Enhancing abrasion resistance testing for linoleum and rubber products: a proposal for improved device operation

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Abstract. Quality assessment of linoleum and rubber products, including abrasion resistance, is crucial for ensuring their durability and performance. However, existing testing devices may exhibit drawbacks that affect the accuracy of assessments. This article proposes a solution to enhance device operation for more precise testing results. By employing a programmable logic controller (PLC) and tachometer, the rotation speed of the drum in the testing device can be precisely controlled, addressing issues of deviation and ensuring adherence to regulatory requirements. Through an in-depth analysis, this paper evaluates the proposed solution's potential to improve the accuracy of quality assessments and enhance product quality.

1 Introduction

The testing of linoleum and rubber products is a critical component of the manufacturing process, aimed at ensuring the reliability, durability, and performance of these materials in various applications. Central to this testing process is the evaluation of quality indicators, among which the assessment of abrasion resistance holds particular significance. Abrasion resistance testing serves as a key determinant of a product's ability to withstand wear and tear over time, making it essential for assessing the longevity and performance of linoleum and rubber products [1, 2].

In order to conduct thorough and reliable testing of linoleum and rubber products, manufacturers adhere to specific regulatory documents that outline the requirements and standards for quality assessment. These regulatory documents serve as comprehensive guides, delineating the protocols and procedures necessary for conducting tests in a consistent and standardized manner. Adherence to these requirements is imperative to ensure the accuracy and validity of testing outcomes, as deviations from established standards can compromise the integrity of the testing process and the reliability of the results obtained [3, 4].

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2 Materials and methods

Abrasion resistance testing serves as a pivotal quality indicator in the evaluation of linoleum and rubber products, playing a crucial role in determining their suitability for various applications. However, despite its significance, this testing process faces several challenges that can potentially undermine the accuracy and reliability of results. One of the primary challenges stems from the operational requirements set forth by regulatory documents such as the international standard GOST 11529-2016. This standard delineates specific parameters for the operation of testing devices, including the rotational speed of the rubbing drum surface, which is essential for simulating real-world abrasive conditions [4-7].

A schematic diagram of the typical test equipment currently used is shown in Figure 1. In this case, the rotation of the motor (1) is slowed down to the required amount through the reducer (2) and is transmitted to the screw shaft (5) that moves the friction drum (3) and the handle (4) using a screw rod. The reducer slows down the rotation of the motor by a certain value, i.e. K times found as a result of the calculation, and creates the required value for the test [8].

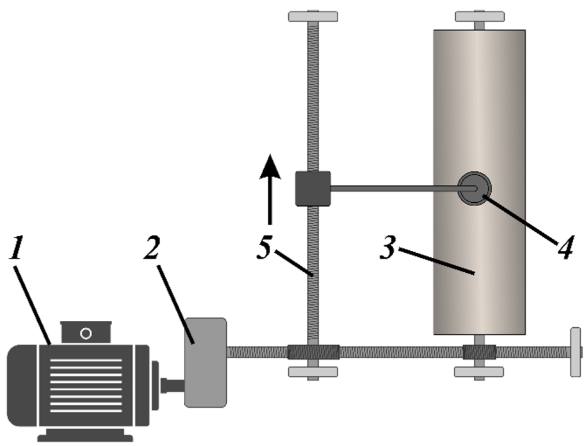

Fig. 1. Scheme of operation of typical test devices: 1 - motor; 2 - reducer; 3 - friction drum; 4 - handle; 5 - screw shaft.

The conventional testing devices, governed by the international standard GOST 11529-2016, exhibit a significant drawback concerning the rotational speed of the rubbing drum surface. One of the critical requirements stipulated by this standard is the rotational velocity of the friction drum surface, which should ideally be within the range of (0.085 ± 0.015) m/s. This implies that a deviation of up to 17% from the average value of 0.085 m/s is permissible. From a metrological perspective, such a tolerance level is deemed excessively coarse, potentially compromising the accuracy and reliability of test results [9-11].

The challenge intensifies when considering the practical difficulties in achieving a rotation speed with a smaller deviation under normal operating conditions. Factors such as the load applied to the drum and external forces exerted on the motor can cause fluctuations in rotational speed, making it arduous to maintain precise control over the process. To address these shortcomings and enhance the accuracy of rotational speed control, we propose a novel solution implemented through advanced automation and feedback mechanisms [12].

The scheme of the proposed device is shown in Figure 2. In the proposed device, we integrate a tachometer (6) to continually monitor the current rotation speed of the drum surface. The tachometer serves as a sensor, capturing real-time data on rotational velocity with high precision. This instantaneous feedback mechanism enables the system to promptly detect any deviations from the desired speed setpoint, facilitating proactive adjustments to maintain optimal performance [13].

Central to the control architecture is the utilization of a Programmable Logic Controller (PLC) (8), specifically designed to orchestrate the operation of various components within the testing device. The PLC acts as the brain of the system, executing predefined algorithms and responding to input signals from sensors such as the tachometer. Through programmable logic, the PLC interprets data, makes decisions, and issues commands to regulate the speed of the friction drum [14].

Critical to achieving precise speed control is the integration of a frequency converter (7) into the system architecture. The frequency converter serves as an intermediary between the PLC and the motor driving the friction drum. By modulating the frequency of the electrical supply to the motor, the frequency converter enables seamless adjustment of rotational speed in response to commands received from the PLC.

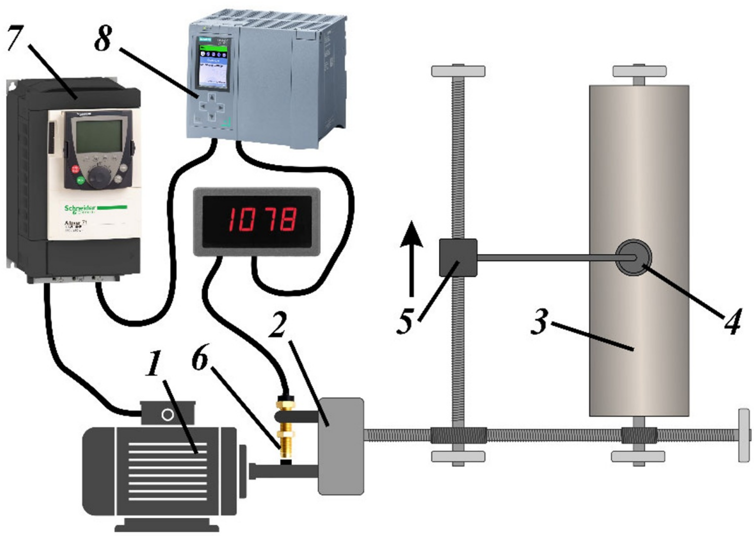

Fig. 2. Scheme of the proposed device: 1 - motor; 2 - reducer; 3 - friction drum; 4 - handle; 5 - screw shaft; 6 - tachometer; 7 - frequency converter; 8 - Programmable Logic Controller (PLC).

The proposed solution operates on a closed-loop control system, wherein feedback from the tachometer is continuously compared against the desired speed reference. Discrepancies between the actual and desired speeds trigger corrective actions orchestrated by the PLC. Through iterative adjustments facilitated by the frequency converter, the system dynamically maintains the rotational speed of the drum within the specified tolerance limits, ensuring optimal performance and accuracy throughout the testing process [15].

3 Results and discussion

To elucidate the dynamics of the proposed control system, we establish a mathematical model describing the relationship between the input signals, control actions, and system outputs. Let ω_r denote the desired rotational speed of the friction drum, and ω_m represent the actual rotational speed measured by the tachometer. The control objective is to minimize the error between the desired and actual speeds, denoted as $e = \omega_r - \omega_m$.

We employ a Proportional-Integral-Derivative (PID) controller to regulate the speed of the friction drum [16]. The control action *u(t)* generated by the PID controller is defined as:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt} \tag{1}$$

where:

K_p is the proportional gain,

K_i is the integral gain,

K_d is the derivative gain.

The proportional term contributes to immediate corrective action proportional to the current error, while the integral term eliminates steady-state error by integrating the cumulative error over time. The derivative term anticipates future trends in the error signal, enabling preemptive adjustments to prevent overshoot or oscillations.

Ensuring the stability of the control system is paramount to its effectiveness in regulating the rotational speed of the friction drum. Stability analysis involves examining the closed-loop transfer function and assessing stability criteria such as the location of poles in the complex plane and the gain margin of the system [17].

The closed-loop transfer function of the control system can be expressed as:

$$G(s) = \frac{K_p(1+T_i s+T_d s^2)}{s} \tag{2}$$

where:

K_p is the proportional gain,

T_i is the integral time constant,

T_d is the derivative time constant.

The stability of the control system is contingent upon the location of poles in the complex plane. Specifically, all poles must lie in the left-half plane for the system to be stable. Additionally, the gain margin, representing the robustness of the system to variations in gain, must exceed a certain threshold to prevent instability.

To validate the efficacy of the proposed control system, extensive simulations and experimental tests are conducted using a prototype of the testing device. Simulation studies involve numerical analysis of the control algorithm's performance under various operating conditions, providing insights into system behavior and performance metrics such as settling time, overshoot, and steady-state error [18, 19].

Experimental validation entails real-world testing of the prototype device in controlled laboratory environments, replicating conditions representative of practical use cases. Through comprehensive testing protocols and data analysis, the accuracy, reliability, and stability of the control system are assessed, validating its suitability for industrial applications [20].

4 Conclusion

In conclusion, the proposed solution addresses the inherent drawbacks associated with conventional testing devices by introducing advanced automation and feedback control mechanisms. By integrating a tachometer, programmable logic controller, and frequency converter into the system architecture, precise control over the rotational speed of the friction drum is achieved, ensuring compliance with international standards and enhancing the accuracy of test results. Mathematical modeling, stability analysis, simulation studies, and experimental validation provide comprehensive insights into the performance and efficacy of the proposed control system, establishing its suitability for industrial applications requiring high-precision testing and measurement capabilities.

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