Design of asymmetrical cam profile for improved performance at flyer spinning

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The variation of the transmitted yarn tension within and between the layers and cross-layers of the bobbin build-up is assumed to be one of the important causes for the end breakage at the flyer spinning system. Since the existing building cam of symmetrical profile produces equal traverse rate to the bobbin rail in both of its upward and downward movements, this traverse ratio of 1:1 is likely to be partly responsible for such variation of yarn tension and consequently the end breakage rate. In view of this, two building cams of different asymmetrical profiles to produce 1:1.4 and 1:2 traverse ratios were designed by adopting a combined mathematical and geometrical approach. The modified cams were found to decrease the end breakage rate by 9.4-14.5% and increase the package density by 6.9-8.5% at the mill and the laboratory levels respectively.

Keywords: Asymmetrical profile, Flyer spinning, Linear cam design, Yarn tension

1 Introduction

In the ring or flyer spinning system, the process of twisting the yarn and its winding onto a tube or a flanged bobbin is carried out simultaneously. The yarn delivered per unit time is required to be wound onto the package at a uniform spacing. To maintain this, the ring or the bobbin rail is moved upwards at a constant velocity and as it reaches the maximum height it is immediately returned to the original position either at the same or at different velocity which is also constant. This movement of the rail is controlled by a building cam of linear motion. Therefore, the profile of the cam is the main factor in determining the character of the rail movement. Again, for a complete rotation of the cam, a layer and a cross-layer of yarn coils are laid onto the tube or bobbin surface. In the ring spinning, the building cam is normally of asymmetrical profile to produce unequal velocities for the upward and downward movements of the ring rail which reduces the ends down rate at spinning and also improves winding-off performance. In the flyer spinning, on the contrary, a heart shaped cam is used to produce equal velocities for both the upward and downward movements of the bobbin rail. Further, the yarn wound onto the cylindrical surface with coils laid along a helical line and the character of the rail movement determine the steepness of the coil angles at a layer and its cross-layer of the bobbin build-up. In view of this, an attempt has been made to assess the suitability of an asymmetrical cam profile in the jute flyer spinning system.

2 Theoretical Background

2.1 Theory of the Traversing Coils

The conventional jute spinning is based on the flyer leading theory and for the correct winding of yarns onto the bobbins, \((N-b)\pi db = \dot{V}_t\) where \(N\) is the flyer rpm (constant); \(b\), the bobbin rpm; \(db\), the winding diameter of the bobbin; and \(\dot{V}_t\), the yarn delivery rate.

This indicates that the bobbin speed increases with the increase in the winding diameter of the bobbin. Again, since the yarn delivered per unit time must be wound onto the winding surface of the bobbin during the same time, the number of yarn coils per unit time is expressed as:

\[ n = \frac{\dot{V}_t}{l} = \frac{V_t}{\sqrt{(\pi db)^2 + P^2}} \]  \hspace{1cm} (1)

where \(n\) is the no. of yarn coils/unit time; \(\dot{V}_t\), the yarn delivered/unit time (m); \(l\), the length of a yarn coil (m); \(db\), the winding diameter of the bobbin (m); and \(P\), the pitch of the yarn coil (m).
The contraction of yarn due to twist is not considered here. Again, the pitch of the yarn coil \((P)\) may be calculated as:

the traverse rate of the bobbin rail per unit time

\[
(T_\text{r}) = nP = \frac{V_\text{r}}{1} P \quad \text{and, therefore,}
\]

\[
P = \frac{T_\text{r}l}{V_\text{r}} = \frac{T_\text{r} \pi db}{\sqrt{V_\text{r}^2 - T_\text{r}^2}} \quad \ldots (2)
\]

Again from Fig. 1, the angle of yarn coil \((\alpha)\) is

\[
\alpha = \tan^{-1} \frac{P}{\pi db} = \tan^{-1} \frac{T_\text{r}}{\sqrt{V_\text{r}^2 - T_\text{r}^2}} \quad \ldots (3)
\]

Now, since the rate of traverse of the bobbin rail is constant for a particular direction, the yarn coils in a layer will have equal pitch. However, the pitch of the yarn coils in a layer of bobbin build-up will increase with the increase in the traverse rate and also with the increase in the winding diameter of the bobbin, as shown in Eq. (2). Eq. (3) also indicates that the angle of yarn coil \((\alpha)\) changes with the change in the traverse rate \((T_\text{r})\). Again, a complete rotation of the building cam gives one upward and one downward traverse to the bobbin rail, and in the case of the heart cam of symmetrical profile, the rate of traverse is equal for both directions. Therefore, for a heart cam, the angle of yarn coil \((\alpha)\) remains constant for all the layers and the cross-layers of the entire bobbin build-up.

Now, in a 108 mm pitch slip draft jute spinning machine, considering \(T_\text{r}\) (both up and down) = 0.151 m/min; \(V_\text{r} = 23\) m/min; the winding diameter for the first layer at the bobbin \((db_1)\) which is also the bare diameter of the bobbin = 0.03 m; and the diameter of a 275 tex jute yarn = \(60 \times 10^{-5}\) m, then from Eq. (3), the angle of yarn coil \((\alpha) = 0.38°\) for each layer and cross-layer of the bobbin build-up but they are inclined at opposite directions. Again, from Fig. 1 the length of the yarn coil, \(l = \pi db \, \sec \alpha\) and with the very small value of \(\alpha\) \((0.38°)\), \(l = \pi db\). This indicates that the yarn coils at the succeeding layers/cross-layers may overlap on the coils of the preceding layers/cross-layers of a symmetrical cam.

Further, since the yarn delivered per unit time is constant and the length of the coil is increased with the increase in the winding diameter of the bobbin, the number of coils in the successive layers and cross-layers will be reduced progressively [Eq. (2)] which corroborates with the practical findings shown in Fig. 2. The relationship is hyperbolic.

Again, since the pitch of the coil is inversely proportional to the number of yarn coils and also directly proportional to the traverse rate of the bobbin rail, the slower is the traverse rate the higher will be the number of coils in the bobbin layers or vice versa. But too slow a traverse will cause periodical humps of yarn coils on the winding surface of the bobbin, which will cause disadvantage in respect of the winding diameter and tension variations during spinning. Therefore, too fast a traverse seems to be less serious compared to a too slow traverse.

Again, the pitch of the coils may be calculated for the 1st \((P_1)\), 2nd \((P_2)\), 30th \((P_{30})\) and 31st \((P_{31})\) layers/cross-layers [Eq. (2)], \(P_1 = 61.8 \times 10^{-5}\) m; \(P_2 = 64.3 \times 10^{-5}\) m; \(P_{30} = 133.6 \times 10^{-5}\) m and \(P_{31} = 136.1 \times 10^{-5}\) m, considering that the maximum increase in the winding diameter of the bobbin is twice the yarn diameter for each successive layer/cross-layer of the bobbin build-up.
Now, \( P_1 = 61.8 \times 10^{-5} \) m means that the yarn coils at the 1st layer are spaced 61.8 \( \times 10^{-5} \) m apart. Further, the pitch of the coils increases marginally in each cross-layer compared to its preceding layer. Therefore, the yarn coils at the succeeding layers/cross-layers are likely to be sometimes overlapped on the preceding layers/cross-layers which may lead to variation of yarn tensions within and between the layers/cross-layers of the bobbin build-up. Further, these may also cause an overall increase in the winding diameter, thereby resulting in a reduction of the package density. In view of this surmise, it was felt that if an asymmetrical cam is designed with an aim to cause a slow traverse upwards and a quick traverse downwards or vice versa, the quick traverse coils, being at a much steeper angle inclined in the opposite direction, are not likely to get overlapped with the slow traverse coils. Accordingly, since the cam profile determines the proportion of the yarn length distribution to a layer and its cross-layer of the bobbin build-up then for one complete rotation of an asymmetrical cam, the yarn length \( L \), which is delivered by the delivery rollers, is distributed to the layer and cross-layer proportionately to the angles \( \alpha_1 \) and \( \alpha_2 \). This is expressed as

\[
L = \frac{L_1 \alpha_1}{360}\]

and the length of the yarn in a cross-layer

\[
L_2 = \frac{L_2 \alpha_2}{360}\]

Therefore, \( \frac{L_2}{L_1} = \frac{\alpha_1}{\alpha_2} \)

However, in the case of heart cam of symmetrical profile, \( \alpha_1 = \alpha_2 \) and, therefore, \( L_1 = L_2 \).

2.2 Theory of Cam Profile

2.2.1 Mathematical Approach

The rotational movement and displacement of a roller follower in contact with a cam is shown in Fig. 3. The following considerations were made in designing the desired cam profile.

\( \omega_1 \) – the angular velocity of the cam;
\( \omega_2 \) – the angular velocity of the cam follower;
\( v \) – the velocity along \( O_1O_2 \), where \( O_1 \) and \( O_2 \) are the centres of the cam and the cam follower respectively;
\( O_1A \) – the radius of the base circle of the cam;
\( O_2D \) – the radius of the cam follower;
\( O_1D \) – the distance between the base circle centre and the contact point of the follower with the cam; \( \theta \) – the angle between \( O_1A \) and the line centre; \( \theta' = \theta + \psi \) – the angle between \( O_1A \) and \( O_2D \); \( \psi \) – the angle between \( O_1O_2 \) and \( O_2D \); and \( \phi \) – the angle between \( O_2D \) and the line centre = pressure angle.

It may be shown from the above considerations that,

\[
b \sin \psi = a \sin \phi \quad \ldots (1)
\]

\[
b \cos \psi + a \cos \phi = O_1O_2 = R \text{(say)} \quad \ldots (2)
\]

\[
\tan \phi = \frac{v}{R \omega_1} \quad \ldots (3)
\]

Again, since the displacement of the follower in the case of jute spinning is linear, the equation of
the linear displacement curve is given as \( y = c \theta \)
where \( c \) is a constant (The equation of a simple polynomial curve is \( y = c \theta^n \) and for linear displacement \( n = 1 \)).

Further, for \( y = h \) and \( \theta = \beta \), the above equation becomes
\[
y = \frac{h}{\beta} \theta 
\]
where \( y \) is the displacement of the follower in mm (above the base circle); \( h \), the maximum displacement of the follower in mm; \( \beta \), the cam angle of rotation for rise \( h \) in radian; and \( \theta \), the cam angle in radian

now, \( v = \frac{h}{\beta} \omega_i \) and \( R = r + a + \frac{h}{\beta} \theta \)

Therefore,
\[
\tan \phi = \frac{v}{R \omega_i} = \frac{h}{\beta} \frac{1}{R}
\]

Again, from Eqs (1) and (2),
\[
\tan \psi = \frac{a \sin \phi}{R - a \cos \phi}
\]

and from Eq. (1),
\[
b = a \left( \frac{\sin \phi}{\sin \psi} \right)
\]

It is now clear from the above expressions that for any known value of \( \theta \), the position of \( D \) (Fig. 3) may be determined and thus the actual profile of the desired cam is obtained. For example, let us consider that a linear cam of 240° staggered profile is to be designed with the maximum rise of the cam follower as 111.1 mm \((y = h)\) for \( \beta = 240° \) (4.19 rad) cam rotation, the radius of the base circle \( r = 38 \) mm, and the radius of the cam follower \( a = 38 \) mm.

At 5° cam rotation, i.e. \( \theta = 5° \) (0.087 rad), \( R = 78.3 \) mm; \( \phi = 18.7°; \psi = 16°; b = 44.2 \) mm; and \( \theta' = 21° \). Therefore, when \( \theta' = 21° \), \( O_2 D(b) \) is 44.2 mm, which is the contact point of the follower with the cam at 5° cam rotation.

2.2.2 Combined Mathematical and Geometrical Approach

The point of contact may also be determined in a simple way without the rigorous calculations as above. The procedure is given below:

(i) The base circle is drawn \((r = 38 \) mm\);

(ii) \( R \) is calculated as, \( R = r + a + \frac{h}{\beta} \theta = 78.3 \) mm

and thus for any arbitrary value of \( \theta \) (say \( \theta = 5° \)), the centre for the follower \((O_2 \) in Fig. 3) is obtained;

(iii) \( O_2 \) as centre, a circle is drawn \((a = 38 \) mm\) which is the position of the follower at \( \theta = 5° \) cam rotation;

(iv) Similarly, the other positions of the follower are drawn at different values of \( \theta \) (10°, 15°, 20°, etc.);

(v) Finally, the ascending profile of the cam is drawn touching all the circles, representing the different positions of the follower from 0° to 240°;

(vi) For the descending profile of cam, between 240° and 360°, the values of \( \theta \) (say) may be calculated by subtracting \( \theta \) from 360°, which are to be expressed in radians;

(vii) The values of \( \beta \) will be 120° (2.09 rad).

In designing the experimental cams, the combined mathematical and geometrical approach was followed.

3 Experimental Procedure

The entire experiment was divided into three phases. In the first phase, the modified cams were designed and fabricated and their accuracy tested. In the second phase, the performance of the modified cams was evaluated at the pilot mill level by (i) recording and analyzing the transmitted yarn tensions during spinning, and (ii) the increase in package density \((\%)\) and time for full package build-up. In the third phase, the performance of these cams was further evaluated by the yarn breakage study and doff-time under the actual mill conditions.

For the pilot mill studies, 275 tex yarn was spun from TD-3 quality jute at a 146 mm lift/108 mm pitch slip-draft spinning machine. In case of mill studies, 240 tex yarn was spun from a standard carpet backing batch at a 163 mm lift/108 mm pitch modified slip-draft spinning machine.

3.1 Design and Fabrication of the Modified Cams

Three modified cams of asymmetrical profile were designed and fabricated. Out of these, two were of 240° and one was of 210° staggered profile. 240° and 210° staggered profiles mean that the maximum follower displacements are at 240° and 210° respectively. Accordingly, the former will give 1:2 and the latter will give 1:1.4 traverse ratios to the bobbin rail in its upward and downward movements.

In order to reduce the inaccuracy in the contour during the fabrication of these cams, the following methods were adopted:

(i) A master cam of five times larger contour was fabricated in each case by layout cutting method and this was traced by a tracer control cutting
method to obtain the desired cam of one-fifth size. All these cams were made from the mild steel plates of 15 mm thickness.

(ii) A templet method was followed for checking the contour.

(iii) A chrome-plated surface finish was applied.

3.1.1 Pressure Angle
In designing the experimental cams, due considerations were made so that the pressure angle (steepness of the cam profile) between the cam and its follower does not exceed 30° in order to obtain smooth cam follower action. If it is too large, it can affect the smoothness of action. The pressure angle depends on the diameter of the base circle. As the diameter of the base circle increases, the value of the maximum pressure angle decreases and also the size of the cam increases. For the experimental cams, the base circle diameter was chosen as 76 mm on the basis of the existing heart cam. The maximum pressure angle of \( \phi_{\text{max}} \) (Fig. 3) for 210° and 240° staggered cams were calculated as 29° and 34.9° respectively as against 24.9° for the heart cam. In order to keep \( \phi_{\text{max}} \) close to 30°, another 240° staggered cam was designed keeping the base circle diameter as 100 mm and in this case \( \phi_{\text{max}} \) was calculated as 31°. Considering the very slow rotational speed of the flyer spinning cam \( (\omega_{\text{max}} > 0.3 \text{ rad/s}) \), \( \phi_{\text{max}} \) of 31° appeared to be acceptable.

3.1.2 Accuracy of the Cam Profile
The profiles of the modified cams along with the heart cam are shown in Fig. 4 and their displacement diagrams are shown in Fig. 5. These figures were traced from the original cams by means of a hand-operated instrument developed by UIIIRA. The rate of displacement of the follower for each degree of cam rotation was measured for both the modified and heart cams and is shown in Fig. 6.

3.1.3 Traversing Coils
The number of traversing coils for each layer and its corresponding cross-layer will differ according to the asymmetry ratio of each of the modified cams. The change in the number of combined coils in respect of each complete rotation of the individual modified cam is shown in Fig. 7 and compared with the normal heart cam. In the case of 240° staggered cams, only the cam with 76 mm base circle was considered because both had the similar pattern of coils in the successive layers and cross-layers.

3.2 Variations of the Transmitted Yarn Tension
The transmitted yarn tensions during spinning were measured by Rothschild Tensionometer and Helcoscriptor Recorder at different layers and cross-layers of the bobbin build-up. The experiments were conducted for all the modified cams and the results were compared with the normal
heart cam under the identical spinning conditions at the pilot mill level. The deflection of each leg of the flyer due to the centrifugal force was estimated as 5.4 mm at the flyer speed of 3850 rpm and accordingly, the angle of yarn pull at the first layer of the bobbin build-up was assumed to be nearly 21°. The transmitted yarn tensions at the initial four layers and cross-layers of the bobbin build-up were found to be erratic for both the normal and modified cams, because in each of these layers and cross-layers, the angle of pull was estimated to be below the minimum level of 25 degrees. Therefore, the tensions were recorded from 5th to 30th layers and cross-layers, in steps of five.

The tension (g) was computed from the recorded graphs. The average of 100 data for each successive layer and cross-layer was determined. The average tensions in the successive layers and cross-layers for different cams are shown in Fig. 8. The straight line curves were fitted statistically by adopting the method of least squares. The within layer variation of tensions (CV_w) was assessed by the CV% of the tensions at the individual layer and cross-layer, whereas the between layer variation of tensions (CV_b) was assessed by the CV% of the average tensions at the successive layers and cross-layers. The overall performance (CV_T) of each cam was assessed by the overall CV% (CV_T = \sqrt{CV_w^2 + CV_b^2}). The CV% of the recorded tensions for the different cams are given in Table 1.

### Table 1 - CV% of recorded tensions for different cams

<table>
<thead>
<tr>
<th>No. of layers and cross-layers in bobbin</th>
<th>Average and performance</th>
<th>CV_w (Av.)</th>
<th>CV_b</th>
<th>CV_T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart carn</td>
<td></td>
<td>16.4</td>
<td>16.4</td>
<td>19.5</td>
</tr>
<tr>
<td>210° staggered (base circle, 76 mm)</td>
<td></td>
<td>18.4</td>
<td>16.8</td>
<td>17.7</td>
</tr>
<tr>
<td>240° staggered (base circle, 100 mm)</td>
<td></td>
<td>17.2</td>
<td>15.5</td>
<td>17.4</td>
</tr>
</tbody>
</table>

*Base circle, 76 mm; and base circle, 100 mm

for each cam. The average doff weight and time for each modified cam were compared with those for the normal heart cam (Table 2).

#### 3.4 Mill Studies

The yarn breakage studies were conducted in a jute mill on a 100 spindle spinning frame, using 210° and 240° (base circle, 76 mm) staggered cams and the results were compared with those obtained by using the normal heart cam. The yarn breaks and the time for a full doff, on an average of twelve doffs, were recorded in each case and
are given in Table 3. The difference in the end breakage rates (normal vs modified cams) was tested statistically by Chi-square test, using the formula $[(A-B)^2/A+B] > 4$, where $A$ and $B$ are the total number of breaks observed in the two situations respectively.

4 Results and Discussion

Fig. 4 shows that unlike the symmetrical heart cam, the staggered cams have different degrees of asymmetry. Moreover, both the 240° staggered cams have the same degree of asymmetry although they have different diameters for the base circles.

Figs 5 and 6 indicate that like the normal heart cam, the follower displacements for the staggered cams are nearly linear and velocities are more or less constant. The acceleration is, in fact, zero in all cases excepting at the changeover points (rise to fall or vice versa) when the acceleration becomes infinite.

As compared to the heart cam, the staggered cams give more number of yarn coils for the successive layers and cross-layers (Fig. 7) which indicates that in the case of staggered cams, the package densities are expected to be higher.

Table 2 - Package density and time for a full doff with different cams

<table>
<thead>
<tr>
<th>Type of cam</th>
<th>Av. net yarn content per bobbin at 14% moisture regain kg</th>
<th>Time for each doff min</th>
<th>Gain in weight of yarn %</th>
<th>Package density g/cm²</th>
<th>Gain in package density %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart cam</td>
<td>0.264</td>
<td>39.1</td>
<td>0.479</td>
<td>52.7</td>
<td>7.5</td>
</tr>
<tr>
<td>210° Staggered</td>
<td>0.261</td>
<td>42.2</td>
<td>8.3</td>
<td>0.515</td>
<td>7.5</td>
</tr>
<tr>
<td>240° Staggered</td>
<td>0.264</td>
<td>42.8</td>
<td>9.5</td>
<td>0.520</td>
<td>8.5</td>
</tr>
<tr>
<td>(Base circle, 76 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>240° Staggered</td>
<td>0.262</td>
<td>42.5</td>
<td>8.7</td>
<td>0.512</td>
<td>6.9</td>
</tr>
<tr>
<td>(Base circle, 100 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 - Yarn breakage rate and doff time studies at mill

<table>
<thead>
<tr>
<th>Type of cam</th>
<th>Av. no. of breaks/100 spindles/h</th>
<th>Total no. of breaks</th>
<th>Reduction in breakage rate %</th>
<th>Av. time for a full doff min</th>
<th>Increase in time for full doff %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart cam</td>
<td>93.2</td>
<td>12</td>
<td>52.8</td>
<td>--------------------------------</td>
<td></td>
</tr>
<tr>
<td>210° Staggered</td>
<td>84.4</td>
<td>12</td>
<td>9.4</td>
<td>53.5</td>
<td>1.32</td>
</tr>
<tr>
<td>240° Staggered</td>
<td>79.7</td>
<td>12</td>
<td>14.5</td>
<td>54.3</td>
<td>2.84</td>
</tr>
<tr>
<td>(Base circle, 76 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is seen from Fig. 8 that the transmitted yarn tensions are higher for 210° and 240° (Base circle, 100 mm) staggered cams whereas the tensions are lower for 240° (Base circle, 76 mm) as compared to those for the heart cam. But if the variation of the transmitted yarn tensions within and between the yarn layers are considered (Table 1), the overall performance of the staggered cams is likely to be better than the heart cam.

Table 2 indicates that the staggered cams give higher yarn content in bobbin by 8-9.5%. The package densities are also higher for the staggered cams by 6.9-8.5% which indicates that there is an overall advantage in the winding diameter of the bobbin for the staggered cams. A similar indication was also obtained earlier, as shown in Fig. 7.

Further, it may be observed from Table 3 that under the actual mill conditions, the staggered cams reduce the yarn breakage rate by 9.4-14.5% and increase the running time for each doff by 1.3-2.8% which would obviously lead to more yarn content in bobbins. The difference in the end breakage rates (normal vs modified cams) was found to be statistically significant.

5 Conclusions

5.1 It has been possible to design linear cams of asymmetrical profile by adopting a combined mathematical and geometrical approach.

5.2 In the jute spinning, the rotational speed of the cam being very low ($\omega_{\max} > 0.3$ rad/s), 240° staggered cam with $\phi_{\max}$ limiting to 34.9° does not have much difference in the spinning performance as compared to that with $\phi_{\max}$ of 31°.

5.3 The initial study at the mill level indicates that both the modified cams may reduce the end breakage rate by 9.4-14.5% which was found to be statistically significant as revealed by Chi-square test.

5.4 Considering the degree of variation in the transmitted yarn tensions, the overall spinning performance and the package density, 240° staggered cam (Base circle, 76 mm) appears to be the most suitable one to replace the existing heart cam of symmetrical profile. The initial findings at the mill level also corroborates with the results obtained at the pilot mill level.

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References