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DEVELOPMENT OF A DIDACTIC SET OF PNEUMATICS AND SERVO PNEUMATICS IN ENGINEERING EDUCATION

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Summary

Control of the work piece position is one of the most difficult and most common problems in manufacturing. This problem is in most cases solved by using an electric axis with a servo or step motor, servo pneumatic or classical pneumatic components. Having this in mind, a didactic set for controlling the work piece position in vertical tubes has been developed and will be described in this paper. This system has been realized by using servo pneumatics and classical pneumatics. In this system, feedback was used for controlling the work piece position in a servo pneumatic system. The feedback was obtained by using a photoelectric sensor. The developed system is a part of the laboratory equipment used by undergraduate and graduate students in the Industrial Engineering and Mechatronics study programme at the Faculty of Technical Sciences, University of Novi Sad, as well as by individuals who already work in industry. This didactic set encourages active participation of students in class and helps them with their tasks, which include learning about the structure of the set and the way of controlling the work piece position.

Key words: *didactic set, pneumatics, education, mechatronics, automation*

1. Introduction

Since industrial applications are becoming more and more complex, industry needs experts with skills across a variety of disciplines, such as control systems, electronic systems, computers, and mechanical systems [1]. The importance of successful training and the preparation of experiment was noticed years ago [2]. Many experts are involved not only in designing new systems, but also in revitalizing existing old systems mostly controlled by hand through complex mechanical devices. The job market requires professionals with engineering skills and problem solving competence, who are able to design, manufacture, implement and service a wide range of equipment.

At the University of Novi Sad, Faculty of Technical Sciences, Serbia, there are various courses at the bachelor's and master's degree level, among them being also the Industrial Engineering and Mechatronics study programmes. Students attend standardized courses, which are designed in such a way that they provide sufficient knowledge in a variety of disciplines that can be applied both in industry and non-industry fields. These courses include also practical activities, designed to provide hands-on experience for students.

There are different opinions regarding the way knowledge can be transmitted to engineering students [3]. Knowledge is necessary for engineers to achieve easier and faster integration into real manufacturing and non-production systems [4, 5, 6, 7, 8 and 9]. The theory of experimental learning presents learning through experience [10], in which learning is a process in which knowledge is gained through practice.

Engineering practice is shaped by a wide range of divergent global factors, and it is incumbent upon educational institutions to transform engineering education so as to prepare students for taking on new challenges [11]. Industrial engineering and mechatronics education requires full understanding of real time applications and problems. Critical thinking and problem solving skills beyond those previous generations possessed in their disciplines are also required, and in fact, students must develop creativity and communication skills to be able to innovate across disciplines [12]. Therefore, there is a need not only to provide literature, but also adequate equipment for solving different multidisciplinary tasks both individually and in a group in order to support such needs and curricula.

Having this in mind, a didactic set of a pneumatic and servo pneumatic system for controlling the work piece position was developed. The problem of controlling the work piece position was chosen since it is a common industrial task [13]. In this didactic set, widespread industrial elements, made by different manufacturers, are implemented and integrated in one system. These elements are: electro-pneumatic components, programmable logic controllers (PLCs), sensors, a Proportional-Integral-Derivative (PID) controller, supervisory control and data acquisition (SCADA), and different communication interfaces. With this didactic set students have a possibility to:

- analyze servo pneumatics and work with standard industrial pneumatic and electro-pneumatic components, such as modular air preparation unit, solenoid valve and proportional solenoid valve,
- analyze and work with an industrial laser proximity sensor with analogue and discrete outputs,
- control the work piece position with a PID controller, work with parameters of the PID controller, and analyze how parameters of the PID controller affect the system stability,
- analyze the existing software for PLCs, and make their own software,
- analyze the existing SCADA system; learn how the SCADA system can be developed and how a PLC and a personal computer (PC) establish communication using standard industrial protocols.

The developed didactic set is used in the undergraduate courses of Industrial Engineering and Mechatronics study programmes, e.g.: Components of Technological Systems, Implementation of Sensors and Actuators, Programming and Implementation of Programmable Logical Controllers, Systems for Supervision and Process Visualization, Computer Integration of Manufacturing Systems, and a course in Implementation of Automated Systems which is held as a graduate course.

A detailed description of classical and servo pneumatic systems is given in Section 2 of this paper. Section 3 describes elements of the didactic set of the pneumatic and servo pneumatic system. A detailed description of the servo pneumatic control software is given in Section 4, and Section 5 contains conclusion.

2. Classical and servo pneumatic systems

Pneumatics is nowadays one of the basic technologies and it has been used for generations for linear pneumatic actuators. There are several advantages of pneumatic actuators, such as simple speed adjustability, overload proof without energy consumption for retention forces, high vibration resistance, low maintenance throughout their entire service life. They are also almost ideal candidates for application in continuous systems [14]. There are also a few disadvantages concerning the air flow, e.g. the air flow differs depending on the construction of pneumatic components [15]. Nevertheless, pneumatic systems are extensively used in industry and non-industry fields, and thus deserve to receive special attention in engineering education.

2.1 Classical pneumatic systems

Basic components of a classical pneumatic system are: compressed air supply, valves, actuators (in most cases cylinders), and sensors. Valve represents a component of the pneumatic system that is used for actuator control. Types of valve actuation are: manual, mechanical, by compressed air, or by solenoid. In most cases, a valve can have 2 or 3 positions, and 2 to 5 ports. Actuator is an end element of the pneumatic system which is used for moving a work piece from one position to another. Types of actuators are: linear (standard, compact, rodless, guided, etc.), rotary (rack and pinion, vane), grippers (parallel, angular) [16]. Sensors are usually mounted on actuators and they are used as part of feedback control for the position detection of actuator moving parts (rod, guide, vane, rack). Several types of sensors are used in pneumatic systems: mechanical, inductive, reed switches, etc.

2.2 Servo pneumatic systems

Components of servo pneumatic systems are basically the same as components of the classical pneumatic system, except that servo pneumatic systems have different control elements (valves) and sensors (measurement systems).

In servo pneumatic systems, the control element represents a proportional valve. An analogue input signal, which is used to control the proportional valve, can be of voltage or current type. Air flow is proportionally controlled depending on the analogue input signal.

Sensors that are used in servo pneumatic systems are mostly some kind of encoders (incremental, absolute, etc.) or distance sensors (optical, ultrasonic). With these sensors, an exact position of actuator moving parts can be detected. Number of positions that can be achieved depends of the sensor resolution, characteristics of the proportional valve, PLC's analog/digital (A/D) converter resolution, etc [17].

An important part of the servo pneumatic system is feedback control that can be achieved by the following elements: PLC, proportional valve, actuator, and sensor. Feedback control is used to realize accuracy and precision needed for the system to function with minimum deviation.

3. Elements of the didactic set of pneumatics and servo pneumatics

The developed didactic set of pneumatics and servo pneumatics was designed with the aim of presenting students the difference between controlling the work piece position with classical pneumatics and with servo pneumatics. This didactic set (Fig. 1.) consists of a table on which the following is mounted: a laser distance sensor (1), two vertical plexiglass tubes (2) with the work piece placed inside the tubes (3), a proportional valve (4), a 3/2 solenoid valve with a one-way flow control valve (5), 24 V DC power supply (6), a programmable logic controller (7), main switch for power supply (8), push buttons (9), and an air preparation unit (10).

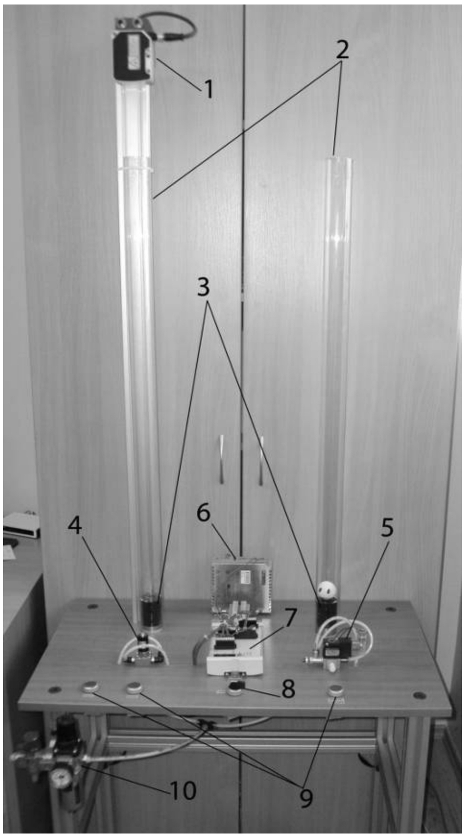

Fig. 1 Didactic set of the pneumatic and servo pneumatic system.

The programmable logic controller (Festo FEC FC660) consists of 32 digital inputs, 16 digital outputs, an analogue output and 3 analogue inputs. Three digital inputs are connected to the push buttons. One push button is a part of the pneumatic system and the other two are parts of the servo pneumatic system. One of the PLC digital inputs is connected to the error signal from the laser distance sensor. There are also two more output signals from the laser distance sensor connected to the digital inputs of the PLC. These signals indicate end positions of the work piece in the vertical tube. Two digital outputs of the PLC are used. Opening and closing of the 3/2 solenoid valve is controlled by one PLC digital output and the other digital output is connected to the laser distance sensor input for laser on/off. One of the PLC analogue inputs is connected to the laser distance sensor analogue output through a voltage-current amplifier, because the output signal from the sensor ranges from 0 to 10 V and the PLC analogue input ranges from 0 to 20 mA. The PLC analogue output is connected to the current amplifier input which amplifies the PLC signal so it can control the opening of the proportional valve. The current amplifier is implemented because the analogue output signal from the PLC is max 20 mA and for the 100 % opening of the proportional valve current of 165 mA must be applied. Non-standard signal range (0-165 mA) was chosen for controlling the proportional valve with the intention to teach students how to deal with the signal conversion problem, if necessary.

The PLC control software is written in the Festo software package FST 4.0, in the Statement List Programming Language. A driver for the PID regulator is implemented in this software package. The PLC is connected to a PC via the TCP/IP communication protocol.

The work piece is a cylinder made of steel, 80 mm in height, 43 mm in diameter and 300 g in weight. If the weight of the work piece changes (another type of the work piece material), PID regulator parameters must be corrected in order to obtain a desired system response. The work piece is placed into a transparent plexiglass tube, 1000 mm in height and

44 mm in diameter. The tube is perpendicular to the table and closed on the bottom side with a plexiglass disc. A fitting for compressed air coming from a one-way flow control valve (pneumatic) and a proportional valve (servo pneumatic) is placed in the center of the plexiglass disc. The tube is opened at the top, so air can freely come out (Fig. 2).

In the pneumatic system, the work piece position is controlled by a 3/2 solenoid valve and a one-way flow control valve (Fig. 2). When the classical 3/2 solenoid valve is closed and the push button „valve ON/OFF" is pressed, the 3/2 solenoid valve opens, and compressed air goes through. The one-way flow control valve is connected to the output port of the 3/2 solenoid valve. The flow rate of the compressed air, which goes through the plexiglass tube, is controlled by the one-way flow control valve. If the head screw of the one-way flow control valve is turned counterclockwise, the air flow and pressure in the tube increase. As a result, the work piece moves upwards. By turning the head screw of the one-way flow control valve clockwise, the air flow and pressure in the tube decrease, so the work piece moves downwards. To keep the work piece in position it is necessary to set exact value of the air flow. Feedback control for the classical pneumatic system (3/2 valve, one-way flow control valve and work piece) is not provided in this phase of the didactic set development.

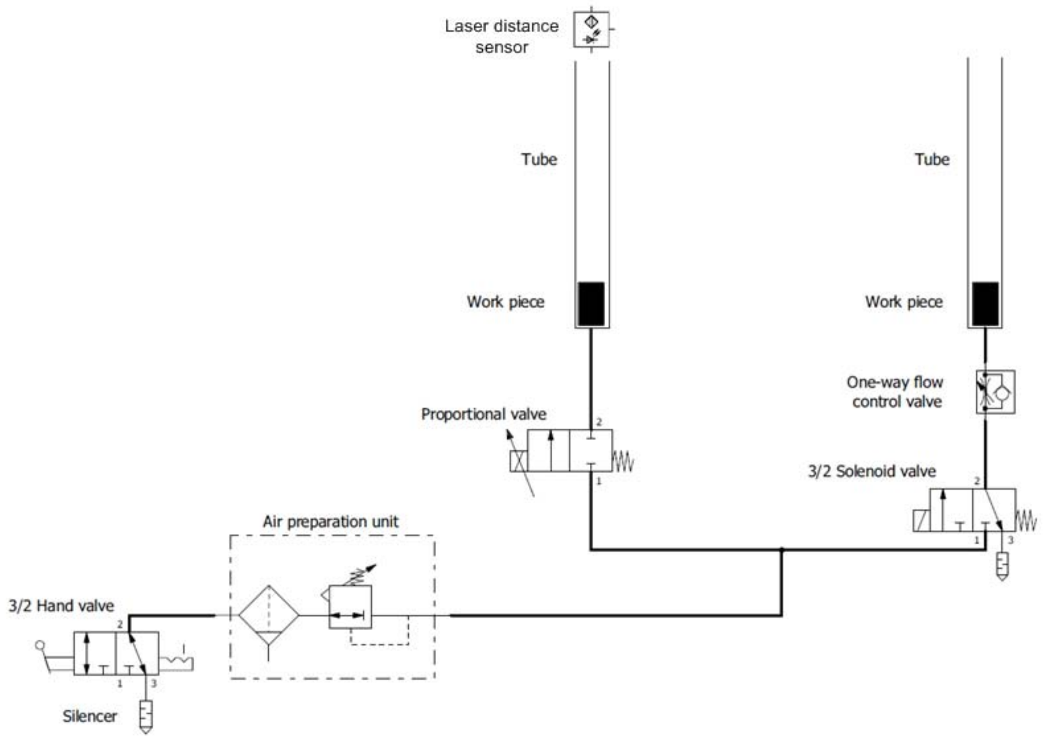

Fig. 2 Electro-pneumatic diagram of the didactic set.

In the servo pneumatic system, the push button "UP" is used for moving the work piece upwards and the push button "DOWN" moves the work piece downwards. Each time the push button is pressed, the work piece moves by one step. The step value is defined by the PC application made for controlling and changing the values of the system parameters.

The proportional valve (SMC PVQ33, Fig. 2) controls the position of the work piece (it controls the movement and the position of the work piece through the vertical tube). Analogue input signal, which controls the proportional valve, ranges from 0 to 165 mA. When the input signal current is 0 mA, the proportional valve is fully closed, and when it is fully opened, the input signal is 165 mA. The compressed air flow rate of the proportional valve is 0 to 75 l/min, and the port size is Rc 1/8".

The laser distance sensor (Balluff BOD 63M) is used for the non-contact distance measurement of the work piece position in the plexiglass tube. This sensor works according to the time measuring principle. Time measuring starts when the emitter emits the laser pulse signal and lasts until the signal reflects from the work piece and returns to the receiver (the emitter and the receiver are placed in the same housing). The measured time is converted into an analogue signal. The sensor attains its full accuracy under constant ambient conditions in min 20 minutes after the power is turned on (in practice, the sensor is usable immediately after powering on, but the collected values are not accurate). The measurement error, that collected the values obtained during the warm-up phase, is 0,5%. The duration of this warm-up phase depends on ambient conditions. If the sensor is switched off for a few seconds and then turned on again, the accuracy of the sensor will remain the same because the sensor is already warmed up. The sensor has 4 LED indicators. The green LED indicates the ready state of the sensor. The yellow LED "Out 1" indicates the active state of the switching output 1, which is in this case used as security measure in case the work piece is out of the sensor measuring range (near the sensor blind zone). The yellow LED "Out 2" indicates the active state of the switching output 2, which is in this case used to detect the position of the work piece at the bottom side of the plexiglass tube (start position). The red LED indicates the status when the intensity of the received signal for a reliable operation is not sufficient. The laser distance sensor has 2 potentiometers. The potentiometers are used to set the switching distances of the sensor independently of each other. The sensor has 4 output signals: error, output1, output2 and analogue. Error output is activated as soon as the work piece is detected. Output1 is activated when the work piece is in its trigger range. The same rule applies to Output2. Analogue output ranges from 0 to 10 V DC proportionally to the work piece distance from the sensor zero point (sensor has a 200 mm blind zone). The sensor has one input (laser on/off). The laser turns itself off as soon as the high signal (logical 1) is present on Pin 8.

4. Servo pneumatic control software

The control of the work piece position in the servo pneumatic part of the didactic set can be achieved in two ways: by using the "UP" and "DOWN" push buttons (see chapter 3) or by using the servo pneumatic control software (see Fig. 3).

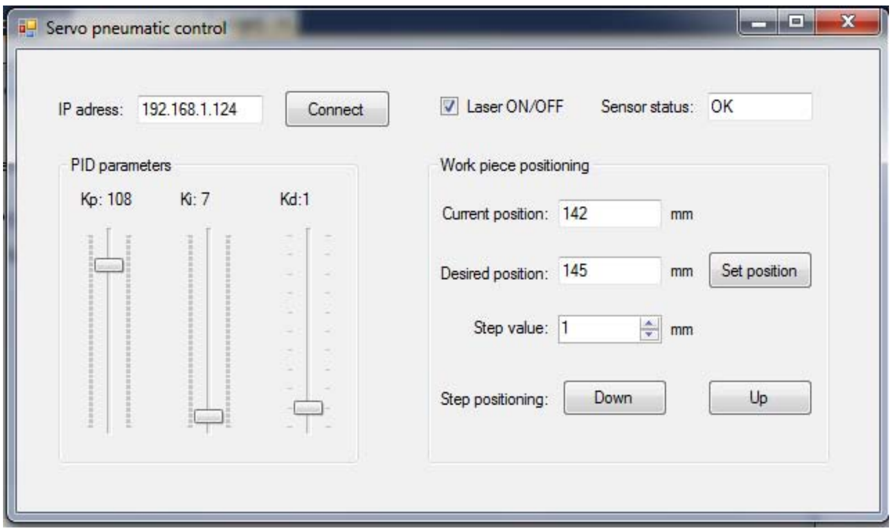

Fig. 3 Servo pneumatic control software.

The servo pneumatic control software for controlling the work piece position by the servo pneumatic system of the didactic set has been developed in Microsoft Visual Basic

2010. The text box for the IP address of the PLC (Fig. 3) is placed in the upper left-hand corner of the application. When the IP address is written in the text box, a user can click on the command button "Connect". Then, the PC tries to establish a connection with the PLC and if connection is established, the text on the command button "Connect" changes to "Disconnect". Otherwise, if the PC cannot establish a connection with the PLC, the error massage box pops up on the screen. The check box for the sensor laser on/off and the text box with the sensor error output status are placed in the upper right corner. If the check box is checked, then the sensor laser is turned on, otherwise the laser is turned off. If "OK" is written in the sensor error output text box status, the laser is turned on and the sensor is functioning normally. Otherwise, the laser is either turned off or there is a malfunction of the sensor. In such cases, "ERROR" will be written in the text box.

There are two group boxes in the application form. The group box from the left side of the application ("PID parameters") is used for reading and writing PID controller parameters from the PLC. There are three track bars in this group, one for each PID controller parameter. Above the track bars there are labels which show the PID parameter name and value. Label "Kp" contains the value of the P parameter, "Ki" contains the value of the I parameter and "Kd" contains the value of the D parameter of the PID controller. When the user moves the track bar slider, the value of an appropriate PID parameter changes and it is written in the PLC's PID controller. A new value of the PID parameter is shown in an appropriate label.

The group box from the right side of the application ("Work piece positioning") is used for reading current and setting a new work piece position. There are two text boxes in this group: "Current position" and "Desired position". Command button "Set position" is placed on the right-hand side of the text box "Desired position". When the user clicks on this button the work piece moves to the desired position. Field "Step value" is used for setting the value of the next step (see Chapter 3). There are two more command buttons in this group: "Down" and "Up". These buttons have the same function as the push buttons placed on the table of the didactic set (see Chapter 3).

Elements of the realized feedback control are: a programmable logic controller, a current amplifier (op. amp. LM358), a proportional valve, a work piece, a laser distance sensor and a voltage-current amplifier (op. amp. LM358) (see Fig. 4).

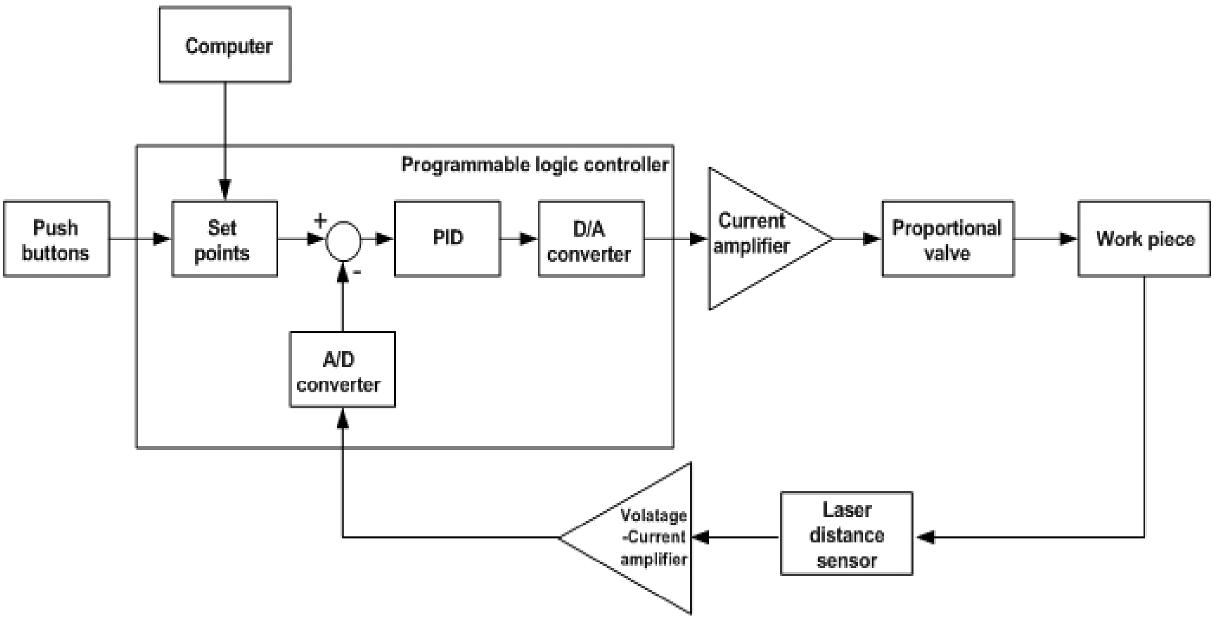

Fig. 4 Elements of the feedback control block diagram of the didactic set of the servo pneumatic system

If the system is fully operational (power and compressed air supply are on) and corresponding parameters of the system are set, then it is possible to assign a desired work piece position. Afterwards, the PLC reads the value of the current position and compares it with the desired position. These values represent PID controller inputs. In regard to the set values the PID controller sets an appropriate value to the PLC analogue output. This value is amplified by the current amplifier and forwarded to the proportional valve, which is then positioned according to the set current value. The response of the control system can be viewed in the separate window. Fig. 5. presents the response of the control system when the initial position is set to 0 mm and the desired position is set to 250 mm.

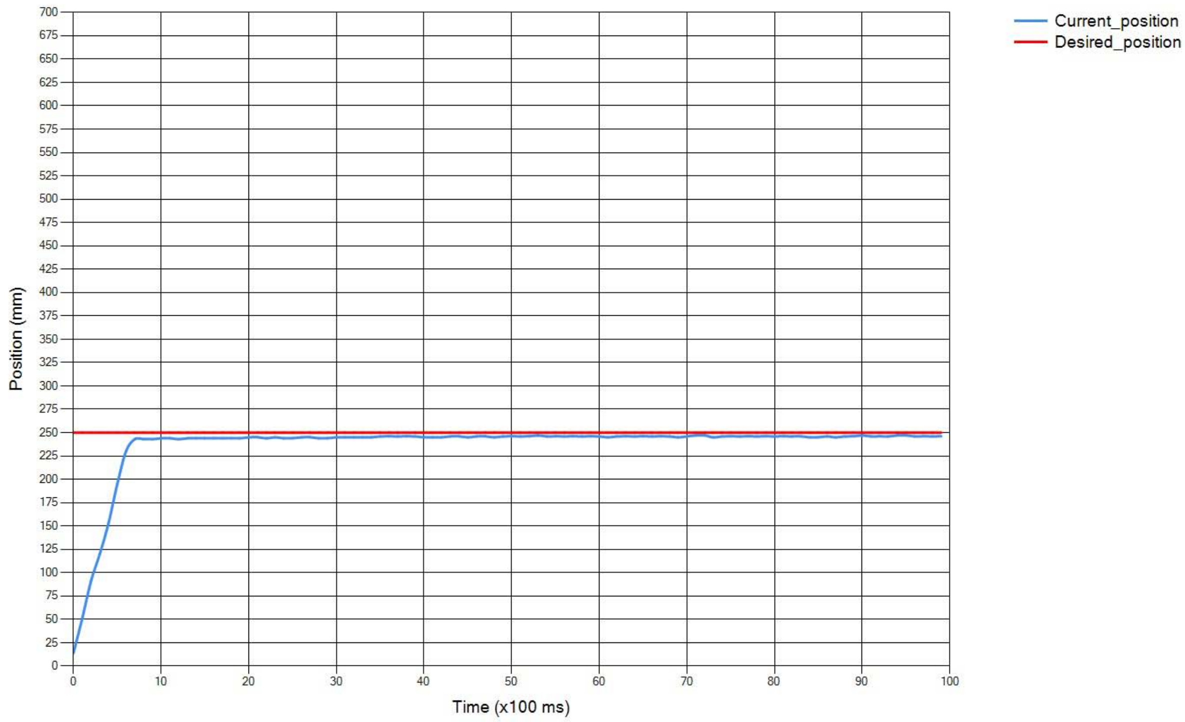

Fig. 5 Response of the control system.

New values of the PID controller are applied when pressing the command button Set position. All responses of the control system with different values of the PID controller are saved in separate files for further analyses. Each student prints out his best result achieved upon adjustment of PID parameters at the end of the exercise with this didactic set. Student's grade will depend on the results achieved in the setting of PID parameters.

5. Conclusion

The didactic set of the pneumatic and servo pneumatic system was developed with the aim of providing students of Industrial Engineering and Mechatronics training based on practical tasks in engineering areas such as implementation of different control strategies, implementation of sensors and actuators, programming and implementation of programmable logical controllers, implementation of automated systems and systems for supervision and process visualization.

The developed didactic set, used for controlling the work piece position in a vertical plexiglass tube, has been realized by using common industrial pneumatic and servo pneumatic components (an air preparation unit, a 3/2 solenoid valve, a proportional valve, a sensor, a PLC with an integrated PID regulator), made by different manufacturers and integrated in one system. The set was designed with the purpose of presenting students the difference between controlling the work piece with classical pneumatics and with servo pneumatics. The open loop control is used, in this case of a classical pneumatic system with a 3/2 solenoid valve and a manually adjusted one-way flow control valve. In the case of a servo pneumatic system, feedback control is realized with a laser distance sensor and it is used for controlling the work piece position. This didactic set shows how the pneumatic and servo pneumatic system works, how feedback control is realized and how the PID regulator functions. The servo pneumatic control software, developed for this didactic set, gives a possibility for controlling and supervising the work piece position and changing parameters of the PID regulator. By changing parameters of the PID regulator students can analyze how these changes affect the system stability and time for response. A similar experience in training students are described in [18], but without using the standard industry components and without comparison of two different control systems. These differences are significant advantages of the didactic set described in this paper.

The didactic set of the pneumatic and servo pneumatic system gives students a better insight into real industrial tasks and conditions. Working with the didactic set students can actively participate in all aspects of the design and implementation of similar systems and elements which are commonly applied in industry and non-industry fields. The plan for the developed didactic set is also to be used in the undergraduate course Artificial intelligence where students can generate different control algorithms based on neural networks, fuzzy logic and hybrid systems, using the same hardware repeatedly.

Future work should be directed to studying how solving of a practical problem affects the learning process. Also, it would be of great importance to investigate how these influences vary among the student population.

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