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regulation of its parameters in order to adjust its characteristics to different needs and types of rail vehicles [5].

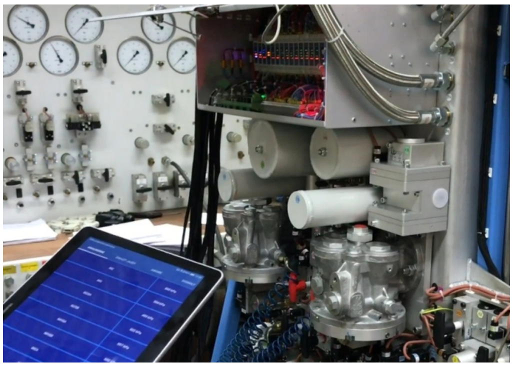

Fig. 5. The modular pneumatic brake board of rail vehicle

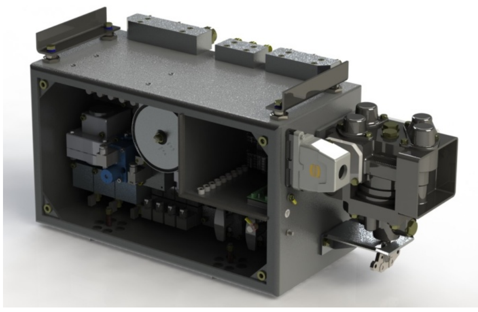

Fig. 6. The modular pneumatic brake board of rail vehicle

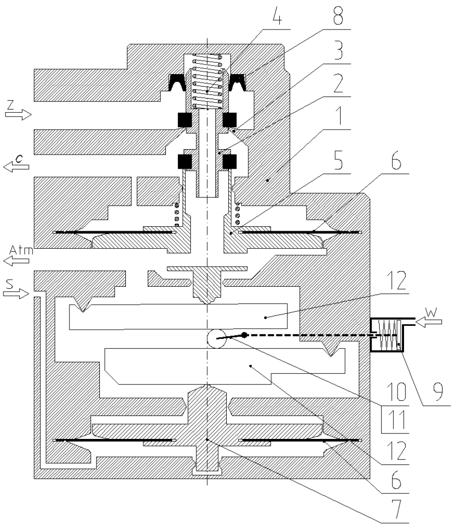

Fig. 7. An illustrative construction of the single stage pressure transformer developed by Łukasiewicz Research Network – Rail Vehicles Institute "TABOR" [7]
(Z – power supply, C – cylinder, S – control signal, W – pneumatic signal of the weight of the vehicle, 1 – relay valve body, 2 – filling valve, 3 – valve seat, 4 – spring, 5 – upper piston with a venting rod, 6 – membrane, 7 – lower piston, 8 – sealing ring, 9 – piston - slide system, 10 – roller, 11 – inclined swing lever, 12 – levers)

The main element of the relay valve consists of a venting rod connected to the piston (5) and the diaphragm (6). It moves in the body (1), up or down depending on the pressure difference occurring on both sides of the diaphragm (6). The supply air (Z) from the auxiliary reservoirs is constantly supplied to each relay valve. When the distributor valve generates a control signal (S), which reaches to the chamber under the lower piston (7) and diaphragm (6), the piston (7) moves upwards and the rod (5) opens the valve (2) via the lever (12), which allows the supply air to enter onto the output side (C) of the relay valve to the brake cylinder capacity. In the opposite situation, when the control signal (S) decreases, the valve closes the supply flow (Z), and the air on the output side (C) of relay valve escapes from the cylinder into the atmosphere through the hollow rod. The pneumatic signal of the weight of the vehicle (W) changes the lever ratio (12) between the pistons (7) and (5) [5].

3 Impact of the applied lubricants on relay valve operation

To meet the requirements demanded from the relay valves with a complicated structure, it is essential to make their subassemblies very precisely and to assemble and adjust them carefully. Because of observation of a certain scatter of the relay valve parameters, there was a need to carry out the detailed tests, allowing to determine the influence factors and optimize the structure in order to ensure the highest possible repeatability and reliability of operation of the relay valves. One of the selected factors of influence was the type of lubricants used in the relay valves [7].

During the analysis of the operation (functioning) of the relay valves in operation in winter, it was found that there was the increase of failure of these devices during this period. Therefore, it was decided to carry out the correctness tests of the relay valves operation at sub-zero temperatures.

During the tests of the relay valve in the climatic chamber it was observed that the type of the used grease had the influence on the operation of the relay valve at different temperatures due to the changes in the resistances of motion. Therefore, three selected types of lubricants were tested in a climatic chamber [7].

The lubricant tests were carried out in the Laboratory for Exploitation Materials of the Poznan University of Technology. The measured parameter was the consistency of the lubricant, specifically its hardness index. For the measurements of the hardness of lubricants, a PL-12DC laser penetrometer, manufactured by the Institute for Sustainable Technologies - National Research Institute in Radom, was used, shown in Figure 8.

The laser penetrometer allows to determine the consistency of the grease. The correct consistency must ensure that the grease does not generate too high resistances. The consistency is graded according to the scale developed by the NLGI (National Lubricating Grease Institute) presented in Table 1. The softer is the grease the lower number is on the scale. During the test, the depth of penetration of the standard cone into a sample of grease is measured in tenths of a millimeter (Fig. 9).

Fig. 8. Laser penetrometer PL-12DC [7]

Fig. 9. Laser penetrometer PL-12DC – view during the test [7]

It is an automatic device, in which it is used the modern laser technology to measure the penetration. The penetrometer is intended, among others, for testing the consistency of petrochemical products (e.g. lubricants, asphalts, paraffins), food products, cosmetic products, as well as mortars and plastic explosives [8,9].

Table 1. Classification of greases under NLGI consistency class [7]

Number NLGI	Penetration according to ASTM (10^{-1} mm)	Appearance at room temperature
000	445 - 475	very liquid
00	400 - 430	liquid
0	355 - 385	semi-liquid
1	310 - 340	very soft
2	265 - 295	soft
3	220 - 250	medium hard
4	175 - 205	hard
5	130 - 160	very hard
6	85 - 115	extremely hard

The following lubricants popularly used in Łukasiewicz Research Network – Rail Vehicles Institute „TABOR" were tested:

– "Vecolit EPX 00" – semi-liquid gear lubricant and central lubrication,
– "Elf MULTI" – lithium calcium grease for bearings,
– "TF silikon + teflon" – silicone grease with the addition of Teflon.

The above lubricants were tested at three temperatures: 24 ° C (room temperature), 0 ° C and (- 26 ° C), which were obtained using a laboratory freezer [7].

The results of the tests carried out in the laboratory are listed in Table 2. A graphical image of the change of the consistency of various greases as a function of temperature is shown in Figure 10.

Table 2. The test results of greases consistency as a function of temperature [7]

Name of lubricant	Vecolit EPX 00			Elf MULTI			TF silikon + teflon		
Temperature	-26 °C	0 °C	24 °C	-26 °C	0 °C	24 °C	-26 °C	0 °C	24 °C
Measurement I	157,4	359,8	443,2	126,0	242,1	273,1	284,3	290,0	308,8
Measurement II	174,2	358,7	437,5	117,0	234,5	266,0	274,3	280,2	305,4
Measurement III	160,7	369,7	446,0	136,1	229,4	263,8	290,4	291,4	306,1
Average	164,1	362,7	442,2	126,4	235,3	267,6	283,0	287,2	306,8

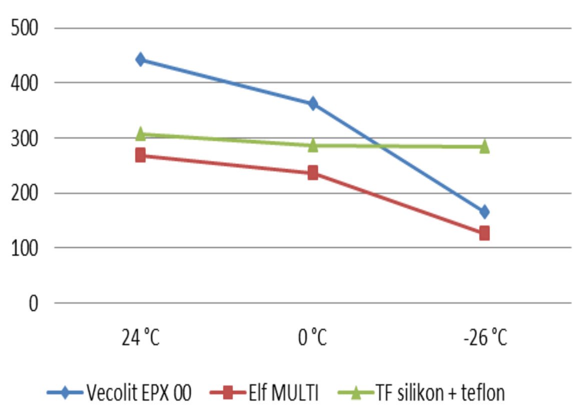

Fig. 10. Consistency of greases as a function of temperature [7]

Figure 11 shows the view of one of the relay valve's elements (valve) with the used Elf MULTI grease and Vecolit EPX 00 grease (used in the relay valve) at temperature -26°C. It is clearly seen that the used lubricants, under the influence of low sub-zero temperature, changed their consistency from the liquid into a solid consistency, which is disadvantageous for the correct operation of the relay valve [7].

The carried out tests have shown that this causes occurrence of large resistances of movement and leads to the suspension of the valve, and thus to the lack of full release of the cylinder (C) in response to the control signal (S), and the occurrence of large leak in the power supply system (Z) of the braking system of the rail vehicle [7]. The pressure characteristics in the relay valve system during operation with frozen grease and the suspended valve are presented in Figure 12.

Fig. 11. View of the used Elf MULTI grease (on the left) and Vecolit EPX 00 grease (on the right) in the relay valve operating at temperature of -26 ° [7]

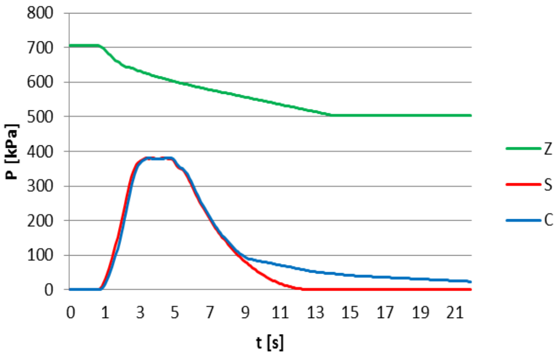

Fig. 12. Exemplary course of the test with a suspended valve of relay valve [7]

However, Figure 13 shows the valve with the used TF silicone + teflon grease, which during operation at -26 °C did not change its consistency and thus provided the correct operation of the relay valve at the sub-zero temperatures.

Fig. 13. View of the used TF silikon + teflon grease in the relay valve operating at temperature of -26 °C [7]

As a result of the above analysis of lubricants, the previously used Elf MULTI grease for TF silicone + teflon grease has been changed. However, further observations of pressure transformers during operation have shown that this grease adversely affects the operation of the relay valve systems having elements made of silicone rubber (piston diaphragms, rubber bellows). Therefore, it was selected the grease, which used in the specific elements of the relay valve construction allows it to function correctly and reliably.

4 Elimination of unreliable elements of the rail vehicles braking system

As already mentioned above, the basic element of pneumatic brake systems of railway vehicles is the relay valve supplied from the auxiliary tank with compressed air, filling brake cylinders during braking. In brake systems of traction units or pre-defined vehicles, the cylinder relay valve is controlled by pneumatic signals coming from the pneumatic brake control system (from the distributor valve) and from the electro-pneumatic brake system. In locomotives, the cylinder relay valve can be controlled by a signal from the distributor valve and from the direct auxiliary brake system.

Until now, the most commonly used system was a relay valve controlled by a signal from these two sources through a double-return valve realizing the alternative function (Fig. 14). This arrangement ensures the cylinder pressure on the vehicle due to a stronger control signal.

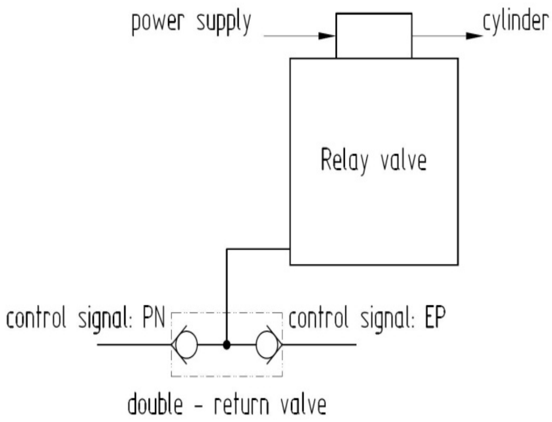

Fig. 14. Diagram of supplying a control signal to the relay valve with a double-return valve

Experience collected as a result of many years of observation, many double-return valves in operation has shown that they sometimes fail, reducing the reliability of the entire system. These failures occurred as a result of slight contamination of the valve or loss of lubricating grease after a long service life. As part of the ongoing development work on increasing the functionality and reliability of the braking equipment in Łukasiewicz Research Network – Rail Vehicles Institute "TABOR", a control system for a relay valve controlled from two sources with an alternative function was developed, in which the commonly known and used double-return valve was completely eliminated from this system. A relay valve with two control pistons was developed (Fig.15), the lower control piston being a moving piston relative to the upper control piston.

Thanks to this solution, it was possible to simplify the relay valve control system by eliminating the double-return valve (Fig.16) and to ensure greater reliability of the system, because the newly developed control system based on two control pistons is completely resistant to dirt that immobilized the double-return valve and does not require special lubrication, which ensures correct operation of the brake system in the long-term operation of the vehicle between inspection repairs.

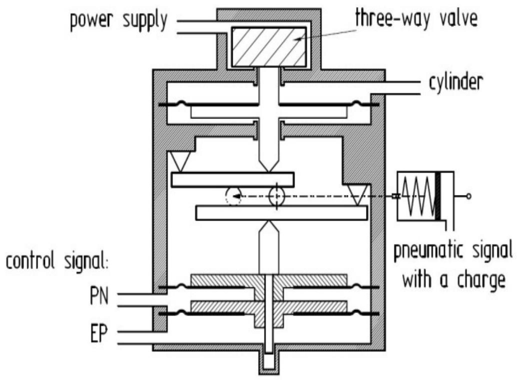

Fig. 15. Construction of the relay valve with a control system with an alternative function

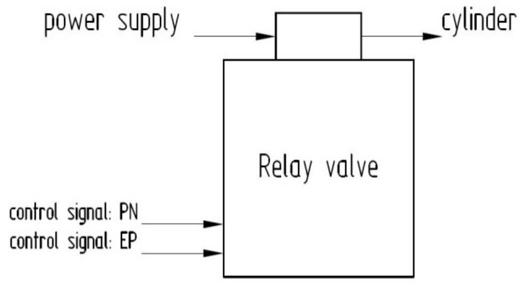

Fig. 16. Diagram of supplying a control signal to the relay valve with an alternative function

Any interruption in the delivery of the control signal causes that the rely valve will not work or will work incorrectly, which results in the lack or incorrect pressure in the brake cylinders and, consequently, no braking or lengthening its distance. This condition directly affects the reduction of train traffic safety.

5 Conclusions

Ensuring the safety of vehicle users as well as people and objects in their surroundings is the main and most important purpose of all vehicle builders. In particular for mass transport vehicles, such as rail vehicles, this is the topic with the highest priority. Therefore, every effort should be made to ensure that every element of the vehicle responsible for safety works with the greatest certainty and has a high reliability factor. In the case of a rail vehicle, such element is the cylinder relay valve located in the brake system.

The relay valves as one of the most responsible elements of the rail vehicle braking system are subjected to continuous analyzes in Łukasiewicz Research Network – Rail Vehicles Institute "TABOR" in order to improve the structure and improve the reliability of their operation. The article identifies two structural factors that are important for the optimization of the structure in the direction of improving the operational reliability and thus ensuring the safety of train traffic.

One of these factors was the applied lubricant. Therefore presented the test results of lubricants in order to select the lubricant with the best parameters as a function of temperature, in application to the relay valve. During the analysis of the test results it was found that the grease used in the relay valve must have the stable parameters in the wide range of temperatures. Especially at low temperatures, it must keep as liquid consistency as possible. Therefore, the silicone grease was introduced in the appropriate systems of relay valve, which has a practically constant consistency in the range of temperature from -30 °C to +40 °C. On the basis of the carried out tests the grease was selected, which used in the specific elements of the relay valve construction allows it to function correctly and reliably, and thus guarantees reliable operation of the rail vehicle brake system.

The second factor was the method of controlling the relay valve with two control signals from the alternative function, the use of which eliminated the unreliable system with a double-return valve. Such a solution not only ensures greater reliability of the braking system and increases train safety, but also simplifies the construction of this system.

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