Xuzhong Su*,
Weidong Gao,
Xinjin Liu,
Chunping Xie,
Bin Huang

Convergence Point of Three-strand Yarn Spinning

Key Laboratory of Eco-Textile,
Ministry of Education,
Jiangnan University,
Wuxi 214122, P. R. China,
*E-mail: mfgucv@163.com

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, Emmanuel and Plate established a theoretical model considering the force balance and two equations obtained about the three variables f (tension), α (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

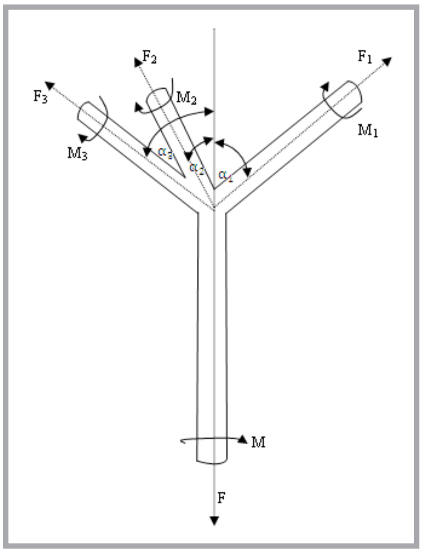

Figure 1. *One kind of asymmetric three-strand yarn spinning.*

Nomenclature

- F - *Tension and elastic torque in the two-strand yarn below the convergence point;*
- M - *Elastic torque in the two-strand yarn below the convergence point;*
- ρ - *Density of the spun yarn;*
- u - *Velocity of the spun yarn;*
- F_i - *Tension of the i-th substrand above the convergence point;*
- M_i - *Elastic torque of the i-th substrand above the convergence point;*
- ρ_i - *Density of the i-th substrand above the convergence point;*
- u_i - *Velocity of the i-th substrand above the convergence point;*
- R_i - *Radius of the i-th substrand above the convergence point;*
- α_i - *Angles between the i-th substrand and twist point axis;*
- F' - *Tension of the virtual intermediate substrand;*
- M' - *Elastic torque of the virtual intermediate substrand;*
- α' - *Angles between the virtual intermediate substrand and twist point axis;*
- α' - *Density of the virtual intermediate substrand;*
- u' - *Velocity of the virtual intermediate substrand;*
- R' - *Radius of the virtual intermediate substrand;*
- n - *Number of substrands.*

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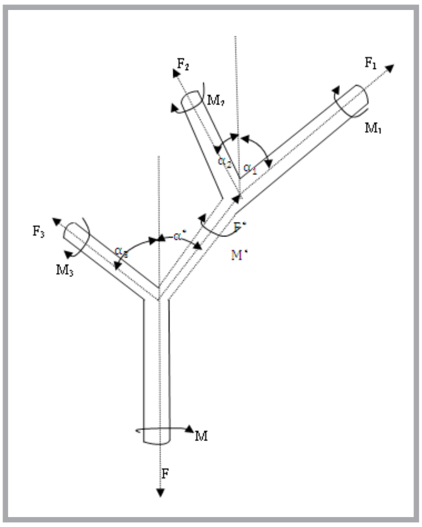

Figure 2. One kind of asymmetric three-strand yarn spinning with virtual intermediate process.

Figure 2. The governing equations for the system shown in ***Figure 2*** can be written as follows:

1. Force balance

$$F_1\cos\alpha_1+F_2\cos\alpha_2=F'\cos\alpha'$$
$$F_1\sin\alpha_1=F_2\sin\alpha_2+F'\sin\alpha' \qquad (1)$$
$$M_1\cos\alpha_1+M_2\cos\alpha_2+R_1F_1\sin\alpha_1+$$
$$+R_2F_2\sin\alpha_2=M'\cos\alpha'+R'F'\sin\alpha'$$

$$F'\cos\alpha_1+F_3\cos\alpha_3=F$$
$$F_3\sin\alpha_3=F'\sin\alpha'$$
$$M_3\cos\alpha_3+M_3\cos\alpha_3+$$
$$+M'\cos\alpha'+R'F'\sin\alpha'=M \qquad (2)$$

2. Momentum equation

$$\rho_1u_1\pi R_1^2u_1\cos\alpha_1+\rho_2u_2\pi R_2^2u_2\cos\alpha_2=$$
$$=\rho'u'\pi R'^2u'\cos\alpha'$$
$$\rho_1u_1\pi R_1^2u_1\sin\alpha_1= \qquad (3)$$
$$=\rho_2u_2\pi R_2^2u_2\sin\alpha_2+\rho'u'\pi R'^2u'\sin\alpha'$$

$$\rho_3u_3\pi R_3^2u_3\cos\alpha_3+\rho'u'\pi R'^2u'\cos\alpha'=$$
$$=\rho u\pi R^2u \qquad (4)$$
$$\rho_3u_3\pi R_3^2u_3\sin\alpha_3=\rho'u'\pi R'^2u'\sin\alpha'$$

3. Mass conservation

$$\pi R_1^2\rho_1u_1+\pi R_2^2\rho_2u_2=\pi R'^2\rho'u' \qquad (5)$$

$$\pi R_3^2\rho_3u_3+\pi R'^2\rho'u'=\pi R^2\rho u \qquad (6)$$

4. Energy conservation

$$\frac{1}{2}\rho_3u_3\pi R_3^2u_3^2+\frac{1}{2}\rho_3u_3\pi R_3^2\omega_3^2R_3^2+$$
$$+\frac{1}{2}\rho'u'\pi R'^2u'^2+\frac{1}{2}\rho'u'\pi R'^2\omega'^2R'^2 \qquad (7)$$
$$=\frac{1}{2}\rho u\pi R^2u^2+\frac{1}{2}\rho u\pi R^2\omega^2R^2$$

$$\frac{1}{2}\rho_1u_1\pi R_1^2u_1^2+\frac{1}{2}\rho_2u_2\pi R_2^2u_2^2+$$
$$+\frac{1}{2}\rho_1u_1\pi R_1^2\omega_1^2R_1^2+\frac{1}{2}\rho_2u_2\pi R_2^2\omega_2^2R_2^2$$
$$(8)$$
$$=\frac{1}{2}\rho'u'\pi R'^2u'^2+\frac{1}{2}\rho'u'\pi R'^2\omega'^2R'^2$$

Solving the above ***Equations 1, 3, 5 and 7***, we get

$$u'=\frac{R_1^2\rho_1u_1+R_2^2\rho_2u_2}{R'^2\rho'} \qquad (9)$$
$$\cos(\alpha_2+\alpha')=\frac{a'^2+a_2^2-a_1^2}{2a'a_2}$$
$$\cos(\alpha_1-\alpha')=\frac{a'^2+a_1^2-a_2^2}{2a'a_1}$$
$$F_1=\frac{a_1}{a'}F'$$
$$F_2=\frac{a_2}{a'}F'$$

Solving the above ***Equations 2, 4, 6 and 8***, we get

$$u=\frac{R_3^2\rho_3u_3+R'^2\rho'u'}{R^2\rho}$$
$$\cos(\alpha')=\frac{a^2+a'^2-a_3^2}{2aa'}$$
$$\cos(\alpha_3)=\frac{a^2+a_3^2-a'^2}{2a\ \ _3} \qquad (10)$$
$$F'=\frac{a'}{a}F$$
$$F_3=\frac{a_3}{a}F$$

where

$$a_1=\rho_1u_1^2R_1^2,a_2=\rho_2u_2^2R_2^2,\cdot$$
$$a_3=\rho_3u_3^2R_3^2,a'=\rho'u'^2R'^2,a=\rho u^2R^2$$

Therefore, eliminating the intermediate variables from equations (9) and (10), we have

$$u=\frac{R_1^2\rho_1u_1+R_2^2\rho_2u_2+R_3^2\rho_3u_3}{R^2\rho}$$
$$F_1=\frac{a_1}{a}F \qquad (11)$$
$$F_2=\frac{a_2}{a}F$$
$$F_3=\frac{a_3}{a}F$$

We can also get cos(α_1) and cos(α_2) by eliminating the intermediate variable α' from ***Equations 9*** and ***10***, but the expressions of cos(α_i) contains α' in this case. For expression $a' = \rho' u'^2 R'^2$, we know that the velocity *u*' is equal to *u* for the actual three-strand spinning system, shown in ***Figure 1***, but the density ρ' and radius *R'* of the virtual intermediate strand are difficult to obtain or are even impossible. This need further study in the future.

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

$$u=\frac{\sum_{i=1}^{n}R_i^2\rho_iu_i}{R^2\rho}$$
$$F_1=\frac{a_1}{a}F$$
$$F_2=\frac{a_2}{a}F \qquad (12)$$
$$\vdots$$
$$F_n=\frac{a_n}{a}F$$

where $a_i=\rho_iu_i^2R_i^2$.

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 α_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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References

1. He JH. Variational Approach to Nonlinear Coupled Oscillators Arising in Siro-

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For more information please contact:

Katarzyna Pieklak
Phone +48 42 631 33 38,+48 507 243 752
e-mail: katarzyna.pieklak@op.pl www.ttww.pl

spun Yarn Spinning. *Fibers & Textiles in Eastern Europe* 2007; 15(60): 31-34.
2. Pracek S. Theory of String Motion in the Textile Process of Yarn Unwinding. *International Journal of Nonlinear Sciences* 2007; 8(3): 451-460.
3. Cheng KPS, Sun MN. Effect of strand spacing and twist multiplier on cotton Sirospun yarn. *Textile Research Journal* 1998; 68(7): 520-527.
4. Sun MN, Cheng KPS. Structure and properties of cotton Sirospun yarn. *Textile Research Journal* 2000; 70 (3): 261-268.
5. Miao M, Cai Z, Zhang Y. Influence of machine variables on two-strand yarn spinning geometry. *Textile Research Journal* 1993; 63(2): 116-120.
6. Emmanuel A, Plate DEA. An alternative approach to two-fold weaving yarn Part II: The theoretical model. *The Journal of the Textile Institute* 1982; 73(2): 107-116.
7. Miao M, Cai Z, Zhang Y. Influence of machine variables on two-strand yarn spinning geometry. *Textile Research Journal* 1993; 63(2): 116-120.
8. He JH, Yu YP, Pan N, et al. Quasi-static model for two-strand yarn spinning. *Mechanics Research Communications* 2005; 32(2): 197-200.
9. He JH, Zhang LN. On convergence point of the Two-strand yarn spinning. *Textile Research Journal* 2008; 78(11): 1022–1024.
10. He JH, Yu YP, Yu JY, et al. A nonlinear dynamic model for two-strand yarn spinning. *Textile Research Journal* 2005; 75(2): 181-184.

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