Operational Tests of a Modular Installation and Transport Assembly of Steel Arch Support in Underground Excavations

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INTRODUCTION

Hard coal in Poland is the main source of energy, widely used throughout the country. Hard coal is mined almost exclusively using longwall techniques based on longwall systems. Shearer (Krauze, 2010; Biały, 2016) and plow (Ajamzadeh et al., 2019) longwall systems are sets of machines that enable effective extraction of coal from seams. Such complexes are offered by many manufacturers and are widely used all over the world (Dyczko et al., 2020). The increasing efficiency of hard coal exploitation and significant daily progress achieved by these sets of machines require an appropriate speed of gallery drilling. Currently, roadways, opening-out excavations and preparatory workings are drilled too slowly, because a compatible set of machines in the form of a powered complex for drilling galleries in underground mines that would enable a significant advance of more than 15 running metres has not yet been developed (Klich et al. 1999, Krauze et al., 2007).

Roadways are excavated using a roadheader or explosive materials. In both techniques, the machines performing the most important functions, i.e. mining, loading and haulage, are technologically advanced. These machines include: a boom-type roadheader, a drilling machine, a mining loader and appropriate means of transport (Klich et al. 1999; Su, 2019). However, after extracting a

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planned amount of coal in a roadway, it is necessary to install a steel arch support so as to ensure the excavation stability and to protect the staff and equipment. At present, the steel arch support is assembled end-to-end, upon completion of the extraction. In addition, it should be noted that the elements of steel arch support are assembled manually or mainly manually, in the face or in a zone that is particularly dangerous for the staff (rock bursts, roof falls, rock and gas outbursts) (Cao et al., 2016; Meng et al., 2016, Bednarek et al., 2020).

INSTALLATION OF A STEEL ARCH SUPPORT IN THE MINE FACE

A roof support, especially the ŁP steel arch support (Rotkegel, 2013; Majcherczyk et al., 2014), is installed in the face of workings in underground mines using a roadheader (Fig. 1). For this purpose, apart from the aforementioned roadheader, a suspended rail and moving equipment are used. It is easy to notice that this process, i.e. the transport of arches and other elements of the frame, lining as well as installation itself, are performed manually. The delivery of support elements to the face as well as handling them in the face during installation are particularly cumbersome and require a lot of physical effort.

Fig. 1 Mounting of a steel arch support using a roadheader

Currently, there are various machines and devices on the market to support the process of installing a roof support in hard coal mine conditions (GTA, 2021), such as:

– working platform and a movable boom mounted on the roadheader arm – in the case of excavating with a roadheader, the most commonly used work platforms are manually extendable on both sides of the arm. The support arm is equipped with a boom for lifting the roof arch. The roof arch is manually placed on the boom. After lifting the roof arch, the staff manually place the side arches and put them together with stirrups;

- working platform – in the case of drilling with explosive materials or with a roadheader, a working platform moving on a suspended rail can be used. Roof arches are manually loaded onto the platform and, next, manually mounted together with side arches;
- working platform with a boom – used in the case of drilling with explosives or with a roadheader. The platform moves on a suspended rail. Roof arches are manually loaded onto the platform and, next, lifted with a boom and bolted together with manually added side arches. The roof arches must be manually placed on the boom;
- working platform with a manipulator – used in the case of drilling with explosives or a roadheader. The platform moves on a suspended rail. The roof arch is taken from the floor by means of a manipulator and, next, pressed to the roof, while the side arches are mounted and bolted together by hand;
- man basket on a caterpillar chassis – also in the case of using explosives. The basket, designed for one or two people, moves on a caterpillar chassis, enabling manual assembly of the support frame;
- mobile manipulator – used for drilling with explosives. The manipulator, moving on its own caterpillar chassis, on a suspended rail or on a floor guide, enables taking the roof arch from the floor and placing it on the roof. Then, the side arches are mounted manually;
- manual binding joists – in the case of drilling with a roadheader or explosives, without any of the aforementioned equipment, various types of manual binding joists are used to lift the roof arch.

However, the above-mentioned solutions have one main drawback – the arch support is assembled while the roadheader is at a standstill (the roadheader is not working). The problem can be solved by using a temporary mechanized roof support. Then, the mining and loading processes are carried out in parallel with the erection of the final support. In this case, the staff installing the support are behind the roadheader, near the border of the temporary and permanent supports.

TEMPORARY MECHANIZED ROOF SUPPORT

The temporary mechanized roof support (Fig. 2) is another machine necessary to create a roadway support complex (Krauze et al., 2021). It follows the face advance, mounting elements on the exposed roof without the presence of the staff in the danger zone. The permanent support is erected behind the cutting machine in a safe area. In addition to a very important aspect of ensuring the safety of the staff and machines, attention should be paid to the key advantage of such a support, i.e. enabling the gallery to be mined and secured at the same time, which significantly increases the advance. Securing the gallery with a yielding arch support directly in the face or behind the temporary mechanized roof support (if it is applied) must be quick so as not to generate unnecessary downtimes of the mining machine (Krauze et al., 2007).

Fig. 2 View of a set of six arches of a temporary mechanized roof support
Source: (Krauze et al., 2021)

The temporary mechanized roof support consists of two ultimate frames and four identical internal frames. The arches in the lower, straight part are equipped with expanding actuators with a stroke of 300 mm; the nominal size of the support is obtained by extending these actuators by 150 mm while the remaining 150 mm is in reserve. The individual segments are connected to each other with four linear actuators. Due to the way they work, these actuators at the ultimate frames are double-acting, and the remaining ones are single-acting. Additionally, the arches are connected with pipe guides that ensure their stability during the support removal. Each frame consists of two side arches and one roof arch. The arches are connected with each other by means of stirrups. It should be mentioned that these are commercially available and currently used arches. The arches are equipped with actuator handles as well as pipe guide handles, which are mounted by means of split couplings, using special mounting sheets. In addition, a significant part of the surface of the support frame is covered with a special lining, which was designed so as to protect the excavation from rock rubble (Krauze et al., 2007; Krauze et al., 2021).

The presented support has been pre-tested in laboratory conditions. As part of the bench tests, the functionality of the support as well as the parameters of the hydraulic system were tested by measuring the pressures on the supply and outflow of selected actuators. The bench tests did not show the need for any corrections or modifications. Next, the complete support was installed in a mine excavation, where underground operational tests were carried out (Fig. 3). The

operational tests were performed only for the temporary mechanized roof support.
As the tests were successful, a search was started for an appropriate transport and assembly platform enabling the elements of the support to be delivered to the site of installation, which in this case was the area behind the roadheader, and facilitating its assembly. In the absence of such a solution, we developed our own concept and model of the platform (Fig. 4). The platform consists of a platform for the staff, a manipulator, an advance drive and a hydraulic power pack. All the elements, i.e. the roadheader, platform and support, make up a mechanized roadheader complex (Krauze et al., 2021).

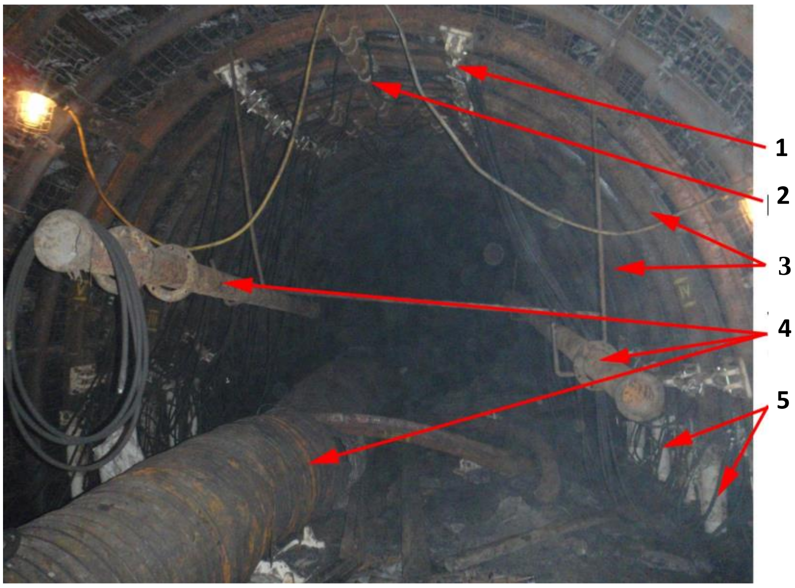

Fig. 3 Operational tests of the temporary mechanized roof support in an underground excavation:
1 – actuators, 2 – pipe guides, 3 – ŁP support steel arches,
4 – excavation equipment, 5 – support feet
Source: (Krauze et al., 2021)

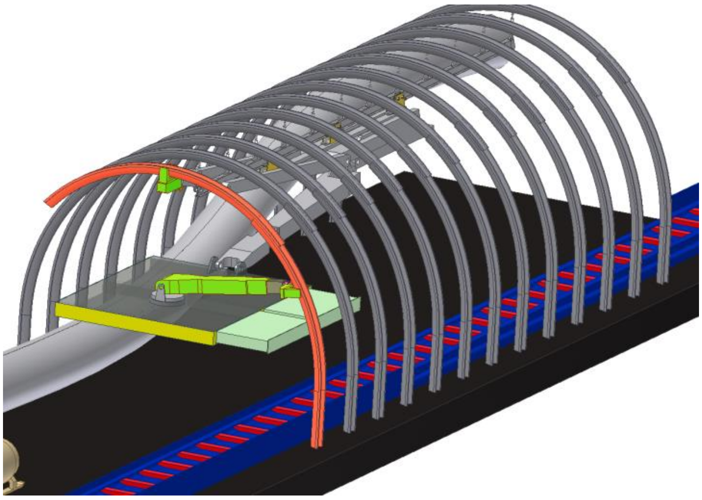

Fig. 4 Model of a platform for erecting a permanent arch support behind the roadheader
Source: (Krauze et al., 2021)

MODULAR INSTALLATION AND TRANSPORT ASSEMBLY

As previously noted, the last device of the powered roadheader complex is a platform equipped with a manipulator, an advance drive and a hydraulic power supply. This set without a platform, which can be used in the face on its own, has been named a modular installation and transport assembly. The device enables transporting the elements of the support frame from the place of its storage to the face, to the area in front of or behind the roadheader, as well as delivering them to the site of installation.

The schematic diagram of a modular installation and transport assembly consisting of a boom, mounted on one traveling beam with a stabilizing foot, and a hydraulic power pack in a gallery with the ŁP steel arch support is shown in Figure 5. The advance drive (tractor) with a hydraulic power supply, connected by an electric cable to the mine's mains, moves separately along the same track of the suspended rails.

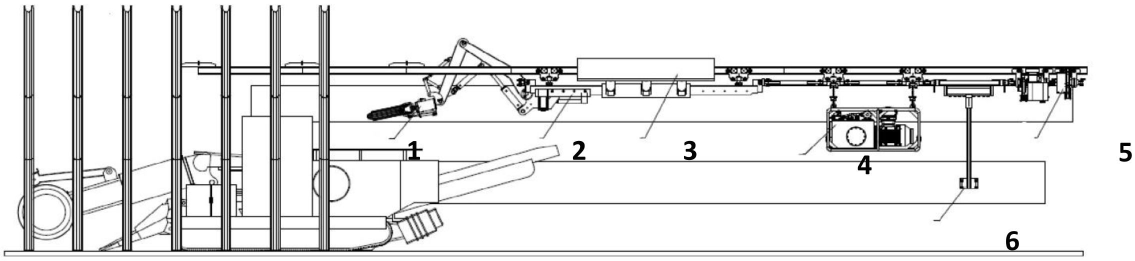

Fig. 5 Schematic diagram of a modular installation and transport assembly in a gallery with useful weight in the transport position: 1 – manipulator, 2 – beam with a davit, 3 – support slide, 4 – hydraulic power unit, 5 – CHM tractor – 15, 6 – control panel

A characteristic feature of this solution is asymmetrical mounting of the equipment on a suspended rail in a gallery and the need to stabilize (balance) the modular transport and assembly unit during the transport of support elements. The boom can only work with the stabilizing foot unfolded.

The manipulator enables taking the support elements from the floor and allows for their direct assembly. It also enables mounting all the support arches. After transporting the arches to the site of installation and placing the roof arch on the roadheader's arm, it is only necessary to manually position the roof arch and side arches.

Particularly important new features of this solution include:

- the ability to work in typical headings of hard coal mines, assuming that a wide range of functions are performed,
- the possibility of mounting all roof and side arches one by one without having to place the side arches manually,
- the possibility of picking up the support arches from the floor without having to load them manually,
- the possibility of transporting a set of arches and stirrups needed to install the entire support frame,

- performance of the assumed functions with a single manipulator and a mechanism for supporting roof arches,
- kinematic possibilities enabling the assumed functions to be performed also in the section of an equipped excavation (equipped with a conveyor, a ventube, a dust collector, etc.),
- compatibility with the roadway complex developed in stages and, in particular, with the temporary support.

It should also be noted that despite the existence of various solutions of manipulators to assist the process of erecting the steel arch support, the proposed solution should be called a new product, offering completely new possibilities, which cannot be labelled merely as improvements.

OPERATIONAL TESTS

The developed 3D model of the modular installation and transport assembly was then subjected to kinematic analysis, collision analysis and strength analysis. Thanks to that, the design was devoid of design errors, which would be expensive and time-consuming to remove at the prototype stage. At the same time, a hydraulic control system was developed for the prototype solution (manual control) and for the industrial version (electro-hydraulic control with a wireless remote control). The next stage involved preparing documentation of the mechanical, electrical and hydraulic parts, which allowed for the prototype solution implementation.

The device required a number of tests therefore a plan of operational tests was developed along with the location and equipment of the test site. This place was located in the hall belonging to FAMA Sp. z o. o., the manufacturer of the modular installation and transport assembly.

The stand (Fig. 6) was equipped with the ŁP steel arch support (1), suspended rails (2), a dummy boom-type roadheader with an operator's cabin in the form of pallets (3) and a complete installation and transport assembly (4).

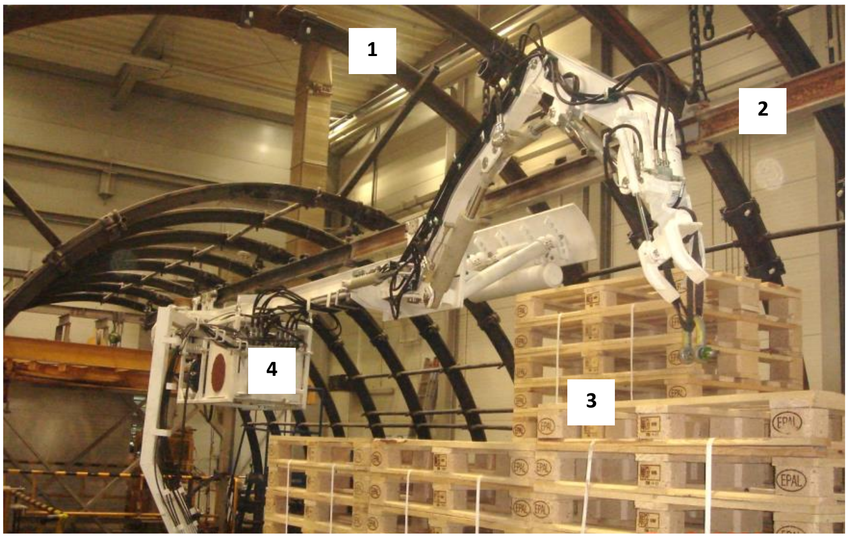

Fig. 6 The modular installation and transport assembly mounted asymmetrically on a suspended rail at the test stand

The test stand allowed checking the mobility and functionality of the manipulator. First, the ride of the manipulator loaded with the steel arch along the excavation and, next, over the operator's cabin was checked to make sure that the required stability of the entire device was obtained (no contact of the folded stabilizing foot with the steel arches) and that the arch could be provided by the roadheader (Fig. 7).

Fig. 7 Ride of the manipulator loaded with the support arch over the roadheader and the operator's cabin (pallet) with the stabilizing foot folded

Then, the kinematic capabilities of the manipulator and its stability at the site of the support frame installation, i.e. between the excavation side and the roadheader, were checked, using a stabilizing foot (Fig. 8).

Fig. 8 Manoeuvring the support arch at the support frame installation site, with the use of (unfolded) stabilizing foot

The conducted tests confirmed the correct work of the equipment, which allowed dismantling and handing it over to the user (the mine).
Figure 9 shows the modular installation and transport assembly installed in an underground excavation.

Fig. 9 The modular installation and transport assembly installed in an underground excavation

The entire installation and transport assembly with the advance drive, hydraulic power unit and cable drum have been installed on the suspended rail, which is asymmetrically attached to the arch support. Along a 30-metre section of the drift (face side, the place where the support arches are stored), the manipulator takes the arches one by one (Fig. 10) and transports them to the installation site (Fig. 11).

Fig. 10 The modular installation and transport assembly in the support elements storage area

Fig. 11 The modular installation and transport assembly at the site of arch support frame installation

Then, the operator can pass and place the support element at the site of its installation, i.e. assist the process of equipping the excavation with a permanent support.

CONCLUSION

The modular installation and transport assembly for a steel arch support perfectly complements the temporary mechanized roof support, creating the mechanized roadway complex with the mining machine.

The presented solution allows the drilling progress to be increased, both in the case of mechanical mining and mining with explosives. However, the key advantage of the presented complex is significant enhancement of work safety in excavated headings.

It should also be emphasized that the described solution can be used individually for the transport and assembly of roadway support elements or other machine and equipment elements.

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Abstract: The roof support, especially the ŁP yielding steel arch support, is transported and assembled in the face with the use of auxiliary machines. This activity in Polish underground mines causes numerous problems, which until present have not been solved. Currently, transport and assembly are carried out manually, while the roadheader and suspended rail are used only to a small extent. Therefore, the modular installation and transport assembly was developed jointly by FAMA Sp. z o. o. and AGH University of Science and Technology. The solution in question enables performing a number of functions (including transport and assembly of all kinds of support arches), which are not available in currently manufactured equipment. The proposed manipulator solves numerous problems occurring during the installation of the steel arch support in an underground mining excavation and significantly improves the process of drilling galleries. This innovative solution considerably differs from the existing ones, and its greatest advantage is versatility with regard to the cross-section and equipment of the roadway, as well as a wide range of functions. In addition, it can also be used for reloading works. The modular installation and transport assembly together with a platform, a temporary mechanized roof support and a mining machine, make up a mechanizes roadheader complex, which enables continuous mining, loading and installing the permanent support in underground workings.

Keywords: underground mining, steel arch support, modular installation and transport assembly, safety