International Journal of Modern Manufacturing Technologies
ISSN 2067–3604, Special Issue, Vol. XII, No. 3 / 2020

PNEUMATIC ELEMENTS OF MACHINES TOOLS

Andrzej Wróbel

Silesian University of Technology, Faculty of Mechanical Engineering, Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Konarskiego 18A, 44-100 Gliwice, Poland

Corresponding author: Andrzej Wróbel, andrzej.wrobel@polsl.pl

***Abstract**:* In this manuscript, pneumatic actuators working as subassemblies and assemblies of machines tools with precise adjustment of parameters such as force or displacement which have been tested.
Currently, modern manufacturing technologies often use machines tools equipped with programmable logic controller (PLC) and regulators. The process of regulation itself is a well-known topic. The case became more complicated if there is a need to obtain the components position using compressed air.
The adjustment of the position of the rodless double-acting pneumatic cylinders with the use of proportional-integral-derivative controller (PID) controller and visualization was subjected to a detailed analysis. Pneumatics is a field of technology dealing with the use of gases (usually air) as a medium transferring energy or information. Due to the type of medium, the problem of exact positioning causes a lot of trouble, because the gases structure is treated as compressible liquids. For the exact positioning of pneumatic drives, various types of position sensors or regulators are used to determine the position with high accurately. The mere application of the regulator does not change the operation of the system, however, it should be properly configured and the appropriate settings should be made. The main purpose was to carry out tests for measuring the position of the pneumatic rodless actuator, using a proportional valve, PLC Siemens S7-1200 controller and the computer program "TIA Portal".
Key words: manufacturing, automation, control, production control, PLC

1. INTRODUCTION

The beginning of the 20th century is assumed as the date of the appearance of PID regulators. Initially, they were used to solve problems with the steering of sea-going ships, but due to their universality, they more and more often play an important role in all processes that require regulation. Currently, regulators based on the technique of predictive and adaptive regulation as well as fuzzy logic are being developed more and more often. And although regulators have been present in automation for so many years, there is still no universal method of selecting their settings. In the literature, there are numerous tips regarding the calibration of regulators, but in practice it is a tedious process and requires both theoretical and practical experience. Automation allows you to increase the efficiency of production lines, improve the quality of products, reduce the amount of waste, and increase the safety of employees, with a relatively quick return on investment. Industrial automation is a very extensive issue, including:

- use of PLC controllers, PID controllers, electropneumatic control systems,
- robotization of enterprises,
- implementation of management systems for the entire enterprise,
- use of CAx systems
- use of industrial networks to transmit information,
- visualization of industrial processes.

One of the listed elements of enterprise automation are controllers and regulators. In general, we can divide the control process into open-loop control and closed-loop control, i.e. in a feedback system (regulation). The first type of control (in open circuit) can be used mainly when it is possible to predict exactly the resulting control effects. Such control is effective and sufficient in many applications.
In practice, however, the control system is influenced by external disturbances, moreover, the controlled object itself shows some variability (so its description or model is not accurate).
Pneumatic linear or angle actuators used in industry are very often used due to their numerous advantages. Among them, it is worth mentioning:

- simple construction,
- cheap components,
- meets explosion-proof standards and ensures safe operation of machines,
- no electromagnetic interference,
- light weight,
- low failure rate.

Listing the numerous advantages of pneumatic systems, one cannot forget about a few disadvantages that the designer must take into account when choosing the type of drive:

- air compressibility,
- lower forces than in the case of e.g. hydraulics,
- high operating costs,
- difficulties in achieving a smoothly variable position of the piston rod.

One of the disadvantages mentioned is the problem with stopping motion in pneumatic systems.
It is possible to stop the piston rod of the pneumatic actuator while it is moving, and for this purpose, directional valves of 5/3 or 4/3 function are used, shown in Figure 1.

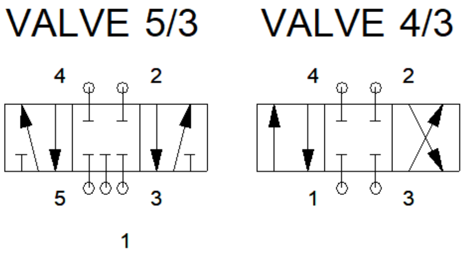

Fig. 1. Diagrams of valves that allow stopping the actuator position [9]

However, practice shows that this stop is not precise, and it is mainly due to the compressibility of the air. Another way to maintain the position of the air cylinder is to use a brake to stop the cylinder rod at any point in its stroke. The force locking the piston rod is always greater than the force of the compressed air actuator. The piston rod brake (Figure 2) of the pneumatic cylinder can be mounted directly on the cylinder as a complete set or delivered as a separate element. However, the presented methods of detention cannot be treated as the so-called positioning.

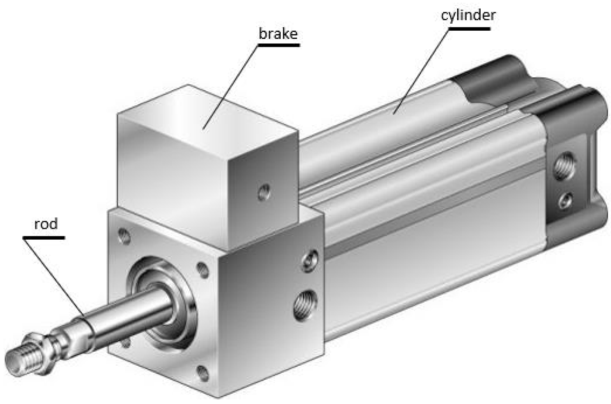

Fig. 2. Pneumatic cylinder with brake [9]

The actuators are widely used, among others on production lines, in pneumatic presses and on lines for packing finished products. They are ofteen found as components of production machines, used in product input or output warehouses, delivering material to manufacturing machines. Pneumatic cylinders with a brake have the ability to block and hold the position, which makes it possible to very precisely achieve and maintain the advance.
Due to the type of medium, the problem of precise positioning causes many problems, because gases, due to their structure, are treated as compressible liquids. In order to improve the positioning accuracy, various types of position sensors and regulators are used. However, the use of the controller itself does not change the operation of the system, it still needs to be properly configured and appropriate settings selected.
The subject presented in this article is one of the activities undertaken at the Department of Automation of Engineering Processes and Integrated Manufacturing Systems at the Faculty of Mechanical Engineering of the Silesian University of Technology [3-7,11].

2. PID CONTROL IN PNEUMATIC SYSTEMS

PID regulators are built of blocks that enable the performance of three mathematical operations; proportional, integral and derivative block. Each of them plays a different role in the control system, and the whole allows for effective reduction of the error value, causing the system to be had in the way we expect. Figure 3 shows a diagram of the control system.

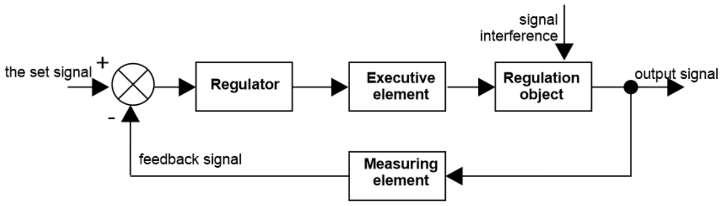

Fig. 3. Diagram of the regulator's operation

The signal generated by the controller is transferred to actuators that directly affect the control object. We can see that the control object is also influenced by other external signals, so-called disturbances. As a result of the measurement, the control effect through the use of a feedback loop is sent to the summation node, thanks to which it is possible to correct the signal.

3. METHODS AND EQUIPMENT

This article presents the process of selecting parameters in the process of adjusting the position of a rodless actuator, using the MPYE-5-M5-010-B pneumatic valve, Siemens S7-1200 PLC controller and the TIA Portal programming environment. The utilitarian goal is to carry out research to select the PID controller settings, under the following assumptions:
- shortest possible reaction time of the actuator to changes in position setting;

- positioning accuracy at the level of 2mm;
- system stability;
- presentation of the influence of control settings on the system behavior.

Figure 4 shows a laboratory stand where the selection of PID controller parameters was tested. They are equipped with a Siemens S7-1200 controller, which acts as a regulator, an HMI panel that allows you to generate graphs and set the value set by the operator.

Fig. 4. Stand for testing the selection of the adjustment parameters of the pneumatic actuator

The laboratory stand used for the tests was equipped with a piston-free, double-acting, powered pneumatic actuator with 0.6 [MPa] and with a stroke of 300 mm. The air flow was controlled by the proportional air flow rate MPYE-5-M5-010-B from Festo (Figure 5).

Fig. 5. View of the proportional valve MPYE-5-M5-010-B

The designations in the drawing indicate successively:
MPYE- Proportional directional control valve,
5 - 5/3-way valve,
M5 - Thread M5,
010 - Analogue voltage signal 0-10V,
B - series B.
The role of the feedback in the laboratory stand is signal with a value of 0 to 10 [V] generated from the MIC 130+ IU / TC ultrasonic sensor by Microsonic (Figure 6).

Fig. 6. Ultrasonic position sensor

The sensor works in the range from 200 to 1300 mm, so it is located at a distance of 200 mm from the actuator so that it is within the sensor operating area. The analog output of the sensor is connected to the analog input of the PLC controller. During operation, in order to provide the correct reading, the sensor's working range was calibrated from 200 to 500 mm. The last - the most important device used in the system is a Siemens PLC controller, model S7-1214 DC/DC/DC. To enable the connection of a proportional valve, an analog output module was also used. During the control process, the output signal generated by the controller is sent to the proportional valve, which extends the actuator. At the same time, the movement of the actuator is recorded by an ultrasonic sensor. Thus, a signal difference between the set signal value and feedback signal, a so-called control error is obtained, in the summation node according to Figure 3. This signal causes a correction in the controller.

4. SELECTION OF PID CONTROLLER SETTINGS

The selection of appropriate controller settings is a key element of the control system, because the knowledge of the system's response to the input and its appropriate correction contributes to faster and more accurate achievement of the set goal. Among the methods of selecting settings, the following are distinguished:

- manual tuning,
- Ziegler - Nichols methods,
- Cohen - Coon method.

In general, the operation of the PID controller is defined by the equation (1) [7,8]:

$$u(t) = K_p \left[\varepsilon(t) + \frac{1}{T_i} \int_0^t \varepsilon(t)\, dt + T_d \frac{d\varepsilon(t)}{dt} \right], \quad (1)$$

where:
K_p - gain of the proportional part P;
T_i - the time of doubling the integrator I;
T_d - time of the derivative term D.
The block used in the PLC named PID_Compact is characterized by the action defined by the formula:

$$y = K_P\left[(b\cdot w - x) + \frac{1}{T_I\cdot s}(w-x) + \frac{T_D\cdot s}{a\cdot T_D\cdot s+1}(c\cdot w - x)\right], \quad (2)$$

where:
y - output value;
x - current value;
w - set value;
s - Laplace operator;
K_p - gain of the proportional part P;
a - integration delay factor;
b - weights of proportional action;
c - weights of the derivative action;
T_I - time of doubling the integrator I;
T_D - lead time of the derivative term D.

4.1 The first method of Ziegler - Nichols

This method consists in determining the approximate solutions of the step response parameters. Inertial systems very often have a step response that looks like in Figure 7.

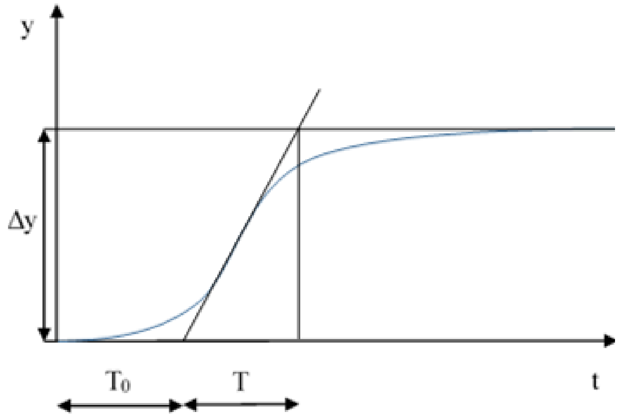

Fig. 7. Step response of the inertial system

The selection of settings consists in inserting the tangent to the step response Δy at the inflection point and reading the time constant T and the delay T_0. Then, one should adopt the settings, which for the PID controller are defined by the equations [8, 9]:

$$K_p = 0.35\cdot\frac{T}{T_0} \quad (3)$$

$$Ti = 2.4\cdot T_0 \quad (4)$$

$$Td = 0.4\cdot T_0 \quad (5)$$

It is estimated that the system will strive for stability over time $5.5T_0$ [8, 9].

4.2 Selection of settings on the laboratory stand

At the beginning, the system was opened (i.e. the feedback was turned off) and its step response was determined at the maximum opening of the valve. Using the trace function, the graph shown in Figure 8 was obtained, on which the tangent was then drawn and the parameters T_0 and T were determined.

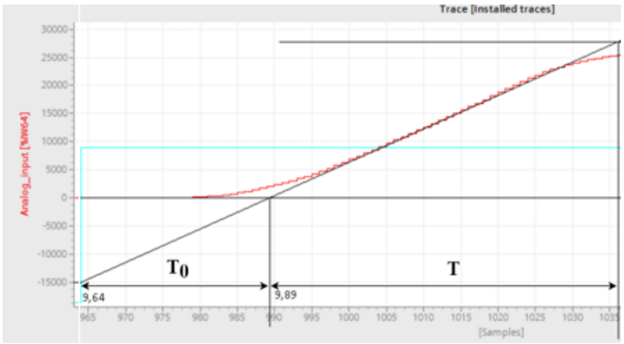

Fig. 8. The open system response in the Ziegler-Nichols method

For the given step response, the values T_0=0.25s and T=0.47s were read. Then both parameters were substituted into formulas (3-5) and the results were obtained:

$$K_p = 0.658,$$
$$T_i = 0.6,\ \ T_d = 0.1.$$

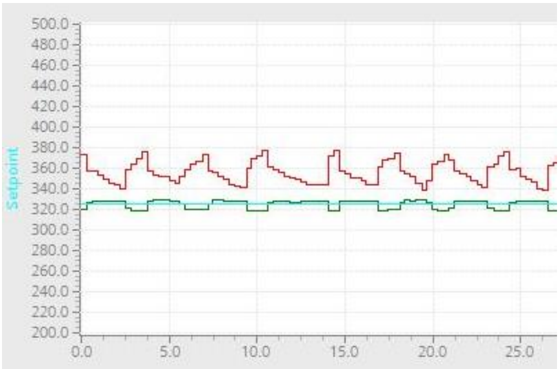

Fig. 9 Obtained the first result of the adjustment Ziegler - Nichols

On Figure 9 the behavior of the system with the use of settings calculated with this method was presented. The actuator was subjected to oscillations with an amplitude of about 3 mm, i.e. the positioning error was about 1%.

4.3 The second method of Ziegler - Nichols

This method consists in bringing the system to the limit of stability (Figure 10), i.e. until in which the system oscillates with a constant value. To do this, turn off the integral and derivative components of the controller by entering the controller settings value equal to 0 in the TIA Portal application, and then gradually increasing the proportional gain value until oscillation occurs. When they occur, the value of the proportional gain is assumed as critical Kkr, and then the period of critical vibrations Tkr is read.

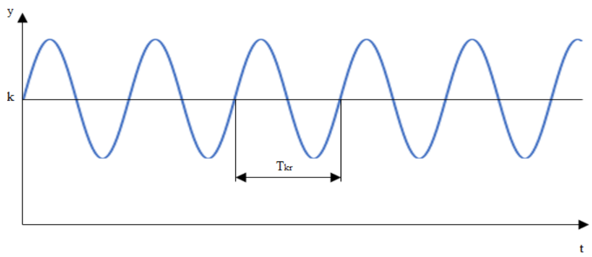

Fig. 10. System brought to the limit of stability

In the next step, the settings corresponding to the given type of controller are adopted in accordance with the recommendations given in Table 1.

Table 1. Settings corresponding to the regulator type

Regulator type	Optimal controller settings		
	K_p	T_i	T_d
P	$0.45K_{kr}$	-	-
PI	$0.45K_{kr}$	$0.85T_{kr}$	-
PID	$0.6K_{kr}$	$0.5T_{kr}$	$0.125T_{kr}$

The advantage of this method is that it can be used without the need to recognize the dynamic characteristics of the system [1, 2, 8].

4.4 Selection of settings on the test stand

First, the influence of the integrating element and the derivative element were turned off in the system by setting both values to 0, and then the value of the proportional element was gradually increased. With the value of Kp = 0.82, the system vibrated shown in Figure 11.

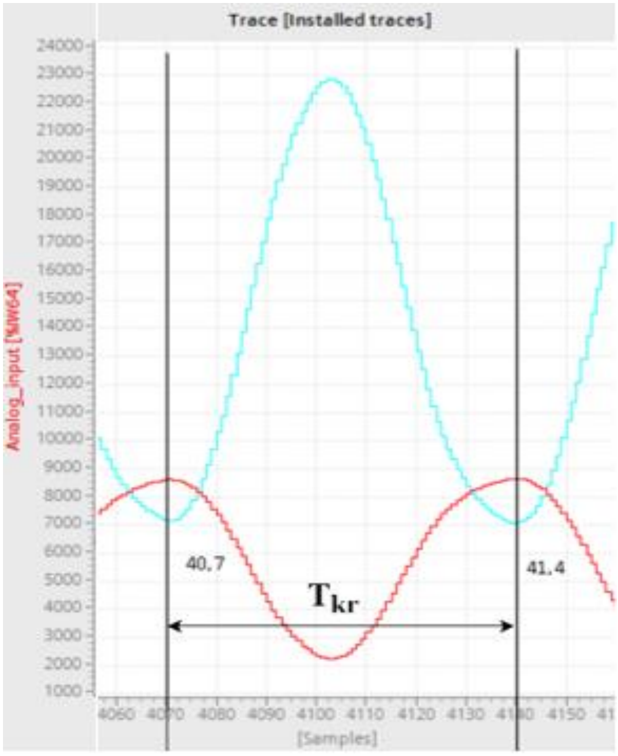

Fig. 11. Critical vibrations during the II Ziegler-Nichols method

On the basis of the obtained graph, T_{kr} = 0.7 s was determined, and then the data was substituted into the formulas presented in Table 1 and the settings were determined:

$$K_p = 0.492,$$
$$T_i = 0.35,$$
$$T_d = 0.0875.$$

The system, similarly to the first Ziegler-Nichols method, started to vibrate, but with much larger amplitude, around 9 mm, i.e. the positioning error was around 3% (Figure 12).

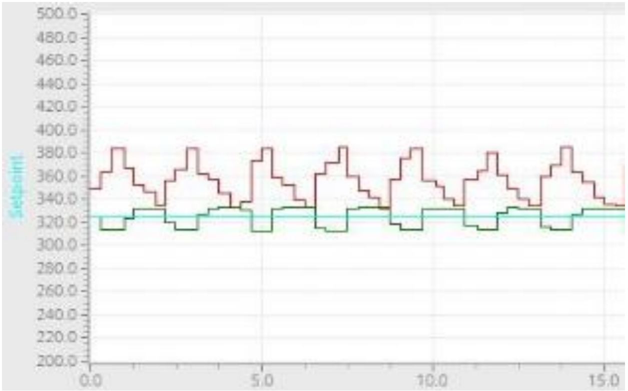

Fig. 12. Results obtained from the 2nd Ziegler-Nichols method

5. SIMULATION OF THE SELECTION OF SETTINGS IN THE FLUIDSIM-P PROGRAM

The FESTO FluidSIM-P application allows you to create a system simulation model together with the use of a proportional valve and PID controller. This tool is an excellent teaching and research environment to help understand the impact of PID controller settings on system behavior. To create a model of this project, you need to build a pneumatic system, and then add control using electronic components, a PID regulator and a voltage generator (Figure 13).

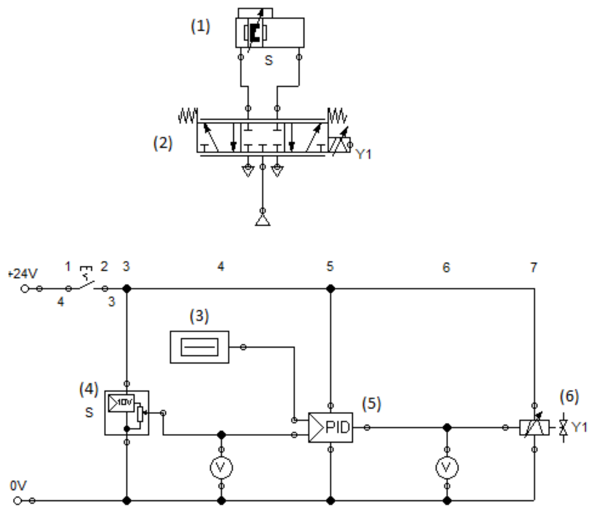

Fig. 13. The circuit diagram made in FluidSIM-P

On Figure 13 the components of the system by numbers were presented:

(1) - double-acting rodless cylinder,
(2) - electrically operated proportional valve,
(3) - voltage adjuster (it is used to select the position setting),
(4) - position encoder (performs the position sensor reading function),
(5) - PID controller,
(6) - proportional valve coil.

The setting of the position is changed by pressing the voltage adjuster (3) once and changing the position of the y offset parameter slider. To enter the settings for the PID regulator, press it and enter the appropriate values in the fields Proportional Gain KP, Integral gain KI and Derivation gain KD.

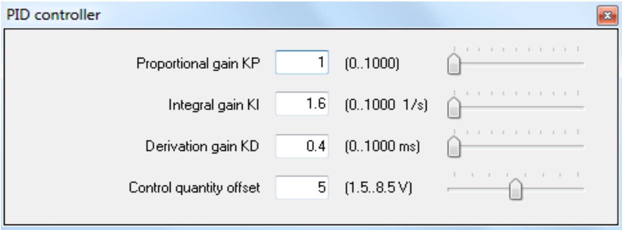

Fig. 14. Parameter window of the PID controller with final settings

As a result of the simulation of the pneumatic system shown in Figure 13, with the consideration of the parameters as in Figure 14, a diagram of the double-acting cylinder position adjustment was obtained (Figure 15). It was noticed that the time to reach a fixed position is shorter than 1s, which met the assumptions.

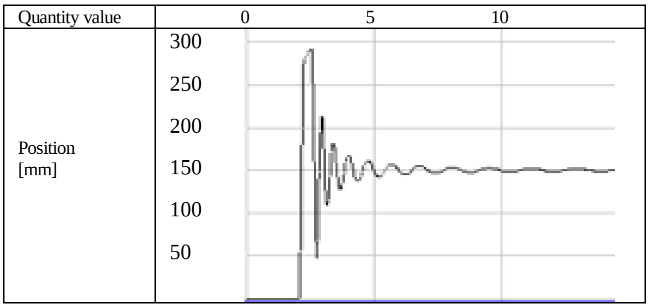

Fig. 15. The simulation result for the settings obtained by the manual tuning method

Figure 15 shows a diagram of the pneumatic actuator position in the time domain. The time is shown in seconds and the current position in mm.

6. CONCLUSIONS

The article attempts to present the selection of PID controller settings in order to achieve a specific position of a double-acting actuator. Due to the high possibilities of process automation, controllers with PID blocks and the regulators themselves are often used in modern production. Despite the fact that regulators have been used in automation for many years, there is still no universal method of selecting their settings. In the literature, there are numerous tips regarding the calibration of regulators, but in practice it is a tedious process and requires both theoretical and practical experience.

This article is an attempt to present the necessary information for the correct selection of the regulator settings in the adjustment process of a double-acting pneumatic piston-less actuator, taking into account the achievement of the intended position.

The article also presents the possibilities of using the FluidSIM-P computer program in the study of the impact of individual PID controller settings.

7. REFERENCES

1. Łaszczyk P., Niedźwiedź M. (2014). *Implementation and testing of the PID control algorithm in Simatic S7-300 / 400 series controllers*, Publishing House of the Silesian University of Technology, Gliwice [in Polish].
2. Skoczkowski S., Osypiuk R., Pietrusewicz K. (2006). *Robust PID regulation with two degrees of freedom*, Polish Scientific Publishers PWN SA, Warsaw [in Polish].
3. Płaczek M., Buchacz A., Wróbel A. (2015). *Use of piezoelectric foils as tools for structural health monitoring of freight cars during exploitation*. Eksploatacja i Niezawodnosc – Maintenance and Reliability; **17**(3): 443–449.
4. Wróbel A., Buchacz A., Płaczek M. (2016). *Selection of the geometric and materials parameters in piezoelectric sensors level*. Vibroengineering PROCEDIA, **10**, p. 277-281.
5. Wróbel A. (2019). *The use of intelligent materials as components in the construction of machines*. International Journal of Modern Manufacturing Technologies, Special Issue, **XI**(3), ISSN 2067–3604.
6. Wróbel A., Kruk P. (2019). *Analysis of the possibility of using autonomous aircraft to deliver parcels-route optimization*. International Journal of Modern Manufacturing Technologies, **XI**(2), ISSN 2067–3604.
7. Wróbel, A. (2012). *Kelvin Voigt's model of single piezoelectric plate*, Journal of Vibroengineering, **14**(2), pp. 534-537, ISSN 1392-8716.
8. https://www.automatyka.siemens.pl/docs/docs_ia/Siemens_easy_book_2014.pdf, Accessed on 15.07.2020
9. https://automatykab2b.pl/technika/46618-strojenie-pid-metody-doboru-nastaw-czesc-1, Accessed on 15.07.2020.
10. http://pneumat.com.pl, Accessed on 1.08.2020.
11. Płaczek, M., Wróbel, A. (2017). *Determining the Response of Piezoelectric Sensors Working as Sensors of Freight Wagon Construction*, Proceedings of the 13th International Scientific Conference Computer Aided Engineering, Editors: Eugeniusz Rusinski, Damian Pietrusiak, Springer International Publishing.
12. Fradinho, J., Nedelcu, D., Gabriel-Santos, A., Gonçalves-Coelho, A., Mourão, A., (2015). *Some trends and proposals for the inclusion of sustainability in the design of manufacturing process*, IOP conference series: Materials science and engineering 95(1), 012142.

Received: August 07, 2020 / Accepted: December 20, 2020 / Paper available online: December 25, 2020 © International Journal of Modern Manufacturing Technologies