EXAMINATION OF THE PNEUMATIC SLIDE VALVE DUE TO THE SAFETY OF PNEUMATIC DRIVES

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Abstract: The work deals with safety issues in industrial pneumatics. Standards and directives regarding the safety of pneumatic drives are discussed and tests of the pneumatic slide valve on the created laboratory stand were carried out. During the tests, the influence of valve unused time on its response time was determined. The value of the minimum operating pressure and its influence on the valve switching time were investigated. The obtained results were confronted with the manufacturer's data and analysed for the safety of pneumatic systems. During the tests, a 5/2 solenoid slide valve with a 24V DC coil was used. The aim was to prove the negative impact of the time duration in which the valve was unused on its operation and the time of activation.
Key words: Pneumatics, safety, testing, slide valve, switching time, valve idle time.

1. INTRODUCTION

Security-related issues are important in every branch of modern industry. Unfortunately, there are accidents that are often caused by the fault of the user or designer of a specific solution or system. It is for these reasons that individual devices and systems of devices are created, which are to prevent any dangerous situations as much as possible. The subject of safety in the broadly understood pneumatics is the most up-to-date and constantly developed along with the emergence of new solutions. More and more demands on reliability and work safety are applied for modern automation systems in which pneumatic solutions are applied. When talking about industrial pneumatic systems, the wide functionality of their application should be emphasized.

The issues of safety and reliability of modern production systems are extremely important in the modern world, especially in terms of the concept of the Industry 4.0. The idea of the concept is based on limiting the participation of people in production processes and further development of modern mechatronic devices and systems based on, among others, the use of so-called Internet of Things. The reliability and safety of use of this type of modern solutions is now becoming the key issue and challenge facing engineers. Development and application of this type of equipment, in which at the same time innovative materials, including composites, or the so-called smart materials are used lead to effects that have never been achieved before. These systems allow, among others, optimization, better energy efficiency and efficiency of both production processes and the technical means themselves that are available nowadays [2, 6, 9, 12].

The work deals with safety issues in industrial pneumatics. During the tests, a 5/2 solenoid slide valve with a 24V DC coil was used. The aim was to prove the negative impact of the time duration in which the valve was unused on its operation and the time of activation. In order to automate tests, the laboratory stand was created. It consists of the Power Panel 520 produced by the B&R Automation with a touch screen, performing the role of a PLC controller, a signal simulator and input/output modules. A digital output module was used to excite the solenoid coils. In order to be able to read the current pressure, a pressure transducer was used. In addition, visualization has been created on the touch panel to control the valve as well as to read the signals necessary to determine the characteristics. In order to read the characteristics and determine the characteristic points, internal Trace tools were used in the B&R Automation environment.

2. SAFETY IN PNEUMATIC DRIVES

The topic of safety in broadly understood pneumatics is the most current and is constantly developing with the emergence of new solutions. Automation systems, where pneumatic solutions are used, are increasingly demanding. When talking about industrial pneumatic systems, it is worth bearing in mind also the wide functionality of using them for hydraulic or electric systems. The control and energy part make up the construction of the pneumatic system. The first of these tasks is to receive and process signals. In the second part, on the other hand, signals from the control part are amplified, and then using components such as valves, for example, generate mechanical work of the actuators. When considering such systems, one should not forget to highlight the advantages and disadvantages arising from their use. The advantages certainly include the working factor (air), which is an easily accessible and friendly medium also in relation to the environment. It is worth noting that pneumatic devices show low sensitivity to factors such as temperature fluctuations, electromagnetic effects and various types of radiation. Additionally, they can be used everywhere where there is a risk of explosion. Another positive feature is the possibility of stepless adjustment of speed and force as well as resistance to overloading. Pneumatic drives are characterized by high durability, while having a low weight in relation to the power unit. However, they are not free from defects. They require the use of additional devices, such as pressure reducers, dryers and silencers. Nevertheless, when confronting the pros and cons, it can be said that a lot of advantages affect the wide application of pneumatics in industry.

One of the many strategies to take care of safety as well as to minimize dangerous events is to use remarks contained in various types of standards and directives. Also, in the field related to industrial pneumatics, all rules and restrictions are contained in such documents as:

• Machine safety - Safety related components of control systems (EN ISO 13849-1: 2015). The security features mentioned in this document are a very important topic, covering issues such as: stop function, manual reset function, start function, local control function, muting function, operation time, parameters or power outages.

• Pneumatic drives and control - General principles for systems (PN EN ISO 4414). The standard contains general principles adopted for pneumatic systems used in industry. The main task is to ensure safety, trouble-free operation, ease of use and high durability of the system, through such elements as: safety requirements, environmental conditions, proper system design, preparation of compressed air, lubrication etc.

• Requirements for the safety of hydraulic and pneumatic systems and their components (PN EN ISO 983);

• Hydraulic and pneumatic drives and control, nominal pressures (PN EN ISO 2944).

A review of the literature on a topic related to safety is important because it shows the problems and requirements that today's industrial pneumatic systems are facing. This gives a clear view of what to emphasize, what to avoid, and what requires additional research and continuous development.

One of the articles which presents solutions in safe industrial pneumatics is the publication [4]. This work presents the approach to the safety problem recommended by the standards described earlier, as well as the positive aspects of using certified components. The authors emphasize the differences between the norm and the directive, which are not always noticed. A standard is a principle of good practice or conduct, except that its application is not required. In turn, directives are pre-imposed rules and conditions of conduct applicable in all EU countries. It is worth emphasizing that even by complying with all standards and directives, risk cannot be 100% excluded. In any case, however, it is worth minimizing them.

Certified devices or components greatly facilitate the work of designers, and then with great ease give the ability to calculate the level of safety of the entire machine. The certificate is nothing other than giving the class Performance Level (PL). The whole procedure allows setting the PL level, but it is very time consuming. Therefore, the use of certified elements with PL assigned significantly affects the time of the design process, its accuracy and safety. The general issues related to the safety of pneumatic systems resulting from the directives PN-EN ISO 4414 and 2006/42 / EC are presented in article [3]. The statement that the main reason for the occurrence of dangerous events with pneumatic systems is the accumulation of compressed air energy is presented. Pressure that is usually found in industry can reach up to 10 bar. For this reason, it is necessary to use elements such as pressure reducing valves or safety valves, whose task is to limit and protect against too high pressure, not only the machine, but also the operators of the device. Those types of security elements are also described in article [5]. It describes how to properly design safe pneumatic systems. The authors indicate that it is necessary to start planning at the very beginning of the design and proper selection of system components is very important. All this to ensure maximum safety for people who later have contact with the device, as well as the machine itself. Conscious design extends trouble-free operation time and the chance of a fault is minimized. The author draws attention to such phenomena as unexpected pressure surges, pulsations or system behaviour during an emergency stop. It emphasizes the importance of using a reducing valve, safety valve and filter. In addition, it is important that the filter can automatically remove excess moisture, and the pressure regulator itself has an indicator showing the current state of pressure at the outlet. The publication also describes the principle of valve selection, along with their proper use. When using pneumatic cylinders, the author draws attention to safety during an emergency stop, and good practice of using cushions or bumpers. An extremely interesting solution is also a cracked line valve, which in the event of a failure limits the sudden pressure drop, thus preventing dangerous situations. The publication also identifies 4 states in which the pneumatic system may be found. These are the state of normal operation, the state of service and adjustment work, the state of failure and the state of readiness. Also interesting is the development of guidelines for the safe use of compressed air, as well as the elementary principles of choosing pneumatic elements.

Nowadays, engineers designing industrial pneumatics can use many programs that are helpful in designing safety systems. One of them is SAB (Safety Automation Builder) software, which allows design of simple and complex safety systems [7]. The environment includes libraries with products from well-known manufacturers, such as Allen-Bradley, which further affects the speed and simplicity of design. The whole algorithm mechanism is based on the EN ISO 13849-1 standard, which includes a chapter showing the individual stages of determining the level of security. The implementation of the project in the discussed environment is based on four steps:

- entering basic data and planning the system placement;
- arrangement of the system by moving the necessary elements together with determining the locations of threats;
- creating security functions by selecting I/O devices, specifying input data and creating logic;
- checking the design with the help of the SISTEMA tool, which results in obtaining a report with a marked security level.

The free SISTEMA tool is used to calculate the PL security level in accordance with EN ISO 13849-1.

The work [8] indicates how important in relation to the safe operation of the whole system is the conscious exploitation of solenoids. The author investigates the problem in which the solenoid valves are used for safety purposes and are activated when the device goes into a state of emergency. In this case, the valve is in most of the rest mode for most of the time, which causes friction and adhesion to become an obstacle. The friction between surfaces of cooperating solenoid elements after, for example, a monthly break in work is greater than in the valve actuating several times a day. The result is the need to overcome more friction than would be the case with a valve working more often. An important phenomenon is also the phenomenon of adhesion, which can occur between valve components. Assuming a long break in the operation of the valve, one should consider that with time there is adhesion between the seal located on the piston and the walls of the solenoid valve. The solenoid spring is designed with excess force to counteract friction as much as possible. Unfortunately, considering these phenomena, combined with too long resting time, even design with excess of spring force is not able to prevent bad operation. Engineers who work with solenoid valves confirm the existence of the problem in industry. The main culprit is a rubber O-ring that falls into the micro-grooves or unevenness of the solenoid cylinder, resulting in increased friction. According to the guidelines of the authors of the studies and the information contained in the EN ISO 13949-1 directive, the valve must be activated at least once a week in order to ensure safety rules.

Another, interesting way to increase safety are the methods of valve testing that do not affect the production process described in [1]. The Partial Stroke Testing (PST) method involves moving the valve about 10% forward and returning it within a short period of time and observing its response. Thanks to this it is possible to determine if the tested valve is blocked. It turns out that it is not necessary to check the valve in the whole range of its stroke, which would also prevent the continuation of the production process. All is needed to do is to perform the PST procedure, which allows to reduce the risk of blocking the valve by up to 80% without affecting the production process. In summary, by introducing to the system the PST system with respect to critical valves, greater safety in use and reduction of the risk of blocking are ensured. At the same time, it should be remembered that PST should be resistant to damage, safe in case of failure, should not falsify process data and should contain internal diagnostics.

Modern technical solutions should also be cited, which is the use of piezoelectric technology in pneumatic valves [10-12]. It is an alternative to currently used pneumatic valves. These types of modern valves are characterized by much greater control precision and repeatability. In addition, they are characterized by quieter operation, which produces less heat. They are dedicated to applications with high requirements, such as the medical industry or in the automation of modern laboratories.

The principle of operating of this type of valves is simple. The rectangular piezoelectric element deforms when the control voltage is applied, causing the valve switching. In addition, it is also possible to use piezoelectric stacks. They have the form of a circular disk, which, when applied the control voltage, increases its thickness at the expense of diameter. Stacks are characterized by high strength but small deformation at the level of 0.2% of the total thickness. Nevertheless, it is possible to use them in micro-positioning.

The advantages of valves with piezoelectric transducers do not end with the ones mentioned above. It should also be remembered that they have significantly lower electrical needs. Also, when calculating the degree of safety of a device equipped with these valves, a much better result can be obtained because of higher spark protection. Considering the speed of action, the superiority of piezoelectric devices, characterized by a switching speed of several microseconds, should also be recognized. An important feature is also a high level of reliability, which allows it to be used in higher-level control systems. Paramagnetic properties are another feature that positively affects a wide spectrum of use in environments with a high degree of electromagnetic

interaction. In addition, these types of valves are characterized by low weight and significantly reduced production costs.
Considering the issues presented above, an attempt was made to determine the switching characteristics of the slide valve and determine the impact of the valve's downtime on those characteristics.

3. ELECTROPNEUMATIC VALVE TESTS

During the tests, a 5/2 solenoid valve with 24V DC coils manufactured by Pneumax, model 488.52.0.0.M11, was used. The goal was to prove the negative impact of downtime at work and the value of the valve supply pressure on its operation time and operating characteristics. A laboratory stand has been used to automate the entire research process, which includes: power panel 520 with touch screen, acting as a PLC controller, signal simulator, I/O modules.
A digital output module was used to excite the coils of the valve. A pressure transducer was required to read the current pressure. The analogue input module can connect transducers with 4-20mA and 0-10V output signal. The 0-10V transducer was used during the tests. In addition, a visualization was developed on the touch panel to control the valve, as well as to read the signals necessary to determine the characteristics. In addition, the option of sending data using the DDE server to the EXCEL program was used. Due to the need to obtain the most accurate results possible, the characteristics and characteristic points were read using an internal Trace tool in the B&R Automation environment.
During the test, the effect of downtime on valve operation time was checked. A time interval of 2 months was selected. During this time the valve was disconnected from the system and was at the room temperature. Elements of the measuring equipment are: PNEUMAX 5/2 electropneumatic valve, DRTR-AL-10V-R10B pressure transmitter, shut-off valve and pneumatic silencer (see Figure 1).
During the tests, the time needed until the valve reached the output pressure equal to the pressure supplying the valve (6 Bar), as well as the time to reach 90% of this pressure was measured.

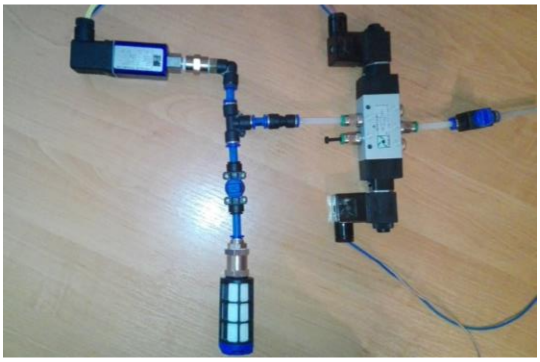

Fig. 1. Elements of the measuring equipment

The first switching time after feeding the left valve coil was recorded (the valve slider was in the left position during standstill) and the second switching time - feeding the right valve coil. During the tests, the valve was supplied with air containing oil mist introduced by means of a lubricator in the air preparation system. The obtained results were compared with valve switching times obtained after several dozen overload cycles. The pressure at the valve output as a function of time obtained during the first start-up after a two-month downtime is shown in Figure 2. The drawing indicates the point of the time to reach the nominal pressure at the valve outlet. Table 1 summarizes the measured times for obtaining the supply pressure and 90% of this pressure at the valve outlet in the case of the first and second valve switching after a period of standstill and the valve after working under normal conditions. The difference in valve response times is significant. The times of obtaining the nominal pressure at the outlet of the valve after a period of standstill are twice as high as in the case of the valve after working under normal conditions. It can be seen, however, that the time to reach 90% of the nominal pressure at the second valve switching is already close to the time obtained on the valve after working under normal conditions, while at the first switching the time to reach the set pressure level is more than six times longer. The results obtained are of great importance in relation to the safety of people and machines.

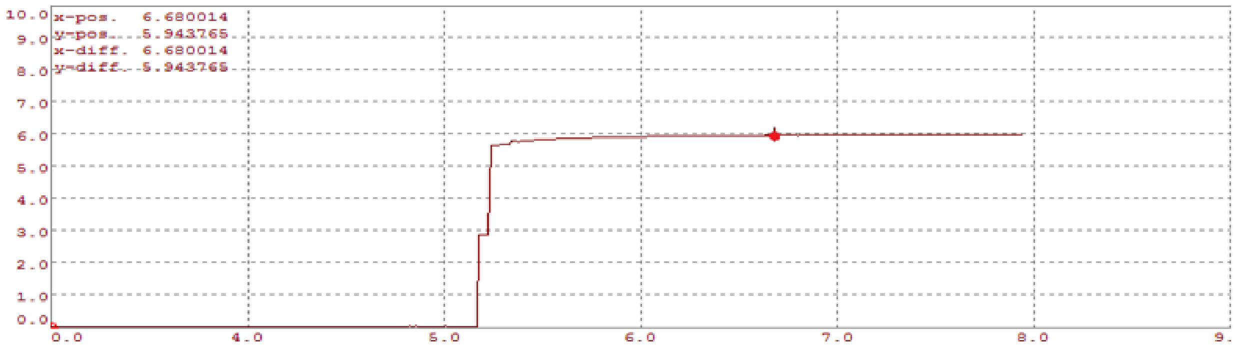

Fig. 2. Pressure at the valve output as a function of time obtained during the first start-up after a two-month downtime

Table 1. The valve switching time after 2 months of downtime and without downtime

	Time to reach steady state (nominal pressure at the output) [ms]	Time to reach 90% of the steady state (90% of the nominal pressure at the output) [ms]
The first switching (after 2 months of downtime)	1510.02	67.53
The first switching (without downtime)	800.01	9.54
The second switching (after 2 months of downtime)	1619.99	15.01
The second switching (without downtime)	924.63	12.50

During subsequent tests, the influence of the supply pressure of the tested valve on the time of reaching its value at the valve output was determined. The minimum supply pressure for the valve given by the manufacturer is 1.5 Bar. The tests were carried out at selected pressures in the range from 0.6 to 4 Bar. An example of obtained dependence of the pressure at the valve output as a function of time, with a supply pressure of 2 Bar is shown in Figure 3. In Table 2 the results of measuring the time to reach the steady state pressure at the valve output at different values of supply pressure are summarized. A significant increase in valve switching time is clearly visible as a result of the reduced supply pressure.

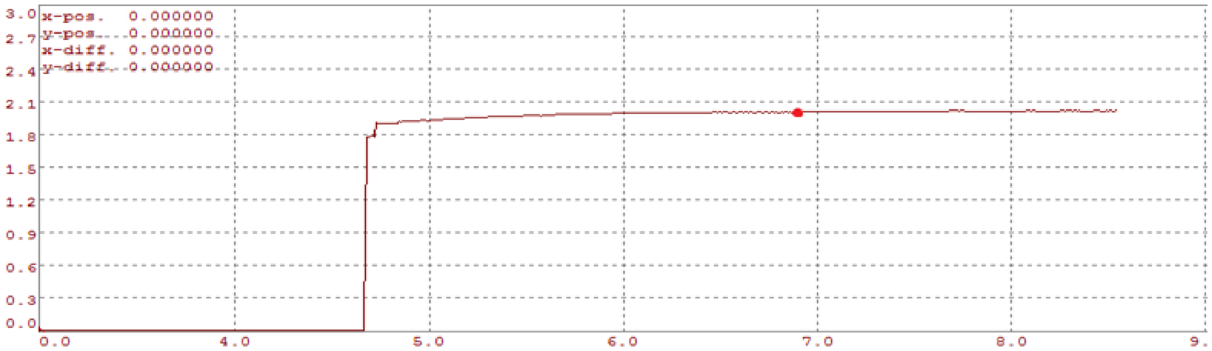

Fig. 3. The pressure at the valve outlet at a supply pressure of 2 Bar as the function of time

Table 2. Time to reach steady state pressure at the valve output depending on the selected supply pressures

Pressure [Bar]	Time to reach the steady state of the pressure, left side [s]	Time to reach the steady state of the pressure, right side [s]
4	1.25	1.625
3	2.275	1.875
2	2.125	2
1.5	2.1	2.15
1	2.95	2.336
0.84	3.5	2.653
0.6	3.55	3.898

The next step was to determine the effect of supply pressure on valve switching time. According to the manufacturer's data, the switching time of the tested 5/2 slide solenoid valve is 30ms. As part of the research, tests were carried out at 3 different levels of the valve supply pressure. A logic shuttle valve was used in the test stand, to which inputs were connected both outputs of the tested spool valve. The configuration of the measuring station is shown in Figure 4. Figure 5 shows an example of a time course of pressure at the output of the tested valve at a supply pressure of 2.1 Bar.

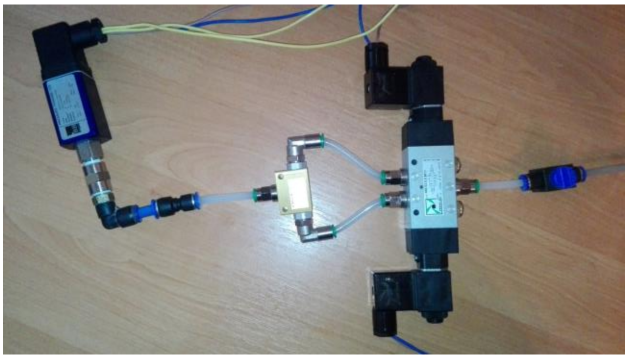
Fig. 4. Elements of the measuring equipment with a logic shuttle valve

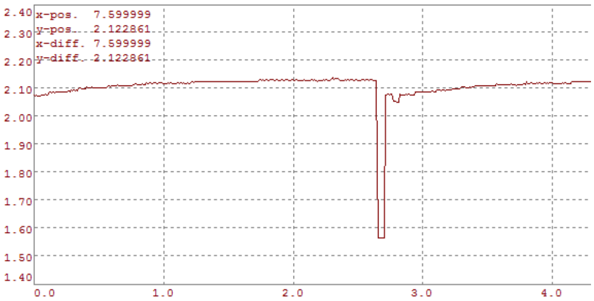

Fig. 5. Time course of pressure at the output of the tested valve at a supply pressure of 2.1 Bar

Table 3 summarizes the measured values of switching times, determining the switching time and the time needed to reach a steady state pressure at the valve output (pressure equal to the value of the supply pressure). One can see a marked extension of the measured values relative to the switching time declared by the valve manufacturer, which is the result of a decrease in the supply pressure.

Table 3. Switching time of the valve at different supply pressure values

Pressure [Bar]	Switching time [ms]	Time to reach the steady state of the pressure [s]
1.3	90	2.485
2.1	70.004	2.169
4	50.001	1.270

4. CONCLUSIONS

The reason for undertaking the electropneumatic slide valve tests described in the work was the extremely significant impact of the work characteristics of this type of elements on the safety of users of pneumatic drives, as well as the correct operation of systems in which such elements are used. The conducted tests showed that the manner of operation and ensuring proper working conditions of the solenoid valves have an extremely significant impact on the characteristics of their operation. In order to avoid the risk of errors and malfunctions of technological devices equipped with electropneumatic drive components, it is necessary to ensure both the correct value of the pneumatic system supply pressure and to eliminate fluctuations in this value, as well as to take into account downtime of the valves, which translates into the characteristics of their operation. As demonstrated during the tests, fluctuations in supply pressure and long downtime of the solenoids can significantly affect the characteristics of their operation, and thus contribute to the incorrect operation of the system and even the health and life threat of its users. In the event of long downtimes, some additional safety systems should be introduced, for example, the Partial Stroke Testing (PST) method consisting of periodically forcing the valve slider to move at a level of about 10% of its stroke in a short period of time and thus protecting against the effects of adhesion between the valve components resulting from its downtime.

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