Design and Optimization of Extraction Process of Sterile Seed Long Fiber

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Abstract. We carried out research & analysis and development & design on the problems such as unreasonable structure of outdated process equipment and device, imperfect matching process and incomplete process link in the sterile cottonseed long fiber extraction, presented structural schemes for main machine and key fittings, and configured novel processing technology for sterile seed long fiber extraction, which achieves higher flexibility and adaptability of the processing technology and a machine-hour processing capacity of 400kg/h which is 2~3 times that of old model. And we proposed that the linear speed ratio of taker-in roller to roller shall not exceed 2.500, and obtained their reasonable speed at the optimum performance. The promoted application of this technology is of great significance to improve quality and efficiency of textile and cotton tailings treatment.

1. Introduction
Sterile seed refers to single seed cotton that has not been fertilized after flowering and does not fully develop. Its surface is attached with short fiber with a length of about 16mm, and a small fluffy ball with hard seed is in the center. As a kind of native impurity, the sterile seed will greatly affect the spinning quality. Hence, for the purpose of improving lint quality, the sterile seed must be eliminated before cotton processing and spinning. However, the long fiber lengthening about 16mm has a great value in open-end spinning. Therefore, saw ginned cotton equipment processing and production line of cotton processing enterprises is usually equipped with the extraction and recovery processes of sterile seed long fiber.

At present, MQT250 dual roller cleaning-batting machine is used as the main machine matching with extraction and recovery processes of sterile seed long fiber. Due to its low processing capacity, 4~6 main machines will be arranged in the extraction and production line of sterile seed long fiber, and each of them is connected in series or parallel through pipelines to collect materials and arrange pipelines. The process matching equipment includes cleaning-batting machine, discharging separator, fan, dust collector, etc., all of which are connected by an air conveying system. Due to low processing capacity of the main machine, large number of equipment, complex structure of the ventilation network, incomplete process link and other reasons, the process production line has a failure rate, which causes poor quality of extracted cotton and makes it difficult to match with the seed cotton ginning production line. Hence, studying the extraction technology of sterile seed long fiber and its supporting technology is of great importance to the safety production of cotton processing enterprises, decline in the loss of cotton fiber and improvement of economic benefit. Figure1 shows the structure of ventilation network.
1. Discharging separator; 2. Air duct; 3. Fan; 4. Dust collector; 5. Feeding tube; 6. Extracted cotton nozzle; 7. Lower impurity removal nozzle; 8. Cleaning-batting machine; 9. Impurity cleaning mechanism

Figure 1. Schematic Diagram of Process Pipeline of Single Main Machine

Many factors could affect the processing properties of sterile seed long fiber extraction. It is found that the continuity, evenness and rack structure of feeding are important factors. Wang Shaobin, Hou Shengtong, Li Hauikun et al. introduced the existing sterile seed recovery process, and expounded various problems resulted from uneven and discontinuous feeding of sterile seed. Wei Jingke improved the feeding structure on account of the uneven feeding of cotton-feeding curtain of MQT-250 cleaning-batting machine, and the feeding by bamboo curtain was changed to feeding hopper, which is conducive to the continuity of feeding. Sun Huimin added an opening device ahead of the cleaning-batting machine. The result shows that fully opening is conducive to the feeding evenness of sterile seed and the reduction of clogging and shut-down failure. Guo Qianru conducted an experimental study on the number, structure and layout of impurity removal blades of lint cleaner. The result shows that the optimum efficiency of impurity removal and reducing the loss of cotton fiber is achieved when the gap between six impurity removal blades and the taker-in roller gradually increases from top to bottom within the range of 1mm~2mm. Zhang Haiyang tested the combing process of cotton and linen blending. The result shows that when the carding channel of needle gear carding cotton is narrowed along the circular motion direction of cylinder, the extrusion force of needle gear on fiber becomes greater, which facilitates impurity removal. Wang Wenguo, Zhang Lingbin et al. conducted an optimization experiment on the production process and dedicated part configuration that affects the carding performance of E62 and E65 combing machines. The result shows that a higher density of top comb can reduce tooth space and enhance the control over fiber bundle, which is conducive to remove short fiber, cotton knot and impurity. Yang Qiulan conducted an experimental study on the structure and feeding mode of lint feeding hopper. The result indicates that the forward feeding of feed plate and cotton-feeding roller makes for smooth feeding and realizing even and continuous feeding.

To sum up, the current research on feeding evenness and cleaning performance is mostly focused on lint, while there is less research on the feeding evenness and processing properties of sterile seed long fiber extraction technology. In this paper, in allusion to the requirements for the evenness and continuity of feeding and the processing capacity, we conducted research and test from the aspects of structure of main machine, structural composition of process, structure and layout of pipeline and fittings, matching equipment, etc., hoping to provide a reference for the optimization and design of sterile seed long fiber extraction machine and equipment.

2. Process Design of Extracting Sterile Seed Long Fiber
The technology of extracting sterile seed long fiber is a cotton tailings treatment technology, of which the effectiveness depends on the structure of the extractor. In this design, we conducted analytical research, development and design with regard to the matters of unreasonable structure of processing technical equipment and device, and imperfect and incomplete matching process of sterile seed long fiber extraction in the current cotton processing and production, and formed the scheme of a novel sterile seed long fiber extraction process.
2.1. Design of technical equipment and device
In view of existing problems in the structure of sterile seed long fiber extractor, we made a lot of innovative design from the aspects of the structure and layout of various parts of the extractor as well as the connection relationship and mode between these parts.

2.1.1. Change of feeding mode
The feeding mode is changed from horizontal feeding to vertical feeding\(^7\), and the constant-speed rotary feeding by multiple rollers is changed to cotton-plucking roller progressive speed feeding, so the cotton layer gradually becomes thinner; laminated accumulation is avoided; feeding is even and continuous; extraction rate is improved; impurity rate is reduced; and mechanical failure is reduced. Figure1 shows the comparison of feeding modes.

![Vertical and horizontal feeding modes](image1.png)

1. Feed roller; 2. Cotton-conveying roller; 3. Cotton-feeding roller

Figure 2. Comparison of Feeding Modes

2.1.2. Impurity removal blades are arranged on one side of fibers picked up by taker-in roller
After the feeding mode is changed, the area where the feeding roller separates fiber from the taker-in roller increases, and the cleaning area through which the material passes becomes longer. Under the action of centrifugal force, impurities are completely exposed to the outer layer. The impurity removal blade can adhere cotton so that the fibers are firmly attached to the surface of taker-in roller, thus reducing unattached fiber. In addition, the impurity removal blade effectively cuts off the outer impurities to improve the performance of impurity removal. (Figure3).

![Impurity removal device](image2.png)

(a) Impurity removal device of dual roller cleaning-batting machine
1. Cotton adhering plate

(b) Impurity removal device of vertical long fiber extractor
2. Impurity removal blade

Figure 3. Contrast Diagram of Position of Impurity Removal Blade

2.1.3. The overall structural layout of main machine is improved
The first and second groups of extraction mechanisms are arranged up and down, with compact structure and small occupied area. In addition, the original two impurity removal channels are merged into one channel, which creates conditions for the lower impurity removal, collection and transportation (Figure4(b)). The original two long fiber discharging devices are simplified as one, so the structure is more compact and the structure is further sized down; the exhaust opening is reduced from four to two, and is directly connected to the blowing fan for lower impurity removal in a short distance within the fan, thus simplifying the structure of ventilation network. This is particularly obvious in installing multiple machines. The fully enclosed connection between components reduces air leakage and greatly avoids mechanical failure (Figure4).
The structure of pipelines and fittings and the process are improved

The conveying pipelines and fittings in the air conveying system are the bridge between the feeding device and the discharging separator, and various factors shall be considered in the analysis and design of pipelines [10]. For this technology, a positive pressure blowing flat pipe tee is connected with the closed-air discharger, and its reasonable structural parameters determine smooth discharging. To analyze how will tee structure affect flow field, a tee of 60° is designed in accordance with the structural requirements of closed-air discharger. Figure 5 shows its structural diagram. The outlet air velocity is set as the conveying air velocity of 10m/s, and the upper branch pipe is sealed, so the right and left flat pipes have the same flow rate. CFD analysis software (Fluent) is used to perform flow field simulation and analyze the pressure distribution in the pipeline to determine the optimal parameter value. Figure 6 shows the flow distribution.

As shown in the velocity vector diagram and pressure cloud diagram, the thickness ratio \( h_j/h_c \) of flat pipes at the inlet to that at the outlet is different, so does the pressure distribution. \( h_j/h_c \) is in direct proportional to the pressure distribution uniformity. However, as vortex in the area of closed-air
branch pipe becomes stronger, when \( h/j/h_c = 6/7 \) and \( 3/4 \), the airflow velocity is \( 3.55 \text{m/s}-5.68 \text{m/s} \); \( h/j/h_c \) is inversely proportional to the inlet pressure and directly proportional to the outlet pressure, with a large pressure gradient. When \( h/j/h_c = 5/8 \), there is no obvious vortex in the area of closed-air branch pipe, but there is some stagnant air flow with a speed of only \( 0.83 \text{ m/s}-1.66 \text{ m/s} \).

Hence, for the purpose of smooth discharging of the closed-air discharger and avoiding reverse flow, the smaller value of thickness ratio \( h/j/h_c \) of inlet to outlet is selected for this design, i.e. (c) or (e).

2.2. Optimization of sterile seed long fiber extraction process
Uneven feeding is one of the fundamental reasons that affect the processing performance. In this paper, a number of improving designs have been made from the aspect of processing structure in view of feeding unevenness.

2.2.1. The cotton assorting system is added
Most of the previous technologies are sterile seed long fiber recovery processes matched with Y88, Y96, Y121, Y139 and Y151 large-scale cotton ginning equipment. Multiple main machines (usually four or six sets) are used together, each of which is equipped with one discharging separator, thus resulting in large number of equipment, complex structure of the processing system and unstable performance.

In this scheme, the main machine is changed from horizontal structure to vertical structure, thus avoid air leakage and improving processing capacity; discharging and assorting by multiple separators in the whole assorting system is changed to one separator and one spiral cotton assorting machine, so the number of separators is only \( 1/n \) (n is the number of main machine) of the original number, and further simplifies the structure of ventilation network; the spiral cotton assorting machine can not only convey materials along the axis to achieve cotton assorting, but can also fully loosen the materials, so that the materials fed to the machine are fully and uniformly loosened.

2.2.2. A secondary extraction bypass is added to improve processing adaptability
There are still a large amount of lint and long fiber not extracted in the lower impurity discharged from the long fiber extraction main machine. A certain amount of effective fibers will be lost if these leftovers are treated as waste. In this scheme, a secondary extraction bypass system is arranged, which is composed of an independent separator and a fan. When the bypass is running, the lower impurities discharged from the extraction main machine are sucked by air to the separator which will discharge them to the opening and cleaning device. After impurities are cleaned and discharged, they will be conveyed to the main process line for the secondary extraction. Secondary extraction is an independent bypass system, which is selected based on the quality requirements for extracted cotton to improve the processing adaptability.

2.2.3. The opening process of outsourced sterile seed raw materials is added
To allow the sterile seed long fiber extraction process to match with the cotton ginning production line and to be used independently, in this scheme, a bale-opening and cleaning integrated machine is developed, and a bypass system for opening and cleaning sterile seed leftovers is designed. The sterile seed leftover cotton bales purchased from cotton processing plants or textile enterprises are firstly opened and cleaned to remove most impurities, and then the sterile seed raw materials in the loose state enter the long fiber extraction process. The cleaning and opening bypass can not only run synchronously with the production line, but can also run independently. The feeding quantity is controlled by frequency conversion of the main machine, and the excessive raw materials will be temporarily stored in the overflow tank. The bypass system is designed to achieve large-scale production and reduce production cost.

2.2.4. The feeding quantity of the main machine is automatically controlled
Due to the matching operation and continuous production with the cotton ginning process, the feeding
evenness and quantity of the original main machine are uncontrollable. The so-called "taking all materials fed" causes mechanical deformation of the cotton-feeding rollers and inconsistent gaps between them over the whole working length, thus affecting the performance of the main machine.

In this scheme, the feeding mechanism adopts an independent power system, and uses frequency conversion to control the motor speed. After multiple tests, we find that the base frequency of 16Hz can realize the optimal performance of the main machine. In the production process, such frequency can be adjusted slightly according to the quality of raw materials and the quality requirements for extracted cotton. With this technology, multiple devices are used in series, which have the consistent feeding quantity, performance and quality of extracted cotton, thus achieving continuous and even feeding and trouble-free production.

Figure 7 shows the process flow of extracting sterile seed long fiber in this scheme.

Figure 7. Process Flow of Air Conveying System

1. Bale-opening and cleaning integrated machine 2. Leftover separator 3. Cotton assorting separator 4. Bar-shaped cotton assorting machine 5. Extraction main machine 6. Overflow tank 7. Cotton collecting machine 8. Long fiber packing machine 9. Leftover spiral conveying machine 10. Fan (3 sets, omitted) 11. Dust removal system (omitted)

3. Online Test of Sterile Seed Long Fiber Extraction Process

This test focuses on the relationship between feeding speed and extraction quality and processing capacity. The long fiber extraction test is carried out by taking the linear speeds of taker-in roller and roller as the test factors, and the processing capacity, extraction quality and fiber damage as the test indexes.

Test material: sterile seed cotton bale, weighted 80 ± 5kg, general grade;
Test equipment: process production line with three main machines.

The taker-in roller speed of three main machine is 1,600r/min, 1,900r/min and 2,200r/min, respectively. The roller speed (frequency) is adjusted online. The test data is shown in the table below:
Table 1 Partial Test Data of Sterile Seed Production Line Performance (roller diameter: 58mm; taker-in roller diameter: 300mm)

| S/N | Linear speed of roller (m/min) | Taker-in roller speed (r/min) | Linear speed of taker-in roller (m/min) | Linear speed ratio of taker-in roller to roller | Machine-hour processing capacity (kg/h) | Effective fiber quantity (kg/h) | Extraction efficiency (%) | Long fiber damage |
|-----|-------------------------------|-------------------------------|----------------------------------------|---------------------------------------------|----------------------------------------|-------------------------------|--------------------------|-----------------------|
| 1   | 0.6                           | 1600                          | 1507                                   | 2500                                        | 156.25                                 | 53.25                         | 85.2                     | Tendency |
|     | 0.6                           | 1900                          | 1790                                   | 2970                                        | 156.25                                 | 56                            | 89.6                     | Obvious   |
|     | 0.6                           | 2200                          | 2072                                   | 3440                                        | 156.25                                 | 57.15                         | 91.44                    | Obvious   |
|     | 0.9                           | 1600                          | 1507                                   | 1670                                        | 234                                     | 89.35                         | 95.459                   | Not obvious |
| 2   | 0.9                           | 1900                          | 1790                                   | 1980                                        | 234                                     | 90.75                         | 96.955                   | Not obvious |
|     | 0.9                           | 2200                          | 2072                                   | 2290                                        | 234                                     | 91.20                         | 97.436                   | Not obvious |
|     | 1.21                          | 1600                          | 1507                                   | 1250                                        | 312.53                                  | 111.25                        | 88.991                   | Not obvious |
| 3   | 1.21                          | 1900                          | 1790                                   | 1480                                        | 312.53                                  | 115.35                        | 92.27                    | Not obvious |
|     | 1.21                          | 2200                          | 2072                                   | 1720                                        | 312.53                                  | 116.55                        | 93.23                    | Not obvious |
|     | 1.51                          | 1600                          | 1507                                   | 1000                                        | 390.67                                  | 143.65                        | 91.926                   | Not obvious |
| 4   | 1.51                          | 1900                          | 1790                                   | 1190                                        | 390.67                                  | 146.45                        | 93.718                   | Not obvious |
|     | 1.51                          | 2200                          | 2072                                   | 1375                                        | 390.67                                  | 147.55                        | 94.422                   | Not obvious |

As can be seen from Table 1, at the same feeding speed, with the increase of the linear speed ratio of taker-in roller to roller, both the recycling quantity of effective fiber and the processing capacity increase. When the linear speed ratio is greater than 2,500, obvious fiber damage occurs, and the short fiber content increases; when the feeding speed is 0.9m/h and the taker-in roller speed is 2,072r/min, the processing capacity is 234kg/h and the extraction efficiency is higher than 95%.

And when the linear speed ratio of taker-in roller to roller is 1,375, the taker-in roller speed is 2,072r/min and the roller speed is 8r/min, the processing capacity is 390kg/h and the extraction efficiency is up to 94.4%. Apparently, the linear speed ratio of taker-in roller to roller and their speed at this time are the most economical matching parameters.

Table 2 shows the quality data of extracted cotton samples after being tested by testing authority. The index data conforms to the national standards, among which the length, evenness and broken fiber indexes are superior to the national standards.

Table 2. Cotton Sample Test Index Record of China Cotton Notary Inspection Wujiaqu Inter-Provincial Joint Laboratory

| Sample No. | Leaf grade | Impurity area % | Reflectivity Rd | Yellow index =a-b | Color grade | Micronaire value | Length | Evenness | Short fiber index | Strength | Extension | Maturity |
|------------|------------|-----------------|-----------------|-------------------|-------------|-----------------|--------|----------|------------------|----------|-----------|---------|
| QTM123     | 2          | 0.19            | 74.2            | 9.3               | 32          | 4.29            | 25.62  | 75.9     | 24.8             | 25.84    | 5.2       | 0.87    |
| GB/T358    | -          | -               | -               | -                 | -           | -               | -      | -        | -                | -        | -         | -       |
| 72-2018    | -          | -               | -               | -                 | -           | -               | -      | -        | -                | -        | -         | -       |

Equilibrium time: From 16:00, Dec. 27, 2019 to 10:00, Dec. 29, 2019, Humidity: 63, Temperature: 22°C, HVI No.: 0911022
4. Conclusions
In this paper, we introduce a new processing scheme for extracting sterile seed long fiber, present the innovative design ideas of technical equipment and pipelines and fittings as well as specific process flow, and draw up the following conclusions:

1) With this technology, the machine-hour processing capacity reaches 400kg/h, which is 2~3 times that of previous technology, and greatly improves the overall performance;

2) The matching technical parameters of the main machine to achieve the optimal processing property is obtained, i.e. taker-in roller speed being 2200r/min, roller speed being 8r/min, and the linear speed ratio of taker-in roller to roller being 1,375; the linear speed ratio of taker-in roller to roller shall not be greater than 2,500;

3) In this technology, the fan is mounted within the main machine, so as to simplify the structure of ventilation network, and reduce the air volume, air pressure and power consumption. According to the test, the system with four main machines can save electricity of 20kw and air of 15,000 m³/h.

4) We present a matching use scheme of lower impurity discharged from sterile seed extraction by closed-air discharger and flat pipe tee, and give the optimal structural parameters of the tee.

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References
[1] Wang Shaobin, Hou Shengtong, Li Huaikun. Introduction to New Technology for Recovering Sterile Seed [J]. China Cotton Processing, 2014(5):16-18.
[2] Wei Jingke. Discussion on Relevant Issues of 6MQT-250 Cleaning-Batting Machine [J]. China Cotton Processing, 2003(3):17-17.
[3] Sun Huimin. Discussion on Improvement and Application of Sterile Seed Cotton Extractor [J]. China Cotton Processing, 2013(1):11-11.
[4] Guo Qianru. Adjustment of Impurity Removal Blade of Saw Ginned Lint Cleaner [J]. China Cotton Processing, 2007(03):12-13.
[5] Zhang Haiyang. Research on Key Technology of China Hemp and Cotton Blended Combing [D]. Zhongyuan University of Technology, 2016.
[6] Wang Wenguo, Zhang Lingbin. Discussion on Technology Improving Carding Effecting of Combing Machine [J]. Cotton Textile Technology, 2012(06):20-23.
[7] Yang Qiulan. Development of New Blowing-Carding Feeding Hopper [D]. Qingdao University, 2009.
[8] Zhao Qiang. FA172A Blowing-Carding Hopper and FT022 Auto Leveler and Their Processing Properties [J]. Textile Science Research, 1993(01):1-6.
[9] 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.
[10] Ding Pingping. Research, Design and Dynamic Analysis for All-harvested Cotton Picker Separation System [D], Shihezi University, 2014.