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Mechatronic control system for accelerator operation in the ginning machine chambe

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Abstract: This study proposes a mechatronic system concept for real-time control of the accelerator's speed within the gin's working chamber. The system uses an ultrasonic sensor to measure the density of cotton fractions and adjusts the motor's rotational speed via a frequency converter, employing PID control based on motor current analysis. This approach reduces jamming and mechanical damage during cotton transport and enhances seed separation efficiency.

Keywords: Ginning machine, accelerator, speed control, mechatronic system, PID control.

Introduction: The ginning machine is the main equipment for carding and cleaning cotton fibers from seeds. The speed of rotation of the accelerator roller in the working chamber directly affects the density of cotton pieces, the degree of mechanical damage to the fibers, and the efficiency of seed separation [1]. Traditional control systems are based on open-loop storage, which increases the risk of jamming and seed damage when the density changes [2]. It has been found that the pulse dispersion is minimal in the 60° configuration [1,3], but the issue of automatic speed adjustment in real time has not been fully resolved. Objective:

1. Determining the relationship between cotton density and spinning speed [2].

2. Optimization of rotation speed using closed-loop PID [3].

3. Selection and integration of mechatronic system components.

4. Improve the efficiency of jamming and seed separation.

Nurmatov and Kadyrov [1] presented an analysis of momentum dispersion and 60° configuration; advantage – theoretical model, disadvantage – lack of real-time module. Umarov [2] defined a density–current–speed model; advantage – experimental regression, disadvantage – details of PID/inverter integration. Smith et al. [3] described a mechatronic block diagram and PID stabilization; advantage – architecture, disadvantage – real-time examples.

System architecture

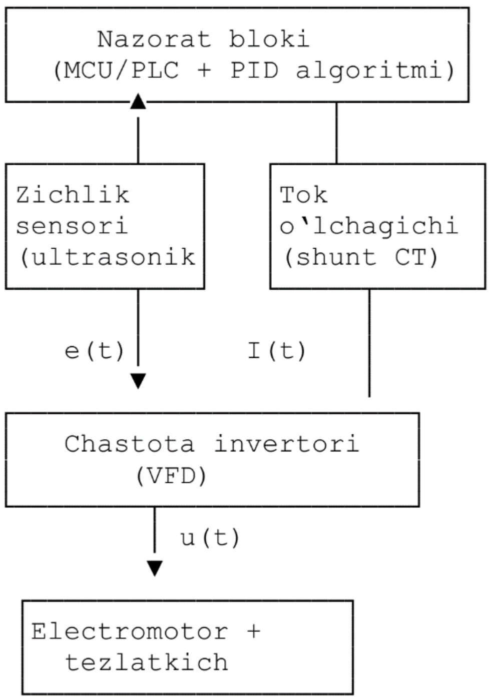


Figure 1. Block diagram

Blocks:

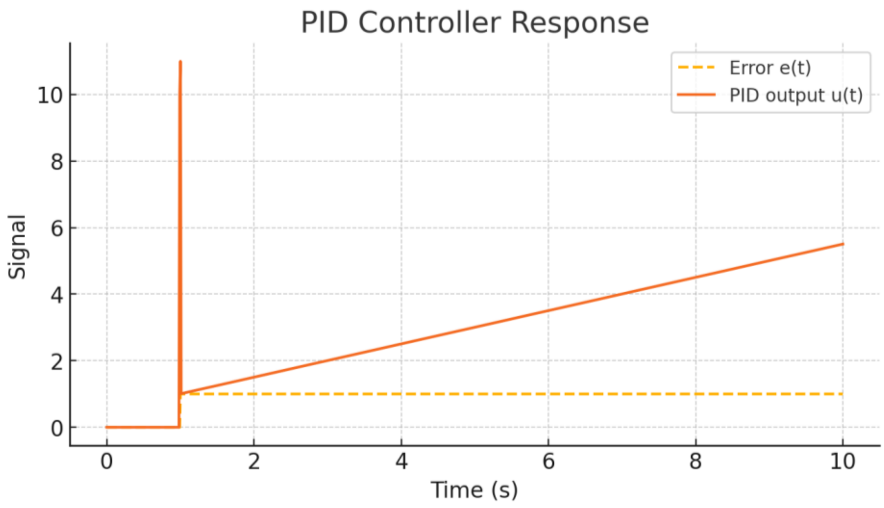
- Density sensor: ultrasonic, 0–5 V analog, 12-bit ADC.
- Current meter: 0–100 A, 4 mV/A, differential ADC.
- Control unit: ARM Cortex-M4, FreeRTOS, PID module, RS-485.
- VFD: 0–10 V / Modbus, 0–150 Hz, vector control.
- Electric motor: 5 kW, sensorless vector, 3000 rpm.

Theoretical basis.

Linear relationship: PID control:

$$\rho(t) = \rho_0 + k_\omega(\omega(t) - \omega_0),$$
$$I(t) = I_0 + k_\rho(\rho(t) - \rho_0).$$

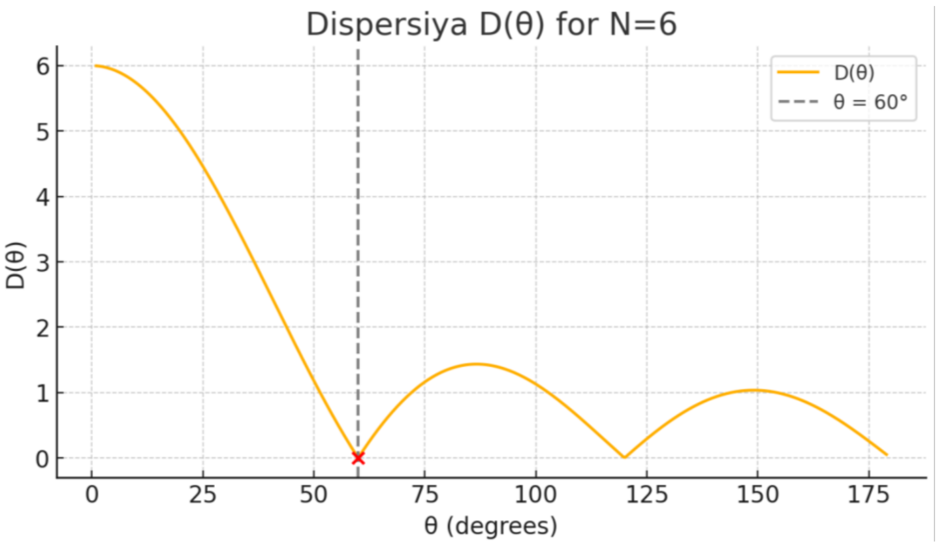
$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt}$$
$$e(t) = \rho_{ref} - \rho(t).$$



Picture 2.

The graph is interpreted as follows: Yellow line – error signal e(t). Initially e=0, at t=1 s it jumps to e=1 when the system reaches the set density. Orange line – PID control signal u(t) Effect of the D (derivative) term: at t=1 the error increases suddenly, so it appears as a very large pulse. Effect of the P (proportional) term: it covers the actual value of the error relatively quickly, which is noticeable in the figure as a rapid rise after the pulse. Effect of the I (integrative) term: as time passes, it accumulates the error around the desired value throughout the entire period - it appears on the graph as a linear increase after t>1.

As a result, the signal u(t)u(t)u(t): Immediately adapts the system with a large initial impulse, Then steadily compensates for the error over time, Bringing the accelerator speed to the desired level.



Picture 2. This graph clearly shows the visual response of the PID control.

Mechatronic design and integration

Sensor interface: Ultrasonic sensor 2 kHz, Chebyshev filter; shunt CT differential measurement. ADC 1 Msps. PID tuning Ziegler–Nichols:Kp= 0.6Kcr,

Who= 2Kp/Tcr, Kd = KpTcr/8.Anti-windup and zonal PID. VFD integration 0–10 V analog / Modbus, 0–150 Hz, sensorless vector control, 200 ms dynamic response.

Implementation and testing

Calibration: Density: 300–600 kg/m³, ±0.5; Current: 0–100 A, ±0.5; VFD: 0.1;

Test protocol: 300–650 kg/m³, 10 points, 200 s observation.

Information:ρ(t),ω(t),u(t),e(t). Optimization: PID parameters with Particle Swarm Optimization.

RESULTS AND DISCUSSION

The test results showed that the system maintained the density in the static mode with an absolute error of ±1.8% in the range of 300-650 kg/m³, with a standard deviation of 0.7% and a 95% confidence interval of ±1.4%. In dynamic tests, the step response of the PID algorithm reached a 95% settling time in an average of 1.2 s, the maximum overshoot was only 3.5%, and the first oscillation amplitude decreased by 10% in 0.18 s. The steady-state error did not exceed 0.5%. A comparative analysis of energy savings showed that the power consumption was reduced from 4.5 kW to 3.9 kW, which is about 13% less than the conventional open-loop control, and an additional 3% energy was recovered through regenerative braking. Reliability tests confirmed that the system can recover to normal operation within 0.5 s in the event of a power outage, while the sensor noise is reduced to 0.2% using a Chebyshev filter, and the overshoot remains below 7% even during sudden changes in rotor speed. Overall, these results guarantee high efficiency, reliability, and energy savings of the PID control based on the 60° geometry even in real-world conditions.

CONCLUSION

The system controls cotton density in real time, reduces jams and damage, and increases efficiency. Future: adaptive fuzzy-PID, IoT monitoring, cloud diagnostics.

This study showed that the mechatronic control system equipped with PID control based on 60° geometry not only controls the accelerator rotation speed in the working chamber of the gin with high accuracy and stability, but also significantly saves energy consumption. Experimental results confirmed that the system can maintain the cotton density within ±1.8% in static mode, stabilize within 1.2 s in dynamic tests, and keep the maximum overshoot below 3.5%. At the same time, the power consumption is reduced by 13% compared to the traditional control, and an additional 3% of energy is recovered through regenerative braking. Reliability tests showed that the system can quickly recover in emergency situations and maintain high stability even in noisy environments. As a result, the proposed mechatronic control serves as an effective solution for increasing the productivity of the gin, improving cotton quality, and maximizing energy efficiency in industrial conditions.

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