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Mechatronic System For Preserving The Natural Properties Of Cotton Stored In Modules

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Abstract: The article analyzes the mechatronic system developed for automated control of microclimate parameters (moisture, temperature, and carbon monoxide gas) during the storage of seed cotton in modules. Using mechatronic principles, the integration of sensors, a controller, and actuators enables the optimization of moisture and temperature regimes. Simulation results in the TRACE MODE environment are presented, along with recommendations for ensuring energy efficiency and maintaining fiber quality stability.

Keywords: Seed cotton, module microclimate, mechatronic system, sensor monitoring, automated control, TRACE MODE SCADA, controller, fan, energy efficiency, fiber quality.

INTRODUCTION:

Long-term preservation of the quality of cotton raw material is one of the main factors that determine its export value and technological efficiency in processing processes [1]. The stability of temperature and relative humidity during storage has a direct effect on the physical-mechanical and hygroscopic properties of the fiber. When continuous control of microclimate parameters in cotton barns is carried out using mechatronic systems, the increase of microbiological activity is effectively limited, uneven distribution of heat is prevented, and air circulation inside the barn is kept stable [2]. This reduces degradation of cellulosic structures and ensures stability of fiber quality and appearance.

General structure of a mechatronic system

Mechatronic systems are a complex scientific direction that integrates the fields of mechanics, electronics, sensors and computer control, through which technological processes are controlled accurately, quickly and optimally. The term “mechatronics” was first introduced in 1969 by specialists from the Japanese company “Yaskawa Electric Corporation”, and initially meant a harmonious combination of mechanical and electronic elements [3].

By the 1980s, mechatronics was formed as an integral field of science and technology, encompassing computer-controlled machine systems [4]. Its main goal is to create intelligent, high-precision automated systems by synergistically combining mechanical units and mechanisms with electronic, electrical and computer components. In modern conditions, such an approach serves as a scientific and practical basis for developing innovative solutions in the fields of microclimate control, energy efficiency and automatic quality monitoring in the cotton industry [5-6].

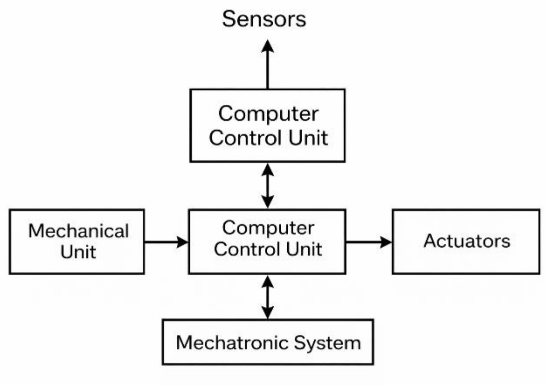

Figure 1. General structure of the mechatronic system

The mechatronic system consists of the following components. Mechanical part: working bodies, transmission links, brakes and clutches. Drive unit: actuators and power converters. Sensors: temperature, humidity and CO_2 sensors. Computer control unit: controller and TRACE MODE software environment. Actuator: fans, relays, starters and valves. In this structure, each module has the ability to process data and implement a response.

Algorithm of operation of the Mechatron system

A rapid increase in temperature in the upper layers of the cotton linter is one of the important factors that negatively affect the morphological and physicochemical structure of the fiber. As a result of a sharp increase in temperature, hydrogen bonds between cellulose microfibrils weaken, which leads to a decrease in the mechanical strength, flexibility and whiteness of the fiber.

Studies have shown that during storage, the temperature should not exceed 35 °C and the relative humidity should not exceed 11%. These parameters allow maintaining the stability of the microstructure in the fiber wall, limiting microbiological activity and preventing hydrolytic degradation of cellulose. At the same time, the microclimate parameters inside the linter can change rapidly as a result of the influence of the external environment (precipitation, wind, fog, sharp changes in air temperature). This leads to a violation of the temperature-humidity balance, condensation phenomena and the appearance of local hot spots in the fiber layers.

To prevent such situations, it is necessary to introduce mechatronic microclimate control systems. These systems provide real-time monitoring of temperature and humidity through sensor measurements and intelligent control algorithms, allowing to maintain uniform thermodynamic stability in all layers of the cotton crop.

Mechatron system components

№	Part name	Main function
1	Sensors blog	Measures temperature, humidity and CO_2
2	Controller (OVEN TRM138)	Receives and analyzes data
3	Electric Ventilation Fans (VC-8M, VC-10M)	Provides air exchange
4	Relay and actuator modules	The machine provides start-up
5	TRACE MODE program	Provides monitoring and signaling

Sensors in the mechatronic system accurately measure the temperature and relative humidity parameters inside the chamber every 5–10 minutes and transmit them to the controller in the form of a digital signal. The controller processes the received data using microprocessor-based analysis and control algorithms and evaluates them in real time. If the temperature value exceeds 35 °C or a tendency for its sharp increase is detected, the system automatically turns on the fan. With the help of the fan, hot air is removed through the air tunnel and thermodynamic stability inside the chamber is restored. After the temperature returns to the set standard limits, the controller automatically turns off the fan, which minimizes energy consumption.

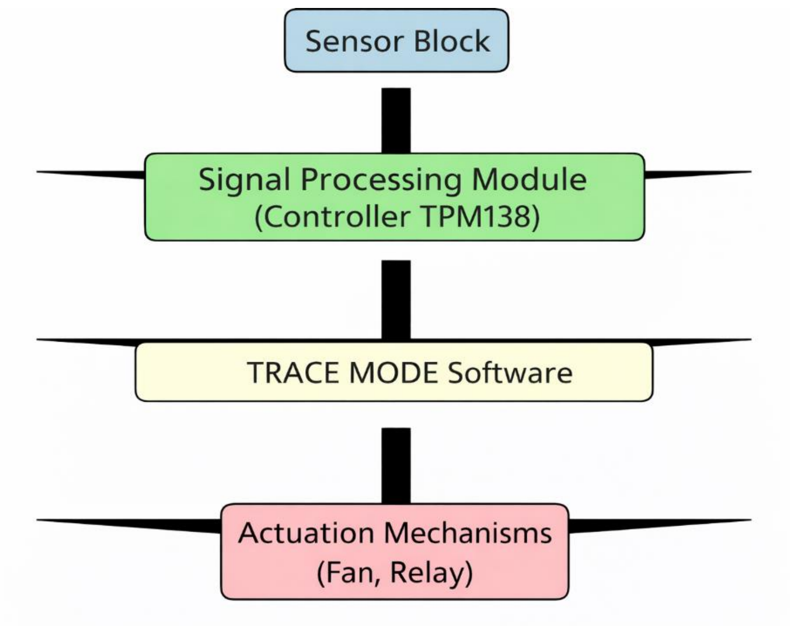

Figure 2. Algorithm of operation of the Mechatron system.

All measurement results, statistical data and control states are archived on the central server in the TRACE MODE environment, which provides a reliable information base for continuous monitoring, analysis and subsequent modeling of microclimate parameters.

The automated control system for microclimate parameters in cotton fields in the TRACE MODE SCADA environment is implemented through the following functional modules:

HMI (Human-Machine Interface) panels are a visual interface for the operator, displaying current data on temperature, humidity and fan activity in real time in graphical and digital form. This module allows the operator to interactively monitor and control the system status. PLC (Programmable Logic Controller) block - receives analog and digital signals from sensors, processes them and automatically controls the execution mechanisms (fans, valves and signal systems) based on developed control algorithms.

Trend Monitor module - is designed to determine the dynamics of temperature and humidity changes over time, forms graphic trends and allows for analysis based on archived data. This module is important for assessing long-term trends in microclimate parameters. Alarm System - automatically sends a notification to the operator or server when the temperature or humidity exceeds the established regulatory limits, thereby ensuring a quick response to emergencies.

With the help of a mechatronic system, manual labor can be reduced by 60% and energy consumption can be saved by 18–22%. Since fans are turned on only when necessary, electricity is saved. The average payback period of this system is 2.5–3 years.

The results of the conducted studies show that as a result of ensuring the stability of microclimate parameters in the gins where the sensor-mechatronic control system was introduced, the physical and mechanical parameters of cotton fiber improved significantly. In particular, under controlled conditions, the tensile strength of the fiber increased by 10–12%, while the elongation and microneural index remained stable.

The sensor module of the mechatronic system made it possible to automatically maintain temperature and relative humidity within the normal limits (T ≤ 35 °C, RH ≤ 11%). This served as an important factor in limiting microbiological activity, preventing cellulose degradation, and preserving the microfibril structure in the fiber wall.

By archiving and analyzing data in real time in the TRACE MODE environment, it was possible to maintain a digital “production log” for each gin batch. This journal allows you to monitor trends in microclimate changes, early detection of technological errors and automate quality control at the next stage. Thus, the results obtained confirm that the use of sensor-based mechatronic systems has a high scientific and practical effect in increasing energy efficiency, reducing the human factor and ensuring the stability of fiber quality in the process of storing cotton raw materials.

The developed mechatronic system has a number of scientific and practical advantages that increase the efficiency of continuous monitoring and optimization of the microclimate in cotton gins. Firstly, the system allows you to monitor and control microclimate parameters in real time. This provides a response to temperature and humidity changes within a few seconds and allows you to quickly stabilize the process.

Secondly, an automatic security and emergency alarm system has been implemented, which sends an alert notification to the operator or the central server when a sharp increase in temperature or deviations from the sensors are detected. This function is important for reducing the human factor and ensuring safe operation.

Thirdly, the sensors have high-precision measurement capabilities, allowing you to measure temperature with an accuracy of ±0.3 °C and relative humidity with an accuracy of ±1% RH. These parameters allow for accurate assessment of dynamic changes in the microclimate and optimization of control algorithms.

Fourthly, the compactness, modular architecture and ease of maintenance of the system modules facilitate its integration into the existing warehouse infrastructure, while reducing operating costs.

Finally, the implementation of this system serves to maintain the physical, mechanical and hygroscopic properties of cotton fiber for a long time, thereby increasing the quality indicators of the fiber and its export value.

Based on the results of the conducted research and modeling, the following scientific conclusions and practical recommendations were developed: Mechatronic systems are recommended as an advanced and effective solution for optimal microclimate management in cotton fields. This approach allows for automatic control and stabilization of physical environmental parameters.

allows you to maintain the quality of the fiber for a long time. With the help of a single control module with integrated sensors, controllers and fans, the relative humidity in the hopper is automatically maintained at ≤ 11% and the temperature at ≤ 35 °C. This limits the increase in microbiological activity and protects the structure of the fiber wall.

The modeling and visual control implemented in the TRACE MODE SCADA environment increased the reliability of the system, its ability to respond quickly and the ability to archive data. This creates the basis for accurate forecasting and ensuring safety in the production process. The modular architecture (sensors - controller - HMI panel) ensures the scalability of the system, i.e. its adaptability to warehouses and hopper configurations of various sizes. This increases its versatility and operational efficiency.

According to the results of the study, under conditions where mechatronic microclimate control is introduced, the quality of cotton fiber improves by 15–20%, which leads to an increase in the volume of export products and increased economic efficiency.

CONCLUSION

Based on the results of the conducted research, it was found that the introduction of mechatronic systems in the control and management of microclimate parameters in cotton gins provides high scientific and practical results. This system, through the integration of sensors, controllers and actuators, ensures automatic maintenance of humidity and temperature at optimal levels (T ≤ 35 °C, RH ≤ 11%), while limiting microbiological activity and protecting the natural structure of the fiber.

The results of modeling developed in the TRACE

MODE SCADA environment showed high reliability, stability and rapid response of the system. The modular architecture (sensor - controller - HMI) allows adaptation to warehouse and gin configurations of various sizes, ensuring the versatility and operational efficiency of the system.

According to the results of the research, under conditions controlled by the mechatronic system, the physical and mechanical parameters of cotton fiber improved by 10–12%, and quality loss decreased by up to 20%. This solution creates a scientific basis for the introduction of energy-efficient, intelligent and human factor-minimizing innovative management systems in the cotton industry. It was also found that by implementing the developed system, it is possible to reduce manual labor up to 60%, save energy consumption up to 18-22%, and increase the export value of raw cotton.

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