Level and Temperature Control Study Using Festo Kit in a Laboratory Stand

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Abstract: In this paper presents the study of the educational kit FESTO, a flexible lab kit that can be used for a series of process control applications. A LabView program was developed for control and simulation of the plant parameters data acquisition (temperature, flow and level control) from the FESTO kit in a laboratory stand.

Key-Words: FESTO, level and temperature control, AXIOM board, Laboratory Stand.

1 Introduction

The educational kit FESTO is a flexible lab kit that can be use for a series process control applications. Using a data acquisition board the analogue or digital data from different sensors can be processed or analysed. There are many possibilities to realise the control process structure for temperature, flow and level control. It is possible using proper computer programs to develop some control algorithms to study and simulation the dynamics of complex industrial processes with interdependence between controlled variables. This paper, presents some possibilities of utilisation of the educational kit FESTO in laboratory activities for students in didactical and research activities, in a laboratory stand.

1.1 Description laboratory stand

The monitoring and diagnose of the industrial systems becomes more and more important due to the fast growth of their complexity, to the necessity of production optimization in order to keep the products competitive comparing to other similar products, and also due to the necessity of reducing the rate for faults which appear, reason for which this will be studied in this project.

For the purpose of fulfilling and materializing the proposed objectives that were mentioned in the previous paragraphs, the development of a laboratory stand will be watched closely (fig.1), in order to implement and verify in this stand some algorithms for detection and localization search of faults in the distributed control systems and for presents some possibilities of utilisation of the educational kit FESTO in laboratory activities for students in didactical and research activities.

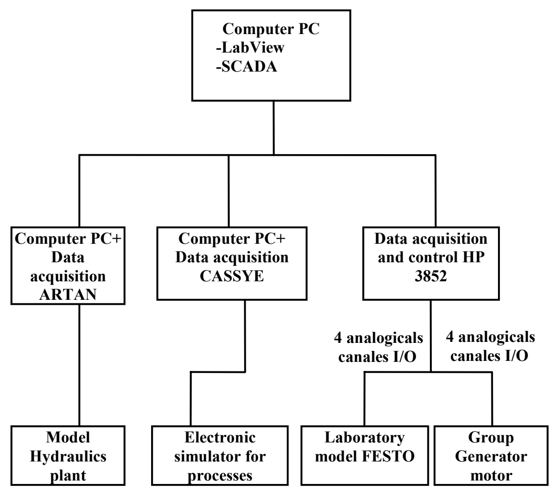

Fig.1 Laboratory stand

In the following paragraphs, the main components of the laboratory stand will be presented, and also the motivation of their use:

LABVIEW revolutionary graphical programming environment, which includes specialized functions for data acquisitions, instrument control, analysis of the measured data and also for displaying and presenting the results. LabVIEW offers the flexibility of a strong programming environment, with no need of difficult programming of the traditional programming languages.

The SCADA System (Supervisory Control And Data Acquisition) for monitoring and diagnosis of the national energetic system – mensures the monitoring of the energetic system, detection and prevention of damages or faults by interconnecting within the national dispatcher the information received from local monitoring centres.

ARTAN PC+ is software which allows conceiving and testing for adjustment loops. The study is made in real time. The possibilities of the program: regulator (adjuster) and computer simulated processes (manual and automatic control); simulated regulator and real external process (manual and automatic control); simulated process and external regulator.

Data acquisition and control HP 3852 – represents a acquisition and control system which allows measurement, analysis and adjustment for an application. With the use of HP 3852, is to be ship-shaped a data acquisition and control with a wide action domain, and easy to adapt to a high number of industrial applications. This device offers: a physical and logical instrument, compatibility with a wide range of products, system optimization.

The Generator – Motor Group – Matlab SIMULINK® will be used to obtain the simulations, based on the block schemes of the automatic adjustment systems of the parts in the thermo energetic group. A simulation and monitoring program for a thermoenergetic group will be created, using PC stations, which will consist of two distinct parts, each one for a specific function of the application. Then the mathematical modelation of the turbine-generator assembly will be done, and also the calculus of the mathematical model of the steam turbine with intermediary heat switch.

The FESTO Installation: the didactic use FESTO installation is a flexible laboratory installation, on which a multitude of applications in the control processes domain can be performed. The didactic installation FESTO is equipped with two tanks of identical quantity, a level transducer with ultrasounds mounted on the superior tank, the variable flow supply pump, local regulator for adjustment of the pumpes flow, heating resistance and temperature transducer mounted on the lower side of the inferior tank, flow transducer to measure the output flow from the superior tank, flow transducer to measure the pumpes flow at water recirculating in the inferior tank, temperature thermometer for measuring water temperature.

So, the installation allows the level, temperature and flow control, and contains individual modules which can be combined in different ways. The installation can be equipped with more levels.

1.2 Description the educational kit FESTO

The educational kit FESTO is a flexible lab kit, which can be use for a series process control applications. The technological process provided by the kit has the following characteristics: the system is modular with step-by-step extension possibilities; authenticity due to industrial original components use; the kit is easy transportable and uses water as working medium eliminating any operational danger; the process is open for new technologies such as process visualisation and technologic control.

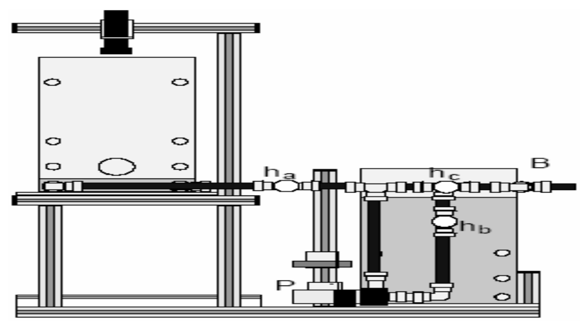

Fig.2 Plant Festo

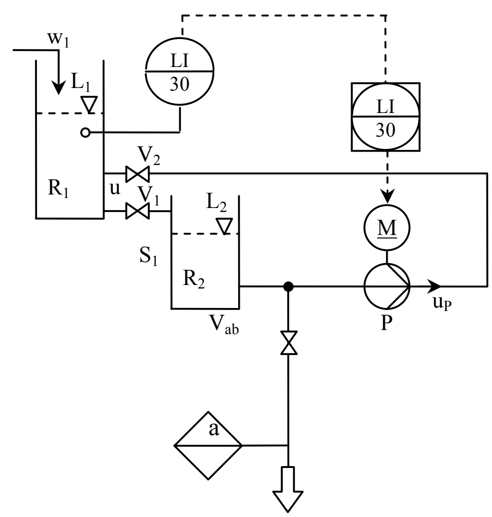

Fig.3 Diagram for level control

1.3 Signal adaptation from FESTO kit to AXIOM board

For data acquisition from the kit sensors, the data acquisition board AXIOM 5411 was used. The board has 16 analogue 0-10V DC inputs and 2 analogue 0-10V DC outputs. Because the analogue inputs of AXIOM board accept a 0-10V DC signal we realised some adaptation of transducers, signals and connection system of kit FESTO to data acquisition board. The level is measured using an ultrasonic sensor. The sensor generates an ultrasonic wave, which is reflected by the water surface and received back by the sensor. For temperature measurement was implemented a temperature sensor PT100 with the given rezistivity-temperature dependence.

2 Mathematical model of the controlled process

The controlled process consist of two tanks, pumps, valves, level and flow measurement, sensors and plastic tubes with elbows. (see fig. 3). The nonlinear model of controlled process considered in the paper is given by the following equations resulted by mass balance and flow balance.

$$\begin{aligned}
\frac{dL_1}{dt} &= -\frac{cS_1}{A_1}\sqrt{L_1} + \frac{u}{A_1} + w_1 \\
\frac{dL_2}{dt} &= \frac{cS_1 A_1}{A_2}\sqrt{L_1} - \frac{u_p}{A_2} \\
u(t) &= u_p(t-\tau) \\
y(t) &= L_1
\end{aligned} \tag{1}$$

Where: L_1 - Level in the first reservoir R_1; L_2 - Level in the second reservoir R_2; S_1 – section of V_1 valve; A_1 and A_2 -the cross section of reservoirs; Up – the pomp flow; w_1- the load flow of the upper reservoir.

The equations have been liniarized in steady state functioning point and the liniarized model is given by the following equations (2):

$$\begin{aligned}
\frac{dL_1}{dt} &= -\frac{cS_1}{2A_1\sqrt{L_1}}\cdot x_1 + \frac{1}{A_1}u + w_1 \\
\frac{dx_2}{dt} &= \frac{cS_1 A_1}{2A_2\sqrt{L_1}}\cdot x_1 - \frac{1}{A_2}u_p \\
u(t) &= u_p(t-\tau) \\
y(t) &= x_2
\end{aligned} \tag{2}$$

where: $x_1 = \Delta L_1$, $x_2 = \Delta L_2$.

The operational forms of the equations (2) are:

$$\begin{aligned}
\left(s + \frac{cS_1}{2A_1\sqrt{L_1}}\right)X_1(s) &= \frac{1}{A_1}U(s) + w_1(s) \\
sX_2(s) &= \frac{CS_1 A_1}{2A_2\sqrt{L_{10}}}X_1(s) - \frac{1}{A_2}u_p(s) \\
U(s) &= U_p(s)e^{-\tau s} \\
U_p(s) &= -A_2 sX_2(s)
\end{aligned} \tag{3}$$

The output of controlled process is given by the equation (4) and the block diagram of the controlled process is given in figure 3.

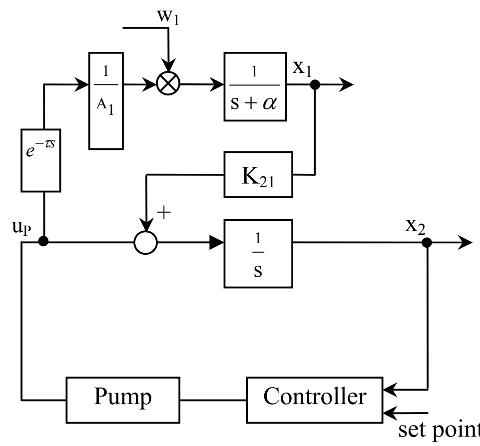

Fig.4 Block diagram of process control

$$Y(s) = X_2(s) = \left(K_{21}\frac{e^{-\tau s}}{sA_1(s+\alpha)} - \frac{1}{sA_2}\right)U_p(s) + \frac{k_{21}}{sA_1(s+\alpha)}w_1 \tag{4}$$

Where $\alpha = \frac{CS_1 A_1}{2A_2\sqrt{L_{10}}}$ and the transfer function input – output is given by equation (5).

$$H_{PF}(s) = \frac{Y(s)}{U_p(s)} = -\frac{1}{sA_2} + \frac{K_{21}\cdot e^{-\tau s}}{sA_1(s+\alpha)} \tag{5}$$

3 The control systems design

The computer control of the plant parameters (temperature and level) is achieved using the control programs developed under LabView software (Cottet and Ciobanu, 1998).

3.1 The board wiring

The connection between the FESTO kit and the data acquisition board is made through a connection adapter and a cable with 24-pin connectors. The kit elements are connected to the AXIOM board as follows: CS0-temperature sensor; 1-green wire-pin CS1-flow sensor; 2-brown wire-pin CS2-level sensor. The connection adapter diagram is presented in figure 5. To draw the connexion scheme much easier, on the lay, the wire ways are drawn with different colours for each circuit way (line) with the corresponding (connexion box points).

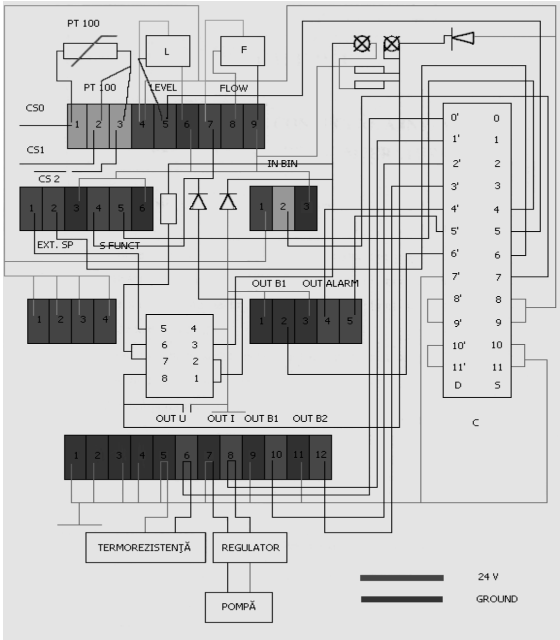

Fig.5 The connection adapter diagram

3.2 The temperature control system

Generally, the temperature control processes are slow processes with significant transport delay. These processes have big time constants usually in the minutes or even hour's range. Moreover these processes are subjected to important perturbations due to the heat and mass exchange with the environment. In the case of temperature control in the system, the liquid temperature may rise through the heater. The liquid is continuously spread by the pump pin heat excenger HE.

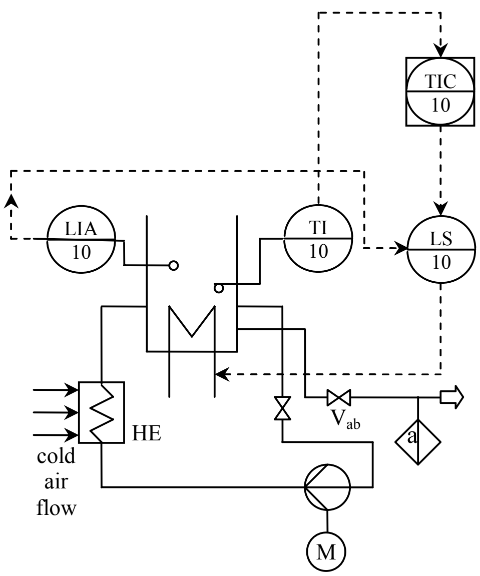

Fig.6 Diagram for temperature control

The heater switches on Start only when the heating bar is totally submerged into the liquid. For temperature control, a bi-positional controller with hysteresis was used. The controller equations are as follows:

$$\varepsilon_k = v - \theta_k \quad (1)$$

$$\text{If } \varepsilon_k \geq \delta \Rightarrow x_k = 0 \quad (2)$$

$$\varepsilon_k \leq -\delta \Rightarrow x_k = 0 \quad (3)$$

$$-\delta \leq \varepsilon_k \leq \delta \Rightarrow x_k = x_{k-1} \quad (4)$$

Where: v- steeping; θ- process variable; ε - error; x- controller output; δ - control parameter imposed by the required level of performance; k- current step;

A small δ will assure a small error but in the same time will generate fast changes of the controller output between zero and one, reducing the life span or even damaging the actuator. Also, δ shall be chosen depending of the process transport delay.

The program installation is done with the Open command in the File menu of LabView. The program resides in the LabView folder and has the name *temp.vi.* The front panel of the virtual controller is presented in the figure 7. After the Open command, the program is launch and the front panel is presented on the screen.

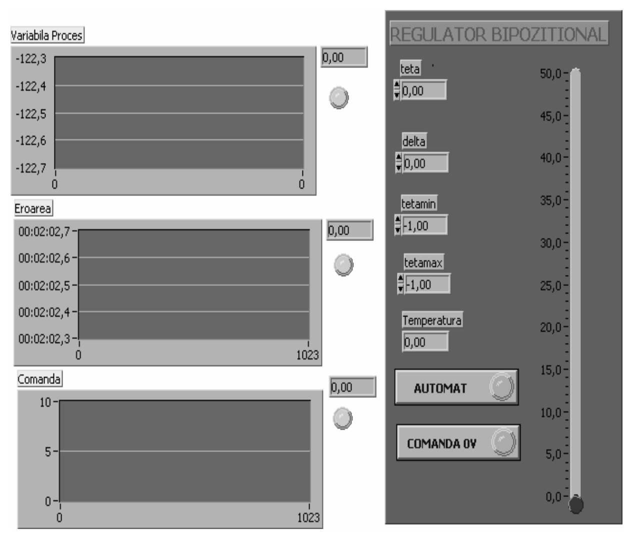

Fig.7 Front panel

3.3 The level control systems

For the adjustment loop of the level, the liquid level in the tank can be controlled, and is measured with the ultrasound level sensor. A perturbation can be introduced in the loop and the liquid can be transferred into the B3 tank partially or totally through the closing or opening of the faucet (fig.3.). The level control in the FESTO kit is achieved using the variable flow pump. The water circuit is consists of the upper and lower reservoirs connected through a system of pipes and valves. The controlled variable is the level in the upper reservoir. The level control processes can be divided in two categories:

- The first category contains the installations where level is a primary parameter or the level influences directly the process. In this case, the level shall be precisely controlled. The FESTO kit may be included in this category.
- The second category contains the installations where level is a secondary parameter and can largely vary. In this case, the precision of the control is not so important and sometime a simple by-positional controller is sufficient.

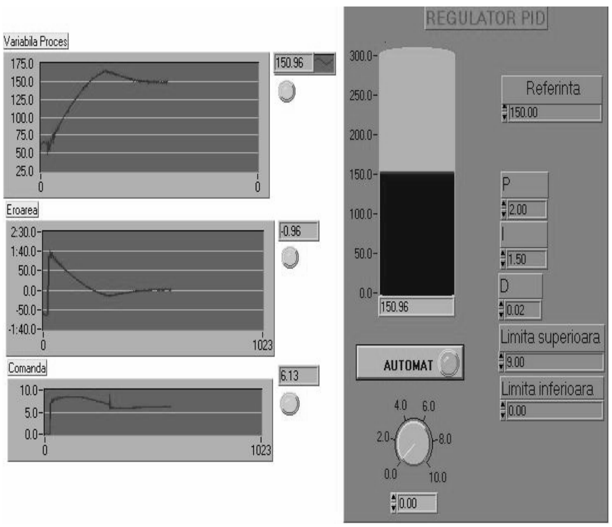

Fig.8 Level control

The input flow or the output flow may control the level. If the installation is part of a process line and the output flow is mandated by the next installation, the input flow is used for level control. If the installation is the last one in a process line and the output flow may be freely modified this flow will be used for level control. The program installation is done with the Open command in the File menu of LabView. The program resides in the LabView folder and has the name *Control_level.vi.*

The front panel has displays for the process variables and control elements for parameters setting. The process variables are displayed on the left side of the panel: temperature, error and controller output. The variables are presented as graphs and as digital values. Next to each graph, there is an LED, which displays the following status: -temperature-RED=zero value (possible fault), GREEN (non-zero value) -error- RED (error absolute value is bigger then 0.1), GREEN (error absolute value is smaller than 0.1) –Controller output- RED (output=10V), GREEN (output=0V) (fig.8).

3.4 Program diagram

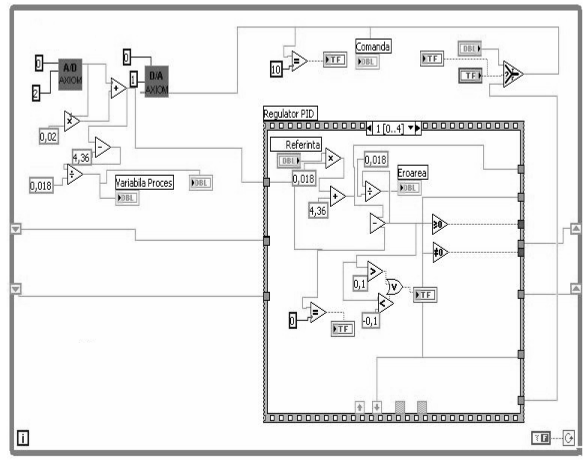

Fig.9 The program block diagram

The diagram is drawn in colours specific to LabView (fig.9). The program is using the voltage for internal calculations. In order to display the temperature, a conversion formula was used: U=0.1085*θ+4, where: u-voltage [V], θ-temperature [°C]. The diagram allows also the output values to be changed from zero and one to adapt the program for other installations. After the Open command, the program is launch and the front panel is presented on the screen. In manual regime, the pump is disconnected from the controller and the pump flow can be manually controlled. The reservoir level will be maintained according with other parameters of the system.

4 Experimental results

The tuning is done experimentally, the parameters being fine-tuned through small changes until the desired response is obtained. This method is using the real operation of all control system elements and can be used regardless the controller type, especially for PID controllers with any interdependence factor. The PID controller tuning is performed as follows:

- The BP and T_i parameters are set at the maximum values and the T_d parameter is set at minimum. BP is lowered until the output oscillates. T_d is raised until oscillation disappears. The process is repeated until T_d raise cannot stop oscillations anymore. In this case, BP is raised to the previous value and T_d is lowered to the previous value to get a stability margin.
- After BP and T_d are set, T_i is lowered until oscillations appear. Then T_i is set at one or two steps higher to get a stability margin. Following this procedure, the following parameters were determined for the level controller (fig. 10): K_R=1.5; T_i=2; T_d=0.02.

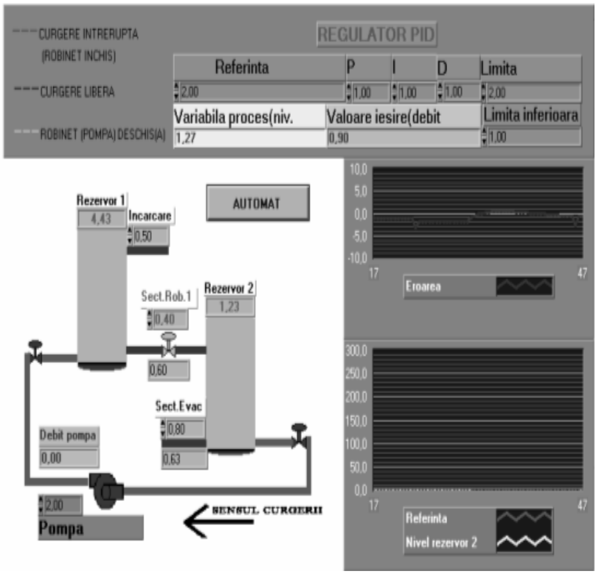

Fig.10 Controller PID

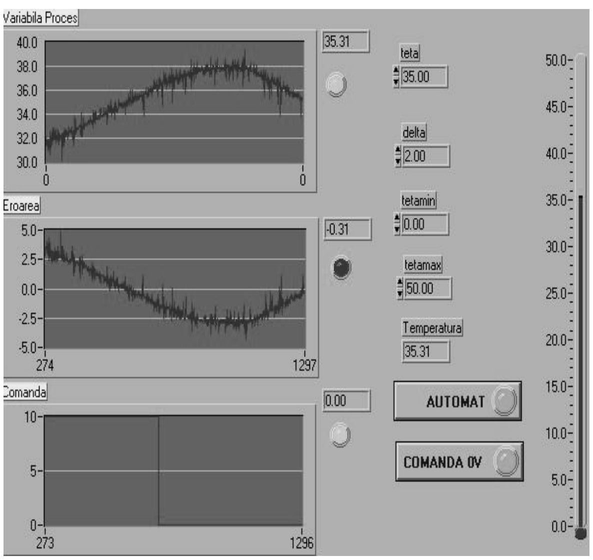

Fig.11 Temperature control

The variables are presented as graphs and as digital values. Next to each graph, there is an LED, which displays the following status: -temperature- RED= zero value (possible fault), GREEN (non-zero value) -error- RED (error absolute value is bigger then 0.1), GREEN (error absolute value is smaller than 0.1) –Controller output- RED (output=10V), GREEN (output=0V) (fig. 11). The precision of the control is not so important and sometime, a simple bi-positional controller is sufficient (fig.12.).

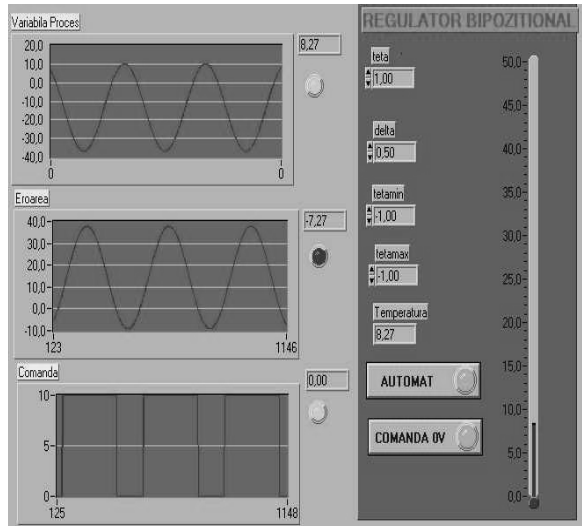

Fig.12 Controller bi-positional

5 Conclusions

This paper is presenting the experimental results obtained in the development of some applications for design and implementation of control systems for industrial installations in the laboratory stand. For that purpose, an educational kit was used manufactured by FESTO-Germany. The kit is provided with necessary sensors for temperature and level. A signal adapter was necessary to connect the sensors to the data acquisition board existent in the laboratory stand. A complex educational system was developed using the FESTO kit, the AXIOM data acquisition board and LabView software. This system may be used for practical work associated with the course Control Systems for Continuous Processes.

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