Technologia i Automatyzacja Montażu

Volume 127, Issue 1/2025, Pages 62-73
https://doi.org/10.7862/tiam.2025.1.5

Original Research

THE WAY OF DETECTING LEAKS IN PNEUMATIC ACTUATORS ON THE EXAMPLE OF A SELECTED PRODUCTION SYSTEM

SPOSÓB DETEKCJI NIESZCZELNOŚCI SIŁOWNIKÓW PNEUMATYCZNYCH NA PRZYKŁADZIE WYBRANEGO SYSTEMU PRODUKCYJNEGO

Artur MACHA[1], Andrzej LOSKA[1,*]

[1] Department of Fundamentals of Machinery Design, Faculty of Mechanical Engineering, Silesian University of Technology, Konarskiego 18a, Gliwice, Poland

* Corresponding author: Andrzej.Loska@polsl.pl

Abstract

Compressed air is a very important energy medium in industrial processes. Leaks in pneumatic systems, inappropriate pressure, improper use of components, etc. are responsible for losses of produced compressed air. Pneumatic actuators, which are key in this respect, are exposed to internal and external leaks, which leads to an increase in their extension and retraction time, a decrease in the force achieved on the piston rod, and in the case of large leaks - to their stopping, causing a failure and necessary downtime of the machine or the entire production line. The article addresses the problem of leaks in pneumatic actuators used within automated production systems. The specificity of operation of pneumatic actuators, problems with their leaks, and available methods of their detection are discussed. For the needs of the tested production system, an original way for detecting leaks in pneumatic actuators was developed, the operation of which was verified using a simulation model in the Simulink environment. This way involves measuring the pressure value in individual pneumatic actuator supply lines with the compressed air supply from the source cut off. The pressure drop in the system and the position of the piston rod indicate the size of the leak and its location. The proposed solution allows for testing actuator leaks on the entire valve island using a single measurement point. The performed simulation analysis allowed to confirm the correctness of the developed way.

Keywords: pneumatic actuators, leak detection, simulation methods, Simulink

Streszczenie

Sprężone powietrze to bardzo ważne medium energetyczne w procesach przemysłowych. Nieszczelności w układach pneumatycznych, nieodpowiednie ciśnienie, niewłaściwe użycie elementów, itp. odpowiadają za straty wyprodukowanego sprężonego powietrza. Kluczowe w tym zakresie siłowniki pneumatyczne, narażone są na wycieki wewnętrzne i zewnętrzne, co prowadzi do zwiększenia czasu ich wysuwania i wsuwania, zmniejszenia siły osiąganej na tłoczysku, a w przypadku dużych wycieków - do zatrzymania ich pracy, powodując awarię i konieczny przestój maszyny czy całej linii produkcyjnej. W artykule podjęto problem nieszczelności siłowników pneumatycznych eksploatowanych w ramach zautomatyzowanych systemów produkcyjnych. Omówiono specyfikę działania siłowników pneumatycznych, problemy ich nieszczelności, a także dostępne metody ich detekcji. Dla potrzeb badanego systemu produkcyjnego, opracowan został autorski sposób detekcji nieszczelności siłowników pneumatycznych, którego działanie zweryfikowano przy użyciu modelu symulacyjnego w środowisku Simulink. Sposób ten polega na pomiarze wartości ciśnienia w poszczególnych nitkach zasilania siłownika pneumatycznego przy odciętym dopływie sprężonego powietrza ze źródła. Spadek ciśnienia w układzie i pozycja tłoczyska, świadczy o wielkości wycieku i jego lokalizacji. Zaproponowane rozwiązanie pozwala na badanie nieszczelności siłowników na całej wyspie zaworowej przy użyciu jednego punktu pomiarowego. Przeprowadzona analiza symulacyjna pozwoliła potwierdzić poprawność opracowanej metody.

Słowa kluczowe: siłowniki pneumatyczne, detekcja nieszczelności, metody symulacyjne, Simulink

1. Introduction

Compressed air is a colorless and odorless medium, so its leaks are difficult to notice. Air leakage is characterized by the generation of high-frequency sound, but the noise of other components of production machines effectively masks the acoustic effect.

About 75% of the cost of compressed air production is energy costs. The remaining costs are the costs of purchasing the compressor, dryer and other components (about 10-15%) and operating costs, which include spare parts, periodic services and repairs (about 10-15%). Leaks in pneumatic systems, inadequate pressure, improper use of components, etc. are responsible for losses of produced compressed air in the region of 20-30%, and in some systems even up to 60% (Whitlam, 2021). In the European Union, compressed air production is 10% - 30% of the total electricity consumption in industry (Radgen et al., 2001).

Pneumatic actuators, which are key in this respect are exposed to internal and external leaks, and this leads to an increase in the time of their extension and retraction, a decrease in the force achieved on the piston rod, and in the case of large leaks - to their work being stopped. The consequence of such a phenomenon could be a failure and necessary downtime of the machine or the entire production line. Incorrect operation of actuators may in some cases, cause product defects (Kalisch et al., 2014).

Effective leak detection of pneumatic actuators influences the systematic planning and implementation of preventive actions, shortening the time of unplanned downtime, reducing the consumption of compressed air and reducing the costs of electricity. Currently, there are being developed various methods and tools allowing for leak detection, However, implementing them in industrial practice requires making major changes to existing systems or purchasing expensive devices, the cost of which often exceeds the possible benefits for the company.

Taking into account the above arguments, the authors of this article presented the results of research on the problems of leaks in pneumatic actuators used in production systems. The effect of undertaken and completed works is developed original way of leak detection. The correctness of the developed way was verified in computer simulation conditions based on a model built for this purpose and data sets originating from a real production system.

The first part of the article presents the pneumatic specificity of double-acting actuators, as well as a review of leak detection methods used in industrial practice. Then, the research object – pallet loading station – Is presented. The main part of the article includes a description of the author's way of detecting leaks in the tested system, followed by an analysis of the correct operation based on a simulation model developed for this purpose. The article ends with conclusions concerning both the problem of leaks in pneumatic actuators and the developed way of detection.

2. Operation specificity of double-acting industrial pneumatic actuators

A pneumatic actuator is a device that converts the energy of compressed air into linear mechanical force and movement. It is a key component in both robotics and industrial automation thanks to the availability of compressed air in most industrial plants (Hu et al., 2018, Szenajch 2016). Pneumatic actuators differ in their design, ability to exert forces, force change during operation, number of positions, type of movement and connection of the driving element with the driven element (International, 2018, Kurmyshev et al., 2020). A typical pneumatic actuator consists of a cylinder with a moving element inside, i.e. a piston and a piston rod (Tomasiak, 2001).

Each cycle of operation of a double-acting pneumatic actuator consists of two movements – the extension of the piston rod and the retraction of the piston rod (Mahmoud et al., 2018; Fracczak et al., 2021, Parr, 2011). Fig. 1 shows the air flow paths during piston rod extension movement.

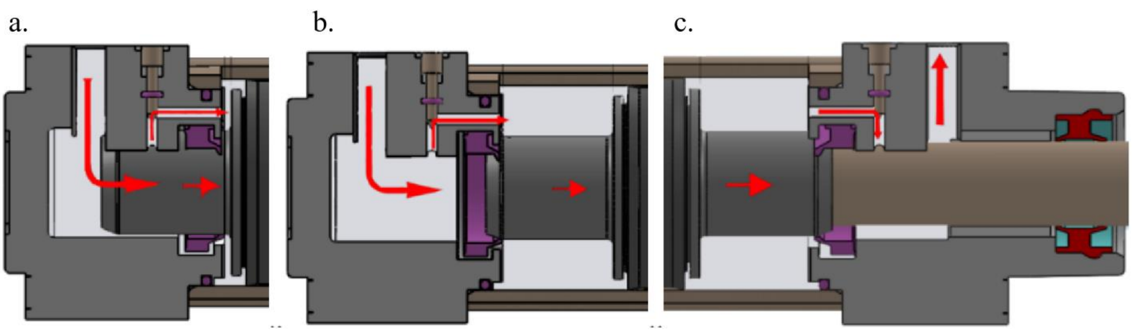


Fig. 1. Air flow during piston rod extension: a. piston start of movement, b. piston leaving the damping phase, c. damping phase start (Mahmoud et al., 2018)

During the extension of the piston rod, the valve is overdriven, which supplies air to the actuator port in its rear cover. Air passes through the return valve into the chamber, where the rear part of the piston is located. In the initial phase, called the damping phase, air first passes through the throttle valve into the compartment between the rear of the piston and the rubber ring, in the rear cover. Once the minimum required pressure is reached, which varies depending on the size and type of actuator, the piston begins to be pushed. When the piston moves back enough to be no longer sealed by the ring, air enters through the gap and its speed increases. Once a certain position is reached, the piston is sealed by a rubber ring in the front cover and air from the second compartment flows only through the throttle valve, causing a slow final movement and starting the next damping phase. During the entire movement, the air that previously filled the second compartment is discharged through the actuator connection in its front cover. After all the air has been pushed out, the piston reaches its final position and the piston rod is in its most extended position (Mahmoud et al., 2018; Fracczak et al., 2021, Parr, 2011).

Fig. 2 shows a stepwise diagram of the piston rod retraction movement.

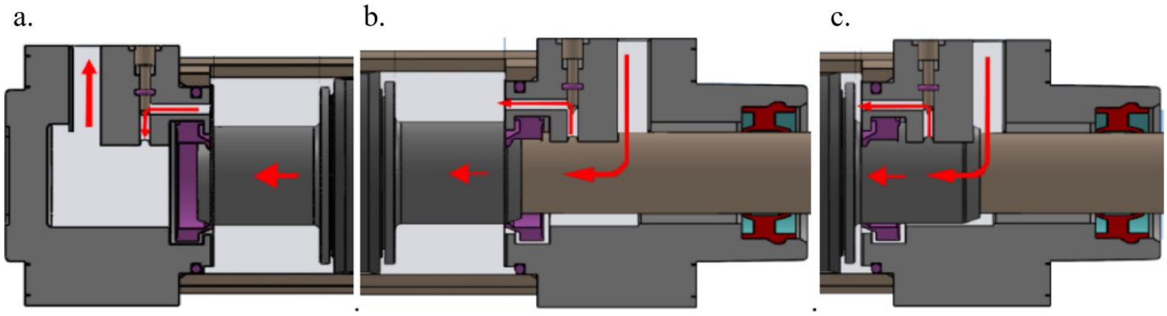


Fig. 2. Air flow during piston rod retraction: a. start of damping phase, b. piston leaving damping phase, c. start of piston movement (Mahmoud et al., 2018)

In order to retract the piston rod, air is supplied to the cylinder port in its front cover. The entire movement pattern is identical to that of extension, but the air flow is in the opposite direction. Once the appropriate pressure is reached in the front compartment, the damping phase begins and the air flowing through the throttle valve causes the piston to slowly move towards the rear cover. When the piston leaves the damping area, a rapid retracting movement of the piston rod begins, and after reaching the second damping area, a slow retracting movement of the piston rod occurs. After all the air has been pushed out of the second compartment, the piston reaches its final position and the piston rod is in the most retracted position.

To control the operation of a double-acting actuator, a two- or three-position five-way valve is required. The valve controls the direction of the compressed air flow and thus forces the appropriate movement of the actuator's piston rod. In the case of three-position valves, it is also possible to stop the piston rod in any middle position, however, due to the high compressibility of air, this position has low repeatability. Three-position valves are often used to protect against piston rod movement in the event of a safety circuit being interrupted, for example by opening a machine door. The valve is controlled by applying a digital signal to the appropriate solenoid valve coil, which causes air flow between the individual connections.

In each cycle of the actuator's work, there are two main forces – the pushing force and the pulling force. The values of these forces differ from each other, therefore the required forces must be determined appropriately so that the selected actuator meets the assumptions of the designed system.

$$F_{tc} = P \cdot \pi \cdot R^2 \quad (1)$$

$$F_{tr} = P \cdot \pi \cdot (R^2 - r^2) \quad (2)$$

where:
F_{tc} – theoretical pushing force [N],
F_{tr} – theoretical pulling force [N],
P – compressed air pressure [bar],
R – radius of piston [mm],
r – radius of piston rod [mm].

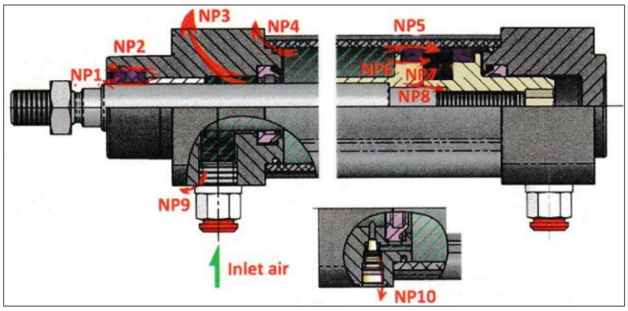
From formulas (1) and (2) it follows, that the pulling force of a double-acting actuator is less than the pushing force of this actuator. If the same pressure is applied to both compartments of the actuator at the same time, the piston rod will extend, because the pushing force will be greater. However, the useful force on the piston rod is different from the theoretical one. This is influenced by pressure changes during filling and emptying of the actuator compartments and friction forces occurring in the seals.

3. Leaks in pneumatic actuators – characteristics and methods of detection

Leaks are the basic and largest group of causes of pneumatic actuator failures. They occur most often at the sealing points of the connections between the elements in the pneumatic system. Seal damage causes leaks which affect the incorrect operation of the actuator itself, as well as increased compressed air consumption. Air leakage is uncontrolled, accidental and always undesirable. They can be eliminated by cyclical replacement of seals combined with early detection of air leaks (Jaafar et al., 2024; Loska et al., 2016, Sun et al., 2021).

Typical locations of air leaks during the piston rod retraction and extension phases are shown in Fig. 3.

a.



b.

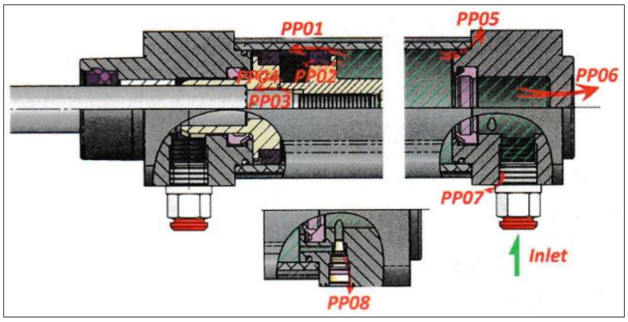


Fig. 3. Location of air leakage points during operation of the pneumatic actuator: a) the piston rod retraction phase, b) the piston rod extension phase (Parr, 2011)

Defects during the piston rod retraction were marked with the appropriate number and the letters NP (Fig. 3a), while defects during the extension were marked with the letters PP (Fig. 3b). Possible leak locations are due to the construction of the actuators.

Because of the large number of actuator seals, leaks can occur in different places and each of them has a different effect on the actuator's operation. At first, these leaks are small and have no visible effect on the actuator's operation, but they will increase over time. In order to maintain the set operating parameters of the actuator, the compressed air flow throttling adjustment is performed at the actuator output. This allows the actuator to work longer, but air losses will be greater and may ultimately lead to complete its damage and unplanned downtime of the machine caused by a failure. Depending on the type and construction of the actuator, as well as the nature of the damage, it is possible to regenerate pneumatic actuators by replacing the seals, repairing the moving parts, or replacing the piston rods. Excessive wear of the actuator may result in irreversible mechanical damage. Regeneration is not always cost-effective, so it is important to consider the ratio of repair costs to the cost of a new device (Zhu et al., 2023; Abela et al., 2022).

There are many leak detection methods used in industrial practice, and the key ones are those that can be used in their places of work and do not require construction and structural changes in the pneumatic system. In this area, it is necessary to mention leak detection sprays, ultrasonic leak detectors, thermal imaging cameras, acoustic emission method and measurement of air flow, pressure and exergy.

Each of the analyzed leak detection methods has its advantages and disadvantages, not all of them are suitable for every pneumatic system. Also important are the organizational and economic circumstances and conditions, which often makes it necessary to individually select the method to suit the technical system requirements and process constraints.

Leak detection sprays can detect even very small leaks. They are very easy to use and one spray can be used to detect leaks in many places in the technical system.

However, they are limited to external leaks, do not allow the detection of internal leaks in pneumatic actuators. It cannot be automated – its use and results must be verified by a trained operator. To ensure the operator's safety, it is necessary to stop the machine when detecting leaks using this method near moving parts. This method is a good solution, if you notice problems with the actuator and you expect confirmation that the source of these problems is an external leak (Whitlam, 2021).

Ultrasonic leak detectors allow for quick analysis of leaks in a large area of the machine. Testing the system for leaks using this method may require stopping the machine in order to safely access its individual components. The ultrasound method is only useful for external leaks, and can be partially automated. It is a good solution in case of necessity of comprehensive machine check for quick location of the leak source (Guenther et al., 2016; Rottländer et al, 2016).

Thermal imaging cameras are the basic equipment of the maintenance department due to their versatility in diagnostic use. This method is used to quickly confirm external leaks in pneumatic actuators, with the possibility of partial automation. Depending on the design of the machine, it may be necessary to stop it. The measurement results may be influenced by heat emitted by other components of the machine (Kroll et al., 2009; Dudić et al., 2012).

The acoustic emission method is a fully automated method for testing leaks in pneumatic actuators. It allows for early and accurate detection of internal and external leaks and testing of pneumatic actuator parameters during operation. The implementation of the acoustic emission method in a specific technical system requires performing tests in order to select appropriate alarm thresholds depending on the actuator model. The method requires considerable resources and the cost of application depends on the number of actuators tested (Kucharski et al., 2023; Nazarchuk et al., 2017).

Testing for leaks in pneumatic actuators by measuring air flow, pressure and exergy allows for automatic measurements to be taken while the actuators are operating. It is possible to detect internal and external leaks. This method allows for the analysis of the operation of several actuators from one measurement point, which reduces the number of necessary changes in the existing system, but requires many tests to be performed in order to accurately train the neural network. The method requires financial outlays related not only to the cost of sensors, but also to computer equipment with appropriate specifications, allowing for the analysis of the obtained data and drawing conclusions based on neural network models (Zhu et al., 2023).

Industry solutions are most often automatic detection systems. Available products are characterized by high accuracy and full technical support from the manufacturer, which allows for the process of implementing such devices into existing systems to be simplified. Some methods and tools also require a monthly subscription fee to access individual options (SMC, 2024a; SMC, 2024b).

4. Description of the research object

The selected research object is the pallet loading station. It is the subsystem of the machine responsible for loading elements onto pallets for transport to further stages of the production process. The key and analyzed components of this subsystem include three gates operated by pneumatic actuators. Fig. 4 shows a top view of the station with pallets placed inside.

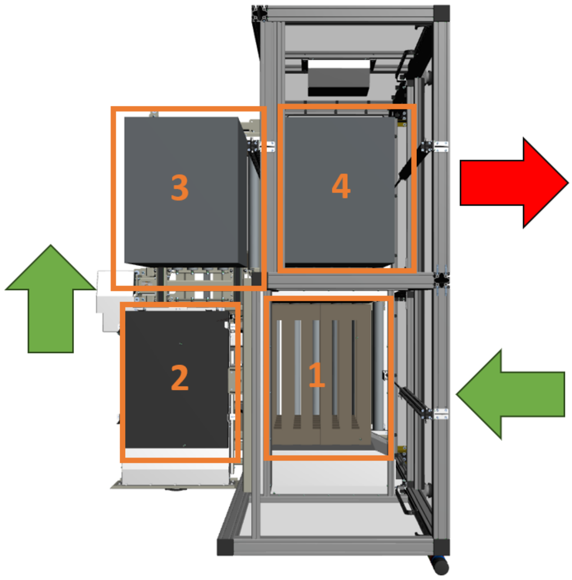


Fig. 4. Research object – pallet loading station

The numbers 1 to 4 indicate the appropriate zones, and the arrows indicate the direction of pallet movement. In zone 1 there is a storage, where pallets inserted by the operator are stored. Access to zone 1 is separated by a gate. In zone 2 there is a storage for spacers used to separate layers of products stored on the pallet. There is no gate between zones 1 and 2, and the pallets move on a chain conveyor under the spacer storage. In zone 3, the pallets stop and then the products are loaded using an industrial robot. Once the pallet is full, the gate between zones 3 and 4 opens and the pallet moves to zone 4. Removing the full pallet from zone 4 is possible after opening the gate located between zone 4 and the exit from the machine.

Each gate is operated by one of the double-acting actuators. They are controlled by 5/3 directional control valves mounted on one valve island. The movement of the gate to the open/closed position is signalled by inductive sensors, which are components of the machine's safety system.

The machine software does not allow the control of the sluice gate when the second gate of this sluice is not closed. In a situation where none of the gates has confirmation of closing, the machine is stopped with an alarm from the safety system. A similar case may occur if the gate did not close or open within the specified time. Additionally, each gate is equipped with an safety edge strip protecting it from collision with an incorrectly inserted pallet or with the operator.

Leaks in pneumatic actuators in the tested system significantly affect the consumption of compressed air and may pose a health risk to machine operators. Initially, they are unnoticeable and may not have a major impact on the machine's operation. Therefore, it is necessary to use appropriate detection systems to prevent them and continuously monitor the wear of pneumatic actuators. In the following sections of the article, it will be presented an original way of testing leaks in pneumatic actuators, which consists of description of the system structure, leakage testing way and simulation analysis of its implementation. Simulation evaluation is currently a flexible and universal form of verifying the structure and operation of pneumatic actuator systems and is the subject of both scientific research (Feng et al., 2013; He et al., 2011), and practical applications.

5. Construction and operation of the leak detection system for pneumatic actuators

The development of the leak detection way was preceded by the formulation of assumptions. It was assumed, that the leak detection system:

- should be applied in an existing pneumatic system,
- should be characterized by a limited number of elements and low cost of implementation,
- should enable leak detection on multiple actuators using a single measurement point,
- should be able to function automatically for preventive leak detection.

Additionally, the test duration should be short enough not to cause production to stop.

The diagram of the pneumatic system with the developed leak testing solution is shown in Fig. 5. The red rectangle indicates the proposed and implemented additions.

The analyzed solution is part of the pneumatic system of the entire machine. Compressed air is supplied to a valve island consisting of 3 monostable solenoid valves 5/3: V1, V2 i V3. Each valve controls the extension or retraction of the cylinder piston rods A1, A2 i A3. The speed of individual movements of the cylinder piston rods can be regulated using throttle-check valves supplying air to the cylinder connections. All cylinders are equipped with pneumatic cushioning allowing for damping of the final movements of the piston rods in order to limit sudden stops in the end positions. The working medium within the entire system is supplied and distributed using flexible pneumatic hoses with an outer diameter of 8 (mm) and an inner diameter of 6 (mm).

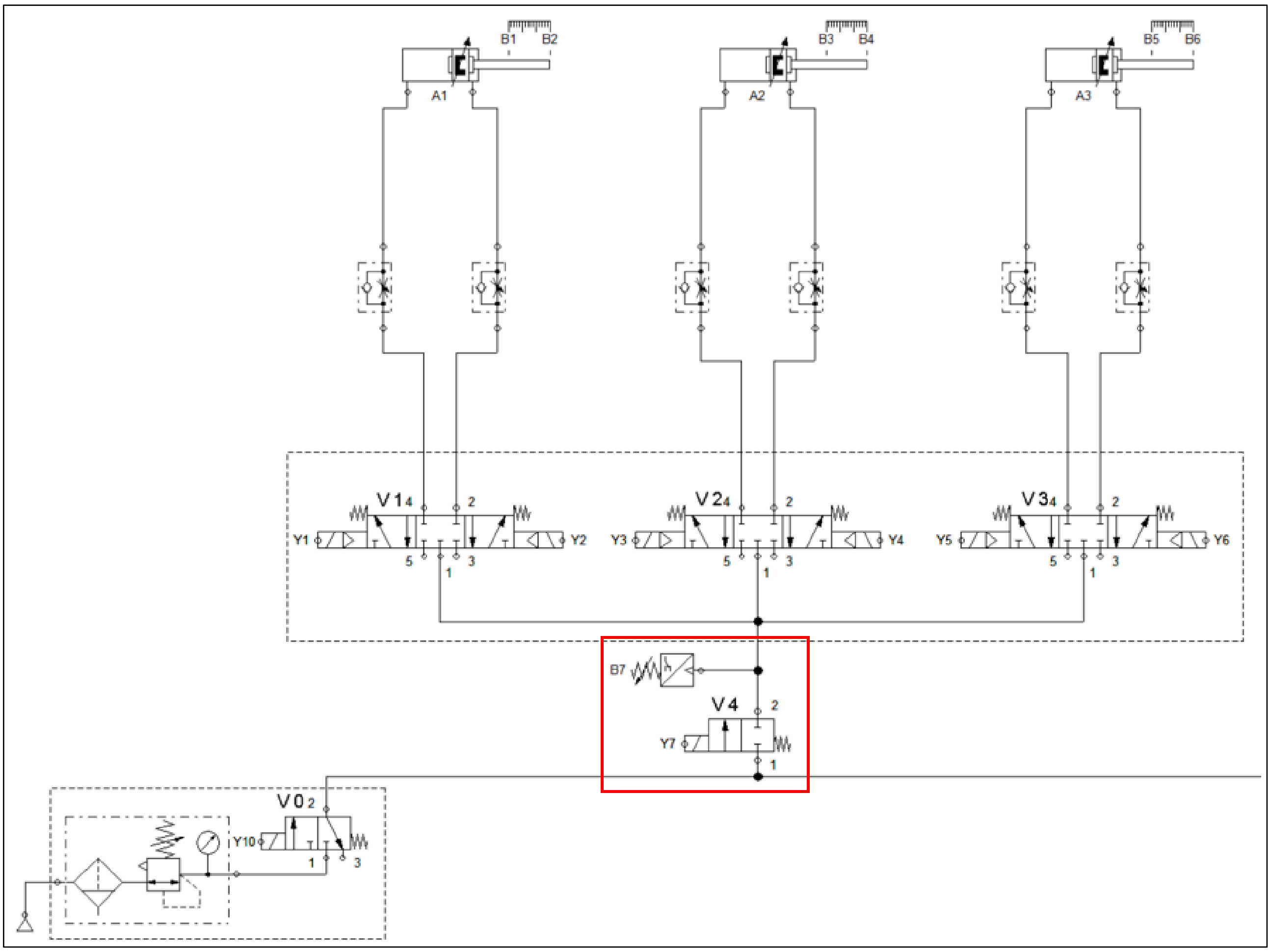


Fig. 5. Diagram of the pneumatic system including the developed leak test solution

The operation of the developed solution consists in monitoring the pressure drop of compressed air in particular pipes supplying the working medium to the actuators. In this case, all valves in the monitored valve island are three-position valves, so there is no need to replace the solenoid valves controlling the individual actuators. The key element of the system is the 2/2 shut-off solenoid valve, located before the valve island. This solenoid valve, controlled by an electric signal, allows for quick shut-off of the air flow from the source to the system, which is important for monitoring the pressure in the system. An electronic adjustable pressure switch was placed between the shut-off valve and the analyzed valve island, allowing data to be sent to the PLC controller. A shut-off valve marked with the symbol V4 and an electronic adjustable pressure switch marked with the symbol B7 were installed before the valve island. These are the only changes that need to be made in the analyzed system.

Compressed air is supplied to the system from the plant's compressed air network and goes to the MSB4-1/4:C3:J1:D14-WP compressed air preparation unit from Festo. The compressed air flow in the system is controlled by five-way, three-position solenoid valves with central exhaust SY5400-5U1 from SMC, marked in the diagram with symbols V1, V2 and V3. Fig. 6 shows the valve terminal used in the system.

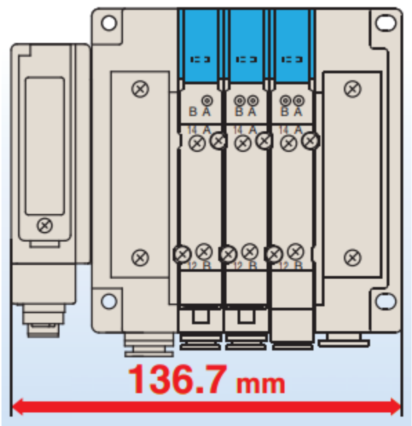


Fig. 6. The EX260 valve island from SMC used in the system

The plate solenoid valves are mounted on a valve island type EX260 from SMC containing 3 stations, controlled by means of a CC-Link communication module. In the diagram (Fig. 5), this island is marked with a rectangle of dashed lines.

For the purpose of cutting off the compressed air supply in the tested part of the system, the M21424V=-EL solenoid valve from PNEUER was used. This valve is marked in Fig. 6 with the symbol V4. To detect the position of the piston rod, there are used magnetic safety switches from ifm electronics MN508S–MN44008-AKOA/-H/US/8P. The sensors are attached to the machine structure and the actuators are mounted at the bottom of the gate. The main contacts of the switch are connected to the machine's safety system, and the auxiliary contacts are used to send information about the piston rod position to the PLC controller. The sensors are marked in the Fig. 5 with symbols B1-B6. A digital precision pressure sensor with a two-color display ISE30A-01-E from SMC is used to monitor the pressure value in the tested part of the system. The adjustable pressure switch is marked in the Fig. 5 with symbol B7. All electronic components are powered by 24V DC, and the pressure used in the system is within the working pressure range of all the elements used.

As part of the developed way, the leakage test of each actuator from a given valve island is carried out individually. When one of the actuators is tested, the solenoid valves of the other actuators should be in the initial position so as not to affect the measurement results.

A pressure drop in a given line will indicate a leak in the actuator, its connections, the line itself or the solenoid valve, in particular:

- a pressure drop in the fully retracted position will indicate an external leak and/or internal leak of the actuator,
- a pressure drop in the fully extended position will indicate an internal leak in the actuator,
- an equal pressure drop in both positions will indicate an internal leak in the actuator,
- a pressure drop in the fully retracted position greater than in the fully extended position will indicate an external leak and an internal leak of the actuator.

6. Simulation model of the leak testing system for pneumatic actuators

The verification of the developed leak detection way was based on the built simulation model of the system. It was used to carry out analytical part of the research. The model was prepared in the Matlab Simulink environment using the Simscape module and pneumatic system components. The created simulation model based on the pneumatic diagram from Fig. 5 is presented in Fig. 7.

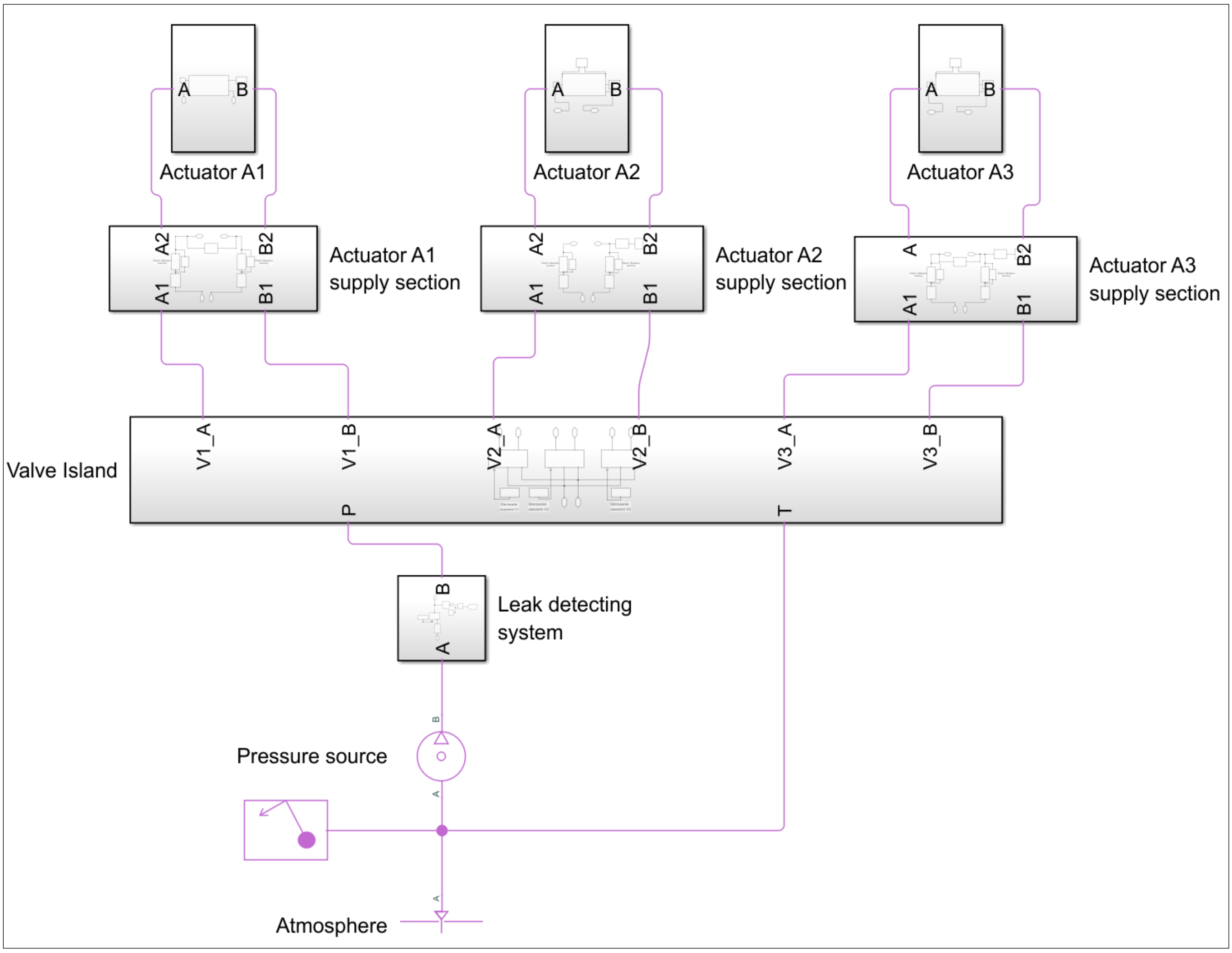


Fig. 7. Simulation model of the pneumatic actuator leak detection system

The model has been divided into 8 subsystems. The order of the subsystems is consistent with the flow of compressed air in the system: first, air is taken from the environment and compressed in the compressor, then it flows through the leak testing system to the valve island from where it is delivered to the appropriate actuators via their supply lines. Selected subsystems of the model are shown in Fig. 8.

The model was developed with the following parameters:

- pressure of compressed air: 4,2 (bar),
- diameters of connections and outer diameters of pneumatic pipes 8 (mm),
- internal diameters of pneumatic pipes 6 (mm),
- mounting of actuators in a vertical position with the piston rod pointing downwards,
- weight of each gate 14,5 (kg),
- the lengths of particular pneumatic lines: for the actuator A1: 5,5 (m) and 6,8 (m), for the actuator A2: 5 (m) and 6,3 (m) for the actuator A3: 4,5 (m) and 5,3 (m),
- the lengths of the pipes before the valve island have been omitted,
- pneumatic actuators: with a stroke 1300 (mm), piston diameter 32 (mm) and piston rod diameter 16 (mm).

Simulation analysis using the developed model requires identification of the position of the actuator control valve slide, the position of the shut-off valve slide, the position of the actuator piston rods and the pressure value in the system before the valve island after the shut-off valve. Additionally, a graph of the displacements of all actuators during the simulation is generated. The diagram of data acquisition and collection from the simulation process is shown in Fig. 9.

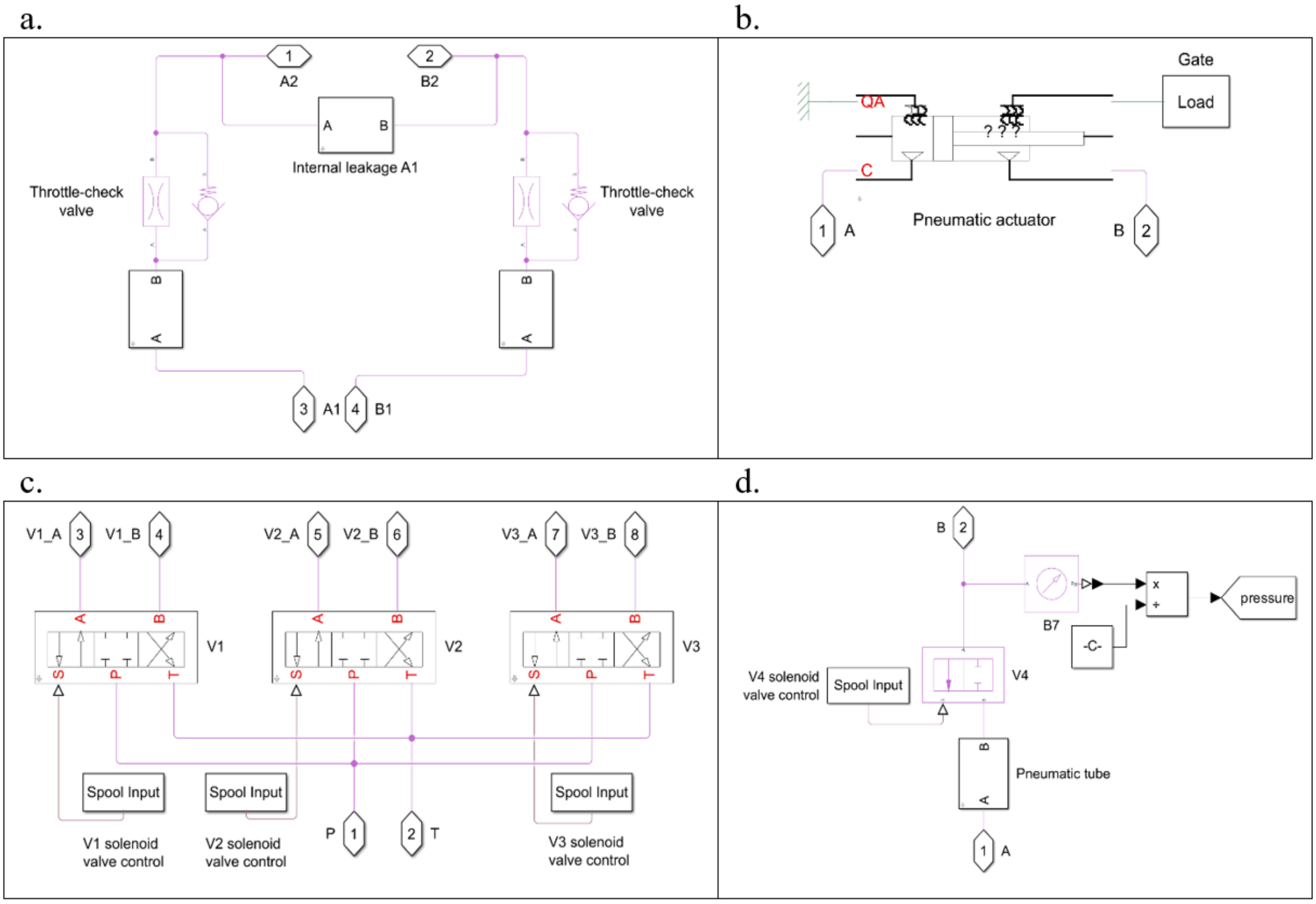


Fig. 8. Selected subsystems of the pneumatic actuator leak detection system: A1 actuator power supply subsystem, b. A1 pneumatic actuator subsystem, c. valve island subsystem, d. leak testing subsystem

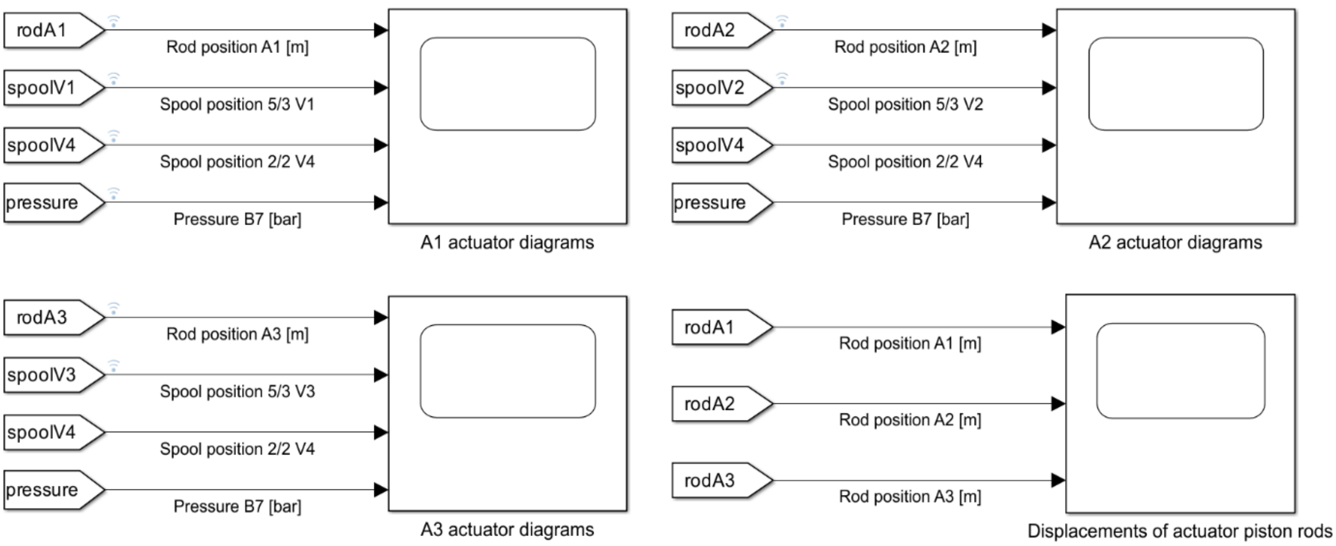


Fig. 9. The scheme of acquiring and collecting data from the simulation process

A Gantt chart showing the leak testing procedure for one actuator is shown in Fig. 10.

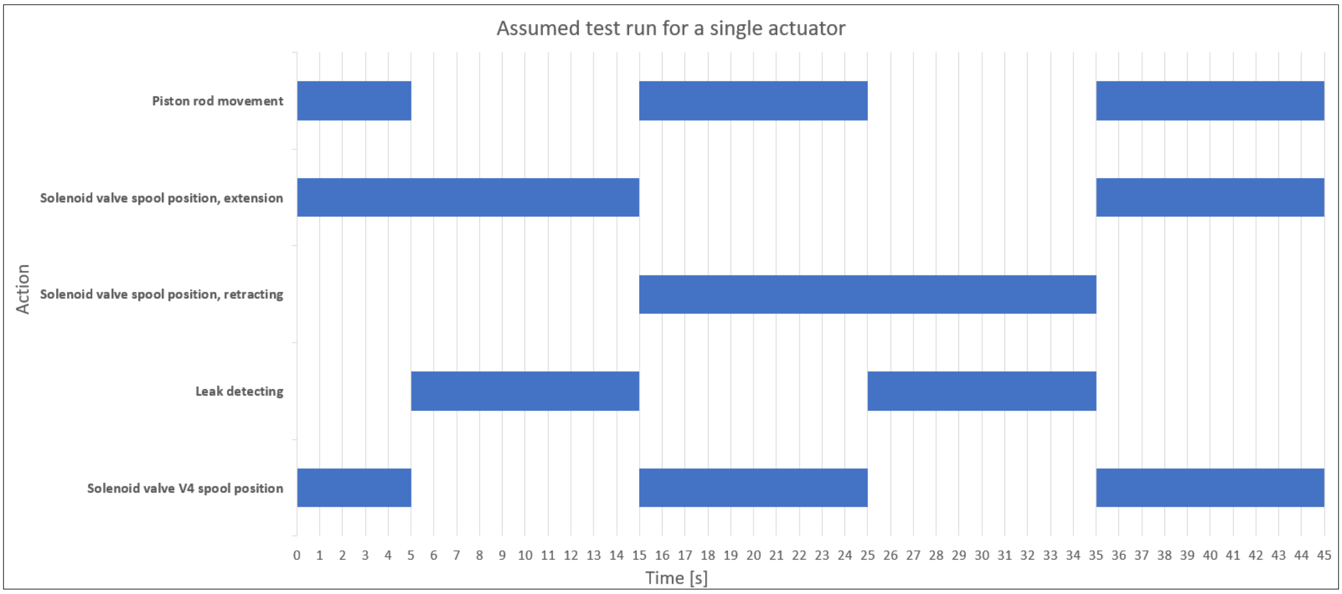


Fig. 10. Gantt chart of the leak test of one actuator

During the analysis, it was assumed that a leak requiring intervention by trained personnel was signalized by a pressure drop of 0.2 (bar) during the 10 (s) test period. After completing the test of one actuator, the described cycle was repeated for the next actuator. The total test time was 135 (s).

The visualization of selected results of the simulations is presented in Fig. 11.

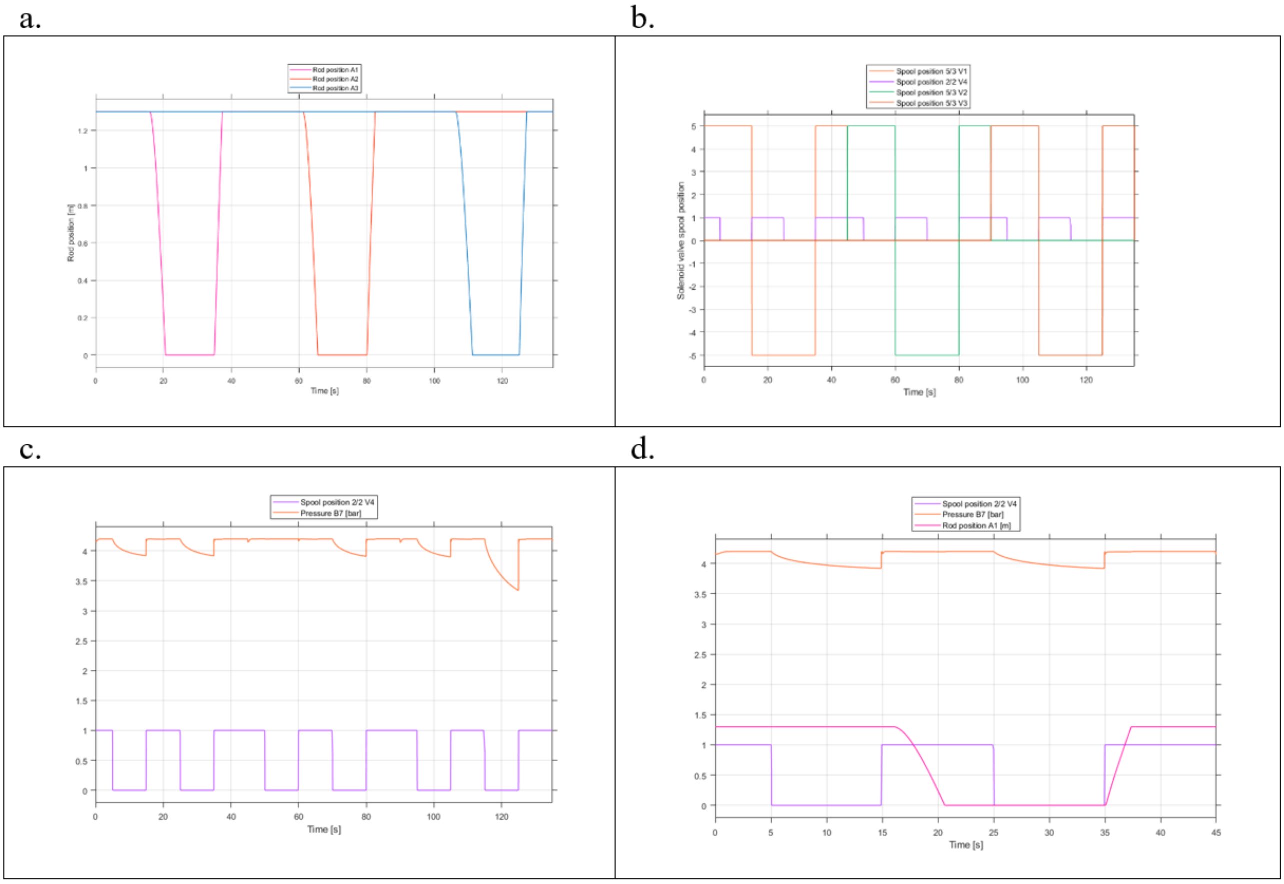


Fig. 11. Visualization of selected results of the simulation process

The values of the obtained pressure drops for each actuator in a given position are presented in Table 1. The leak diameter is one of the basic geometric measures of the size of a leak. It defines the reference diameter value of a circular surface corresponding to the surface of the real leak.

Table 1. The values of pressure drops of the actuators for individual leak diameters

Actuator	Pressure drop in the fully extended position [bar]				Pressure drop in the fully retracted position [bar]			
	Leak diameter [mm]							
	0,2	**0,3**	**0,4**	**0,5**	**0,2**	**0,3**	**0,4**	**0,5**
A1	0,01	0,03	0,11	0,28	0,01	0,03	0,11	0,28
A2	0,00	0,00	0,00	0,00	0,01	0,03	0,11	0,29
A3	0,01	0,03	0,11	0,30	0,02	0,11	0,38	0,86

The results obtained in the analysis are consistent with the assumptions, in particular:

- the pressure drop for actuator A1 was equal in both positions, which indicates an internal leak,
- the pressure drop for the A2 actuator was only in the extended position, which indicates an external leak,
- the pressure drop for the A3 actuator was greater in the extended position than in the retracted position, which indicates internal and external leakage.

7. Conclusions

The aim of the research conducted and presented in the article was to develop a way for detecting leaks in pneumatic actuators operating in production systems. The task was carried out on the example of a pallet loading station, where pneumatic actuators are used to open and close three gates through which pallets pass. These actuators are responsible for the operator's safety, and their failures are time-consuming due to the way they are installed.

The formulated goal was achieved through simulation studies based on the developed way and model prepared in the Matlab Simulink environment. A series of simulations were carried out for different sizes of internal and external leaks of the three tested pneumatic actuators. The obtained results allowed to confirm the operation of the developed leak detection system.

Leaks in actuators are a very common cause of their damage. Leaks in pneumatic cylinders do not always affect their cycle length, but they significantly affect the consumption of compressed air on the machine. Internal and external seals are the most sensitive elements in the construction of pneumatic actuators. Internal and external seals are the most sensitive elements in the construction of pneumatic actuators.

The developed leak detection way involves in measuring the pressure value in individual pneumatic actuator supply threads with the compressed air supply from the source cut off. The pressure drop in the system, its magnitude and the position of the piston rod in which it was detected, indicates the size of the leak and its location. The proposed solution allows for testing actuator leaks on the entire valve island using a single measurement point.

The duration of the test depends on the assumed accuracy of the detected leak. The longer the tightness is checked in a given part of the pneumatic system, the smaller the leak can be located. The disadvantage and at the same time the advantage of the presented concept is the fact that the detected leaks will be located not only in the actuator itself, but also at its connections, on pneumatic lines, throttle-return valves and solenoid valves themselves. Therefore, the exact location of this leak cannot be determined using this way, but it will allow to limit this place to a specific part of the pneumatic system. The duration of the test can be significantly reduced by testing several actuators simultaneously, provided that they can operate at the same time. If no pressure drop is detected, it can be assumed that there are no compressed air leaks in any of the tested locations in the system. Detection of a pressure drop during such a test may require testing of individual actuators individually or, for example, only half of the actuators. It should be taken into account that in the case of small leaks on several actuators, they may be detected by the system when testing multiple actuators at once, while when testing individual actuators, this drop may be small and may not be detected.

The pressure drops depend on the amount of air in the system. The analyzed actuators have a stroke of 1300 (mm), therefore the amount of air in the chamber is large and a small leak will cause a smaller pressure drop than in the case of the same leak in a smaller actuator.

The development of the solution is also possible by recording the collected data. Analysis of historical data will allow for determining the rate of wear of seals, as well as determining the pressure drop values at which failure occurs. Determining the limit pressure difference will allow for preventive replacement of actuators before the machine stops due to failure. The use of learning algorithms will also allow for faster data analysis and faster selection of alarm thresholds in the case of installation in other pneumatic systems.

References

Abela, K., Refalo, P. (2022). Analysis of pneumatic parameters to identify leakages and faults on the demand side of a compressed air system, Cleaner Engineering and Technology, Vol. 6,100355. https://doi.org/10.1016/j.clet.2021.100355.

Dudić, S., Ignjatović, I., Šešlija, D., Blagojević, V., Stojiljković, M. (2012). Leakage quantification of compressed air on pipes using thermovision. Thermal Science, 16(2), pp. 571-581. https://doi.org/10.2298/TSCI120503191D.

Feng, Z.G., Zhang, X.J. (2013). Study on fault simulation for pneumatic actuator model. 3rd International Conference on Mechatronics and Intelligent Materials (MIM 2013), Mechatronics And Intelligent Materials III, PTS 1-3, 706--708. https://doi.org/10.4028/www.scientific.net/AMR.706-708.1025.

Fracczak, L., Nowak, M., Koter, K. (2021). Flexible push pneumatic actuator with high elongation. Sensors and Actuators A 321, 112578. https://doi.org/10.1016/j.sna.2021.112578.

Guenther, T., Kroll, A. (2016). Automated detection of compressed air leaks using a scanning ultrasonic sensor system. IEEE Sensors Applications Symposium, pp. 1-6. https://doi.org/10.1109/SAS.2016.7479830.

Hu, W., Mutlu, R., Li, W., Alici, G. (2018). A structural optimisation method for a soft pneumatic actuator. Robotics 7(2), 24. https://doi.org/10.3390/robotics7020024.

International Organization for Standardization (2018). Pneumatic fluid power – Cylinders with detachable mountings, 1 000 kPa (10bar) series, bores from 32 to 320 mm - Basic, mounting and accessories dimensions. (ISO 15552:2018). https://www.iso.org/standard/66921.html.

Jaafar, M.A.I.B., Abas, A., Khairil, K.A. (2024). Real-time leakage predictions of pneumatic controlled actuator during cycle test using machine learning, The International Journal of Advanced Manufacturing Technology 134: pp. 4577-4592. https://doi.org/10.1007/s00170-024-14362-5.

Kalisch, M., Przystalka, P., Timofiejczuk, A. (2014). Application of selected classification schemes for fault diagnosis of actuator systems. ACSIS-Annals of Computer Science and Information Systems, Volume 2, pp. 1381--1390, https://doi.org/10.15439/2014F158.

Kroll, A., Baetz, W., Peretzki, D. (2009). On autonomous detection of pressured air and gas leaks using passive IR-thermography for mobile robot application. 2009 IEEE International Conference on Robotics and Automation, Vol. 1-7, pp. 998-1003. https://doi.org/10.1109/ROBOT.2009.5152337.

Kucharski, S., Makiewicz, S., Katz, T., Starzyński, G., Ranachowski Z., Woźniacka S. (2023). Evaluation of fatigue damage of a railhead using an indentation test, acoustic methods and microstructural observations. International Journal of Fatigue, Vol. 167, Part B, 2023, 107346, https://doi.org/10.1016/j.ijfatigue.2022.107346.

Kurmyshev, E., Jiménez, M., Castaneda, C. (2020). Experimental study of double-acting cylinder. Experimental Techniques, 44(2), pp. 355-367. https://doi.org/10.1007/s40799-020-00359-8.

Loska, A., Moczulski, W., Wyczółkowski, R., Dąbrowski, A. (2016). Integrated system of control and management of exploitation of water supply system. Diagnostyka. 17(1), pp. 65-74.

Mahmoud, H., Mazal, P. (2018). Diagnostics of the function of pneumatic actuators using acoustic emission. Brno University of Technology Vutiom Press, Brno.

Nazarchuk, Z., Skalskyi, V., Serhiyenko, O. (2017). Acoustic emission. Methodology and application. Springer International Publishing.

Parr, E.A. (2011). Hydraulics and pneumatics: A technician's and engineer's guide. 3rd Edition, Elsevier Ltd., Burlington.

Radgen, P., Blaustein, E. (2001). Compressed Air Systems in the European Union, Energy, emissions, savings potential and policy actions. LOG_X Verlag GmbH, ISBN: 3932298160.

Rottländer, H., Umrath, W., Voss, G. (2016). Fundamentals of leak detection. Leybolg GmbH, Cologne.

SMC Corporation, Air Management System – Operation Manual. SMC Corporation. https://www.smcworld.com/upfiles/manual/en-jp/files/PFxx-OMA1007.pdf.

SMC Corporation, Automatic leak detection system. SMC Corporation. https://static.smc.eu/binaries/content/assets/smc_global/solutions/packaging/alds-a_leaf_en.pdf.

Sun, B., Yang, X., Ren, Y., Wang, Z., Antosz, K., Loska, A., Jasiulewicz-Kaczmarek M. (2021). Failure-based sealing reliability analysis considering dynamic interval and hybrid uncertainties. Eksploatacja i Niezawodnosc – Maintenance and Reliability 23 (2), pp. 278-284, https://doi.org/10.17531/ein.2021.2.7.

Szenajch, W. (2016). Napęd i sterowanie pneumatyczne. Wydawnictwo Naukowe PWN, Warszawa.

Tomasiak, E. (2001). Napędy i sterowania hydrauliczne i pneumatyczne. Wydawnictwo Politechniki Śląskiej, Gliwice.

Whitlam, Liquid Gas Leak Detector Spray, Talon, (2021). https://www.jcwhitlam.com/Product/1/90/139#.

Zhu, H., Wang, Z., Wang, H., Zhao, Z., Xiong, W. (2023). Fault diagnosis of two parallel cylinders in pneumatic system with a minimal number of sensors. Electronics 12(15), 3261. https://doi.org/10.3390/electronics12153261 Electronics, t. XII, nr 15, 2023.