Convergence Point of Three-strand Yarn Spinning

Abstract
A theoretical model for the three-strand yarn spinning system is obtained by using the analysis method for the two-strand case presented by He et al. and setting a series of virtual intermediate variables. Then the convergence point of the three-strand yarn spinning is obtained by eliminating the intermediate variables.

Key words: three-strand yarn spinning, theoretical model, convergence point.

Introduction
The convergence point of multiple-strand yarn spinning plays an important role in controlling the stability of the spinning procedure and quality of spun yarns [1]. Therefore research on the convergence point of the multi-strand yarn spinning, especially the two-strand yarn spinning (Sirospun), has been attracting increasing attention and many interesting results have been established [2 - 5].

Two-strand yarn spinning (Sirospun yarns) is conducted on a conventional ring frame by feeding two rovings simultaneously and has been widely used in the worsted industry. For convergence point analysis of the two-strand case, Emmauel and Plate established a theoretical model considering the force balance and two equations obtained about the three variables \( f \) (tension), \( \alpha \) (angle with the twist point axis), and \( m \) (elastic torque) [6]. Hence the model could not be solved since the numbers of independent equations are less than those of the independent variables, i.e., one additional equation is needed to match the number of independent variables. In order to make the system closed, an experimental procedure was adopted by Miao et al. [7]. Then to overcome this difficulty, He et al. considered the system as self-contained [8] and provide an adequate number of equations by assuming the system obeys the basic laws of mechanics, including force balance, mass conservation and energy conservation. Then the convergence point of two-strand yarn spinning was determined by solving these equations [9].

Three-strand yarn spinning can be designed for smart fabric, having many advantages over two-strand spinning yarn. three-strand yarn can be prepared in a single processing step, and far-reaching implications are emerging for its use in applications including intelligent textiles and multi-functional materials [1]. In this paper, a theoretical model of the three-strand yarn spinning system is given. Using the analysis method of the two-strand case presented by He et al. [10], a series of virtual intermediate variables are set. Then the convergence point of three-strand yarn spinning is obtained by eliminating the intermediate variables.

Model and convergence point
The system in Figure 1 should also obey the basic laws of mechanics: force balance, momentum equation, mass conservation, and energy conservation, just as in the two-strand case presented by He et al. [7]. However, if we use the analysis method of the two-strand case directly, seven equations can be obtained about nine variables, hence the model could not be solved either. To overcome this difficulty, a virtual intermediate process is assumed and a series of virtual intermediate variables are set as shown in

![Figure 1](image)

One kind of asymmetric three-strand yarn spinning.
The governing equations for the system shown in Figure 2 can be written as follows:

1. Force balance

\[ F_i \cos \alpha_i + F_i \cos \alpha_2 = F' \cos \alpha' \]
\[ F_i \sin \alpha_i = F_i \sin \alpha_2 + F' \sin \alpha' \]
\[ M_i \cos \alpha_i + M_i \cos \alpha_2 + R_i F_i \sin \alpha_i + + R_i F_2 \sin \alpha_2 = M' \cos \alpha' + R' F' \sin \alpha' \]

\[ F' \cos \alpha_i + F_i \cos \alpha_2 = F \]
\[ F_i \sin \alpha_i = F' \sin \alpha' \]
\[ M_i \cos \alpha_i + M_i \cos \alpha_2 + \]
\[ M' \cos \alpha' + R' F' \sin \alpha' = M \]

2. Momentum equation

\[ \rho u_i \rho R_i^2 u_i \cos \alpha_i + \rho u_i \rho R_i^2 u_i \cos \alpha_i + \]
\[ \rho u_i \rho R_i^2 u_i \sin \alpha_i = \]
\[ = \rho u_i \rho R_i^2 u_i \sin \alpha_i + \rho u_i \rho R_i^2 u_i \sin \alpha' \]
\[ \rho u_i \rho R_i^2 u_i \cos \alpha_i + \rho u_i \rho R_i^2 u_i \cos \alpha_i = \]
\[ = \rho u_i \rho R_i^2 u_i \sin \alpha_i = \rho u_i \rho R_i^2 u_i \sin \alpha' \]

3. Mass conservation

\[ \pi R_i^2 \rho u_i + \pi R_i^2 \rho u_2 = \pi R^2 \rho u' \]
\[ \pi R_i^2 \rho u_i + \pi R^2 \rho u' = \pi R \rho u \]

4. Energy conservation

\[ \frac{1}{2} \rho u_i \rho R_i^2 u_i^2 + \frac{1}{2} \rho u_i \rho R_i^2 u_i^2 + \]
\[ + \frac{1}{2} \rho u_i \rho R_i^2 u_i^2 + \frac{1}{2} \rho u_i \rho R_i^2 o_i^2 = \]
\[ = \frac{1}{2} \rho u_i \rho R_i^2 u_i^2 + \frac{1}{2} \rho u_i \rho R_i^2 o_i^2 R^2 \]

Solving the above equations, we get

\[ u' = \frac{R_i^2 \rho u_i + R_i^2 \rho u_2}{R_i^2 \rho} \]
\[ \cos(\alpha_i + \alpha') = \frac{a_i^2 + a_2^2 - a_i^2}{2a_i a_2} \]
\[ \cos(\alpha_2 - \alpha') = \frac{a_2^2 + a_2^2 - a_i^2}{2a_i a_2} \]
\[ F_i = \frac{\alpha_i}{a} F' \]
\[ F_2 = \frac{\alpha_2}{a} F' \]

Solving the above equations, we get

\[ u = \frac{R_i^2 \rho u_i + R_i^2 \rho u_2}{R_i^2 \rho} \]
\[ \cos(\alpha_i) = \frac{a_i^2 + a_2^2 - a_i^2}{2a_i a_2} \]
\[ \cos(\alpha_2) = \frac{a_2^2 + a_2^2 - a_i^2}{2a_i a_2} \]

The need further study in the future.

Based on the analysis above, we obtain the following result for the multiple-strand spinning system:

\[ u = \frac{\sum R_i^2 \rho u_i}{R^2 \rho} \]
\[ F_1 = \frac{\alpha_i}{a} F \]
\[ F_2 = \frac{\alpha_2}{a} F \]
\[ F_i = \frac{\alpha_i}{a} F \]

where \( a_i = \rho u_i^2 R_i^2 \).

**Conclusion**

A new theoretical model for the three-strand yarn spinning system has been proposed and corresponding convergence point has been obtained by eliminating the intermediate variables. Furthermore the convergence point of the multiple-strand spinning system has been presented, which lays a foundation for practical system design. The present study reveals that the tension on the convergence point of each strand \( F_i \) depended only on the flow characters of each strand and its resultant yarn for the multiple-strand spinning system. But the expressions of the angle \( \alpha_i \) and elastic torque \( M_i \) of each strand at the convergence point need further study. However, experimental verification is not given to validate the model in the paper at present. Such experimental work is under way and the results will be reported in the future.

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