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A Linear Dynamic Model for Rotor-Spun Composite Yarn Spinning Process

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Abstract. A linear dynamic model is established for the stable rotor-spun composite yarn spinning process. Approximate oscillating frequencies in the vertical and horizontal directions are obtained. By suitable choice of certain processing parameters, the mixture construction after the convergent point can be optimally matched. The presented study is expected to provide a general pathway to understand the motion of the rotor-spun composite yarn spinning process.

1. Introduction
Rotor spinning has been adopted worldwide in textile industry. Its main advantages over ring spinning[1] or air-vortex spinning[2,3] are high yarn output rates, reduced production costs, increased bulkiness and improved evenness of the yarns. However, the relatively low breaking strength and wrapper fibers of yarn surface are still matters of concern [4,5]. These disadvantages may be improved by combining staple fibers with a continuous filament yarn in rotor spinning process. Some researchers studied experimentally the spinning conditions and characteristics of rotor-spun composite yarns [6,7]. Nield and Ali [8] suggested a mechanism for producing open-end-spun core-spun yarns. Cheng and Murray[9] studied the effects of spinning conditions on structure and properties of open-end cover-spun yarns; Pouresfandiari et al.[10] focused their work on spinning conditions and characteristics of open-end rotor spin hybrid yarns; Matsumoto et al.[11] revealed twisting mechanisms of open-end rotor spun hybrid yarns; Zhang et al.[12,13] gave twisting characteristics of rotor-spun composite yarns.

In recent years, rotor-spun composite yarn spinning has resulted in a great amount of research. Although various experimental studies have been conducted for a long time, yet a complete mathematical model has not been obtained. In this paper, according to our previous work on Siro-spinning [14], a linear dynamic model is established for the discussed problem.

2. Spinning process of open-end rotor spun combination yarns
Figure 1 illustrates the schematics of the rotor-spun composite yarn spinning process. The filament yarn is fed from a supply bobbin by means of a tension device and a suitable guide to the filament feed rollers, then it moves straight through the filament guide tube and is drawn into the rotor freely by suction. In the rotor the filament yarn is combined with the staple fiber strand to form the composite

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yarn, which is drawn through the doffing tube and finally on to the take-up roller. The filament guide tube is positioned along the axis of rotation of the hollow rotor shaft.

3. Mathematical Model

The characteristics of the composite yarn depends mainly upon how and where the two strands of fibre and filament are combined and mixed, so the convergent point, the point O in Figure 2, is of crucial importance. We first assume the system is in a stable condition. With our self-contained theoretical model which we will discuss in another paper, we can determine the convergent point with ease. Due to some perturbations, the convergent point (equilibrium position (O) in Figure 2) moves to an instantaneous new position (O'). The distances x and y are measured from the equilibrium position. We set OA as the strand of fibres, OB as the filament and OC as the composite yarn, see Figure 2. As the reason of the structure of the rotor as in the figure 1, B and C are in the same vertical line. Here we chose a control volume D, which was chosen in such a way that the mass centre coincides with the convergent point (O) of the strand of fibres, the filament and the composite yarn.
Here A(L-R, -h), B(L, -h), C(L, H-h), C_0(x_0, y_0), C'
\left\{ \frac{x-L}{y-(H-h)} \left[ y_0-(H-h) \right] + L, y_0 \right\},
O(0,0), O'(x,y). L, h can be settled by our self-contained theoretical model.

By a simple geometrical analysis component of forces in x- and y-directions can be written in the forms

\[ \sum F_x = F_1 - F_{1x} + F_{2x} - f_1 - f_2 - f = M \frac{d^2x}{dt^2} \]  
\[ \sum F_y = F_y - F_{1y} - F_{2y} = M \frac{d^2y}{dt^2} \]

Where \( F_1, F_2 \) and \( F \) are, the tension of the strand of fibres, the filament and the composite yarn, respectively. And \( f_1, f_2 \) and \( f \) are, respectively, centrifugal forces acting on the strand of fibres, the filament and the composite yarn. Here, M is the total mass of a fixed control volume. The mass M is the determined from the relation \( M = \rho_1 l_1 + \rho_2 l_2 + \rho_3 \), where \( l_1, l_2 \) and \( \rho_1, \rho_2 \) are, respectively, length and density per unit length of the staple strand and the filament above the convergent point, \( l \) is the distance of the two-strand yarn below the convergent point, and \( \rho \) is the density per unit length of the resultant composite yarn.

The centrifugal forces can be written in the forms

\[ f_1 = m_1 \omega^2 r_1, \quad f_2 = m_2 \omega^2 r_2, \quad f = m \omega^2 r. \]

And \( f_1, f_2 \), and \( f \) are, respectively, centrifugal forces acting on the strand of fibres, the filament and the composite yarn. \( r_1, r_2 \) and \( r \) are respectively the rotating radius of centre of mass for the strand of fibres, the filament and the composite yarn:

\[ r_1 = \frac{x-(L-R)}{2} + L - x = \frac{L+R-x}{2} \]

Similar expressions can be obtained for \( r_2 \) and \( r \).

Masses of the strand of fibres (\( m_1 \)), the filament (\( m_2 \)) and the composite yarn (\( m \)) can be expressed in the forms

\[ m_1 = \rho_1 \cdot O'A = \rho_1 \left[ (x-L+R)^2 + (y+h)^2 \right]^{1/2} \]

Similar expressions can be obtained for \( m_2 \) and \( m \). Where \( \rho_1, \rho_2 \) and \( \rho \) are respectively, the linear densities of the strand of fibres, the filament and the composite yarn.

By a simple geometrical analysis component of forces in x- and y-directions can be written in the forms

\[ F_{1x} = F_1 \left( x-L+R \right) \left[ (x-L+R)^2 + (y+h)^2 \right]^{-1/2} \]
\[ \approx F_1 \left( R-L \right)^2 + h^2 \right]^{-1/2} \left[ 1 + \frac{x}{R-L} - \frac{x(R-L)+yh}{(R-L)^2 + h^2} \right] \]
Similar expressions can be obtained for $F_x$, $F_y$, $F_{2x}$, $F_{2y}$, $f_1$, $f_2$, $f$.

Substituting equations (3)-(6) results in

$$\frac{d^2x}{dt^2} + Ax + By + k_1 = 0$$

(7)

$$\frac{d^2y}{dt^2} + Cx + Dy + k_2 = 0$$

(8)

Here $A$, $B$, $C$, $D$, $k_1$ and $k_2$ are the parameters getting from equations (3)-(6).

When $R=19\text{mm}$, $H=0.9\text{mm}$, $\omega = 45000\text{rpm}$, $|F_1|=20cN$, $|F_2|=18cN$, $|F_3| \approx 0$ to produce 58tex rotor-spun composite yarn with 70D filament, by our quasistatic model we can get that $L=-12.53$, $h=0.47$, $y_0=0.42$. Substituting these numbers into equations (7) and (8), we can get new equations as follows,

$$\frac{d^2x}{dt^2} + (4.8372e+009)x-(8.1583e+007)y+(2.3268e+009)=0$$

(9)

$$\frac{d^2y}{dt^2} + (3.6978e+003)x+(1.2322e+007)y-(4.5759e+004)=0$$

(10)

We can get the phase diagram and the trajectories of the convergent point from equations (9) and (10), as Figure 3 and Figure 4, which show that the system is stable. And the trajectories are in a certain scope for cosine or sine with time, which is of the same amplitude. The wavelength of vibration experiences first increasing and then decreasing regularity. Various trajectories of the convergent point ($O'$) can be obtained by suitable choice of the parameter, as show in Figure 4. The parameters can also be improved by the trajectories of the convergent point.

**Figure 3** Phase diagram of the convergent point
4. Conclusion
We have proposed a linear theoretical model dealing with for the first time a seemingly complex dynamic industrial process of critical importance for the textile industry, especially the specialists in design and manufacturing, which can be applied directly to the spinning process investigation. And the presented model provides a general pathway to study the instability during the rotor–spun composite yarn spinning process.

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