Comparative analysis of hydraulic power systems for a powered roof support aimed at obtaining optimal power parameters

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Abstract. Hydraulic power systems for powered roof supports, depending on the place of installation of hydraulic aggregates, can be divided into local and central systems. Central systems are gaining popularity and a number of their features are more advanced compared to the local system. However, it is widely believed that their main disadvantage is the necessity to install pipelines with larger lengths, which can have a significant impact on the obtained hydraulic power supply parameters by occurring pressure losses on the pipeline length. This paper discusses the impact of these parameters on the correct operation of the powered roof support section, which is connected with the uninterrupted continuity of the production cycle in a longwall.

1. Introduction
The increase in the global demand for energy raw materials, such as coal, forces underground mining plants to maintain the current level of extraction and even to increase the output [2]. The increase in production may be obtained by operating in deeper seams. This in turn leads to an increase in natural hazards. One of such threats is methane, which significantly limits the progress of extraction [10, 13]. In order to maintain the current state of extraction and to influence its increase, intensive research is carried out on methane hazard modelling in order to effectively combat it [8, 10, 12].

Currently, in the research concerning the hydraulic system of the powered roof support section, much attention is devoted to control systems and active pressure monitoring in the under-piston space of a hydraulic leg [5, 6, 7]. Thanks to the rapid development of electronics, information technology and automation, particular emphasis is placed on the modernization of electrohydraulic control systems, striving to develop appropriate methods and algorithms enabling fully automatic operation of powered roof supports in shearer’s mechanization systems [1, 5, 9]. These activities are to be adopted primarily to increase the level of safety and improve the efficiency of extraction. However, for these systems to fulfil their functions, the powered roof support section should be supplied with an emulsion at an appropriate flow rate and under appropriate pressure. These parameters are to guarantee a properly selected hydraulic power system.

The basic elements of hydraulic aggregates used in hydraulic power systems of the powered roof support are emulsion tank, pump units, high pressure and flow filter assemblies. Figure 1 shows a schematic diagram of a hydraulic unit for powering a powered roof support. The idea of operation and construction of hydraulic aggregates in the applied power systems is almost always identical, and the
individual elements differ mainly in the parameters and technical solutions used. Emulsion from the reservoir through the suction line (marked in blue) goes to the pumps, from where it is pumped through the filter into the pressure pipe under high pressure. After powering the roof support, the emulsion flows through the discharge pipe to the tank through the filter.

![Schematic diagram of a hydraulic aggregate](image)

**Figure 1.** Schematic diagram of a hydraulic aggregate: 1. Oil-and-water emulsion tank, 2. Main pump unit, 3. Additional pump unit, 4. High pressure filter, 5. Outflow filter.

Depending on the place of installation of hydraulic aggregates and the number of powered longwall complexes, hydraulic power systems of the powered roof support can be divided into local and central systems (Figure 2). The local systems are located in the mining region close to the mining wall, most often in the collective slip or in the access drift. Typically, this system powers the powered support sections located within one exploited wall. This is the most commonly used solution in Polish mines so far. The central system is characterized by the fact that hydraulic aggregates are usually located near the shaft in a specially prepared and separated chamber. The central pumping station can power the powered support in several or all of the walls in a given mine. Therefore, the pumping units included in the central pumping station are characterized by higher capacity levels than those usually used.

Due to the location, this central power supply system has a number of advantages over local systems, including:

- obtaining an emulsion with better purity, because the aggregate elements are not in contact with dusty air,
- no need to relocate aggregates and perform work related to the preparation of their location in a way that guarantees correct and safe operation,
- possibility of monitoring pump operation parameters and their diagnostics with the use of automation elements.

However, the central hydraulic power supply system has a significant disadvantage, it is necessary to press the emulsion with pipelines of relatively large lengths. This involves increasing the resistance of the working fluid flow, resulting in a greater reduction in the pressure of the emulsion along the length of the pipeline. Unfortunately, this phenomenon adversely affects forces developed by hydraulic cylinders in the support section.
2. Assumptions for powering a roof support
Requirements for the hydraulic power supply systems of the powered roof support are determined by the assumed technical purpose, whose criterion is usually obtaining planned daily excavation. Sections of the powered roof support in the mining wall cooperate with the mining machine and the face conveyor and, thanks to functional and geometrical connections, they form a powered system. This means that the design of the bus supplying the support must be preceded by an analysis of the interaction of individual machines in terms of meeting the assumed technical purpose criterion. As part of such analysis, first of all, the required advance speed of the shearer should be determined to obtain the planned extraction, based on information on geological and mining conditions, technical factors and available technical equipment.

An important parameter affecting the process of completing the hydraulic power supply system is the time in which the support section must be moved to a new location in order to secure the newly developed roof of the excavation [3]. In order to maintain the continuity of the production cycle in the longwall, this time can not be longer than the time the shearer crosses the route equal to the scale of the support section (Figure 3), in other words, the roof development speed should be at least equal to the required advance speed of the shearer.

Figure 2. A schematic diagram of hydraulic power systems:
A. Local system, B. Central system.
Figure 3. Relationship between the time of advance of the powered roof support and the speed of the shearer [3].

For the assumed assumption, the minimum required emulsion flow rate in the supply system of the support section can be determined. The intensity should be such as to ensure that all activities related to moving the section to a new location within the determined time (Figure 4). The absorptivity of the powered roof support section will be influenced by the parameters of the hydraulic cylinders, the control system, and the number of control functions simultaneously carried out. In the case of high required roof installation speeds, it is worth considering the dynamic properties of the hydraulic system, such as capacitance, which affects the reaction time of the system during calculations. In order to determine the total required capacity of the hydraulic power unit, it is also necessary to pay attention to the loss of emulsion due to leaks and to the absorptivity resulting from moving the face conveyor [3].

Figure 4. Theoretical absorptivity of selected powered roof support sections depending on the roof development speed [3].
Figure 5. Percentage participation of individual activities in relation to the total time of moving the powered roof support unit KW-08/22-POz/ZRP.

The flow resistance of the working medium and the resulting pressure losses in the supply and control system, in particular the hydraulic shifter, also significantly affect the time of the support section advance [4]. The research team used measurements of the time of the KW 08/22 POz/ZR support sets advance in the mining longwall and theoretical relations to determined that the section moving operation occupies the largest part of the total advance time (Figure 5. Percentage participation of individual activities in relation to the total time of moving the powered roof support unit KW-08/22-POz/ZRPFigure 5) and is the most important in terms of obtaining the required roof development speeds. It can also be noticed that the operation of sliding out of leg lasts longer than sliding down. This results from the fact that it is necessary to recharge the pressure in the pressure bus. The supply bus should be constructed in such a way as to limit the occurrence of pressure losses.

3. Pressure losses in pipelines feeding a longwall system

Optimal selection of pressure and flow pipelines requires knowledge of pressure losses on their length depending on the flow of the working medium. The oil-water emulsions in coal mines are usually supplied through galvanized pipes. Figure 6 shows the pressure loss in the pipeline depending on the flow rate of the working fluid, the analysis covered the 4 most commonly used nominal diameters. The loss of pressure decreases with increasing diameter of the hydraulic conduit. On the basis of the analysis of the obtained results, it is not recommended to use pipes with a nominal diameter of 32 mm, when it is necessary to press emulsions with a high flow rate or a long distance [3].
Figure 6. Pressure loss on a section of 100 m pipeline comprising pipes of a given diameter.

4. Comparison of pressure losses in the central and local hydraulic supply systems

The comparative analysis included the case of supplying one of the excavations of KWK ROW Ruch Chwałowice mine. It is a longwall III in part IIIz of the mine in seam 408/1, which was decommissioned as the resources were depleted. The powered roof support located in this longwall (KW-08/22-POz) was powered by the local system during normal operation. Obtaining planned daily output was possible thanks to the use of 4 pump sets type T-100/32 manufactured in Poland (Figure 7). The total performance obtained in this way could amount to 400 l/min, which corresponds to the efficiency achieved by one Inoxihp PM400 pump (Figure 8) used in a central hydraulic pumping station.

Figure 7. Pump type T-100/32.  
Figure 8. Pump type Inoxihp PM400.

Figure 9 presents a schematic diagram of the underground infrastructure of the KWK ROW Ruch Chwałowice mine. It was prepared on the basis of mining maps that enabled obtaining information on the depth of the given excavations, their length and mutual location. Thanks to the knowledge of the difference in the depths of individual workings, static pressure in the pipeline can be determined, which is particularly important from the point of view of the flow pipeline. The length of the excavations, which corresponds to the length of the pipelines installed in them, affects the resistance of the working fluid flow. The analysis presented in this paper covered only the length of excavations,
because in the case under consideration the differences in depth did not play a significant role in comparing the two hydraulic power systems.

The Figure presents the location of the pressure and flow pipeline in the district supply system was marked in a blue, the location of the pipelines in the central system was marked in red. The local power system consisted of:

- DN50 pressure pipeline, 1044 m long,
- DN80 pressure pipeline, 1044 m long.

Pipelines in the central system should be divided into local and header ones. The header pipelines are the main lines where the emulsion goes to the mining regions (they are characterized by a larger diameter), from where individual longwall excavations may be directed by local pipelines. The purposefulness of such a division can be justified by the fact that assembly and disassembly of pipelines with larger diameters is more labour-intensive and time-consuming. Here, the central power supply system consists of:

- DN80 pressure header pipeline, 1228 m long,
- DN100 discharge header pipeline, 1228 m long,
- DN50 pressure local pipeline, 1024 m long,
- DN80 discharge local pipeline, 1024 m long.

![Figure 9. Scheme of underground infrastructure level 700, Chwałowice hard coal mine.](image)

The length of pipelines used in the case of supplying the discussed longwall system is more than twice as high using the central power supply system. In the present situation, this longwall was the only one maintained in the mentioned part IIIz of the mine. Pressure losses were determined in pipelines for a flow rate of 400 l/min. For pipe diameters covered by the analysis, pressure losses per 100 m of pipelines are presented in Table 1. The main reason for the pressure loss in long pipelines is the fluid friction against the conduit walls, local obstacles such as elbows or narrowings have a much smaller effect on pressure loss and are taken into account by increasing linear losses by 10%. Linear
losses depend on flow conditions, fluid properties and hydraulic hose parameters. These properties can be described by Reynolds number [14].

Table 1. Pressure loss over a 100 m section of the pipeline with a given diameter at a flow rate of 400 l/min.

| Pipe’s diameter (mm) | Pressure loss (MPa) |
|---------------------|---------------------|
| 32                  | 3.4                 |
| 50                  | 0.33                |
| 80                  | 0.029               |
| 100                 | 0.009               |

Based on the results presented in Table 1, pressure losses in the discussed systems were determined together with 10% of local losses:
- pressure pipeline in the local system – 3.79 MPa,
- discharge pipeline in the local system – 0.33 MPa,
- pressure pipeline in the central system – 4.18 MPa,
- discharge pipeline in the central system – 0.44 MPa.

The difference in pressure losses in individual systems is small and amounts to 0.39 MPa for pressure pipelines, and 0.11 MPa in the case of discharge pipelines. It results from the fact that pipes with larger diameters are installed in header pipelines, thanks to which lower flow velocities and linear loss coefficients were obtained. The flow of oil-water emulsion in the pipes of the hydraulic supply systems of the powered roof support is most often turbulent, which means that the fluid particles move in a disordered manner. The pressure loss along the length of the hydraulic hose is proportional to the square of the speed, therefore it is very important to obtain low flow rates of the working medium. An increase in the diameter of the hydraulic hose results in a decrease in the Reynolds number, which results in a more favourable linear loss factor [14]. In this case, replacing the local system with the central one did not significantly worsen the hydraulic power supply conditions. However, this does not change the fact that the pressure loss in the supply pipe alone was 13.9% of the supply pressure. The analysis also included calculations for the case of a central system in which the flow rate in the header pipelines is 800 l/min and in the local 400 l/min. This assumption is to simulate the supply of two longwall systems. In this case, the difference between the pressure loss in the local and central system was slightly higher and amounted to 1.35 MPa, the total pressure loss was 17.3% of the supply pressure. The distribution of losses in pipelines is presented in Figure 10 and Figure 11.

In both cases, however, the pressure pipeline DN50 installed in the bottom gate, not the type of hydraulic power system used, has a decisive influence on the pressure loss.
Figure 10. Pressure losses on the length of pipelines in individual hydraulic power systems when the flow rate is 400 l/min.

Figure 11. Pressure losses on the length of pipelines in individual hydraulic power systems when the flow rate in the header pipelines is 800 l/min and in the local 400 l/min.

5. Conclusion
The central hydraulic power supply system in mines where the operation is based on longwall system has many advantages over the local system, including [3]:

- better cleanliness of the working fluid,
- a uniform emulsion quality,
- simpler device control - grouped within one chamber,
- possibility of automatic diagnostics, introduction of computers to the central pumping station,
- no possibility of damage to the pumps due to the transport of other materials (it happened despite the maintenance of the correct dimensions of the excavation, that the materials transported to the longwall broke the wires in the pumps),
- no need to relocate devices and prepare for them the right place in the mining area,
constant supervision of the operator over the operation of pumps,
short distance to the shaft shortens the transport of the elements required to repair any failures.
The disadvantage of the central hydraulic system of the powered roof support is the necessity of using pipelines of relatively large lengths. The assembly of header pipelines is labour-intensive and time-consuming. It is also necessary to incur higher investment costs. The length of the pipelines also influences the increase of flow resistance of the oil-water emulsion, which is associated with greater pressure losses, which, however, can be eliminated by appropriate selection of pipe diameters.

Thanks to the use of larger diameter pipes, lower flow velocities are obtained which is extremely important because the pressure loss is increasing proportionally in the square of this velocity. The difference in pressure loss in the considered systems was small and amounted to 0.39 MPa in the pressure pipeline and 0.11 MPa in the discharge pipeline, this was obtained by using pipelines with the correct diameter. In the second discussed case, in which the supply of 2 longwalls from the central pipeline of the central hydraulic supply system and one longwall from the local system was simulated, the difference in pressure loss was 1.35 MPa in the pressure pipeline. These differences should not cause significant changes in hydraulic supply conditions between the systems used.

Designing hydraulic power systems for powered roof support systems should be preceded by an analysis of geological and mining conditions, technical factors and technical equipment, so that the selected supply system is an integral part of the longwall system.

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