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THE HARDWARE STRUCTURE OF THE CONTROL SYSTEM FOR THE EROSIVE WEAR TESTING MACHINE

Key words

Erosive wear, control system, safety system, research apparatus.

Abstract

The article presents the control system for the device for testing the resistance to erosive wear of materials. The apparatus allows testing the effect of a stream of abrasive, usually aluminium oxide, colliding the surface of a material, usually coated with a selected surface layer. The device allows testing up to eight samples in a single cycle at different angles of collision and with different parameters. In addition, the test might be performed at high temperatures.

The control system of the apparatus is supposed to provide reliability, safety, the ability to drive all elements of the apparatus to their technical limits, flexibility, and ease of use.

The article presents the structure of a control system, its tasks, and solutions to the goals set and the challenges. Further, the article also discusses the safety system applied in the apparatus, its structure, and specific behaviour.

Finally, the structure of control software is presented with the distribution of particular tasks amongst the hardware processing units.

Introduction

Modern research apparatus tend to automate as many of the operations as possible thus gaining in precision of measurements, performance of testing, and repeatability of results. The control systems for such devices are overlooked and often underestimated elements that play a critical role in the development of a functional and useful device. Even with a simple process, there is more and more data to be processed and more and more variables to be controlled in real time with greater accuracy. Additionally, the expectations of the final user of such a device require highly developed programming skills to provide an apparatus that is simultaneously easy to use, intuitive, flexible, and precise.

The paper describes the electronic system built to control the research apparatus used for testing the resistance to erosive wear of materials. The main goals that are set for the control system are its reliability, safety, ability to drive all elements of the device to their technical limits, flexibility, and ease of use. The questionable requirement of driving the elements to their technical limits is a simple statement that the functionality of the device cannot be limited by the control system. For example, if the chamber may be heated up to 650°C, the control system should be able to measure and control even higher temperatures.

1. Test device

There exist several international standards for performing the test of erosive wear, but there are few ready-made solutions and most devices were built as an experiment by researchers themselves [1]. The device described in this paper is a unique design developed by engineers from Institute for Sustainable Technologies – NRI in Radom and allows both standard and non-standard testing [2].

The device under discussion is a machine for testing the samples of materials, possibly coated with specific surface layers, against the erosive wear [1, 2]. The test consists in subjecting the material to the operation of a stream of air mixed with an abrasive, usually aluminium oxide. The test lasts for several minutes, and within the given time period, a certain mass of the abrasive should be discharged. The research may be conducted at room temperature or in higher temperatures up to 600°C.

The main element of the apparatus is a test chamber CH (Fig. 1), which contains a turntable TT with eight grippers for samples, and the turntable is driven by a 24V DC motor M. The air is supplied by the plant's network, and it let through the air dryer AD, main valve V, and then split into three lines with use of shut-off valves V and proportional valves PV. The first line is fed into the abrasive feeder F and the two other tines are fed into the test chamber CH through heaters H and jet J. The abrasive feeder is driven by a 10V DC motor M.

The streams of clean air and abrasive are mixed in the jet J inside the test chamber CH.

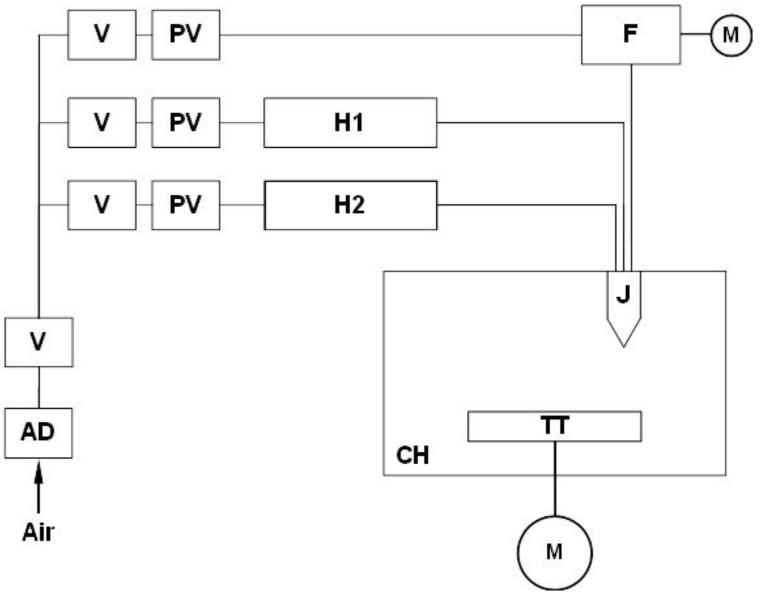

Fig. 1. Block schematic of the test device: AD – air dryer, CH – test chamber, F – abrasive feeder, H – heaters, J – jet, M – motors, PV – proportional valve, TT – turntable, V – valve

There are two separate air heaters in the system, since heating the air to all ranges of temperatures with any pressure and flow of air may be required. The "small" heater, H1, is 100W while the "big" heater, H2, is 1200W, and the heaters inside the test chamber consume up to 900W. Technically, the chamber is able to sustain a temperature of 700°C and the heaters are able to sustain a temperature of 900°C. The assumption for the system is design to operate at a maximum testing temperature of 600°C. The safety system (see below) is set to cut off energy when the temperature reaches 630°C, so there is little overhead tolerance for the temperature controllers.

2. Control system

There are several parameters to be controlled within the system. As mentioned above, there are three heating circuits, eleven valves (three of them are proportional), two motors (one with a brake), a HMI display, and an operator's panel. Sensors measure temperature at five points (heaters 1 and 2, the test chamber, input air, and the main bearing of the turntable). The position and speed of the motors, input air pressure, air humidity, and several limit/reference switches are also electronically monitored. There are a total of eleven digital inputs, twenty-seven digital outputs, eleven analogue inputs, three analogue outputs, and two Ethernet lines. Nevertheless, the system is going to be extended with calibration modules as needed for the ongoing research.

The control system (Fig. 2) is based on the Programmable Logic Controller PLC from BECKHOFF, type CX5020 [3]. It is based on the Intel Atom processor and works under control of a Windows CE system. That PLC was selected for the task, because its modular structure allows flexible extension and modification and consists of independent modules that can be freely added and removed from the system. The system is operated with use of 7” HMI display with a touch screen, which allows insight into the state of the machine, including temperatures and the states of valves, but it does not allow process control. Process control is facilitated by the external PC (laptop). The PC computer is the master control device and offers full interface for the researchers using the apparatus. Both the HMI display and PC communicate with the PLC via Ethernet connections, which are installed on the main module of the PLC using the ADS communication method.

Shut-off valves V and heaters H are controlled with digital outputs DIO. Depending on their type, the PLC modules allow 0.5 A or 2 A of current, which is more than enough for operation of the valves. The temperature limiters (TL), which are used in the safety system, use the digital lines (DIO) to report their state and to accept the reset signal. Analogue inputs/outputs (AIO) are used to control the proportional valves and to inspect the temperatures in the system using thermocouples.

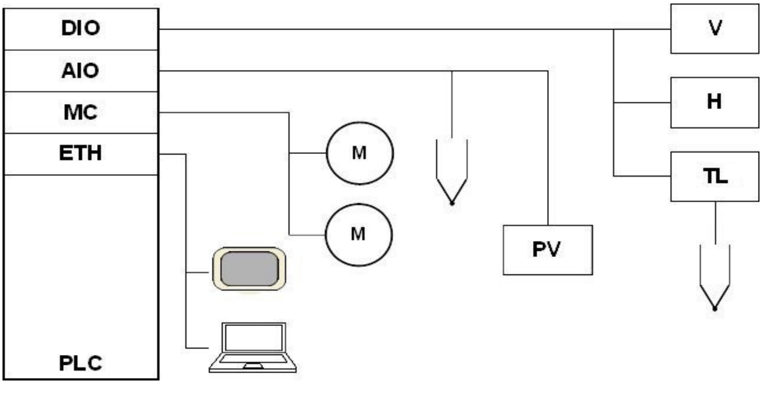

Fig. 2. Simplified block diagram of the control system: AIO – analogue input/output, DIO – digital input/output, ETH – Ethernet link, H – heaters, M – motors, MC – motion control unit, PLC – programmable logic controller, PV – proportional valves, TL – temperature limiters, V – valves

There are special modules in the PLC system for controlling the motors. The KL2552 module is a two-channel control module that allows closed loop control of speed and position of the motor shaft using incremental encoders. The module generates independent bipolar PWM signals for two motors supplied from the same source, so there is a limitation that the two motors must use the same supply voltage, which ranges from 8V to 50V and with maximal load of 5A per channel. The producer supplies the appropriate libraries for motion control and with the proper level of master software (TwinCAT NC PTP or higher), and the axes are easily configured as independent objects in the system. The described apparatus uses two of these modules, since motors use different voltages.

The heaters (H) are controlled via digital outputs, but the relays and air heaters use separating transformers, which are needed to adapt the standard power supply to the requirements of the air heaters. The test chamber heaters are plugged directly to the power supply using relays. All power circuits for the heaters are switched with the use of SSRs (Solid State Relays with zero-crossing detection), which allows easy implementation of a group control method. The heated elements show fairly high inertia, so the PLC generates a slow PWM signal with cycle of 5s, and the shortest on/off time of 20ms, which allows precise control of the power and guarantees only symmetrical supply (equal number of positive and negative halves of the current).

3. Safety system

The requirement to have the ability to drive the components of the apparatus beyond their technical limits creates a danger to the equipment and operators. To ensure the safety of the system, there should be redundant methods of protection applied. First, the PLC software has a separate thread fixed to a separate task dedicated only to monitoring the parameters of the device and ability to cut off the power of the device. The second mean of protection is a separate, parallel to PLC circuit, safety system based on independent temperature monitors/limiters [4].

The safety system of the device has two goals set: to prevent injury of the operator from the moving elements or high voltage and to prevent physical damage of the device from overheating. The principle of the operation of the safety system consists in the separation of the power supply into low voltage supply (that is 24VDC), and a high voltage supply. The activation of any safety device will shut off the high voltage supply preventing either electric shock or further heating of the elements of the device, but still the logic (in particular the valve control) is active. There are three reasons for this:

- First, the air dryer is not supposed to be switched off instantly without prior procedure for air shut-off;

- Second, the air heaters must have the cooling active when they are hot or heated, and failure to do so will damage the heaters; and,
- Third, temperature limiters need to monitor the temperature constantly and the cooling must be controlled by PLC.

The abovementioned safety devices are the safety switch SS (kill switch) and three temperature limiters (TL), which are combined in a series (Fig. 3) in the power supply for the relay's R coil. Switching the high voltage part of the system is only possible when none of the safety devices is active and the PLC sets the proper digital output DO to high. The relay at the end of the line switches the power, which allows heating or moving elements to operate.

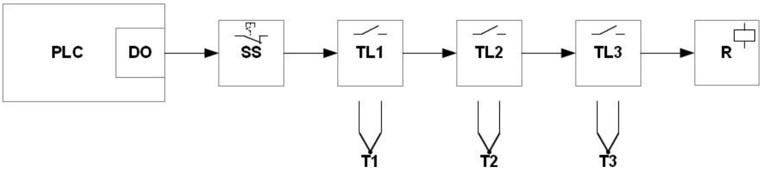

Fig. 3. Block schematic of safety system: DO – digital outputs, PLC – programmable logic controller, R – relay, SS – safety switch, T – thermocouples, TL – temperature limiters

The temperature limiters monitor the temperature independently from the PLC. The thermocouples used in the system for heaters are customised and include two separate measuring elements in each sensor housing – one for the PLC and one for the temperature limiters. The PLC monitors the temperature in the whole system by means of specialised software PID controllers supplied in a special software library by the producer of the PLC. The controller's blocks include the temperature limits for all the elements that are the boundary for the control algorithm and will not be exceeded. Therefore, the safety system is a redundant circuit and will possibly be activated only in case of total failure of the control system.

4. Software

The software of the control system (Fig. 4) is split into several modules based on three main hardware platforms. The PLC is meant to control the hardware only. It controls the proper sequences of valves, heating, and motion and runs the operator's panel. Additionally, the PLC stores the calibration maps for the system, which allows the user to operate with natural values of the process and not the device; for example, instead of setting the pressures and motor velocities for the abrasive feeder, the operator simply inputs the value of abrasive velocity and output, and the PLC calculates the appropriate values for the parameters of the device.

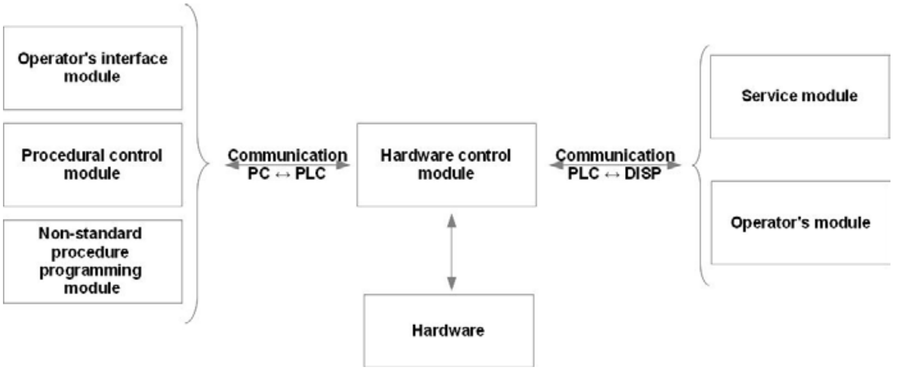

Fig. 4. Modular structure of control software

The PC computer is responsible for the user interface (Fig. 5a) and for the process flow. It is used for collecting the data from the user, which includes the settings of the parameters of the process as well as other data, such as the material type, coating type, and the researcher's name. The PC controls the PLC by commissioning macro commands to the PLC, and PLC carries out the commands by running microinstructions.

Fig. 5. View of the control software windows (a) and view of the operator's panel windows (b)

The HMI display (Fig. 5b) provides a simplified operator's interface for quick insight into the state of the machine and the service module that allows access to the service menu. This menu grants access to the selected internal data of the PLC and to special calibration procedures that allow the determination of the velocity of the abrasive with a given pressure of the air.

Fig. 6. View of the presented machine (description in the text)

Summary

The apparatus for testing the resistance to erosive wear of materials (Fig. 6) developed at Institute for Sustainable Technologies – National Research Institute in Radom is equipped with a control system that allows the control of the parameters of the process in the required range, and it has easy and intuitive operation and flexible generation of research procedures.

The control algorithms are spread amongst several processing units to ensure safe and stable operation of the system. A combination of multiple control units requires effective communication, which is provided by Ethernet links, and an advanced safety system that is independent of any of the control units.

The presented apparatus is equipped with an adjustable and extensible control system, which allows not only standard tests but also non-standard and non-typical tests for the research purposes.

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Struktura sprzętowa układu sterowania urządzenia do badania zużycia erozyjnego

Słowa kluczowe

Zużycie erozyjne, system sterowania, system bezpieczeństwa, aparatura badawcza.

Streszczenie

W artykule zaprezentowano system sterowania urządzenia do badania odporności materiałów na zużycie erozyjne. Urządzenie pozwala na testowanie wpływu strumienia ścierniwa, zazwyczaj tlenku glinu, uderzającego w powierzchnię materiału zazwyczaj powleczonego wybraną warstwą wierzchnią. Urządzenie pozwala na badanie w jednym cyklu ośmiu próbek, przy różnych kątach padania strumienia ścierniwa na powierzchnię z różnymi prędkościami. Możliwe jest również prowadzenie badań w podwyższonej temperaturze.

System sterowania urządzenia ma zapewnić niezawodność, bezpieczeństwo, możliwość sterowania elementami urządzenia powyżej ich technicznych możliwości, elastyczność i łatwość użytkowania. Wymaganie sterowania elementami urządzenia powyżej ich technicznych możliwości oznacza założenie, że funkcjonalność urządzenia badawczego nie może być w żaden sposób ograniczona przez układ sterujący, co pociąga za sobą konieczność implementacji rozbudowanych algorytmów i systemów zabezpieczeń.

Zaprezentowano strukturę sprzętową systemu sterowania, jego zadania, rozwiązania postawionych celów oraz wyzwania. W dalszej kolejności omówiono system bezpieczeństwa zainstalowany w urządzeniu, jego strukturę oraz specyficzne zachowanie.

W ostatniej części zaprezentowano strukturę oprogramowania sterującego wraz z rozdziałem jego funkcji pomiędzy sprzętowe jednostki przetwarzające.