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Numerical simulation of three-dimensional flow field in three-line rollers and four-line rollers compact spinning systems using finite element method

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In this investigation, the airflow velocity principle in the condensing zone of three-line rollers and four-line rollers compact spinning systems has been studied and the relationship between the flow distribution in velocity component and the yarn properties is discussed. The important effect is the accurate description of the yarn track in the condensing zone. The yarns of 9.72tex, 14.58tex and 29.15tex fineness have been spun on three-line rollers and four-line rollers compact spinning systems respectively. The hairiness, the breaking force and the evenness of the spun yarns are tested respectively. With the help of a high-speed video camera, a periodic movement of the fibres in bundle in the condensing zone has been detected firstly and the yarn tracks are described. Numerical simulations are investigated using ANSYS software. The yarn tracks are different. The flow velocity component on transverse condensing direction of fibres in bundle has the direct condensing effect, which is beneficial for ameliorating evenness. The flow velocity component on output and thickness direction of fibres in bundle has the assistant condensing effect and can improve spun yarn strength and reduce yarn hairiness.

Keywords: Compact spinning, Flow field, Finite element method, Four-line rollers, Three-line rollers, Yarn track

1 Introduction

Since exhibited for the first time at ITMA 99 [1], compact spinning has been developed and used in many spinning mills, which meets the demands of manufacturers and consumers in a way. Compared to foreign spinning industry, the development of domestic lattice apron-type compact spinning is at low speed, which is restricted by undesired special wares such as groove tube[2-5] and immature spinning technology including poor stability, and working reliability in spinning process. Research on pneumatic compact spinning system mainly focuses on process optimization, equipment update and yarn property improvement.

Research on pneumatic compacting spinning system always emphasizes on the velocity distribution in the condensing zone, and the important influencing factor of numerical simulation of pneumatic compacting spinning is the velocity extraction[6,7]. However, the velocity extraction of the numerical simulation of three-line rollers and four-line rollers compact spinning systems were not according to the actual yarn tracks in spinning process. For example, the velocity extractive curve of the numerical simulation was along the suction flume sides[8-10]. The extractive curve of three-dimensional flow field of four-line rollers compact spinning was one line, which is perpendicular to output direction of fiber strand in the condensing zone[11-15]. In this study, the extractive curve was obtained by the yarn tracks in the condensing zone, which were obtained in spinning process with the help of a high-speed-video-camera. In order to reveal the principle between yarn counts yarn tracks in the condensing zone, 9.72tex, 14.58tex and 29.15tex were chosen for this work. Furthermore, the comparison between three-line rollers and four-line rollers compact spinning of 9.72tex, 14.58tex and 29.15tex were also studied in this investigation.

First, in order to accurately describe the yarn tracks in the condensing zone, two-dimension coordinate has been created which is based on suction flumes of three-line rollers and four-line rollers compact spinning systems respectively. A periodic movement of fiber strand in the condensing zone was detected with the help of a high-speed-video-camera and the yarn tracks are described in two-dimension coordinate. Second, numerical studies on the three-dimension flow field are analyzed using ANSYS software. Furthermore, the velocity extractions of flow field distribution were according to the yarn tracks in two-dimension coordinate and the principles

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are obtained. Finally, combined with yarn experiment, the relationship between the distribution of three-dimension flow filed and yarn properties is studied.

2 Materials and Methods

2.1 Compact Spinning Systems and Experiment

Three-line rollers compact spinning and four-line rollers compact spinning, belonging to pneumatic compact spinning, are the two of the most widely used compact spinning system at present, which are achieved by using lattice apron to condense the fiber strand and improve the yarn qualities. Compared with three-line rollers compact spinning, there is one more delivery roller in four-line rollers compact spinning, which makes the movements of the yarn in the condensing zone more complex directly and leads to the difference of the yarn tracks in the condensing zone.

Cotton yarn of the fineness 9.72tex, 14.58tex and 29.15tex cotton were respectively spun on the ring spinning frame modified by three-line rollers and four-line rollers compact spinning systems. The linear density of the cotton roving is 3.58g/10m.

3 Results and Discussion

3.1 Two-dimension Coordinate in Condensing Zone

Since one of the most critical influences on the condensing effect is suction chute, two-dimension coordinate in the condensing zone of three-line rollers and four-line rollers compact spinning systems is built (Fig.1). We set the extended line of the upper boundary of suction chutes as x–axis of the coordinate. These origins of two-dimension coordinate are kept at the left and respectively set at 18 mm apart (Fig.1).

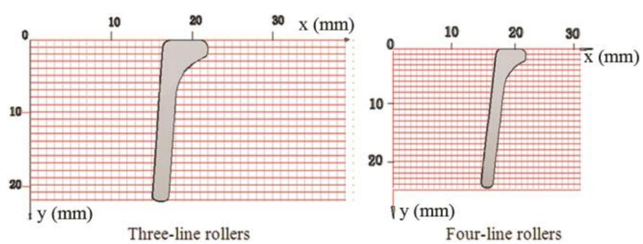

Fig. 1—Two-dimension coordinate in the condensing zone of lattice apron-type compact spinning

3.2 The Yarn Tracks in Condensing Zone

In this section, we attempt to respectively describe the yarn extractive curves in the condensing zone of 60s, 40s and 20s of three-line rollers and four-line rollers compact spinning systems. First, the yarn tracks in the condensing zone are obtained by using high-speed video camera (Fig. 2). It shows that the yarn track in the condensing zone is affected by different yarn counts and compact spinning systems. Second, all kinds of the yarn extractive curves were obtained by extracting the center line of the yarn tracks in two-dimension coordinate respectively (Fig. 3). In case of three line rollers, we describe yarn extraction curves of 9.72tex, 14.58tex and 29.15tex yarns with 21 points, which are intersects at each X-axis (from Y=2 to Y=22). Yarn extractions of four-line rollers compact spinning with 26 points, are also shown in Fig. 3. There are intersects at each X-axis (from Y=1 to Y=26).

3.3 Numerical Simulation of Flow Velocity

In this section, we attempt to reveal principles of velocity distributions and the difference between three-line rollers and four-line rollers compact spinning. Through ANSYS/General Postprocessor, the flow velocity is obtained which displays the velocity distribution principle. Velocity extractions of 9.72tex, 14.58tex and 29.15tex of three-line rollers and four-line rollers compact spinning systems are

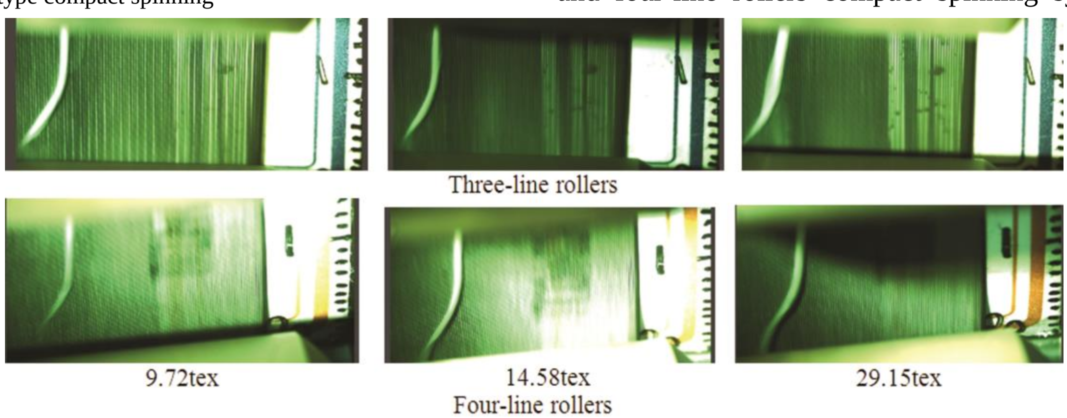

Fig. 2—Yarn tracks of three-line and four-line rollers compact spinning

found along the yarn extractive curves in Fig. 3. The results are respectively shown in Figs 4-6 and the abscissa are the points which represent the yarn tracks in condensing zone. The flow velocity of three-line rollers and four-line rollers compact spinning systems with value of h=5mm is simulated.

3.3.1 Velocity Component on X-axis Direction

The velocity component on X-axis direction (output direction of fibres in bundle) is given in Fig. 4. Here, the positive and negative values represent that the velocity direction follows the negative and positive path on the X-axis respectively. The velocity component of 9.72tex three-line rollers compact spinning is symmetric with Y= 10 and the value of four-line rollers is negative from 2 m/s to 10 m/s. Compared with four-line rollers compact spinning, the velocity value of 14.58tex three-line rollers has the similar trend and the higher positive value. It is shown that the velocity value of 29.15tex three-line rollers compact spinning is negative ,which is symmetric with Y=12 and that of four-line rollers is almost positive. Since the negative values possibly keep beneficial hairiness, we can infer that the hairiness of 9.72tex, 14.58tex and 29.15tex three-line rollers compact spinning is respectively more, less and more than that of four-line rollers compact.

3.3.2 Velocity Component on Y -axis Direction

In this section, Y-axis direction represents transverse condensing direction of the fibre stand and the diagram of the velocity component is given in Fig. 5. Here, the positive and negative values represent that the velocity direction follows the positive and negative directions on the Y-axis. The plot of 9.72tex three-line rollers compact spinning is symmetric with respect to Y=8. The velocity component of 9.72tex four-line rollers has the different principle and the value of 0-9 points is from 0-10m/s and the value of 9-21 points is from 0 m/s to -4 m/s. The velocity principle of 14.58tex three-line rollers and three-line rollers compact spinning is

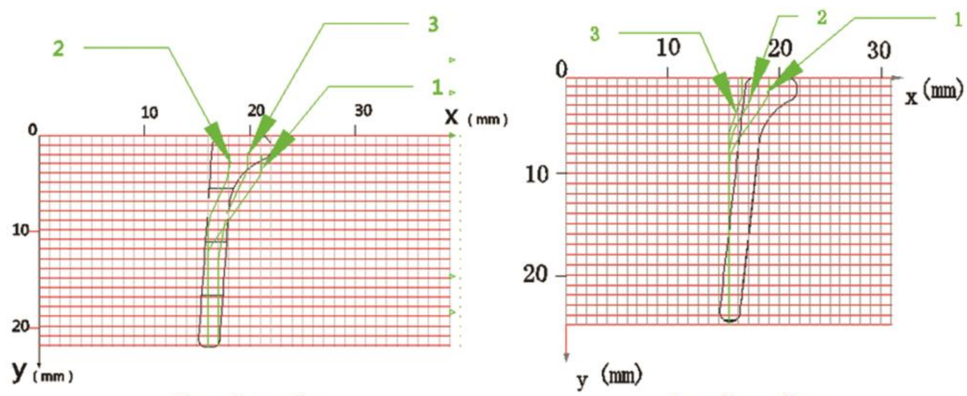

Fig. 3—Yarn extraction of three-line rollers and four-line rollers compact spinning [(1) 9.72tex, (2) 14.58tex, (3) 29.15tex]

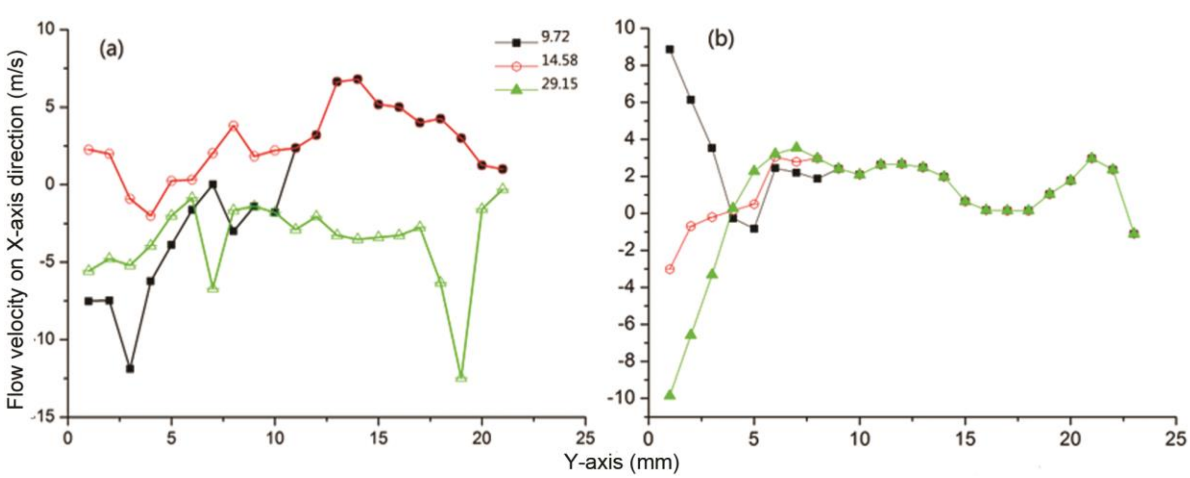

Fig. 4—Plot of flow velocity component on X-axis directions of three-line rollers compact spinning and four-line rollers compact spinning [(a)Three-line rollers and (b) Four-line rollers]

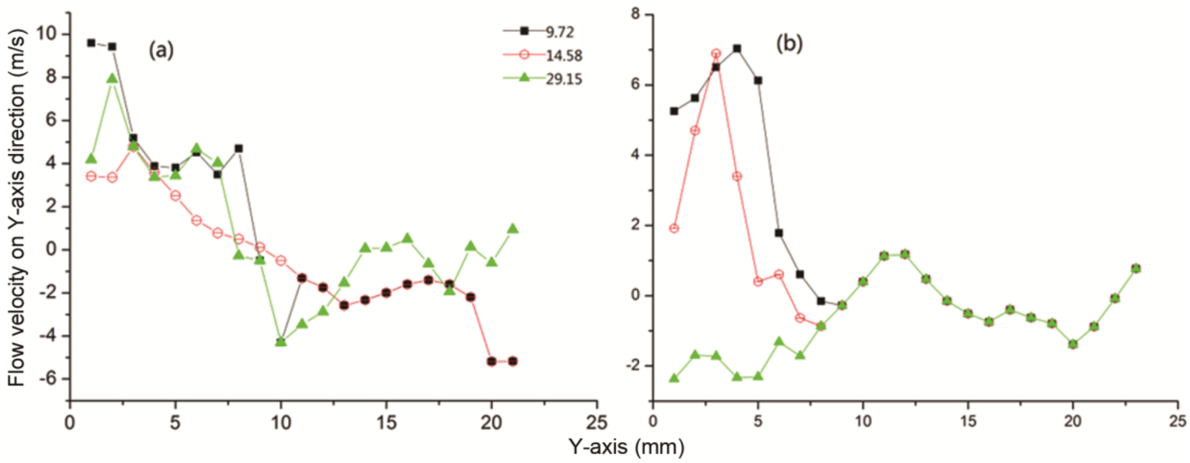

Fig. 5—Plot of flow velocity component on Y-axis directions of three-line rollers compact spinning and four-line rollers compact spinning [(a)Three-line rollers and (b) Four-line rollers]

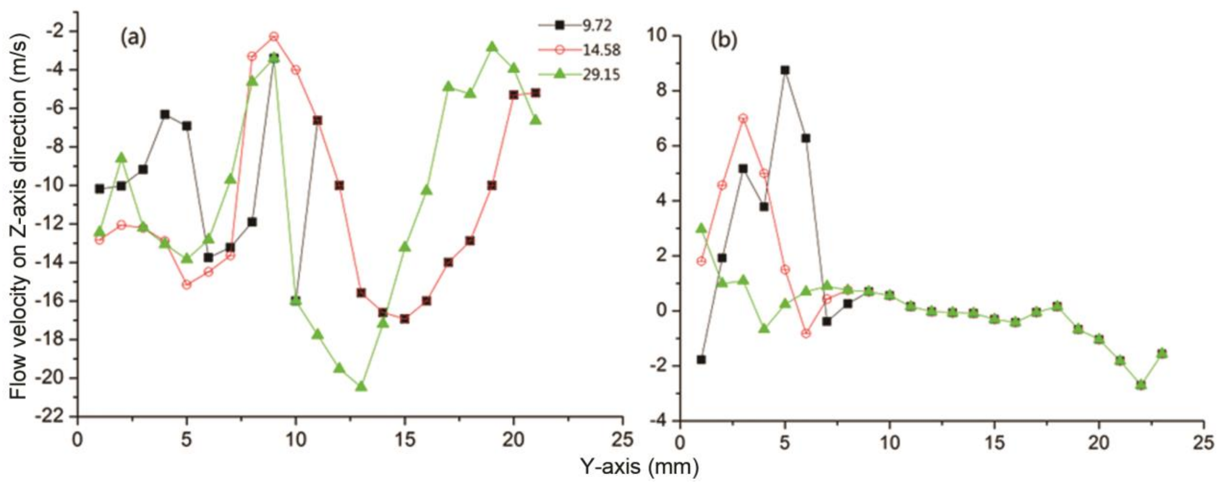

Fig. 6—Plot of flow velocity component on Z-axis directions of three-line rollers compact spinning and four-line rollers compact spinning [(a)Three-line rollers and (b) Four-line rollers]

similar to that of 9.72tex. The velocity component of 29.15tex three-line rollers compact spinning is symmetric with respect to Y=8. The value of four-line rollers is negative and the plot is symmetric with respect to Y=12. The fiber strand in the condensing zone of three-line rollers compact spinning is affected by the initial twist, which is produced by the symmetrical velocity component. We can imply that the evenness of 9.72tex, 14.58tex and 29.15tex three-line rollers compact spinning will be better than those four-line rollers.

3.3.3 Velocity Component on Z –axis Direction

Z-axis direction represents thickness direction of the fibre strand. The negative value of the velocity component on Z-axis direction makes the fiber stand to attack lattice apron and improves the transverse condensing effect. The diagram of the velocity component on Z-axis direction is given in Fig. 6. It is show that the velocity component of 9.72tex, 14.58tex and 29.15tex three-line rollers compact spinning are from -2m/s to-20m/s, while flow velocity component of four-line rollers is from 0m/s to10m/s. The velocity component of three-line rollers compact spinning is beneficial for ameliorating evenness and yarn structure is possibly presumed to be more stable than that of four-line rollers.

3.4 Yarn Preparation and Evaluation of Physical Properties of Yarn

All tests were performed after the yarns were kept in standard atmospheric conditions for at least 24h under standard conditions (65±5% relative humidity, 20±2˚C). The test specimen is 5 bobbins from different spindles and each bobbin is tested 10 times.

The hairiness, the breaking force and the evenness of the spun yarns are tested and the results are given in Tables 1-3.

The specimen was tested using YG172 yarn hairiness tester. The test length is 10 m and the test speed is 100 m/min. The testing results of yarn hairiness are given in Table 1. It is obviously shown that the harmful hairiness (>3 mm) of yarn count 60s of four-line rollers reduces by 4.5% than that in three-line rollers compact spinning, which increases by 5.9% for 14.58tex and reduces by 6.5% for 29.15tex. In Fig. 4, the negative values possibly keep beneficial hairiness. The velocity value of 9.72tex and 29.15tex three -line rollers compact spinning is negative, which have more hairiness. The flow velocity of 40s of three-line rollers compact spinning is higher than that of four-line rollers and has less hairiness.

In this section, the evenness was tested using Uster Tester.5-S800 evenness tester under a speed of 400 m/min. The test length is 400m. The measured results are given in Table 2.

Table 2 shows that the evenness of 9.72tex, 14.58tex and 29.15tex three-line rollers compact spinning is better than that of four-line rollers. The evenness of 9.72tex three-line rollers compact spinning reduces by 3.3%, 40s by 2.1% and 20s by 3.5% than that of four-line rollers compact spinning. In this study, yarn counts were spun under the same experimental conditions. Therefore, the most critical influence on the evenness is the airflow distribution in the condensing zone. As compared to four-line rollers, three-line rollers compact spinning has the symmetrical airflow distribution, which may ameliorate the evenness (Fig. 5). The airflow distribution principle matches testing results of yarn evenness.

The breaking force of yarns was tested on YG068C fully automatic single yarn strength tester at a speed of 500 mm/min with pre-tension of 0.5 cN/tex. The yarn tension of different counts is adjusted by 0.5

Table 1—Testing results of yarn hairiness

Yarn count, tex	Compact spinning system	Hairiness (≥1 mm)/10m	Hairiness (≥2 mm)/10m	Hairiness (≥3 mm)/10m	H
9.72	Three-line rollers	650.00	217.80	71.80	2.35
	Four-line rollers	646.00	219.00	60.20	2.31
14.58	Three-line rollers	651.40	185.90	80.50	3.22
	Four-line rollers	886.20	203.90	103.20	3.40
29.15	Three-line rollers	1547.80	477.80	122.80	5.37
	Four-line rollers	1536.80	580.20	192.00	5.04

Table 2—Testing results of yarn evenness

Yarn count, tex	Compact spinning system	Evenness CV%	Thin (-50%)	Thick (+50%)	Neps (+200%)
9.72	Three-line rollers	12.62	5.00	33.00	80.00
	Four-line rollers	13.04	5.00	45.00	95.00
14.58	Three-line rollers	12.08	3.00	10.00	35.70
	Four-line rollers	12.29	0.00	18.40	42.50
29.15	Three-line rollers	11.70	0.00	10.00	35.00
	Four-line rollers	12.11	0.00	15.00	45.00

Table 3—Breaking strength results

Yarn count, tex	Compact spinning system	Breaking strength cN	Breaking Elongation, %	Work of break cN·cm	Breaking tenacity cN/tex
9.72	Three-line rollers	218.00	5.76	310.62	22.52
	Four-line rollers	222.36	6.09	331.92	22.88
14.58	Three-line rollers	289.00	5.90	410.74	19.82
	Four-line rollers	292.35	6.42	450.85	20.05
29.15	Three-line rollers	645.05	6.82	1029.70	22.13
	Four-line rollers	655.01	7.23	1134.00	23.22

± 0.1cN/tex. The test length is 500 mm and the test speed is 500 mm/min. The testing results are given in Table 3.

It is obscure that for 9.72tex, 14.58tex and 29.15tex three-line rollers compact spinning, the tensile properties are better than that of four-line rollers compact spinning. On the one hand, transverse condensing effect of three-line rollers compact spinning in the condensing zone is better than that of four-line rollers compact spinning. On the one hand, the value of flow velocity component on Z-axis is higher and the fibre in the condensing zone is more effectively in control than that of four-line rollers compact spinning. The measured results match the results of numerical simulation (Fig. 6).

4 Conclusion

The yarn tracks in the condensing zone of 9.72tex, 14.58tex and 29.15tex three-line rollers and four-line rollers compact spinning systems are described with the help of a high-speed-video-camera and numerical simulation is investigated by using finite element method. The yarn extractive curves are described along the center line of the yarn track and each plot is different.

Combining with yarn experiment, the relationship between the distribution of flow field in the condensing zone and yarn properties has been discussed. The negative values on X-axis possibly keep beneficial hairiness. The velocity value of 9.72tex and 29.15tex three -line rollers compact spinning is found negative, which have more hairiness. The yarn evenness is affected by the velocity distribution on Y-axis and three-line rollers compact spinning has the symmetrical airflow distribution, which has better yarn evenness. The value of flow velocity component on Z-axis is higher and the fibre in the condensing zone is more effectively in control. For 60s, 40s and 20s of three-line rollers compact spinning, the value of flow velocity component on Z-axis is higher than that of four-line rollers compact spinning and the fibre in the condensing zone is in more effectively control with the better breaking force.

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