Acrylic Fiber Spinning with a Rotary Ring

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Abstract

This paper describes the results of the investigation of the possibility of high-speed and stable acrylic spinning with rotary rings. Results of the test are as follows:

- (1) The wear of travellers on the rotary ring is far less than that on the stationary ring.
 - (2) At high-speed (15,500rpm), yarn fluffs caused by the rotary ring are significantly less than those by the stationary ring.
 - (3) Strength and elongation of single yarns produced by the rotary ring are superior to those by the stationary ring under certain spinning conditions (at 15,500 rpm and at the start of the spinning). But no significant difference is found under other conditions.
 - (4) At high-speed rotating, melt yarn by the rotary ring is less than that by the stationary ring.
 - (5) Yarn end-down and traveller fly-away with the rotary ring are significantly lower than those with the stationary ring.
 - (6) The power consumption by the rotary ring does not differ from that by the stationary ring.
- From the above results, it is concluded that the rotary ring is effective for high-speed spinning of acrylic yarns.

1. Introduction

It is reported that traveller wear is reduced and yarn quality is improved by rotary rings without any more useful effects^[1]. This paper is to report the possibility of high-speed and stable performance with rotary rings in acrylic spinning to which high-speed spinning is regarded difficult with stationary rings due to yarn melt.

2. Instrument

2.1 Rings

Rotary ring: Rotor spin ring, No.1 flange ring I.D. 50 mm, fitting diameter 63.5 mm (Refer Fig. 1).

Stationary ring: Rotary rings are used after their rotors are fixed by winding yarns around the gap between the stator and the retaining ring.

2.2 Spinning equipment

Figure 2 shows the delivery part of the production type spinning frame and the multi-purpose tester.

The multi-purpose tester is a spinning tester with only one spindle by us.

The setting values shown in Fig. 2 shows those at the lowest point of the ring rail movement, and the setting values in the bracket is those of the multi-purpose tester.

Fig. 1 Cross section of rotary ring

2.3 Spinning conditions

Spinning tests are done under the conditions shown in Table 1.

Table 2 shows spindle revolutions and traveller counts used.

Fig. 2 Delivery part

Table 1 Spinning conditions

Ring:	No. 1 flange, 50 mm I.D.
Fiber:	Acry c 1.5 d×51 mm cut
Yarn count:	Nm 52 (30's)
Number of twists:	17.0 T/inch
Lift:	8 inch
Balloon control ring:	52 mm (Round wire wave type)
Traveller:	Hi-Ni OH type, Hi-Ni OH-WZ type
Spindle revolution:	13,500 to 15,500 r.p.m.
Temperature and humidity:	21 to 24°C, 56 to 62% RH

Table 2 Spindle revolution vs. traveller number

Spindle revolution	Traveller number
13,500 rpm (35.3 m/sec)	2/0
	3/0
14,500 rpm (37.9 m/sec)	3/0
	4/0
15,500 rpm (40.6 m/sec)	4/0
	5/0

Brackets () show circumferential speed of traveller.

The circumferential speed of traveller, 35.3 m/sec at spindle revolution of 13,500 rpm in Table 1 corresponds to the stringest condition to actual spinning operation at present^[2].

Accordingly, the spindle revolution of 14,500 and 15,500 rpm is extremely strict conditions to stationary rings.

3. Investigation Items

The investigation items are shown in Table 3.

Table 3 Investigation items

Investigation items	Stage of cop building	Spinning frame	Measuring instrument
Spinning tension	Start of spinning, middle cop, full cop	Multi-purpose tester	Tension meter
Ring revolution	"	"	Strobo
Traveller wear		Production type spinning frame	
Yarn fluff	Start of spinning, middle cop, full cop	"	F-index tester
Strength and elongation of single yarn	"	"	Uster single yarn strength and elongation tester
Melt yarn	"	"	
Power consumption	"	"	Watt-hour meter
Vibration of of ring (Stator)	Start of spinning, middle cop	Multi-purpose tester	Vibrometer, FET analyzer
Yarn ends-down, traveller fly-away		Production type spinning frame	

4. Test Method

4.1 Spinning tension

The tension is measured with an electric resistance type tension meter and the pick-up is of 3 needle type.

Under the stable condition after 5 to 10 minutes from starting the tester, average tension and variation are measured. The results are given in the average value of three tests.

In measuring the tension, it is necessary to keep the contact angle between the pick-up and the yarn always constant. Accordingly, a lappet bar is fixed at the lower point of the lappet bar movement, to each (cop) positions of built-up amounts for measurement. Then, the pick-up is inserted between the front roller and the snail wire.

Conditions of the ring, the balloon control ring, and the snail wire to each cop are shown in Fig. 3 and Table 4.

Table 4 Setting of multi-purpose tester

Stage of cop building	a (mm)	b (mm)	c (mm)
Start of spinning	12	83	28
Middle cop	84.5–134.5	83	52
Full cop	150–200	83	73

Fig. 3 Conditions of multi-purpose tester

4.2 Ring revolution

While increasing the spindle revolution gradually from 10,000 to 16,000 rpm under the spinning conditions, the spinning tension and the ring revolution are measured by every increase in the spinning tension of about 5 g. The number of tests is 3 and the traveller used is Hi-Ni OH type 4/0.

4.3 Traveller wear

After spinning one doffing under each spinning condition, travellers are sampled and the wear extent is classified into major, ordinary and minor. Each ratio is shown in percentage to the total number of samples ($N = 36$).

4.4 Yarn fluff

After spinning one doffing under each spinning condition, yarn fluffs of 1 mm and 3 mm long per 10 meter for a cop were measured 10 times to each stage of cop building.

The results are the averages per cop with six samples.

4.5 Single yarn strength and elongation

After spinning one doffing under each spinning condition, yarn strength and elongation are measured at each stage of cop building. The results are shown in averages of total number of samples ($N = 6$).

4.6 Melt yarn

After spinning one doffing under each spinning condition, yarn melt state is measured at each stage of cop building. That is, the number of melt and blacked lumps existing on the measuring surface shown in Fig. 4 is counted one time at each stage of cop building, and the degree of melting is classified into six ranks as shown in Table 5.

Fig. 4 Cop

Table 5 Classification of melting

Degree of melting	Number of blacked blocks
0	–10
1	11–30
2	31–50
3	51–70
4	71–90
5	91–

The results are shown in average of total number of samples ($N = 6$).

Heat influence to acrylic fiber is known as follows:^[3]

Softing temperature is 190–240°C. Melting point is not clear, and the fibers burns shrinking, leaving a black lump. So, the above way applied to discriminate the melt state is considered appropriate.

4.7 Power consumption

After spinning one doffing under each spinning condition, instantaneous power is measured at each stage of cop building.

The results are shown in the instantaneous power per 36 spindles. However the cop diameter is 45 to 46 mm and the cop weight is approximately 155 g (including the weight of the bobbin).

4.8 Vibration of ring (Stator)

As shown in Fig. 5, the pick-up of the vibrometer is pressed against the stator to detect the stator vibration (vibration acceleration). Its frequency is analyzed with a FFT analyzer.

Fig. 5 Ring vibration measuring method

The spinning conditions are:
 Number of samples: $N = 2$; Traveller: Hi-Ni OH type 2/0, Hi-Ni OH-WZ type 2/0; Spindle revolution: 13,500 rpm; Stage of cop building: Start of spinning and, middle cop.
 Other conditions are shown in Table 1.

4.9 Yarn breakage and traveller fly-away.
 After spinning one doffing under each spinning condition, yarn end-down and traveller fly-away are cheked. The results are shown in the number of yarn end-down and the number of traveller fly-away per one doffing (3.75 hr).

5. Results

5.1 Spinning tension

Figure 6 shows the spinning tension at the spinning start.

Fig. 6 Spinning tension

No difference in the average spinning tension and in the variation of spinning tension are seen between rotary rings and stationary rings under any condition.
 Difference on account of the traveller type is also insignificant. This is also applicable at other stages of cop.

5.2 Difference between acrylic spinning and cotton spinning

Results of the cotton spinning test^[1] showed that the spinning tension of rotary rings is higher than that of stationary rings. The difference was particularly outstanding at the start of spinning and at the full cop, and the difference amounted to about 5 g. However, the results obtained this time were different. Accordingly, additional tests were done to confirm the results. The spinning condition was at low-speed as shown in Table 6. Other conditions were the same as described in Table 1. The cop stage is at the start of spinning only. Table 7 shows the result of this spinning test.

As indicated there, the spinning tension is higher with the rotary ring than with the stationary ring under any condition.

Table 6 Spinning conditions

Test No.	Spindle speed (r.p.m.)	Traveller	Number of sample
1	10,500	OH type No. 2	3
2	"	OH-WZ type No. 2	1
3	9,500	OH type No. 3	1

Table 7 Spinning tension

Ring	Rotary ring		Stationary ring	
	Average tension	Variation of tension	Average tension	Variation of tension
Test No.				
1-1	42.5 g	9.0 g	33.5 g	7.0 g
1-2	40.0	10.0	37.5	7.0
1-3	41.0	10.0	38.5	7.0
2	42.5	7.0	40.0	10.0
3	42.5	9.0	35.0	6.0

The number of testing was only 5, but no spinning tension of the stationary ring is higher than with the rotary ring in any case.
 Accordingly, the spinning tension with the rotary ring is regarded higher than with the stationary ring at low spindle revolution from 9,500 to 10,500 rpm.

5.3 Spindle revolution vs. spinning tension

From the result mentioned above, it is assumed that there is the relationship between the spindle revolution and the spinning tension with both types of rings as shown in Fig. 7.

A, B, and C areas in Fig. 7 can be explained as follows:

Area A—Since the spinning condition is comparatively lenient and the frictional coefficient between the ring and the traveller is increased by the ring rotation^[1], the spinning tension of the rotary ring is higher than with the stationary ring.

Area C—Since the spinning condition is rather hard, the traveller wear increases sharply with the stationary ring (including scorching), and the increase in the spinning tension due to the wear is greater than the increase in the frictional coefficient of the rotary ring, the spinning tension of the stationary ring is higher.

Area B—This is the intermediate between area A and area B where the spinning tension is equal with both rings of rotary and stationary.

From the above assumption, it is regarded that the result of this test corresponds to B area, and that of the cotton spinning test^[1] corresponds to A area.

Fig. 7 Spindle revolution vs. spinning tension

Fig. 8 Spinning tension vs. ring revolution

5.4 Ring revolution

Figure 8 shows the plots of the ring revolution against the spinning tension measured simultaneously.

The relationship between these two is divided into two areas: one the start of spinning, the other medium and full cop. The average tensions in two areas differ by about 10 g, but these averages are obtained at approximately equal revolution.

In other words, the ring revolution is kept at a certain level despite the tension change due to the cop stage.

The above characteristics can be proved by the following theoretical description.

The driving power necessary for the ring revolution is the frictional force between the ring and the traveller, and is expressed by the following equation^[3].

$$\mu R = T_1 \sin \varphi K \dots \dots \dots (1)$$

Where

μ : Frictional coefficient between traveller and ring

R : Reaction from ring to traveller

T_1 : Yarn tension in ballooning direction

φ : Winding angle around bobbin

$$K = \left(1 - \mu_0 \sqrt{\frac{1 + \sin \gamma \cdot \cos \varphi}{2}} \right) \dots \dots \dots (2) \\ / \left(1 + \mu_0 \sqrt{\frac{1 + \sin \gamma \cdot \cos \varphi}{2}} \right)$$

μ_0 : Frictional coefficient between traveller and yarn

γ : Angle of T_1 to vertical shaft

The values T_1 , φ , γ , and μ_0 are assumed respectively as shown in Table 8. The setting of φ is based on 50 mm ring diameter, 25 mm of bobbin diameter at the start of spinning, 34 mm of cop diameter at half cop and full cop (average cop diameter between chases).

The results of calculation of frictional force between the ring and the traveller are shown in Table 9.

Table 8 Parameters

Stage of cop building	Start of spinning	Middle cop	Full cop
Parameter			
T_1	40 g	30 g	30 g
φ	$\sin^{-1} 25/50$	$\sin^{-1} 34/50$	$\sin^{-1} 34/50$
γ	0°	10°	0°
μ_0	0.3	0.3	0.3

Table 9 Frictional force between ring and traveller

Stage of cop building	Frictional force
Start of spinning	30.8 (g)
Middle cop	32.4 (g)
Full cop	31.4 (g)

This indicates that the frictional force between the ring and the traveller does not change so much by the stage of cop as the spinning tension, and is maintained approximately constant. Accordingly, the ring revolution is to be kept at a certain level regardless of the change in the spinning tension by the stage of cop.

Also, as shown in Fig. 8, the relationship between the spinning tension and the ring revolution does not change by the type of travellers, and is kept approximately the same.

5.5 Spinning tension vs. ring revolution

Figure 9 shows the relationship between the spinning tension and the ring revolution at each cop under the conditions and by the method shown in Paragraph 4.2. The relationship differs depending on the stage of cop building: start of spinning, middle cop and full cop: even at low spinning tension. It is given by the following equations (3) and (4) derived from the theoretical equation shown in the report.

Fig. 9 Spinning tension vs. ring revolution

$$\omega_R = \frac{1.0T_1 - 23.9}{0.27 \times 10^{-1} + 0.1 \times 10^{-2}T_1} \left(\begin{array}{c} \text{Start of} \\ \text{spinning} \end{array} \right) \dots (3)$$

$$\omega_R = \frac{1.4T_1 - 23.9}{0.27 \times 10^{-1} + 0.14 \times 10^{-2}T_1} \left(\begin{array}{c} \text{Full} \\ \text{cop} \end{array} \right) \dots (4)$$

where ω_R is the ring revolution (rad/sec), T_1 (g) the spinning tension in the ballooning direction.

The calculation by eqs. (3) and (4) shows a continuous line (start of spinning) and broken lines (full cop) in Fig. 9. The theoretical values agree well with the test values, indicating that the theory^[1] is also applicable to the acrylic spinning in this report.

5.6 Traveller wear

Figure 10 shows the traveller wear after one doffing, and the percentage is to the number of travellers ($N = 36$) used.

Fig. 10 Traveller wear

Traveller wear is evidently lower with rotary rings than with stationary rings, but the difference tends to decrease as the spindle revolution increases.

5.7 Yarn fluff

Figure 11 shows the yarn fluff at the half cop. When a heavy traveller is used, fluff with rotary rings remains approximately constant irrespective to the spindle revolution. With stationary rings, however, the number of fluffs substantially increases as the spindle revolution increases. At 15,500 rpm of spindle revolution, in particular, the difference is significant, and fluffs with rotary rings are considerably less than with stationary rings.

When a light traveller is used, the difference between rotary rings and stationary rings is insignificant. The same is true at other stages of cop.

5.8 Single yarn strength and elongation

Figure 12 shows the single yarn strength and the elongation at the start of spinning.

When a heavy traveller is used, single yarn strength and elongation with rotary rings are kept approximately equal against the spindle revolution. At 15,500 rpm of spindle revolution, however, the strength and the elongation are substantially lower with stationary rings.

There is no difference between rotary rings and stationary rings when light travellers are used. The difference is not detected even at other stages of cop building.

Fig. 11 Yarn fluff

Fig. 12 Single yarn strength and elongation

5.9 Melt yarn

Figure 13 shows the measurement of melt yarns. At low spindle revolution, no difference is seen between rotary rings and stationary ring. But, at high spindle speed, melt yarn tends to be less with rotary rings.

Fig. 13 Melt yarn

5.10 Yarn end-down and traveller fly-away

Figure 14 shows yarn end-down and traveller fly-away. Yarn end-down with rotary rings are approximately 1/2 of those with stationary rings.

With rotary rings, traveller fly-away is kept close to zero at any spindle revolution. But with stationary rings, traveller fly-away was frequent at 15,500 rpm of spindle speed.

Fig. 14 Yarn ends-down and traveller number

Fig. 15 Power consumption

5.11 Power consumption

Figure 15 shows the power consumption, in which difference is seen between rotary rings and stationary rings.

5.12 Ring (stator) vibration

Elastic vibration peculiar to rings is generated as the traveller runs on the ring flange. By the swing vibration and the elastic vibration, the stator is vibrated. This vibration mechanism is regarded equal to both rotary rings and stationary rings.

Fig. 16 Ring vibration

Figure 16 shows the result of vibration measurement, after averaged 256 signals each observed for 20 msec. The horizontal axis indicates frequency (kHz), and the vertical axis power spectrum in the unit defined by

$$1(\text{dBV}) = 20 \log_{10} \frac{\text{Input voltage}}{1\text{V}}$$

The vibrometer gives 60 mV to 1 G vibration acceleration.

With rotary rings, the vibration peak is at low frequency around 250 Hz, and the vibration goes down at higher frequency. With stationary rings, the tendency is similar to that with rotary rings, but the 2nd peak is seen at high frequency around 8 kHz.

The difference in the vibration level between rotary rings and stationary rings is noted with no respect to traveller types and stages of cop building.

"A" point in Fig. 17 is a contact point between the ring and the stator, at which point the stator is pushed 250 times a second by the ring at the peak frequency of 250 Hz. Because the traveller revolution is approximately equal to the spindle revolution, and the spindle revolution of 13,500 rpm roughly coincides with the peak frequency of rotary rings, it is assumable that the traveller is always at the point where the ring is pushing the stator (point A in Fig. 17).

Fig. 17 Revolving condition of traveller and ring

As the peak frequency of the stationary ring agrees to that of the rotary ring, so the vibration of the stationary ring at the peak of low frequency is considered to be caused by the traveller running.

From Fig. 16, it is seemed that the power applied by the traveller to the ring is cyclic since the frequency distribution of the rotary ring is similar to the frequency distribution of linear systems.

The frequency distribution with stationary rings should be the same if the applied power is cyclic as with rotary rings. Since a peak is noted around 8 kHz, it is considered that the applied power by the traveller to the stationary ring contains high frequency. So the vibration of the stationary ring is considered more complex than that of the rotary ring.

This result leads us to conclude that traveller running is more stable with rotary rings than with stationary rings. The stable traveller running with rotary rings gives favourable results to yarn fluff and traveller wear.

7. Conclusion

(1) Within the range of our spinning conditions, no difference is seen in the spinning tension between rotary rings and stationary rings.

(2) Traveller wear is far less with rotary rings than with stationary rings.

(3) Yarn fluff is significantly less with rotary rings at high speed (15,500 rpm) than with stationary rings. But no difference is seen at other revolutions.

(4) Single yarn strength and elongation are better with rotary rings under certain conditions (at 15,500 rpm of spindle speed and at the start of spinning) than with stationary rings, but no difference is seen under other conditions.

(5) Melt yarn is less with rotary rings than with stationary rings at high-speed.

(6) Yarn end-down and traveller fly-away are significantly lower with rotary rings than with stationary rings.

(7) Power consumption does not differ between rotary rings and stationary rings.

(8) From the point of ring (stator) vibration, traveller running may be stable with rotary rings.

From these consideration, it is concluded that rotary rings are effective for high-speed spinning of acrylic yarns.

References

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