Optimization of Machine Parameters of Rotor Spinner

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The Box and Behnken design has been applied successfully for optimizing rotor speed, rotor diameter and opening roller speed.

Keywords: Opening roller speed, Rotor diameter, Rotor speed, Rotor spinner

Optimization of open-end spinning has been extensively studied \(^1-9\) by using a rotatable central composite design \(^1\). One disadvantage of such a design is that it may not be practicable to select some levels of the variables. For example, when the influence of rotor diameter on yarn tenacity is to be assessed, the various levels of rotor diameters that have to be chosen in coded levels are -1.414, -1, 0, 1, and 1.414 for the two-variable design and -1.682, -1, 0, 1, and 1.682 for the three-variable design. If the medium level of rotor diameter is 46 mm, then the rotor diameters required are 31.86, 36, 46, 56, and 60.14 mm for the two-variable design, and 28.18, 36, 46, 56, and 62.82 mm for the three-variable design, considering the availability of rotor sizes such as 36, 46 and 56 mm. However, rotors of 29.18, 31.86, 60.14 and 62.82 mm diameters are not readily available and one has to fabricate them for specific experiments. One possible way of overcoming this drawback is to run the experiments in parallel as was done by Barella\(^1\). This approach, however, increases the size of the experiment many times depending upon the availability of rotors of different diameters. This drawback also can be overcome by using the design developed by Box and Behnken\(^11\). In the present study, an attempt has been made to apply the above design to optimize the rotor speed, opening roller speed, and rotor diameter.

Materials and Methods

Material - J-34 cotton (60% roller ginned and 40% saw ginned) of 24 mm staple length and 4 µg/in. micronaire value was used.

Sliver preparation - The cotton was processed in a conventional blowroom and carded on an MMC tandem card. The card sliver was given two passages of drawing on a Platts drawframe of the conventional 4/4 drafting system, to produce a finisher sliver of 3.28 ktx (0.18 Hk).

Factorial design - In the Box and Behnken design\(^11\) the variables are selected at three levels, viz. -1, 0, and 1. The response \(Y\) is given by a second-order polynomial, i.e.

\[
Y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} \sum_{j=1}^{k} b_{ij} x_i x_j
\]

where \(x_i\) is the \(i\)th variable, \(k\) is the number of variables and \(b_0\), \(b_i\), and \(b_{ij}\) are the regression coefficients associated with the variables.

In order to find out the regression coefficient, the response \(Y\) has to be found out by using different experimental combinations of the variables under consideration. For the case of three variables, the experimental plan is given in Table 1 and the actual levels of the three variables, viz. rotor speed, rotor diameter, and opening roller speed, are given in Table 2.

Spinning and testing of yarn - Yarns were spun in accordance with the experimental plan. A Suessen OE spin-tester was used to spin yarns of 32.8 tex (18s

| Table 1 - Experimental Design for 3 Variables |
|---|---|---|
| Sl. No. | Levels of variables |
| \(x_1\) | \(x_2\) | \(x_3\) |
| 1 | -1 | -1 | 0 |
| 2 | -1 | 1 | 0 |
| 3 | 1 | -1 | 0 |
| 4 | 1 | 1 | 0 |
| 5 | -1 | 0 | -1 |
| 6 | -1 | 0 | 1 |
| 7 | 1 | 0 | -1 |
| 8 | 1 | 0 | 1 |
| 9 | 0 | -1 | -1 |
| 10 | 0 | -1 | 1 |
| 11 | 0 | 1 | -1 |
| 12 | 0 | 1 | 1 |
| 13 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 |

\(x_1\) - Rotor speed; \(x_2\) - Rotor diameter; and \(x_3\) - Opening roller speed.
Table 2—Actual Levels Corresponding to Coded Levels

<table>
<thead>
<tr>
<th>Variable</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor speed, rpm</td>
<td>-1 30,000</td>
</tr>
<tr>
<td>Rotor diameter, mm</td>
<td>36</td>
</tr>
<tr>
<td>Opening roller speed, rpm</td>
<td>4000</td>
</tr>
</tbody>
</table>

cotton count) with a tex twist (cotton twist factor, 4.5) factor of 43.07.

An Uster dynamometer was used for testing the single yarn tenacity and breaking elongation. The yarn unevenness and imperfections were measured on an Uster evenness tester. The yarn quality index (YQI) was calculated from the expression:

\[
YQI = \frac{\text{Yarn tenacity (g/tex) \times Breaking elongation (\%)}}{\text{Unevenness (U\%)}}
\]

Experimental analysis—The results of all the responses for the various experimental combinations were fed to an ICL 2960 computer. Suitable computer programs were developed for calculating the regression coefficients according to the following formulae:

\[\begin{align*}
    b_0 &= \bar{y}_0 \\
    b_i &= A(iy) \\
    b_u &= B(iiy) + C_i \sum_{j=1}^{15} (ijy) - \bar{y}_u/S \\
    b_{ij} &= D_{ij}\bar{y}_u
\end{align*}\]

where \(\bar{y}_u\) is the average value of the regression coefficients observed at the centre points.

\[A = \frac{1}{8}; B = \frac{1}{4}; C_i = -\frac{1}{16}; D_{ij} = 1/4; S = 2\]

\[(iy) = \sum_{u=1}^{15} x_{iu}y_u\]

\[(iiy) = \sum_{u=1}^{15} x_{iu}y_u\]

\[(ijy) = \sum_{u=1}^{15} x_{iu}x_{ju}y_u\]

The regression coefficients were tested for significance at 95% confidence level. Only significant terms were considered for further analysis of results. The response surface equations for all the yarn characteristics along with the correlation coefficients between the experimental values and the calculated values obtained from the response surface equations are given in Table 3. The response surface agrees fairly well with the experimental data, as is evident from the high correlation coefficients. Contour maps were constructed using the response surface equations.

**Results and Discussion**

*Yarn tenacity*—Figs 1-3 show the influence of rotor speed and opening roller speed on yarn tenacity (g/tex) for different rotor diameters. The contours clearly show that an increase in rotor speed results in an initial increase followed by a decrease in yarn tenacity, while an increase in opening roller speed invariably reduces the yarn tenacity. The contour lines are ellipses with a maximum falling within the experimental field. The rotor speed and the opening roller speed at which the maximum tenacity occurs are respectively 51,000 rpm and 5000 rpm for 36 mm rotor diameter; 48,000 rpm and 4500 rpm for 46 mm rotor diameter; and 40,500 rpm and 4000 rpm for 56 mm rotor diameter.

A comparative study of Figs 1-3 reveals the influence of rotor diameter on yarn tenacity at various rotor speeds and opening roller speeds. At lower rotor speeds, the yarn tenacity is hardly affected when the rotor diameter is increased from 36 to 46 mm, while it is significantly reduced when the rotor diameter is further increased to 56 mm. At higher rotor speeds, the yarn tenacity is invariably reduced as the rotor diameter increases. The reduction is comparatively low for the increase in the rotor diameter from 36 to 46 mm than from 46 to 56 mm.

Manohar et al.\(^{1,2}\) observed that the yarn diameter decreases with an increase in rotor speed. The yarn diameter, which can be taken as an indication of yarn compactness, can significantly affect the yarn tenacity. A decrease in yarn diameter signifies more compactness and thus a gain in tenacity. This gain is counteracted by the losses due to increase in the percentage sheath fibres\(^{13}\) and decrease in fibre orientation\(^{14}\) when the rotor speed is increased. It is likely that for moderate rotor speeds of up to 50,000 rpm or so, the decrease in tenacity due to these factors is more than compensated for by the increase due to the greater compactness of fibres in the yarn.
Breaking elongation—The response surface equation shows that the breaking elongation is affected only by the rotor speed and rotor diameter while the opening roller speed has hardly any effect on it. An increase in either the rotor speed or rotor diameter tends to decrease the breaking elongation. The rate of drop in elongation is much higher at lower rotor speeds than at higher rotor speeds.

Unevenness—The influences of rotor speed and opening roller speed on yarn unevenness (U%) for different rotor diameters are shown in Figs 4-6. The unevenness increases with increase in rotor speed. On the other hand, unevenness decreases with increase in the opening roller speeds of up to 7250 rpm irrespective of the rotor diameter. Further increase in the opening roller speed tends to marginally increase the unevenness. Thus from the consideration of yarn unevenness, the optimum opening roller speed seems to be around 7250 rpm. Such a marginal increase in unevenness has also been observed by Chattopadhay et al. However, some other authors have observed a marginal decrease in unevenness after a opening roller speed of 7000 rpm. Large rotor diameters produce comparatively more even yarn.
The decrease in unevenness with increase in rotor diameter is attributed to the increased number of doublings and better fibre separation at the collecting point and the longer distance between the successive belts. Yarn quality index (YQI)—The influence of rotor speed and opening roller speed on YQI for different rotor diameters is shown in Figs 7-9. It is seen that YQI decreases with increase in rotor speed but increases with increase in opening roller speeds of up to a certain level beyond which it starts decreasing. This level seems to depend on the rotor speed. At lower rotor speeds, YQI starts decreasing at lower opening roller speeds, indicating that both speeds of rotor and opening roller jointly influence YQI. Regarding the effect of rotor diameter, a small rotor tends to give a higher YQI. As the rotor diameter is increased, YQI decreases.

Yarn imperfections—The rotor speed and the rotor diameter significantly affect the neps, as is evident from the response surface equation in Table 3. Neps increase with increase in either rotor speed or rotor diameter. The effect of rotor speed is more predominant than that of rotor diameter.

The increase in neps with increase in rotor speed and rotor diameter has also been observed by Manohar et al. This increase in neps has been attributed to the
high incidence of sheath fibres and poor fibre opening as the rotor speed goes up. In the case of rotor diameter, even though the sheath fibre per cent came down with increase in rotor diameter, the number of wraps per unit length increased; this has been shown to be responsible for the increase in neps as the rotor diameter is increased.

Figs 10 and 11 show the influence of rotor speed and opening roller speed on thick and thin places respectively. The number of thick and thin places is less at lower rotor speeds. With increase in rotor speed, both the thick and thin places increase progressively.

On the other hand, increase in opening roller speed decreases the number of thick places, while the number of thin places decreases up to a speed of 7500 rpm and starts increasing thereafter. The rotor diameter does not seem to have any effect on thick and thin places.

Conclusions

1. There is an optimum rotor speed and an opening roller speed for realizing maximum yarn tenacity. The optimum values are dependent upon the rotor diameter used.

2. An increase in opening roller speed decreases the yarn tenacity and the number of thin places. The optimum opening roller speed for highest yarn quality index lies between 6000 and 7500 rpm depending upon the rotor speed. Minimum unevenness and the least number of thin places are observed at an opening roller speed of 7250 rpm.

3. An increase in rotor diameter from 36 mm to 46 mm hardly affects any of the yarn characteristics. Increasing it further to 56 mm, however, adversely affects the yarn tenacity and the yarn quality index. The unevenness steadily decreases with increase in rotor diameter while the breaking elongation and the nep count remain unaffected.

References

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