Natural lubrication mechanism of twisting in ring spinning and its experimental analysis

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Abstract. In the spinning process, the natural lubricating film between the ring and the traveller changes the dry friction between them. In this paper, the composition of natural lubricating film is analyzed by DA1-180M microscope observation and Fourier infrared spectrometer. The eddy current sensor was used to detect the movement of the traveller on-line. The number of abnormal acceleration of the traveller reflects the stress stability of the traveller, and the lubrication effect of the natural lubrication film was analyzed. The experiment shows that the natural lubricating film is composed of the spun fiber, which can make the stress of the traveller relatively stable in the short term, but in the long term its lubricating effect cannot eliminate the wear between the ring and the traveller.

1. Introduction

In the ring spinning frame, the ring and the traveller are used for twisting, winding and tension control in spinning system. As a pair of friction pairs, the ring and the traveller are always the research hotspot in the field of ring spinning. At first, Grosberg P and Qasim S.H. [1] found that the friction between the ring and the traveller in high-speed movement is dry friction, and the ring and the traveller would wear very fast under the condition of dry friction [2]. Due to the complexity of the machine and potential pollution of the yarn, the lubricant cannot be added directly during the spinning to reduce the friction between the ring and the traveller.

Since the 1960s, it has been considered that there is a natural lubrication effect between the traveller and the ring, which can reduce the abrasion between the traveller and the ring. However, the formation mechanism and the composition of natural lubricating film have not been fully analyzed and explained. Jiang Baichun, Liu Pingping[3] claimed that the formation of natural lubricating film occurs when the yarn passes through the traveller, the cotton wax on the fiber surface is scraped off, while the contact surface temperature between the traveller and the ring is very high. When the scraped cotton wax touches the friction surface between the traveller and the ring, it will melt into liquid state and stick on the surface of the ring, gradually forming a natural lubricating film. Wenhui Tang [4] showed that when the traveller is running at high speed, the fibers are constantly wiped off the surface of the yarn, which is squeezed on the contact surface between the traveller and the ring by the traveller. During the long-term movement of the traveller, a layer of natural lubricating film is gradually formed. The lubricating film changes the state of dry friction between the traveller and the ring.
2. The formation mechanism of natural lubricating film

2.1. Formation process of natural lubricating film
In order to observe the formation process of the natural lubrication film, I-Speed 7 high-speed camera is used to capture the images of the high-speed rotation of the traveller and the yarn. As shown in Figure 1, when the yarn pulls the traveller for periodic movement, the yarn will pass through the area between the traveller and the ring, and contact with the traveller and the ring at the same time. When the traveller is running at high speed, it constantly rubs against the yarn and wipes the short fibers on the surface of the yarn, and rolls the short fibers on the ring and gradually forms a lubricating film under the long-term effect.

2.2. Micro morphology of natural lubricating film
The lubrication film was scraped off the inner wall of the ring; the morphology of the lubrication film was observed through a microscope. As shown in Figure 2, in addition to the thin-film material, there are also unbroken fibers. It shows that the lubrication film is composed of fibers.

2.3. Composition analysis of natural lubricating film
In order to confirm the composition of the natural lubricating film, the infrared spectrogram of the lubricating film scraped off on the ring and the roving was determined by Antaris II Fourier infrared spectrometer.

Cotton fiber is cellulose fiber, which mainly contains O-H, C-O-C, -CH-, and -CH2-. As shown in Figure 3, in the infrared spectrum curve, the absorption peak wave number of 3320cm\(^{-1}\) is group O-H; the absorption peak wave number of 2900cm\(^{-1}\), 2918cm\(^{-1}\) is -CH2; the absorption peak wave number of 1155cm\(^{-1}\), 1157cm\(^{-1}\) is ether bond C-O-C; the absorption peak wave number of 1025cm\(^{-1}\), 1027cm\(^{-1}\) is ketone group C=O. The absorption peaks of infrared spectra of roving yarn and lubrication film are basically the same. It can be followed that the lubrication film scraped off the ring that spins pure cotton yarn is formed by cotton fiber.

3. Experimental analysis of the natural lubricating film
Since it is difficult to directly measure the dynamic friction coefficient between the traveller and the ring, in this experiment the speed change of the traveller in the spinning process is measured by the eddy current sensor, and the acceleration change of the traveller is calculated by data processing. According to the change of the acceleration of the traveller, the change of the force on the traveller is reflected, and the influence of the natural lubricating film on the traveller is indirectly obtained.

3.1. Theoretical speed and acceleration of the traveller
According to Newton's second law: \(F = ma\). The magnitude of the acceleration of the object is proportional to the acting force. Therefore, the change of the acceleration was used in this research to reflect the change of the force of the traveller in the movement process.
In the process of spinning, the rise and fall of the ring rail is regular. Taking a rise and a fall of the ring rail as a cycle, the theoretical acceleration of the traveller should change periodically during the cycle.

Theoretically, the rotating speed of the traveller \( n_t \) is calculated by equation (1) [5]

\[
n_t = n_s \cdot \frac{n_f \cdot d_f}{2r_x}
\]

According to equation (1), \( n_s \) is the spindle speed, \( n_f \) is the front roller speed \((r/min)\), \( d_f \) is the diameter of front roller \((m)\) and \( r_x \) is the winding radius of the bobbin \((r/min)\).

![Figure 4. Schematic diagram of bobbin.](image)

As shown in Figure 4, \( d_x-a \), \( d_x \) and \( d_x+a \) are respectively the winding diameter of yarn winding on the bobbin in adjacent time. When the ring rail rises, the radius decreases. According to equation (1), the theoretical speed of the traveller decreases.

\[
d_x^2 - a^2 < d_x^2
\]
\[
\frac{1}{d_x} < \frac{d_x}{(d_x + a)(d_x - a)} \tag{3}
\]

\[
\frac{2}{d_x} < \frac{d_x - a + d_x + a}{(d_x + a)(d_x - a)} \tag{4}
\]

\[
\frac{2}{d_x} < \frac{1}{(d_x + a)} + \frac{1}{(d_x - a)} \tag{5}
\]

\[
- \frac{n_f d_f}{d_x - a} + \frac{n_f d_f}{d_x} < - \frac{n_f d_f}{d_x} + \frac{n_f d_f}{d_x + a} \tag{6}
\]

\[
n_s = \frac{n_f d_f}{d_x - a} \left( n_s - \frac{n_f d_f}{d_x} \right) < n_s - \frac{n_f d_f}{d_x} - \left( n_s - \frac{n_f d_f}{d_x + a} \right) \tag{7}
\]

\[
n_{t+1} - n_t < n_t - n_{t-1} \tag{8}
\]

\[
a_{t+1} < a_t \tag{9}
\]

As shown in equation (9), when the ring rail rises, the theoretical acceleration of the traveller decreases; that is, the change value of the traveller’s acceleration should be negative. Similarly, it can be deduced that when the ring rail falls, the theoretical acceleration of the traveller increases; that is, the change value of the ring’s acceleration should be positive. The theoretical speed curve of the traveller is shown in Figure 5.

### 3.2. On-line detection of the traveller’s movement

As shown in Figure 6, an eddy current sensor was installed next to the ring to measure the speed of the traveller. The eddy current sensor was aligned to the racetrack position of the traveller on the ring. During spinning, the traveller rotates at a high speed in the magnetic field and cuts the magnetic field lines to produce eddy current. The superposition of secondary magnetic field generated by the eddy current and the original magnetic field results in the change of coil current. The dynamic speed measuring system connected with the sensor detects the pulse generated by the rotation traveller, and calculates the speed of the traveller[6]. In this research, the data detected by the sensor is sent to the computer connected with the dynamic speed measuring system every 1 second.

![Figure 6. Installation diagram of eddy current sensor.](image)

During measuring, the eddy current sensor will be affected by the size of the measured object, excitation voltage and conductor temperature [7]. In addition, the value measured by the eddy current sensor will be affected by the measuring distance. When the distance between the probe of the eddy current sensor and the measured object is larger, the intensity of the eddy current will become smaller.
Therefore, the spinning temperature and the position of the eddy current sensor probe were maintained as much as possible to reduce the errors.

3.3. Analysis of factors affecting lubricating film

3.3.1. The influence of new and old degree of ring on lubricating film. When the natural lubrication film exists, it is speculated that the lubrication effect brought by the natural lubrication film will make the force on the traveller more uniform. In this experiment, the rings of different years from 2015 to 2018, namely four rings with different old degrees, were used for spinning. The movement of the traveller was compared to observe the validity of natural lubrication film.

As shown in Figure 7, the actual speed curve of the traveller is not smooth during a cycle. When the ring rail drops, the overall speed of the traveller increases, but there will be fluctuation of the falling speed in the middle, which is different from the theoretical speed curve of the ring in Figure 5. The difference between theory and reality is due to the unstable movement of the traveller. Therefore, the positive value of acceleration change in the rising period of the ring rail is counted as an abnormal value, and the negative value of acceleration change in the falling period of the ring rail is counted as an abnormal value, so as to calculate the number of abnormal values in each period. The number of abnormal values of the traveller acceleration is taken as the index to measure the smoothness of the movement of the traveller. The less the abnormal values are, the more stable the operation of the traveller is, and the more abnormal values are, the more unstable the operation of the traveller is.

As new ring has gone through the ripening period, but the ripening period is not as long as 1 year. Therefore, the influence of the ripening period can be ignored in this experiment. When using rings of different years, the average number of abnormal acceleration values of traveller is shown in Figure 8. When use ring of the year 2018 year and the year 2017, the number of abnormal acceleration values is almost the same. It means that the ring of the year 2017 is worn and natural lubrication film is not formed completely. Therefore, the movement of the traveller is unstable. When using ring of the year 2016 years for spinning, the number of abnormal accelerations of the traveller greatly decreases. At this time, the natural lubrication film has been formed. Due to the lubrication effect of the natural lubrication film, the force on the traveller is relatively stable, and the number of abnormal accelerations of the traveller decreases. However, when using ring of the year 2015 year, the abnormal acceleration value of the traveller increases again, which can indicate that in the long run the
lubrication effect of natural lubrication film cannot overcome the negative influence of the ring wear. After the ring is used for a long time, the instability of the traveller will still be obviously reflected. Theoretically, with the increase of the service life of the traveller, the inner wall of the traveller will gradually form a natural lubricating film. However, because of the centrifugal force, the fiber will not remain in the inner wall of the traveller to form a natural lubricating film. In addition, it is difficult to form a lubricating film within the short life of the traveller.

3.3.2. The influence of humidity on lubricating film. Generally, the temperature of spinning process is 26℃-32℃, and the relative humidity is 56%-60%[9]. If the humidity is too high, the traveller is easy to fly off the runway, and the surface of roller and apron is easy to adhere to fibers, affecting the drafting. If the humidity is too low, some fibers are prone to generate static electricity, the fiber adhesion is poor, and the yarn has more hairiness[10].

As the humidity will affect the fiber, and the lubricating film is formed by the fiber, so the humidity may affect the lubricating effect of the lubricating film. Therefore, the rotation speed of the traveller is measured under different humidity, and the stability of acceleration is analyzed.

Taking spinning cotton yarn as an example, the number of abnormal values of the acceleration change of the traveller is calculated. As shown in Figure 9, with the humidity of 45%, the number of abnormal acceleration is the largest. With the humidity of 55%, the number of abnormal acceleration decreases obviously, and when the humidity rises to 65%, the number of abnormal acceleration increases slightly. At the humidity of 55%, the acting force on the traveller is the most stable and the lubrication effect of the natural lubrication film is the best.

![Figure 9](image.png)
**Figure 9.** The number of abnormal acceleration value of the traveller under different humidity.

![Figure 10](image.png)
**Figure 10.** The number of abnormal acceleration value in spinning different roving.

3.3.3. The influence of different fibers on lubricating film. As shown in Figure 10, the number of abnormally accelerated values in spinning pure cotton yarn is smaller than that in spinning poly-cotton blended yarn, and the stability of traveller acceleration in spinning poly-cotton yarn is not as stable as that in spinning cotton yarn.

This phenomenon is due to different fibers; the lubrication effect of natural lubrication film is also different. For roving, there is cotton wax on the surface of cotton, and in the production of chemical fiber, in order to adjust the friction of chemical fiber, oil agent is usually added, resulting in the existence of oil agent on the surface of polyester. On the other hand, the experiment shows that when the new traveller is used for spinning, after running for a period, the contact side of the ring will often appear raised white residue. Cotton is a natural fiber that is not prone to static electricity, but polyester is a chemical fiber that is relatively easy to generate electricity from friction. In the process of high-
speed rotation of the traveller, polyester fiber produces a large amount of static charge and adheres to the inner wall of the wire ring.

4. Conclusion
In this paper, the composition of natural lubricating film was analyzed by microscope observations and Fourier infrared spectrometer. The eddy current sensor was used to detect the movement of the traveller on-line. The stress stability of the traveller was reflected by the number of abnormal acceleration of the traveller, and the stability of acceleration of the traveller was tested in different conditions, so the lubrication effect of the natural lubrication film was analyzed. The results are as follows:

(1) After a long period of spinning operation, there will be a layer of natural lubricating film composed of the spun fibers on the inner wall of the ring.

(2) In the short term, the existence of the natural lubrication film on the ring can make the force on the traveller relatively stable, but in the long term, the role of the natural lubrication film cannot reduce the wear between the ring and the traveller.

(3) It turns out that humidity will have a certain impact on the lubrication of the lubrication film. Based on the test under the three humidity conditions, the results show that at 45% humidity, the lubrication effect of the natural lubrication film is the worst and the movement of the traveller is the most unstable. In contrast, at 55% humidity, the lubrication effect of the natural lubrication film is the best and the movement of the traveller is the most stable.

(4) In the process of high-speed operation of the traveller, due to the influence of centrifugal force, it is difficult to leave fibers on its inner wall to form a natural lubricating film. However, polyester fiber will remain on the surface of the traveller due to the effect of static electricity, which is not conducive to the stability of the operation of the traveller.

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