Design and Optimization of Feeding Device for Sterile Seed Long Fiber Extractor

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Abstract: The feeding status of feeding device is an important factor that affects the performance of the main machine and even the process line. Taking the assembly layout of the feeding device and the structure of key parts as the research object, we conducted research design and analysis of the feed roller and cotton-feeding roller structure and their configurations. The results show that vertical feeding is conducive to the continuous and uniform feeding of materials; the combined use of cotton-plucking feed roller with roller is superior to the combination of multiple rollers; the progressive differential feeding mode makes for gradually thinning the material bed, improving the long fiber extraction rate, reducing the impurity rate, reducing the unattached fiber and greatly improving the machine performance; Φ58×1200mm cotton-feeding roller with a hexagonal spindle structure has higher deformation resistance than simple hollow structure. The research can be a reference for the optimization and design of sterile cottonseed extraction machine and equipment.

1. Introduction
China is a country with large-scale production and consumption of cotton. During cotton processing and spinning, a lot of sterile seeds will be discharged to improve the lint quality. Although the sterile seed is a kind of fibrous impurities, with long fiber lengthened below 16mm attached to its surface, it is still valued in spinning. Therefore, in order to avoid the loss of cotton fiber, the leftovers of sterile seeds shall be extracted and recycled.

At present, MQT250 dual roller cleaning and batting machine is the main machine matching with extraction and recovery processes of sterile seed long fiber, which has a horizontal structure. In most of feeding modes, materials are carried by a storage hopper and stored temporarily for accumulation, and then fed horizontally, obliquely and horizontally. The feeding mechanism is composed of seven rollers with same diameter and speed (Figure1). The bending deformation of cotton-feeding rollers resulted from unsmooth, uneven and discontinuous feeding and frequent feeding of lumped sterile seeds can affect the extraction quality, processing capacity, failure rate and other mechanical properties of the main machine and the service life of key parts. Hence, the research on the structure and matching parameters of the sterile seed feeding device is of great significance to design the extraction machine of sterile seed long fiber, improve the main machine performance and achieve large-scale production.

Various factors can affect the feeding performance of sterile seeds. The research shows that the key factors include the feeding mode, the structure of feeding parts, running parameters and matching of feeding parts, etc. B.J ger and Zhang Jiaming [1] found that after the differential pulling of multiple rollers, the cotton bundle and layer gradually became thinner, so that the feeding was more even and smooth. Yang Qianlan [2] developed a novel blowing-carding feeding hopper, of which the feeding parts...
adopt feeding plate and cotton-feeding roller structures. In the lower hopper parts, the uniform output of sliver is controlled by pressure. The results showed that the increased grapping force from the feeding plate and cotton-feeding roller could improve the carding effect, and the pressure control ensures the uniform output of sliver. Zhao Qiang [3] studied FA172A blowing-carding hopper. It was found that after the action on cotton by feed roller and plucker roller, the cotton blowing and carding become continuous and uniform, which improves the carding effect. Yang Qiaoyun [4] analyzed the hopper structure and cotton feeding form of FA225 carding machine. The results showed that the cotton-feeding roller adopting forward feeding was conducive to the carding effect.

In addition to the above factors, the internal structure and deformation resistance of the feed roller are of great influence on the feeding evenness. In this paper, we studied and tested the structural layout, feeding part structure and running parameters of the feeding device, and analyzed the influence of feeding status on the performance of main machine, thus providing a reference for the optimization and design of sterile seed long fiber extraction machine.

2. Design of Feeding Device for Sterile Seed Long Fiber Extractor

2.1. Feeding device structure design
The feeding mode is changed from horizontal feeding to vertical feeding [4] (Figure 2). The feeding device adopts two cotton-plucking rollers and two feed rollers (structural layout in Figure 2), instead of the original seven rollers with the same structure, which use surface friction for conveying and feeding.

Cotton-plucking roller #1 conveys materials by the friction force and pushing action of the cotton-plucking blade, which improves the feeding reliability and ensures even materials in the hopper. A pair of cotton-conveying rollers #2 is used to pull and level materials to make the cotton layer thinner and even in thickness. Cotton-feeding roller #3 is mainly used to further pull and get thinner the material, and also to compact and grip the material in preparation for the pickup of fibers by the taker-in roller. In addition, the feeding speed is changed from constant speed of seven rollers rotating for feeding to progressive differential feeding, which provides conditions for pulling and thinning the cotton layer. This scheme is designed from the structural layout, parts structure and speed matching, which solves the problems of discontinuous and uneven feeding, and guarantees the performance improvement of the main machine.

2.2. Roller structure design
The structure and running parameters of feed roller, cotton-conveying roller and cotton-feeding roller decide the feeding status.

2.2.1. Stress analysis of materials [5]
During movement, materials are extruded and pulled by the roller and gradually become thinner. Figure 3 shows the stress analysis of materials during movement. The roller exerts acting force (R), friction stress (f) and gravity (mg) on the cotton. Friction stress (f) and gravity are the forces that drive
the cotton layer to move, while acting force (R) is the resistance force. Therefore, a necessary condition for smooth feeding \cite{5} is that the resultant force of gravity and friction force in the vertical direction shall be greater than or equal to that of acting force (R) in the vertical direction, i.e.:

\[ 2f \cos \alpha + mg \geq 2R \sin \alpha \]  

(1)

Figure 3. Schematic Diagram of Stress Analysis of Cotton

Since \( mg > 0 \) and \( R \geq 1 \), \( f \geq \tan \alpha \) is true. Let \( f = \tan \varphi \), then \( f = \tan \varphi \geq \tan \alpha \), i.e. \( \varphi \geq \alpha \).

Let the initial feeding thickness of the cotton layer be \( A \), the thickness of cotton being extruded by the feed roller be \( a \), and the roller radius be \( r \), then:

\[ 2r(1 - \cos 2\alpha) = A - a \]  

(2)

\[ r = (A - a) / 2(1 - \cos 2\alpha) \]  

(3)

Let \( \varphi = \alpha \)\cite{5}, then the feed roller radius \( r \) is:

\[ r = (A - a) / 2(1 - \cos 2\varphi) \]  

(4)

Wherein, \( \varphi \) is the friction angle between the cotton and the feed roller surface, which is generally \( 19^\circ \sim 31^\circ \) for sterile seed cotton. This device takes \( \varphi = \alpha = 30^\circ \)\cite{6}. Let the compression ratio be \( \mu = a / A \), then \( a = \mu \cdot A \).

2.2.2. Determination of roller diameter

Relevant data of cotton-plucking roller, cotton-conveying roller and cotton-feeding roller are substituted into the formula (4). Table 1 records the relevant data and calculated diameter.

Table 1. Relevant Data of Cotton-plucking Roller, Cotton-conveying Roller and Cotton-feeding Roller and Calculated Diameter

| Category                      | Item          | \( A \) (mm) | \( a \) (mm) | \( \mu \) | \( r \) (mm) | \( d \) (mm) | \( \varphi \) |
|-------------------------------|---------------|-------------|-------------|--------|-------------|-------------|--------|
| Cotton-plucking roller        |               | 140         | 100         | 0.71   | 40          | 80          | 30°    |
| Cotton-conveying roller       |               | 70          | 30          | 0.42   | 40          | 80          | 30°    |
| Cotton-feeding roller         |               | 32          | 3           | 0.09   | 29          | 58          | 30°    |

2.2.3. Surface structure of cotton-plucking roller

As shown in Figure 4, the smooth cylindrical roller (a) only stops and extrudes the cotton, which is conducive to the temporary storage of materials, but bad for material feeding. Six-blade (b) and eight-blade (c) cotton-plucking rollers rotate to drive the material feeding, and the blade quantity decides the contact area between materials and the plucking roller. The larger the area is, the greater the downward force on the material is. This is more conducive to feeding.
Hence, we used the eight-blade structure (c). Figure 5 shows the schematic diagram [7] for blade structure. The blade quantity Z=8; the central angle of each blade is 45°; edge EC of V-shaped blade is perpendicular to edge CD; line CO is the center line of quadrangle ECDO. Solve the quadrangle ECDO and obtain: CD=15mm, CO=40mm, OD=30mm. Therefore, the diameter of feed roller is 60mm.

2.2.4. Surface structure of cotton-conveying roller
The cotton-conveying roller is used to further pull and get the cotton layer thinner, so a certain extrusion force is required. Under the action of extrusion and friction, the cotton layer can be pulled to become thinner, and will not be pulled out while the cotton-feeding roller is working. As a result, the roller surface shall produce sufficient friction force and have enough area to realize extrusion for gripping. Figure 6 shows the structure and parameters.

2.2.5. Surface structure of cotton-feeding roller
In order to ensure a reliable gripping of cotton layer by cotton-feeding roller, we adopt a fine axial tooth groove structure. When a pair of rollers is installed and operated with staggered teeth, cotton fibers are firmly held between the gap of two teeth, so when the taker-in roller picks up fibers, those fibers not hooked will not slip off. See Figure 7 for the surface structure.

3. Optimization and Design of Cotton-feeding Roller Shaft

3.1. Structural scheme of roller body
As the L/D ratio of the two rollers is greater than 20, and the gap between them is small, if there is cotton ball passing by while the machine is running, the roller will be subject to a local force of sudden changes, which causes the roller to bend and deform, resulting in inconsistent gaps over the whole length, and even mechanical failure in serious cases. So the key point of our design is to solve the deformation of the roller.

As is known to all, the bending capacity of hollow shaft is greater than that of solid shaft, so we use hollow structure as the basic structure of the roller shaft. See the schematic diagram of the structure in Figure 8(a). In addition, we also make an assumption of a child-mother assembly structure as shown in
Figure 8(b).

(a) Scheme I: Solid shaft head and circular hollow shaft tube

(b) Scheme II: Circular hollow shaft head and tube, with hexagonal spindle

Figure 8. Schematic Diagram of Roller Structure

3.2. Static analysis of roller

3.2.1. Pro-processing

The model of cotton-feeding roller assembly is established and the grid is divided; the linear pressure on the roller is calculated to be 0.22Mpa based on the processing capacity (500kg/h) of the feeding device and the package form and weight of sterile seeds, so a uniform load of 0.22Mpa is applied to the roller shaft; both shaft heads of the roller rotate relative to the shell, so a cylindrical surface shall be added for restriction.

3.2.2. Static analysis of roller

Figure 9 shows the cloud diagrams of the deformation, strain and stress of hollow roller.

Table 2 shows the static characteristics of hollow roller under linear pressure.

| Item type         | Location of maximum value | Value                                      | Remarks            |
|-------------------|---------------------------|--------------------------------------------|--------------------|
| Bending deformation | Central position of hollow shaft | Maximum displacement: 0.022038mm | 1.317 times that of Scheme II |
| Strain            | Central position of hollow shaft | Maximum: 6.2388e-5Mpa, with a strain range of 6.0148e-10~6.2388e-5Mpa. Maximum: 11.469Mpa, with a stress range of 9.8543e-6~11.469Mpa. | 1.324 times that of Scheme II |
| Stress concentration | Central position of hollow shaft |                                    | 1.434 times that of Scheme II |

Figure 10 shows the cloud diagrams of deformation, strain and stress of the roller assembly of the same length and diameter and equipped with spindle.
Figure 10. Finite Element Analysis of the Hollow Shaft of Cotton-feeding Roller (Scheme I)

Table 3 shows the static characteristics of cotton-feeding roller assembly with hexagonal spindle under linear pressure.

Table 3. Static Characteristics of Cotton-feeding Roller Assembly with Hexagonal Spindle under Linear Pressure (Scheme II)

| Item type                | Location of maximum value       | Value                                      |
|--------------------------|---------------------------------|--------------------------------------------|
| Bending deformation      | Central position of hollow shaft| Maximum displacement: 0.016736mm            |
| Strain                   | Central position of hollow shaft| Maximum: 4.7103e-5Mpa, with a strain range of 1.1236e-7~4.7103e-5Mpa. |
| Stress concentration     | Central position of hollow shaft| Maximum: 7.9983Mpa, with a stress range of 0.01241~7.9983Mpa. |

3.3. Analysis results
The analysis shows that the maximum stress, strain and deformation of hollow roller and assembly roller with hexagonal spindle occur at the middle position, and the deformation resistance of assembly roller with hexagonal spindle is superior to that of hollow roller (about 1.3 times). The stress and strain ranges of the assembly roller are also larger than those of hollow roller. Therefore, the assembly structure with hexagonal spindle is adopted for the cotton-feeding roller.

4. Conclusion
In this paper, we presented a novel design of vertical feeding device for sterile seed long fiber extractor, and drew the following conclusions:

(1) Vertical feeding ensures continuous and even material feeding with no block formed, thus avoiding mechanical failure.

(2) By replacing the constant-speed feeding structure of multiple rollers with the combined use of cotton-plucking feed roller with roller, the clogging of feeding hopper is avoided, and the feeding continuity is ensured.

(3) The progressive differential feeding mode is conducive to make the material bed thinner, improve the fiber extraction rate, reduce impurity rate and unattached fiber, and greatly improve the machine performance.

(4) Φ58×1200mm cotton-feeding roller adopts an assembly structure with hexagonal spindle to reduce deformation and prolong the service life of the roller.
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References
[1] B.J ger, Zhang Jiaming. Cotton Feeding by Hopper or Roll [J]. Textile Technology Overseas (Textile), 1981(26): 5-8.
[2] Yang Qiulan. Development of New Blowing-Carding Feeding Hopper [D]. Qingdao University, 2009.
[3] Zhao Qiang. FA172A Blowing-Carding Hopper and FT022 Auto Leveler and Their Processing Properties [J]. Textile Science Research, 1993(01): 1-6.
[4] Yang Qiaoyun. Structural Characteristics and Production Practice of FA225 Carding Machine [C]. China Textile Engineering Society. Proceedings of "Jinsheng Cup" No. 1 National Forum for Young and Middle-aged Scientific and Technological Workers in Cotton Textile Industry. China Textile Engineering Society: China Textile Engineering Society, 2005:136-139.
[5] Wang Liping. Research of Design Theory for Composite Straw Grinder [D]. Northeast Forestry University, 2010.
[6] Basis of Cotton Spinning Editorial Board. Basis of Cotton Spinning (Volume II) [M]. China Textile & Apparel Press, 2007.
[7] Zong Rong. Analysis & Research on Cylinder Mechanism of JWF1207 Carding [D]. Qingdao University of Science and Technology, 2012.