A Study on Drying Control of Seed Cotton based on BP Neural Network Model

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Abstract. In order to solve the storage, transportation and processing problems caused by too high or too low percentage of moisture regain in cotton processing, a general online flexible combination intelligent drying process scheme was designed based on two drying equipment, vertical drying tower and tower dryer. Firstly, based on BP neural network model, the relationship between the initial percentage of moisture regain, target percentage of moisture regain and hot air temperature is established. Secondly, DS18B20 single-bus temperature sensor is used to construct the multi-point temperature detection feedback system of drying system. Then, based on the feedback signal of temperature measurement, the temperature set value output by BP neural network model and the fuzzy PID model of seed cotton drying, the opening control of the heat source regulating valve is realized, so that the measured temperature at the entrance follows the set temperature quickly and accurately. Finally, the percentage of moisture regain of seed cotton was adjusted by controlling the hot air temperature at the mixing point, and the seed cotton was dried to the most favorable condition for processing. The test results show that the whole set of intelligent control process has high accuracy and can be used in actual production.

1. Introduction
Cotton processing industry has a strong seasonality, in order to adapt to the seasonality of cotton growth, processing and circulation enterprises all adopt the mode of "seasonal acquisition, centralized processing and year-round sales" to organize their own business activities. Enterprises need to buy seed cotton in the mature season, and then stack or store for later processing. In the whole process of cotton processing, moisture content has a decisive effect on cotton quality. In the storage and transportation stage of cotton, if the percentage of moisture regain of seed cotton is too high, the cotton stacking will rot and deteriorate because of the high internal temperature and humidity, which will cause the seed cotton to turn yellow, affect the pneumatic transmission, and even lead to the deterioration of cotton fiber and spontaneous combustion. If the percentage of moisture regain of seed cotton is too low, it will lead to excessive swelling force of cotton fiber, and it will be difficult to pack, and even lead to "collapse" of cotton bale due to the failure to reach a certain density and weight. In the process of post-processing, if the percentage of moisture regain of seed cotton is too high, the friction coefficient on the surface of cotton fiber will increase, resulting in the difficulty of removing impurities from the surface of cotton fiber and
the increase of lint impurity rate. Excessive percentage of moisture regain in the ginning process will increase the friction between the cotton roll and the working box wall, leading to problems such as endless brushing, stopping of the cotton roll, rib blockage and so on, which will further reduce the work efficiency and processing quality of the ginning. If the percentage of moisture regain of seed cotton is too low, the rigidity of cotton fiber will increase, the fracture ratio will decrease, and the cotton fiber will break easily due to external force impact during processing, which will affect the internal quality of lint.

At present, most of the domestic equipment for processing machine-picked cotton is equipped with a two-stage drying system. In the actual process, the processing personnel will measure the percentage of moisture regain of seed cotton from time to time, and make the drying plan at the same time. There is a certain delay in the percentage of moisture regain detection of seed cotton, which leads to the inaccuracy of the drying scheme. High or low percentage of moisture regain of seed cotton will have adverse effect on cotton quality in storage, transportation and processing. Therefore, how to formulate accurate and immediate drying scheme and how to implement this scheme is undoubtedly an urgent problem to be solved in China's cotton processing industry at present.

In this paper, a set of drying process for seed cotton was designed, and the drying scheme for seed cotton with different percentage of moisture regain and the method to realize the drying scheme were put forward. The drying scheme was determined by the percentage of moisture regain measured in the early stage, and the relationship between percentage of moisture regain and temperature was established by using BP neural network. The percentage of moisture regain was controlled by controlling the temperature of the drying system. At the same time, modeling and experimental verification are carried out on how to get the temperature setting value through percentage of moisture regain, and a control method is proposed to make the actual temperature of hot air at the entrance of drying system follow the set temperature quickly and accurately.

2. Drying Principle

Studies have shown [1] that in the cleaning process of seed cotton, when the seed cotton percentage of moisture regain is greater than 9%, with the increase of percentage of moisture regain, the adhesion between impurities and cotton fibers will gradually increase, making it difficult to remove impurities. But at the same time, the vitality between cotton fiber and cotton seed decreased (FIG. 1), resulting in the increase of seed crumbs with fiber, resulting in an increase in the amount of impurities in the rolled lint and a heavier burden on lint cleaner. High percentage of moisture regain of packing lint will affect the storage quality of bale. When the percentage of moisture regain is less than 6%, although the cleaning effect is improved, the fracture strength of cotton fiber will be reduced [2]. During the cleaning process, cotton fiber is easy to break, damage the length of fiber, increase the content of short fiber, and make the inner quality of lint worse. Therefore, it is not only necessary to dry seed cotton before processing, but also to accurately control drying quantity, so that the percentage of moisture regain control in a reasonable range. The influence of percentage of moisture regain on the vitality, fracture strength and damaged fiber is shown in figure 1.

![Figure 1. Effect of percentage of moisture regain on strength, fracture strength and damaged fiber.](image-url)
After consulting a large number of domestic and foreign research data and combining with the experience of experts, it is found that in order to ensure the quality of the ginning, the seed cotton drying control process should keep the moisture content of seed cotton in 6.5%–8%, that is, the percentage of moisture regain in 6.95%–8.71% [3-4].

Seed cotton drying equipment is mainly divided into three types: vertical drying tower, tower dryer, pulse - baffle combination dryer, vertical drying tower and tower dryer are used as the first and second drying equipment respectively in this process.

Previous studies have found that the factors affecting the drying efficiency of seed cotton include: hot air temperature, exposure time, air volume and the relative speed between cotton and air. In this process, constant speed fan is used to transport cotton, so the acting time between seed cotton and hot air is relatively stable, about 7s~10s. In addition, the structure of tower dryer and vertical drying tower is relatively fixed, so the three factors of exposure time, air volume and relative speed between air and cotton are fixed. The control strategy of this process is: according to the initial percentage of moisture regain of seed cotton (percentage of moisture regain before drying), controlling the hot air temperature at the mixing point (entrance) of seed cotton and air, thus the percentage of moisture regain of seed cotton is controlled within a numerical range suitable for cotton processing [5-6].

Seed cotton drying takes advantage of the moisture release capacity of cotton fibers and the capacity of air to hold water. With air as medium, for air heating in the first place, when the air reaches a certain temperature and the relative humidity of the air decreases, the seed cotton is mixed with air, a temperature difference, humidity difference, and pressure difference is formed between the cotton fibers and the hot air, the adsorbed water molecules in the cotton fibers are forced to gradually diffuse outward and absorbed by the hot air, so as to achieve the purpose of drying seed cotton. The higher the temperature of the air, the lower the relative humidity, the higher the saturated humidity, the greater the humidity difference between it and cotton fibers, the better the drying effect. The increase of temperature has a great influence on the saturation humidity of air. When the temperature rises from 25℃ to 100℃, the temperature only increases by 3 times, while the saturation humidity of air increases by 25 times [7].

Vertical drying tower: hot air blows seed cotton with wet, lumpy and more impurity – containing into the top of the vertical drying tower. The lumpy seed cotton is formed into loose and flaky seed cotton flow by the first guide roller, and then slides down the aluminum row to the next guide roller, and then is sent to the next set of aluminum rows. The whole process is repeated five times to keep each bundle of cotton fiber in full contact with the hot air, making full use of energy efficiently while the seed cotton flowing. On the other hand, the opening of the guide roller makes the seed cotton ball become fluffy, thus enhancing the drying effect of drying tower. After the seed cotton pass down through the drying tower, the hot air transports the seed cotton to the next process.

Tower dryer: The seed cotton in the cotton conveying pipe enters the top layer of the dryer with hot
air from the top of the tower dryer. Inside the drying tower, the seed cotton moves layer by layer from top to bottom with the hot air, and the seed cotton in the semi-suspension state is wrapped by the hot air, which generates heat exchange between the two, and the hot air absorbs the evaporated water in the seed cotton, so as to dry the seed cotton. Dry seed cotton with hot and humid air movement to the bottom of the tower dryer, from the lower exit into the inner cotton suction pipe, so as to enter the next process.

3. Seed Cotton Drying Scheme

3.1. BP Neural Network Model

In practical application, the traditional BP algorithm is difficult to be competent, which is due to some defects and shortcomings of the traditional BP network, which are mainly shown as follows:

(1) The algorithm can make the weight converge to a certain value, but it cannot guarantee that it is the global minimum value of the error plane, because the gradient descent method may produce the local minimum value.

(2) The learning rate is fixed, the convergence rate is slow, and a long training time is required. For some complex problems, the training time of BP algorithm may be very long.

In view of the above situation, this paper adopts two improvement strategies of additional momentum method and adaptive adjustment of learning rate to improve the learning speed of the network and increase the reliability of the algorithm. The momentum method reduces the sensitivity of the network to the local details of the error surface and effectively restrains the local extremum of the network [8]. Adaptive adjustment of learning rate is conducive to shortening learning time [9-10]. The two improvement strategies are as follows:

The momentum term \(\alpha \omega^{(k-1)}\) is introduced into the standard weight adjustment formula \(\Delta \omega^{(k)} = \delta g^{(k)} y^{(k)}\), namely:

\[
\Delta \omega^{(k)} = \alpha \omega^{(k-1)} + \delta g^{(k)} y^{(k)} \tag{1}
\]

Where \(\alpha\) is the forgetting factor, value in \([0,1]\), \(\omega^{(k-1)}\) is the weight before adjustment. When the correction quantity \(\delta g^{(k)} y^{(k)}\) is the same sign as the previous time, equation (1) increases the weight correction quantity, thus improving the convergence speed. When the sign of this correction is different from that of the previous one, it indicates that there is a certain oscillation. Equation (1) reduces the weight correction quantity and plays a stabilizing role.

In order to make step A generate appropriate adjustment with iteration, adaptive step size is introduced:

\[
\delta^{(k)} = \delta_0 \frac{1}{1+k/k_0} \tag{2}
\]

Where \(\delta_0\) represents the initial learning parameter, and \(k_0\) is an appropriately selected constant in the range of 100–500. When \(k<<k_0\), the learning rate is approximately constant \(\delta_0\), corresponding to the search stage. The network is quite far from the global minimum value and the step size is relatively large, so that the network can rapidly decline towards the minimum value of the error surface. When \(k>>k_0\), the learning rate decreases by the proportion of each \(1/k\), corresponding to the convergence stage, the network is very close to the global minimum, with relatively small step size, and can be gradually reduced along with the iteration, so that the network can carry out fine-tuning of weights.

In this paper, the BP neural network model is established based on the standard algorithm, and the momentum term and adaptive step size are introduced to improve the performance of the network. In the seed cotton drying system, the percentage of moisture regain of seed cotton after drying equipment is only affected by the percentage of moisture regain before drying and the hot air temperature at the mixing point [11]. Other influencing factors are relatively fixed [12]. This article respectively to the vertical drying tower and tower dryer modeling, there is a certain delay in percentage of moisture regain detection of seed cotton, which is not conducive to continuous control, while the temperature measurement and control are relatively easy to achieve. Therefore, BP neural network is used in this paper to establish the relationship between the initial percentage of moisture regain, target percentage...
of moisture regain and hot air temperature, and then a temperature fuzzy control model was established to control the percentage of moisture regain of seed cotton after drying by controlling the hot air temperature at the mixing point.

3.2. BP Neural Network Model of Vertical Drying Tower
Based on a large number of experimental data on site and the experience of experts in the field, a BP neural network is established. The input of the model is the percentage of moisture regain before the drying of the seed cotton and the percentage of moisture regain after the drying of the seed cotton. The output of the model is the hot air temperature value at the entrance of the drying tower. Establish a BP neural network with the 2-5-1 structure shown in figure 4.

![BP neural network model of vertical drying tower](image)

**Figure 4.** BP neural network model of vertical drying tower.

The response surface of the BP neural network model of the vertical drying tower is shown in figure 5. It can be seen that the percentage of moisture regain before drying and after drying of the vertical drying tower have a nonlinear relationship with the temperature of the hot air at the entrance. When the percentage of moisture regain before drying is kept constant, the higher the temperature at the entrance, the lower the percentage of moisture regain after drying. As the percentage of moisture regain before drying increases, to achieve the same percentage of moisture regain after drying, the temperature of the hot air at the entrance needs to be increased.

![Response surface of vertical dryer BP model](image)

**Figure 5.** Response surface of vertical dryer BP model.

In order to verify the correctness of the model, the following experiments were carried out in this paper. Three groups of different inlet temperatures were set at 65.2℃, 90.7℃ and 120.5℃, 9 groups of
cotton with different percentage of moisture regain before drying were measured. The experimental data of percentage of moisture regain after drying are shown in table 1. After calculation, the sum of square error, standard deviation and multiple correlation coefficient of the experimental data and the established vertical drying tower BP neural network model are 0.457, 0.239, and 0.983 respectively, which proves that the model has high accuracy and can be used to guide production.

| Percentage of Moisture Regain After Drying | 65.2°C | 90.7°C | 120.5°C |
|-------------------------------------------|--------|--------|---------|
| Percentage of Moisture Regain Before Drying (%) | 14.21  | 10.81  | 10.20   |
|                                            | 12.08  | 9.90   | 7.88    |
|                                            | 10.12  | 9.15   | 6.87    |
|                                            | 9.20   | 7.93   | 6.82    |
|                                            | 8.02   | 6.86   | 5.41    |
|                                            | 6.88   | 6.05   | 4.43    |
|                                            | 6.13   | 5.80   | 4.31    |
|                                            | 5.15   | 4.60   | 4.11    |
|                                            | 4.01   | 3.71   | 3.64    |

3.3. BP Neural Network Model of Tower Dryer
Use the same method as 2.2 to build the BP neural network of the tower dryer with 2-5-1 structure. figure 6 is the model response surface of the BP neural network of the tower dryer.

**Figure 6.** Response surface of BP model of tower dryer.

In order to verify the correctness of the model, three groups of different inlet temperatures were set at 65.1°C, 89.8°C, 120.1°C, and 9 groups of cotton with different percentage of moisture regain before drying were measured. The experimental data of percentage of moisture regain after drying are shown in the table 2.
Table 2. Experimental data of tower dryer.

| Percentage of Moisture Regain Before Drying (%) | 65.1°C | 89.8°C | 120.1°C |
|-----------------------------------------------|--------|--------|---------|
| 14.13                                        | 12.80  | 11.68  | 10.62   |
| 12.02                                        | 10.92  | 8.91   | 8.30    |
| 9.84                                         | 9.34   | 8.47   | 7.59    |
| 9.01                                         | 7.94   | 7.33   | 6.91    |
| 8.08                                         | 7.30   | 6.50   | 5.62    |
| 7.03                                         | 6.49   | 5.41   | 4.58    |
| 5.97                                         | 5.71   | 5.18   | 4.33    |
| 5.10                                         | 4.67   | 4.43   | 3.21    |
| 3.93                                         | 3.83   | 3.51   | 3.08    |

After calculation, the sum of square error, standard deviation and multiple correlation coefficient of the experimental data and the established tower drying tower BP neural network model are 0.534, 0.259, and 0.976 respectively, which proves that the model has high accuracy and can be used to guide production.

3.4. Drying Plan

It can be seen from figure 5 and figure 6 that compared with the vertical drying tower, the drying efficiency and heat utilization rate of the tower dryer are lower. Studies have shown that a seed cotton drying system consisting of a tower dryer, if its pipes and dryers are not heat-insulated, only 16% of the hot air heat energy is used to remove the cotton moisture, and the remaining 84% or radiation loss, or lost through the system in the form of hot air. Therefore, it is very important to insulate the hot air pipeline, and the drying plan will also be affected by the heat utilization rate of the two dryers.

Due to the high thermal energy efficiency of the vertical drying tower, it is placed before the first stage of seed cotton cleaning. The drying plan should give priority to the use of the first-level drying equipment. When the percentage of moisture regain of the seed cotton is too high and the first-level drying equipment cannot meet the drying requirements, the second-level drying equipment should be used. In the vertical drying tower stage, try to adjust the percentage of moisture regain to a suitable value. This control strategy is beneficial to improve the cleaning efficiency of the first-level seed cotton cleaning equipment located between the first-level and second-level drying equipment. The temperature of the hot air inlet of the drying tower should be strictly controlled within 120°C to avoid serious damage to the cotton fiber due to excessive temperature.

In order to meet the requirements of seed cotton cleaning and ginning process for percentage of moisture regain, according to expert experience, this process controls the percentage of moisture regain \( W_{obj} \) after drying to about 7.8%. When the percentage of moisture regain is less than 7.8%, the two-stage drying equipment is not activated. When the percentage of moisture regain of the seed cotton is greater than 17%, it has exceeded the processing capacity of the two-stage drying equipment. The seed cotton should be air-dried, or a multi-stage (greater than two-stage) series drying equipment should be used. The specific plan when 7.8%<\( W_{VFD} <17% \) is:

(1) When the initial percentage of moisture regain is 7.8%<\( W_{VFD} <13% \), only the first-level drying equipment is required. According to the established vertical drying BP model, the inlet temperature \( T_{VED} \) is:

\[
T_{VED} = BP_{VED}(W_{VFD}, W_{obj})
\]

and the target percentage of moisture regain after drying is \( W'_{VFD} = W_{obj} = 7.8\% \).

(2) When the initial percentage of moisture regain after drying is \( W'_{VFD} = W_{obj} = 7.8\% \), two-stage drying equipment needs to be activated at the same time, the vertical drying tower is in full load operation, and the temperature at the inlet \( T_{VED} \) is controlled within 120°C. The percentage of moisture regain after...
primary drying is $W'_{VFD}$, the initial percentage of moisture regain $W_{TD} = W'_{VFD}$ before secondary drying, the control temperature $T_{TD}$ of the tower dryer is:

$$T_{TD} = BP_{TD}(W_{TD}, W_{obj})$$

and the target percentage of moisture regain after drying is $W'_{TD} = W_{obj} = 7.8\%$.

4. Control Method of Drying

4.1. Wire Bus Temperature Multi-Point Detection

This process adopts two-stage drying equipment, which requires real-time measurement of the temperature of hot air and seed cotton mixing points, hot air pipes, heat sources, etc., to provide temperature measurement feedback signals for adjusting the heating equipment. Based on the above characteristics, the process adopts the single-bus temperature multi-point detection technology based on DS18B20. This technology is a digital single-bus integrated temperature sensor. The temperature measurement products built by it have the advantages of simple system, high temperature measurement accuracy, convenient connection, more temperature measurement points, and less occupied ports. DS18B20 supports 1-Wire bus interface, the measurement temperature range is -55°C~+125°C, the resolution of 9-12 digits can be set by the program, and the accuracy is ±0.5°C. The site temperature is transmitted by the digital signal of the 1-Wire bus, the anti-interference of the system has been greatly improved, and the field wiring is more flexible [13-15].

At the same time, taking full advantage of the single bus, multiple DS18B20 for drying temperature detection are connected to the 1-Wire bus. The single-bus connection gives the communication protocol some unique characteristics. Communication first needs the bus controller to send out a "reset" signal to synchronize the bus, and then select the controlled device for subsequent communication. The instruction to select the controlled device is a "network" instruction or a read-only memory (ROM) instruction. When a particular device is selected, before the next "reset" signal is sent, all devices except the selected device are suspended and subsequent communications are ignored. Once a device is used for bus communication, the host can issue specific device instructions to it and read and write data to it. This is because each type of device has different functions and uses, and once the device is selected, there will be the only agreement.

In the DS18B20 Datasheet, there is no mention of the number of devices connected to a single bus, which can easily make people mistakenly believe that any number of devices can be connected. This is not the case in practical applications. Once there are more than 8 devices on the 1-Wire bus, it is necessary to solve the bus drive problem of the microprocessor. In order to test the drive capability of a single bus, all 1-Wire bus components in this process share a data line, and the pull-up resistor is provided by a 5K potentiometer. In this way, the pull-up effect can be adjusted according to the number of additional sensors on the actual system. The experimental measurement shows that under the condition of 100m, the relationship between the measured pull-up resistance and the number of 1-Wire bus components is shown in figure 7.

![Figure 7](image)

Figure 7. The relationship between the resistance of the pull-up resistor and the number of 1-Wire bus components.
4.2. Fuzzy PID Control of Seed Cotton Drying

Using the seed cotton drying BP neural network model, the set value of the temperature at the hot air inlet can be obtained according to different initial and final percentage of moisture regain. The next problem to be solved is how to control the heat source regulating valve so that the actual temperature measured at the inlet quickly and accurately follows the set temperature change.

The drying process is affected by factors such as heating efficiency, heat exchange efficiency, atmospheric environment, and fan speed. At the same time, due to the existence of large delay links such as hot air pipeline transmission and heat exchange, the traditional controller has a poor control effect. This article combines fuzzy control with traditional PID control, and uses fuzzy control theory to set the PID controller's proportional, integral and derivative parameters. The fuzzy PID control model of seed cotton drying established in this paper is shown in figure 8.

![Figure 8. Temperature fuzzy PID control.](image)

The fuzzy PID controller takes the deviation e and deviation change ec between the set value of the mixing point temperature and the actual measured value of the mixing point temperature as input quantities, and obtains the fuzzy quantities E and EC respectively after the fuzzification process, and then performs fuzzy inference on this basis. The output is the PID control parameter correction values Δkp, Δki and Δkd, and then the PID parameters kp, ki and kd are adjusted online, and then the opening control amount of the heat source regulating valve is output. The flow chart of the whole process is shown in figure 9.

![Figure 9. Drying process flow chart.](image)

5. Experimental Verification

Figure 10 shows the results of a drying experiment. It can be seen that this is a transition process between two module with different percentage of moisture regain. At the 42nd minute, the percentage of moisture regain of cotton changes suddenly, which is adjusted by the fuzzy PID controller. The percentage of moisture regain of the dried seed cotton is controlled at about 7.8%, which meets the requirements of later processing.
Figure 10. Initial percentage of moisture regain and percentage of moisture regain after drying.

The experimental data of the target temperature and measured temperature of the mixing point of the two-stage dryer are shown in figure 11, and the temperature control error of the mixing point is shown in figure 12. When the initial percentage of moisture regain of seed cotton is about 11%, the system only uses the first-level drying equipment, and the measured temperature can follow the set temperature well, and the error is within 4°C. In the process of on-site processing, when a pile of seed cotton is processed and the next pile is replaced, the percentage of moisture regain of the seed cotton changes. The percentage of moisture regain of the latter pile of seed cotton is higher, at about 14.7%, and the system also enables two-stage drying equipment. The temperature of the hot air at the entrance of the vertical drying tower is controlled at the upper limit temperature of 120 °C, and the temperature of the hot air at the entrance of the tower dryer is controlled at about 98 °C. There is a certain overshoot in the initial stage. The percentage of moisture regain of the dried seed cotton is basically controlled in the vicinity, which meets the control requirements of the drying process for the percentage of moisture regain.

Figure 11. Target temperature and measured temperature of the mixing point of the dryer.

Figure 12. The temperature control error of the mixing point of the dryer.

6. Conclusion

(1) Designed a set of control technology that can accurately and instantly formulate the drying plan and precisely control the drying volume. The process adopts vertical drying towers and tower dryers as the first and second drying equipment. The control strategy is: according to the initial percentage of moisture regain of the seed cotton (the percentage of moisture regain before drying), control the hot air temperature at the mixing point (entrance) of the seed cotton and air, so as to control the percentage of moisture regain of the seed cotton within a numerical range suitable for cotton processing.

(2) The designed drying scheme is: when the percentage of moisture regain is less than 7.8%, the two-stage drying equipment is not used. When the percentage of moisture regain of the seed cotton is
greater than 17%, the seed cotton should be aired, or multi-stage (more than two-stage) tandem drying equipment should be adopted. When 7.8%<WVFD<17%, the specific plan is: when the initial percentage of moisture regain is 7.8%<WVFD<13%, only the first-level drying equipment is required; when the initial percentage of moisture regain is 13%<WVFD<17%, two-stage drying equipment needs to be activated at the same time, the vertical drying tower is in full-load operation, and the temperature at the entrance TVFD is controlled within 120°C.

(3) Use BP neural network to establish the relationship between initial percentage of moisture regain, target percentage of moisture regain and hot air temperature, and then establish a temperature fuzzy control model; adopt DS18B20-based single-bus temperature multi-point detection technology to provide temperature measurement feedback signal for adjusting heating equipment; the established seed cotton drying fuzzy PID control model outputs the opening control amount of the heat source regulating valve, and controls the heat source regulating valve so that the measured temperature at the entrance quickly and accurately follows the set temperature. The entire process has high accuracy and can meet the actual production needs of the cotton processing process.

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