11. Wool Combing

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Learning objectives

On completion of this topic you should be able to:

- Outline the objectives of wool combing
- Describe the design of a typical rectilinear comb
- Explain the steps in rectilinear combing – feeding, initial combing, final combing and drawing off, and sliver formation
- Discuss the means by which noils are removed, and the balance required in setting the amount to be removed
- Explain the purpose of re-combing
- Calculate: tear ratio, noil(%), romaine, regain and combing production
- Discuss the factors that affect the combing quality of fine wools

Key terms and concepts

Combing (Nobel and rectilinear), nips per minute, doublings, noils, finisher gilling, packaging, re-combing, tear, noil(%), romaine, percent fibres less than 30 mm, combing production.

Introduction to the topic

Wool combing is a comprehensive term when used in its widest sense, and it embraces all the operations carried out in a topmaking plant. It includes the processes of raw wool scouring, drying, carding, backwashing and preparer gilling. Then follows the actual combing operation, and the sequences of topmaking processes concludes with two gilling steps called top finishing (or finisher gilling). Combing is not included in the semiworsted or woollen processing routes.

Wool combing, the single process, is indispensable in the manufacture of a worsted yarn. The card has disentangled the fibres in the mass of scoured wool and has mixed them in a roughly parallel formation. However, during the carding process many fibres will have been broken, and the card sliver will consist of a variety of fibre lengths. Some vegetable matter will have been removed but fragments remain.

Gilling is able to mix, align and straighten fibres but a gillbox has no capability to remove short fibres or vegetable matter from sliver. Combing enables finer, stronger, more uniform and less hairy yarns to be spun at higher efficiency. This is because it aligns the fibres and removes, as noil, fibres generally shorter than 20 -30 mm, vegetable matter and neps. Typically, the mean fibre length (Hauteur) is increased by 10 -15 mm and its coefficient of variation is reduced by 10% to 20%, while more than 95% of the vegetable matter and neps are generally removed.

However, because of the fibre arrangement in the combed material, further gillings are required to restore the sliver to a form that is suitable for spinning. The product is called a *top*.

The references for this topic are Lawrence (2002) and Oxtoby (1987).

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11.1 Introduction to combing

The objectives of combing are:

1. To remove the proportion of short fibres not suitable for worsted products. These are commonly known as noils and may be recycled for use in the woollen industry
2. To remove from the wool all vegetable matter and neps (small clusters of entangled fibres)
3. To arrange the long fibres that remain into a parallel formation and assemble them into a *combed sliver*.

A number of combed slivers are blended together by gilling to form a ball of sliver called a *top*.

Combing is essential to achieve the strong, fine, smooth, uniform yarn required for worsted products. It is necessary have a top of highly straightened parallel fibres that are free of short fibres, neps and foreign matter such as vegetable matter fragments. Short fibres tend to increase yarn bulk (which is not required in worsted yarn), give rise to a hairy appearance and reduce the yarn strength.

The efficiency of the previous scouring, carding and gilling operations influence the combing process, by affecting the amount of fibre breakage and the proportions of top and noil produced.

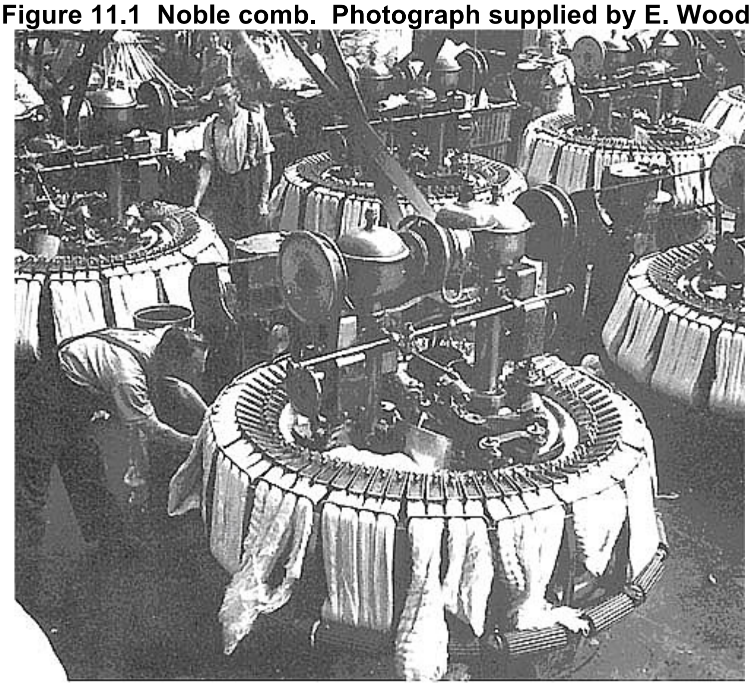
All methods of wool combing are based on similar principles, but the methods for putting them into practice differ. The basic operations in a combing machine are:

1. Feeding the uncombed sliver into the comb
2. Holding the fibres and combing the free end by pin treatment; any fibres which are not held will be combed away (the noil)
3. Holding the portion which has just been combed, and repeating the combing operation on the previously uncombed fibres, again removing noil
4. Forming an endless sliver of combed fibres from the tufts that have just been combed.

A number of designs of combing machines have been used throughout the history of wool combing, in particular Nobel (circular, 1853), Rectilinear (intermittent, 1846), Lister (nip motion, 1851) and Holden (square motion) machines. However, the two most important types have been the Noble comb and the 'French' or rectilinear comb.

The Noble comb (Figure 11.1) was the most popular type of comb in the English system of combing for many years, because of its simplicity, low cost of upkeep and high production. Production rates varied from 25-45 kg/hour depending on the quality and state of the wool.

Figure 11.1 Noble comb. Photograph supplied by E. Wood.



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While the Noble comb is quite versatile, major alterations are required when changing from one quality of wool to another. At least four different sets of comb circles are required for merino, fine crossbred, medium crossbred and long wools.

Other disadvantages are:

1) There is always a small portion of uncombed wool
2) A Noble comb ‘makes its own noil’ through fibre breakage
3) Frequent maintenance and replacement of components is required.

Most wool today is combed using the rectilinear comb and the Noble comb has greatly diminished in importance. This is because production rates of rectilinear combs have increased. The trend in wool combing has been the cause of (1) increasing use of dry-combed, as opposed to oil-combed tops, and (2) the shorter mean fibre lengths of wools typically being processed nowadays. Also the modern trend has been towards machines that are not fibre specific – the ability of the Noble comb to process only long fibres is a disincentive to improving the process through machinery development. Long fibre combing now only represents a limited market.

Despite recent design innovations in rectilinear combing, the production rates of combs are well below those of gillboxes, and hence combing can be regarded as a bottleneck in topmaking.

11.2 Rectilinear combing

While the Noble comb operation is essentially continuous, the rectilinear (or French) comb has an intermittent action, with modern machines reaching up to 260 nips (or) cycles per minute. It is capable of combing wools that are too short (i.e. <100mm) or too contaminated with burrs for the Noble comb. The comb is not heated and oil is added to the sliver before combing.

Another advantage is that the whole length of the fibre is combed, that it produces the clearest (i.e. nep-free) top and there is greater control over the amount of noil removed.

A modern worsted rectilinear comb (NSC) is shown in Figure 11.2, with the two-tier creel at the far end. This is a fully-enclosed model which delivers a single sliver of about 20-37 ktex into a large coiler can. This has a capacity for about 20kg of sliver. Air currents are used to remove fly and dust.

Figure 11.2 Single-head rectilinear comb. Source: NCS Schlumberger.

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Preparatory processes

The comb is fed with up to 32 doublings from a creel or can, giving a total input of about 320-420 ktex. An increase in total input sliver thickness will theoretically give an increased rate of production, without influencing the proportion of noil produced or the mean fibre length of the comb sliver. However, in practice, excessive input causes overloading and inefficient combing.

The slivers for combing have usually been gilled three times. This improves the fibre alignment and ensures that the majority of any remaining hooks are fed into the comb trailing. Hence fibre breakage and the amount of noil produced in combing are minimised.

There is an optimum quantity of fibre lubricant to be applied, with regard to the amount of noil produced. Thorough wool scouring may give a residual grease content of about 0.8% for merino wool, but a lower grease content is preferable to minimise nep formation in carding. With low residual grease content, the addition of about 2% fatty matter (for vegetable and mineral oils), or 1% for water-soluble compounds, facilitates effective noil removal in wool combing.

11.3 Rectilinear combing actions

The general layout of a modern rectilinear combing machine (NSC PB33) is shown in Figure 11.3. The combing area of this machine is shown in Figure 11.4.

Figure 11.3 Cross-section view of a rectilinear combing machine. Source: NCS Schlumberger.

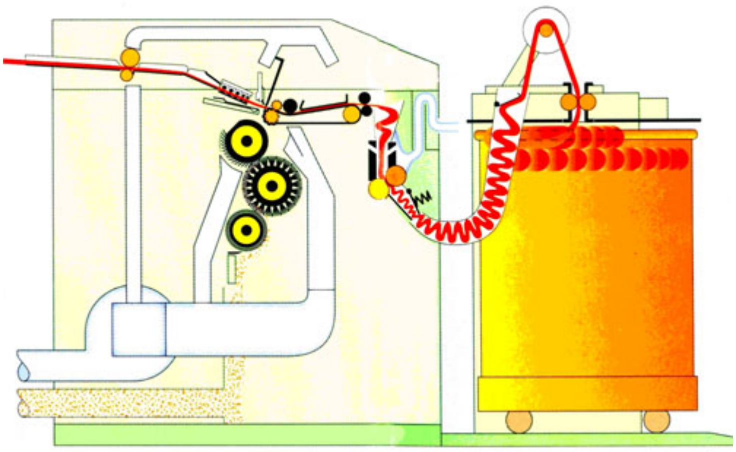
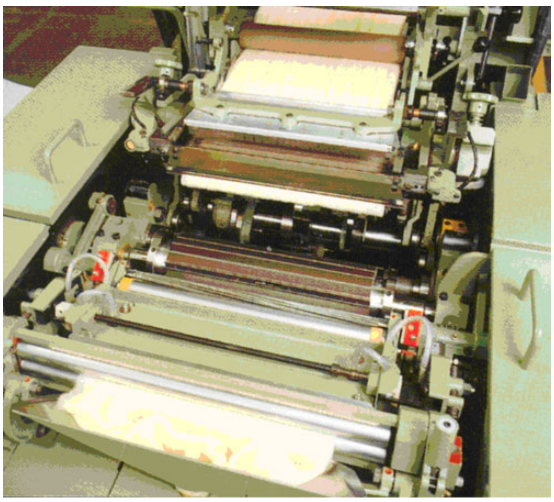


Figure 11.4 View of combing area of a rectilinear comb. Source: NCS Schlumberger.



A side elevation view of a rectilinear wool comb is shown in Figure 11.5.

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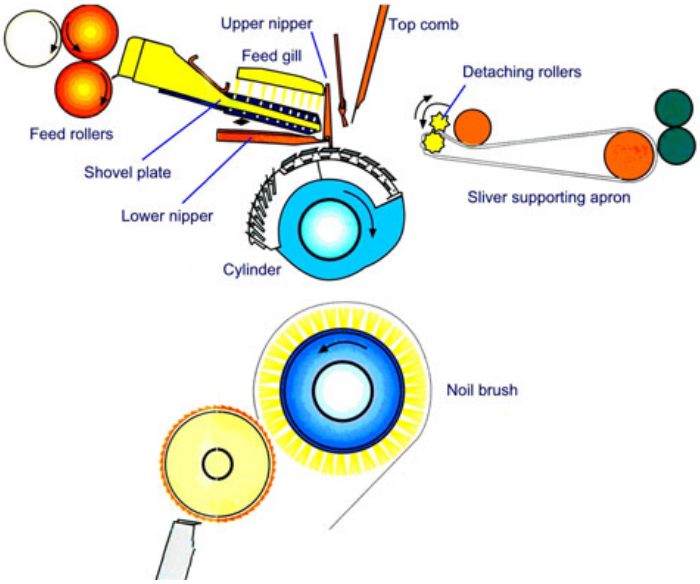
Figure 11.5 Rectilinear comb – side elevation. Adapted from: NCS Schlumberger.

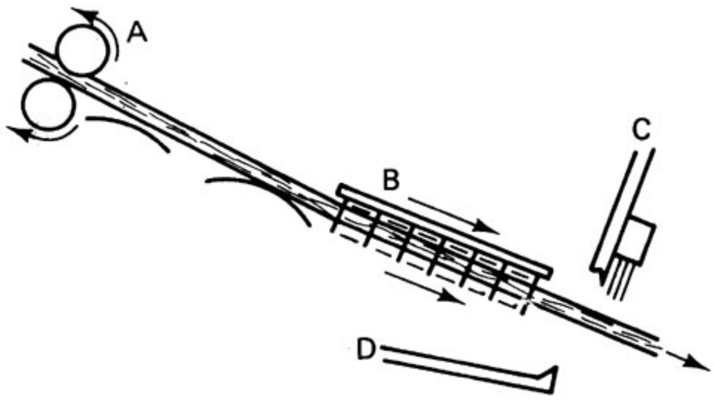


The sequence of combing actions is quite complex. Auer (1999) explains the process of combing and noil selection in more detail than is presented here.

Feeding

The feed roller A and feed gill B feed a fringe of fibres through the open nippers (C and D) (Figure 11.6). The length of feed may be around 6.5 mm, and depends on the length of the wool and the amount of burr present. The length of the feed fringe is determined by the feed rollers in conjunction with the feed gill; this setting, along with the total sliver thickness delivered to the comb determines the production rate.

Figure 11.6 Combing cycle: feeding. Source: Wood, 2006.



Initial combing

The nippers C, D close and lower the fringe of fibres into the pins of the cylinder E (Figure 11.7).

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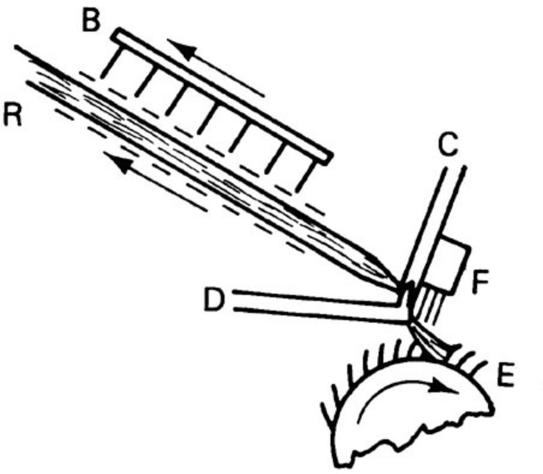
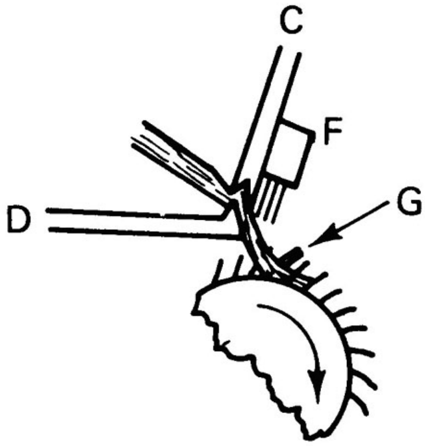
Figure 11.7 Combing cycle: initial combing. Source: Wood, 2006.



Penetration of the pins is aided by a brush F, and for burry wools a de-burring blade G may momentarily push the fibres down into the last few fine rows of pins (Figure 11.8). The use of the de-burring blade is of little benefit when combing wools containing a low level of vegetable matter. As it may present mechanical difficulties when running at high speed its omission may be preferred.

Figure 11.8 Combing cycle: action of de-burring blade. Source: Wood, 2006.



During the initial combing cycle the feed gill B rises and moves back along with the feed grid R before being lowered ready for the next feeding cycle (Figure 11.7).

Under normal conditions the combing efficiency of the cylinder is very good; nevertheless some neps and particles of vegetable matter may remain in the fringe and may then appear in the comb sliver.

The direction of feed into the comb may influence the amount of noil removed because when fibres are combed with hooks leading, both ends of the hook may be held by the nipper while the loop is broken by the cylinder pins. When the hooks are trailing there is less fibre breakage.

The cylinder has a diameter of about 150 mm and it carries about 20 comb bars. The pins are usually thicker and more widely spaced on the first 10 bars (ranging from 4 – 17 pins/cm) and closer on the last ten bars (i.e. 19 – 30 pins/cm for fine wool types; 19 – 24 pins/cm for coarser wools).

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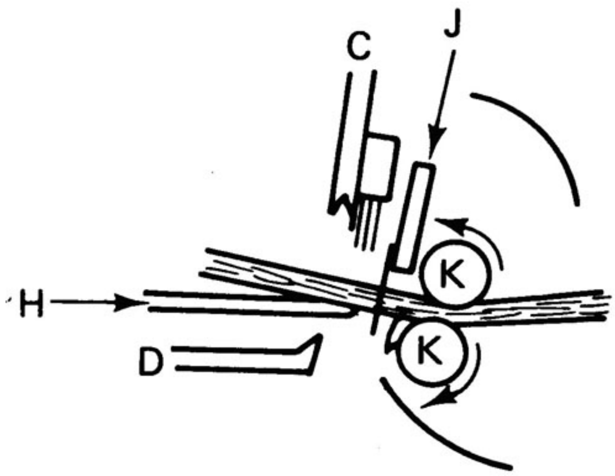
Final combing and drawing off

The nippers C, D rise up and open and at the same time the shovel plate H moves forwards between the open nippers to support the fringe as the top comb J descends and the detaching rollers K draw the fringe of fibres away (Figure 11.9).

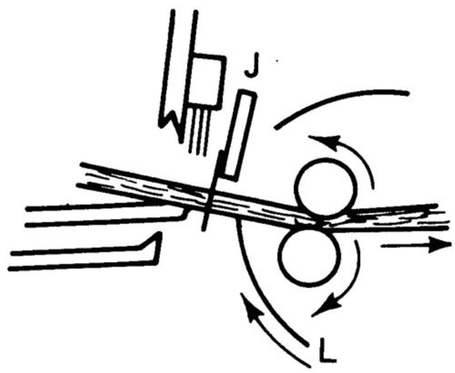
Figure 11.9 Combing cycle: final combing and drawing off. Source: Wood, 2006.



In order to enable long fibre lengths to be drawn away, the detaching rollers K are usually mounted on a carriage which moves away from the nippers at the same time as the detaching rollers rotate to withdraw the fringe.

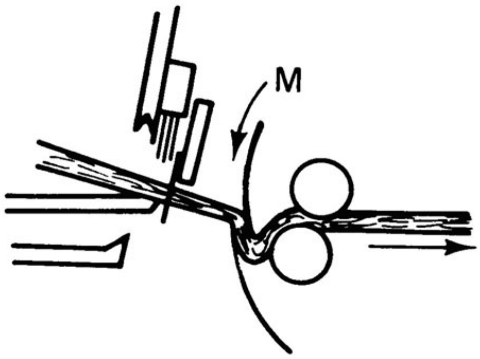
At this stage on some models of comb, the counter-sword L rises to support the fringe of fibres in the top comb (Figure 11.10).

Figure 11.10 Combing cycle: counter-sword raised. Source: Wood, 2006.



With very long fibre lengths, drawing off may be further assisted by the top sword M moving down (Figure 11.11). This causes the tail ends of the fibres to be drawn forward over the edge of the counter-sword.

Figure 11.11 Combing cycle: Top sword lowered (for very long fibres).



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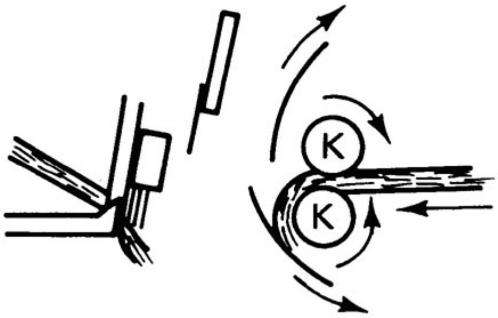
On modern machines the mechanical complications of the sword and counter-sword have been replaced by a pneumatic suction duct. This is mounted on the carriage which moves the detaching rollers back and forth.

Sliver formation

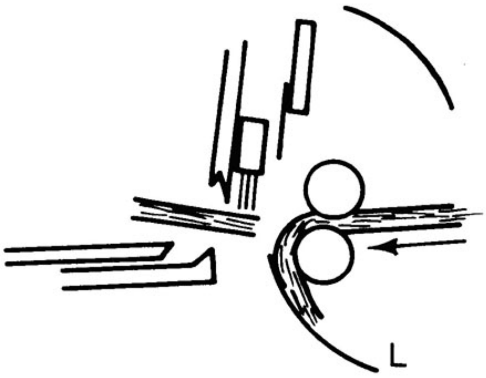
After completing the drawing-off action, the carriage starts to move towards the nippers, and the detaching rollers recoil to start feeding out the tail ends of the previous fringe (Figure 11.12). As the carriage approaches the nippers, the parallelisation of the fibres is controlled by the air suction, with the duct positioned close to the lower drawing off roller K.

Figure 11.12 Combing cycle: recoil of the detaching rollers. Source: Wood, 2006.



On other models the fibres are controlled by the counter-sword (Figure 11.13)

Figure 11.13 Combing cycle: overlapping of tufts about to commence. Source: Wood, 2006.



As the carriage approaches close to the nippers, the detaching roller K first stops rotating. Then just before the leading end of the initially combed tuft is reached, they start to rotate in the forward direction and grip the new fringe (Figure 11.9). This overlaps the new tuft of fibres over the previous one by a chosen amount which determines the thickness of the delivered sliver. The continuous sliver thus formed is supported by the apron (see Figure 11.5) before being condensed through a funnel and delivered into a coiler can.

Noil removal

In the usual arrangement of the rectilinear wool comb the detaching rollers are mounted on a movable carriage. The length of the fringe presented to the cylinder by the closed nippers is approximately equal to the noil setting. This is the distance between the nip of the detaching rollers K and the nippers C, D when the carriage is at its closest position to the nippers.

In theory, the noil will include some fibres with lengths about as long as the noil setting, as well as all the fibres shorter than (noil setting – length of feed). The combed sliver will contain all fibres greater than the noil setting, along with some fibres down to (noil setting – length of feed). Whether fibres of length L in the range:

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noil setting > L > noil setting – length of feed

become sliver or noil is determined by the proximity of the leading end of the fibre to the leading end of the fringe immediately prior to detachment.

In practice, because fibre breakage around 15 – 30% may occur, the mean fibre length of the comb sliver will be shorter, and the amount of noil greater, than would be expected from these theoretical considerations.

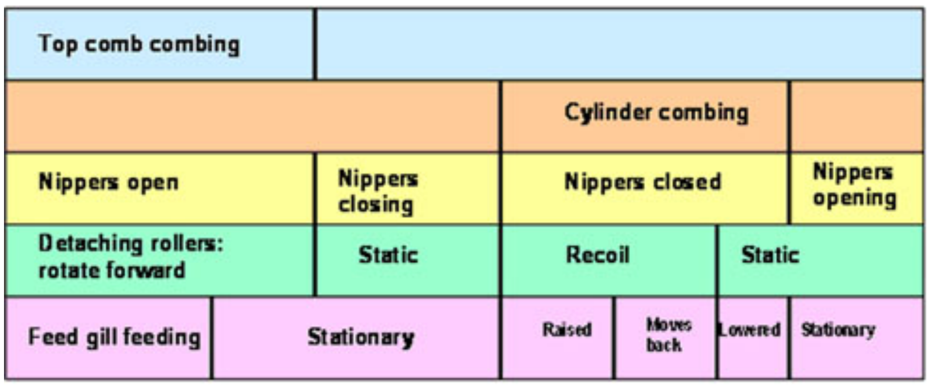
The least distance possible for the noil setting is about 20 mm, so that provision can be made to produce noil with fibres not longer than 20 mm. An increased noil setting for a given batch of wool produces an almost linear increase in the amount of long fibres in the noil, together with more neps and vegetable matter being removed. However the accompanying increase in mean fibre length of the comb sliver is limited, even though the proportion of short fibres is reduced. This is because there is usually an associated increase in fibre breakage with an increased noil setting.

A balance must be achieved between the clarity of the comb sliver (i.e. freedom from neps) and the amount of noil produced. If both maximum clarity and minimum noil extraction are required, the length of both the feed and noil settings must be reduced, giving a lower production rate.

The fibres and impurities collected by the cylinder pins are removed by a rotating noil brush (as shown in Figure 11.5), and transferred by a doffing type action to a roller covered in card clothing. The fibres are removed from the card roller by a reciprocating doffer comb and delivered into a container. Stray, very short fibres, dust and vegetable particles are released by the brush (called comb shoddy) and transferred pneumatically to another container.

In practice, some parts of the combing cycle that have been described separately here, actually occur simultaneously. The basic way in which the actions may be synchronised is shown in Figure 11.14, although differences may arise for different machines or types of material.

Figure 11.14 Timing diagram of a rectilinear wool comb. Source: Wood, 2006.



Introducing crimp

Combed sliver has poor cohesion caused by the 'open-end' nature of combing. The combed sliver is really made up of overlapping tufts of fibres which have minimal intermingling. The common method for improving sliver tenacity is to fit a crimper, or stuffer box onto the output of the comb.

Crimpers are simply two angled plates into which the sliver is forced by a pair of nip rollers. When the space between the plates is full of sliver, the incoming sliver at the nip rollers is folded left and right by the high pressure into a crimped state. The fine crimp that is induced in the sliver increases the intermingling between the fibres thereby increasing the cohesion of the tufts.

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A typical crimper unit, with its 'J-tube' which transfers the crimped sliver to the coiler, is shown in Figure 11.3.

While the tenacity of the sliver is increased by crimping, the combed sliver is still significantly weaker than the equivalent gilled sliver. Therefore crimping does not eliminate the need for further (finisher) gilling.

11.4 Finisher gilling and packaging

Finisher gilling (or top finishing) after combing, is similar to preparer gilling, which was outlined in the previous topic. The purposes of finisher gilling are:

1. To redistribute the fibres of various lengths in the combed sliver to give uniform drafting and cohesion
2. Restore maximum fibre alignment and parallelisation
3. The make the linear density of the sliver regular
4. To provide further mixing through doubling
5. To bring the moisture content of the sliver up to the required level.

The absence of very short fibres in combed slivers (having been removed as noil) enables more drafting to be carried out in finisher gilling than in preparer gilling.

Generally two finisher gilling operations are required to produce a top of acceptable quality and specified linear density (ktex). The first finisher gill usually has an autoleveller unit, and is fed from 8 – 30 doublings of comb sliver, depending on the comb sliver thickness. Moisture is usually added to the fibres at this stage. The second gilling involves only 4 – 5 doublings.

Packaging

The second finisher gill may be fed from 2 – 8 doublings and delivers the sliver in an appropriate form for packaging. For example, to form a *bump top,* a sliver is coiled into a can before being compressed by a hydraulic ram. Whilst in a compressed form the slivers are firmly tied. Alternatively, a *ball top* is formed by feeding sliver through an oscillating nozzle on to a rotating spindle. The sliver gradually builds up on the spindle. A top wound onto a solid core is called a *bobbin*.

The product is typically a 20-25 ktex top in a package of around 24kg and which is up to 1,100 metres long. The tops are individually packaged in polythene before being packed in bales for transportation to a worsted spinning plant.

Hanks are loose multiple loops of top, tied at the circumference and which can be used for intermediate batch top dyeing. However, bobbins, balls and bumps are also suitable for top dyeing.

Re-combing

When coloured worsted tops are required, it is the usual practice to dye the wool in top form, wound in a ball. They are then either gilled, or gilled and re-combed (usually the latter) followed by two or more gilling steps.

Re-combing was originally introduced for dyed tops, in order to separate and align fibres that had become entangled during dyeing and also to remove neps and slubs formed during dyeing. Any neps and short fibres not removed by the first combing are also removed. A crimping box was introduced to improve the cohesion and crimp of dyed tops.

Today re-combing is carried out after top dyeing when fibre blends are involved and also when producing high quality tops. This step is particularly important when spinning high quality weaving yarns (25 tex and finer). Re-combing is regarded as a cost-effective step of improving spinning and weaving efficiencies and improving fine yarn and fabric quality in terms of yarn faults (neps and slubs).

Re-combing and gilling is also required after other wet processes such as shrink-proofing.

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11.5 Combing production and quality

Expressing yield and noil production in combing

The yield of fibre from combing and the amount of noil produced can be expressed in a number of ways, using the parameters Tear ratio, Romaine(%) and Noil(%):
Tear ratio = mass of comb sliver / mass of noils : 1
Noil(%) = mass of noils x 100 / (mass of comb sliver + mass of noil)
Romaine(%) = mass of noils x 100 / (mass of wool into carding)
For example, for a consignment that produces 420kg of comb sliver and 35 kg of noil:
Tear ratio = 420 / 35 : 1 = 12 : 1
Romaine = 7.7%

Moisture content

Wool fibres are hygroscopic and therefore tend to change considerably in mass (weight) when exposed to varying conditions of dampness or dryness. For buying or selling purposes it is often necessary to establish the moisture content or regain of wool in scoured or processed form.

The regain measures the moisture content as a percentage of the absolute dry weight of the material. It can be determined by accurately weighing a sample of the material before and after it has been thoroughly dried, say in current of hot air.

Regain = Weight of moisture x 100 / Bone-dry weight of material

= (original weight – dry weight) x 100 / dry weight

Having determined the moisture regain, it is possible to calculate the 'correct invoice weight' of a consignment of top, i.e. the weight adjusted to a standard regain value such as 18%.

For example, suppose a 120kg consignment of top is found to have a regain of 14.5%. The bone dry weight W_{dry} of the consignment is found by the following calculation:

$14.5 = (120 - W_{dry}) \times 100 / W_{dry}$
➔ $0.145 = (120/ W_{dry}) – 1$
➔ W_{dry} = **104.8 kg**

The correct invoice weight W_c of the consignment, at a standard regain of 18% is calculated as follows:

$18 = (W_c - W_{dry}) \times 100 / W_{dry}$
➔ $0.18 (W_c / 104.8) – 1$
➔ W_c = **123.7 kg**

The correct invoice weight at a standard regain of 18% is 123.7 kg.

Combing quality

A good measure of combing quality of fine wools is the percentage of fibres shorter than 15 mm in the top. This level of short fibre should be below 1.8 – 2.0% (by number). It is affected by:

- the total fatty matter content of the sliver (minimum 0.6 – 0.7%)
- the relative humidity (ideally 70-75%)
- the ambient temperature in combing area (20 – 24^{o}C)
- the regain of the wool (ideally around 20%)
- the comb setting.

The comb also breaks fibres, the breakage rate decreasing with decreasing fibre length, friction, combing intensity and with increasing fibre alignment and fibre strength. Fibre breakage during combing can range from around 17 – 31%. Trailing hooks in the sliver fed to the comb are less likely to be broken during combing, hence the importance of having an odd number of gilling operations between carding and combing, assuming cans are used to collect the output sliver at each stage.

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The percentage of fibres shorter than 30 mm and of noil in the finished top are influenced by:

- Raw wool characteristics (e.g. fineness, staple length uniformity, staple strength,..)
- Quality of scouring and associated processes such as opening and cleaning
- Quality of carding (card production, settings, speed)
- Quality of combing (comb setting, maintenance).

Combing production

The production rate of a modern comb is approximately 1.2 times the mean fibre diameter (micron) of the wool. Hence a 20 micron wool will have a production rate in combing of around 24 kg/h, and a 30 micron will have a production rate of around 36 kg/h.

The production rate of a combing machine depends on the following:

- Total sliver feed mass per unit length — L, grams
- Combing speed — n, nips per minute
- Feed rate — f, mm per nip
- Noil — W%
- Running efficiency — E%
- Number of heads — N_H

The production rate P (kg/h) is then given by:

$$P = (100 – W) . L . n . f . E . N_H \times 60 \times 10^{-10}$$

Table 11.1 shows recommended loadings on a comb for a range of fibre diameters. The equivalent production rates are also shown, taking the feed per cycle as 7 mm and assuming that the speed of the comb is 240 cycles per minute (which is close to the maximum currently possible of 260 cycles per minute).

Table 11.1 Combing production rates. Source: Wood, 2006.

Mean fibre diameter of sliver (µm)	Loading on comb (ktex)	Production rate (kg/h)
18	380	38
25	500	50
34	600	60

It is quite common however, to run combs slower in order to improve the quality of the sliver, particularly for finer wool. Table 11.1 shows that fine wool is more costly to comb than coarser wool since the production rate of the comb is less.

Readings

The following readings are available on CD:

1. Atkinson, K. 1999, Combing: Latest Developments and Future Trends, Woolwise PowerPoint Presentation, CRC for Premium Quality Wool.
2. Auer, P. 1999, Combing Principles, Woolwise PowerPoint presentation, CRC for Premium Quality Wool.
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4. Wool Science Review, 1953, 'The Scientist Looks at the Wool Industry: Combing,' *Wool Science Review*, vol. 11, p. 3.

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- Canesis Network Ltd, Slow Motion Combing.

Summary

In its widest sense the term 'wool combing' embraces all the operations carried out in a topmaking plant. It therefore includes the processes of raw wool scouring, blending and lubricating, carding, backwashing and preparer gilling. Then follows the actual combing operation and the process concludes with two finisher gilling steps.

Wool combing, the single process, is indispensable in the manufacture of a worsted yarn because it enables finer, stronger, more uniform and less hairy yarns to be spun at higher efficiency. It aligns the fibres and removes short fibres, vegetable matter and neps. As a result the mean fibre length of the sliver is increased. This topic describes the key features of a rectilinear comb and the series of actions the machine performs in producing a combed sliver. The important aspects of combing quality and production are also discussed.

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Glossary of terms

Apron	Small flat, continuous belt that controls fibres in drafting or transfers combed fibres in a comb
Ball top	Package of top formed by winding it onto a rotating spindle
Bump top	Package of top formed by coiling it into a can, then compressed
Combing	The straightening and parallelising of fibres, and the removal of short fibres at impurities using a comb or combs and assisted by brushes or rollers
Doublings	The number of sliver ends fed into a comb or gillbox in parallel
Fatty matter	Greasy film on wool fibre consisting of residual grease or processing lubricant
Nep	A small tangle knot of fibre
Nips	The combing cycle, measured from when the nippers close to hold the sliver for initial combing
Noils	The short fibres separated from the longer fibres in combing. Some VM is usually mixed with the noils
% Noil	The ratio (as a percentage) of noil to (top + noil)
% Romaine	The ratio of noil to card input, expressed as a percentage
Re-combing	A second combing operation in worsted processing, often carried out after top dyeing
Rectilinear combing	The most common type of wool combing process, sometimes called French combing
Sliver	A thick continuous strand of staple fibres, without twist
Tear	A measure of combing yield; the ratio of mass of combed top to the mass of noils, usually between 8 – 12
Top	The product of the topmaking process, the raw material to worsted spinning; a sliver which has been combed and gilled to become a highly regular sliver with well aligned, parallel fibres

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