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Development of a charging system ensuring the load-carrying capacity for powered roof support

The powered roof support is an essential part of the protection of the mining wall. Its main task is to support the roof of the wall excavation and, as such, it must resist the coal mass that has the potential to collapse the mining pit. The force with which the powered roof support acts on the roof of the excavation is called load-carrying capacity. This paper describes the problem of the load-carrying capacity of powered roof support, in particular reviewing their charging systems. The research aims to ensure that the required initial load-carrying capacity is obtained and the working load-carrying capacity is maintained. This paper presents the research results of a double-block prototype equipped with an automatic charging system. We present the results of both bench and operational testing in real conditions.

Słowa kluczowe: *powered roof support, hydraulic prop, load-carrying capacity, bench tests, tests under real conditions*

1. INTRODUCTION

Mining is an important component of the economies of many countries, including Poland. Man has extracted mineral resources for centuries, and their use forms the basis of industrial development and enables technical progress. At the current level of economic development, mining activity is increasingly problematic, with demands primarily connected to reducing adverse environmental impacts [1] and improving work safety [2, 3]. At the same time, deteriorating mining and geological conditions associated with selecting difficult-to-access deposits require even greater efficiency and effectiveness of the work carried out to ensure economic profitability [4]. The increase in the depth of exploitation of deposits also leads to increased natural hazards and the need for continuous development [5, 6].

In coal mining, the development of automatic wall complexes is essential [7–9]. A wall complex is a set of machines constituting the basic equipment of a mining wall. It is used to mechanize the mining, loading and transport of coal. The mechanized wall complex consists of a mining machine, a conveyor, and a powered roof support [10]. These machines are characterized by the interdependence of design and movement; they work in a serial system. The failure of one of them causes the entire complex to stop working, thus stopping the mining process as well. Therefore, the reliable operation of each element of the wall complex is vital for stable extraction [11].

The authors of this article have decided to tackle the issue of improving the reliability of powered roof support. This topic is of particular importance due to the deteriorating working conditions of powered roof supports. Coal mining in increasingly low-lying coal beds generates an increase in the load that the powered roof support must be able to carry. The mines exploit increasing numbers of coal beds in conditions of rock mass shocks. Thus, the powered roof support, in addition to carrying static loads, is exposed to the dynamic impact of the rock mass [12]. For this reason, bench tests concerning the dynamic load of powered roof support are carried out [13–15]. The results of bench tests are supplemented by in-service and in situ research [15–17].

This paper addresses the problem of the powered roof support's load-carrying capacity, which is crucial for adequately maintaining the excavation's roof and, thus, for safety during exploitation [18]. This paper aims to ensure that the required initial load-carrying capacity is obtained, and the working load-carrying capacity is maintained. This goal can be achieved by introducing a specific change in the prop's hydraulic system. The change involves replacing the traditional prop block with a double block with automatic pressure charging. Bench and exploitative tests were conducted to confirm that the adopted concept and the proposed system are correct. The research results are presented in this article.

2. LOAD-CARRYING CAPACITY OF A LONGWALL POWERED ROOF SUPPORT

The force with which the powered roof support acts on the excavation's roof is called the load-carrying capacity. During the operation of the powered roof support, the following types can be distinguished [10]:

- initial load-carrying capacity (P_w),
- working load-carrying capacity (P_R),
- nominal load-carrying capacity (P_N).

The following dependencies describe the load-carrying capacity of the powered roof support:

$$P_w = \frac{\pi d^2}{4} \cdot p_{zas,N} \tag{1}$$

$$P_R = \frac{\pi d^2}{4} \cdot p_{rob,N} \tag{2}$$

$$P_N = \frac{\pi d^2}{4} \cdot p_{nom,N} \tag{3}$$

where:

d – the prop's diameter [m],
p_{zas} – the supply pressure [Pa],
p_{rob} – the working pressure (safety valve opening pressure) [Pa],
p_{nom} – the nominal pressure [Pa].

The initial load-carrying capacity is obtained when the powered roof support expands and depends on the pressure present in the power supply line of the wall. After the powered roof support carries the pressure of the roof rocks, the section gradually increases the load-carrying capacity to its working value, at which the prop reveals its amenability. It depends on the opening pressure of the safety valve in the prop's valve block. Nominal load-carrying capacity, on the other hand, is the maximum force value for which the powered roof support section is designed [10].

The load-carrying capacity of the sections is mainly determined by the parameters of the hydraulic props – namely their diameter and pressure in the sub-piston space. Therefore, to ensure proper operation of the powered roof support, it is necessary to maintain the appropriate pressure in the sub-piston space of the props.

3. REVIEW OF THE CHARGING SYSTEMS OF LOAD-CARRYING CAPACITY FOR POWERED ROOF SUPPORT

The powered roof support is supplied with pressurized liquid from the hydraulic network. The hydraulic mining network usually consists of a central pump station built underground and hydraulic lines that bring the liquid to the mining walls. Typically, one pipeline brings the pressurized medium to the powered roof support (pressure pipeline), and the other drains the liquid from the powered roof support back to the pump station (drain pipeline). Main lines run along the excavation wall – one supplying liquid to individual sections (power supply line) and the second draining the medium from the section (drain line). The power supply line has a liquid at a pressure of approx. 20–30 MPa. The mine hydraulic network operates in a closed circuit. The hydraulic medium moves from the pump station to the powered roof support and back. The liquid flow is accompanied by high resistance and pressure drops. The liquid pressure in the power supply line is subjected to considerable fluctuations, adversely affecting the section's initial load-caring capacity.

The initial load-carrying capacity depends directly on the liquid pressure in the power supply line at the time of expansion of the section [19]. In addition to the instantaneous pressure value in the supply line, the initial load-carrying capacity of the powered roof support is also affected by the human factor. The operator can expand the powered roof support to a more or less substantial degree. The above factors indicate that the initial load-carrying capacity will differ depending on the section of the powered roof support [19]. Thus, the sections will exert different pressures on the excavation roof, causing stress of different values over subsequent sections. As a result, the roof might crack or crumble, which makes exploitation difficult.

In addition, due to pressure drops in the supply line and human error during the powered roof support's expansion, the sections may not achieve the required initial load-carrying capacity. A load-carrying capacity that is too low can lead to excessive settling of the roof rocks and stratifications, resulting in the roof rocks falling and collapsing [20].

Thus, solutions are sought to achieve the required pressure in the props' sub-piston spaces and minimize differences in the load-carrying capacity of individual sections. Various types of devices have been developed to boost the load-carrying capacity of powered roof support [21].

3.1. Hans Berger Meßtechnik GmbH device

Hans Berger Meßtechnik device (Fig. 1) allows the simultaneously charging of two props.

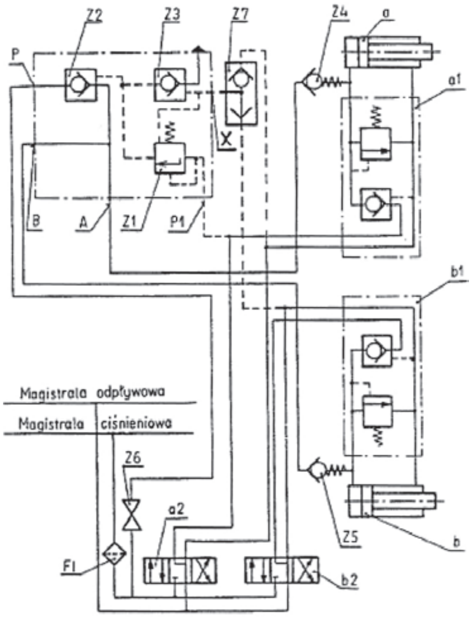

Fig. 1. The load-carrying capacity system of the prop with Hans Berger Meßtechnik GmbH device [21]
a, b – prop, a1, b1 – valve block, a2, b2 – distributor,
A, B, P, P1, X – connection, Z1 – threshold valve,
Z2, Z3 – controlled check valve, Z4, Z5 – check valve,
Z6 – shut-off valve, Z7 – circuit switch,
Fl – filter

The charge flow is closed and opened by valve Z2. From connection P, the device is directly connected to the power supply via the shut-off valve Z6 and filter F1. The charging device starts to operate automatically when the pressure in the sub-piston space of the prop reaches the value set at the threshold Valve Z1. When the pressure in the sub-piston spaces of the props is equal to the pressure in the power supply line, the charging device stops working. In the event of a pressure drop in the sub-piston spaces, the charging system is automatically activated.

3.2. Richard Voß Grubenausbau GmbH device

Richard Voß device (Fig. 2) allows for only one prop to be charged. During the expansion of the section, the liquid flows into the sub-piston space of the prop and, at the same time, into contact A of the charging device. When the pressure value in the prop's sub-piston space exceeds the value of the threshold valve setting, the charging system is switched on. Then the liquid can flow from the power supply line to the under-piston space of the prop. Thus, recharging begins.

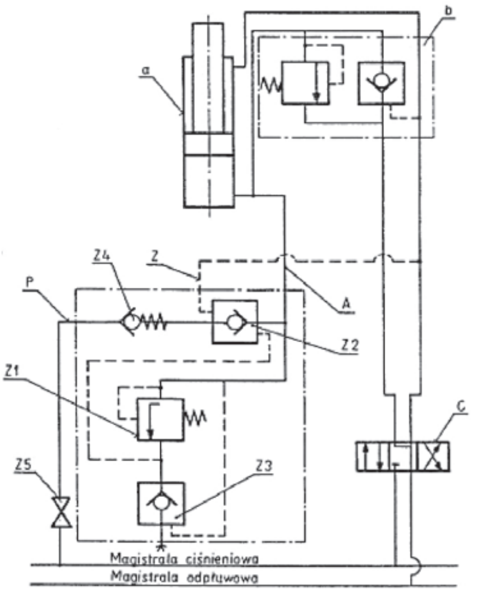

Fig. 2. The load-carrying capacity system of the prop with Richard Voß Grubenausbau GmbH device [21]
a – prop, b – valve block, c – distributor,
A, P, Z – connection, Z1 – threshold valve,
Z2, Z3 – controlled check valve, Z4 – check valve,
Z5 – shut-off valve

When the pressure in the sub-piston space of the prop is equal to the pressure in the power supply line, the Z4 Valve is closed, and the recharge halts. After a pressure drop in the sub-piston space, the device starts recharging – until the pressure in the power supply line is equal to that in the prop's sub-piston space.

3.3. KOMAG KDS device

The KOMAG KDS device (Fig. 3) is built of two separating threshold valves A and B. Valve A is set to the threshold pressure, i.e. the pressure at which the charging starts. Valve B is set to the initial pressure of the powered roof support.

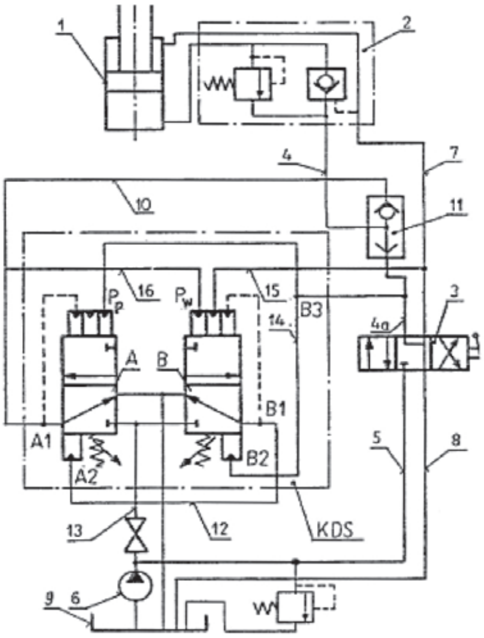

Fig. 3. The load-carrying capacity system of the prop with KDS device [21]
1 – prop, 2 – valve block, 3 – distributor, 4, 4a, 5, 7, 8, 10, 12, 13, 14, 15, 16 – hydraulic hose, 6 – pump, 9 – tank, 11 – circuit switch, A, B – separating threshold valve, A1, A2, B1, B2, B3 – connection

When the pressure of the liquid in the sub-piston space of the prop exceeds the value to which Valve A is set, the valve is activated. At the same time, Valve B is switched off, which triggers the charging. When the pressure in the sub-piston space reaches the expected initial load-carrying capacity value, Valve A is switched off, and Valve B is switched on simultaneously and this is also when the prop stops charging.

3.4. UDS device

The UDS device (Fig. 4) is designed to work with one prop; it is an additional element in the hydraulic system. During the expansion of the powered roof support, the liquid flowing into the prop, with an adequate increase in pressure in the sub-piston space, opens valve Z1, triggering the recharge. The UDS device allows for charging with the liquid at a specific pressure. Set-ups of the threshold valves Z2 and Z4 control this pressure. After the powered roof support expansion, the recharge will be activated after the pressure drop in the prop's sub-piston space.

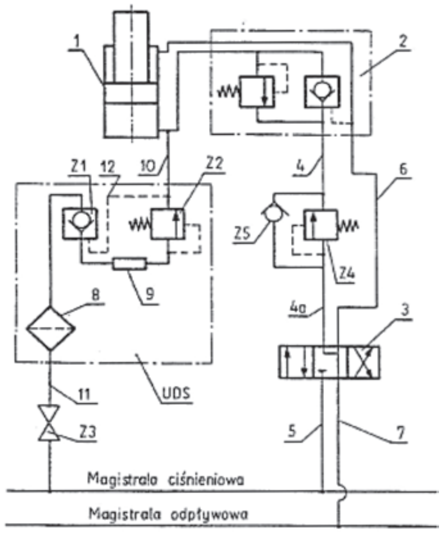

Fig. 4. The load-carrying capacity system of the prop with UDS device [21]
1 – prop, 2 – valve block, 3 – distributor, 4, 4a, 5, 6, 7, 10, 11, 12 – hydraulic hose, 8 – filter, 9 – nozzle, Z1 – controlled check valve, Z2, Z4 – threshold valve, Z3 – shut-off valve, Z5 – check valve

The modernized version of the UDS device (Fig. 5) can adjust the flow rate of the charge liquid. In addition, this device recharges both props of the powered roof support section. During the powered roof support's expansion, the liquid flowing into the prop simultaneously flows into the UDS device. When the pressure of the liquid entering the prop reaches the value of the pressure initiating the operation of the UDS device, the charge liquid flow is opened.

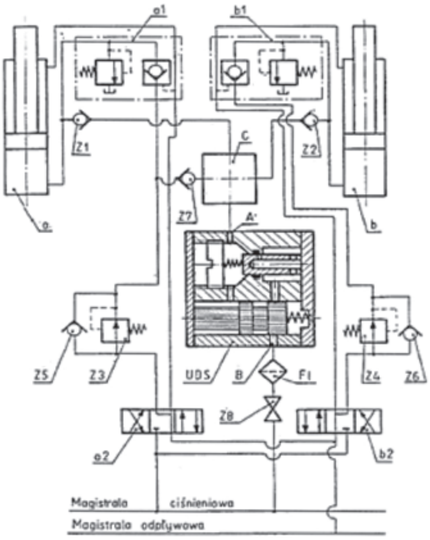

Fig. 5. The load-carrying capacity system of the prop with modernized version of the UDS device [21]
a, b – prop, a1, b1 – valve block, a2, b2 – distributor, c – tee, A, B – connection, Z1, Z2, Z5, Z6, Z7 – check valve, Z3, Z4 – pressure reducer, Z8 – shut-off valve, Fl – filter

3.5. The active pressure maintenance system from Elsta

The active pressure maintenance system from Elsta (Fig. 6) automatically diagnoses the pressure's state in the props and the ability to dose the pressure. The key elements of the active monitoring system of the powered roof support section are the µRUFUS pressure maintenance sensors, which consist of devices of electronic and electrical equipment, a hydraulic valve control unit, hydraulic valves and transmission wires. An electric valve built into the prop controls its pressure. If the operator applies too little pressure to the hydraulic prop, the support system automatically activates and corrects the load-carrying capacity of the sections [22].

Fig. 6. The active pressure maintenance system from Elsta [22]

4. DOUBLE BLOCK WITH AUTOMATIC PRESSURE BOOST

The authors propose their own system for recharging the load-carrying capacity of the powered roof support (Fig. 7) based on a prototype double block with automatic pressure boost (2). The proposed block (2) consists of a threshold valve (2c) with a check valve (2d). The threshold valve (2c) placed in the block has an opening pressure setting of 9 MPa. The automatic pressure boost function does not work below this value. The charging system is activated when the pressure exceeds 9 MPa during the props' expansion. The block is connected to the power supply line via a second check valve (6). The use of an additional check valve (6) is intended to eliminate the possibility of fluid backflow to the power supply line in the event of contamination of the check valve (2d) [23]. The system and the prop are protected against excessive increases in the working load-carrying capacity of the medium by safety valves 4 and 5. In the event of an excessive increase in pressure in the prop's sub-piston space, valve 4 will drain a certain amount of liquid outside the system. On the other hand, valve 5 is supposed to protect against the destruction of the hydraulic cables connecting the valve block to the over-piston space of the prop, adequate protection in the event of an internal leak and a pressure increase in the over-piston space.

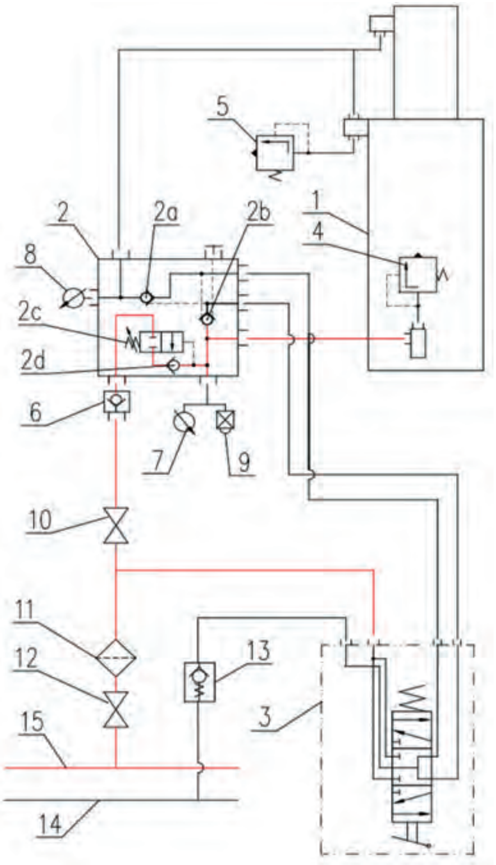

Fig. 7. The prop's hydraulic system with double block with automatic pressure boost

When charging, it is necessary to protect the prop from liquid backflow. It is vital that the prop's over-piston and sub-piston space are protected in case of an internal leak in the prop. In the proposed double block, the over-piston space is protected by check valve 2a, while the sub-piston space is protected by check valve 2b.

The charging function replenishes all pressure losses in the sub-piston space of the prop [24, 25]. The proposed system minimizes the effects of internal leaks of the prop [26]. In addition, the system ensures the expansion of the props to the required initial load-carrying capacity equal to the maximum pressure value in the power supply line. The required load-carrying capacity is achieved despite pressure fluctuations in the power supply line and interruptions to the expansion performed by the operator. To confirm the validity of the accepted concept, i.e. to ensure initial and work load-carrying capacity, bench and in-service tests in real conditions were carried out.

5. RESULTS OF BENCH AND IN-SERVICE TESTS OF THE SYSTEM

The bench tests consisted of measuring the pressure in the sub-piston space of the prop and the pressure in the power supply line. The measurements were carried out by a portable measuring device, the Parker Service Master Plus. The sampling rate was 10,000 measurements per second. Based on the tests, pressure variation against time was generated. Figure 8 shows a view of the test bench with the prop and the tested block. An example graph of the measurements is shown in Figure 9.

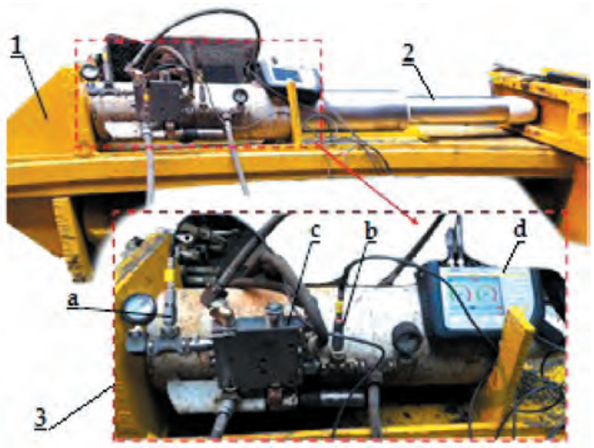

Fig. 8. View of the test bench
1 – frame of test site, 2 – hydraulic prop, 3 – tested system, a, b – pressure sensors, c – double block with pressure charging, d – measuring device

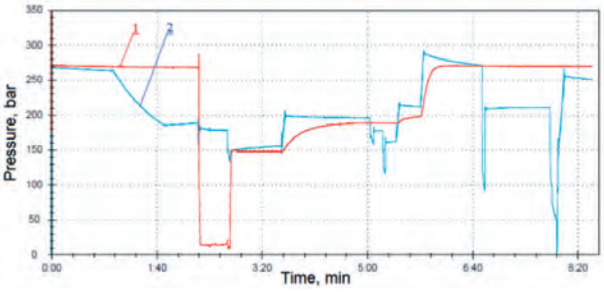

Fig. 9. The course of the pressure in the space under the piston of the hydraulic prop (1) and in the power supply line (2)

At the start of the measurement, the pressure in the sub-piston space of the prop was 270 bar. After 1.00 min, The pressure in the power supply line began to drop. Despite this, the pressure value in the prop's sub-piston space remained at a constant level of 270 bar. Thus, the required load-carrying capacity was maintained. At 2.20 min, the prop is removed, and the pressure drops to near 0. Then at 2.50 min, the prop was expanded again. At the time of the prop's expansion, the pressure in the power supply line was 150 bar. This allowed the operator to expand the prop to obtain 150 bar in the prop's sub-piston space. By 3.40, the power supply line pressure had risen to 200 bar. Then the automatic charging system replenished the pressure in the sub-piston space to a value of approx. 190 bar. Then the pressure increased in the power supply line at 5.30 min (up to 220 bar) and 5.50 min (up to 290 bar). At that time, the block recharged further. The pressure in the prop's sub-piston space has increased to 270 bar thanks to automatic recharging. Thus, the prop has obtained the required load-carrying capacity. The load-carrying capacity was maintained, despite subsequent pressure drops in the power supply line.

After the positive results of the bench tests, the system was tested in real conditions. The proposed system was installed in the mining wall. For the purpose of the study, the authors selected a prop with an internal leak. This allowed them to assess the block's usefulness in minimizing the leak's effects. During the tests, the pressure in the sub-piston space of the prop was measured. A DOH DROPS wireless pressure sensor was used for this purpose. An example graph of the measurements is shown in Figure 10.

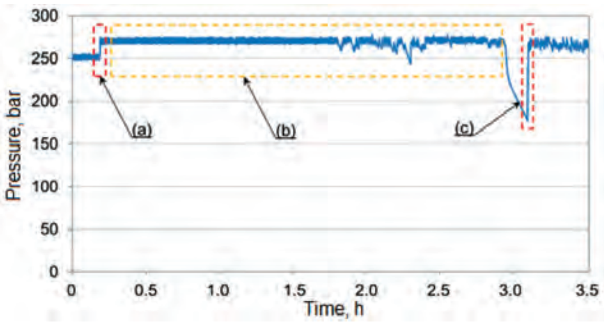

Fig. 10. The course of the pressure in the space under the piston of the hydraulic prop
a, c – pressure boost, b – maintenance of the load-carrying capacity

The graph (Fig. 10) shows the course of pressure variation in the sub-piston space of the prop. When there was pressure charging, its value increased from 250 bar to approx. 270 bar. It is likely *a* pressure increase in the power supply line, making it possible to implement automatic recharging. For the next few hours (area *b*) the pressure was maintained at approx. 270 bar, despite the internal leakage of the prop. After 3 hours, there was a pressure drop. The system automatically replenished the pressure to 270 bar (*c*). The section divider cannot be seen in the diagram, meaning the wall was at a standstill. The measurements presented could be implemented during a maintenance shift. There is also no characteristic pressure increase during the prop's operation, which may indicate an incorrect geometry of the section.

6. CONCLUSIONS

One of the important factors for properly maintaining the wall excavation's roof is ensuring the required load-carrying capacity of the powered roof support. The prop's hydraulic system maintains the powered roof support's load-carrying capacity. The authors propose changing this system by introducing a double block with automatic pressure charging. The proposed block is intended for use in the control system of the direct adjacent type. The idea of the system is to provide powered roof support with initial and working load-carrying capacity.

The bench and in-service tests' results confirmed the adopted concept's validity. The automatic charging function ensures that the prop is expanded to the maximum pressure value in the power supply line. This means that the proposed system makes achieving the required initial load-carrying capacity possible, despite pressure fluctuations in the power supply line. The system also eliminates the problem of the influence of the human factor when expanding the section to its load-carrying capacity. Suppose the operator interrupts the expansion before the required load-carrying capacity is obtained. In that case, the charging system will automatically replenish the pressure in the sub-piston space to the value resulting from the power supply line's pressure. The tests also confirmed that the system maintains the working load-carrying capacity despite the pressure drops in the power supply line. In addition, the system minimizes the effects of internal leaks. The results confirm that the initial hypotheses are correct and that it is possible to introduce changes in the powered roof support's hydraulic system. The presented prototype block can be introduced to the market, confirmed by the positive result of EC type examination according to the PN EN-1804-3 standard.

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