Hairiness of yarns: Relative merits of various systems

By: Dr. N. Balasubramanian

Hairiness of yarns: Relative merits of various systems

By: Dr.N.Balasubramanian

Hairiness is lower in air vortex spinning compared to air-jet spinning and while hairiness increases with cotton content in air jet. no such trend is found in air vortex spinning. Says Balasubramanian.

Protruding fibres, loops (from the surface of yarn) and loosely wrapped wild fibres constitute hairiness. Hairiness is a unique feature of staple fibre yarns that distinguishes it from filament yarns. Hairiness is generally regarded as undesirable because of the followi ng reasons:

1. It adversely affects the appearance of yarns and fabrics. Hairiness is one of the factors that go to determine the appearance grade of the yarn. Higher hairiness downgrades the appearance grade. Hairiness in yarns leads to fuzzy and hazy appearance of fabric. According to Uster 15% of fabric defects and quality problems stem from hairiness. Warp way streaks and weft bars are caused by high hairiness and variation in hairiness. Periodic variation in hairiness has been traced to be a cause for alternate thin and thick bands in fabrics.

2. It affects performance of yarn in subsequent stages. Adjoining warp threads cling together in the loom shed because of long hairs in yarn, which in turn resist separation of sheet during shedding. This leads to more warp breaks and fabric defects like stitches and floats.

3. Excessive lint droppings in sizing, loom shed and during knitting are encountered with hairy yarns because of shedding of hairs and broken hairs.

4. In printed goods, prints will be hazy and lack sharpness if yarn is hairy.

5. In sewing, breakages will be high with hairy yarns and removal of hairiness by singeing is invariably practiced.

6. Pilling tendency will be more with higher hairiness. Pilling is a major problem with knitted and polyester blend fabrics.

7. It increases air drag on rotating packages and balloon. A recent studyl1), which is based on a model predicting friction co-efficient of yarn on the surface of a rotating package, shows that air drag on ballooning yarn and rotating package increases with hairiness. Removal of hairs by singeing reduces the air drag by about 26% in cotton and 33% in woollen rotating packages. Air drag on balloon in ring spinning is reduced by 9% in cotton yarns upon singeing. As a result of the friction, hairiness in yarn increases power consumption(2).

Is hairiness undesirable?

In spite of these drawbacks, hairiness has some beneficial effects. It adds to the textile character of the fabric and contributes to comfort, liveliness, skin friendliness and warmth. This will be apparent from a comparison of fabrics made from filament yarn and staple fibre yarn of the same type of fibre and count. Fabric made from filament yarn will have 'plastic' feel. Warmth found in woollen cardigans, shawls and flannel fabrics is to some extent due to hairiness.

Hairiness also adds to fullness and cover of fabric. Further hairiness assists weft insertion in air-jet looms because of grip provided by it. In a study!3) based on a computerised model simulating weft insertion in air-jet weaving, hairiness is shown to assist insertion velocity and insertion rate. With increase in hairiness, friction between yarn and air surface increases, thereby increasing velocity of weft insertion. This is supported by the work of Celeb!4) who developed an air index tester to simulate weft insertion in an airjet weaving machine. Yarns with a higher hairiness give a higher air index value indicating faster weft insertion. Thus a certain amount of hairiness is desirable from foregoing considerations but beyond that it causes problems enumerated earlier.

Removal of hairiness

Hairiness is removed or suppressed by singeing, waxing, application of lubricant, enzyme treatment and sizing. Singeing can be done at yarn or fabric stage. The material is passed through a gas or electric burner. Size of the flame and setting between yarn/fabric and flame must be carefully chosen to prevent scorching and damage to material. Knitted fabrics are not singed. Yarn used for knit ting is therefore waxed to lay the hairs on the surface.

Singeing is also not preferred in polyester blends as bead formation is encountered which could lead to specks in dyed fabrics and result in a rough feel. Sewing threads are passed through a liquid containing silicone based surface-active agent to lay the fibres on the body and make the surface smooth. Knitted yarns from carded cotton yarns exhibit high pilling because of hairiness.

Application of wax or surface-active agent reduces hairiness but affects absorbency of fabric. Enzymatic treatment for removing the hairs is free from this defect and the improvement is moreover permanent. Treatment with cellulase enzyme removes hairs and reduces pilling tendency(5,6). Weight loss from the treatment depends on the hairiness and is highest for fabrics from carded ring spun yarns followed by combed ring spun yarns, rotor and air-jet yarns(15, 82). In another study, acid cellulase treatment of fabrics from lyocell, rayon and cellulose acetate were examined(7). In addition to removal of surface fibres and fuzz, cellulase treatment reduced pilling tendency with lyocell and rayon but had no effect on cellulose acetate.

Measurement of hairiness

Hairiness consists of protruding fibres, looped fibres and loosely wrapped wild fibres.

Subjective methods

Yarns can be graded for hairiness by comparison of appearance. Relative levels of hairiness in two yarns can be easily judged by comparison of full bobbins. Wrapping the yarn on a black board and comparing them can also be employed for grading hairiness. Uster has developed yarn hairiness grade standard boards. This will assist in grading of yarns. Paired comparisons by a number of unbiased observers can determine statistically significant differences in hairiness through estimation of co-efficient of consistency.

Microscopic methods

Before instruments were developed, hairiness was measured by viewing the yarn under a microscope. Barella(8,g,10) was one of the earliest to use this method. Image of yarn is projected on a screen and number of protruding hairs and loops in a known length are counted. Length of protruding hairs is also measured with the help of micrometre eyepiece scale. From this, total length of hairs per unit length is determined.

Onions and Yates(11) used photographic standards to grade the hairiness of projected yarn image. Pillai12) projected the yarn on Projectina microscope and counted the number of protruding ends and loops in 10 mm length. Length of protruding fibres is measured by a curvimeter on a tracing of yarn . image. Jedryka(13) took photographs of yarn image under microscope with a magnification of sax. The boundary levels of yarn were marked. Four zones parallel to the boundary line were drawn on either side. The lines were equidistant with space between adjoining lines being kept as half the diameter of yarn. Hairiness is determined by the number of intersections the fibre makes with the lines marking the zone on either side.

This method gives the hairiness as per the length of the hairs. About 50 to 100 yarn samples are examined from which a'Verage hairiness is determined. Major difficulty in microscopic methods is in identifying the boundary of yarn. Looped fibres, wild fibres, low twisted portions, variation in yarn diameter and cross-section smudge the boundary. High variation in hairiness is found both within and between bobbins and as a result, large number of yarn specimens has to be examined to get a fairly reliable estimate. This makes the method laborious and time consuming.

Photoelectric method

Several instruments are available for measurement of hairiness based on photoelectric method.

Shirley-Atlas Hairine.'is Tester

A measuring head consisting of a photocell placed close to the yarn counts the number of interruptions made by the protruding hairs to an LCD beam. The measuring head is infinitely adjustable from 1 to 10 mm from the surface of yarn. This enables measurement of hairiness as per the length of hairs. Nip rollers at 50 to 300 m/min drive yarn by an electronic variable speed drive. Latest version is operated by a Pc. Continuous chart of hairiness can also be obtained through a recorder or printer. A portable battery operated model is available for on line measurement of hairiness with a standard measuring head of 3 mm. Portable model will enable detection of spindles giving high hairiness.

Zweigle Hairiness Tester

This also uses a measuring head with a photocell and a laser light source. The instrument measures hairiness of 9 length zones from 1 to 1 2 or 15mm fibre length in a single run of the yarn and produces a running chart of hairiness. Faults of a periodic nature can be detected. The equipment is controlled by a PC, which carries out statistical analysis of the results. There is facility for checking and matching all the optical channels with the reference value set ex works. Calibration with the yarn that has been checked on a master Hairiness tester is also possible. The above facilities improve reproducibility of results. An automatic bobbin changer up to 24 bobbins is available which makes the instrument fully automatic. Most of the research work on hairiness is based on tests on this instrument.

Meiners Dell Hairiness Tester

The instrument measures simultaneously hairiness of hair lengths from 1 to 10 mm in steps of 1 mm. A single run of the yarn gives hairiness for all lengths at a selected speed. A portable model is also available which enables online measurement of hairiness.

Changling Hairiness Tester

This uses a laser light source and a sensitive integrated photocell for measuring number of projecting hairs. Measurements of hair number for lengths from 1 to 9 mm are possible. Apart from estimates of number of hairs, length wise, another parameter that is commonly used is S3 value, which indicates the number of fibres, which protrude beyond 3 mm length.

lister tester

Uster Evenness tester has a hairiness attachment. Measuring field consists of homogenous rays of parallel light from an infrared light source. Scattered light from the protruding hairs of yarn, placed in this field, reach an optical sensor, which converts it into an electronic signal. The body of yarn itself is dark as it is not transparent and so does not contribute to the measurement. The protruding fibres are bright and reflected light from these fibres alone contributes to measurement.

Hairiness thus measured is an estimate of total length of protruding fibres in a cm length and is termed as Hairiness index. Hairiness index of 4 means that the total protruding length of hairs in 1 cm length is 4em. Zellweger has been publishing periodically Uster standards for hairiness based on survey of mills worldwide. While this method has the merit that it gives a single index to characterise the hairiness, it has the drawback that it does not provide information on long length and short length hairs separately.

Thus two yarns may have the same hairiness index but one may have more long hairs and fewer short hairs than other. Since long hairs are more objectionable than short hairs, information on the level of hairs as per their length will be more useful. While some studies have shown a good correlation between hairiness by Shirley hairiness tester and Uster tester(14), others have found little association(15). While Uster hairiness index is based on all hair lengths, S3 is based on hairs 3 mm and longer. So these two measures will correlate well only when number of hairs vs hair length relation is similar.

Krifa et al(58) found good correlation between Uster hairiness index of compact and normal ring spun yarns spun from a number of cottons. But Zweigle hairiness S3 values of compact and normal ring spun did not show any correlation. This once again confirms that Uster hairiness index and S3 values do not always go hand in hand. Uster tester further gives co-efficient of hairiness over measured lengths 1 em (normal) 10, 100, 300, 10000, 5000 cm or in other words variance length curve of hairiness. Presence of periodicity in hairiness can also be determined by spectrogram of hairiness.

Premier Electronic Tester

Premier Qualicenter, which is similar to Uster tester, has an attachment to measure hairiness by hair count as well as Hairiness index method.

Speed of testing affects hairiness results(15, 16). Hairiness is found to reduce with test speed in SOL tester(16). Direction of hairs, air drag and rubbing action against guides affect hairiness results. This could be one of the reasons for the different results obtained on different instruments. Humidity conditions in testing room as also conditioning time of yarn, affect hairiness. ASTM standard 05647-01 (1995) gives a standard method for measuring hairiness with photoelectric instruments. This will be helpful to minimise variations from laboratory to laboratory.

Online measurement

Barco profile optical measuring unit, Uster Quantum clearer and Loepfe yarn spectra and lab pack enable online measurement of yarn diameter and hairiness. The unit is fitted on clearer of winding unit and on rotor machine and sets aside packages, which give hairiness beyond a preset limit. Online measurement monitors the entire production and enables identification and prompt correction of defective units, which give high hairiness.

Weighing technique

Difference in the mass of yarn before and after singeing(17) is used as a measure of hairiness. Flaw in this method is that a large amount of yarn has to be singed to get an accurate estimate. Moreover, singeing does not fully remove fu lly projecting hairs particularly of shorter length.

Factors inf1uencing hairiness
Raw material

Fibre length, short fibre content, fineness and rigidity are the most important properties of fibre that influence hairiness(12,18,19). A significant correlation is found between hairiness and fibre length and uniformity ratid59). Number of fibre ends per unit length increases as fibre length reduces and a each fibre end is a potential soLirce of hairiness, yarns from shorter and variable cottons are mpre hairy. As a result any process from picking to ginning to opening of cotton that results in fibre breakages will increase hairiness in yarns.

This is supported by the study of Mclister and Rogers(20) who found yarns spun from spindle harvested cotton had less hairiness than that from stripper harvested cotton. Spindle harvesting, being gentler than stripper harvesting, results in fewer fibre breakages thereby leading to less hairy yarn. Ginning conditions that result in fibre breakages and increase short fibre content increase hairiness(21).

Moist seed cotton and dry seed cotton ginned at zero heat (ambient temp, 25° C) had a low short fibre content and low hairiness when spun on air vortex machine. Seed cotton stored under ambient conditions ginned under standard heat (55° C) had a high short fibre content and resulted in yarns with high hairiness. Hairiness increases with coarseness of fibre, because of higher resistance to twisting. For the same reason yarns from fibres with higher flexural and torsional rigidity have higher hairiness. Ahmad et al(21) found that hairiness is higher with very low and very high micronaire cottons.

Hairiness is lowest with cottons of 4.2 - 4.4 micronaire. With low micronaire cottons, fibre breakages will be higher and sticking tendency will also be more. As a result, hairiness will be higher. With high micronaire cottons, fibre rigidity will be more leading to higher hairiness. Fibre length and short fibre content have maximum influence on hairiness followed by fibre finenessI18,19). Zhu and Ethridge(23) developed a theoretical model to predict hairiness from fibre properties employing a back propagation neural network algorithm.

Prediction from fibre properties by HVI is found superior to prediction from AFIS and FMT. Fibre length has the maximum influence on hairiness. Wang et al(24) found that wool fibres with higher crimp and curvature result in less hairiness. Further, hairiness increases with increase in cashmere in wool/cashmere blends. As cashmere had lower fibre length, proportion of cashmere is more on the surface, thereby increasing hairiness. Surface fibres in the yarn mostly contribute to hairiness. In blends made on ring spinning, shorter and coarser fibre constituent occupies preferentially the surface and so will contribute more to hairiness.

Jackowskil25) found blended yarns have higher hairiness than yarns made from component fibres. On the contrary, Barella and Vigd26) found that hairiness was more in polyester than cotton yarn and 50/50 blend of these fibres has an intermediate value. The discrepancy between these findings may be because of difference in fibre fineness and length of the blended fibres. Fibres prone to static generation
generally result in more hairy yarns because of repulsion of fibres. This is the reason why
yarns from polyester and other synthetic fibres have higher hairiness than those from natural fibres. Higher hairiness is found in polyester yarns than cotton yarns in quickspin rotor spinning by Das et al(271.

Mode of formation

Hairiness is produced at two zones in ring spinning.

1. At the delivery point of front roller.

2. In the ring/traveller junction. A small amount of hairiness is also made at lappet and separator.

Selvedge fibres in the strand do not get fully integrated into yarn, as twist does not flow right up to the nip because of spinning triangle. The effect is more for the trailing portion of fibre, as the tension in the fibre drops to zero, the moment trailing end leaves front roller nip. Trailing portion of majority of selvedge fibres therefore show up as hairs. The leading portion of fibres at the extreme end of selvedge may also project as hair, because of their nonintegration into strand.

Some of the loosely bound leading as well as trailing portion of fibres will develop into hairs because of abrasion at traveller/ring junction. BarellaI8,28) found that trailing hairs were about 56-64% and leading hairs about 30-40% in a yarn. By dividing the yarn cross-section into 5 concentric zones of equal radial spacing, Wang et al(241 found that the outer most zone formed 36% and outer two zones 64% of the total yarn cross-section. They therefore concluded that trailing hairs come from fibres in the outer two zones and leading hairs come from fibres in outer most zone of yarn.

Spinning triangle at front roller nip is however not symmetric because the twist flow is more to the right side than to left side of the strand (in Z twisted yarns). This is because, as shown by Mortonl291, front bottom roller does not permit folding under of left side of fringe. Fibres in left selvedge of strand therefore contribute more towards protruding hairs and wild fibres. This is confirmed by the studies of Wang et al(3O). If the distance travelled by a fibre in the left side of spinning triangle could be reduced by some means, hairiness can be reduced. Towards this end, Wang and Cheng(31) spun yarn on the spindle to the left of drafting roller on a woollen ring frame as this should reduce the height of spinning triangle at the left. Contrary to expectations, this resulted in more hairiness than conventional spinning. On the other hand, spinning yarn on a spindle to the right of drafting roller gave less hairiness than conventional and spinning on left side spindle.

Yarn parameters

Count and twist have considerable influence on hairiness. Coarser yarns have more hairiness than finer yarns because of higher number of fibres in crosssection in the former. Atlas and Kadoglul181 found that yarn count has the maximum influence on hairiness Yarn hairiness chart therefore bears a close correspondence with irregularity chart, with coarser regions having more hairiness than finer portions. Hairiness reduces with increase in twistl281 because of shorter spinning triangle and more effective twisting in of surface fibres into yarn. With firmly bound fibres chances of release due to abrasion at traveler/ring junction is minimised. Hairiness is therefore more in hosiery yarns, which have low twist.

Process Parameters

Preparatory

Pillayl321 found fibre parallelisation reduces on hairiness. Hairiness therefore comes down with increase in number of draw frame passages. With more draw frame passages, fibre orientation is increased and fibre hooks are reduced. As a result fibre extent along the length of strand is increased which is the reason for reduction in hairiness. For the same reason combed yarns have less hairiness than carded yarns.

Further with combing, short fibre content is reduced which is another reason why hairiness is reduced. A compact roving by use of front zone floating condenser at speed frame will bring down hairiness, as this will reduce strand width at ring frame. Floating condenser can be used behind front roller at speed frame without any working problems in hanks 1.4Ne and finer but with coarser hanks from short staple cottons. choke up of condenser is encountered.

Ring Frame

Strand Width

Strand width at the front roller nip has the maximum influence on hairiness. Strand width is much wider than final yarn diameter and as a result twist does not flow right up to nip of front roller as shown in Figure 5. Selvedge fibres do not get fully twisted into yarn. If the strand width is reduced, twist will flow closer to front roller nip and spinning triangle will be smaller and fibres in selvedge will be integrated better into yarn.

As will be discussed later, compact spinning was devel oped based on recognition *of* this fact. A coarser roving hank and higher ring frame draft will therefore increase hairiness. This is confirmed by studies by Pillay(32). Floating condenser behind front roller has been tried to reduce strand width but did not meet with success because *of* choke up fibres in the condenser. Further, front zone setting has to be increased to accommodate floating condenser and this will increase irregularity.

Spindle speed

Higher spindle speed is generally found to increase hairiness(33,34). This is because *of* the larger balloon at higher speed. With a larger balloon, traveller ti It wi II be more and this will reduce the space available for yarn passage and

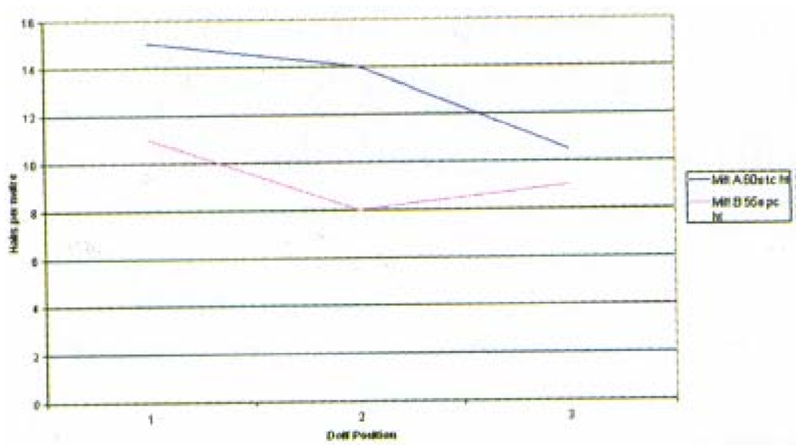

Figure 1: Effect *of* doff position on hairiness

there will be chafing and abrasion *of* yarn. Twist flow at lappet will also be reduced. Moreover, yarn will dash against separator with bigger balloon thereby generating hairiness. Chaudhuri135) however found that hairiness is not affected by spindle speed in acrylic yarns.

Doff position

Doff position and chase positions have a significant influence on hairiness.

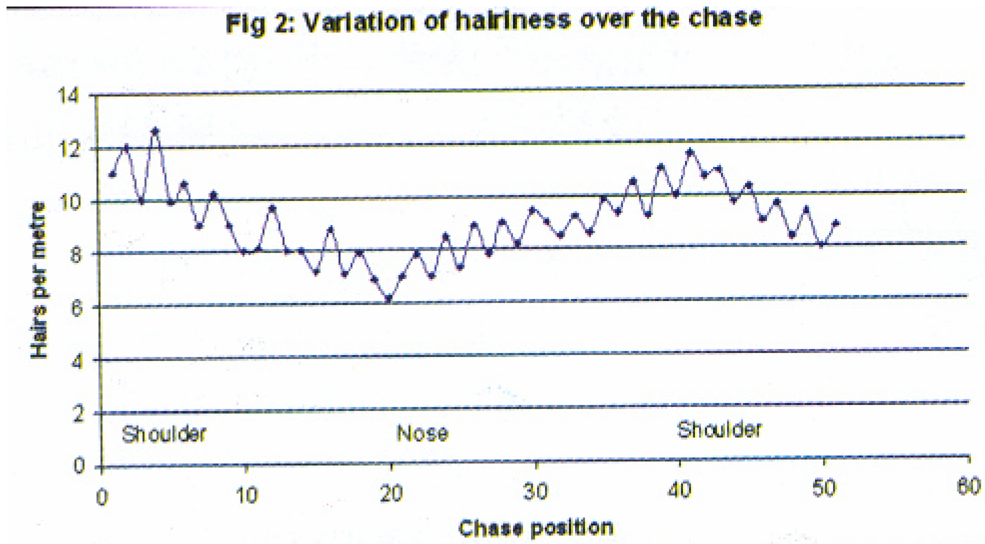

Figure2: Effect of chase position on hairiness

Table 1: Hairiness in thick and thin bands			
		Thick band	**Thin band**
Number of fibres protruding beyond	4d	6.9	26.8
d- diameter of yarn	8d	13.2	8.5

Krishnaswamy, Paradkar and Balasubramanian(36,37} compared the hairiness *of* yarns at different doff positions in mills and found hairiness to be higher at cop bottom position as shown in Figure 1. This is because *of* larger balloon found at cop bottom, which increases traveller tilt and causes dashing *of* yarn against separator. In some cases, an increase in hairiness is found towards the end *of* doff.

Chase position

Hairiness is more at the shoulder and reduces progressively towards the nose *of* the chase as shown in Figure 2. The balloon is bigger at shoulder and traveller tilt is more. Yarn also dashes against separator. Both these factors increase hairiness. The periodic variation in hairiness in the chase, thus caused, is sometimes a source *of* hairiness138,39).

A mill was experiencing high fabric rejections due to weft bar. The weft bar consisted *of* alternate thick and thin bands with varying amplitude and periodicity. Thick and thin band portions did not show any difference in pick spacing, count, twist or diameter *of* yarn. But the hairiness *of* yarn was found to be markedly higher in thick band portion compared to thin band portion as shown in Table I.

The yarn from thick band is found to be more hairy. As a result, hairs in this portion cover interspaces between yarns and more light gets reflected leading to a denser appearance. Length *of* yarn in one period *of* thick and thin band was found to be , close the length *of* yarn in one chase *of* ring bobbin. The cloth was woven on Sulzer loom where 2 splits were made side by side. Cloth width in each split was close to one half *of* tJle length *of* yarn wound during chase movement *of* ring rail.

As a result, yarn from shoulder regions goes to one split and that from nose goes to the next split. But as the yarn made during one half *of* chase movement is slightly longer than cloth width in one split, a gradual shift in poisoning *of* yarns from shoulder to the nose region takes place. Yarns from shoulder and nose regions group together alternately in the fabric leading to formation *of* thick and thin bands.

Traveller

Weight, profile and type *of* cross-section *of* traveller have critical influence on hairiness.

Weight

Heavier traveller up to a limit reduces hairiness(40} because *of* improved flow *of* twist to front roller nip. As a result pilling *of* knitted material reduces. Higher tension associated with heavier traveller will also help to firmly twist the surface fibres into yarn.

Profile

Elliptical traveller has a low bow size and as a result limited space is available for passage *of* yarn. Chafing *of* yarn will therefore be more resulting in increased hairiness. 'C' shape traveller has a high bow size, which provides ample space for passage *of* yarn. Hairiness will be least with this traveller. But as centre *of* gravity is higher with 'C', it results in unstable flight and traveller fly especially at high speeds.

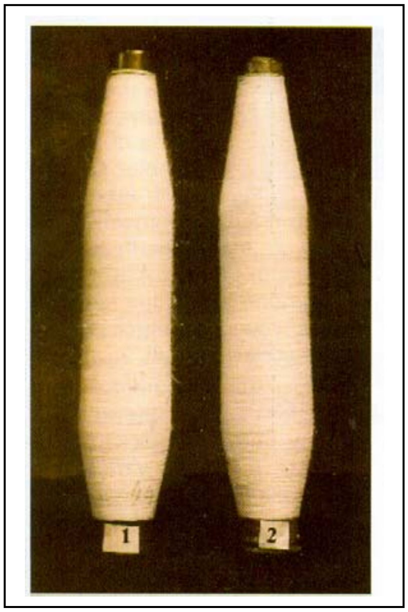

Figure 3: Comparison of hairiness of bobbins with clip and 'C' type travelers.

1- Hairy bobbins, 5/O HRW Clip
2- Good bobbins, 5/O 'C'

Further traveller profile does not match with profile of anti wedge rings, which leads to unsteady traveller flight and rapid wear. As a compromise, Clip and EM1 and EM2 travel¬lers »,ere developed. While having an elliptical profile these travellers have a higher bow size than elliptical. Hairiness will therefore be lower with these travellers compared to elliptical without compromising on speed. Bow size becomes more critical when rings are worn out.

In one mill hairiness was high on 44s warp yarn, due to worn out condition of rings. The rings were No:1 flange antiwedge and traveller used was HRW clip. As change of ring will take time, and -since spindle speeds were not high, 'C' type traveler was used in place of clip. A marked reduction of hairiness was found(41) with 'C' as will be seen from Figure 3. As iC' type traveller wears out fast, traveller replacement cycle has to be accelerated.

Cross-section

Round wire or half round wire cross-section will give less hairiness than flat' wire. This is because of reduced frictional resistance to yarn 'movement by the former.

Application of lubricant to traveler

Application of ,specially developed lubricant to the traveler(36.37,42) has' been found helpful in reducing hairiness by 20-30%. The reduction is more prominent immediately after application of lubricant and gradually reduces with passage of time. Application of lubricant once in 6-9 days is therefore necessary to good full benefits. It is important to ensure while choosing the lubricant that it does not stain the. yarn. BTRA has developed luricants meeting this requirement.

Coated travelers

Travellers with coatings, such as silver and ceramic coating and chromium plating, are available for reducing traveler wear and for extending traveler changing frequeny. Because of their smooth finish, friction between yarn and traveller is reduced, which brings down hairiness. Usta and Canoglu(4O) found that with heavier travellers, silver coating brings down hairiness.

Traveller Changing Frequency

Hairiness is found to increase over the traveller replacement cycle because of traveller wear. With traveller wear, traveller. Flutter occurs during flight, which leads to increased abrasion. Rate of increase in hairiness is initially slow but after a poi nt of time becomes rapid as shown in Figure 4. For hosiery, sewing threads and pic blends, where low hairiness is desired, traveller replacement frequency has to be kept low.

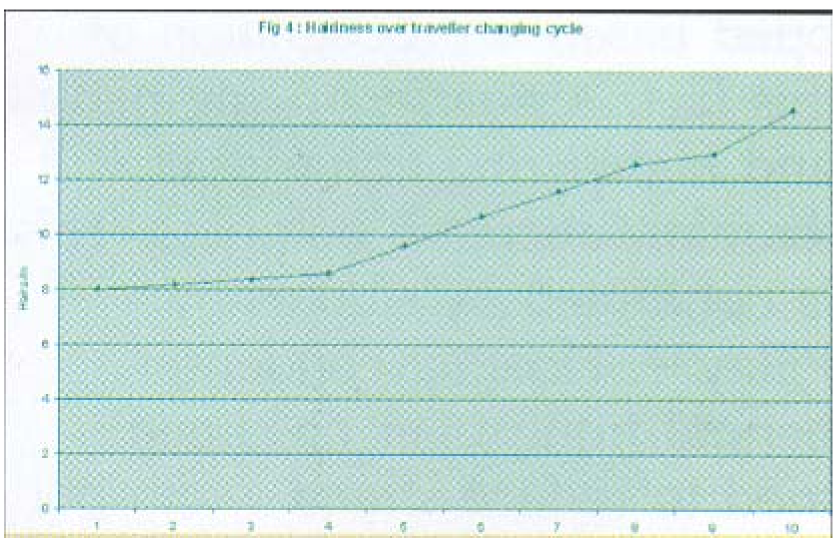

Figure 4:Variation of hairiness over traveler changing cycle

New Traveller Design

Newer Ring and traveller designs like Spicon of BRT and Orbit by Rieter have been developed to reduce traveller wear. With such designs the traveller in its running position lies in a plane close to resultant of all forces acting on it and as a result traveller tilt is minimum. As a result, hairiness is lower with such ring/traveller combinations. Moreover round wire cross-section could be used without compromise on speeds.

Ring

Flange Number, and wear and tear influence hairiness considerably.

Flange Number

Higher flange number gives more space for passage of yarn and will reduce hairiness. But traveller wear will be more and higher speeds cannot be achieved in finer counts. Normally No: 2 flange should be used up to 20s count and No: 1 flange should be used for counts 30s and above. For bringing down hairiness, No: 2 flange may be used in counts of border range.

Table 2: Effect of ring life on hairiness			
Mill	Count	Age of ring years	Hairiness Hairs/m
A	31^{s} P/C	4	26.4
		New	21.7
	40^{s} P/V	4	7.7
		New	4.6
B	60^{s} HT T/C5	5	11.0
		1	2.9

Wear and tear

Worn-out ring is a major cause of hairiness and variation in hairiness in a mill(43). As wear was pronounced, the bobbins were highly hairy and exhibited whisker like defects. Rings were not changed for 9 years in the mill and were extremely worn out. Upon replacing the rings a substantial reduction of hairiness was seen(43).

When rings are more than 3 years old hairiness starts increasing. Replacement of rings will bring significant reduction in hairiness. Some typical results are given in Table 2, to show the effect of ring life on hairiness.

Yarns spun on pilot plant ring frame give lower hairiness(36) and higher strength(44) than those on mill's ring frame though same roving bobbins were used as feed material. This is because rings in pilot plant ring frame are worn out to a lesser, extent than mills ring frame because of less running.

Lappet

Abrasion against lappet is a source of hairiness. This gets aggravated when lappet is grooved or is worn out. Some manufacturers have come out with glass finish lappet, which minimises friction and thereby reduces hairiness. Height of lappet above the ring bobbin has to be optimised to reduce not only end breaks but also hairiness. If lappet to bobbin tip distance is high, balloon will be longer. This will reduce twist flow and also increase area of contact between yarn and lappet. As , have shown a lower hairiness with reduction in lappet height. Care should however be taken to ensure that yarn 'does not touch bobbin tip while lowering lappet height.

Disturbed spindle ,centring

Disturbed spindle centring is one of the major causes for the spindle-to-spindle variation in hairiness. On spindles where centring is disturbed, hairiness is found to be higher and upon accurate centring hairiness comes down significantly(37). When spindle is not centred traveller movement is not smooth because of peak tensions in yarn. Traveller tilts and flutter also increases leading to higher hairiness.

Separator

Plastic separator will increase hairiness because of static generation. Disturbed, slanting and bent separators generate hairiness because of excessive dashing of balloon on separator.

Spindle and bobbin vibrations

Vibration of spindle arises because of worn out spindle tip and bearing. Bobbin vibrations arise not only from spindle vibration but also from eccentricity in bobbin and improper fit. When bobbin vibrates hairiness increases because of uneven traveller flight.

Plastic bobbin

Plastic bobbins generally give more hairiness than wooden bobbins especially with polyester blend yarns. This is because of static generation.

Relative humidity

Recommended humidity in ring frame department is 55- 60%. At higher humidity levels, fibres tend to stick to drafting rollers resulting in protruding hairs and loops. At low humidity levels static generation causes repulsion of fibres, particularly with p/v and p/c blends, leading to more hairiness.

Table 3: Increase in hairiness upon winding with yarns of different levels of hairiness, hairs/m

Typeof yarn	Less Hairy Yarn				More Hairy Yarn			
	3mm	5mm	6mm	7mm	3mm	5mm	6mm	7mm
Ring Yarn	3.0	0.18	0.06	0.04	20	1.7	0.33	0.10
Wound Yarn	13.6	0.9	0.22	0.12	18.9	1.71	0.48	0.19

Winding

Hairiness increases in winding(4S,46,47,48,49). This is because of abrasion of yarn against tension disc, guide eyes, balloon breakers and winding drum. Extent of increase varies from 50 to 150%. Extent of increase in hairiness increases with winding speed(46). Lang et a 1(48,49) showed, through a theoretical analysis, that hairiness increase takes place mainly at tension discs because of frictional resistance offered by disc surface to projecting hairs.

As the yarn moves forward, these fibres get pulled out of yarn. Loosely bound surface fibres may also become projecting hairs because of rubbing action. The authors used a parameter K and a critical length to estimate the effect of winding on hairiness increase. Friction coefficient between yarn and friction disc has the maximum influence on K. Increase in initial tension of yarn will reduce generation of hairiness.

A very interesting finding of practical significance is that initial level of hairiness in ring yarn has considerable influence on the extent of increase in hairiness in winding(sO). Ring bobbins judged to be more hairy and less hairy were selected from a ring frame in a mill spinning 60s. The yarns were separately wound on Autoconer. Hairiness of ring yarns and wound yarns are given in Table 3.

Short length hairs increase by 4-4.5 times with winding with 'less hairy' yarns. But with 'more hairy' yarns, short length hairs do not increase with winding. Long length hairs however show an increase with winding with both 'less hairy' and 'more hairy' bobbins.

Longer hairs being on the surface of yarn are more likely to come in contact with tension disc and so get pulled out because of frictional resistance. This is the reason why they increase with both type of yarns.

With 'more hairy yarns' the surface of yarn body and short length hairs are well buried under long length hairs and therefore do not come into contact with the tension disc. There is therefore no generation of short length hairs at tension disc and short length hairs therefore do not show an increase with winding with such yarns. Moreover, with 'hairy' yarns, most of the fibres whose ends are loosely anchored on the surface have already developed into hairs in ring frame itself because of abrasion at traveller/ring junction. Therefore there are fewer such fibres that can develop into in to hairs during winding. This is not the case with 'less hairy' yarns as there are many loosely anchored fibres in the yarns. The work of Dash et al(51) supports this winding. The authors found that hairiness increase in winding is more in compact yarns (which have low hairiness) than normal yarns.

Modifications to reduce hairiness

Compact spinning

As pointed out earlier, major cause for hairiness is the spinning triangle at front roller delivery point, which restricts flow of twist up to nip. In compact spinning, a condensing zone is introduced after normal drafting zone, as shown in Figure 5. As a result, the strand width becomes closer to yarn diameter and the size of spinning triangle is considerably reduced. Selvedge fibres get fully integrated into yarn and projecting fibres are markedly reduced.

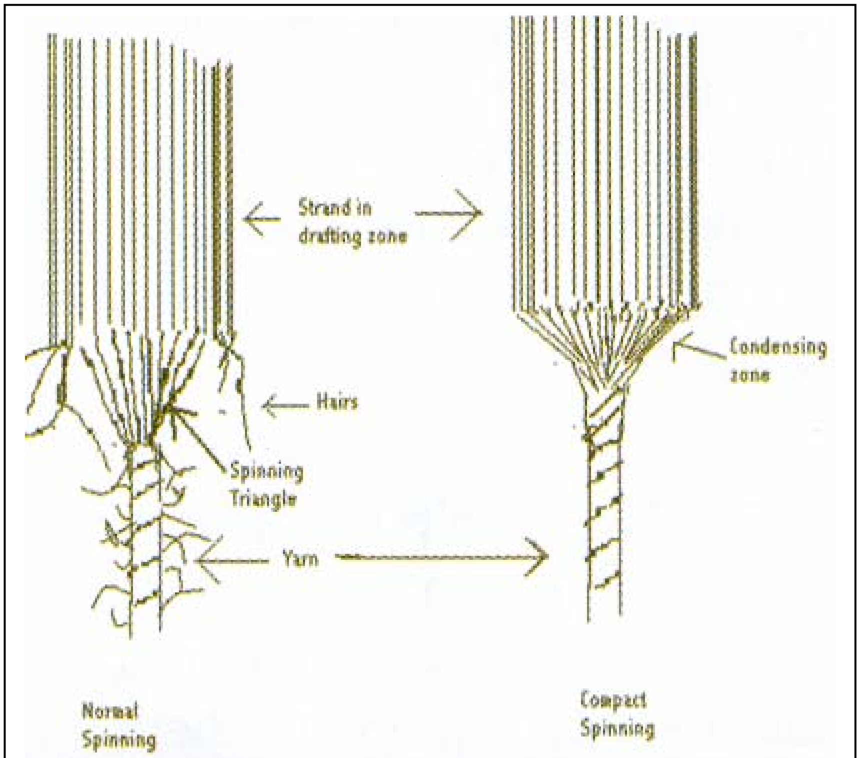

Figure 5: Comparsion of compact and normal spinning.

Several manufacturers have developed compact spinning based on different versions of condensing system.

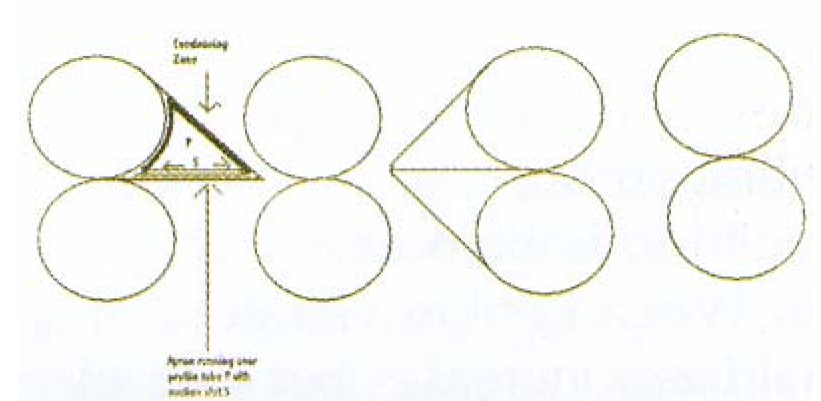

Figure 6: Zinser Aircom Tex compact spinning.

Zinser Aircom Tex

Condensing zone has a pair of rollers in front of regular drafting. The top roller drives an apron, which has a set of perforations in the middle. The drafted strand is guided underneath the apron. The perforations consist of elliptical and circular pores. The apron runs over a profile tube, which has a slot in the region S (Figure 6) through which suction is applied. The strand follows the perforation track of the apron thereby getting condensed.

Suessen EliTe

The condensing zone consists of a lattice apron, located at the bottom and driven by the delivery top roller as shown in Figure 7. The apron runs over a profile tube, which has a slot S, at the middle. Suction is applied through the slot. Front top roller of drafting system drives the delivery top roller through a gear. The diameter of delivery roller is slightly higher than front roller of drafting system, due to which the fibres in the strand are delivered in a straightened condition. Air drawn through inclined slot causes rotation of fibres around their axis, which contributes to better integration of short fibres into strand.

Rieter comforspin system.

A perforated drum replaces the front bottom roller of drafting (Figure 8). A stationery insert, I, with a specially designed suction slot, in the middle over a length S, is located inside the drum. Apart from the normal top roller a second nip roller, with weighting, is also placed on the drum. Condensation of strand takes place in the zone between the top roller and nip roller As a result of suction inside the drum, the fibres follow the suction slot and get condensed. An air guide element ensures that suction operates in the slot area. The system is suitable only cottons beyond 1.07-inch length and is therefore applicable for finer counts.

Toyota RX240NewEST

Condensing unit is similar to Suessen and consists of a pair of delivery rollers and a perforated apron running over a suction tube with a suction slot. Condensing takes place as the perforations span a narrow width.

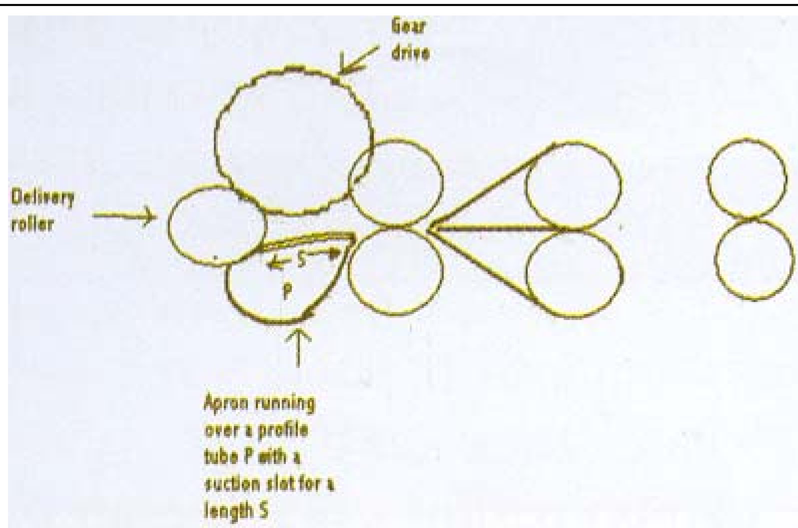

Figure 7: Suessen EliTe compact system.

Delivery rollers, driven by gear, drive the apron. Each condensing unit covers 4 spindles and can be conve¬niently dismantled. Retrofitting to Toyota normal ring frame RX240New is possible.

Rotorcraft

Instead of suction, Rotorcraft and lakshmi machine works make use of a magnetic compacting system to condense the strand. Front bottom roller supports two top rollers in between which a magnetic compactor is placed. The compactor is pressed against the bottom roller by permanent magnets. The shape of the compactor enables condensation of strand. The main merit of this system is that it can be retrofitted into an existing ring frame, which should bring down the cost. Further power required to produce air suction and costs associated with it are reduced.

Cognotex

Compact spinning machine is similar to Rieter Comforspin and is designed for long staple fibres like wool. Angled balloon rollers are used as front rollers in the compacting zone to accommodate longer fibres.

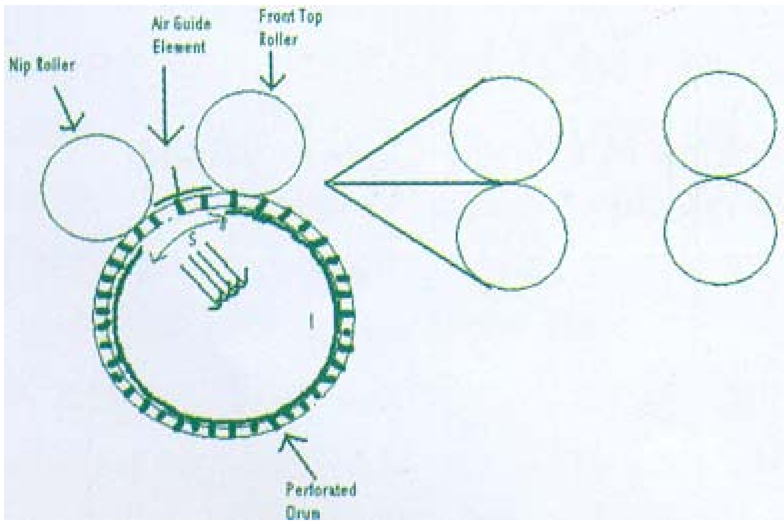

Figure 8: Rieter Comforspin compact spinning system

Officine Gaudino

This is also for long fibres. Instead of suction, mechanical compacting is done. A smooth bottom front roller and angled top roller are located in front of drafting zone. The axle of top roller is in a slanting position in relation to axle of bottom roller. These rollers run at a slightly slower speed than the front roller of drafting. The negative draft, thus created, together with offset top roller create a false twisting action, which condenses the strand. The system can be retrofitted to an existing ring frame. A noticeable feature of the system is the much lower cost (only 20% higher than normal ring frame) compared to other compacting systems (where costs are 200-250% higher than normal).

Considerable reduction in hairiness by compact spinning has been reported by many authors(52,53,54,55,56,57,58). The extent of reduction varies with the type of raw material, current levels of hairiness, type of compact spinning, count and twist factor. On an average reduction in hairiness is about 10 - 30 % in Uster Hairiness index and about 50 - 80 % in S3 values. Reduction in hairiness is more with short staple cottons and those with high short fibre content than with long staple cottons and those with low short fibre content(59,60) .

As mentioned earlier there is a significant negative correlation between hairiness and fibre length and fibre length uniformity in normal yarns. But the correlation reduces with compact spinning because of higher order of reduction in hairiness with short staple and non uniform cottons<60). With long staple cottons with high uniformity ratio, there is not much reduction in hairiness with compact spinning.

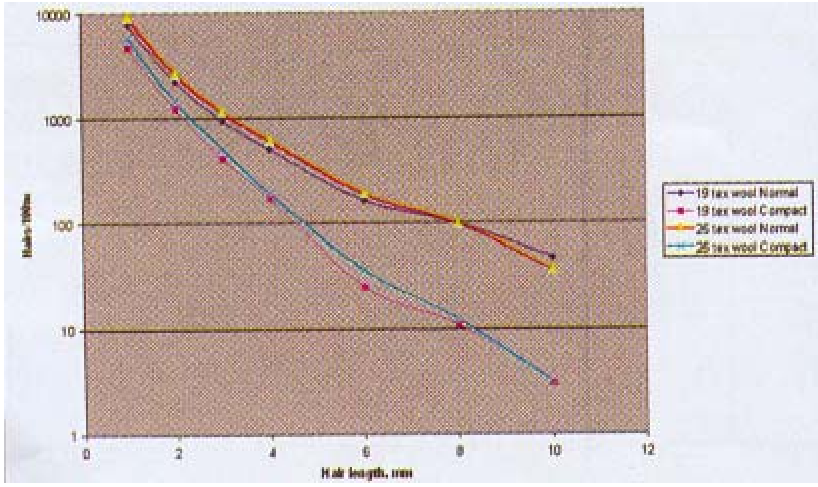

Figure 9: Variation of hairiness with hair length on woollen yarn.

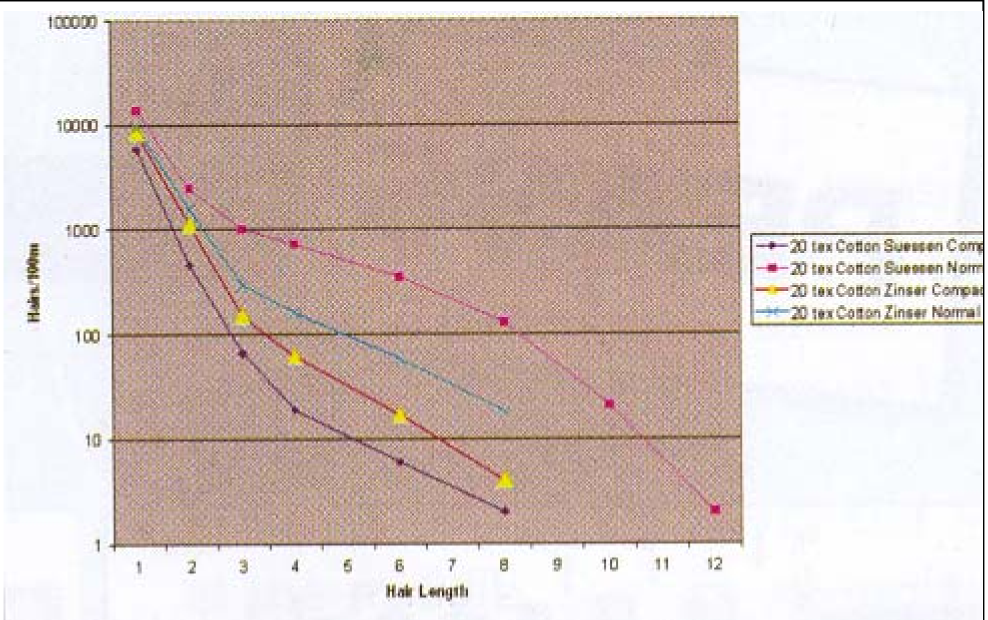

Figure 10: Variation of hairiness with hair length in cotton yarn

Fibre length distribution of projecting hairs follows an exponential distribution(61,62,24). While Barella(61,62) found that data falls in 2 or 3 different segments, Wang et al(24) found that in the case of worsted yarns, the data fits in one single curve. Hairiness is plotted against hair length based on the data of Celik et al(561 and Nikolic et al(54) in Figures 9 and 10.

Hairiness reduction with compact spinning becomes more marked above 2 mm length. Slope of hairiness versus hair length on semi logarithmic scale is not linear but appears to be curvilinear especially in the case of cotton yarns. It could be considered as made up of several linear segments with varying slopes as proposed by Barella and Manich(621. In the case of woolen yarns, the departure from linearity is only slight.

Extent of reduction in hairiness obtained with compact spinning with different hair length is given in Figure 11.

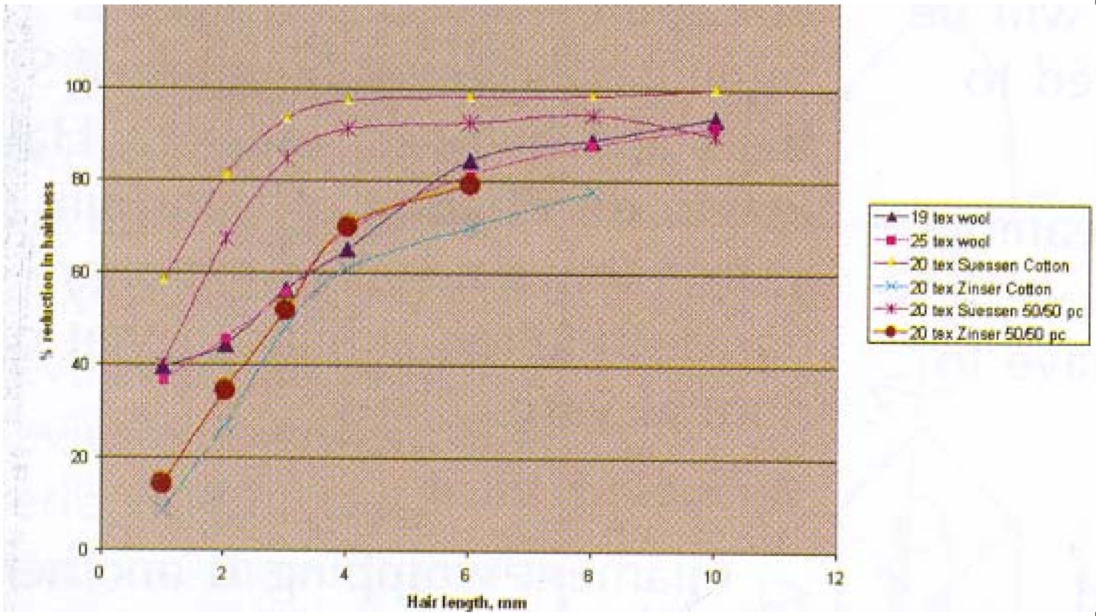

Figure 11: Reduction of hairiness with compact spinning for various hair lengths

Reduction in hairiness increases with hair length in all the cases and the increase is more prominent beyond 2 mm length. This means that long length hairs are more effectively reduced in compact spinning. Long length hairs are generally more objectionable from the point of view of appearance and breakages and performance in subsequent stages. Compact spinning is therefore preferable with high quality apparel material and modern weaving units with shuttle less looms.

Strength of yarn improves by 5-15% and elongation by 5-8% in compact spinning. Strength improvement is more prominent at low twists and in 100% cotton yarns(63,64). In normal yarns, projecting fibres do not fully contribute to yarn strength. When these fibres are fully integrated into yarn as in compact spinning their contribution to yarn strength and elongation improves. This is the reason for the increase in strength and elongation of yarn in compact spinning.

Strength improvement is also more with short staple cottons and those with high short fibre content because of higher order of reduction in hairiness. Basal and Oxenham(63) examined the structure of compact and normal yarn using a tracer fibre technique and image analysis application version 3.0. Compact yarns have a high rate and amplitude of migration, which is likely to improve inter fibre friction. This may be another reason for the higher strength of these yarns.

Yarns from compact spinning, with a lower twist factor, have a lower hairiness and comparable strength with normal yarn with normal twist factor(S6,64). This means that higher productivity can be achieved in compact spinning which should enable rapid payback of investment. Carded compact yarns have a lower hairiness and broadly comparable strength with combed normal yarn(64). An interesting feature is that carded compact yarns have a higher strength than combed normal yarns with cottons having low short fibre content. But with cottons having high short fibre content, combed normal yarn has higher strength than carded compact yarns.

Overall, there appears to be scope for reducing comber noil with compact spinning. This provides another avenue for getting rapid return on investment. However, it must be noted that normal combed yarns have a lower Uster U%, imperfections and better appearance than carded compact yarns This is because improvements from combing arise not only from removal of short fibres but also from removal of neps and parellelisation. Except in some isolated cases, there is no reduction in Uster evenness and imperfections in compact spinning. This is because drafting conditions determine irregularity and condensing the strand has little effect on it.

Comparison of compact spinning systems

Of the three systems, condensing zone is used after normal drafting zone in Zinser and Suessen. In Rieter, condensing is done on the front bottom roller of drafting system itself. A bigger diameter front bottom roller (drum) is used for this purpose and this increases the setting length in front zone. This restricts the use of this system for long staple cottons.

Between Zinser and Suessen, condensation of strand takes place right up to delivery point in the Suessen system. In Zinser, strand traverses a small distance after release from condensing zone before it reaches delivery nip. This can result in partial loss of condensation. But the suction slot is much wider and bigger in Zinser than in Suessen and Rieter systems. This improves the condensation and minimises choke up of perforations. Further, suction level is also more in Zinser. Hairiness reduction is found to be better with Suessen system compared to Zinser in the work of Nikolic et al(S4) (shown in Figure 12). This could be because condensation takes place right up to delivery nip in the Suessen system.

However, contrary results were found by Goktepe et al(6S) who have compared the three compacting systems*. They found the system with apron at the top (Zinser), had the lowest hairiness value. Compact spinning system with apron at the bottom (Suessen) has the highest hairiness value and the system where front bottom roller is replaced by drum (Rieter) has an intermediate hairiness value in coarse to medium counts (21' and 315). This may be because of bigger suction area and suction pressure in Zinser system. High variations in hairiness and higher irregularity were also observed in the system with apron at the bottom due to choke up of fibre and dust under perforations. Rieter system however gives the lowest hairiness value in medium to fine yarn (415).

Apart from hairiness reduction and strength improvement, compact spinning offers some other benefits which may help to pay back the higher cost of investment.

- Twist factor can be reduced by 5-10%, without affecting the strength, which would increase ring frame productivity by a corresponding amount.

- Since majority of end breaks occur near the spinning triangle, end breakages will be lower because of smaller spinning triangle This offers scope for increasing spindle speed and for getting a higher productivity.

- Though cost reduction can be achieved by use of a lower grade mixing and by reduction of comber noil, these are not recommended, as they will increase yarn irregularity and imperfections and downgrade appearance.

- Size pick up can be reduced in sizing, as hairiness is low.

- As yarn has a higher strength and elongation and lower hairiness, warp breaks will be lower in weaving. The resultant improvement in weaving efficiency will depend upon several factors like type of loom, loom speed, cloth construction etc; but on an average about 2 -5 % improvement can be obtained.
- Compact spinning has however the following limitations:

- The improvements in hairiness and strength are marginal with long staple cottons with higher uniformity in fibre length. The system will have limited advantageous in combed counts, as short fibre content wi II be low.

- Hairiness of yarn will increase in winding and the extent of increase is also higher than that in normal yarns.

- Power consumption will be higher as power is required to run suction motor.

- Maintenance and cleaning cost will be higher as the perforated aprons, slots have to be cleaned regularly.

Solo spinning

Wool mark, CSIRO and WRONZ have developed Solospun system for reducing hairiness in wool and wool blend yarns. This is a clip on attachment to front top roller of drafting, which holds solospun rollers, shown in Figure 12. Solospun roller is placed just below the front top roller and rests on bottom roller and loaded by means of a spring. The surface of solospun roller is made up of 4 segments separated by land, which is flush with the roller surface.

There are a series of slots that are offset in each segment. Twist flow to front roller is intermittently blocked by this arrangement and as a result drafted strand is split in to a number of sub strands. Twist passing through the solospun roller twists the sub strands. Upon emerging from solospun roller, the sub strands are twisted into yarn by final twist. As a result the protruding fibres are entrapped into the yarn and final yarn has fewer protruding fibres. Twisting principle of solospun yarn has been studied by Cheng et al(66).

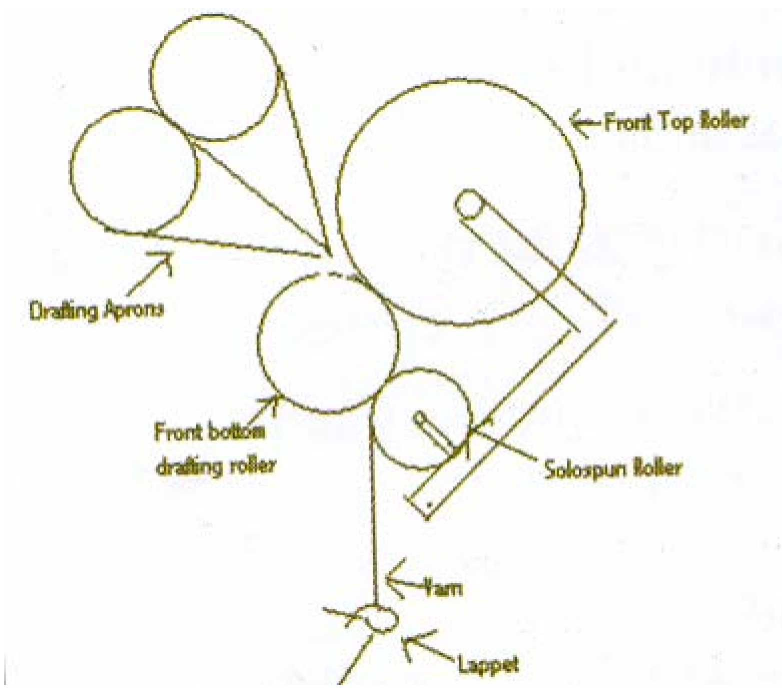

Figure 12: Solospun spinning system.

Solospun worsted yarns have significantly lower number of S3 hairs and hairiness index(67). Hair length distribution of solospun yarn follows negative exponential distribution similar to that of normal yarns.

Wrapped yarn

Filament wrapping is another means to reduce hairiness by binding the protruding fibres on the yarn body. The filament is fed, through a guide fitted above front top roller, to the strand emerging from front roller. Twist introduced during spinning will wrap the filament round the yarn body. Stop motion has to be fitted to each spindle to stop the production in the event of filament/roving break or exhaust.

False twisting in winding

Though compact spinning reduces hairiness, the benefits obtained are partially lost in winding as hairiness increases in winding as shown in Figure 13. The extent of increase is also more with compact yarns.

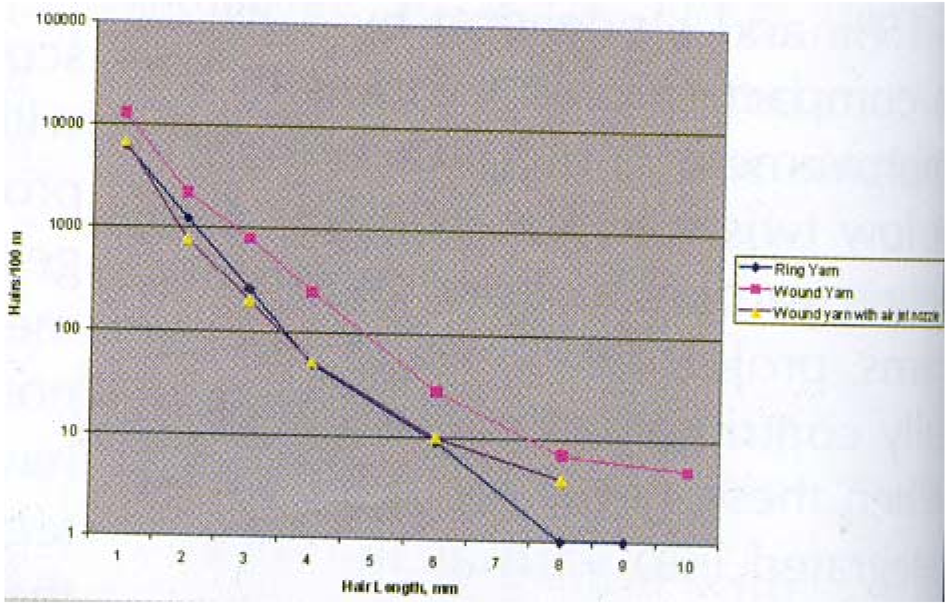

Figure 13: Increase in hairiness with winding.

By passing the yarn through an air-jet nozzle unit or any other false twisting arrangement prior to winding, hairiness can be reduced and several manufacturers have come out with such systems. Figure 14 shows an outline of an air-jet nozzle unit in winding.

The swirling air in the air-jet unit wraps the protruding fibres around the yarn body. The merits of such attachments compared to compact spinning are:

1. Low investment
2. Retrofitting to an existing winding machine is possible.

Muratec has developed an air-jet device known as Perla A, which is fitted on their Process caner 21 C. Savio has developed a 'hairless device' consisting of air-jet nozzle. The geometry and shape of the air-jet has to be designed carefully to achieve entangling and wrapping effect Muratec has also developed another unit Perla D where instead of air nozzle, a disc driven by servomotor, is used to give false twist to yarn.

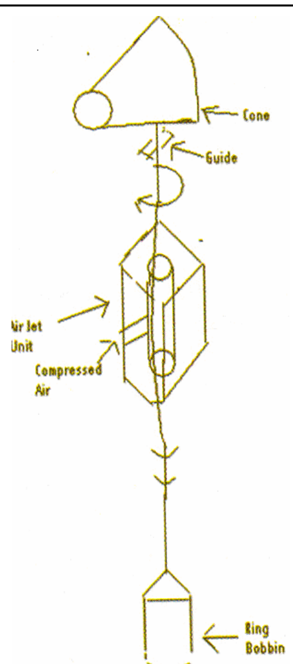

Figure14: Air-jet nozzle in winding

Winding speed up to 1800 and 1200 m/m can be achieved with Perla A and Perla D respectively. The benefits obtained in compact spinning can be maintained by using such a false twisting unit in winding, as shown in Figure 13. Hairiness increases in normal winding but with an air-jet suction unit hairiness in wound yarn is maintained close to that in ring bobbin. Several authors have reported significant reduction in hairiness by air-jet nozzle in winding(68,69,7).

Air pressure and type and size of air nozzle have influence over the extent of reduction in hairiness. Higher air pressure and lower orifice angle give greater reduction in hairiness(69,70,7l). Strength is unaffected and a marginal deterioration in evenness of yarn is found with air-jet unit. Computer fluidic dynamics was used to simulated airflow pattern inside the jets(72). Air velocity in the core of the jet leads to wrapping of protruding fibres over the body of yarn.

Two-phase model used to simulate wrapping of protruding hairs on yarn was attempted by Zeng et aWl).

This showed that yarn hairiness reduction occurs because of wrapping of hairs on yarn. Optimum nozzle pressure of 1.5 - 2.5 bar and a jet orifice angle of 40 - 500 were found by this model. Too high a nozzle pressure and very low nozzle angle increase air recirculation zone and are therefore not advisable. It is not clear if the wrapped hairs will stay wrapped or wi II get released upon abrasion at next stage.

Air-jet unit at ring frame

Studies have also been made to incorporate an air-jet unit between lappet and front roller of ring frame!73,74,75,76,77). Yarn from front roller nip passes through the nozzle and compressed air is forced through an orifice into the nozzle. The air vortex produced by the air current winds the protruding fibres on the yarn body due to false twisting. After the yarn emerges from the air-jet unit, real twist binds the wrapped fibres firmly into yarn. Starter yarn is fed to the lower end of the air-jet unit and airflow sucks the yarn through it to facilitate piecing.

Air pressure, orifice size and angle have considerable influence on hairiness reduction(7l). Higher air pressure and smaller orifice size reduce hairiness to a greater extent but such nozzles are not preferable from working point of view. Too high nozzle pressure and low orifice angle increase air recirculation zone and so affect wrapping action. An air pressure of 0.5 kgf/cm2 is adequate to reduce hairiness(76). Nozzle distance of 10 cm from front roller nip and nozzle angle of 450 gives best results in terms of yarn quality(76,77).

Nozzle which produces air current in the same direction as that of yarn twist gives greater reduction in hairiness than that where air vortex is in opposite direction to yarn twist(74). On the other hand, airflow movement against the direction of yarn movement gives more reduction in hairiness(76). Yarn evenness deteriorates significantly with the use of air-jet in ring spinning. Fabrics made from yarns with air-jet attachment as weft show a lower pilling tendency, which arises from lower hairiness. Use of air-jet in ring spinning is still at experimental stage and most of the studies reported are on laboratory model spin tester. The effect of air-jet unit on end breakage rates and piecing time, have to be still studied. No commercial versions of ring frame with air-jet unit have so far been developed.

Relative merits of compact spinning and air-jet in winding

It would useful to consider the relative merits of compact spinning and air-jet unit in winding.

- ❖ Compact spinning involves much higher investment and retrofitting is also not possible in mo t of the systems. It should therefore be considered in products where hairiness plays a critical role like hosiery, high value apparels, sewing threads.
- ❖ At the same time, compact spinning has the merit that it improves strength and elongation of yarn apart from hairiness. Twist in the yarn can be reduced enabling higher ring frame productivity. Higher spindle speed is also possible, as end breakages will be reduced.
- ❖ Power cost will be higher with compact spinning.
- ❖ The benefits from compact spinning in terms of reduced hairiness is partially lost in winding as hairiness increases in winding.
- ❖ Air-jet unit in winding involves lower cost, as retrofitting of the unit to an existing winding machine is possible.
- ❖ Strength and elongation do not improve with air-jet unit. Slight deterioration in evenness and imperfections is also seen with some yarns.
- ❖ Thus to get full benefits from compact spinning, air-jet unit should be incorporated in winding.

Hairiness in different spinning systems

Hairiness is higher in ring spinning than rotor, air-jet and air vortex spinning systems Reasons for high hairiness in ring spinning have been discussed earlier.

Rotor Spinning

Fibres are well controlled in rotor and get attached to sweeping tail of yarn. Number of protruding ends is therefore lower but protruding loops are higherl78J. Fibres are more densely packed near the centre and mean fibre position is closer to the centerl791 in rotor yarn. Wrapper fibres bind any fibre protruding outside. As a result, hairiness is lower in rotor yarn than ring yarnl19J. Rotor yarns have about 20% lower hairiness than ring yarnsl8OJ. Higher twist and higher rotor speed reduce hairinessl1SJ. Plain naval with smooth surface reduces hairiness. Spiral shaped ceramic naval reduces hairinessl81). Naval with groove which is used for introducing false twist, increases hairiness because of rough surface.

Air-jet Spinning

In Murata air vortex yarns, core fibres have no twist and are wrapped by surface fibres. More than half of yarn cross section is made of wrapper fibres. Uniformity of wrapping of wrapper fibres and higher number of wrapper fibres results in low hairiness in air vortex yarns. So etal 182J found lowest hairiness, for hair length 3 mm and above, with air vortex yarns followed by rotor yarns and ring yarns. As a result weight loss in enzymatic treatment is highest in ring spun yarns followed by open end and air-jet yarns83. Higher delivery speed in air vortex spinningl84,8S1 increases hairiness. Higher nozzle pressure reduces hairinessl84,8s1 but adversely affects evenness of yarn. Higher nozzle angle and smaller spindle diameter reduce hairiness in air vortex spinningl84J.

Air-jet spinning is the first version of jet spinning and air vortex is the second improved version by Murata. In air-jet spinning, edge fibres on the selvedge of drafted strand form wrapper fibres. In air vortex spinning, fibres in the selvedge region of emerging strand (which is about half of the total number of fibres) are thoroughly separated to form wrapper fibres. Number of wrapper fibres is therefore much higher in air vortex than air-jet spinning. Hairiness is therefore lower in air vortex spinning compared to air-jet spinningl86J. While hairiness increases with cotton content in air-jet, no such trend is found in air vortex spinning. So air vortex is more suitable for cotton rich blends.

References

1. Spinning, Textile Research J, 2006, 76, pp 559.

2. L Chang, Z X Tang, and X Wang: Effect of Yarn Hairinesson Energy Consumption in Rotating a Ring Yarn Package, Textile Research J, 2003, 73, 949.

3. S Adanur and S Bakhtiyarav: Characterisation of Air-jet yarn Interface in Air-jet Weaving, NTC Project F99AE10 (formerly Z99-A 10), Auburn University.

4. N G Celab: Analysis of Yarn Flight Characteristics in Air-jet Weaving Machine, Honors Thesis, West Virginia University, 2006.

5. N Ozdil, E Ozdogan and T Oktem: Effect of Enzymatic Treatment on Various Spun Yarn Fabrics, Fibres and Textiles in Eastern Europe, 2003,Oct/Dec, pp 43.

6. J Pere, N Puolakka, P Nousiainen and J Burchart: Action of Purified Tricho derma Reesel Cellulases on Cotton Fibres and Yarn, J Biotechnol, 2001, Aug, 89, pp 247.

7. A Kumar, C Purtell and Lapolahttp: Enzymatic Treatment of Man-made Cellulosic Fabrics, Textile Chern Color, 1994, 29, 10, pp 25.

8. A Barella: J Textile Institute, 956,47, pp 210.

9. A Barella: Yarn Hairiness, Textile Progress, 1981, 13(1).

10. A Barella, The Hairiness of Yarns, Textile Progress, 1992, 24(3).

11. W J Onions and Yates J: Textile Institute, 1954, 45, T783.

12. K P R Pillay: A Study of Yarn Hairiness in Cotton Yarns - Part I, Effect of Fibre and Yarn Factors, Textile Research j, 1964, 34, pp 663.

13. T Jedriyka, Textile Research J, 1963, 33, pp 663.

14. V K Kothari, S M Ishtiaque, and V G Ogale: Hairiness Properties of Polyester Cotton Blended Fabrics, Indian J of Fibre and Textile Research, 2004, 29, pp 30.

15. G K Tyagi, Hairiness of Viscose OE Rotor Spun Yarns in Relation to Test Speed and Process Parameters, Indian J of Fibre and Textile Research, 2004, 29, pp 35.

16. X Wang and L Chang: An Experimental Study on Effect of Test Speed on Yarn Hairiness, Textile Research j, 1999, 69, pp 25.

17. H R Boswell and P P Town end J: Textile Institute, 1957, 48, T135.

18. S Atlas and H Kadoglu: Determining Fibre Properties and Linear Density Effect on Cotton Yarn Hairiness in Ring Spinning, Fibres and Textiles in Eastern Europe, 2006, 14, July/ Sept, pp 48.

19. A Barella and A M Manich J: Textile Institute, 1988, 79, pp 189.

20. D D Mclister and C D Rogers: Effect of Harvesting Procedures on Fibre and Yarn Quality of Ultra Narrow - Raw Cotton, J of Cotton Science, 2005, 9, pp 15.

21. S Gorden: Effect of Short Fibre and Nep Level on MVS Yarn Quality, Australian Cotton Grower, 2002, 23, No 1, pp 28.

22. I Ahmad, M Nawaz and M Tayyab: Interaction Study of Staple Length and Fineness of Cotton with Ultimate Regularity sciences, 2004, 4, (1), pp 48.

23. R Y Zhu, M D Ethridge: Predicting Hairiness of Ring and Rotor Spun Yarns and Analysing Impact of Fibre
Properties, Textile Research j, 1997, 67, pp 694.

24. X Wang, L Cheng and B McGregor: The Hairiness of Worsted Wool and Cashmere Yarns and the Impact of Fibre Curvature on Hairiness, Textile Research J, 2006, 76, pp 281.

25. T Jackowski: Textol Text Industr, USSR, 1961, 5, pp 28.

26. A Barella and J P Vigo: Annal, Sci, Text, Belges, 1975,23, pp 133.

27. D Das, S M Ishtiaque, T Mac, D Viet and T Gries: A Quick Reliable and Economic Method for Evaluating the Properties of Rotor Spun Yarns, Autex Research j, 2004,4, No 3, pp 123.

28. A Barella: Influence of Twist, J Textile Institute, 1957, 48, pp 268.

29. W E Morton: The Arrangement of Fibres in Single Yarns, Textile Research j, 1956, 26, pp 325.

30. X Wang, W Huang, and X Huang: A Study on the Formation of Yarn Hairiness, J Textile Institute, 1999, 90, Part 1, No 4, pp 555.

31 . X Wang and L Chang: Reducing Yarn Hairiness with a Modified Path in Worsted Spinning, Textile Research j, 2003, 73, pp 327.

32. K P R Pillay: A Study of Yarn Hairiness in Cotton Yarns - Part II; Effect of Processing Factors,

Textile Research j, 1964, 34, pp 783.

33. M S Parthasarathy: Factors Affecting Hairiness of Terene Cotton Yarns, Proceedings of 8th Jt Tech, Conference, 1966, ATIRA, Ahmedabad, pp 28.

34. B C Goswamy: Hairiness of Yarn, An Improvement over Existing Microscopic Technique, Textile Research j, 1969, 39, pp 324.

35. A Chaudhari: Effect of Spindle Speed on Properties of Ring Spun Yarn, IE (I) Journal, 2003 Aug, 84, pp 10.

36. R Krishnaswamy, T L Paradkar and N Balasubramanian: Some Factors Affecting Hairiness of Polyester Blend Yarns, BTRA Technical Report No 04.2.8, 1989 June.

37. R Krishnaswamy, T L Paradkar and N Balasubramanian: Some Maintenance Measures to Control Hairiness of Polyester Blend Yarn, J Textile Association 1990 March, pp 297.

38. W Nutter and B White head: Ring Spinning as a Source of Weft Bars in Cloth, Textile Recorder, 1961, Oct 79,ppl02.

39. N Balasubramanian and S Sekhar: Weft Bars and Weft Way Defects, Indian Textile j, 1982, Dec pp 101.

40. F Usta and S Canoglu: Influence of Traveller Weight and Coating on Hairiness of Acrylic Yarns, Fibres & Textiles of Eastern Europe, 2002 Oct/Dec, pp 20.

41. B N Bhanot, Optimisation of Spinning Performance and Organisation for Better Yarn Quality and Spinning Performance, MText Thesis, BQmbay University, 1974.

42. G V Kumar and J Zacharia: Study on Ring Yarn Hairiness with Special Reference to the Effect of BTRA Ring Cleaner-cum-Lubricant, BTRA Scan, 1997, 28, (3), pp 6.

43. N Balasubramanian, G K Trivedi and B N Bhanot: Replace Worn-out Rings to Get Better Yarn Quality, BTRA Scan, 1975, 6, pp 6.

44. N Balasubramanian: A Critical Study of Yarn Quality and Spinning Perfor mance in the Mills, Part 1Evaluation of Mill's Processes, BTRA Research Project Report 18, 1973 Dee.

45. A Barella and j Pvigo: Effect of Repeated Winding on Hairiness of Open-end and Conventional Cotton and Viscose Rayon Yarns, j Textile Institute, 1974, 65, pp 607.

46 S Peykamian and j PRust: Yarn Hairiness and the Process of Winding, Textile Research J, 1992, 62, pp 685.

47. A Barella: The Hairiness of Yarns, Textile Research J, 1993,63, pp 431.

48. j Lang, S Zhu, and N Pan: Change of Yarn Hairiness During Winding Process Analysis of Protruding Ends, Textile Research j, 2006, 76, pp 71.

49. j Lang, S Zhu, and N Pan: Change of Yarn Hairiness During Winding Process Analysis of Trailing End, Textile Research J, 2004, 74, pp 905.

50. R Krishnawamy, T L Paradkar and N Balasubramanian: Influence of Winding on Hairiness: Some Interesting Findings, BTRA Scan 1990 june, pp 8.

51. j R Dash, S M Ishtiaque and R Alaguruswamy: Indian J, Fibre and Textile Research, 2002, 27, pp 362.

52. P Artz: ITB - Yarn and Fabric forming, 1997, No 2, pp 41.

53. K P S Chang and C Yu: A Study of Compact Yarns, Textile Research J, 2003, 73, pp 345.

54. M Nikolic, Z Stjepanavic, L Lesjak and A Skritof: Compact Spinning for Improved Quality of Ring-spun Yarns, Fibres & Textiles in Eastern Europe, 2003, 11, Oct/Dec, pp 43.
55. M M Ahmad: Compact Spinning and Advantages of EliTe Yarns, Pakistan Textile J, 2004, Feb.

56. P Celik and H Kadoglu: A Research on the Compact Spinning for Long Staple Yarns, Fibres & Textiles in Eastern Europe, 2000, 12, No4, Oct/Dec, pp 27.

57. H Stalder: Ring Spinning Advance, Meliand Textil berishte International, 2000, 6(1), pp 22.
58. M Krifa, E Hequet and D Ethridge: Compact Spinning New Potential for Short Staple Cottons" Textile Topics, 2002-2, pp 2.
59. M Krifa, E Hequet and M
D Ethridge: Food and Fibre Commission-funded Project Report, Tex Tech University, 2002, Spring.

60. M Krifa and E Hequet: Compact Spinning - Effect on Cotton Yarn Quality Interaction with Fibre Characteristics, Textile Research J, 2006, 76, pp 398.

61. A Barella and A M Manich: Yarn Hairiness Up date, Textile Progress, 26, (4).

62. A Barella and A M Manich, Hair Length Distribution of yarns Measured by Means of Zweigle Hairiness Tester, j Textile Institute, 1993, 84, (3), pp 326.

63. G Basel and W Oxenham: Comparison of Properties and structures of Compact and Conventional Spun Yarns, Textile Research j, 2006, 76, pp 567.

64. M Krifa and D Ethridge: Compact Ring Spun Yarn An Examination of Productivity Issues, Textile Topics, 2, pp 2.

65. F Goktepe, D Yilmaz and Goktepe: A Comparison of Compact Yarn Properties Produced on Different Systems, Textile Research j, 2006, 76, pp 226.

66. L Cheng and X Wang: Relationship Between Hairiness and Twisting Principles of Solospun and Ring Spun Yarns, Textile Research j, 2004, 74, Sept.

67. L Chang and X Wang: Comparing Hairiness of Solospun and Ring Spun Worsted Yarns, Textile Research J, 2003, 73, pp 640.

68. M Miao and X Wang: Reducing Yarn Hairiness with an Air-jet Arrangement in Winding, Textile Research j, 1997, 67, pp 481.

69. K P Chellamani, D Chattopadhyay and K Kumaraswamy: Yarn Quality Improvement with an Air-jet Arrangement in Cone Winding, Indian j of Fibre and Textile Research, 2000, 25, pp 289.

70. S S Salem and M Azam: Impact of Air-jet Nozzle Pressures and Winding Speed at Autoconer on Imperfections and Hairiness of 20s Cotton Yarn, Pakistan Textile J, 2004, March.

71. Y Zeng and C W Yu: Numerical and Experimental Study On Reducing Yarn Hairiness With jet Ring And jet Wind, Textile Research j, 2004, 74, March.

72. R S Rengaswamy, V R Kothari, A Patnaik, A Ghosh and H Punekar: Reducing Yarn Hairiness In Winding By Means Of jet: Optimisation Of jet Parameters, Yarn Linear Density And Winding Speed, Autex Textile j, 2005, 5, Sept, pp 128.

73. K P S Cheng and C H L Li: jet Ring Spinning and its Influence on Yarn Hairiness, Textile Research j, 2002, 72, pp 1079.

74. K Ramachandran and B S Dasaradan: Design and Fabrication Of Air-jet Nozzles For Air Vortex Ring Spinning System To Reduce Hairiness Of Yarn, IS (I) JournalTX, 2003, 84, Aug, pp 6.

75. X Wang, M Miao and Y Lhow: Studies in Jet Ring Spinning - Part I; Reducing Hairiness with Jet Ring, Textile Research J, 1997, 67, pp 253.

76. R S Rengaswamy, V K Kothari, A Patnaik, and H Punekar: Airflow Simulation in Nozzle for Hairiness Reduction in Ring Spun Yarns - Part I; Influence of Airflow Direction, Nozzle Distance and Air Pressure, J of Textile Institute, 2006, 97, Issue 1, pp 89.

77. A Patnaik, R S Rengaswamy, V K Kothari, and H Punekar: Airflow Simulation in Nozzle for Hairiness Reduction in Ring Spun Yarns - Part II, Influence of Nozzle Parameters, J, of Textile Institute, 2006,
97, Issue 1, pp 97.

78. J Lunnenschloss and E Hummel: Textil Praxis, 1968, 23, pp 591.

79. Y Huh, Y R Kim and W Oxenham: Analysing Structural and Physical Properties of Ring, Rotor and Friction Spun Yarns, Textile Research J, 2002, 72, Feb.

80. G M E Kog and T Ogulata: Textil Teknik, 1999 Sept, pp 88.

81. Anon: Fibres and Textiles in Eastern Europe, 2006, July! Sept, 14, pp 357.

82. A K Soe, M Takahose, M Nakajima and T Matsuo: Structure and Property of MVS Yarns in Comparison to Ring and Rotor Yarns, Textile Research J, 2004, 74, pp 819.

83. A Khoddomi, M Siavashi, S A H Ravandi and M Morshed: Enzymatic Hydrolysis of Cotton Fabrics with Weft Yarns Produced by Different Spinning Systems, Iranian Polymer J, 2002, 11, No 2, pp 99.

84. G Basal and W Oxenham: Effect of Some Process Parameters on the Structure and Properties of Vortex Spun Yarns, Textile Research J, 2006, 76, pp 492.

85. H G Ortlec and S Ulku: Effect of Some Variables on Properties of 100% Cotton Vortex Spun Yarns, Textile Research J, 2005, 75, pp 458.

86. G Basal and W Oxenham: Vortex Spun Yarn vs Air-jet Spun Yarns, Autex Research J, 2003, 3 No 3.

* The authors have refrained from naming the system but from diagrams, the system referred can be easily identified.

About the author:

Dr.N.Balasubramanian, who is a B.Sc.(Tech)(Madras University), M.Sc.(Bombay University, Ph.D.(Leeds University), A.T.I., F.T.I. (Textile Institute, Manchester) has been conferred Honorary Fellowship of the Textile Institute, Manchester in 2005. This award is in recognition of creativity and advancement of knowledge as a result of ingenuity and application over many years. He has over 45 Years of experience in R&D and consultancy in spinning, nonwovens, testing, quality control, training and ISO 9000. He retired as Joint Director of Bombay Textile Research Association, Mumbai, India. Has published over 120 papers in leading textile journals, including the journal of textile institute, Textile Research Journal, Indian Journal of fibre and textile research and Indian Textile journal.He has successfully guided many students to Masters and Doctorate degree of Bombay University and has presented over 100 papers in textile conferences, seminars and workshops. Presently he is a consultant to leading textile mills and nonwoven units in India. He conducts regular refresher and training courses for mill technicians and is a visiting professor at textile colleges. The author is ex-Joint Director of Bombay Textile Research Association (BTRA) & presently a Consultant, residing in Mumbai. Tel: 022-2528 0767/098697-16298.
Email**:** **balasubramanium@vsnl.com**