed to lie overnight to ensure thorough penetration and spreading of the oil. This method is used for small blends only and large lots are oiled automatically because of labour-saving, material-saving and better control.

In the automatic system of oiling, the oil is applied continuously to the blend as it is transferred to the blending picker or it is sprayed on in the form of a mist after the picker.

3.3.1 Gravity feed method

In this method, the oil emulsion is fed into a horizontal pipe, fastened directly over the conveyer, with evenly spaced holes along its length. The emulsion drips directly onto the blend as it passes below the pipe. Feeding of the emulsion and regulating the quantity of emulsion to be applied are difficult.

3.3.2 Brush method

The emulsion is fed to an oscillating pipe above a rotating brush roller. The brush roller hits a flipper bar directly below itself spraying the oil with fine droplets of emulsion. A version with an oscillating, instead of a rotating, brush is also available. Control of the amount of emulsion to be applied and uniformity of distribution is relatively easy.

3.3.3 Spray method

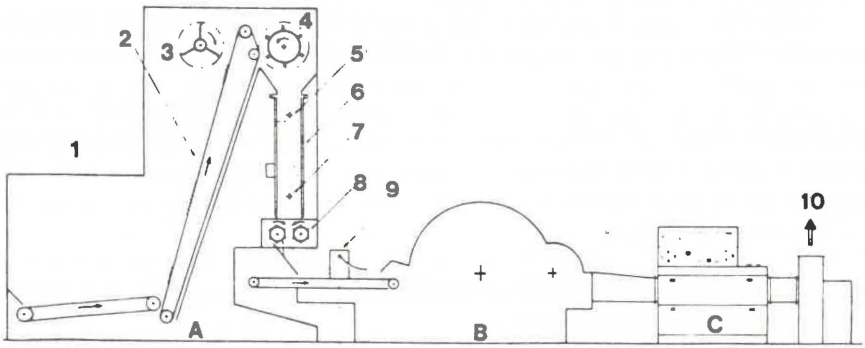
In the spray method, the oil emulsion is applied to the blend in a fine atomised mist spray.

The "Vortex" oiling system consists of a chamber which is filled with a mist of oil produced by the atomising heads which protrude into the chamber. The material passes through the chamber and out through a small orifice which adjusts itself in area automatically according to the volume of material passing at any time, thereby minimising the oil or vapours entering the fan and subsequent ducting.

The "Atomist" system[39] operates on the same principle. It is normally fitted after the last opener in a line, where the fibres are oiled under conditions most favourable for the take-up of oil. The oil is fed to the Atomist by means of a duplex unit which enables emulsions to be applied without premixing. For this purpose, separate tanks are fitted for the water and oil, the mixing of the two components taking place in the oiler body through a special mixer-jet. An air cushion in the stock tanks is maintained by a compressor to ensure a constant flow of the components. Viscosity and temperature of the lubricant

are monitored and controlled.

The amount of spray is applied automatically according to the height of the material feed on the apron conveyor. Constant fibre stock feed is controlled by a volumetric metering hopper feeder. A diagram of the Atomist system is given in Figure 5.



A	Metering hopper feed MHF-1	B	Opener
C	"Atomist"		
1	Materials from bins	6	Vibrating chute
2	Spiked sheet	7	Lower level control
3	Paddle beater	8	Metering rollers
4	Doffer	9	"Auto-Regulo"
5	High level control	10	Materials out to cards

Fig. 5 — Diagram of Atomist oiling system[40]

3.4 Lubricant additives

Lubricants contain additives to prevent oxidation, to control static electricity and to increase fibre cohesion[35].

Oxidation of fatty acids, fatty oils and mineral oils are catalised by metals such as iron and chromium. Wools may contain small traces of these metals and anti-oxidants are therefore added to prevent the oils from oxidising making removal difficult during subsequent scouring of the yarn.

Static charges normally develop when the wool is dry or is subjected to conditions of high friction. Wool, in the dry state, is a good insulator and charges can therefore not leak away. This problem is solved by adding substances to increase the conductivity of the wool. This is achieved by the addition of emulsifiers to the lubricant.

Inter-fibre friction is increased by the addition of colloidal silicon[35] or by the addition of fumed alumina dispersion[42]. It is claimed that yarn strength is increased by 10%, yarns are loftier and 'fly' on the card is reduced whereby

carding yield is increased by up to 4%. The fumed alumina dispersion is positively charged which bonds it to the negatively charged wool. The particles attract neighbouring fibres and hold them together, increasing the friction and preventing the fibres from sliding past each other.

3.5 Movement of Oil in Stored Blends

It has been suggested that oil applied to a blend may seep to the bottom of the bales when stored for prolonged periods of time. It was, however, found[41] that no significant seepage of oil took place when a bale of wool, oiled with 8 per cent oleine, was stored for a period of four months. It was also shown that when wool, oiled with 20 per cent oilene, was stored in contact with the same wool but unoiled, no transfer of oil took place. It was therefore concluded that seepage of oil does not occur in oiled wool blends when stored for normal periods prior to carding.

4. SLUBBING FORMATION — CARDING

4.1 Historical Development[43,44]

4.1.1 The Card

Carding is defined as a process whereby an entangled, matted mass of fibres is reduced to a filmy web by working between two closely-spaced, relatively-moving surfaces clothed with sharp points.

In early days, wool was carded by hand. In this process the wool was opened between the teeth of two hand cards by relative motion of the cards so that the teeth worked in a point to point action. Upon completion of the opening process the direction of motion was changed so that the cards worked in a point to back action to perform a stripping action.

In 1748 Lewis Paul patented a flat surface carding machine with pins aimed at mechanisation of the hand carding principle. A circular revolving card was also covered in the same patent. Daniel Bourne however, is credited with the development in 1748 of the first cylindrical card. This was described as a carding machine with rotating rollers covered by card clothing. A major obstacle, however, was that all the carded material was delivered in the form of sheets and these had to be piecened before a continuous yarn could be spun. In 1775 a breakthrough in producing a continuous sliver was made by Arkwright. His machine incorporated most of the principles of modern carding machines. It also had an automatic feeder by means of which cotton, in roll or lap form was fed to the machine. The cylinder of the card was covered with sheets of card clothing with gaps between them and the working action took place between these and stationary flats fitted above the cylinder. These flats were made of wood onto which card clothing was nailed. By fitting a doffer and a doffer comb to the machine the fibre could be removed in a continuous web, which was drawn through a funnel and a pair of rollers and then coiled in a can.

These cotton cards were also used for the carding of short wools, but the action was too harsh and stock cards were, therefore, still used for wool carding for some time after Arkwright's card had been patented. Carding machines consisting of a scribbler part for opening and some mixing of wool fibres, and a carder for final mixing and forming a web were first used in Yorkshire in 1780.

4.1.2 The Condenser

Before the introduction of what is now known as the condenser, the carded wool was processed or given a preliminary drawing and spinning on what was then known as the Billy. The Billy was, in essence, a spindle drafting machine and the slubbings thus produced were then subsequently spun on the mule.

The principle of subdividing the web from the carder was patented in 1776 by Thomas Wood. This led to the development of the double ring doffer in 1825 by Ezekiel Hale of Haverhill, Massachusetts.

Credit is given, however, to John Goulding of Worcester, Massachusetts for developing a reliable and practical mechanism producing continuous lengths of level slubbing. Goulding's patent of 1826, combined a ring doffer with a condenser thereby eliminating the Billy and short rolls of slubbing.

Goulding claimed to have brought together a number of inventions. His system consisted of taking the ribbons produced by the ring doffer, consolidating them by means of rotating tubes or reciprocating rollers, and then winding the slubbings by friction drive into a number of individual cheeses on a long condenser bobbin. Edward Winslow is credited for developing this friction drive. It is surprising, however, that Goulding made use of a friction drive and did not use a surface drive because a patent was filed by John Rhodes in 1786 for winding by surface contact.

Ring doffers are not covered with clothing over their entire surface which means a loss in production. Goulding developed a traversing mechanism so that the ring doffer, and in some cases the workers, was traversed to give a more even slubbing and to avoid piling up of fibres as endless rings on those sections of the cylinder and workers not cleared by the doffer. However, it was subsequently found that traversing of the ring doffer could be eliminated by fitting the clothing onto the doffer in a zig-zag manner. Another alternative was to use two ring doffers with the rings arranged in such a manner that fibres over the entire width of the cylinder could be transferred to the doffers.

Today, condensing is mostly done by splitting of the continuous web, delivered by a tape doffer completely covered with fillet clothing, by means of endless tapes. The ribbons of fibre are then rolled into slubbings by rubbing them between reciprocating endless aprons and the slubbings are wound onto cylindrical tubes utilising a system of surface winding. This practical tape condenser was patented by Celestin Martin of Verviers, Belgium in 1869. The

number of tapes (or series tapes) Martin used was replaced by one endless tape by Jean Sebastian Bolette of Pipinster, Belgium, described in a patent registered in 1879.

Condensing of the web strips into slubbing was initially accomplished by means of rotating tubes. Rotating rubbing rollers with a reciprocating motion and covered with leather were first introduced in the USA in 1830. Two types were used; namely either three 64 mm diameter rollers reciprocating and rotating against a 178 mm diameter rotating roller or seven reciprocating and rotating top rollers each set to two of eight rotating bottom rollers of the same diameter. In the latter arrangement, the slubbings could be attenuated as they passed between the rollers if the speeds were increased progressively, e.g. the mass per unit length of the slubbing could be reduced by about 25% of that of the web delivered by the card.

Rubbing leather aprons were introduced into Europe in 1940. These aprons consisted of two leather belts, the same width as the machine, with both rotating and reciprocating lateral motions. They were kept tight and parallel by two parallel driving rollers revolving inside the aprons.

4.1.3 Burr removal

Until 1880, burrs were removed mechanically by adding two small rollers, from which strips of iron plate projected, to the card. These rollers were placed upon the first opening or dividing rollers of the card. The edges of the strips were set very close to the surface of the card teeth and the rollers revolved at high speed in order to hit the vegetable matter from the wool. In 1880 Mm Harmel patented the first crushing rollers. The web from the doffer was passed between two rollers, the one being smooth and the other fluted. These rollers were uniform in diameter over their length and were brought close together to crush the burrs without damaging the wool.

Crushing rollers used on modern machines today were patented by the Spaniard, Antonio Peralta Albero in 1935. These rollers are normally placed after the scribbler doffer. The web passes between the perfectly cylindrical, smooth rollers while pressure is applied to the top roller. Vegetable matter present in the web is crushed by the rollers and drops out at the Peralta rollers, at the next feed rollers or at the next cylinder.

4.1.4 The Hopper

Before any feeding mechanism was developed, the card was fed by lashing tufts of fibre onto the fast moving cylinder of the machine. This operation was dangerous and in 1772, John Lees of Manchester introduced a feed sheet made of cotton cloth stitched into an endless apron with a width equal to the carding machine width, kept taut by two rollers which was driven and fed wool to the card. The endless aprons were marked across their widths to give equal areas and equal portions of wool, measured by means of a scoop, and were spread

uniformly over these areas by hand.

To obtain more accurate feed of fibres to the card two feed rollers were placed between the cylinder and feed apron. These rollers were later covered with card clothing and Lindsay and Proctor suggested in 1872 the use of rollers with intersecting teeth. This latter development resulted in better control over wool locks and allowed the wool to be fed forward more uniformly to the cylinder.

Next a licker-in roller was placed between the card cylinder and feeding rollers. This was done to remove vegetable matter and also to speed up the delivery of fibres between the feed rollers and the cylinder because excessive fibre breakage occurred when the slowly fed fibres were hit by the fast moving cylinder. The licker-in, covered with strong clothing, could open the wool tufts better and thus reduced the risk of damage to the cylinder card clothing.

A weighing hopper was patented in 1869 by Evan and King from Glasgow. In 1873 Tathams filed a patent for improving the hopper of Evans and King and started manufacturing them in 1884. The most successful hopper at the time was, however, the one patented by William Clovent Bramwell in 1876. In this type use was made of a moving lattice and a bin to feed the fibre into the weigh pan. The feed lattice stopped when the pan received the set mass of fibres and the mass of fibres was then deposited automatically onto a feed sheet which moved forward continuously to feed the card. The weigh pan was then reset automatically and the cycle re-started.

4.1.5 Intermediate Feeds

Initially scribbling and carding were carried out in two separate operations and no automatic transfer of sliver between the two parts of the card existed. In fact scribblers and carders were listed separately in mill inventories. The endless sliver was placed in cans and then withdrawn manually for laying on the carder feed sheet. In another system the sliver trailed on the floor from where it was lifted on to the carder feed sheet where it was wrapped around pegs at each side of the feed sheet. As the pegs approached the feed rollers they were removed and put into holes a greater distance away from the feed rollers.

In about 1850 Chissold fitted a traversing pair of rollers above the feed sheet. This made it easier for the sliver to be conveyed from the scribbler to the shuttle by means of an overhead lattice. Layering on the feed sheet can be either parallel or in a diagonal position. This latter way of layering was used in the well-known Apperley feed.

In 1842 a patent was granted to Henry Brown and Thomas Walker of Selkirk in Scotland which described a system by means of which an endless sliver formed by one part of a carder could be placed in a container or for plating in a zig-zag manner. In 1844 Henry Brown patented a system for forming, conveying and layering the sliver to make a unit capable of giving,

with the aid of a traversing shuttle, a continuous and automatic intermediate feed between two carding machines. This is most probably the origin of the Scotch feed still being used today.

In the ball and bank feed system, the sliver from the scribbler part is rolled into balls. These are then placed on a creel or bank holding from 30 to 60 balls and the slivers, one from each ball, are fed to the next carding part.

4.1.6 Card Clothing

The rollers of a carding machine are covered with card clothing having either a base of leather or layers of fabric through which wire or steel teeth protrude at a predetermined angle. Many cards are still today clothed with strips of leather card clothing across the width of the roller. This type of clothing is mostly fitted to cards with wooden rollers, although it is also fitted to cards with metal rollers, provided the latter have been drilled and plugged correspondingly. The majority of cards are, however, clothed with endless fillet wrapped in a helical fashion around the roller to provide a roller completely covered with working teeth.

Whatever foundation is used, this must be pricked and wire staples inserted through the hole. Up to about the middle of the eighteenth century staples were inserted into the clothing by hand. A patent for pricking holes in card clothing was given to William Pennington in 1756 and John Kay invented two machines, one for pricking the leather and the second for cutting and bending the wire. The latter machines were improved by William Kay in 1774. Many patents were registered but the fully automatic machine which pricks the foundation, cuts the wire, forms and bends the wire and finally puts it through the foundation originated from a patent granted to Clement Sharp and Amos Whitmore of Cambridge, Massachusetts in 1799.

Several patents were filed for foundation materials including one by William Horsfall in 1840. Linen and cotton foundations were introduced in 1871.

Rigid wire was also introduced at around this time and Francis Alton Calvert was granted a patent for the improvement of such wire in 1849. Calvert later entered into partnership with Garnett who invented the Garnett machine — a well known machine used for the opening of hard waste.

In conclusion it can be said that by about 1876, when the hopper was evolved, the card had all the basic essentials of a modern card. (See Fig. 6).

4.2 **Modern refinements**

Although the process of carding remained the same through time, certain refinements have been made to improve quality, to increase production and to increase efficiency. These improvements were made to all the basic parts of the woollen card and only the most important ones will be discussed below.

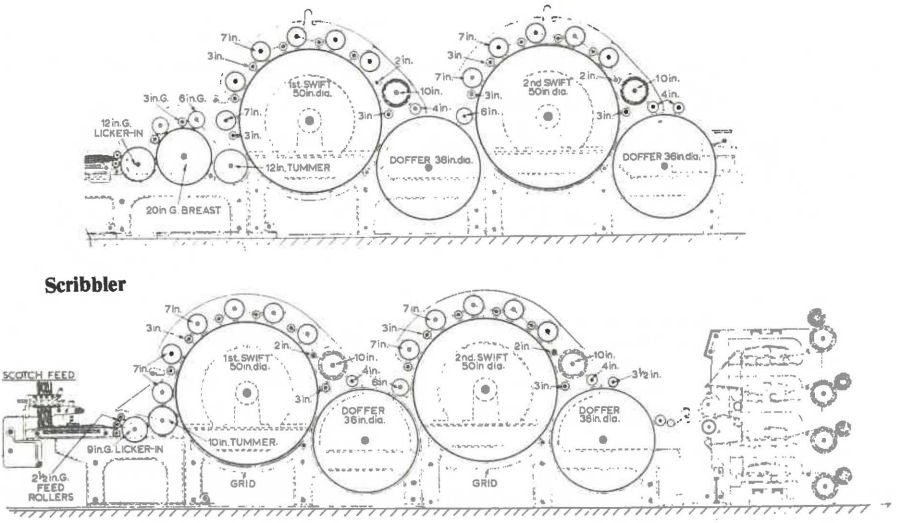


Fig. 6 — Arrangement of Semi-Continental Type Woollen Card[45]

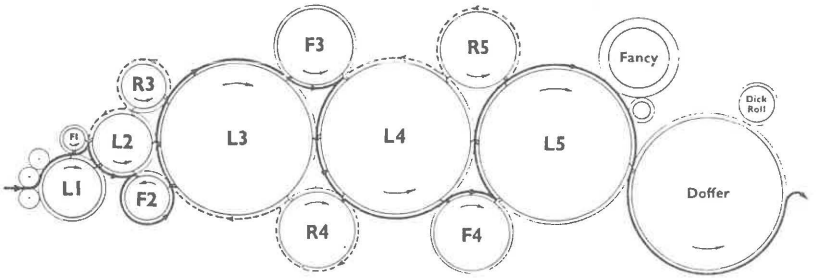
4.2.1 The card

In order to increase production and general efficiency, carding speed has been increased by the use of more suitable materials, improved bearings and higher precision in engineering[46]. Cards being 3,5 m wide have become a reality[47].

The woollen card takes up a lot of floor space, doffers use only a small area for carding action and simply serve the purpose of conveying the fibre web and as a whole, the machine is not sufficiently versatile. It was with these facts in mind that the 'Crosrol' carding machine was patented and further developed by Varga[46]. This latter Roller Train Card was a complete departure from conventional cards. The scribbler consisted of five swifts of which the largest was 50 cm in diameter, one doffer of the same size and one fancy. This machine was only 3,6 m long compared with 7,6 m of a conventional scribbler with breast and two swifts[48].

The operation of the Roller Train Card is shown in Fig. 7.

In principle each swift strips the preceding one and their surface speeds must increase from the feed to the delivery side. Carding during the initial stages is therefore gentle which keeps fibre breakage to a minimum, and the intensity increases as the tufts become more open. The scribbler has a maximum of eight workers and all except one is arranged between adjacent swifts. Four workers are used to work with one swift and is being stripped by



Explanation of signs —

= Working arcs of co-operating rollers

= Stripping arcs of co-operating rollers

= Where wire gives up fibres

= Where wire receives fibres
also indicating direction of wire-ends

Route of fibre movement —

When moving (carried) forward

When returned for recarding

R = Return worker (returning fibres to preceding swift)

F = Forwarding worker (carrying fibres to following swift)

L1, 2, 3, 4, 5 Swifts, each stripping preceding swift

The numbers on the workers indicate the swift with which the respective worker is in working co-operation

Fig. 7 — Diagram showing the operation of the Roller Train Card[48].

the following swift and three workers arranged to work with a following swift and return material to the preceding swift. One worker is placed over the last swift and fitted with a stripper.

In conventional carding most of the carding action takes place between the first worker and swift for a particular part of the machine. In the case of the Roller Trains scribbler there are five swifts and five corresponding first workers, including the three which returns material to the preceding swift for further opening. This gives considerable carding power as well as good mixing and levelling of the material.

The carder part is similar to the scribbler section except that the fifth swift and doffer are both 100 cm in diameter with three pairs of workers and strippers over the last swift. The larger swift and doffer are used because it was found, due to the small arc of contact between the two 50 cm diameter rollers, that the fibres in the web passed on to the condenser were not as straight as is the case with a normal carding arrangement. In the latter case, with a large swift and doffer, the fibres held by the doffer are retained for a longer period of time and therefore much better combed by the swift. It was also found that the levelling action of the conventional worker/stripper arrangement over the last swift was beneficial.

Diagrams of the Roller Trains, Scribbler and Carder are given in Figs. 8 and 9, respectively.

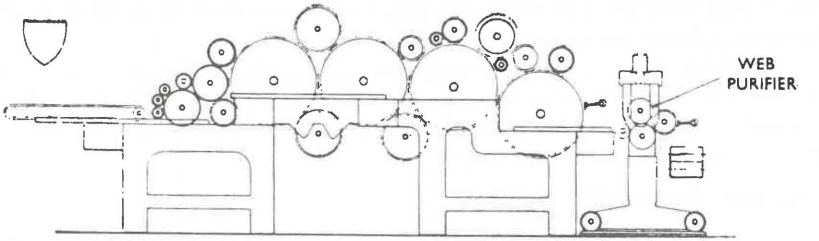


Fig. 8 — Roller Trains system scribbler

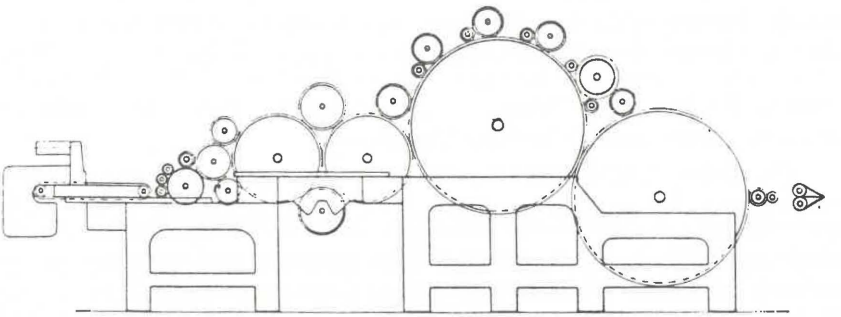


Fig. 9 — Roller Trains system carder[46]

The swifts were coupled to one drive unit and the workers to a separate drive while both driving units were variable in speed. By keeping the speed of the feed rollers and doffers constant the production was not varied but by changing the surface speeds of the swifts and workers the carding power could be changed. The latter could also be changed by changing the settings between the rollers. Changing the speeds of the actual carding rollers relative to each other gave the card more versatility than had been known before. Carding action could be adjusted to what was required for a particular blend or fibre and mixing and levelling of blend components were found to be better than with a conventional card[46].

4.2.2 The Condenser

Developments of the condenser comprised fitting a traversing creel to wind the slubbing onto the bobbins. This addition allowed for the slubbing to be wound onto the bobbin tubes without tension and longer lengths could be produced.

The most significant development was the development of the triple rub condenser by means of which the production capacity of the card is increased by drafting the slubbing between the tape rollers and the last rubbing section. This meant that the web from the tape doffer could be made heavier and the slubbing delivery speed increased[49].

Drafting of the slubbing is achieved by variable speed drives fitted to the second and third rubbing sections. A total draft of 57% is claimed by the manufacturers, Houget Duesberg Bosson, but in practice a draft of 20% to 28% is considered to be practical.

4.2.3 Burr Removal[50]

It was found that when pressure was applied to the cylindrical rollers of the early Peralta web purifiers, the rollers tended to sag and lose contact in the centre. Rollers were therefore slightly cambered by grinding them in a convex manner. Several other modifications were made, i.e. a card clothed doffing roller to remove the web from the rollers and a doffing comb to clear the roller. Better control of pressure was achieved by fitting a hydraulically actuated flexible spring system. The felt cleaning blades were replaced by laminated plastic blades requiring less pressure.

The major disadvantage of cambered rollers was that a specific pressure was required. Too low a pressure would result in ineffective crushing on the open sides of the rollers while too high a pressure would result in the rollers being sprung apart in the middle. This problem was overcome by using perfectly cylindrical rollers but off-setting the top roller slightly in relation to the bottom roller. Correct pressure setting is obtained when waste builds up evenly over the width of the top scraper blade.

4.2.4 The hopper

An efficient and reliable hopper fitted to a woollen card is essential for the production of yarns with minimum variation in linear density along the length of the slubbing produced. A number of improvements have been made to ensure proper operation of hoppers which include enclosed bearings, pans mounted on hardened steel knife edges and improved drives.

Despite all the mechanical and engineering improvements, the human error in filling the hopper remains a problem. It is a well known fact that when a hopper is tightly packed, more material is pressed on the pins of the lattice than when the load in the hopper is low. Therefore, a brushful of material fed into the scale pan can vary with a corresponding variation in the linear density of the slubbing produced[51]. It is therefore essential that the level of material in the hopper remains constant.

This problem has been solved by the double hopper. The latter consists of two similar hoppers but only the second one is fitted with a weighing pan. The first hopper is controlled by the second hopper so that the second hopper feeds

the scale pan from a constant level, supplied by the first. More even weighing is obtained and the material is opened further by the extra lattice and its levelling combs.

Increasing card production, carding speed and carding width in recent times demanded a very fast cycle of movement from the conventional weighing pan hopper. This led to the development of chute feeding of cards and an increase in the use of electronically operated weighing mechanisms.

One of the first electronically operated feeding systems is the Servolap (Fig. 10) manufactured by Houget Duesberg Bosson[52]. This consists of a source emitting gamma rays which penetrates the material and are sensed on the other side by a scintillation counter. This signal is transformed into an electrical impulse which is inversely proportional to the density of the material. A signal is also received from a tacho-alternator fitted to the swift. These three signals are compared with pre-set memories in an electronic unit. A deviation in the signal from either the scintillation counter or the signal from the swift results in an appropriate change in speed of the feed rollers.

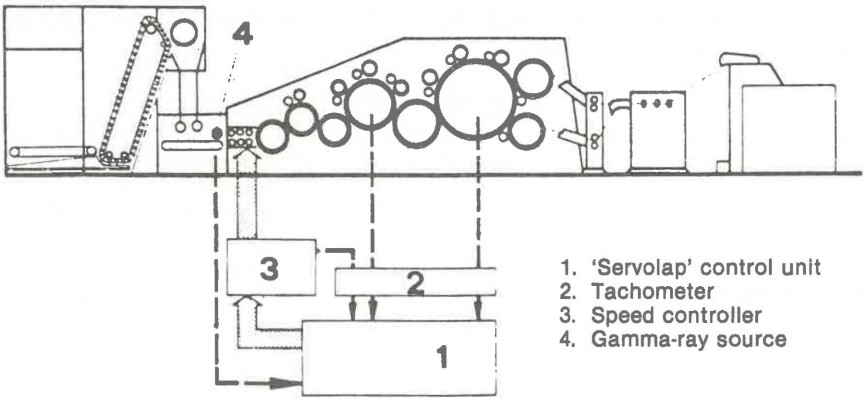


Fig. 10. — Feed roll speed regulation by isotope radiation measuring system (Houget Duesberg Bosson)[47]

In the system supplied by Octir (Fig. 11) a precision balance is employed to continuously weigh the area feed conveyed by the lattice apron[47]. The measured signal together with the preset signal is compared with signals from the feed and delivery speeds by a computer and any deviation from the desired feed rate is compensated for by changing the speed of the feed apron.

1. Weighing system
2. Feed Apron
3. Spiked lattice of hopper feeder

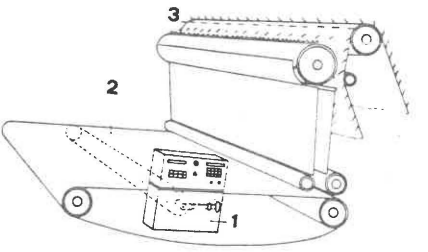


Fig. 11 — Automatic feed regulating system (Octir)[47]

The chute feed system developed by Davis & Furber (Fig 12) is also based on a continuous monitoring of the area mass of the feed[47]. Height of the material in the chute is controlled photo-electrically and uniform condensation of the material is obtained by the constant vibration of the chutes. Compression rollers, fitted below the chute, feeds the material to the weighing table to the feed rollers. Any deviation in mass is electronically sensed and the speeds of the compression and feed rollers are automatically controlled according to the mass change.

1. Photocell
2. Vibrating chute
3. Compression rolls
4. Feed rolls
5. Weighing table
6. Weight compensation
7. Flexing beam with electronic sensor for regulating the compression and feed roll speeds.

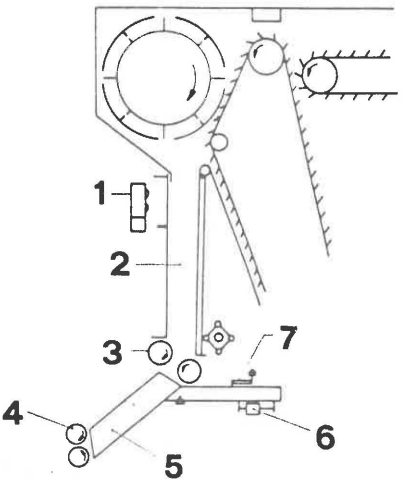


Fig. 12 — Automatic feed levelling system (Davis & Furber)[47]

The Haigh-Chadwick system also uses a chute feeding system[47]. A carbon-fibre reinforced weighing plate arranged between the feed apron and the feed rollers sustains the mass, (see Fig. 13) which is transmitted by a load cell to a control unit for display. The speed of the feed lattice is varied by a servomotor.

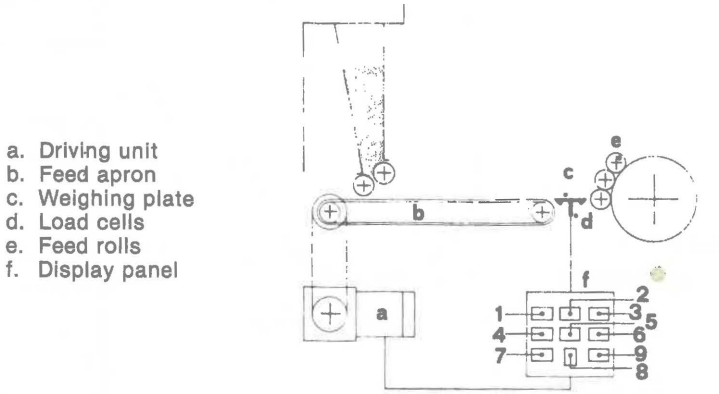


Fig. 13 — Microfeed automatic feed levelling system[47] (Haigh-Chadwick)

4.2.5 Sliver density control

Variation in linear density along the length of slubbing produced by the woollen card cannot be levelled out in spinning because low drafts are used and no levelling process such as drawing, as in the case in worsted processing, is employed. WIRA therefore developed their Autocount[53] system to level out the variations along the length of the web between the tape doffer and condenser (Fig. 14).

The WIRA Autocount is based on a closed-loop control system. Variations in web mass along its length are detected photo-electronically by the measuring head (M) and the signal from this, which is an analogue of the web thickness, is recorded by the recorder (R) and passed on to the controller amplifier (C). This signal is compared with the speed ratio between the swift and doffer and the necessary correction in the doffer speed is determined. The correction signal is fed to the Kopp-variator which varies the speed of the doffer accordingly. The change in doffer speed causes a change in the web mass which again is detected by the measuring head.

4.2.6 Intermediated Feeds

Woolen carding machines normally consist of two or three parts, i.e. a scribbler and carder parts or a scribbler, an intermediate and carder parts. The

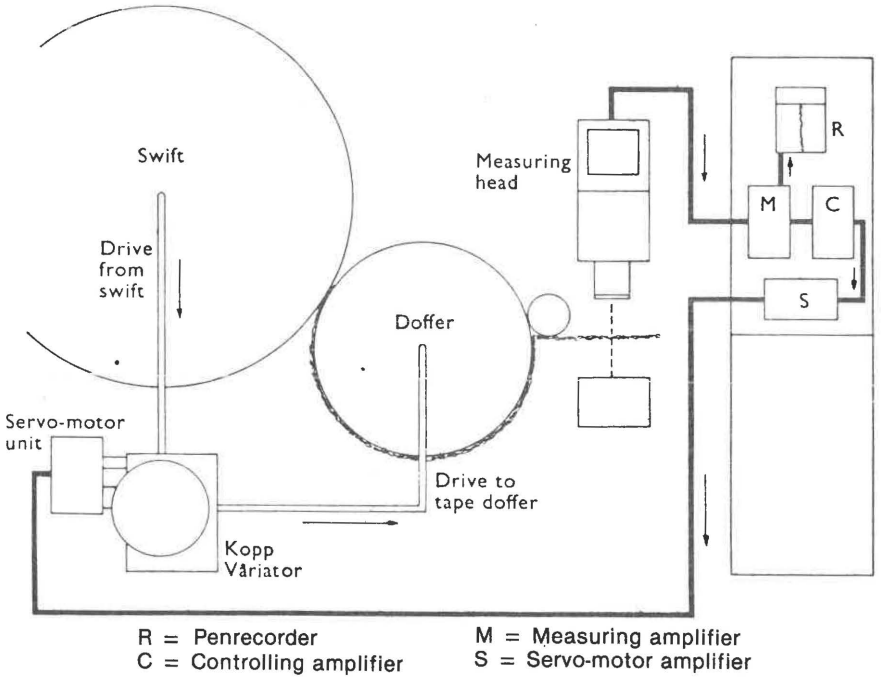


Fig. 14 — The WIRA Autocount[54]

reasons for having two or three parts are to re-distribute the material passing through each part evenly across the full width of the machine, to give an even feed to the next part and to increase mixing of the fibres[55]. To achieve the latter, the parts are connected by intermediate feeds.

The Scotch feed, initially developed by Henry Brown in 1844, condenses the sliver from the doffer of the scribbler or intermediate to a width between 20 cm and 40 cm either by a side or centre draw. The sliver thus formed is transported on a lattice feed to the next part where it is laid across the width of the feed sheet by means of a traversing carriage. This type of feed is suitable for a very wide range of materials and types of machines but suffers from certain disadvantages, i.e. the sliver is not supported between the drawing off rollers and the overhead lattice. The sliver is also unsupported between the overhead delivery point above the carder feed sheet and the carriage and it does not have the fibre mixing capabilities of the more recently developed broad band straight or cross fibre feeds. Refinements to this type of intermediate feed has been limited to the incorporation of modern engineering techniques.

The *broad band straight fibre feed* folds the web delivered by the doffer, about 30 times and about 40 cm wide onto a diagonally placed sheet moving to the side of the machine[55]. The folded sliver is conveyed between pairs of lattices vertically, overhead and downward to the feed sheet of the next carder part. The *broad band cross fibre feed* transports the web, delivered by the doffer, by means of a sheet to the side of the machine. The condensed sliver is then transported between pairs of lattices, in a similar fashion to the broad band straight fibre feed, to the next carder part.

In the *ball and bank* feeder[55] the material from the scribbler is made into a round sliver by means of a side drawing roper and passed into a balling machine which produces balls of equal lenghts of sliver. These balls, usually about 60 in number are placed in a bank or creel in front of the intermediate part feed rollers and fed through a heck plate to the rolls. This type of feed can not be used on high production carding sets, but finds its major application in the production of fine high quality lambswool yarns. It produces a more even yarn and has advantages for shade mixing. Modernisation to this type of intermediate feed has also been limited to the incorporation of improved engineering principles.

4.2.7 Card wire

Three types of card wire are available to the carder: leather sheets, fillet and Garnett or metallic wire.

The use of leather sheet clothing for covering woollen cards has decreased and is only used to a limited extent on the scribbler part of cards. This latter type of clothing has been largely superseded by fillet type clothing.

The foundation for fillet wire consists of a number of layers of woven fabric made from cotton or linen. The foundation must be strong enough to hold the wire staples firmly — it must not stretch and it must be resilient to share the strains in carding with the wire teeth[56]. Should the foundation not hold the teeth firmly, they become loose and if the foundation is too hard the teeth will break at the surface of the foundation.

The plies of the foundation were, until recently, bonded together with Para rubber and a layer of vulcanised rubber was placed on top of the cloth to prevent the foundation from being softened and the plies eventually separated by the lubricating oils. With the increase in popularity of mineral oils as lubricating agents, it has become essential to vulcanise the plies together.

In the 1930's a fillet, consisting of the cloth base with a cushion on top of the cloth which consisted of a thick layer of rubber and fibre or flock was developed and formed the basis of modern card clothing. Recently a cushion foundation consisting of granulated cork and rubber has been developed. The latter layer is cemented onto the foundation and reaches to just below the bend of the wire. A non-slip layer is applied to the underside of the foundation which prevents the teeth from working under the foundation. This Eccoprene

type of foundation can be used for carding of a large variety of materials[56].

Modern techniques are employed in hardening and tempering the wires used. Tempering is carefully controlled so that the wire will not break or bend by the forces imposed on it by the carding process. The points of the teeth are sometimes glass hardened in order to maintain a keen working point for longer periods. The wire must also be perfectly smooth so as not to allow fibres to hook onto rough spots.

The shape of the teeth of the wire can be prepared, by special methods of grinding, to perform different requirements through the carding machine, e.g.[56]:

double convex wire which is used during the early stages of carding because it gives the necessary strength to the teeth in the working direction while the pinning density is relatively low;
ovoid wire also gives strength in the working direction and is used in leather foundation for feed rollers and licker-ins;
diamond point wire, where the point is formed by special methods of cutting the wire to a point, is also used on breast parts of the card and *cadmium plated* wire is used in the heavy woollen trade where rust is a problem.

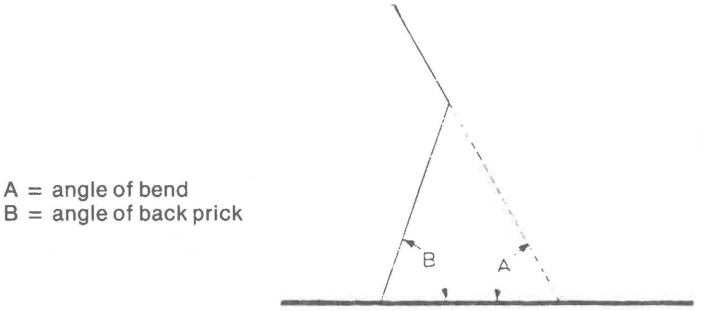


Fig. 15 — Card wire tooth[56]

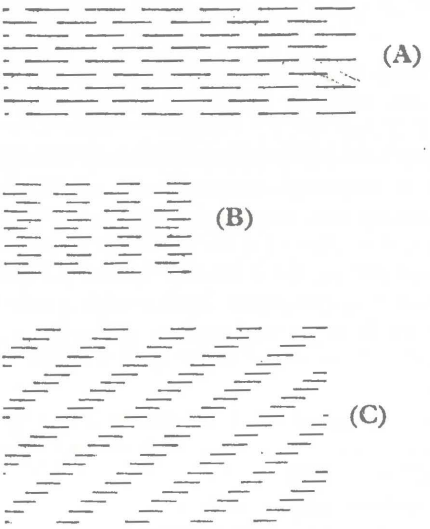
The "keenness" of a card, i.e. its power to seize and hold a tuft is affected by the angles of back-prick and bend of the wire staples in the fillet[56] (Fig. 15). These angles are varied to change the carding power of the various rollers on the card. It also facilitates the transfer of fibre from one roller to the next and gives strength to the teeth. If the staples were inserted into the backing in the forward angle required all the load will be placed on the foundation and the teeth would break or bend and the foundation will be ruined. The wire would also be forced backwards and would come into contact with the wire of the roller with which it works. By bending the wire the strain is distributed between the wire and the foundation.

The keenness of carding wire may be less during the initial stages of carding as compared to the later stages. A doffer may be slightly keener than the swift. With different foundations the height of the knee, the angle of back-prick and bend may vary. The angle of back-prick normally varies between 62 and 75° and the angle of the bend between 62 and 70°[56].

In modern card fillet the staples are set in one of three different patterns (see Fig. 16), i.e. plain, rib or twill.

Plain setting is used mainly for sheet cards. Rib setting is used for fillet clothing. The latter setting gives an even distribution of teeth up to the edge of the fillet. Twill setting is mainly used for fancies.

Metallic or Garnett wire is extensively used in the cotton trade. In the woollen trade it is fitted onto cards for the production of yarns from synthetic fibres but is is not suitable for greasy or heavily oiled wool. When processing synthetic fibres fettling is not required but with greasy wool blends the metallic wire is greased up and fettling becomes more difficult than with fillet wire. Metallic wire is mainly used on the breast part of the woollen card to break up large fibre lumps.



A = Plain setting B = Rib setting C = Twill setting

Fig. 16 — Fillet Wire settings[56]

4.2.8 Vacuum fettling

The development of vacuum fettling around 1950 proved to be one of the modern developments which were to be accepted by woollen yarn producers. It offered a number of advantages such as reduced labour costs, longer card

clothing life and automatic removal of waste[57] when compared with manual fettling.

Card wire fills up with fibres, dirt and grease during carding and fibre control is lost which results in the production of poor quality webs and slubbings. If fibres of a different shade or different physical properties to the previous lot are carded, contamination is inevitable. It is therefore essential that a card be fettled between batches varying widely in fibre physical properties or colour and when the wire gets clogged with fibre and dirt.

It must be noted that after fettling, slubbings are lighter than normal until such time as the wire is built up with fibre up to the bend. It is also preferable to fettle the card in sections rather than the entire card in one operation, e.g. fettle the scribbler during one fettling cycle and the carder during another or fettle the strippers and workers separate from the swifts and doffers.

Under normal circumstances a card is fettled by a fettling team of four men, working in pairs, digging the fettlings from between the card wires with a steel comb or with fettling boards. This is a dirty, hard job and, if not performed in the right way, irrepairable damage may be the result. The working life of card clothing is shortened drastically if fettling is carried out too frequently.

In vacuum fettling the fibres and dirt are sucked out from inbetween the teeth of the wire by specially designed nozzles, mounted at an optimum distance from the wire surface, by vacuum produced by a water cooled rotary pump. For the swifts and doffers the nozzles are fixed at the correct distance from the wire and is traversed automatically across the roller by a suitably driven roller while the card is running. In the case of the workers, strippers and other smaller rollers, the rollers are rotated by a portable electric or pneumatic motor while a hand-held nozzle is moved across the roller. All the waste and fettlings are collected in a container from which it can be easily removed.

Advantages of vacuum fettling are[57] as follows:

1. It is not necessary to remove workers and strippers and settings therefore remain unchanged;
2. waste is collected in a container from which it can be removed;
3. cleaning time, in general, is shorter; whereby downtime is minimised;
4. labour savings of up to 50%;
5. efficiency of cleaning is higher, and
6. card wire life is extended by 30% to 50%.

4.3 Arrangement of woollen cards

The main objects of carding are to separate the fibre tufts into individual straightened fibres and to mix all the components of the blend intimately in order to produce a continuous, uniform slubbing with respect to density, quality, colour and linear density[58]. In addition, fibre breakage must be kept to a minimum and as much foreign matter as possible must be removed.

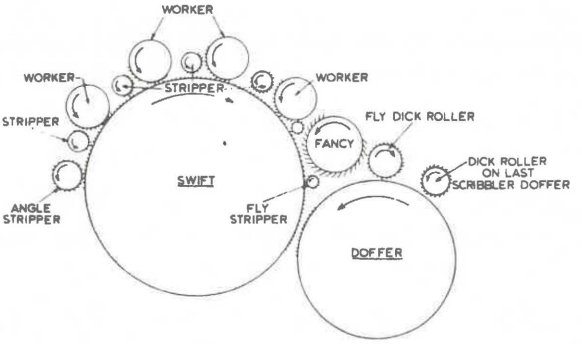


Fig. 17 — Arrangement of rollers in a single swift part[58]

A carding part consists of a number of rollers, i.e. swift, a doffer, a fancy, from three to six pairs of workers and strippers and ancilliary rollers such as angle and fly strippers and Dick rollers (See Fig. 17).

A woollen card consists of several of these individual card parts arranged and put together to form the complete machine. The most popular arrangements are the Yorkshire, Continental and Semi-Continental types.

*4.3.1 **The Yorkshire set*** consists of two basic parts, a scribbler or breaker card and a carder or finisher. The scribbler may consist of three, four or even five swift parts, the first being known as the breast. The carder or finisher has two parts. Each swift part normally has four pairs of workers and strippers to a swift. The two parts are normally connected by either a centre or side draw and a Scotch feed. The rollers are normally made from wood and covered by strip clothing. All the drives to the workers, strippers and fancies are inside the frames and the machines are not covered nor do they have any grids underneath. Speeds are therefore low and it was claimed that the carding action was more gentle than is the case with Continental and Semi-Continental sets (See Fig. 18).

*4.3.2 **The continental set*** is composed of three swifts with a small breast, the latter clothed with metallic wire. The first swift is the scribbler; the second, the intermediate and the third swift is the carder. The two intermediate feeds may both be of the continuous straight fibre feed, or a centre draw Scotch feed between the breaker and intermediate may be used[63] (See Fig. 19).

*4.3.3 **Semi-continental sets*** are made up of a small metal clothed breast, a scribbler and carder interconnected by a centre draw Scotch feed or a parallel fibre feed. Both the scribbler and carder parts consist of two swift parts each (See Fig. 20).

*4.3.4 **Scotch sets*** consist of a two-part scribbler with a breast, ball-and-bank feed, single intermediate, Scotch feed, two part carder and condenser. These sets are used in the Scottish trade for the production of very fine and novelty hosiery yarns.

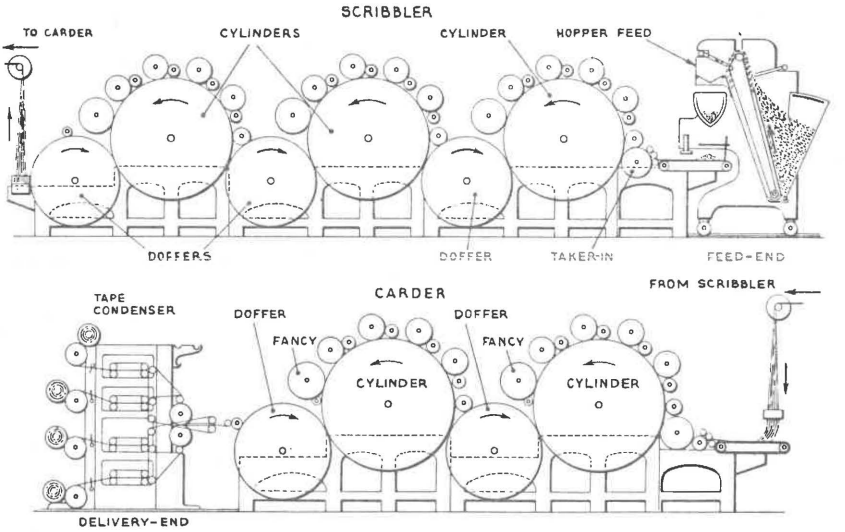


Fig. 18 — Yorkshire set consisting of hopper, three part scribbler, Scotch feed, two part carder and series tape condenser

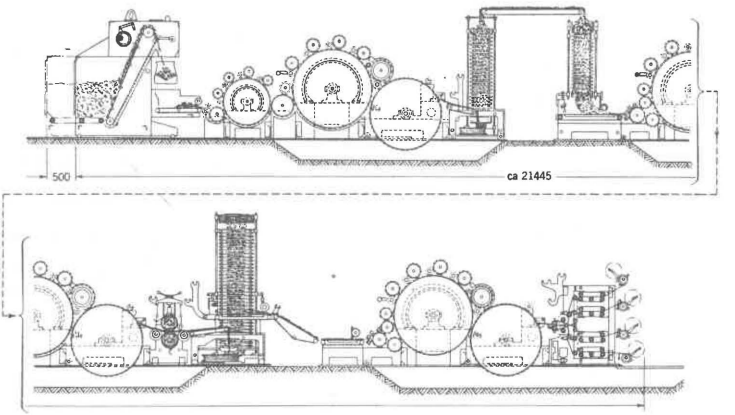


Fig. 19 — Continental set consisting of hopper, breast and one part scribbler, broadband cross-fibre feed, single part intermediate, peralta rollers, broadband straight fibre feed, single part carder and series tape condenser

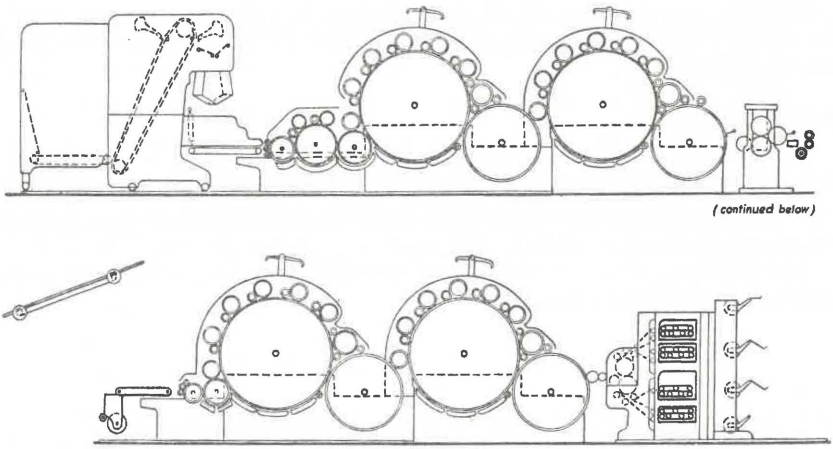


Fig. 20 — Semi-Continental set consisting of hopper, breast and two part scribbler, peralta rollers, Scotch feed, two part carder and single tape condenser.

All rollers are normally made of metal and the drives are carried outside the frames. Doffers, swifts and fancies are supported in roller bearings while the strippers, workers and ancilliary rollers run in sleeve bearings. The production rate on this type of card is high and high speeds are attained together with a more versatile machine with regard to speed variations.

Each of the three types of machine is fitted with a feed sheet, feed rollers and a licker-in before the scribbler (see Fig. 21a), while on the carder a tummer and tummer worker are placed between the licker-in and the swift (see Fig. 21b). The latter arrangement is incorporated to remove the impurities crushed by the crush rollers and to give a more even feed to the first swift of the carder[56].

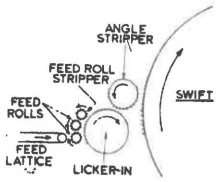


Fig. 21a — Feed sheet, feed rollers and taker-in[45].

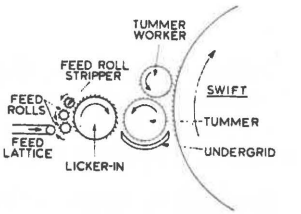


Fig. 21b — Showing tummer worker between taker-in and swift[45].

Carding sets are also fitted with aluminium side plates to prevent fibre blow-out at the sides of the machine as well as a fly or dick roller between the fancy and the doffer.

4.4 Carding Actions

Irrespective of the arrangement of a woollen carding set, to separate, open, clean, mix and condense the dispersed mass of fibres, the basic actions of working, stripping and brushing[59] must be performed by the interaction between the teeth of two rollers designed to carry out the particular action.

The working action as performed between the teeth of the swift and the workers is illustrated in Fig. 22.

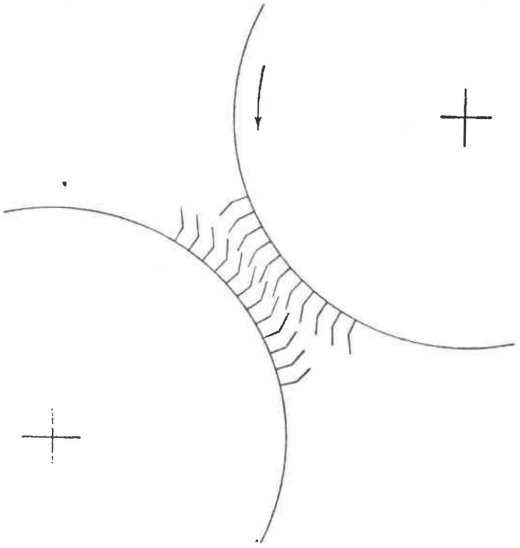


Fig. 22 — Working action between a fast moving swift and a slow moving worker (Point to Point).

During working the fibres are opened out and combed by the card wire working in a point to point action.

A stripping action is performed between the wire teeth of the workers and strippers in a point to back action. This is illustrated in Fig. 23:

Brushing or raising of the fibres to the tips of the wire teeth of a slower moving roller, the swift, is performed by a faster moving roller, the fancy, by an arrangement of wires operating with a back to back action. (See Fig. 24).

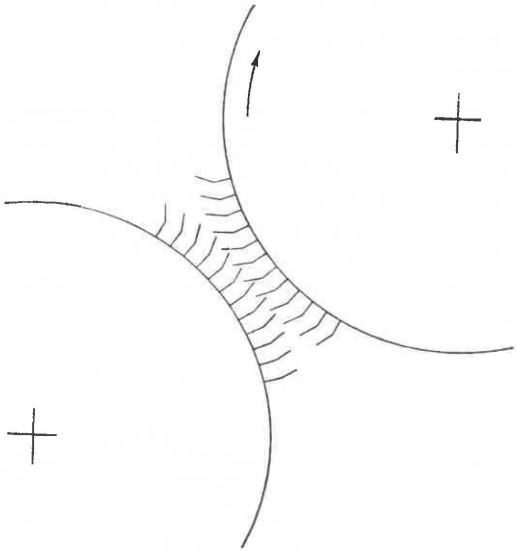


Fig. 23 — Stripping action between a slow moving worker and a fast moving stripper. (Point to back)

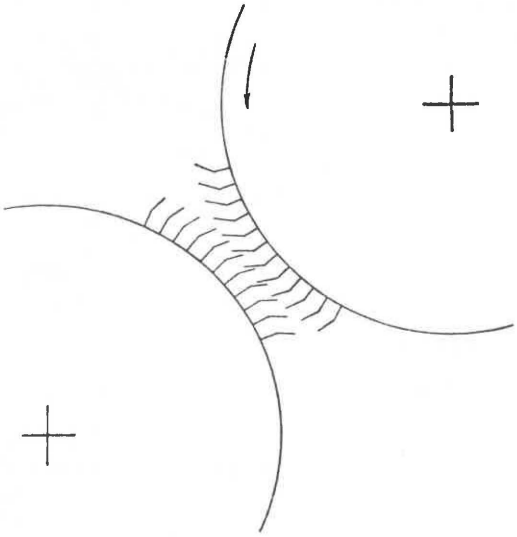
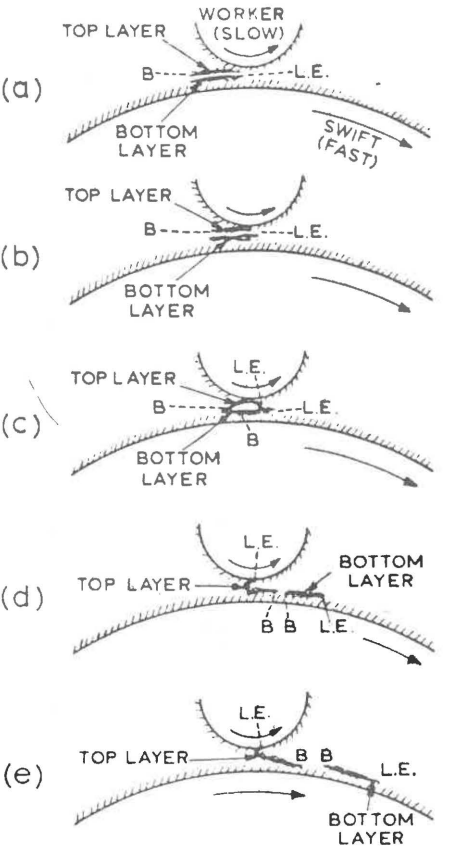


Fig. 24 — Brushing action between a slow moving swift and a fast moving fancy (Back to back).

These are the first principles of carding and the actual process involved as described by Marshall[58] are summarised below.

4.4.1 Working Action

Fibres are put onto the swift in a more or less lengthwise direction with a leading end and a back end. The leading ends of the fibre tufts that protrude from the surface of the swift, are arrested by the worker wires. The back ends of the tuft, which are still in contact with the bottom layer in the swift teeth, are carried forward by the swift at high speed. The top layer is thus peeled off the bottom layer and the back end of the top layer, which has now become a leading end, is combed by the swift wires. This sequence of events is illustrated in Figs 25a to 25e.



B = back end of fibre tuft
L.E = Leading end of fibre tuft

Fig. 25 — Sequence of actions taking place during working between the worker and swift[58].

As this combing takes place, all the fibres which are not embedded in and held firmly by the worker, or are lying crosswise, are combed out and pulled back onto the swift. Thus locks, tufts or bunches of fibres are desintegrated into smaller units and by repeated worker swift interaction, reduced to individual fibres. This process of opening up the tufts effects cleaning and mixing of the fibres.

4.4.2 Stripping action

Stripping is a point to back action but this takes place in two dissimilar methods. The first is the stripping of the worker by the stripper where the surfaces of the two rollers move in opposite directions at the arc of cooperation. The second is the action of the swift in removing the fibres from the stripper where both surfaces move in the same direction, but the swift has a much higher surface speed.

The inclination of the wires at the cooperation area between the worker and the stripper is such that the direction of pull exerted by the stripper wires on the fibres is approximately the same as that towards which the wires point at a and b as illustrated in Fig. 26. The fibres, therefore, will slip off the worker wires at a point up to that at which the angle, enclosed by the wires of the worker and the web, is slightly less than 90°. The fibres on the worker still have the original back end of the fibres in the leading position. These fibre ends were combed by the swift wires and they will be drawn into the teeth of the stripper wires and the original leading end of the fibres protrude from the surface of the stripper. These original front ends will then be carried forward by the faster moving swift teeth while the original back ends are held by the stripper.

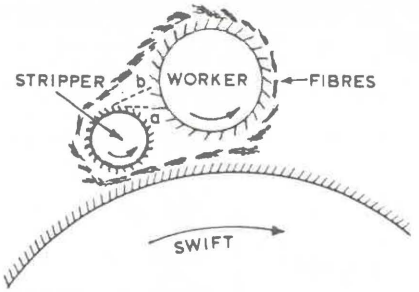


Fig. 26 — Stripping of the worker by the stripper[58].

Before leaving the stripper, however, the fibre ends are carried some distance upwards with the stripper, and therefore these released ends will tend to stand up on the swift. It should be noted that the portion of the lock or tuft of fibres originally retained by the swift at the arc of cooperation with the first worker was drawn into the swift wires, the succeeding workers are much more likely to split or divide further the fibres released by the stripper. The fibres

retained by the swift originally will only receive further carding until they have been raised by the action of the fancy and then come into contact with the teeth of the doffer.

4.4.3 Fancy Action

The fancy, fitted with long flexible wire teeth, which has a higher surface speed than that of the swift and its teeth set to intersect with those of the swift, lifts the back ends of the fibres which lay in a straightened position in the swift wires (see Fig. 27). The front ends of the fibres are retained by the swift wires.

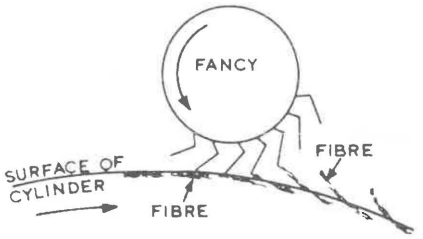


Fig. 27 — The fancy lifting the fibres from the swift surface[58].

4.4.4 Doffer Action

The doffer rotates in the same direction as that of the worker and its teeth point in the same direction as well. Its action would be the same as that of the worker, if the fibres were presented to it in the same manner but it is the back ends of the fibres, lifted by the fancy, that are caught and held by the wires of the doffer. The faster moving swift combs the fibres which are held by the doffer and any which are not held firmly by the doffer are combed back onto the swift (See Fig. 28).

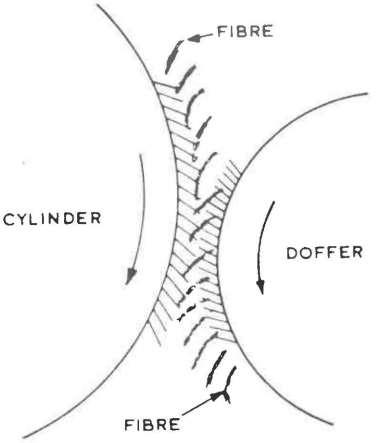


Fig. 28 — Transfer of fibres from the swift to the doffer[58].

4.5 Collecting power of a worker

The doffer collects about 20% of the fibres presented to it by the swift[58] while new fibres are fed to the swift as it revolves. The workers divide the material which pass at their arc of co-operation with the swift and as the stripper returns the worker's share to the swift, after some time has elapsed, this provides a continuous series of doublings, doubling some of that which has gone before with fibres arriving later. This results in mixing and levelling of the fibres. The effectiveness of this levelling action depends on how the material is shared between the worker and the swift. The fraction of the material retained by the worker has been called the "Collecting Power" or "Lifting Power" of the worker. Collecting Power, p, is also defined as the probability of a fibre approaching a worker being picked up by the worker[60].

The collecting power of a worker is an indication of the levelling and mixing of fibres on the card and it is also indicative of the carding ability of a worker. To quantify and understand how the mixing and carding ability of a worker is influenced by changes in speed, setting and condition of the card wire, it is necessary to know how collecting power is determined and how the latter can be applied to practical carding. The carding power of a worker and its practical significance to the carder have been described by Martindale[60] and his work is summarised in the following paragraphs.

The collecting power of a worker can be easily determined if the diagram in Fig 29 is considered.

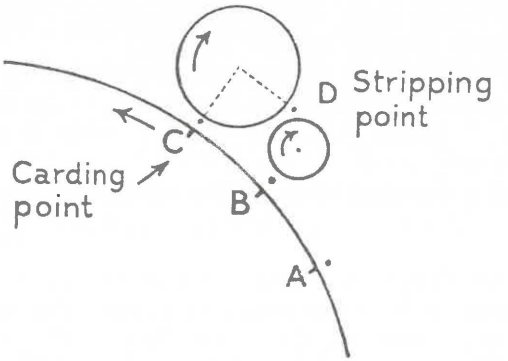


Fig. 29 — Illustration of fibre tuft division between swift and worker.

In Fig. 29 suppose:-

x is the uniform rate of feed past A in g/min.
m is the mass of wool on the worker in g.
n is the speed of the worker in rev/min
f is the fraction of the worker surface covered with wool.

Then:-

1) The swift carries x g/min to B.
2) The worker returns $\frac{M}{f}$ g/rev = $\frac{nm}{f}$ g/min to the swift.
3) These two amounts unite at B, so the total amount carried to C is:-
   $x + \frac{nm}{f}$ g/min.
4) But the worker returns:-
   $\frac{nm}{f}$ g/min to the swift (2) above
5) Therefore the fraction of wool collected by the worker at C is:-

$$\frac{\frac{nm}{f}}{x + \frac{nm}{f}} = \frac{m}{m + \frac{xf}{n}}$$

Thus the Collecting Power, p, is given by the formula:-

$$p = \frac{m}{m + \frac{xf}{n}}$$

Martindale[60] carried out a series of experiments in which the Collecting Power of the workers on a carding machine was determined, while several factors, such as worker speed, setting and condition of the wire, were varied. The most important findings were the following:

1. Improving the keenness of the wire of a worker by grinding gave an increased value of p suggesting better opening of the material.
2. Close settings resulted in a slight increase in the value of p resulting in increased carding power.
3. The value of p decreased from input to output side, showing that the work done by the workers on a card decreases as the material moved around the bend.
4. Values of p decreased less on the intermediate than on the scribbler as the material passed from the 1st to the 4th worker. The decrease in the value of p was even smaller on the carder than on the intermediate. It was suggested that the progressive decrease was connected to the material being more open when transferred from the one part to the next.
5. The value of p was found to be higher for the first worker on a succeeding part than the last worker of the preceding part, i.e. the first worker on the intermediate had a greater collecting power than the fourth worker on the scribbler. It was suggested that as the fibres were carried forward by the swift a certain amount got pushed into the teeth of the swift by pressure either from the stripper or the worker. This was confirmed by the decrease

in collecting power of the workers as the wool progressed through a particular carding part. It was therefore essential that the wool be lifted to the top of the swift wires so that the workers can card it again. This is achieved by the fancy and doffer and then feeding to the next swift. It was concluded that the transfer of wool from one part to another by a fancy-doffer arrangement was beneficial to actual opening action, and as a consequence of this, that three swifts with four workers each would give better carding than two swifts with six workers each.

6. In carding the same wool without oil and with an addition of 10% oil no significant effect on collecting power was found.
7. Increasing the speed of the workers produced an appreciable increase in the collecting power of the workers. This suggested that high worker speeds was conducive to better carding action. It was, however, found that yarn strength was low when the workers of the carder part were run at high speeds. The yarns thus produced also had a "twitty" appearance as compared to yarns produced with low worker speed on the carder part. Yarns made with high speeds on the scribbler and intermediate workers gave slightly stronger yarns than that produced with slow worker speeds on these parts. The reason why an increase in speed of the worker increased collecting power was said to be because in a given short interval of time more clean points are presented to the swift and therefore there is not the same tendency for the worker teeth to become clogged with wool.

All the findings indicated that the value of p was closely associated with the amount of carding done by a worker. The belief was that higher values of collecting power would give better carding. This belief was based on the fact that the more wool lifted by a worker the more was given a second chance at being carded and as some of the wool was picked up a second time, and so on. This is best illustrated in Fig. 29. Suppose a tuft of wool, with a mass M approaching the point C and p for the worker = 0,5 then the tuft will be split up in successive passages round the worker (see Fig. 30). If p = 0,7 the tuft will be split up at C as shown in Fig 31.

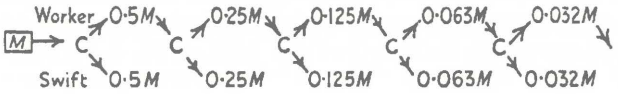


Fig. 30 — Illustration of the division of a fibre tuft between the swift and a worker, when p = 0,5.

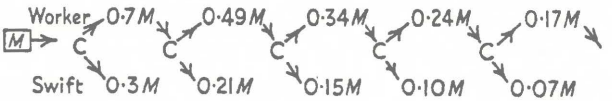


Fig. 31 — Illustration of the division of a fibre tuft between the swift and a worker, when p = 0,7

conditions were changed. It was shown that by increasing the worker speed and setting the workers closer to the swift reduced the number of neps in the carded web. It was also said that, with higher worker speeds and closer worker settings, the amount of worsted and woollen threads added to the blend decreased in the web produced. These results showed that collecting power and carding or opening power were closely associated, suggesting that a high collecting power would increase carding power[63]. It was suggested that to obtain good woollen carding high worker speeds on the scribbler and intermediate sections of the card should be used to obtain efficient carding and low worker speeds on the carder part to form an even slubbing.

The action between the swift and the doffer is essentially the same as that between a swift and a worker. It was shown[64] that the collecting power of the doffer was affected by the same factors affecting the collecting power of a worker. In these trials a worker and stripper was mounted below the swift. This underslung worker would collect a fraction of the fibres, escaping the doffer, in a fashion similar to that of a normal worker. An increase in the fraction or mass of fibres collected by the underslung worker would indicate a low doffer efficiency and *vice versa*. The efficiency of the doffer was also influenced by the action of the fancy and it was therefore necessary to study the influence of fancy setting and speed together with the action of the doffer itself. It was concluded that doffer efficiency was increased by increasing the doffer speed and running with closer doffer settings. Increasing the speed of the fancy increased the efficiency of the doffer because the fibres were more effectively lifted from the swift but the effect diminished as the loading, brought about by decreased doffer speeds and a higher feed rate, of the swift increased and the effect was even found to reverse when the swift was very heavily loaded. It is interesting to note that the findings recorded above for a woollen card were also found to be valid for a cotton card[65].

The action of the fancy is complicated and not clearly understood. It is, however, interesting to compare the findings of Marsh[65] from his geometrical study of fancy action with those of Martindale discussed in the preceding paragraphs. Marsh showed that the relative motion of fancy wire tip and the slowly moving swift is a looped curve as shown in Fig. 33.

Marsh stated that the fibres are raised to the surface of the swift wire by the fancy wires by pushing the fibres in front of itself, mainly in a downward movement towards the swift. This motion suddenly changes into a forward motion as the fancy wires approach its deepest point of penetration, against the backs of the swift wires, the fibres thus tend to ride up the backs of the swift wires. This latter process is assisted by the forward inclination of the swift wires. After the fancy wires reach their deepest point of penetration of the swift wires, they still move forward but start to retreat from the swift wires thereby lifting the fibres from the swift wire. The fancy wires move away from

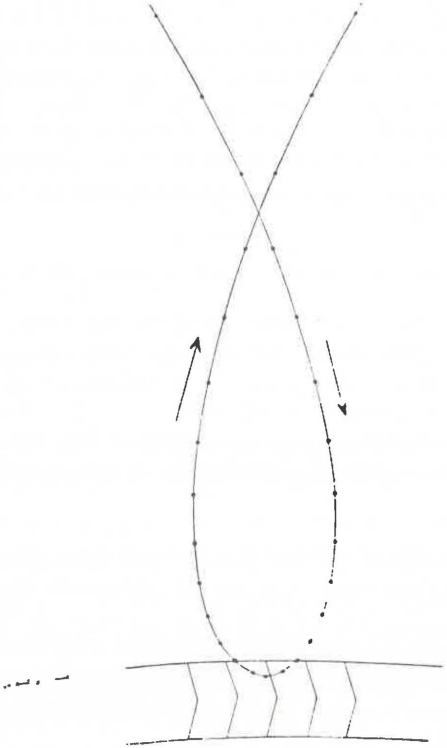


Fig. 33 — Diagram illustrating the looped curve followed by a fancy wire relative to the swift[65].

the swift wires at a very small angle with regard to their direction of motion and the actual lifting action is therefore due to friction between the fibres and the fancy wire as well as the friction of the fibres against the swift wires.

As the fancy wires leave the swift wires the forward motion decreases and hence the force exerted by the fibres on the fancy wires also decreases. The fancy wires therefore spring back to their original position whereby further raising of the fibres takes place.

Marsh showed that when fancy lead is increased the loop of the curve, followed by the fancy, broadens, thus the length of the path that the fancy wires sweep through the swift wires increase. This is also true when the penetration of the fancy wires into the swift wires was increased. This latter phenomenon explains Martindale's findings that increased fancy lead results in more effective lifting of the fibres from the swift. This suggested that with the increase in sweep of the fancy wires more pressure is exerted on the fibres

to slip up the backs of the swift wires and an increase in the pressure on the fancy wires, so that when they eventually leave the swift wire the release of the force on the fancy wires is bigger, resulting in a more forceful spring back of the fancy wires to their original position, thereby lifting the fibres more effectively from the swift wires. In the case of high loading of the swift, the fancy may press the fibres too deeply into the swift wires making it impossible to lift or the fancy wires may bend to such an extent that they simply slip over the fibres in the swift wires.

It has been stated above that fibres are delayed on a card due to the workers collecting a fraction from the swift and the doffer which also collects a fraction only of the fibres presented to it by the swift, the rest being recirculated again around the swift. This delay of fibres on a carding part has been termed the delay factor. Delay factor is influenced by setting of the rollers (workers, doffer and fancy) to the swift, as well as the speed of these rollers. Carding power therefore can be related to the mean delay factor because carding power increases with an increase in delay factor[66].

4.6 **Delay Factor**

Delay factor is a measure of the average time that fibres take to pass through a part excluding the time spent on the doffer[66-69]. The magnitude of the delay factor is dependent on the collecting fractions of the workers and doffer. The average time D that the fibres are held in a part is L/I revolutions of the swift, where L is the load of workable fibres held by the swift and workers which will ultimately appear in the carded web and I is the input to the part per swift revolution.

The load of workable fibres can be calculated[69] in terms of the doffer collecting fraction, f^*, the collecting fractions of the workers p_1, p_2, etc. and the times n_1, n_2, etc., that the fibres are held by the workers. The collecting fraction is the fraction of the mass of fibres presented to that roller by the swift in a given time and which is taken by the roller in the same time.

The output per swift revolution is the input I, the total load of workable fibres over the swift is I/f, since a fraction f of the load I/f has to equal the output I.

The doffer collecting fraction[70] is the fraction of fibres removed from the fibres presented to it by the swift.

Thus $f = \frac{sw}{SW}$

where s = surface speed of the doffer
w = average density of fibre per unit area of the doffer
S = surface speed of the swift
W = average density of fibre per unit area of the swift.

The mass of fibres returned from the worker, by the stripper, per swift revolution must also be taken into account. (See Fig. 34).

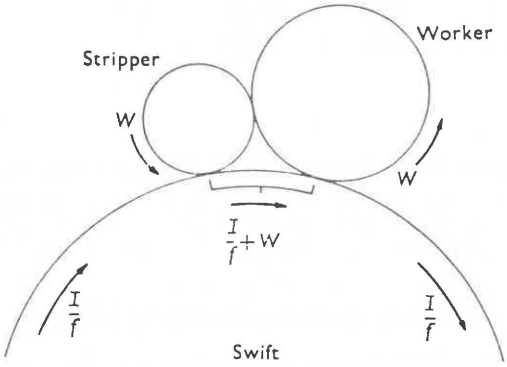


Fig. 34 — Load carried by a worker[69].

Under equilibrium conditions the mass W taken up by the worker per swift revolution is again returned by the stripper. If p is the collecting fraction of the worker, then

$$p = \frac{W}{I/f + W}$$

or

$$W = \frac{I}{f} \times \frac{p}{1-p}$$

The total load carried by the worker, if they are held for n revolutions, before they are returned to the swift, is:

$$nW \text{ or } \frac{I}{f} \cdot \frac{np}{1-p}$$

The total load L on the swift and the workers therefore, is:

$$L = \frac{I}{f}(1 + \frac{n_1 p_1}{1-p_1} + \frac{n_2 p_2}{1-p_2} + \text{etc})$$

Where the subscripts 1,2, etc., depict the first, second , etc.,... workers.

The delay factor $D = \frac{L}{f}$

Therefore $D = \frac{1}{f}(1 + \frac{n_1 p_1}{1-p_1} + \frac{n_2 p_2}{1-p_2} + \text{etc})$

swift revolutions.

The delay factor of a carder part can be determined by means of a direct method in which the feed to the machine is stopped, the card run empty, weighing of the fibres run off and subtracting the mass of fibre on the doffer — this gives the workable load of fibres, L. The delay factor, D, is then given by $\frac{L}{I}$ where I is the feed rate to the card. The direct method can, however, only be used on card clothed with Garnett wire because when a card clothed with flexible wire is run off the workable fibres pull some of the fibres embedded in the swift wire with them, giving rise to too high a value of loading.

Delay factor in the latter case must therefore be done by means of an indirect method. This has been done by changing the input to the card during running conditions and then measuring the change in web output by means of the WIRA Autocount[67,71]. This can be explained if the idealised case, as illustrated in Fig. 35, is considered.

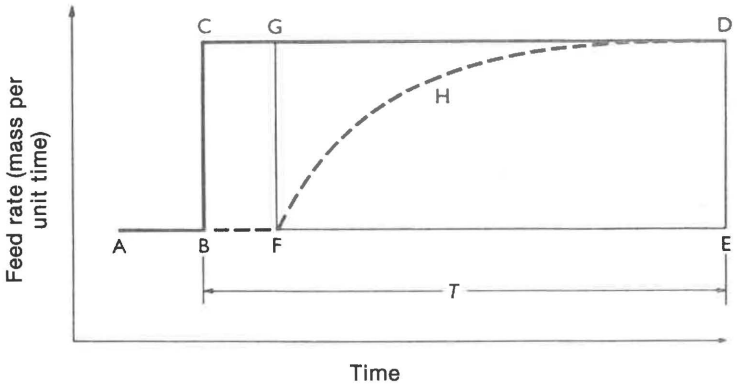


Fig. 35 — Measurement of delay factor[71]

If the input to a card is suddenly increased as with A B C D in the figure, the extra fibre fed to the card in the time, *T*, is proportional to the area of B C D E. The mass of fibre coming from the doffer per unit time will change according to A F H D, i.e. the extra mass of fibre coming from the doffer during time, *T*, will be proportional to the area F H D E. Hence the total increase in load by the entire part, because of the increase in input is proportional to the area B C D H F. The area B C G F is proportional to the increase of the load carried by the doffer and the area of F G D H proportional to the increase in load carried by the swift and workers. The delay factor is then the area F G D H (the change in the total load of the swift and workers) divided by the distance B C (the change in input). If the change in input is in g/sec and the load in grammes then the delay factor is in seconds, while, if the change in input is in g/swift rev then the delay factor is in swift revolutions. Delay factors are normally given for a single carding part and the mean delay factor for two or more carding parts is the sum total of the delay factors of the individual parts.

High values of delay factor promote good mixing which means that inconsistant weighings of a hopper will be levelled out and mixing of fibres differing in physical properties will be blended effectively, thus resulting in a more uniform slubbing linear density. If, however, the delay factor is too high due to slow rotation of the doffer, reducing its collecting power, the cylinder becomes overloaded, carding is inefficient and neps increase. For a cylinder to perform a proper carding action and to accept a maximum rate of fibre feed, the doffer should clean the cylinder effectively to keep the fibre load low by running the doffer at a high surface speed[72].

Delay factor is influenced by several carding parameters and possibly by different fibres. Several workers reported their findings on this matter and the most important factors are summarized in the following paragraphs.

Delay factor decreases as the doffer surface speed increases[70,73,74]. Delay factor is not changed by changing the diameter of the doffer[67,70,73]. Setting distance between the doffer and swift has no significant influence upon delay factor[74].

A change in worker speeds has a insignificant influence upon the delay factor. Reversing the direction of rotation of the workers leads to a decrease in the delay factor. Delay factor is, however, increased when more workers are introduced[70,73,74]. Delay factor is insensitive to worker to swift setting distance[74].

Delay factor is not significantly influenced by fancy lead or depth of penetration into the swift for the ranges encountered in practice. Fitting two fancies to the swift does not influence the delay factor but the loading of the swift decreases[70,74] while more of the load was carried by the workers[70].

Delay factor was found to be insensitive to changes in production rate as

well as changes in fibre type[70,74]. It was, however, suggested that longer fibres give a higher doffer collecting fraction resulting in a lower delay factor[74].

It was also found that delay factor was not influenced by a change from normal to coarser card clothing[67]. In fact, no difference in delay factor was found even between garnett wire and normal fillet[74], neither did old nor new clothing produce any change in delay factor[74].

Some of these results can be explained on the basis of the formula for delay factor[70]. Changing the speed of the workers does not cause the delay factor to change. The value of the worker collecting fraction, p, is small (normally in the order of 1/20) so that $1 - p$ is approximately 1 and if the worker is speeded up, n increases while p is increased. The term np divided by $(1-p)$ only changes fractionally and the change in the delay factor, D, will be insignificant.

Changing the direction of rotation of the workers has an insignificant influence on p but reduces n, the time the fibre spends on the worker, and consequently reduces the delay factor.

The delay factor, however, is very sensitive to changes in the doffer collecting fraction[70], f. For example, if the doffer speed is increased, the collecting fraction might change from 1/15 to 1/20 and the term $1/f$ in the formula will become 15 or 10, respectively, thereby reducing the delay factor significantly.

4.6.1 Practical application of delay factor

It has already been said that the average time that a fibre is held within a carding part is called the delay factor and that the delay factor for more than one card part is the sum total of all the parts, i.e. the delay factor of a four part card, each having a delay factor of 50 seconds, will have a delay factor of 200 seconds. The average time taken by fibres to pass through the card will, however, be longer due to the additional time spent on the scribbler feed sheet, the intermediate feeds and the underside of the doffers. The mixing and levelling action of a carding machine will therefore improve when the number of parts increase due to an increase in the delay factor. This is illustrated in Fig. 36.

It should be noted that the frequency of the variation is not changed but only the amplitude of the variation. Fig. 36 shows the percentage of a variation of a given frequency which will remain after having passed through the various number of carder parts. It can be clearly seen that the card can quite easily cope with variations of a high frequency and that the mixing and levelling action becomes progressively better the more the number of card parts being employed.

In order to apply the influence of delay factor upon the levelling and mixing action of a carding machine it is necessary to have an understanding of the irregularities introduced into the slubbing during the process of carding.

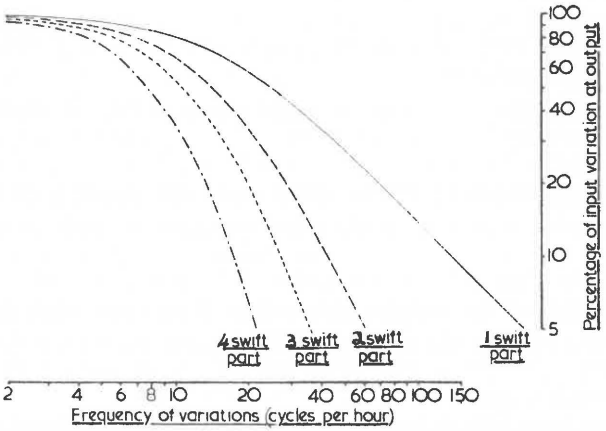


Fig. 36 — Curves showing the smoothing effect of passage through various numbers of carding points on variations over a large range of frequencies[70]

Slubbing irregularity can be divided into two categories[75,76], the first being variation between individual slubbing ends across the card and the second being variation along the length of the individual slubbings. Variation across the card cannot be eliminated entirely because it is a function of tape tension and of fibre blend composition. It does, however, remain constant for a particular blend and can be reduced to a minimum by proper tape tension adjustment, or correct layering of cross feed on the carder feed lattice or both. This minimum value was recorded as being within a range of 8% of the mean value[66]. Variation in linear density along the length of the slubbing consists of variations[75,77,78] of different amplitude and frequency and can have a range of as much as 25%[66].

Slubbing variations along the length can be classified into the following categories[66]:

1. short-term variations have periods less than one second and one equivalent to approximately 20 cm of slubbing,
2. medium-term variations with a period between 1 second and 1 minute,
3. long-term variations with a period of 1 to 6 minutes, and
4. very long-term variations with a period over 6 minutes.

Variations along the slubbing which have a significant amplitude are below 10 cycles/hr and those above 120 cycles/hr. The lower frequency variations or very long-term variations are related to hopper malfunctioning when the hopper is allowed to run down low in material and then suddenly filled again or when the card is filling up after fettling.

Variations produced within the individual carding parts are of the upper frequency band. The lower frequencies within this band are dependent on the

frequency of cyclic operation of the various parts, such as roller speeds and intermediate feeds, and the upper-frequencies depend on the random nature of the carding process itself[66].

Mean delay factor is a measure of the average time for which any fibre is held within a carding part. If the period of a variation at the input is large compared to the mean delay factor, the mixing action of the part will not be able to reduce the amplitude of the output variation significantly while, on the other hand, if the amplitude of the input variation is small compared to the mean delay factor, the amplitude at the output will be significantly reduced. Thus, upper frequency band variations are caused by the carding part immediately before the output and lower frequency variations may be produced at any point in the card before the output. Low frequency variations are mainly caused by the hopper being allowed to run almost empty and then suddenly overfilled again[66].

If it is assumed that a hopper scale pan deposits its weight 90 times per hour onto the feed sheet but in a manner which leaves gaps between successive weighs. If Fig. 36 is considered it will be seen that after passage over one swift the amplitude at the output is only 15% of the original value. After two swifts the amplitude is less than 5% of the original value and after three parts the effect will be hardly noticeable[79].

It can be shown, on a similar basis, that a missed hopper weigh will still show up after the scribbler but will be undetectable at the condenser. Thus, as the fault is delayed in each carding part the amplitude is reduced.

The joints produced by intermediate feeds when the sliver is layered across the feed sheet of the carder part can be a source of irregularity, but once the fibres have passed a two-point carder the effect is levelled out[79].

In conclusion it can be said that as the delay factor of a card is increased its ability to reduce irregularities increases. However, care must be taken that irregularities are not introduced at the last carder part because such irregularities can not be efficiently dealt with and any such irregularities will appear in the slubbing and finally in the yarn due to the inability of the mule or woollen ring spinning frame to deal with them. In most carding machine arrangements, the card part consists of two swifts because it gives an increased delay factor between the carder feed sheet and the condenser. The first part produces a more uniform feed without tufts to the important last carder part.

The same principles of delay factor also apply when fibres within a blend differ with regard to their length, diameter, colour, etc. In order to mix the fibres properly the card must have a certain minimum delay factor. This was illustrated by placing alternate weighs of blue and white fibre on the feed sheet of a card with a breast, three single-swift parts, a Scotch feed and a parallel-fibre feed. No difference in shade could be detected at the condenser and only after alternate groups of four weighs of white and blue wool had been fed to

the card, a difference in shade could be detected. This can again be explained when Fig. 36 is considered. From this figure it can be seen that as the frequency of the variations decrease, i.e. the number of weighs in the alternate groups decreases, the percentage of the input variation appearing in the output increases[79].

In another experiment[79] white wool was fed to one half and black wool to the other half of the width of a scribbler consisting of three swifts. The two colours were brought together in the Scotch feed and then carded on a two swift carder. The resultant colour mix was found to be acceptable. Mixing on the entire part of five swifts would have been even better and it was therefore concluded that the mixing ability over the full set was more than adequate. It can be seen from Fig. 36 that input variation is reduced significantly over two swifts and over four swifts the mixing and smoothing effect is more pronounced.

4.6.2 Delay factor and carding power

Apart from smoothing out irregularities and mixing the fibres in the blend, the card must also open out the tufts of fibres. A measure to assess the opening ability of a card is by the determination of the average number of times a fibre passes through the setting region between the swift and workers and the swift and doffer before they leave the card. This is called the Carding Power[73,80], and is given by the formula:

$$C = \frac{1}{f}\left(1 + \frac{1}{1-p_1} + \frac{1}{1-p_2} + \frac{1}{1-p_3} + \text{etc}\right)$$

where f = doffer collecting fraction
p_1 = worker collecting fraction of the first worker
p_2 = the collecting fraction of the second worker, etc.

As is the case with delay factor, p is small and carding power is therefore approximately equal to $(1 + x)$ divided by f where x is the number of workers on the part[80]. This once again emphasizes the importance of f, the doffer collecting fraction. Although no provision is made for n, worker speed, in the formula, p is dependent on the speed of the worker itself, and hence will the value of carding power. It must be remembered that the value of C is only an average value of possible passages through the carding regions of a single-swift part.

Carding power increases as the delay factor increases[73,74] which means that the longer a fibre spends within a part, the greater its chances of passing through the setting regions. This holds for changes brought about by changes in doffer and worker speeds but when the direction of rotation of the workers is reversed, however, carding power remains unchanged, though the delay factor is decreased.

When delay factor and carding power are increased by reducing the doffer speed, the swift loading is increased. It is therefore important that a balance be obtained to maintain an effective swift loading to level out irregularities while adequate carding is performed to produce a web with the minimum number of neps.

4.7 Nep formation during carding

A nep can be defined as an entanglement of fibres which are not removed during carding, or can even be introduced during carding by maladjustment of the card. Neps rise to the surface of the yarn during spinning and influence yarn and fabric appearance, limit the yarn linear density, the end breakages during spinning is increased and the cost of mending and finishing is increased[81].

Nep formation is influenced by fibre properties and card parameters. It has been found that fine fibres tended to produce more neps than coarse fibres[82]. All other fibre properties being constant it was shown that longer fibres have a higher nep potential than shorter fibres. It was suggested that the longer fibres broke more during carding giving rise to more neps in the resultant webs[81]. It was also shown that for nylon the number of neps in the web increased as fibre crimp increased[83]. Neppiness was also found to increase with an increase in grease content when wool was carded and increased rates of production exaggerated the situation[81].

It was found that vegetable content[76] did not effect nep content of carded webs but it was suggested that in practice high nep content was associated with high burr content, because high burr content wools were normally carded under conditions of low regain.

Nep formation during carding is influenced by the regain of the material. High nep contents result when wool is carded which is too dry or too wet. It was found[64] that fewest neps were formed when wool was carded with a regain between 30% and 50%. Regains as high as the latter are impracticable and 20% — 25% regain is recommended when carding fine, clean wools[81].

Machine variables such as roller speed and settings also influence nep formation. Nep content is reduced by an increase in swift speed[81], and it was suggested that at high swift speeds the swift loading decreased which allowed fibre bundles to be disentangled to a greater degree. Fast worker speeds also produce less neps but the effect is not as great as the difference due to worker-swift setting. Nep content also increases when the surface speed of the fancy is reduced in relation to the speed of the swift[81]. This is possible due to the fancy not being able to lift the fibres efficiently from the swift which then becomes clogged with fibre and the workers are then unable to open the

material between them and the swift, but rolling the material instead producing an excessive number of neps.

It was also reported[83] that an increase in doffer speed resulted in a less neppy web when Sarille staple fibre was carded. Nep content of the web also decreased when closer doffer settings was employed. The reduction in the number of neps was ascribed to the increased carding action by the doffer-swift setting.

In the carding process it is the card wire that performs opening and mixing of the fibre tufts and factors such as wire density, fineness, profile, angle of bend and the type of foundation are all important factors in determining the quality of the carded web and hence yarn quality.

Nep content is markedly affected by the density of the card clothing[81,85,86]. In a series of experiments[86] in which a 70's quality wool was passed repeatedly through a card clothed with fillet wire, having different densities of card wire, it was found that after a single pass through the card, clothing coarser than 400 points/inch^2 gave neppier webs while clothing denser than 400 points/inch^2 did not produce less neppy webs. This is illustrated in Table 2.

TABLE 2
NUMBER OF NEPS PER GRAM IN CARDED SLIVER AFTER REPEATED PASSAGES THROUGH A CARD CLOTHED WITH FILLET OF VARIOUS PINNING DENSITY[86].

No of Passages	Card Clothing Count/Crown and Number of points/inch^2:					
	Diamond Point 64	60/6 144	80/8 256	100/12 400	120/12 576	140/12 784
1	348	413	372	122	143	185
3	590	684	725	35	40	5
6	655	1198	1110	17	3	1

Considering the results in Table 2 vertically down the columns, representing the number of neps formed by carding the same wool 1, 3 and six times with the same wire density, it will be seen that with densities increasing up to 256 points/inch^2, nep content increased with repeated carding with the same wire, while the nep content decreased when the wire density increased from 400 — 784 points/inch^2.

In practice, however, carding proceeds over a number of swifts where the wire density increases from the hopper to the swift. The results are given in Table 3.

TABLE 3
NUMBER OF NEPS PER GRAM IN CARDED SLIVER AFTER PASSAGE THROUGH A CARD CLOTHED WITH PROGRESSIVELY INCREASING WIRE DENSITY[86]

	Card Clothing	Count/Crown and Number of Point/inch^2			
Diamond Point 64	60/6 144	80/8 256	100/12 400	120/12 576	140/14 784
348	660	912	600	690	206
	413	757	568	295	137
		372	376	245	37
			122	89	33
				143	77
					185

Looking at these results horizontally, a picture is obtained of nep formation or reduction as the fibres proceed through a card. When fine fibres are carded with coarse wire during the initial stages of carding the nep content increases even though the succeeding swifts are clothed with finer or denser wire, e.g. when carding the 70's wool with 64 points/inch^2 gave 348 neps/g and this increased to 660 when carded with 144 points/inch^2 and 912 neps/g after 256 points/inch^2. If, however, the first swift is clothed with finer wire, i.e. 256 points/inch^2 then successively denser swifts reduce the nep content. Thus, the least neppy web was produced by the three swift arrangement starting with 400 points/inch^2. In practice, however, a four swift arrangement will be more suitable introducing a first card with a wire density of 256 points/inch^2 to reduce the strain imposed on the wire by the unopened fibre tufts. This should then be followed by three swifts having 400, 576, 784 pins/inch^2, respectively.

In a similar series of experiments[87-89] it was shown that by substituting coarse swifts and doffers on the carder of a woollen card for the original fine ones can:

1. reduce neps and threads (the latter having been added to the original fibre blend),
2. give slightly stronger yarn,
3. reduce the need for fettling,
4. reduce end to end variation between ends across the card, and
5. extend the life of swift and doffer wire due to the coarser wire being used.

Increasing the count and crown[90] of the doffer wire led to an increase in nep and thread content in the webs produced because it then captured more fibrous material from the swift which was passed on instead of re-presenting them to the swift for more carding. It was also suggested that good use can be made of increasing the number of points/inch^2 of fillet wire by increasing the

crowns instead of the counts. It was also found that if a finer gauge of wire was used, but maintaining the same number of points per inch^2 it captured more fibre entanglements than the thicker wire, therefore workers should be clothed with fillet with as fine a wire gauge as possible and doffers as coarse a gauge as possible. Covering the workers and doffer with fillet with a sponge foundation reaching up to the bend of the wire produced webs containing more neps and thread compared with the normal vulcanised fillet. It was stated that the sponge type wire did not allow the same accumulation of neps and threads between the wires of the teeth thereby passing them on too quickly and thus reducing the carding action. It was suggested that fillet with an ordinary vulcanised foundation should be used.

Fibre length was not significantly affected by using fillet with differences in the number of points[86,90] per inch^2 or for the two types of foundations[90]. It was also found that fibre breakage did not increase with an increase in the number of passages through the card and it was said that fibre breakage seemed to depend on the original fibre length and state of the raw material and that once the fibres have been disentangled from their raw state, breakage due to card wire or repeated carding is insignificant[86]. This implies that fibre breakage mainly occurs during the initial stages of carding which is in agreement with other workers that found that the majority of fibre breakage in carding occurred at the feed roller licker part[91-93].

Wire keenness, or the degree of sharpness of the card wire, was found to affect nep formation during carding[92]. It was shown that neppy webs were produced when carding 70's wool. A marked improvement in nep removal was accomplished when the doffer was ground. A similar effect was obtained when the swift was also ground, however, the effect of grinding the swift was not as profound as when the doffer was ground and it appeared as though the major contribution of the ground swift was to decrease the size of the neps. It was also shown that when side grinding was followed by surface grinding, which tended to bring about a flatter top on the wire, with a better defined edge, less neps were present in the web compared with the web produced when surface grinding was followed by side grinding. At the same time it was found that the 37 mm worsted threads, added to a 70's wool blend, were removed or opened when both the swift and doffer were ground but when the doffer was ground and the swift left unground, the number of threads emerging in the web increased. This suggested that the forces relating to the profile of the wire that reduces nep formation are not necessarily the same as those which maximize fibre-bundle separation and the use of very different wire profiles on the two cylinders may produce interactions that inhibit the maximum carding efficiency.

When side grinding is performed on card wire a wedge shaped point is formed (see Fig. 37).

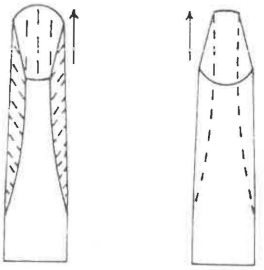


Fig: 37 — Types of wire point (the arrows indicate the direction of the point)[93]

Conventionally a tooth is formed in which the broadest segment of the wire is presented first to the fibres to be carded. It was found that if the wedge was arranged so that the narrow edge of the wedge became the leading edge, the general efficiency of the carding process was improved[93]. The nep content of the webs was 50% lower when conventional card wire was substituted by the unconventional wire on the swift, doffer and workers. Worsted threads added to the 70's wool blend were removed after six passages through the card and, in general, it was demonstrated that the new type of wire effected better opening and mixing of the fibres.

The angle of the bend of the swift and doffer wire can also influence nep formation during carding[94]. The angle referred to is the angle formed between the foundation and the line joining the wire above the bend. It was found that with an angle of 65° on the swift the angle of bend, when varied between 57° and 73°, of the doffer was not critical. When the swift teeth were 57°, the doffer could not capture the fibres from the swift, the latter becoming overloaded resulting in excessive nep formation. If, on the other hand, the angle of bend of the swift wire was 73°, it was found that it was unable to pass the fibres from the swift to the doffer and the nep content again rose. It was suggested that the best carding results may be obtained by using a swift clothed with 65° wire and a doffer with 57° wire.

The fancy can also contribute to nep formation during carding especially when the surface speed of the fancy is low[81]. The latter case allows the swift to build up with the fibres and become choked and the workers are then unable to disentangle the material between them and the swift thereby rolling the material thus forming neps. For the particular experiment it was found that the minimum number of neps was formed when the fancy lead was 30% in relation to the swift speed.

Nep formation was also found to be related to the angle of bend of the fancy wire[95]. It was found that a large number of neps were formed when a fancy clothed with wire with a 50° bend was used, 80° bend on the other hand produced excessive amounts of fly. It was found that neppiness was related to

build-up of fibres in the swift and a high fibre build-up of the swift produced a neppy web. It was recommended that the angle of bend for the fancy should be between 60° and 70° with an overall better performance nearer 70°.

4.8 Metallic Wire Clothing and Woollen Carding

Metallic wire has been used on cotton and worsted cards for a number of years, while the woollen trade have preferred to continue to use fillet wire on their cards. Certain advantages are claimed for metallic clothing as opposed to flexible wire[96]:

1. longer working life,
2. increased efficiency due to decreased fettling times, and
3. improved yarn yields.

In a series of trials[96] on a woollen card flexible wire was replaced in stages with metallic wire, by progressively covering more rollers, i.e. swifts and doffers. The results of these trials showed that by covering the swifts and doffers, except the condenser doffer, with metallic wire did not increase fibre breakage or affect the physical properties of the yarns. It was not necessary to fettle the swifts and doffers. Wear of the flexible wire fancies was no greater than when flexible wire was used on the swifts. The same amounts of processing oils could be used.

The contribution of carding variables to the formation of neps in wool webs using a card with metallic swifts and doffers were also reported[97,98]. It was found that nep formation or removal is mostly controlled by the doffer and it was found that by minimizing the land area of the doffer teeth (see Fig. 38), i.e. as keen as possible, the number of neps was markedly reduced. Nep content was also decreased by setting the doffer as close as possible to the swift thereby reducing the number of fibres being re-cycled.

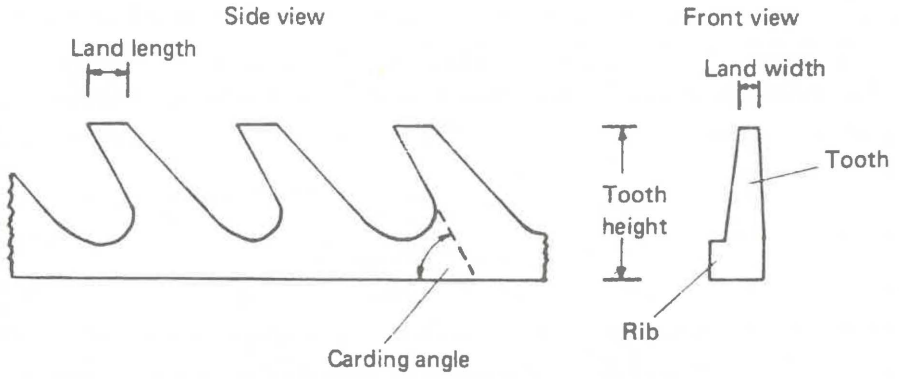


Fig. 38 — Metallic card clothing terminology[97]

It was found that the sharpness of the worker wire was not as critical as the sharpness of the doffer, but reducing the land area by grinding (in this case flexible wire) led to a significant reduction in the number of neps formed in the web. A fancy roller on the swift also reduced the number of neps. In the case of a metallic covered swift it was found that the depth of fancy penetration was not critical and the recommended depth of penetration was stated to be 0,102 mm[97].

The angle of inclination was found not to be very important and it was recommended that for the swift wire an angle of 81° and a doffer between 45° and 65° or otherwise a 65° swift with a 55° doffer was recommended.

In conclusion it was said that the choice between flexible and metallic wire on the workers was a matter of personal choice because it did not have a large effect on nep removal. However flexible wire was more convenient because it could be sharpened and flexible wire was cheaper than metallic wire.

4.9 Fibre transfer between swift and doffer

There is little alignment of fibres in a woollen slubbing. The fibres tend to lie along the axis of the slubbing but the orientation in any one plane is low. Although the fibres are aligned in one direction on the card swift due to the action of the fast moving swift with the slower moving workers, the alignment is destroyed by the fancy and the mode of transfer of the fibres from the swift to the doffer and again by removal from the doffer by either a stripping roller or doffer comb. Parallel arrangement is lost when the fibres are piled onto the slow moving doffer by the fast moving swift. The latter transfer gives rise to the formation of trailing and leading hooks in the web[99].

The configuration of fibres in a carded viscose web was investigated[100] by adding a small quantity of black tracer fibres into the lap feed of a cotton card. The tracer fibres that emerged in the web were divided into five groups according to their shape, as shown in Fig. 39.

Group 1 Hooks leading	Group 2 Hooks trailing	Group 3 Hooked both ends	Group 4 No Hooks	Group 5 Other
				–
Direction of Web delivery →				
16,25	47,75	13,25	20,75	2

Fig. 39 — Shape of fibres and the percentage present in the carded cotton web.

It was found that the majority of fibres were hooked at their trailing ends as in group 2. It was also found that hooks of group 2 were larger than those of group 1. Fibres hooked according to group 1 have been termed as minority hooks and those in group 2 as majority hooks. The high incidence of trailing hooks was ascribed to the mechanism of fibre transfer from swift to doffer. It was stated that as the fibres on the swift approached the doffer the leading part of the fibre became attached to the doffer wire while the tail end of the fibre was swept past the point of attachment so that the tail end emerged first in the web. No feasible explanation was given for the formation of minority hooks. It was, however, observed[101] that the number of leading and trailing hooks on the cylinder was nearly equal to the number of trailing and leading hooks in the web. It was suggested that the direction of hooks was changed during transfer due to fibre reversal taking place in the actual transfer from swift to doffer.

Ghosh and Bhaduri[102], working with a hand-operated bench model card and introducing yarn pieces as tracers, observed that more than 50% of the fibres reversed their direction during transfer from the cylinder to doffer and that both theories put forward by Morton and Summers[99] and Modi and Joshi[101] were totally acceptable. Sengupta and Chattopadhyay[103] demonstrated that the majority of fibres changed their configuration during transfer and that new hooks were formed while previously formed hooks were removed. Transfer of fibres took place both with and without reversal of ends, and those fibres that transferred without reversal change their configuration more. The authors suggested that leading or minority hooks were formed by buckling of the front end of the fibre. When the front end of a fibre moving at high speed on the cylinder came into contact with the relatively slow moving doffer surface, it buckled, and if the fibre was loosely held by the cylinder, it got transferred to the doffer without reversal and the transfer depended on the nature and extent of positive control exercised by the cylinder on the rest of the fibre.

It was concluded[103] that a large proportion of the fibres changed their configuration during transfer from the cylinder to the doffer. Hooks were formed and previously formed hooks were removed. Hooked fibres were also removed from the cylinder with or without reversal and with or without change in configuration.

It was shown that[104] in cotton carding as the number of leading hooks increased in the web, the number of neps increased and yarn imperfections increased. The relationship between minority hooks and neps was studied by Simpson[105].

The cylinder-to-doffer transfer region was divided into an upper and lower zone (See Fig. 40). A change in carding parameters causing an increase in the ratio of cylinder-to-doffer speed resulted in an increase in the fibres

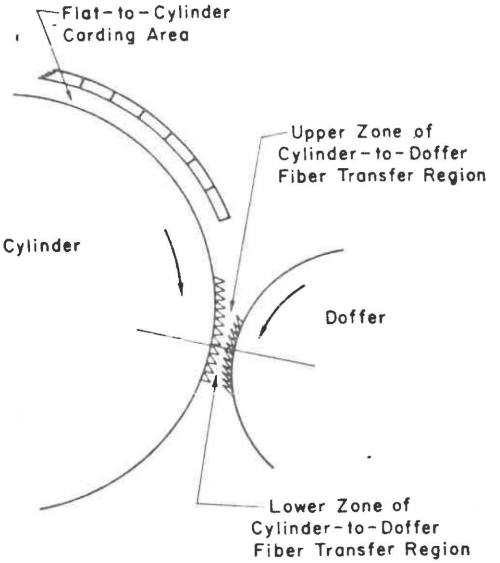


Fig. 40 — Schematic diagram of cylinder-to-doffer fibre transfer area and flat-to-cylinder carding area[105].

transferred in the upper zone which would cause an increase in the formation in trailing hooks and a decrease in the number of leading hooks and neps. In this case the fast moving cylinder combed the leading ends of the fibre which would reduce nep formation. On the other hand, when the cylinder-to-doffer speed ratio decreased, fibre transfer took place in the lower zone, which caused the carding action to decrease and resulted in increased minority hook and nep formation. It was suggested that for cottons that nep easily it was necessary to card at low doffer speeds.

The presence of hooked fibres in a sliver or strands of fibre, reduces the effective fibre length or fibre extent in the strand, resultant yarns will therefore be weaker and more end-breakages will occur. The presence of hooked fibres in a woollen carded web is of greater importance than in either cotton or worsted gilling because no doubling, drawing or drafting and combing processes are employed during which fibre hooks are removed. It must also be remembered that the ribbons or fibre strips are condensed by the reciprocating aprons of the condenser which adds another dimension to the random orientation of the fibres in the woollen slubbing. It is, however, this random orientation which forms the basis of the lofty and bulky character of the woollen yarn. This random arrangement is also the reason why condenser slubbing is restricted as far as drafting is concerned[99].

4.10 Woollen condensing

The purpose of condensing is to split the web coming from the last doffer of the carder into continuous narrow strips or ribbons of fibre which are then converted into cylindrical slubbings by a rubbing action performed by rotating reciprocating aprons. The slubbings are wound onto bobbins in a traversing manner to facilitate easy removal or unwinding in subsequent spinning into yarn.

There are two classes of condensers[106,107]:

1. Ring doffers, and
2. Tape condensers.

Ring doffers can be subdivided into two types: single and double-ring doffers. Tape condensers are subdivided into series, single or endless and the Bolette steel tape types. Steel tape condensers are seldom used today and will be excluded from further discussions.

4.10.1 Ring doffer condensers

The single ring doffer is still used, to a limited extent, for the production of fine hosiery yarns, for short wools and "Angola" blends (a blend of wool

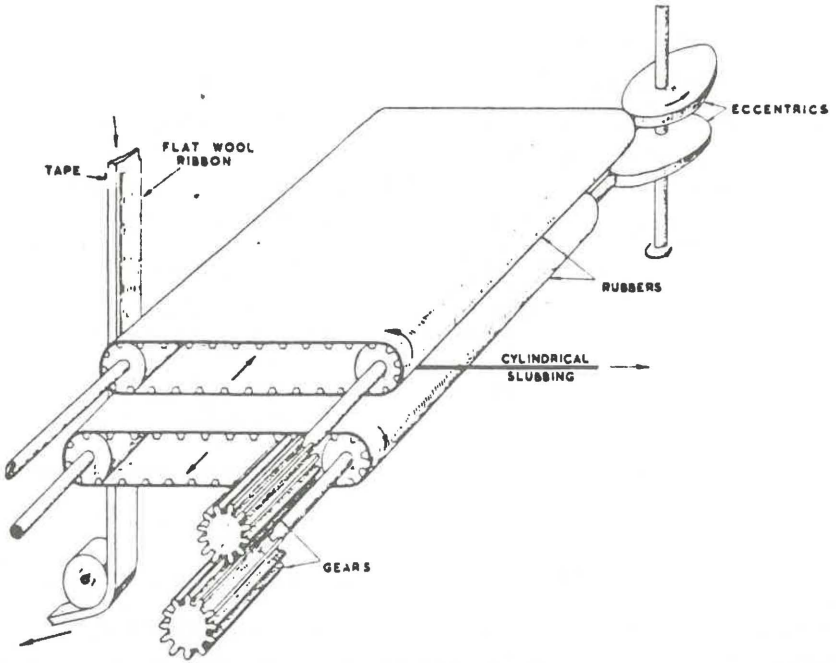


Fig. 41 — Diagram illustrating the action of the rubbing aprons and eccentric motion[106].

and cotton). This type of condenser produces very even yarns because every slubbing receives exactly the same treatment and division of the web involves no cutting or tearing whereby fibre breakage is limited.

The ring is made up of concentric rings of card clothing around the doffer with inter-spacing leather bands so that gaps occur circumferentially. Fibres are removed from the swift only in the spaces where clothing is fitted to the doffer. Fibres adjacent to the spaces remain on the swift and are removed by slow sideways traversing of the ring doffer or the workers on the last swift.

The ribbons of fibres are stripped from the doffer and then passed between a pair of aprons which rotate and reciprocate at the same time thereby transporting the ribbons forward while at the same time they are rubbed into cylinderical slubbings (See Fig. 41).

Double ring doffer condensers are used in the carding of coarse type carpet yarns. In this type of condenser two ring doffers (see Fig. 42) are arranged in such a way that the rings with card wire of one doffer are directly opposite to the spaces of the second doffer. In this arrangement the fibres that are left on the swift adjacent to the spaces between the card wire rings of the top doffer are removed by the rings of card wire on the bottom doffer.

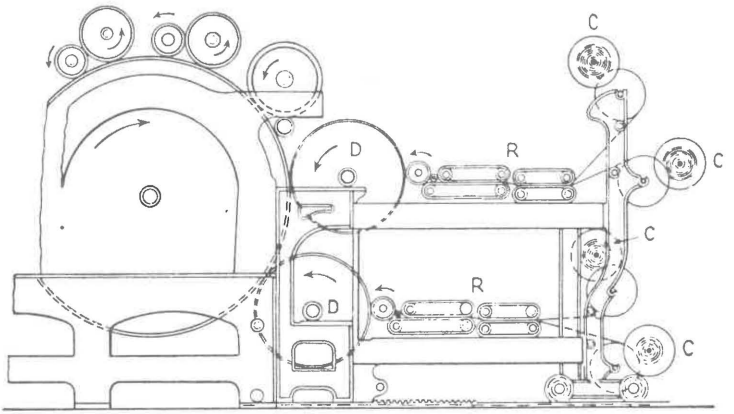


Fig. 42 — Illustration of a double doffer condenser (D = ring doffers; R = rubbing aprons; C = condenser bobbins)[107].

The top doffer gets the first chance to remove fibres from the swift and it therefore tends to collect the longest fibres whereby the linear density of the slubbings produced from the top doffer is higher than that of the slubbings produced from the bottom doffer. It is for the latter reason that the card wire rings on the top doffer are narrower than those of the bottom doffer.

Sometimes different settings and speeds between top doffer and swift and bottom doffer and swift are used to compensate for the difference in linear density between the slubbing of top and bottom doffer. In many cases the slubbings produced on the top and bottom doffers are kept separate and are spun on different frames.

4.10.2 Tape condensers

The web, extending the width of the card, is split or divided by a combined tearing and cutting action between the tapes and a pair of calender or dividing rollers. The latter function may be performed by either a series of tapes or a single or endless tape condenser.

4.10.2.1 Series tape condenser

In the case of the series tape condenser, each individual ribbon of fibres is carried by a separate tape, i.e. a condenser with a hundred ends will have a hundred tapes. The tapes are arranged into an upper set and a lower set, the individual tapes being positioned side by side (see Fig. 43).

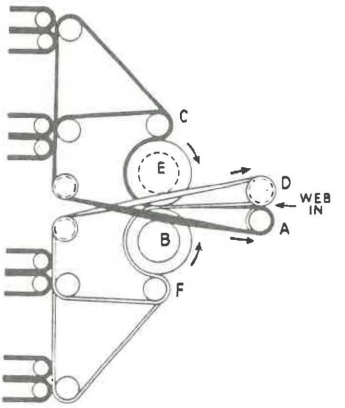


Fig. 43 — Threading of series tape condenser (A and D = entry rollers; B and E = bottom and top tape cylinders)[107].

The web enters through the entry rollers (A and D) and is subsequently split between the tapes and the tape cylinders (B and E). The tapes which pass around the bottom entry roller, A, transport the fibrous ribbons to the top rubbing aprons while the tapes passing around the top entry roller, D, deliver the ribbons to the bottom section of the machine (See Fig. 43).

A disadvantage of the series tape condenser is that variation in linear density between tapes can occur when the tension on the various tapes is not uniform. A tighter tape tends to take more fibres than an adjacent slack tape, thus producing a slubbing of higher linear density.

4.10.2.2 Endless tape condenser

In construction, the endless tape condenser does not differ greatly from the series tape condenser, but instead of a series of tapes, it has one endless tape to split the carded web into an appropriate number of separate ribbons. This is illustrated in Fig. 44.

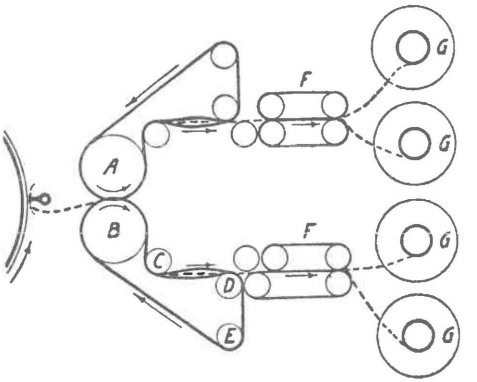


Fig. 44 — Schematic representation of single tape condenser (A and B = dividing rollers; C, D and E = plain rollers; F = rubbing aprons; G = slubbing bobbins)[108].

The important parts of the endless tape condenser are the dividing or calender rollers. Both rollers have grooves to accommodate the appropriate tape width and thickness. (See Fig. 45). The rings between the grooves are set so that the rings of one roller exactly cover the grooves of the other.

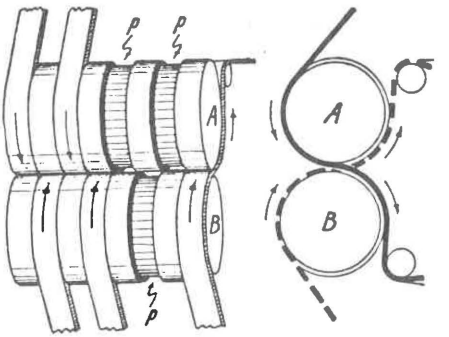


Fig. 45 — Schematic presentation of the path followed by a tape on a single tape condenser (A and B = dividing rollers; p = grooves).

The single tape is disposed across the width of the machine and follows a distorted figure eight path[108]. The tape runs from the top, into a groove of the upper calender roller, A, into the nip between rollers A and B and then down over a ring on the bottom calender roller B. The tape then follows its path over the plain roller, C, and then is twisted by half a turn to present the fibrous strip to the rubber aprons, F. The tape then continues its path over the plain rollers, D and E, returning onto an adjacent groove in calender roller B, into the nip, up over a ring on calender roller A. The continuous web is thus split into several ribbons or strips. These strips are presented to the reciprocating and rotating aprons (F in Fig. 41) where they are rubbed into cylindrical slubbings which are wound onto bobbins.

4.10.3 The condenser creel

The section of the condenser in which the slubbings are wound by surface drums onto the bobbins is known as the creel. The slubbings are normally traversed onto the bobbins by guiding the slubbings through thread guides which slowly oscillate. With the introduction of spinning frames with increased gauge or pitch, i.e. increased spinning ring diameter, it was necessary to develop condenser creels which could produce wider cheeses to coincide with the spaces between adjacent spindles on the ring frame. This was accomplished by the development of the following two types of condensers:

1. the tandem-creel tape condenser
2. the traversing-creel tape condenser.

4.10.3.1 The tandem-creel condenser

In the tandem-creel condenser there are twice the number of bobbins than on a normal condenser. This is achieved by fitting two lines of surface drums at each height, one behind the other. This arrangement allows cheeses to be wound of double the width compared with the condenser with a single creel.

4.10.3.2 The traversing-creel condenser

In this type of condenser the creel is much wider than the normal condenser. The yarn guides are stationary and the wide cheeses are wound onto the bobbins while the creel oscillates from side to side.

Spinning efficiency is increased when the abovementioned two types of condensers are used because the length of yarn per cheese or bobbin is increased thus decreasing spinning down time by decreasing time lost for piecening in of new bobbins.

4.11 **Slubbing Variation**

Slubbings vary in mass per unit length both individually along their lengths, called variation along, and also from one to another, called variation across. Variation along the length of the slubbing has been dealt with in a

previous section and the main causes of such variation can be given as[106]:

1. irregular hopper feeding,
2. belt slippage in a carding part,
3. generation of static electricity causing irregular delivery of wool,
4. changes in drafting,
5. the "cushion effect" or deformation of the cheeses caused by their being pressed onto the surface drums by the force of their mass and the mass of the bobbins onto which they are wound, and
6. variation of the distances between the reciprocating rubbers and the amplitude of oscillation of the rubbers themselves can cause variation between bobbins.

Variation across the web is mainly caused by the process of web division either by tapes or ring doffers. The fibres in the web are arranged in a random manner and when the web is split into ribbons, fibres near or across the ribbon edges must either be broken or be pulled one way or the other across the splitting edge, thus creating variations in the ribbon widths because a fibre lost from one ribbon is gained by the ribbon next to it. Any variation on the tape doffer wire, differences in tape tension, their condition and non-uniformity of width will all increase the variation. A further cause of variation across can be a tape doffer set wider from the swift on one side than at the other side, a hollow ground swift or doffer. It is quite frequently found that the side ends are lighter than the centre of the web. This is normally caused by the intermediate feed to the carder part not delivering across the full width of the feed lattice. One side can be slightly heavier than the other due to draughts across the card[109].

Variation in the slubbing is transferred to the yarn. Yarn evenness is a function of slubbing evenness because no intermediate drafting and doubling processes are employed between carding and woollen spinning. The low drafts employed in woollen spinning is not very effective in levelling out unevenness in the slubbing. It is therefore essential that slubbing variation both across and along be maintained within acceptable limits in order to produce an acceptable yarn.

4.12 Stationary carding plates

An interesting new development in woollen carding is to replace the worker-stripper pairs by stationary carding plates. In a series of experiments[109] stationary carding plates were compared with the conventional worker stripper pairs with regard to fibre mixing, hook formation during carding as well as yarn physical properties. The most important findings were the following:

1. Lower swift loadings were obtained with carding plates as compared to workers,
2. swift loading was lower with carding plates and the delay factor therefore much lower,

3. less neppy webs were produced at close settings with the plates than with workers,
4. plates gave better fibre orientation and less hooks than the workers,
5. cross card variation and short term regularity was better for plates than with workers, and
6. yarn tenacity remained the same for plates and workers.

5. DRAFTING AND TWIST INSERTION — SPINNING

5.1 Historical development[110].

The basic principles of drawing and spinning date back many thousands of years and earliest information can be drawn from the remains of the Stone Age period. Spindle whorls were used as fly-wheels to facilitate the regular rotation of the spindle. Whorls, made from clay, on a wooden spindle were used by the ancient Peruvians, and whorls dating back to the Stone Age were found in the Swiss lakes. A conical wooden spindle of which the heavy base served as a fly-wheel was used by some primitive civilisations.

The process of hand spinning was developed into an art and it is remarkable when it is considered that a certain Mary Pringle spun wool to a linear density of about 6 tex (i.e. 6g per 1000m). Even more amazing is Ann Ives who, at the end of the eighteenth century, spun a strong woollen yarn of approximately 3 tex. These were of course exceptions and it was recorded that an ordinary spinstress of the eighteenth century spun a yarn of 38 tex while the superfine qualities were around 13 tex. It was also recorded that in 1851 a cotton yarn of 0,3 tex was spun on a mule. Although the latter yarn was not suitable for weaving, this must surely be considered as a remarkable achievement in machine spinning.

5.1.1 Hand spindle spinning

The ancient hand spindle was made from a piece of wood 9 mm in diameter and 25 cm long, pointed at each end, a nick made at the top end for securing the material to be spun and the lower end was inserted into a round, heavy whorl.

When long combed fibres were spun a distaff was used to hold the fibrous material, while short carded fibres were held in the hand in a roll. The distaff was made of wood, longer and slightly thicker than the spindle, and had a cleft top on which the fibres to be spun were loosely hung.

Whether held in a roll or on a distaff, the supply of material into the drafting zone was controlled by the forefinger and thumb of the upper hand, those of the other hand being used to draft the fibres. Spinning was started by twisting a short length between the fingers, a few turns then wrapped around the spindle and caught in the notch at the top and the spindle was set spinning by means of a dexterous movement of the hand. While the spindle was rotating the fibres were drafted between the finger and thumb of the two hands, the

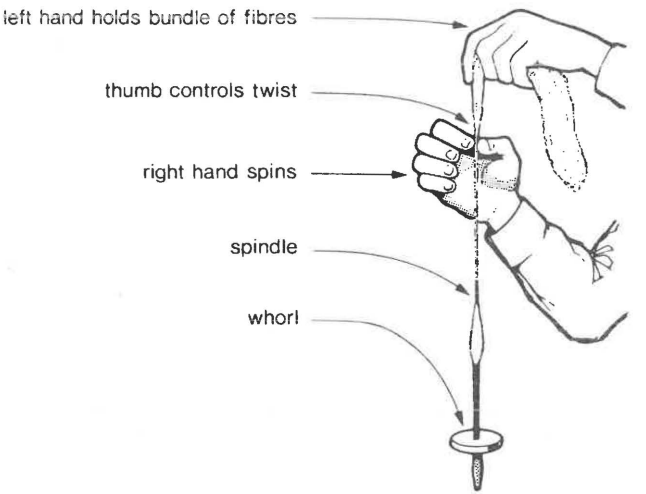


Fig. 46 — Illustration of how the spindle and whorl was manipulated in spinning a yarn[111].

lower hand also preventing too much twist from running up from the spindle into the drafting zone until the material had been drawn to the requisite fineness (See Fig. 46). The finger and thumb of the upper hand controlled the twist running up to draw more fibres into the drafting zone. The spindle having ceased to rotate with sufficient speed, the yarn was unhooked from the notch and wound on to the spindle. The last few turns were taken round the top of the spindle, the yarn secured in the notch again and the procedure repeated.

5.1.2 The One-thread wheel

The simple spindle persisted in Europe until the fourteenth century when it was superseded by the hand wheel which had been used in the East from very early times. It consisted of a large hand-driven vertical wheel driving by means of a band, a small pulley attached to a horizontal spindle (see Fig. 47). Spindle speeds of 4000 rev/min were reached on this one-thread wheel.

The hand carded or combed fibres were sometimes spun in two stages; first a roving was made and then the yarn was spun. The wheel was turned with the right hand, the fibres held in the left hand and drafting started with the finger and thumb of the left hand a few centimetres away from the spindle tip. Drafting was effected, while the spindle was turning, by pulling the material at an angle of approximately 30° to the spindle tip, allowing the last turn of yarn to slip off at each turn of the spindle, thus inserting one turn of twist. At the

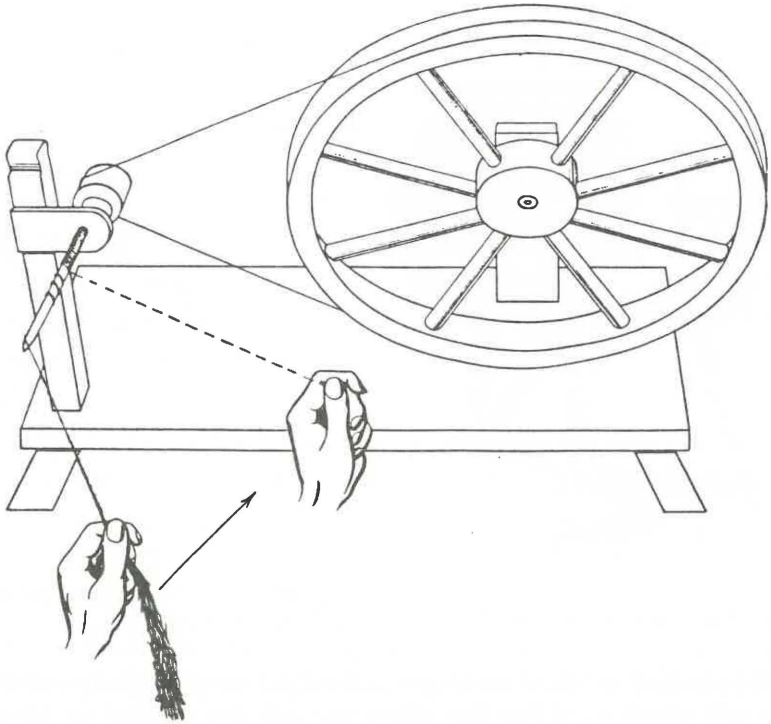


Fig. 47 — The One-thread wheel.

end of the drafting cycle the wheel was given an extra turn without drafting to impose extra twist. The wheel was then stopped, revolved in the reverse direction just enough to wind off the few turns of yarn on the end of the spindle, after which it was turned in the original direction to wind the yarn onto the spindle. The one-thread wheel was later fitted with a crank and treadle thus allowing both hands to manipulate the thread.

5.1.3 The Saxony wheel

In the middle of the sixteenth century the bobbin and flyer was introduced thus allowing drafting, twisting and winding to be carried out simultaneously.

The bobbin and flyer was credited to Johann Jürgen of Brunswick and appeared in 1555. Although Jürgen developed the bobbin and flyer, Leonardo da Vinci (who died in 1519) left sketches depicting the principle of the bobbin and flyer — he even incorporated a traversing motion for building up the yarn on the bobbin.

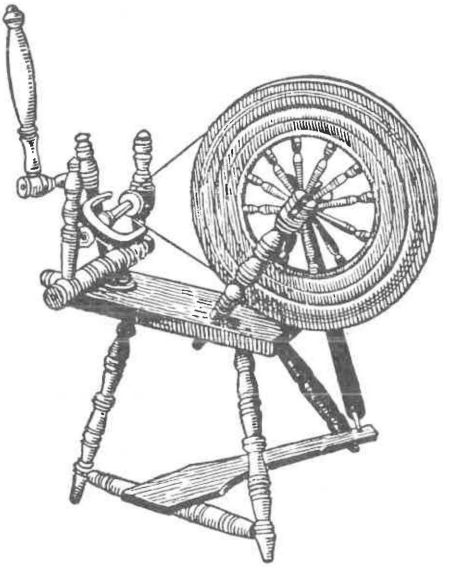


Fig. 48(a) — The Saxony Wheel[112].

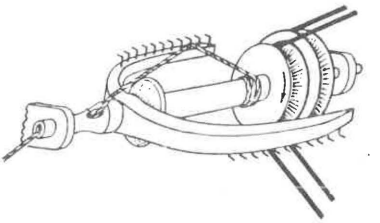


Fig. 48(b) — Bobbin and flyer incorporated in the Saxony Wheel[112].

On the Saxony Wheel both flyer and bobbin were driven by a band from the treadle-driven wheel (See Fig. 48(a)). Spinning and winding was carried out simultaneously but the spinstress had to move the thread successively along a row of hooks on the arm of the flyer to traverse the thread along the bobbin. The action was no longer that of a spindle draft, but was somewhat analogous to roller drafting.

The flyer was fixed to the spindle and the bobbin was a loose fit on the spindle, both spindle and bobbin were fitted with wharves, that of the bobbin being smaller, giving bobbin lead (see Fig. 48(b)). The driving belt tension was adjusted, by horizontal movement of the bobbin and flyer support, with a screw. Variation in driving belt tension was essential because a certain amount of belt slippage was required to allow for drag as the diameter of the bobbin increased.

5.1.4 Spinning Jenny

Hargreaves made his first spinning Jenny in 1764 with only eight spindles. His patent of 1770 described a machine with 16 spindles which later was increased to 120. In the Jenny the slubbings were led from a creel in the lower part of the machine to a carriage, through a wooden clasp fitted to the carriage and then to the fixed inclined spindles.

The spinning process was started with the traversing carriage right forward at the spindle end and the yarn leading off the spindle to the open clasp on the carriage, the latter was moved a short distance backwards with the left hand to unwind a length of roving from the creel. The clasp was closed and the carriage moved further backwards, thus drafting the slubbing while twist was inserted at the same time by rotating the wheel connected to the spindles, with the right hand. Before reaching the far-rear-end the carriage was stopped while the spindles continued turning to insert the required amount of twist. The carriage was then moved further backwards and the direction of the spindles reversed to unwind the yarn from the spindle tips. The yarn was then wound onto the spindles by pushing the carriage forward and turning the spindles in the original direction. The yarn was traversed on the spindles by means of a faller wire, connected to a piece of wool which was operated by the toe. As the carriage reached the forward position the yarn was allowed to run up to the spindle tip by manipulating the presser wire. The clasp was opened and the cycle repeated.

5.1.5 Slubbing Billy

The Slubbing Billy was developed soon after the Spinning Jenny to prepare rovings for the latter as well as the mule.

The principles employed in the Billy were similar to those used on the Jenny. The main differences were that the spindles were incorporated in the carriage and the carded slubbings were laid side by side on a slanting apron over a roller and between two wooden clasps, through which the slubbings were delivered and clamped during drafting and twisting.

5.1.6 Roller Drafting

In 1738 the first patent describing roller drafting was filed by Lewis Paul. Roller drafting was not carried out to any appreciable extent until the development of Arkwright's spinning frame in 1769.

5.1.7 Arkwright's Water Frame

Arkwright's frame was the first spinning machine to be driven mechanically by water. He used four pairs of rollers giving a total draft of 6,25, the bottom ones being driven to give speed ratio's of 1:1,16:1,33:6,25. Twisting and winding were carried out by a bobbin and flyer. No traversing mechanism was incorporated in the machine and the yarn passed round hecks of one of the flyer arms and had to be moved by the spinner.

In Arkwright's second patent of 1775, a traversing mechanism similar to the lifter plate of the modern flyer frame was incorporated. The latter consisted of a shaft driven by a belt. To the shaft a heart-shaped cam was fitted at each end which lifted and lowered the rail carrying the bobbins. Only

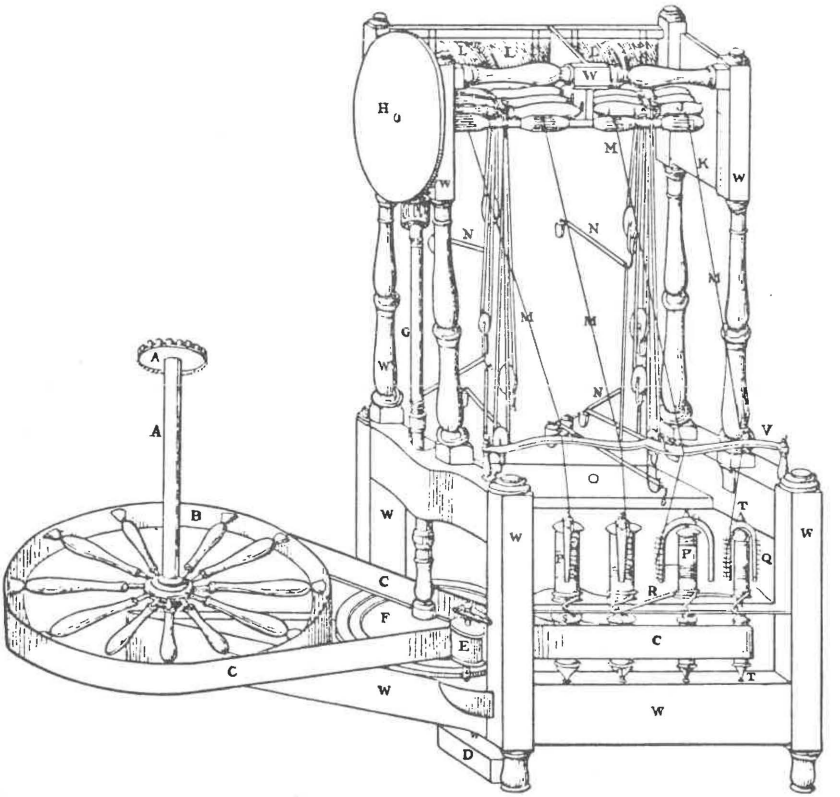


Fig. 49 — Arkwright's Water Frame[110].

three pairs of rollers for drafting were incorporated with speed ratios of 1:1,16:18,4.

The Spinning Jenny and the Water Frame came into use at about the same time. The lofty yarns from the Jenny were used for weft while the yarns from the Water Frame were more suitable for warp threads.

5.1.8 Crompton's Mule

Crompton's mule, completed in 1779, was a combination of the Spinning Jenny and Arkwright's Water Frame. It incorporated the moving carriage and spindle drafting of the former and the roller drafting of the latter. In this mule the rovings were drafted between rollers, which also acted as a clasp to hold the yarn when the carriage, holding the spindles, was drawn out. After a certain length of roving was given out, the rollers were stopped, the carriage

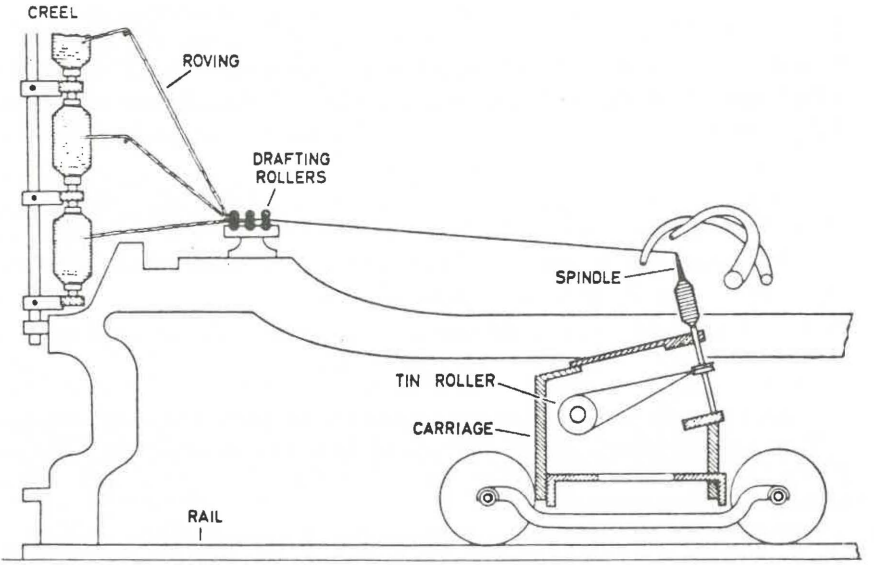


Fig. 50 — The working elements of Crompton's mule[111].

with spindles continued to recede a short distance to draft the twisted slubbing. By means of this system it was claimed that by drafting with both rollers and spindles the thread was stretched more gently and equally producing a much finer quality yarn. For woollen spinning spindle draft alone was used (see Fig. 50).

In 1825 Richard Roberts patented the self-acting mule and added to Crompton's mule the quadrant winding motion for controlling spindle speed and the shaper for controlling the faller wires. These additions made the mule self-acting. Some minor refinements were made to Roberts's mule but the basic principles employed remained the same.

The sequence of operations taking place during the spinning of a yarn on the mule were the following[113,114]:

1. Lengths of slubbings were delivered while the carriage with spindles retreated at the same speed as the delivery. The spindles revolved at the same time, at constant speed, thus inserting twist into the slubbing as it was being delivered.
2. Once the required length of slubbing had been delivered the feed rollers stopped while the carriage continued to retreat and the spindles continued to insert twist. During this stage the slubbing was drafted by the process of spindle drafting.

3. At the end of the carriage draw, final twist was inserted into the yarn, while the spindles rotated at a higher speed than during the drafting phase. During this phase of extra twist insertion the yarn contracts, which imposes a high tension on the yarn. To reduce the tension the carriage was slowly moved inward for a short distance. This latter step being known as "jacking-in".

4. The next phase was called "backing-off", during which the spindles were rotated in the opposite direction to the spinning direction to unwind the yarn from the spindle tips. The faller and counter-faller wires came into action at the same time to take up the tension.

5. Once "backing-off" was completed the carriage ran in, the spindles were rotated in the same direction as the original spinning direction and the yarn was wound onto the cops in a conical shape while being guided by the faller wire and correctly tensioned by the counter-faller wire. The yarn package, with its conical shape, meant that the spindle had to rotate at different speeds to correct for the variation in cop diameter, the speed changes being effected by the quadrant.

6. At the end of winding the carriage was stopped at the delivery beam and the faller wires were withdrawn.

7. The cycle of operations was repeated.

The mule was a complicated and cumbersome machine. Although the various mechanisms were fairly simple it was, however, only the most experienced spinner who could tune a mule to spin a good quality yarn. The essential movements of the mule consisted of three basic elements, the delivery rollers, carriage and spindles whose relative motions had to be correctly co-ordinated to constitute the spinning cycle. Roberts's mule had to be driven from one central line shaft and this single source had to be subdivided into three main elements and these had to be co-ordinated by means of belts, pulleys, gears and clutches. The line shaft turned at constant speed and variable speed devices had to be incorporated to drive the three elements at variable speeds.

The line shaft was later replaced by one single electric motor which offered no real advantage in power consumption, increased production or ease of operation. In 1954 the electronically controlled mule was developed[115]. In this mule the three basic elements were driven by separate electric motors and the headstock and quadrant replaced by electronic devices. This gave a machine much more simple to operate than the conventional mule. It meant that a spinner could change spinning conditions while the mule was producing by simply changing control knobs. Production was increased by 30%, power consumption was decreased and a better quality yarn could be spun.

5.2 Principles of mule spinning

The sequence of operations performed by the mule can be subdivided into three sections: drafting, twisting and winding-on. Yarn delivery during the initial stages can be looked upon as an essential preliminary to drafting, jacking-in as a necessary consequence of twisting, and backing-off as a prerequisite of winding-on[116].

The objectives of spinning a woollen yarn from the carded slubbings are to give strength to the yarn and to increase the uniformity of the yarn[117].

Strength is given to the yarn by the insertion of twist into the open strands so that the individual fibres are bound closely around each other, thus establishing a large number of contacts at which additional frictional forces will operate to resist fibre movement when tension is applied to the yarn.

Yarn uniformity is improved by drafting while a low amount of twist is inserted. The levelling action is brought about by the fact that short thick places have a higher modulus of torsional rigidity than the thinner parts, and therefore are less twisted. Conversely, short, thin portions take up more of the inserted twist because these have lower resistance to torsion and will resist drafting forces. If a drafting force is applied under these conditions during spinning, the short thick places of the slubbing will be drafted more than the thin parts thereby resulting in a more even yarn. To produce the most uniform yarn an optimum amount of draft and twist is required.

This state of affairs implies that provided sufficient twist is inserted during attenuation, to maintain cohesion of the thread as it becomes finer, drafting can go on indefinitely. In practice this does not happen, levelling of the thread takes place but when drafting is carried out beyond a certain maximum point, levelness is impaired and the ends start to break. The process of spindle drafting, or drafting of a twisted slubbing, is a complicated process and has been the subject of investigation by several research workers[118-124].

Angus and Martindale[118] developed an instrument which was attached to a mule to measure the tension developed in the thread during spinning on the mule. They also constructed an apparatus[119] in which the process of spindle drafting on the mule could be simulated and the tensions developed during drafting could be recorded under experimental conditions.

It was found that the tension during the initial stages of drafting was zero but this drafting force increased fairly rapidly as elongation increased. Subsequently the rate of increase declined to zero, so that the force-extension curve passed in turn through a point of inflexion and a minimum. Thereafter the force declined, as extension was further decreased, until such time as the thread broke and the force again became zero. This effect is illustrated in Fig. 51.

As the twist level of the slubbings increased the maximum force developed increased and the point of rupture occurred at a lower extension, until at the

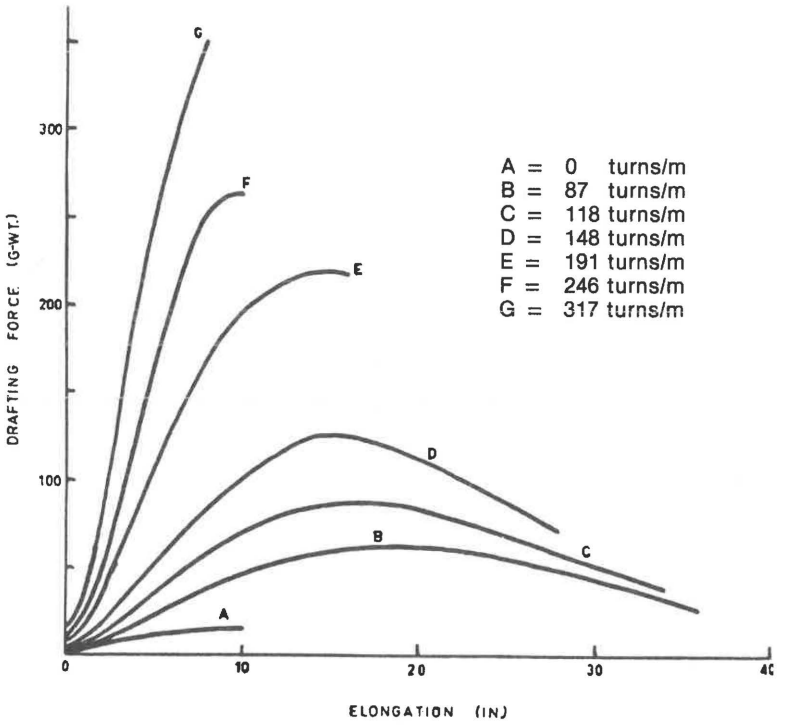


Fig. 51 — Force-elongation curves for Cheviot slubbings with different levels of twist[119].

highest twist content no maximum was reached.

The influence of draft upon the slubbing irregularity was also investigated. The authors made use of a quantity designated the "smoothing coefficient", to investigate the change in irregularity as drafting of the thread proceeded. The smoothing coefficient, defined as the ratio of the coefficient of variation of mass per unit length of yarn to that of the original slubbing. It was found that as draft increased the smoothing coefficient decreased until a minimum value was reached at a certain optimum draft. Increasing the draft further led to a rapid increase in the yarn irregularity. As twist level increased the point of optimum draft occurred at lower values. (See Fig. 52).

These results together with those obtained from the force-elongation curves suggested that minimum irregularity was obtained at approximately that value of extension at which the force-extension curve passed through its point of inflexion. It was also shown that the maximum extent of draft

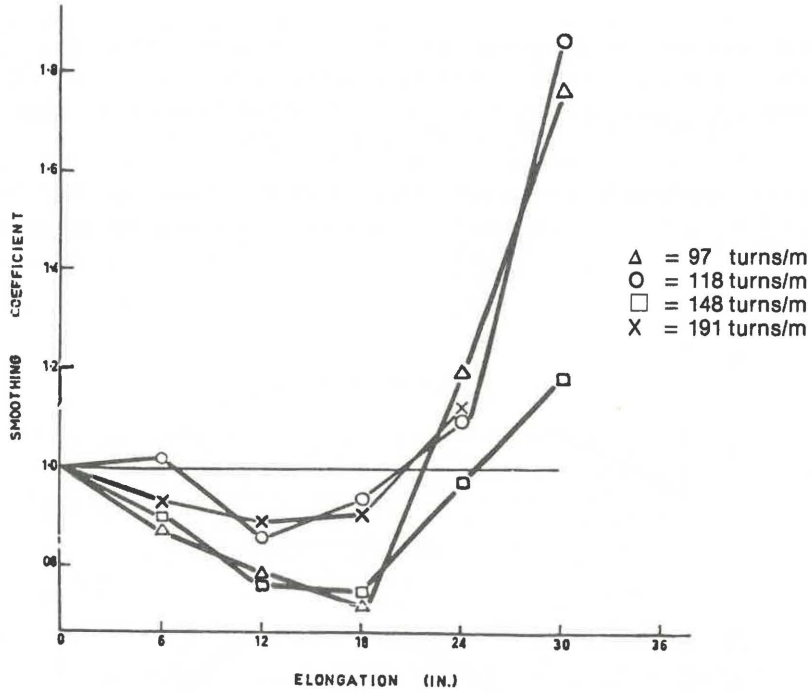


Fig. 52 — Effect of draft on thread irregularity of Cheviot wool with different twist levels[119].

required an optimum amount of twist to be inserted during the process of drafting itself.

In the spindle drafting apparatus used in the investigation drafting was carried out with the spindle in a horizontal position and in the normal spinning position where the spindle is inclined from the vertical towards the delivery rollers. During these experiments it was found that greater drafts could be applied in the case where the spindle was in the near-vertical position without deterioration of yarn uniformity. This was presumably caused by the plucking action produced by the yarn slipping over the spindle tip after the spindle made half a turn. The plucking action of a drafting thread causes a continual vibration along the thread which might have some effect on fibre activity and presumably promote conditions favourable to fibre movement.

It was found that during the drafting of some of the slubbings that an irregular decline in force occurred after the maximum force had been reached when observing the force-elongation curves. This is illustrated in Fig. 53.

These fluctuations were not found during initial stages of drafting while the force was increasing. This occurrence of sharp falls followed by a partial recovery of the force was due to a slip-stick phenomenon, the slip-stick effect having been produced by fibre movement within a thick place (slip) and the twist redistributing itself and locking the thin part formed (stick).

The author suggested that spindle drafting proceeded in two successive phases, each being due to a different mode of fibre behaviour. The first phase of drafting was characterised by an increase of force with elongation resulting in the reduction of the slubbing irregularity. This was due to stretching and

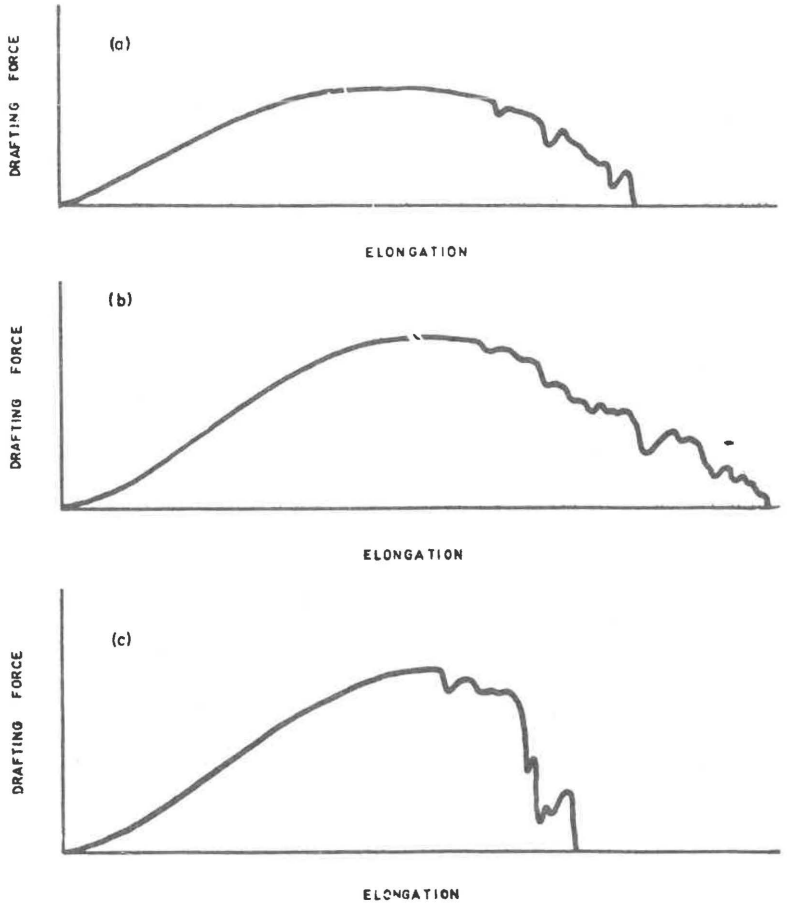


Fig. 53 — Force elongation curves for Cheviot slubbings showing slip-stick effects when force is declining[119].

straightening of the fibres into a more parallel arrangement of the fibres. The second phase of the drafting process commenced when the fibres could not be straightened any further and started to slip. The latter phase was characterised by a decrease in the drafting force owing to a decrease in the number of fibre contacts resulting in an increase in yarn irregularity. Increased irregularity was caused by the lag of redistribution of the twist.

This two-stage theory of spindle drafting was confirmed by the behaviour of a worsted roving when subjected to spindle drafting. The shape of the force-elongation curve was found to be the same as that obtained for woollen slubbings but the maximum force was generated after only 5% of extension while the maximum force for the woollen slubbings was reached at an extension of approximately 50%. The low extension resulted from the high degree of parallelization of the fibres in the worsted roving, therefore leaving limited scope for fibre straightening during the first phase of spindle drafting.

In subsequent work carried out by Hogley and Martindale[122], it was again found that worsted rovings and cotton rovings gave only 5% extension at the maximum force applied. This was also found to be the case for a silk waste blend produced on a woollen card. Extension in the latter case was 20% and it was suggested that this low extension was due to the silk fibres being more straight in the woollen slubbing produced. These results confirmed once again the two-phase drafting theory of Angus and Martindale.

McNair and Chamberlain[120,121] stated that the theory of spindle drafting put forward by Angus and Martindale was oversimplified. Their view was that a carded sliver contained fibres in various states of curliness and that the less curled ones would be straightened very quickly during drafting, and these fibres would slip as drafting proceeded. It was suggested that if fibre straightening was the main effect during the first phase of drafting, the extension produced should be reversible and the sliver should return to its original length when allowed to relax. This was found not to be the case. They found that reversible extension was limited to 5% of the original length. Their findings on drafting during actual mule spinning confirmed the findings of Angus and Martindale. Some of the results obtained by McNair and Chamberlain are, however, noteworthy. They found that, during drafting, the irregularity decreased to a minimum and then increased rapidly upon a further increase in draft. The minimum irregularity was not significantly influenced by the amount of twist inserted. The amount of twist required to obtain the maximum possible draft, without producing a yarn of higher irregularity than the original slubbing, was found to be critical and the maximum draft that could be employed never exceeded 1,7.

The authors found that when extension was increased beyond the point where the smoothing coefficient reached unity, irregularity increased rapidly and twits started to form. A twit is characterised by a short thick place contained between two very thin places. It was found that 20% of the fibres

contained within the twit passed through the latter and the ends being tightly bound in the thin places by twist, the thick place, thus being locked in and could not be drafted any further. These thick places always contained a burr, a nep or a tuft of entangled fibres.

This purely adventitious occurrence of aggregates of the same order as the diameter of the thread was said to be the limiting factor in drafting of the sliver.

Kurosaki, Konda, Okamura and Watanabe[124] found, when investigating the process of spindle drafting using black dyed tracer fibres and drafting in methyl salicylate, that crimped and wavy fibres in a sliver were straightened out as tension was applied and became fully extended at about 40% elongation. At higher values of elongation, relaxation occurred, tension decreased and at 65% elongation rupture occurred. It was also shown by the abovementioned research workers that the fibre extent (projected fibre length) increased in the extended or drafted sliver as compared to the undrafted sliver. It was found that fibre extent increased when twist was inserted during drafting. This uncurling and increase in fibre extent as elongation increased to the point where maximum force developed and the subsequent decrease in force as draft increased further once again confirms the two-stage theory of spindle drafting by Angus and Martindale. The same authors[124] also found that at the point of maximum tension during drafting, yarn breaking strength was a maximum and that the coefficient of variation (CV%) of breaking strength was a minimum but increased sharply as draft increased above the point for optimum breaking strength. They showed that at the point where maximum tension developed during drafting, yarn strength, Young's modulus, torsional rigidity, tensile recovery and degree of packing showed maximum values.

Grosberg and his co-workers[125] investigated the process of drafting on a woollen ringframe. They found that the most important factors influencing drafted thread properties were the amount of draft applied, the amount of twist inserted during drafting and their interaction. They found that up to a draft of 1,2 the levelness coefficient (ratio of CV of slubbing after drafting to the CV of the slubbing before drafting) was unity irrespective of twist inserted. For drafts of 1,2 to 1,3 the irregularity increased rapidly for all twists until the slivers broke at a draft of approximately 1,7. These workers[125] suggested a three stage theory for spindle drafting. They suggested that the first stage of drafting involved an increase in fibre extent (projected fibre length along the yarn axis). It was stated that Angus and Martindale's 'crimp-removal' should be defined as the decrease in linear density due to the increase in fibre extent without changing the number of fibres in the cross-section. The second stage, according to Grosberg and his co-workers, began when the draft ratio exceeded the ratio of average fibre length to average fibre extent and during

this phase the number of fibres in the cross-section changed while irregularity increased. The final stage took place when the sliver broke due to the force required to break the sliver being less than the force required to draft the sliver.

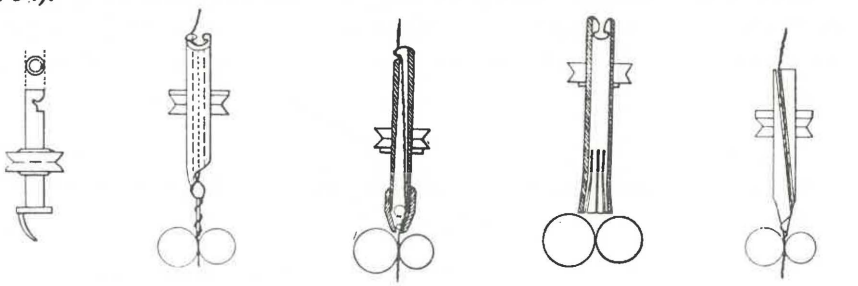
From the foregoing discussions it is obvious that the process of spindle drafting or drafting of a twisted slubbing is still not a clearly defined process and provides scope for further investigation.

5.3 The woollen ringframe

The first woollen yarns to be ringspun were spun on worsted frames. This was not accepted by the trade because it was claimed that the yarn was wrapped up too much by the higher twist used on the frame, it was deficient in felting properties and it lacked loftiness.

The preparation of slubbing for the mule and the ringframe was carried out on the same machines and it was therefore necessary to develop a process of drafting on the ringframe which would be similar to that of the mule, i.e. drafting while twist is inserted to give the necessary cohesion and fibre control.

Drafting on the woollen ringframe was carried out between two pairs of rollers between 38 to 50 cm apart and the idea of inserting twist into the drafting zone by means of a twister-tube was evolved in 1866. Several forms of twister tubes were developed to insert twist between the pairs of drafting rollers and several devices were employed[126] in the tubes to grip the yarn (See Fig. 54).



(a) Martin's Patent (1887) | (b) Josephy's Patent (1901) | (C) Martin's Patent (1903) | (d) Houget's Patent (1903) | (e) Josephy's Patent (1912)

Fig. 54 — Various types of early twister-tubes[126].

In these early forms of twister-tubes several methods were devised to grip the slubbing while it was being twisted during passage through the tube into the nip of the front rollers, e.g. a needle extending beyond the exit of the tube

(Fig. 54 (a) and (b)), steel balls inside the constricted part of the bore (Fig. 54 (c)), grooves cut lengthways on the inner surface of the trumpet-shaped tube (Fig. 54 (d)), and the off-centre drilled hole (Fig. 54 (e)).

The twister-tube with the extending needle has been retained on some newer frames and in some cases the one needle has been replaced by a cluster of intersecting needles directed downward and inward (See Fig. 55).

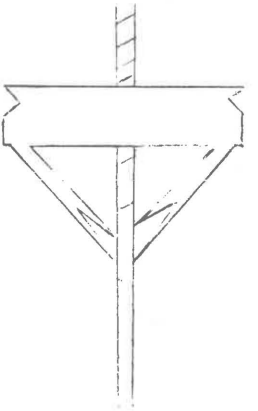


Fig. 55 — False twist tube with needle arrangement.

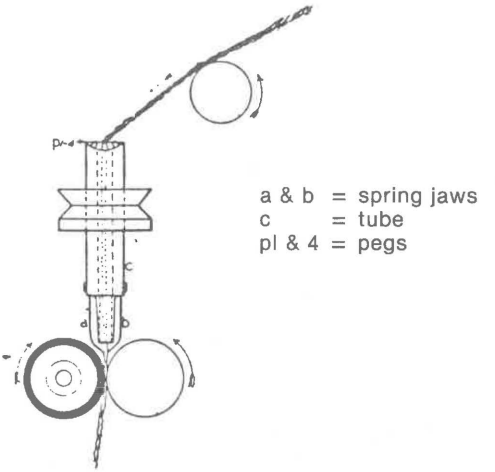


Fig. 56 — Twister-tube with pegs and spring jaws[126].

A hook, nick or pegs at the mouth of the tube to pluck the slubbing while it was being rotated and drafted was common to several of these patents and this has been retained on several modern machines.

In 1930 a twister-tube was introduced to which a pair of spring jaws was fitted to grip the slubbing. Pegs to pluck the slubbing were also included in this type of twister-tube (See Fig. 56).

The most popular form of false twist tube being used today is the false twist tube with pegs on the entrance side and with centrifugal jaws at the yarn exit (See Fig. 57).

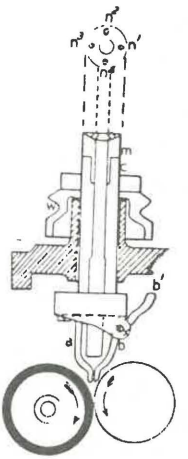


Fig. 57 — Twister tube with pegs and centrifugal jaws[126].

Jaw, a, is fixed, while jaw, b, is pivoted on pin X. When the tube is rotated, balance weight, b^1, swings outwards and downwards by centrifugal force, whereby the lower part of b is forced against fixed jaw, a, thus gripping the yarn firmly to facilitate the insertion of false twist. At the same time, the pegs create a plucking action on the twisted slubbing, similar to that on the mule when the yarn slips over the tip of the spindle during the drafting and twist inserting phases.

Another early approach, originally devised by Crompton, was to cause the front rollers to rotate in two planes, i.e. to revolve at right angles to the axis of the thread while also rotating to deliver the thread to the spindle[127]. In this system the slubbing is positively twisted and simultaneously fed forward in a controlled fashion. Permanent twist is introduced into the drafting zone and it is claimed that a more even yarn is produced due to elimination of ineffective control of fibre movement in the short twistless section of the slubbing between the twister-tube jaws and the front rollers.

5.4 Principles of woollen ring spinning

On the woollen ringframe, slubbing is fed from the bobbin L, through the guide H, between the delivery rollers (back rollers) A into the drafting zone, over deflector rod D, into the false twister-tube C to the front rollers B (See Fig 58). The drawn sliver is passed through the pot eye G, underneath the traveller T and is wound onto the tube S. Twist is inserted in the yarn with the aid of the traveller as it rotates around the ring, but at a lower speed than the spindle. Twist is therefore inserted and the twisted yarn wound onto the tube.

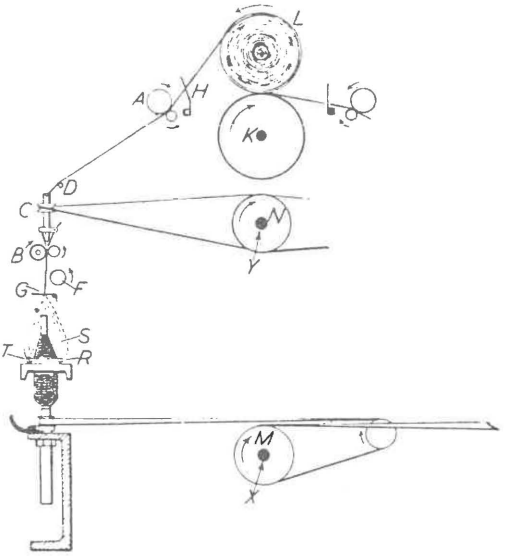


Fig. 58 — One side of woollen ringframe[128].

5.4.1 Drafting on the ringframe

The drafting zone in the woollen ringframe between the feed rollers (F) and delivery rollers (D) is approximately 50 cm long. The slubbing is also unsupported and the necessary cohesion during drafting is obtained by the insertion of false twist by the twister-tube (T).

As the slubbing proceeds through the drafting zone (See Fig. 59) it receives Z twist between F and T.

If n = the rate of rotation of T in rev/min

and x = the rate of feed in m/min

then the twist inserted between F and T in turns per m = n/x.

As x m/min of slubbing passes through the twister-tube (T), it carries n turns of Z twist into the zone TD, the Z twist, however, being exactly

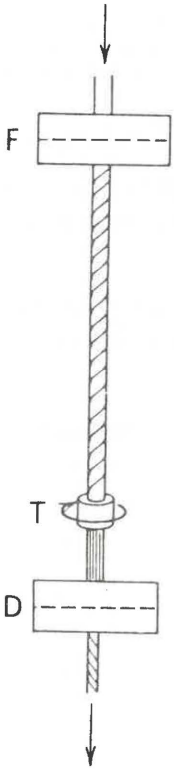


Fig. 59 — False twist insertion in woollen spinning.

neutralized by the *n* turns of S twist inserted into the length TD; thus the length of TD contains zero twist[129].

Drafting will tend to take place within the zone TD, resulting in uneven yarn and poor spinning performance. This problem is overcome by placing the nipper-jaws, incorporated in the twister-tube, very close to the nip of the delivery rollers, D, and the distance TD is almost zero.

It was shown that drafting within the drafting zone of the woollen ringframe took place within the first 10 to 13 cm of the drafting zone where the twist was relatively low, draft then decreased as the twist increased, until the slubbing entered the twister tube where some drafting took place due to the fibres being pulled forward by the delivery rollers[130].

There is no hard and fast rule with regard to the amount of false twist to be inserted. This varies with the raw material. The false twist imposed depends

on the false twister-tube speed and the angle at which the slubbing enters the tube. As a general rule it can be stated that short fibres require more drawing twist than longer fibres and as draft is increased false twister-tube speed has to be decreased[131].

The angle at which the slubbing enters the twister-tube affects the amount of false twist imposed for a given speed. This angle is adjustable by changing the height of the deflector rod D, in Fig. 58. The latter height also affects the plucking action of the pegs. It is, however, seldom changed.

Some continental firms have recently started to market woollen ringframes in which drafting is accomplished in a two zone drafting system. In the first zone the slubbing is drafted in the conventional way, i.e. drafted while twist is inserted, and in the second the yarn is drafted in the untwisted form between rollers. This is illustrated in Fig. 60.

It is claimed that much higher drafts, i.e. up to 2, can be employed and that a more even yarn can be spun on the two zone spinning machines[132].

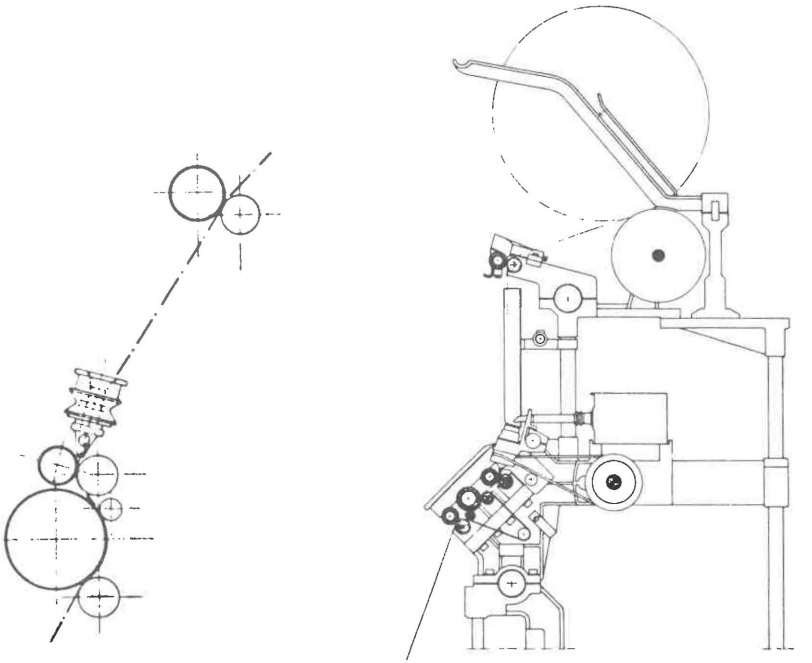


Fig. 60 — Illustration of woollen ringframes in which the two systems of drafting are incorporated[132].

5.4.2 Twist insertion and winding

As the strand of untwisted parallel and drafted fibres emerges below the front rollers of the ringframe, it has no strength and twist must be inserted to give them cohesion and thus strength to the yarn. Twist induces lateral forces which act by means of friction to prevent the fibres in the yarn from slipping over one another[133]. Apart from imparting strength to the yarn, twist has a profound effect on fabric end-use properties. Twist affects yarn tensile properties, diameter and bulk which in turn will influence fabric softness or handle in general. An increase in twist leads to closer packing of the fibres within the yarn which determines fabric cover, crease recovery, air permeability and various other characteristics. Hairiness is also influenced by twist and this will have an influence on fabric pilling[134].

The fibre strand that emerges from the front rollers is passed through the traveller on the spinning ring onto the spinning tube fitted over the spindle. Twist is inserted by the spindle that rotates the yarn package about the axis of the yarn. The traveller slides on the inside of the ring and rotates around the rotating spindle but friction between the traveller and the ring as well as the drag caused by the balloon cause the traveller to lag behind the spindle. The difference in speed between the spindle and traveller causes the yarn to wind on the package and the difference in speed adjust itself automatically as the tension varies[133] with variation in diameter of the chase.

During ring spinning a balloon is formed due to the action of centrifugal force which creates a tension in the yarn which is proportional to the surface area of the balloon and the spindle speed[2]. In woollen spinning yarn linear density is normally high compared to the worsted system and to obtain an adequate length of yarn the yarn packages must be larger which means that frames with larger diameter rings must be used. When larger rings are used an acceptable spinning speeds are maintained, yarn tension is increased due to the larger balloon, and a higher end-breakage rate is the result. To reduce yarn tension the spindle tops are changed to allow spinning with a reduced or collapsed balloon. Centrifugal force is reduced whereby spinning tension is reduced and fewer end-breaks occur.

Amongst the changes to the spindle top are the Pross Spindle by Houget Duesberg-Bosson, as well as the thistle and crown tops by other manufacturers. In all cases the yarn is wrapped around the spindle, thus collapsing or suppressing the balloon. In this way yarn tension between the yarn guide above the spindle and the front rollers is reduced while, at the same time, the twist is encouraged to run back into the weak, twistless region just below the front rollers, thus reducing the number of end-breaks.

5.5 Woollen type yarns produced by unconventional methods

During the past two decades several new spinning systems have appeared on the market. Of these the Rotor, Air-vortex, Electrostatic and Dref spinning

methods are the only systems producing yarns with a random fibre orientation. Of these only commercial yarns are produced on the rotor spinning and Dref systems.

These methods are all examples of open-end spinning. The latter is defined as a spinning process in which a 'break' in the fibre stream occurs, i.e. where twist is inserted by rotation of the yarn tail as opposed to the yarn package and where winding is independent of twist insertion[135].

5.5.1 Rotor spinning

In the rotor system fibre is supplied to the machine by means of a sliver A (see Fig. 61). The Sliver is opened and separated into individual fibres by an opening roller, B, covered with metallic card wire or pins, rotating at a speed around 8 000 rev/min. Trash and dirt are separated from the fibres by the separating edge, E. The dirt particles are removed by air through F.

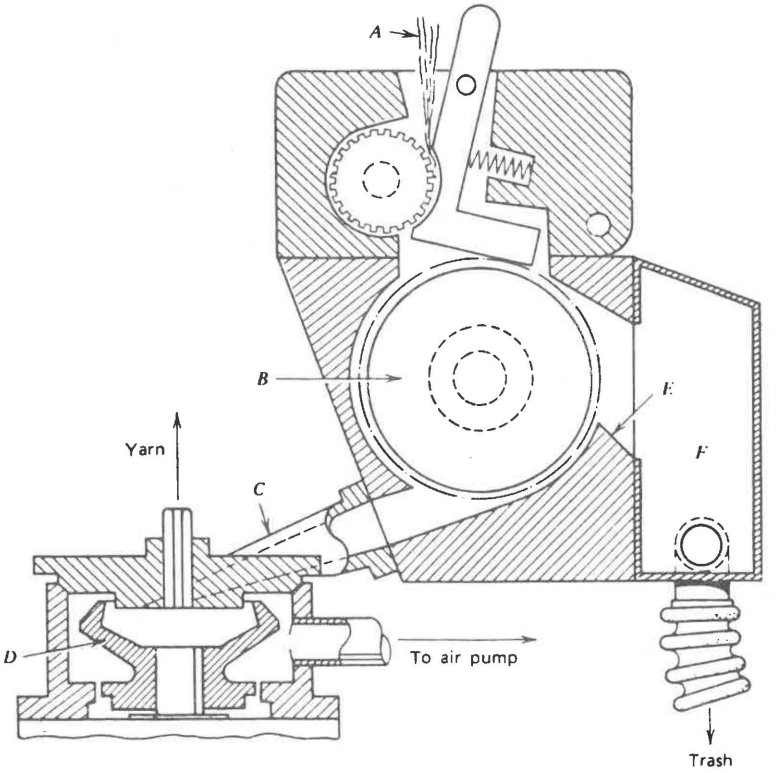


Fig. 61 — Typical rotor spinning arrangement[136].

The stream of individual fibres is drawn through the tube C by an airstream, and is then deposited into the rotor D. The yarn emerges through the yarn delivery tube[136].

For every one turn of the rotor one turn of twist is inserted in the yarn. The twist runs back along the yarn into the rotor-groove and as the yarn is being withdrawn and fibres continuously supplied to the rotor, the tail end of the twisted yarn binds the fibres into the twisted end thereby supplying a continuous thread. Rotor speeds as high as 100 000 rev/min are not uncommon today.

The differences in properties between ring- and rotor-spun yarns are the following[137]:

1. Rotor yarns are weaker,
2. Rotor yarns are more uniform in cross-sectional size and strength,
3. More single fibres are projecting from ring-spun yarns while more fibre loops are projecting from rotor-spun yarns,
4. Rotor yarns have a better abrasion resistance,
5. Rotor yarns are more bulky and produce fabrics with better cover,
6. Fabrics knitted from rotor-spun yarns are harsher than those knitted from ring-spun yarns.

When long staple fibres such as synthetic- and wool fibres are spun, machines equipped with larger rotor diameters are used which means that the spinning speed has to be reduced. Short staple machines can be used for the spinning of long staple fibres but in this case the fibres are broken by a stretch-breaking process followed by a second or re-breaking operation[138] to obtain fibres of a suitable length for spinning on the short staple machines.

5.5.2 Dref Spinning

Sliver is fed to the carding cylinder, rotating at speeds between 2 400 and 4 510 rev/min, by means of the feed rollers[139]. The fibres emerging from the carding roller are lifted from the latter and blown downwards, by means of an air jet, into the nip of the perforated drums. The fibres are controlled in the nip by the vacuum created through the vacuum tubes. The perforated drums rotate in the same direction whereby the fibres are rolled (twisted). The twisted yarn is removed by take-off rollers and wound onto a package (see Fig. 62).

Dref yarns are relatively free from fibre slubs and neps. The yarns are, however, hairier, harsher and more irregular than conventional ring spun yarns[140].

Open-end spinning machines have not as yet replaced the conventional woollen ringframe for the production of hosiery and apparel yarns. The reason may be because open-end fabrics are harsher than ringspun fabrics while a soft and lofty handle has always been associated with woollen fabrics.

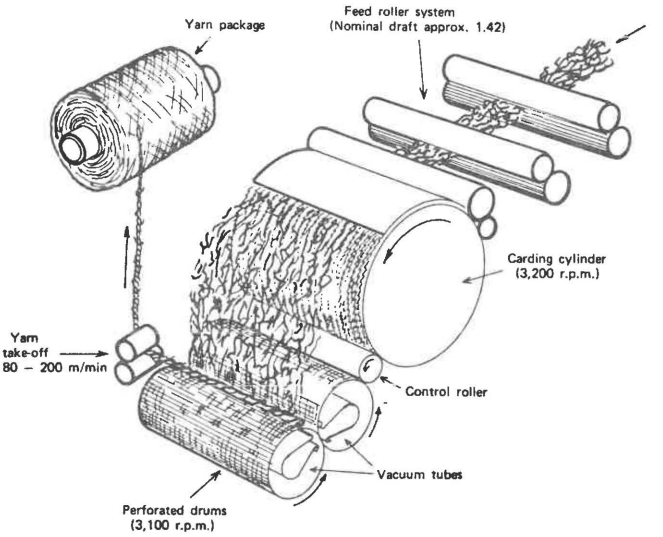


Fig. 62 — Schematic diagram of Dref spinning system[141].

THE USE OF PROPRIETARY NAMES

The names of proprietary products, where they appear in this publication, are mentioned for information only. This does not imply that SAWTRI recommends them to the exclusion of other similar products.

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