Impact of carding parameters and draw frame speed on fibre axial distribution in ring - spun yarn

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Fibre axial distribution of cotton ring - spun yarn using three process variables, viz. card draft, coiler diameter of card and delivery speed of draw frame, has been studied. It is observed that the percentage of trailing, leading and total hooks and their extents on ring-spun yarn decrease with the increase in draw frame delivery speed and coiler diameter at carding machine. The above parameters also decrease as the card draft increases. Since the fibre extent and spinning - in coefficient are related to the efficacy of hook removal, these parameters improve as the delivery speed and coiler diameter increase and deteriorate as the card draft increases. It is also observed that the fibre overlap index decreases as the delivery speed and coiler diameter increase; the parameters however increase with the increase in card draft. It is interesting to note that the spinning-in coefficient and fibre overlap index do not show positive relationship.

Keywords: Card draft, Coiler diameter, Delivery speed, Fibre extent, Fibre hooks, Fibre pair overlap index, Spinning-in coefficient

1 Introduction

The primary purpose of staple yarn structure is to provide the means of utilizing the fibre length. Fibres encounter different levels of deformation during various stages of spinning. Looking closely at the conventional ring - spun yarn structure, it is observed that the fibres, which form the yarn body, are parallel along the helix of twist and the total length of fibre is not fully exploited due to the formation of hooks and loops during the spinning process.

Fibre configuration in ring - spun yarn is often characterized by fibre hooks and their extent, fibre overlap index and spinning- in coefficient. The fibre orientation in sliver, roving and yarn, and its influence on yarn properties have already been discussed. The average drafting tenacity is directly related to the total number of hooks present before drafting. Improvement in yarn quality is observed with the reduction in hooks and hooks extent in the yarn. The axial fibre distribution has significant influence on yarn properties.

Considering the importance of high draw frame delivery speed and accordingly the sliver preparations to achieve the objective, it has been observed that the draw frame delivery speed and its preparatory, viz. card draft and coiler diameter, can have strong influence on the fibre orientation parameters of the sliver. The effect of the above parameters may transmit up to the yarn fibre assembly affecting its structure and properties. Considering these aspects, the present work is aimed at investigating the yarn structure in terms of fibre hook percentage, fibre hook extent, spinning - in coefficient and fibre overlap index in relation to card draft, coiler diameter of card and draw frame delivery speed.

2 Materials and Methods

2.1 Materials

Cotton fibre (J-34 and S6 in equal proportion) was used as raw material for the preparation of samples. The average length, strength, elongation and micronaire of the cotton fibre were 28 mm, 29.7 g/tex, 7.55 % and 4.2 respectively. Samples were prepared with the variation in delivery speed, coiler diameter and card draft in accordance to experimental design. Tables 1 and 2 show the level of process variables in accordance with experimental design. The samples were prepared after randomization for effective statistical analysis and the validity of the inference drawn. All the 15 samples from the finisher draw
frame were passed through speed frame LF 1400 A and ring frame LR 6 in the actual running condition of the mill. Roving hank 1.20 Ne (492.08 tex) was used to produce 40s (14.76 tex) carded hosiery yarn.

2.2 Methods

To study the fibre extent, fibre hook configuration and fibre overlap in the yarn, the classical tracer fibre technique has been used as proposed\(^\text{10}\). During laying of fibre mixing, 0.3 % green medium shade fibre taken by weight was added in the mixing for yarn preparation. The theory of spinning- in coefficient (\(K_F\)), as proposed by Kasparek\(^\text{11}\), was used to study the fibre extent in the yarn, as defined below:

\[
K_F = \frac{\sum_{i=1}^{n} L_i / n}{L} \times 100 = \frac{L_0}{L} \times 100
\]

where \(L_i\) is the individual fibre extent; \(L_0\), the arithmetic mean of the individual fibre length projection along the axis of the yarn; \(n\), the number of observations; and \(L\), the mean fibre length.

The study of fibre overlap is a new approach to observe the longitudinal behavior of fibre in the yarn\(^\text{3,8}\). The objective of measuring fibre overlap index is to get a direct interpretation of contact length between the fibres, which has earlier been interpreted from the fibre extent. Fibre overlap index is a measure of the ratio of total projected overlap length (along yarn axis) of the two simultaneously overlapping tracer fibres to the mean length of fibre. A total of 400 tracer fibres from 10 bobbins per sample was observed for the fibre extent study, whereas for fibre overlapping study, 800 fibres were considered. The types of hook (classified as leading, trailing and both side hooks in respect of direction of their delivery from the machine) and hook extent have been studied on microscope. Finally, equations relating to three process variables (delivery speed of draw frame, coiler diameter and draft of card) with hook, fibre extent and fibre overlap index were obtained through backward elimination regression method\(^\text{8}\). Table 3 shows the relationship between above-mentioned process variables with structural characteristics of yarn.

The regression equations relating to fibre orientation parameters, i.e. proportion of curved fibre ends \(M(\rho)\) and coefficient of relative fibre parallelization \(M(Krp)\) of draw frame sliver with fibre configuration at ring yarn are presented in Table 4.
3 Results and Discussion

It can be observed from Table 3 that the impact of process variables on the percentage of hooks, hook extent, fibre extent, spinning- in coefficient and fibre overlap index parameters is significant as confirmed from their higher $R^2$ values. Calculated $F$ values are well above the table values; on the other hand $p$ values in all the cases are substantially lower than 0.05. All the regression equations were obtained through backward elimination methods in which terms are eliminated based on $F$ values of 0.10 during step - wise regression. However, in Table 4, the $R^2$ value for total hook percentage is quite low (0.376); the reason has been stated in the text.

### 3.1 Effect of Process Variables on Different types of Hook and Hook Extent

It can be observed from Table 2 that the percentage of trailing hooks is less than that of the leading hooks. This is due to favorable material feeding condition to the drafting system which results in the effective removal of trailing hooks during the subsequent drafting stages. A similar finding has also been reported\textsuperscript{12,13}. As the delivery speed of draw frame increases the trailing hook percentage decreases with marginal increase towards highest speed. This may be due to the increase in the coefficient of relative fibre parallelization, as reported earlier\textsuperscript{8}. But at the extremely higher delivery speed the time spent by the fibre in the drafting zone becomes very less and hence...
the removal of hooks probably may not be possible due to very short dwell period. It is observed that as the coiler diameter increases the trailing hook percentage in the yarn decreases (Table 3). This is due to fibre hook straightening at the subsequent drafting stages and reduction in proportion of curved fibre ends in the sliver, as explained earlier. It can further be observed that as the card draft increases the trailing hook percentage also increases, particularly after a certain level of draft. At lower delivery speed the leading hook percentage remains constant, but it decreases as the delivery speed increases. Coiler diameter also shows the same trend. It is observed that the nature of changes in trailing hook proportion with the change in process variables is different from that of leading hook proportion (Table 3). It may however be noted that since the fibre assembly is consolidated in the form of yarn, the total hook in the yarn is a major concern, influencing its structure and properties.

Figure 1 shows that the total hook percentage decreases with the increase in delivery speed at draw frame. On the other hand, as the card draft and coiler diameter increase, the initial change in the total hook percentage is small and thereafter it increases with the card draft and decreases with the coiler diameter. It is evident from regression equation (Table 4) that M(ρ) and M(Krp) can explain the total hook percentage only up to a limited extent (38% of correlation). This can be explained by the fact that the proportion of curved fibre ends [M(ρ)] is an indirect index and does not provide any idea about the number of hooks at draw frame sliver. It is also observed from Table 4 that M(ρ) and M(Krp) are related with the product of hook proportion and hook extent ($R^2=0.542$). It is apparent from Fig. 2 that the said parameters increase with the increase in M(ρ) but decrease with the increase in M(Krp). Table 5 shows that card draft of 93, coiler diameter of 11 inch and delivery speed of 700 m/min are the optimum values for total hook percentage. It can be observed from Table 2 that leading hook extent is higher than trailing hook extent. This is due to the removal of trailing hook during draw frame and ring frame drafting. It has been noticed that as the delivery speed and coiler

Fig. 1—Combined effect of process variables on total hook percentage (a) delivery speed & card draft, and (b) coiler diameter & card draft

Fig. 2—Effect of proportion of curved fibre ends M(ρ) and coefficient of relative fibre parallelization M(Krp) on the magnitude of hook
diameter increase the trailing hook extent decreases. At lower card draft, as the delivery speed increases the leading hook extent first remains constant and then increases. However, at higher card draft, as the delivery speed increases the leading hook extent remains constant (Table 3). It is also observed that as coiler diameter increases the leading hook extent decreases. Table 5 shows that the optimum values of total hook extent can be obtained with card draft of 81, coiler diameter of 12 inch and delivery speed of 700 m/min.

It can be observed from Fig. 3 that as the delivery speed increases, total hook extent remains unchanged at lower card draft but it decreases sharply at higher card draft. However, as the coiler diameter increases the total hook extent decreases. The above behavior can be explained partly with the help of fibre orientation indices $M(\rho)$ and $M(\text{Krp})$ of draw frame sliver (Table 4 and Fig. 4). As the proportion of curved fibre ends $M(\rho)$ increases the total hook extent increases, whereas with the increase in coefficient of relative fibre parallelization $[M(\text{Krp})]$ the total hook extent decreases.

### 3.2 Effect of Process Variables on Fibre Extent and Spinning-in Coefficient

It is observed from Fig. 5 (a) that at all levels of card draft, the spinning-in coefficient and fibre extent (the behavior of fibre extent being similar) increase with the increase in draw frame delivery speed. It is mainly due to the reduction of hook percentage and hook extent with the increase in draw frame delivery speed and drafting at subsequent stages. It is important to note that the observation can be supported by the $M(\rho)$ and $M(\text{Krp})$ values of breaker sliver. With the increase in draw frame delivery speed, the value of $M(\rho)$ decreases and that

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Card draft</th>
<th>Coiler diameter</th>
<th>Delivery speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total hook, %</td>
<td>93</td>
<td>11</td>
<td>700 m/min</td>
</tr>
<tr>
<td>Total hook extent, mm</td>
<td>81</td>
<td>12</td>
<td>700 m/min</td>
</tr>
<tr>
<td>Fibre extent, mm</td>
<td>100</td>
<td>12</td>
<td>884 mm</td>
</tr>
<tr>
<td>Spinning-in coefficient</td>
<td>100</td>
<td>12</td>
<td>850 mm</td>
</tr>
<tr>
<td>Fibre overlap index</td>
<td>100</td>
<td>10</td>
<td>400 mm</td>
</tr>
</tbody>
</table>

Fig. 3—Combined effect of process variables on total hook extent (a) delivery speed & card draft, and (b) coiler diameter and card draft

Fig. 4—Effect of proportion of curved fibre ends $M(\rho)$ and coefficient of relative fibre parallelization $M(\text{Krp})$ on the total hook extent
of M(Krp) increases as observed earlier; the phenomenon eventually influences fibre extent and spinning-in coefficient at the ring-spun yarn.

It is also observed from Fig. 5 (b) that with the increase in coiler diameter, the spinning-in coefficient and fibre extent (the behavior of fibre extent being similar) increase, which is attributed to the decrease in the value of M(ρ) and increase in the value of M(Krp) of breaker draw frame sliver and also due to the reduction in percentage of hook and hook extent in the yarn. The influence of card draft on the spinning-in coefficient is shown in Fig. 5. It is evident that with the increase in card draft, there is a decrease in fibre extent and spinning-in coefficient in yarn. It is evident from Figs 1 and 3 that as the card draft of M(Krp) increases, the total hook percentage and total hook extent also increase, thereby reducing the value of fibre extent and spinning-in coefficient of yarn. Figure 6 shows that there is a considerable level of interaction observed between proportion of curved fibre ends and coefficient of relative fibre parallelization along with their influence on fibre extent in the yarn. At lower level of M(Krp), as the M(ρ) increases the fibre extent decreases, but at higher level of M(Krp) the fibre extent increases with the increase in M(ρ). The increase in fibre extent with the increase in M(ρ) can be well justified at higher level of M(Krp), possibly due to efficient removal of hooks, fibre straightening and fibre parallelization during drafting. It is also observed from Table 5 that the optimum values for spinning-in coefficient can be achieved through card draft of 100, coiler diameter of 12 inch and delivery speed of 850 m/min.

3.3 Effect of Process Variables on Fibre Overlap Index

Table 3 and Fig. 7 show the nature of change in fibre overlap index (FOI) parameter with the change in process variables. It is found that with the increase in both coiler diameter and delivery speed the value of fibre overlap index decreases. As the draw frame delivery speed increases the inertia effect becomes more prominent and subsequent drafting at various stages maintains the higher relative movement between the fibres. This leads to moving apart of the fibre and hence reduces fibre overlapping in the yarn. During drafting of material strand due to twist and

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**Fig. 5**—Combined effect of process variables on spinning-in coefficient (a) delivery speed & card draft, and (b) coiler diameter & card draft

**Fig. 6**—Effect of proportion of curved fibre ends M(p) and coefficient of relative fibre parallelization M(Krp) on fibre extent
different radial position of fibre in the sliver and roving, fibre tension during the drafting will not be uniform, which, in turn, affects the fibre overlapping index. It may be noticed that the sliver doubling at draw frame is not a decisive factor while influencing the extent of fibre overlapping. It is further observed that with the increase in delivery speed and card draft (except at –1 coded value of coiler diameter), the value of fibre overlapping index decreases with the increase in coiler diameter. It may be due to the stretching of sliver with the increase in coiler diameter, as explained earlier. It is observed that at constant values of delivery speed and coiler diameter, the fibre overlapping index increases with the increase in card draft. However, the value of fibre overlap index decreases at constant value of card draft as the delivery speed and coiler diameter increase. It is also evident from Table 5 that the optimum value of fibre overlap index can be achieved at a card draft of 100, coiler diameter of 10 inch and breaker draw frame delivery speed of 400 m/min. It is interesting to note from the above study that when spinning-in coefficient increases, the fibre overlap index decreases with the change in proposed process variables. It is evident from the results that the fibre straightening and relative fibre movement mechanism at different stages of spinning do not follow the positive relationship. Figure 8 shows that the fibre overlap index increases with the increase in M(ρ) and decreases with M(Krp). There is strong interaction effect of M(ρ) and M(Krp) while influencing fibre overlap index. At lower level of M(Krp), fibre overlap
index increases with the increase in \( M(\rho) \). But at higher level of \( M(Krp) \), the influence of \( M(\rho) \) is relatively less. However, fibre overlap index decreases as \( M(Krp) \) increases.

### 4 Conclusions

4.1 Trailing, leading and total hooks and their extents on ring - spun yarn decrease with the increase in draw frame delivery speed and coiler diameter of card.

4.2 In general, the above axial parameters of yarn decrease as the card draft increases. Since the fibre extent and spinning-in coefficient are related to the efficacy of hook removal, the parameters improve as the delivery speed and coiler diameter increase, but they decrease as the card draft increases.

4.3 Fibre overlap index decreases as the delivery speed and coiler diameter increase, however it increases with card draft.

4.4 The behavior of fibre extent and fibre overlap index in the yarn significantly depends upon the proportion of curved fibre ends \( M(\rho) \) and coefficient of relative fibre parallelization \( M(Krp) \) in the sliver. Spinning-in coefficient and fibre overlap index do not show positive relationship.

**Industrial Importance:** Since at higher draw frame delivery speed and coiler diameter, two major yarn structural parameters namely fibre extent and spinning-in coefficient improve, the industry can achieve higher productivity without compromising the sliver and subsequently yarn quality.

### References