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DESIGN AND EXECUTION OF A PNEUMOTRONIC LABORATORY STATION USING PROPORTIONAL CONTROL

Abstract: The paper presents the construction process of a pneumotronic station for exercises in the field of proportional technique in pneumatics. The stages of selecting elements, designing of the frame of the station in the Siemens NX system, writing software and creating visualizations for the HMI panel are presented. The stand was equipped with a proportionally controlled pneumatic axis, with a pneumatic cylinder mounted on it, equipped with a vacuum generator, which allows for lifting flat elements. The next stages of creating software for station control are also presented. The process of creating an algorithm controlling the automatic cycles of the station and the stage of building the visualization on the HMI panel are presented.

1. Introduction

Initially, the proportional technique was used only in hydraulic systems. It was not until the 1980s that a control system proportional to pneumatics was introduced. This technique combines pneumatic systems with electronic control systems. Progressive changes are aimed at increasing the simplicity of pneumatic systems application while improving their accuracy [1-3]. The proportional technique allows to control the process using analog signals. Proportional elements of pneumatic systems allow for continuous change of the pressure or flow rate directly proportional to the analog signal given to the control element. Proportional technology is widely used in industry. Practical examples of using this technique are [1,2,4]:
- adjustment of the paper roll tension in the paper industry. In this system, the electrical signal from the controller is converted into a pneumatic signal that causes the adjustment cylinder to be displaced so that the appropriate paper tension is maintained on the roll supporting the sheet of paper.
- the pressure control system, where the transmitter converts the current pressure in the pipeline, into an electrical signal, based on which the control signal is determined, causing the control valve to open or close properly.

- filling of liquids in the food industry by control of the actuator with a bottle filling tube. A vertical displacement of the tube is carried out so that it is lifted with the increasing level of liquid in the bottle.
- applying an adhesive, in which, depending on the transporter's speed, the adhesive must be applied to different surfaces in an appropriate quantity. The signal informing about the change of the transporter's speed, causes the appropriate pressure regulation, which changes the position of the ball in the adhesive dispenser.

The work involved the design of a pneumotronic station, which is the application of a pneumatic positioning system. The station consists of a proportional controlled axis, which allows obtaining four predefined positions and a vertical axis, which is an application of a classical electropneumatics. The vertical axis actuator is controlled by a solenoid valve. In addition, it is also possible to rotate on the vertical axis using a rotary actuator, with a range of up to 90 degrees. The stand provides the opportunity to learn about the practical application of the proportional system used in real systems existing in industry. Working at the station also allows you to familiarize yourself with the programming methods of the PLC controller, which implements the given algorithm for controlling the pneumotronic system. The concept of pneumotronics is related to electrically operated pneumatic drives that are programmable. Pneumotronics is a combination of information technology, pneumatics and electronics.

2. Development of a pneumotronic laboratory station using proportional technique

Positioning in pneumatics is a difficult issue due to the nature of the phenomenon of converting compressed air energy into mechanical work. This is a non-linear phenomenon, which makes it difficult to predict the behaviour of the actuator during positioning. Therefore, manufacturers develop and propose their own pneumatic proportional systems. In the developed laboratory stand for proportional positioning the axis of the FESTO company was used consisting of the following elements:
- SPC11-MTS-AIF axle controller,
- proportional directional valve MPYE-5-1 / 8-HF-010-B,
- rod less cylinder GPL-25-650-PPV,
- GDC-HD25-GK-D2 heavy duty guide,
- absolute MME-MTS-750-TLF-AIF digital encoder.

It is presented in Fig. 1. The number 5, in Figure 1 denotes the axis controller, with the help of which the whole drive control takes place, giving the control signal to the proportional directional valve (6). The axis is supplied with air, which should be properly prepared. By means of the air preparation unit (8), the air is filtered into particles with a maximum diameter of 5μm. The valve is supplied with air at a pressure of 5-7 bar. It is not recommended that the air be oiled. Controlling the position of the linear actuator (1) was carried out by a proportional valve. Information on the position of the actuator is provided by the linear encoder (2) directly to the controller. In drives of this type, the need to use limit switches and pneumatic absorbers was eliminated [5]. The current piston position of the actuator is measured by means of an encoder. The MME-MTS type encoder is a closed profile with an external guide. The position measurement is made using magnetostrictive phenomenon [6]. The distance measurement is made by the difference in the time of generating the impulse and its reflection from the encoder's sensor [7].

The position is remembered by the encoder even after disconnecting the power supply, therefore it is not required to base the axis when restarting the station.

The transfer of information between the encoder and the axis controller takes place digitally after the Controller Area Network (CAN) interface with the SPC-AIF protocol. This protocol enables fast data exchange between devices. This controller allows for quick axis movements up to four positions. The two positions are the end positions of the manipulator, while the additional two intermediate positions can be stored in the controller's memory.

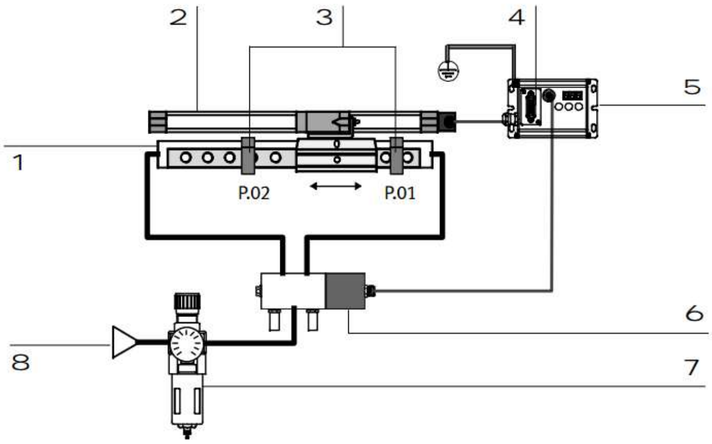

Fig. 1. The diagram of a proportional controlled pneumatic drive axle [5]

The MPYE directional proportional valve is like a simple solenoid valve, but it is equipped with a slider with its position control (2). Electronics located in the valve housing allows to control opening the valve using the analog signal. Opening the valve is directly proportional to the value of the analog signal. Valves of the MPYE series could be controlled by the voltage as well as the current signal. Flow rates are in the range of 100 - 2000 l / min. The valve used in the laboratory station is a five-way valve. The control is carried out by means of an analog voltage signal in the range of 0 - 10V. The valve hysteresis is about 0.4%. The valve operation pressure is in the range from 0 to 10 bar [8].

The axle is equipped with an additional vacuum lifter that allows lifting flat elements such as plates. The lifter consists of a double-acting cylinder with guides and a rotary actuator at the base. In addition, rubber suction cups have been installed in the base, allowing for the removal of a flat element by creating a vacuum. It is possible to perform vertical movements and rotation in the base. The entire manipulator is equipped with an adapter, which makes it possible to mount it on the actuator's cart. The cooperating axes form a system with three degrees of freedom.

The controller parameters should be configured in accordance with the axes operating conditions, which depend on the type of encoder the axis is equipped with and the mass to be moved, mounted on the bogie [5]. Parameters that can be configured in the SPC11 controller:

- gain parameter (A), responsible for acceleration of the drive,
- damping parameter (C), affects the behaviour of the drive during commuting to the final and intermediate positions,

- system option (S), is determined by two symbols. The first is the indicator of the drive measurement system, the second is the characteristic value of the drive's length ratio and its diameter,
- nominal length of the axial stroke (L). Nominal drive pitch length given in millimetres, parameter entered when the drive has an incremental encoder,
- the distance from the starting position (r), the value given in millimetres, the parameter entered in the case of the incremental encoder,
- options (o), additional options that allow assigning other actions performed on the controller's inputs and outputs.

The manufacturer provides suitable parameter configurations for different axle operating conditions. The parameters should be selected with extreme caution, because incorrect selection may cause undesirable axes or even damage. The parameters must be entered into the controller when the axis is first started or when the operating conditions of the axis have been changed [5].

In order to prepare the laboratory stand, it was necessary to prepare a frame on which the axis was mounted. The structure is made of aluminium profiles. The first step was to implement the project in the Siemens NX 10 software. Three concepts for the construction of the frame were developed. When developing the design, it was necessary to consider not only the weight of the entire axis, but also the inertial forces accompanying the dynamic movements of the actuator. After selecting the concept, details such as the place where the plate was installed with the controller and the valve were refined, and a countertop made of galvanized sheet with a thickness of 5mm was designed. A detailed executive drawing of the station is shown in Fig. 2.

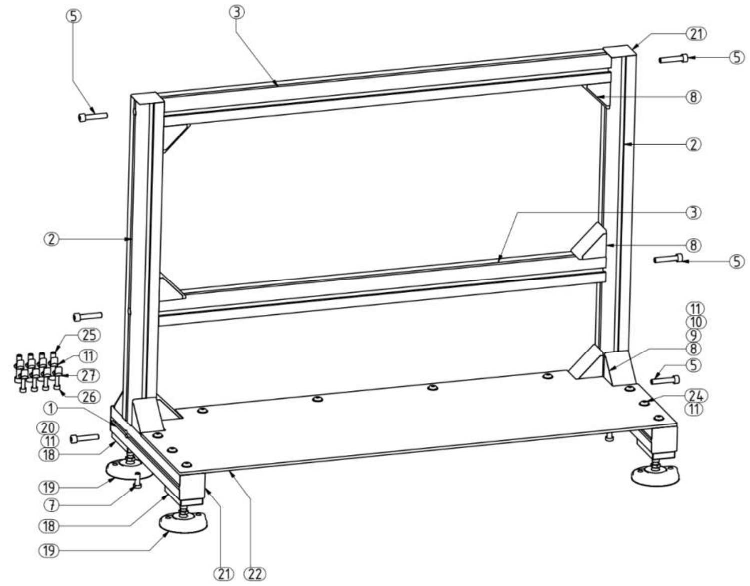

Fig. 2. The executive drawing of the laboratory station

An element supporting the encoder sensor was mounted to the axis, thanks to which the sensor moved along with the actuator. At the beginning this element was made of steel angles. In order to achieve a better presentation, the own supporting element for the encoder sensor was designed using the Siemens NX 10 system and made in 3D printing technology. It is presented in Fig. 3.

Fig. 3. Design of the element supporting the encoder's sensor

The element was made in the FDM technique on a 3D MakerBot printer. It was made of ABS material which is characterized by high hardness and impact strength compared to PLA. The print fill was 40%, the layer height was 0.75 mm. The ready to use laboratory stand is presented in Fig. 4.

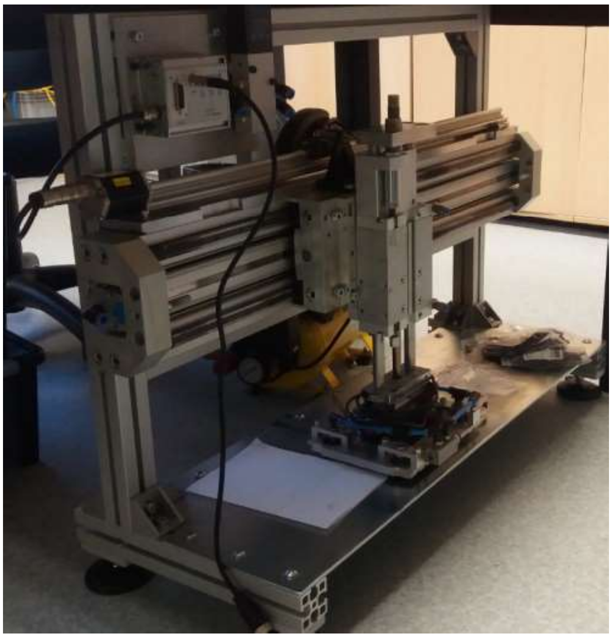

Fig. 4. The ready to use laboratory stand

The station is controlled by a Siemens S7-1200 PLC controller and the Siemens Comfort Panel 1500 operator panel. A compact controller has been used, which has built-in outputs and digital inputs. In addition, the unit has been equipped with a module that extends the number of digital outputs. The controller has two built-in PWM generators and high-speed HSC counters for counting pulses from the encoder. In addition, the unit is equipped with a PROFINET interface. Using the PROFINET interface, the controller is connected with the

HMI touch panel, by means of which the work visualization is displayed. The PROFINET interface also loads the driver program from the computer.

The S7-1200 series driver cooperates fully with the TIA Portal programming platform (Totally Integrated Automation) [9]. A program for the Siemens S7-1200 controller that supports two operating modes was written. The first mode is manual mode, in which single operations are performed by the user through the HMI panel. It is possible to move the horizontal axis to one of the predefined positions. Displacement of the vertical axis and twisting the base. The automatic mode includes four sequences of movements performed in a loop until the sequence execution is interrupted or another automatic program is selected.

Figure 5 shows the visualization made on the HMI panel. The panel has buttons for handling automatic sequences and for performing individual operations in manual mode. The drawing of the station with the indicators signalizing the position of the manipulator on it is also shown.

Four programs of automatic sequences were written. Each sequence consists of elementary tasks performed by pneumatic axes. A submission of movements performs a specific task.

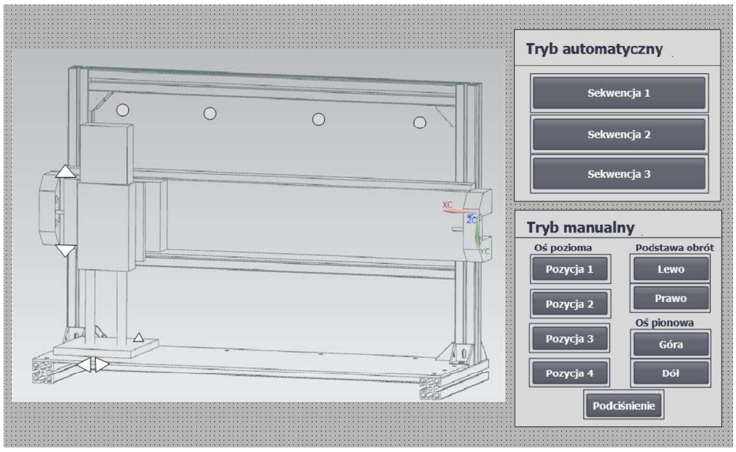

Fig. 5. The visualization made on the HMI panel

3. Conclusions

The proportional technique in pneumatics gives a wide range of applications in many industries, as well as finds its application in medicine. The biggest advantage of proportional control is the possibility of smooth flow or pressure control, which is not possible in conventional pneumatic or electropneumatic systems. The biggest obstacle in the use of proportional pneumatic systems is the high cost of control elements. Controlling proportional elements requires complex control algorithms based on m.in. genetic algorithms, fuzzy logic, neural networks. This is due to the nonlinearity problems of converting compressed air energy into mechanical energy of actuators, where the high compressibility of the air in combination with the static friction on the actuator's piston causes large problems with positioning. Proportional valves are controlled by analog signals, where at the output of the control element a direct proportional signal is obtained in the form of pressure or air flow. In electropneumatics, the control is carried out only by digital signals, which is much less flexible. The control based on Boolean logic does not give the same flexibility as in the case of continuous control. The laboratory stand was developed to bring these issues closer in the didactic process as well as to conduct research on pneumotronic propulsion systems.

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