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Developing a New Drafting System for Ring Spinning Machines

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ABSTRACT

In order to raise yarn quality, a new drafting system concept for ring spinning machines is developed in this study, along with an analysis of its controlling effects. To optimize the new drafting system, its structural parameters are studied and two empirical equations for yarn unevenness and nep count model its design. The equation of yarn unevenness is used to find the optimum structural parameters of the new drafting system. Practical spinning tests with the optimized system prove that it can reduce unevenness, thin places, thick places, and neps in spun yarns, and that the equation for yarn unevenness can be used to satisfactorily estimate the unevenness of spun yarns.

Ring spinning machines in the modern short-staple spinning mill, without exception, are fitted with three-line double-apron drafting arrangements (hereafter referred as normal drafting devices). In the break draft zone, fiber guidance is still provided by the rollers alone, so that the fibers in the fiber strand cannot be controlled properly. If the draft effect in the break draft zone can be improved, not only can yarn quality be higher, but also the break draft ratio can be greater so that the total draft ratio can be raised.

In order to improve the draft effect in the break draft, we have developed a new design concept for a drafting system for ring spinning machines. We then analyze its controlling effects, optimize its structural parameters, and finally present the results of spinning tests with the new system.

New Design Concept of the Drafting Arrangement

The new drafting arrangement [2], shown in Figure 1, extends the upper apron unit to cover the two drafting zones. Part of the upper apron unit in the main draft zone is the same as that of the normal drafting device. Part of the upper apron unit in the break draft zone pushes the fiber strand down into a position lower than the straight path line linking the two nip points of the rear roller pair and the middle roller pair.

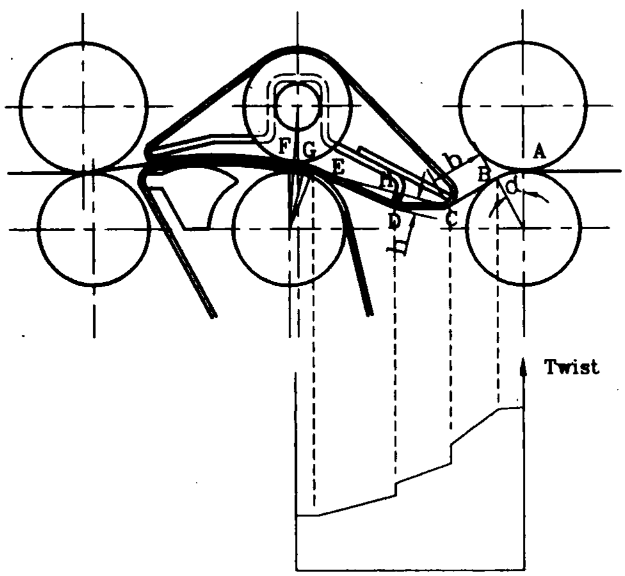

FIGURE 1. New concept drafting system and fiber strand twist distribution in break drafting zone.

The new drafting arrangement design has several advantages. First, the fibers in the fiber strand can be better controlled and guided in the break draft zone. There are

[1] Deceased.

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two corners, C and D, on the upper apron unit in the break draft zone. Corner C pushes the fiber strand down to deflect around a small arc of the rear lower roller like the INA drafting arrangement. Corner D pushes the strand to deflect around the surface of the apron, CDEF. Therefore, except for the small section BC, the fiber strand will be controlled and guided when it is passing through the break draft zone.

Second, its mechanism is simple. In the new design, the system does not require additional parts and only two existing parts need to be replaced, the upper apron-tensioning device and the upper apron. The upper apron-tensioning device can be redesigned in combination with the two parts in the main draft zone and the break draft zone, and simply formed from sheet metal by a punch press.

Finally, the new design is convenient for renovating existing ring spinning machines. Only the two parts need to be replaced, and there are no other changes. Furthermore, the upper apron and the upper apron-tensioning device are very easy to replace, so the cost and the skill required for the renovation are minor.

Analysis of Controlling Effects

STROKE OF UPPER APRON ON FIBERS

The speed of the upper apron is equal to the peripheral speed of the middle rollers. The speed of the fiber strand entering the break draft zone is equal to the peripheral speed of the rear rollers. Since there is a draft ratio from 1.05 to 1.5 between the rear roller pair and the middle roller pair, the speed of the upper apron is greater than the speed of the fiber strand entering the break draft zone. When the fiber strand touches the upper apron at point C, there is a relative motion between them and the upper apron will stroke the strand.

The stroke produces two effects: First, it straightens fiber leading hooks. The fibers in the strand may be leading hooked, trailing hooked, or double hooked. When the free fiber leading hooks on the outer layer of the fiber strand touch the surface of the upper apron at point C, the upper apron will accelerate the free fiber leading parts, while the trailing part of the fiber is moving with the body of the fiber strand at a relatively lower speed. Thus, the fiber is straightened before the whole fiber reaches drawing speed, and the leading hook is eliminated, thus reducing yarn hairiness.

The second effect is that some trailing hooks are created. When the free fiber trailing ends on the outer layer of the fiber strand touch the surface of the upper apron at point C, the upper apron will also accelerate the free fiber trailing end and form a new trailing hook if the leading part of the fiber is moving with the body of the fiber strand at a relatively lower speed. But these trailing hooks can be straightened later. When the fiber leading end enters the nip region of the drawing roller pair (*i.e.*, the front roller pair in the main draft zone), the leading end will be accelerated while the trailing part of the fiber is moving with the body of the fiber strand or the upper apron at a relatively lower speed. The fiber is then straightened before the whole fiber reaches drawing speed, and the trailing hook is eliminated. Therefore, although the upper apron in the break draft zone may create some new trailing hooks, they will be eliminated after they pass through the front roller nip.

FAVORABLE TWIST DISTRIBUTION

The roving in the break draft zone is moving under tension due to the speed difference between the middle roller pair and the rear roller pair. Roving has certain twist and will be untwisted under tension. If there is no control, low twist levels may cause false drafts or even roving breaks. In the new design, when the roving is in contact with the upper apron, the frictional force between them will resist the untwisting of the roving, and the two corners, C and D, will press the roving to resist the transmission of the untwisting. The higher the pressure, the greater the ability to resist untwisting. Therefore, the twists of fiber strands on both sides of the pressing point are not equal to each other, that is, the twist is not reduced linearly at the point, forming a step as shown in Figure 1. Thus, the twists in section DE are smaller than those in section CD, which are, in turn, smaller than those in section BC. In each section, the twist is reduced linearly. Different sections will have different slopes according to specific conditions, such as section length, friction, and so on. This twist distribution of fiber strands is favorable for the stability of the position where the fibers are accelerated, so that the yarn will possibly be kept as even as the original fiber strand.

Section AB: In this section, the roving just enters the break draft zone and is pressed by the upper apron to deflect around the arc of rear lower roller. Therefore, there is a frictional force between the roving and the rear lower roller in this section that resists the untwisting of roving. Thus, both the roving twist and the cohesive friction are the greatest. Since this section is much shorter than the fiber lengths, all the fibers are nipped by the rear roller pair, although the fiber leading ends have passed the nip point. Therefore, the fibers entering this section cannot be accelerated.

Section BC: In this section, there is no control on the roving, so it can be untwisted freely. Therefore, the roving twist close to point C is smaller than that at point

B, and the twist is reduced linearly. But the length of section BC is very short and the twist cannot be reduced too much, so it is still relatively higher. When the leading ends of long fibers reach point C, their trailing ends have not passed the nip point of the rear roller pair. Therefore, the long fibers cannot be accelerated by a few adjacent fibers whose trailing ends are accelerating.

Although it is possible that there are some short fibers in the section whose trailing ends have passed point A, they also cannot be accelerated for two reasons: First, the trailing ends of the short fibers are in section AB where the cohesive friction is greater than that near point C due to the higher twist and high friction between the fiber strand and the rear lower roller in section AB. Second, most of surrounding fibers are not accelerated. Even if there are some long fibers whose trailing ends are being accelerated in section BC, the drawing force on the leading end of short fibers by a few adjacent fibers moving at a higher speed is not great enough to overcome the cohesive friction on the trailing end of the short fibers. Therefore, no fiber is accelerated in section BC.

Section CD: In this section, the fiber strand is in contact with the upper apron. Although the fiber strand can be untwisted, it is not so easy as in section BC. The slope of varying twist in section CD is thus smaller than that in section BC. When the leading ends of long fibers reach point D, their trailing ends have not passed the nip of the rear roller pair or just passed it and are in section AB. Since the clamping force on the trailing end is always greater than the drawing force on the leading end by the adjacent accelerating fibers, the long fibers still cannot be accelerated or drawn apart. For short fibers, their trailing ends will be in section BC when their leading ends reach point D. But in this case, two things happen. First, the twist of the fiber strand in section BC is higher than that in section CD with greater difference. Thus the cohesive friction between fibers in section BC is greater than those in section CD. Second, corner C inserts great pressure on the fiber strand, so there is frictional resistance between the upper apron and the fiber strand and more condensation of fibers at point C. Therefore, the resistance at point C will be much bigger than the cohesive friction of fibers in section CD.

These two factors result in greater resistance on the trailing part of the short fibers than the drawing force acting on the leading part of the short fibers by the adjacent fibers or the upper apron moving at higher speeds. Therefore, short fibers also cannot be accelerated in this section.

Section DE: In this section, the situation is very similar to that in section CD. For long fibers, when the leading ends approach point E, the trailing end will be in section BC. Since there are two corners along the fiber length, the twist difference of the fiber strand between the leading end and the trailing end will be bigger, so that adding the resistance at the two corners means the resistance on the trailing part will be higher than the drawing force on the leading part by the adjacent fibers or the upper apron moving at higher speed. For short fibers, the situation is not so favorable as for long fibers because there may be only one corner along the fiber length, and the drawing force on the leading end is bigger since its leading end is near the nip region. But the short fibers also cannot be accelerated in this section like those in section CD as reported above, only if the position of point D is selected properly.

Section EF: In this section, the fiber strand is in contact with the lower apron, moving at the peripheral speed of the middle lower roller, and clamped by the upper and lower aprons. Since the frictional force between fibers produced by the clamping force is much higher than that on the trailing part of the fibers, both long and short fibers will be accelerated. The length of section EF decides the range of accelerating points. If the length of arc EF is small enough, by choosing the position of point D properly, the range of accelerating points can be very small and close to the nip of the middle roller pair.

To sum up, in the new design, the fibers passing through the break draft zone cannot be accelerated until they reach section EF. Since section EF is very short and close to the nip of the middle roller pair, the evenness of the spun yarn will be possibly stay as good as that of the fed roving. Therefore, our new design concept for a drafting system can improve yarn quality.

Choice of Structural Parameters

As illustrated above, the new design only changes the upper apron and its tensioning device. The upper apron depends on its tensioning device, and its length can be calculated easily if its tensioning device can be optimized. Therefore, to optimize the new drafting system is to optimize the upper apron-tensioning device. Since the part of the upper apron unit in the main drafting zone is the same as that of the normal drafting device that has been optimized, only the part of upper apron unit in the break drafting zone needs to be optimized, that is, the positions of two corners, C and D, of the upper apron unit need to be properly selected.

ANGLE α

To get the position of point C, the position of point B has first to be decided. It can be indicated by the central angle α of the rear lower roller corresponding to the arc contacted by the fiber strand (see Figure 1).

If $\alpha = 0$, the fiber strand is not in contact with the arc of the rear lower roller and therefore cannot be controlled by the rear lower roller. With the increment of angle α, the contacting arc becomes longer, so the fiber strand will be controlled more by the rear lower roller. But angle α cannot be too big, otherwise the angle between sections BC and DC becomes too small, which will cause breakage of the fiber strand. Therefore, we have chosen the range of angle α between 30° and 60° for further studies.

FLOATING LENGTH b

It is obvious that straight line BC is tangential to the circumference of the rear lower roller. If angle α is fixed, the position of line BC can be determined. Thus, the position of point C can be found if the length of line BC is equal to a floating length b.

If floating length b is too short, it is possible for the upper apron to slide against the rear lower roller. On the other hand, if floating length b is too long, the controlling effect of the upper apron will become much smaller. Therefore, we have selected a range of floating length b between 5 and 15 mm for further studies.

HEIGHT h

When the position of point C is fixed, a tangential line from point C to the circumference of the lower apron on the middle lower roller can be drawn. If the tangential point is point G, line CG can be bisected by a line DH perpendicular to line CG. Point H is the intersecting point between line CG and line DH. The position of point D can be obtained if length DH is equal to a height h.

According to our analysis of controlling effects, fibers will be accelerated when their leading ends reach arc EF. If the length of arc EF is small enough, the range of accelerating points can be very small and close to the nip of the middle roller pair. If height h is greater, it is obvious that arc EF will become longer. But corner D is needed to increase the controlling effect on the fiber strand in section CDE. We have thus chosen a range of height h between 0 and 6 mm for further studies.

Mathematical Models with α, b, and h as Independent Variables

As illustrated above, once we know the three structural parameters α, b and h, we can obtain the positions of corners C and D of the upper apron unit. Therefore, the question arises, what are the optimum values of α, b and h that produce the best yarn evenness? The problem is a multivariate-optimization one, involving the general function

$$Y = f(\alpha, b, h) + \epsilon \quad , \tag{1}$$

where Y is the dependent variable or the response and, in the present case, yarn unevenness (CV%); α, b, h are the independent variables; and ϵ is the random-error component.

A second-order polynomial in some region of the independent variables is usually used as the required function [6, 8]. Thus, we have

$$Y = b_0a_0 + b_1\alpha + b_2b + b_3h + b_{12}\alpha b + b_{13}\alpha h + b_{23}bh + b_{11}\alpha^2 + b_{22}b^2 + b_{33}h^2 \quad , \tag{2}$$

where $a_0 = 1$, and $b_0, b_1, \ldots, b_{33}$ are the coefficients to be determined.

It is unlikely that the polynomial model will be a good approximation to the response function over the entire space of the independent variables, but in relatively small region, its accuracy should be acceptable [6]. Mathematically, if the small region of the response surface being considered is adequately fitted by the approximating polynomial function, then the analysis of the fitted surface will be equivalent to the analysis of the actual system. The coefficients of the polynomial function can be determined if a suitable experimental design is employed and the least-squares procedure is used to analyze the results.

DESIGN OF EXPERIMENTS

Experimental designs for fitting functions to response surfaces are often called "response-surface designs." The most widely used design for fitting a second-order model is the central composite design [1, 3, 6, 8], consisting of a 2^k ($k = 1, 2, \ldots, n$, the number of factors or independent variables) factorial or fractional experiment augmented by $2k$ axial points and n_0 center points at $(0, 0, \ldots, 0)$.

Table I shows the experimental design matrix used for the central composite design for $k = 3$, where X_1, X_2, and X_3 are the levels of α, b, and h, respectively, and are dimensionless, γ is the distance of axial points from the center and is equal to 1.682 for rotatability, and $n_0 = 6$ [1, 8].

With reference to the design matrix, we decided the values of independent variables corresponding to the various levels according to the ranges of α, b, and h discussed in the last section. The middle values of ranges are set as zero levels. The maximum values of ranges are the γ levels and the minimum values of ranges are the

TABLE I. Experimental design matrix and spun yarn qualities.

No.	X_1	X_2	X_3	CV%	Thin places	Thick places	Nep count
1	1	1	1	15.46	4	43	80
2	1	1	−1	15.26	8	57	97
3	1	−1	1	15.68	9	79	129
4	1	−1	−1	16.83	9	81	90
5	−1	1	1	14.91	4	40	85
6	−1	1	−1	14.99	1	63	109
7	−1	−1	1	18.53	10	90	123
8	−1	−1	−1	16.88	9	72	101
9	γ	0	0	15.35	7	60	98
10	$-\gamma$	0	0	16.74	10	65	90
11	0	γ	0	15.17	4	69	103
12	0	$-\gamma$	0	16.68	9	85	110
13	0	0	γ	15.85	7	68	114
14	0	0	$-\gamma$	16.96	12	85	90
15	0	0	0	15.54	8	63	85
16	0	0	0	15.30	9	53	92
17	0	0	0	15.95	10	75	96
18	0	0	0	17.29	9	87	105
19	0	0	0	15.60	9	67	97
20	0	0	0	15.87	10	80	115

$-\gamma$ levels. Thus, the 1 levels can be obtained by adding the middle values to

$$\Delta = (\text{maximum value} - \text{minimum value})/2\gamma \quad , \quad (3)$$

and the -1 levels by subtracting Δ from the middle values. Therefore, the relationships between the levels X_1, X_2, and X_3 and the independent variables α, b, and h can be represented as follows:

$$X_1 = (\alpha - 45)/\Delta = (\alpha - 45)/8.92 \quad ,$$

$$X_2 = (b - 10)/\Delta = (b - 10)/2.97 \quad ,$$

$$X_3 = (h - 3)/\Delta = (h - 3)/1.78 \quad . \quad (4)$$

Table II lists the values of α, b, and h corresponding to the five levels of X_1, X_2, and X_3.

IMPLEMENTATION OF EXPERIMENTS

For the twenty experiments given in Table I, fifteen different upper apron tensioning devices and fifteen corresponding different length upper aprons are needed. However, it is impractical to make fifteen different moulds to produce fifteen different length aprons with thicknesses suitable for cotton spinning, and to make fifteen different punch moulds to produce fifteen different upper apron-tensioning devices with the fixed structures from sheet metal in this stage. Therefore, for the twenty experiments, we designed and fabricated an adjustable upper apron-tensioning device and used a longer existing upper apron originally employed for wool spinning.

According to the design matrix in Table I and the corresponding structural parameter values in Table II, we adjusted corners C and D of the upper apron unit to the required positions for each experiment. We then used the adjusted upper apron-tensioning device with a longer upper apron for wool spinning to spin cotton yarns on a modern spinning machine under otherwise identical conditions. The spinning parameters are listed in the laboratory column of Table III. We tested the quality of the yarns spun with the twenty different upper apron units using the ASTM standard test method D-1425-81, and the results are listed in Table I.

TABLE II. Values of the design parameters corresponding to X_1, X_2, and X_3.

	$-\gamma$	−1	0	1	γ
Angle α	30°	36°	45°	54°	60°
Length b, mm	5.00	7.03	10.00	12.97	15.00
Height h, mm	0	1.22	3.00	4.78	6.0

TABLE III. Spinning parameters.

	Laboratory	Mill
Yarn count	18.22 tex	13 tex
Twist factor	327	360
Draft ratio in break drafting zone	1.30	1.29
Total draft ratio	28.5	39.1

MATHEMATICAL MODELS

We used the least squares method with simplified orthogonality [1, 3, 8] to determine the coefficients for the polynomials. We derived the relationship between the unevenness (CV%) of spun yarns and the levels of structural parameters of the new drafting system from spinning experiments as follows:

$$Y_1 = 15.9273 - 0.3235X_1 - 0.7205X_2 - 0.0913X_3 + 0.465X_1X_2 - 0.315X_1X_3 - 0.0475X_2X_3 + 0.0277X_1^2 - 0.0147X_2^2 + 0.155X_3^2 \quad . \quad (5)$$

The relationship between the nep count of spun yarns and the levels of structural parameters of the new drafting system is

$$Y_2 = 98.3086 - 0.6257X_1 - 6.1341X_2 + 4.42X_3 - 1.5X_1X_2 + 3X_1X_3 - 12.75X_2X_3 - 1.3706X_1^2 + 3.0488X_2^2 + 1.4578X_3^2 \quad . \quad (6)$$

It is usually the practice to regard probabilities of 0.05 and less as an indication of significance. However, Yin *et al.* [8] demonstrated that when an empirical model is developed by considering only a small region of the response surface, the model is more useful if probabilities of 0.25 and less are taken as indicating significance. The F-test [5], shows that the two equations are all significant at the level of 0.1, so the two equations can be used for further analysis and optimization.

Optimizing the Structural Parameters

In optimization problems, it is common practice to use the response function with the independent variables in the nondimensionalized form in order to numerically simplify the manipulations for deriving the solution [7]. Since X_1, X_2, and X_3 are the levels of α, b, and h and are dimensionless, the equations above may be used to determine the optimum values of structural parameters of the upper apron unit within the constraints of $\pm\gamma$, *i.e.*, ± 1.682, for X_1, X_2, and X_3. This optimization problem can thus be expressed as

$$\text{Find } \mathbf{X} \text{ which minimizes } f(\mathbf{X}) \quad (7)$$

subject to

$$X_1 + 1.682 \geq 0$$

$$X_2 + 1.682 \geq 0$$

$$X_3 + 1.682 \geq 0$$

$$-X_1 + 1.682 \geq 0$$

$$-X_2 + 1.682 \geq 0$$

$$-X_3 + 1.682 \geq 0$$

where $\mathbf{X} = [X_1, X_2, X_3]^T$, $f(\mathbf{X})$ is the objective function that is Y_1 for yarn unevenness (optimum $Y_1{}^*$ should be the minimum yarn unevenness) or Y_2 for the nep count of yarns (optimum $Y_2{}^*$ should be the minimum nep count of yarns).

Since this is a nonlinear constrained optimization problem, we have chosen the Complex Method [7] to solve it. Table IV lists the results of optimization with the computer program [5] developed according to this method.

Since the aim of new drafting system design is to improve yarn evenness, we can obtain the optimized parameters (α^*, b^*, and h^*) of the upper apron unit according to Y_1 (CV%) and Equation 4, as follows: $\alpha^* = 30.00021°$, $b^* = 14.99993$ mm, and $h^* = 0.45303$ mm.

TABLE IV. Results of optimizations.

Objective function	X_1	X_2	X_3
$Y_1{}^* = 13.67$ (CV%)	−1.68187	1.68188	−1.42800
$Y_2{}^* = 65.04$ (nep count)	−1.68170	1.68190	1.68180

TABLE V. Test results of yarns spun with two kinds of upper apron units.

	Normal unit			Optimized unit		
	No. 1	No. 2	Average	No. 1	No. 2	Average
CV%	14.37	14.45	14.41	13.63	13.75	13.69
Thin places	4	5	4.5	2	3	2.5
Thick places	48	51	49.5	44	36	40
Nep count	100	88	94	82	92	87

Verification Tests

In order to experimentally verify the results from the optimization with the mathematical model of yarn unevenness, we adjusted the upper apron-tensioning device according to the optimized values α^*, b^*, and h^*, then used this optimized unit to spin cotton yarns on the same ring spinning machine under the same conditions as before. After that, we replaced the upper apron unit with a normal upper apron unit without the part in the break drafting zone, and spun the yarns under the same conditions. We tested the qualities of both spun yarns using the ASTM standard test method D-1425-81, and the results are listed in Table V.

The computed optimum value using the mathematical model of yarn unevenness (CV%) is 13.67% (see Table IV), and the CV% of the yarns spun with the optimized upper apron unit is 13.69% (see Table V). It is clear that they are very close to each other. The results therefore prove that the model for yarn unevenness can be used to satisfactorily estimate spun yarn unevenness. The results also confirm that the upper apron unit made to the optimum practical dimensions gives the degree of improvement predicted by the model.

Spinning Tests in a Mill

We also used the new upper apron unit in a mill for spinning tests. Two spindles in a ring-spinning machine running in the mill were equipped with the new upper apron unit adjusted to the optimized parameters. Under the mill's spinning conditions, yarns were spun on the two spindles with the new upper apron unit and the original normal upper apron unit, respectively. The spinning parameters are listed in the Mill column of Table III. We tested the qualities of both spun yarns using the ASTM standard test method D-1425-81, and the results are listed in Table VI.

TABLE VI. Results of spinning tests in a mill.

	New optimized unit			Original unit in mill		
	No. 1	No. 2	Average	No. 1	No. 2	Average
CV%	15.52	15.64	15.58	15.92	17.00	16.46
Thin places	13	13	13	17	20	18.5
Thick places	76	63	69.5	75	71	73
Nep count	69	67	68	82	60	71

A comparison of the CV% of the yarns from the new optimized upper apron unit and the original normal upper apron unit in the mill shows that

$$\text{Difference} = 15.58\% - 16.46\% = -0.88\% \quad . \quad (8)$$

With a t-test [5], the difference is significant at the level of 0.02, which also proves that the new upper apron unit reduces yarn unevenness. It is obvious from Table VI that the numbers of thin places, thick places, and neps in yarns spun using the new upper apron unit are all lower than those using the original normal upper apron unit. Therefore, the spinning test in a mill also proves that the new drafting system can improve the quality of spun yarns.

Conclusions

In order to raise yarn quality, we have developed a new drafting system in this study. The spinning tests with the optimized drafting system conform with practical spinning results with the theoretical optimized values of the model for yarn unevenness. Yarn evenness is closely related to and worse than the evenness of the fed roving. Since the fed roving has a certain unevenness value, the reduction of yarn unevenness (CV%) is very limited. Furthermore, the normal drafting system has been studied and improved for a long time. The system used in the modern ring-spinning machine has reached the optimized results for this concept, so a reduction in yarn unevenness, even 1%, is very difficult. The fact that, using the new drafting system, yarn unevenness can be reduced about 1% illustrates that the new system can improve yarn evenness further.

We used an adjustable upper apron tensioning device and a longer existing apron for wool spinning in this study, but the adjustable device is not as stable as the one with a fixed structure due to manufacturing accuracy, which reduces the effect of improved yarn evenness with the new drafting system. In addition, the apron for wool spinning is 1.2 mm thick, 0.2 mm thicker than that for cotton spinning, which is not the most suitable for cotton spinning and thus also limits the improvement of yarn evenness with the new drafting system. Therefore, if the optimized upper apron-tensioning device is made from sheet metal by punch presses and has a fixed structure, and the upper aprons are made by a special mould and have the required length and the thickness suitable for cotton spinning, there will be a more significant improvement in yarn evenness.

In this study, the optimum values of α^* and b^* are very close to the limiting values imposed previously by the experimental setup. It seems reasonable to extend the ranges of the two parameters for further optimization, and so this study is a basis for further research.

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