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# Innovative Mine Floor Grinding Machine

*This article describes the process of development of the Hydroma floor grinding machine. It describes the current methods of solving exploitation problems related to uplifting of the floor in mining facilities and the issues of the need to maintain proper cross-sections of roadways under current mining exploitation conditions in order to ensure the continuity and safety of mining facility operations. The existing methods of floor grinding were analyzed in terms of cost, labor intensity, safety, and environmental protection. The following section outlines the process of developing a mine floor grinding machine at Urządzenia i Konstrukcje Spółka Akcyjna, namely the stage of technical and marketing analysis is discussed, during which the needs and possibilities of implementing the floor grinding machine were assessed, as well as the process of preliminary research and design, construction and tests conducted on a prototype grinding machine. The operation of the floor grinder – which is driven by an electric motor to grind the elevated rock bed, load and transport the grinded rock to the hauling trucks, all performed by remote control – is described. In conclusion, the advantages of the Hydroma grinder are discussed, as it performs the work efficiently, effectively and safely, without exposing the environment to harmful emissions.*

Key words: *longwall mining, longwall grinding machine, longwall face raising*

## 1. INTRODUCTION

In practically every industry there are works or technological processes that need to be carried out and without which the whole task or product cannot be realized, while at the same time these works are arduous, marginal, and often difficult to mechanize (they are mainly based on manual work). In the mining industry, and particularly in hard coal mines in Poland, one such onerous task is floor grinding in roadways, necessary to restore their original (nominal) dimensions. The uplifting of the floor is a natural process. "In many hard coal mines, problems with swelling and uplifting of the floor as a result of the high pressure of the rock mass and unfavorable mining and geological conditions start to occur a few weeks after the opening and preparation of the roadways, with the result that the dimensions and cross-section of the roadways are reduced. Difficulties then arise with regard to the proper operation of transport equipment, material transport and the restriction of the free cross-section of the roadways for the flow of air to the faces" [1].

Deformation of the floor can account for 80–90% of the total vertical conversion [2]. Ensuring the proper functioning of the roadways requires that the floor is kept to nominal diameters, i.e. the floor rock is ground and removed [1].

## 2. PROPER MAINTENANCE OF THE CROSS-SECTION OF MINE GALLERIES

Currently, exploitation has to be carried out under increasingly difficult geological mining conditions which require the mine to go deeper and deeper, resulting in specific hazards – methane, rock bursts, high temperatures, as well as those related to the exploitation pressure resulting in the frequent uplift of the floor (Fig. 1a, b).

In conditions of the increasing depth of exploitation and the related rise in temperature in the mine seams, as well as the increase in methane release during mining, it becomes crucial to maintain the correct parameters of the cross-section of the roadways which constitute the ventilation network of the mine. The correct cross-sections of the roadways make it possible to supply the right amount of air while maintaining the permitted air flow velocities in the roadways [2] (air flow velocities are regulated by mining regulations). Therefore, finding a way to maintain the dimensions of the mine roadways under the prevailing rock mass pressures is one of the basic factors ensuring a proper atmosphere in the mine roadways and eliminating methane hazards. “Excessive deformation of the floor makes it necessary to retrieve it, or results in reinforcement of the lining or complete reconstruction of the roadways” [2]. Maintaining the original geometry of the roadways is important, not only to ensure the proper ventilation of the mine roadways, but it is also important to remove the effects of uplift of the floor if there is a built in route for the transportation of mined rock by conveyors or railways, which may cause stopping of the transport of mined rock and/or the transport of materials and people by the railways [1, 2].

*a)* *b)*

*Fig. 1. Floor uplift: a) with marked floor crack lines; b) with marked uplift lines*

## 3. METHODS OF MAINTAINING THE REQUIRED CROSS-SECTIONS OF MINE ROADWAYS

Over the years, numerous attempts have been made to comprehensively mechanize the process of maintaining the floor, thereby reducing the time taken to carry out this work. However, to date, these attempts have not resulted in a successful solution. In empty roadways (without any built-up space at the floor), there are usually no obstacles to performing this work and a roadheader is often used, which can quickly and effectively restore the original geometry of the roadways. The problem arises when the roadways in question are already equipped with railways and/or conveyor. In this case, floor maintenance becomes difficult and time-consuming. In such cases, a combination of manual work, supported by the so-called „small mechanization” tools, and loading machines (if there is sufficient space) is used. Loading machines are commonly used in the Polish coal mining industry. They are used to pick up loose floor material and to load the excavated material after blasting the upraised floor during the mining works (using the blasting technique) and to pull materials in various places in the mine’s infrastructure. Loaders are self-driven machines based on a crawler chassis with an electrohydraulic drive in which all control functions are carried out hydraulically. The hydraulic pump is driven by an electric motor, powered by an unrolled cable connected to the mine’s electricity line. The disadvantage of this type of machine is that, in excavating operations, the bucket/clamp of the loader can only handle loose and cracked rock, but is unable to crush it. Another inconvenience may be the lack of a parallel mucking-out system, in the form of mine cars or containers suspended from a rail or conveyor, which forces the bucket to be moved to a potential unloading location. This has the effect of extending working time with operations that are not productive [3].

In the mining industry, attempts have been made to eliminate the disadvantages and inconveniences in the operation of loaders to give this type of machine new functionalities, e.g. by increasing the working range of the bucket, redesigning the arm in a similar manner to solutions used in construction machinery, i.e. the ability to quickly change the bucket for a small drum. Such attempts were made, among others, by a team at the AGH Department of Mining, Processing and Transport Machinery under the direction of Prof. Krzysztof Krauze on the basis of the ŁBT-700EH loader [1]. However, all of these attempts have failed to fully solve the problem of how to mechanize the floor grinding process, as they were based on a machine whose original purpose was different and therefore could not prove itself in such a specific line of work.

## 4. ASSUMPTIONS FOR THE CONSTRUCTION OF A MINE FLOOR GRINDING MACHINE

The company Urządzenia i Konstrukcje SA from Żory, Poland (UiK SA) made an effort to comprehensively design and build a machine from scratch which would be specifically dedicated to the mechanical grinding and transportation of excavated material. Until now, the problem of simultaneous mining and loading of the grinded rock was not solved. The simultaneous mining and loading of the rock is a complicated operation, which is why the machine solutions developed thus far have proposed the loading and gathering of the rocks only after the grinding had been made [1]. Among other things, due to the innovativeness of the solution – simultaneous mining and loading – the project entitled »Development of an Innovative HYDROMA Grinding Machine for Underground Mine« was submitted to the “Intelligent Development Operational Program” announced by the National Centre for Research and Development, where it was positively verified, as a result of which contract No. POIR.01.01.01-00-1117/18 was signed and funding was awarded for the implementation of this project.

## 5. DESIGN AND CONSTRUCTION OF THE GRINDING MACHINE

The technical team established by UiK SA performed a market survey among potential users regarding the expectations and features that such a product should meet.

As a result of the survey, the types of rock present in the floor were determined, and their parameters were examined with a view to select the power of the cutting unit of the floor grinding machine. Depending on the mine, level of extraction and gallery, different types of rock can be found in the floor zone, such as: clayey coal, claystone with coal laminae, coal shale, crushed claystone, layered siltstone, sandstone, masonry, crushed claystone with sandstone inserts, claystone with coal laminae, etc. For these rocks, the following parameters have been examined. The compressive strength $R$ (range from 8 MPa to a maximum of 70 MPa), volumetric weight (12.0–25.8 kN/m ), demouldability (0.4–1.0) fracture index RQD (5–70%), compactness index (0.4–5.9) were examined, among others.

At the same time, the shape and form of the occurrence of the uplifted floor were examined – Fig. 1a,b. The following formal assumptions were made in the design of the new machine: compliance with the Machinery Directive 2006/42/EC and ATEX 2014/34/EU, as well as the standards harmonized with them, i.e: PN-EN 12100:2010; PN-EN ISO/IEC 80079-38:2017-02; PN-EN ISO 80079-36:2016-07; PN-EN1127-2:2014-08.

Basing on the results of these tests, minimum parameters were determined in the creation of the first assumptions, which were in line with the expectations of the technical division at the audited mines. On this basis, the design team had to resolve the contradictions between the small dimensions of the machine and the requirement for a wide range of operation and functionality when designing. The proper selection of the mining drum was also a problem due to the shape of the uplifted floor and the variability and heterogeneity of its structure and construction [4].

The following key technical assumptions were made:

Mechanical design:

- weight of not more than 12 tons,
- travel speed not less than 6 m/min,
- travel on longitudinal slopes ±18°, transverse slopes ±5,
- height of grinding machine not more than 1.5 m,
- cutting drum (Fig. 2), with operating speeds of 20–25 rpm (speed 1) and 40–50 rpm (speed 2) – allows adjustment of the drum performance
- excavated material loading table with integral chain conveyor,
- a chain speed not less than 0.6 m/s,
- an assumed operational life of the pick not less than 8 hours for the assumed compressive strength of the floor.

Electrical components:

- main drive motor for the hydraulic pump,
- chain drive motor for the transport conveyor,
- main control box with frequency converter and protection.

Hydraulic circuits:

- two hydraulic pumps (one operating in closed circuit to operate the drum, the other operating in open circuit to drive the crawler trucks, loading arms, cylinders),
- loading arms drive motors,
- crawlers drive system.

## 5. TESTING OF A PROTOTYPE OF THE HYDROMA FLOOR GRINDING MACHINE

In order to reliably test the prototype under pressure of the high level of requirements for the new machine, a testing area with a test track was built in our company.In selected mines we examined the parameters of the floor, as well as fragments/chunks of the rocks. We used them in prepared mixes for test grinding in the test area. Three blocks were made from different compositions of B1, B2, B3 mixes. Dimensions of the blocks L/W/H: 2.8 m × 1.4 m × 1 m (Fig. 3). Their uniaxial compression strengths ranged from approximately $R = 20$ MPa to approximately $R = 70$ MPa. During the test, the blocks prepared in this way were arranged variously in relation to each other. At the same time, the grinding machine moved along a specially prepared rock and coal bed of varying granulation. During the cutting of the rock, blocks were placed in the testing ground that made it possible to simulate the grinding of the floor with different planes of approach: face, side, horizontal, and simultaneous grinding of several surfaces. Moving the Hydroma on the arranged testing ground made it possible to assess its stability during operation and its mobility while passing through difficult terrain.

A series of tests – about 30 trials in different variations over a period of almost 20 hours – allowed us to identify shortcomings which were immediately corrected/modified or, if necessary, entire subassemblies were reconstructed.

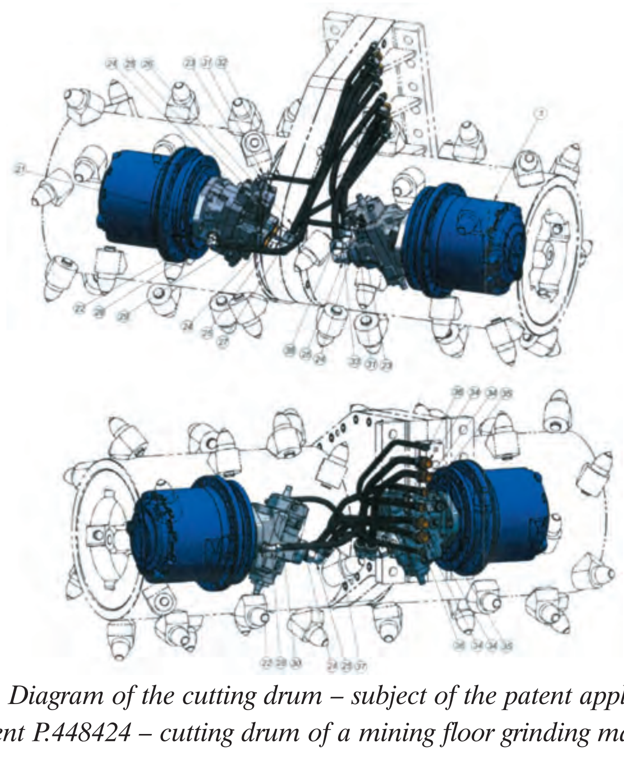

*Fig. 2. Diagram of the cutting drum – subject of the patent application. (Patent P.448424 – cutting drum of a mining floor grinding machine)*

*Fig. 3. Operation of floor grinding machine – grinding of blocks with chunks of floor rock on the testing ground*

Among other things, the problem with the malfunctioning feeder and the blocking of the loading arms (Fig. 4) was modified and resolved. The original design of the arms was too close to each other and because they were made entirely of steel it caused rocks to wedge between the arm and block them when larger pieces of rock were hit. As a result of the modifications, the ends of the arms were made of the original flexible scrapers.

*a)* *b)*

*Fig. 4. Loading arms: a) before modernization; b) after modernization*

As part of the modifications made to the Hydroma prototype, the water spray system was improved to primarily prevent ignition and explosion as well as to reduce dust and cool the knives [5] (Fig. 5). The effectiveness of this system was confirmed by tests at the Central Mining Institute PIB KD Barbara Dust Hazard Control Department. The installed water jet system provides an adequate level of safety for this type of mining machine and does not require additional spraying devices, e.g. behind-the-knife jets.

*a)* *b)*

*Fig. 5. Spraying system test stand: a) test trials; b) spraying system operation*

An additional foot placed at the rear was designed and constructed (Fig. 6) to allow support against the ground which stabilizes the machine during operation, especially on inclines. The varying strength of the bedrock causes the machine to vibrate. This is not a problem when the machine is working horizontally. Increasing the longitudinal inclination above >10, can cause the machine to slide during grinding. The support foot stabilizes the machine during operation. Unfortunately, this increases the operating time – the support prevents the machine from moving forward but allows the grinding system to work stably.

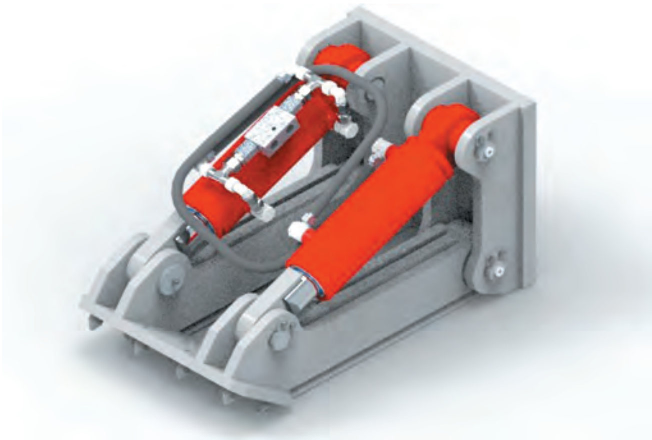

*Fig. 6. Supporting foot for the Hydroma floor grinding machine*

An essential component of this machine is a dedicated control system with algorithms and procedures in place to take into account the various conditions during normal operation and in emergency situations [6]. The control of the operation of the Hydroma floor grinding machine itself is implemented by means of a control panel (Fig. 7), allowing:

– the operator to be at a safe distance – outside of the environment of the pollution caused by the ground being excavated such as dust and noise,
– the possibility of introducing the grinding machine into areas exposed to various hazards – danger of landslides, falling objects, impact of other working machines, etc.,
– working in areas that are difficult to access without endangering the operator,
– the possibility of working in an environment that has a negative impact on people or poses a threat to their safety – chemical, biological, hydrogen and dust hazards, etc.

*Fig. 7. The control panel of the Hydroma floor grinding machine*

The proposed solution does not include cameras associated with the grinding machine. The operator can stay away from the grinding machine, but within its operating range, so as to allow its safe operation.

In more than 30 trials on the test track, the Hydroma floor grinding machine performed its work over a distance of more than 600 m.

In simulated start – stop cycles, carried out 50 times, the drive motor warmed up to 60°C (measured at the motor winding).

## 6. TEST RESULTS

Test performed on the prototype confirmed the key technical assumptions (mentioned earlier). The final weight of the Hydroma prototype (Fig. 8) was 12 tons and its height did not exceed 1.1 m. Positively result of tests allowed the Hydroma prototype to be prepared for examination and testing for compliance with the Machinery Directive 2006/42/EC and ATEX 2014/34/EU and their harmonized standards, i.e: PN-EN 12100:2010; PN-EN ISO/IEC 80079-38:2017-02; PN-EN ISO 80079-362016-07; PN-EN1127-2:2014-08.

The final result of the project was the TRL 9 technological preparation level. The built and tested machine exhibits a compact design when compared to roadheaders and loaders, an exceptionally low height of –1.1m, which allows it to work in galleries occupied by other machines, equipment or installations. It allows the performance of independent floor grinding, loading and hauling the excavated material via an integral conveyor. The Hydroma's design allows it to be equipped with a dedicated conveyor, increasing flexibility and convenience in planning the extraction location. The operator can control all of the machine functions via radio from a safe location. The machine's small dimensions, relatively low weight and clever design make it quick and easy to change its location between galleries and levels. In sections where this is possible, the grinding machine moves by itself within the range of the electrical power supply. To change location, only the power cable has to be rewired. In the event of further transport to another level, for example, it is possible to quickly dismantle and reassemble the machine in several pieces.

*Fig. 8. Prototype of the Hydroma floor grinding*

Comparing the work of the Hydroma floor grinding machine to previous floor cutting methods, the following results were obtained:

1. With the blasting method – complete elimination of blasting gases:

| Harmful factor | Unit | When using the blasting method | When using the grinding machine |
|---|---|---|---|
| Content of toxic components (NO) in gases | [l/kg] | 8.6 | 0.0 |
| Toxic constituents content (CO) in gases | [l/kg] | 18.3 | 0.0 |

2. With manual working methods assisted by so-called „low mechanization" tools:
   – reduction of inhalable dust concentrations:

| Harmful factor | Unit | When using the blasting method | When using the grinding machine |
|---|---|---|---|
| Geometrical concentration (GM) of inhalable dust in a gallery during floor cutting | [mg/m$^3$] | 8.25 | 7.0 |

– reduction in labor intensity and costs:

| Harmful factor | Unit | When using the blasting method | When using the grinding machine |
|---|---|---|---|
| Number of man-hours to remove 250 m of uplifted floor | [h] | 312.5 | 20.8 |
| Cost of removal of 1 m of uplifted floor* | [PLN/m$^3$] | 800.00 | 123.85 |

* Costs according to 2018 analysis.

## 7. SUMMARY

The results of the R&D project entitled. „Development of the HYDROMA Innovative Mine Floor Grinding Machine" not only resulted in the attainment of the TRL9 technological preparation level, but the achieved research and test results show that the floor grinding machine solves many problems related to the cutting of the uplifted floor. The use of Hydroma will make it possible to extend exploitation of galleries by restoring or maintaining their nominal cross-sections, without causing difficulties or interruptions in their operation. This will simplify logistical processes for the movement of materials, machinery, and equipment in such roadways and transport routes that are prone to disturbances in the form of the uplifting of the floor. This translates directly into a reduction in mining costs (other methods currently used to restore the functionality of roadways are disproportionately more expensive, as shown earlier), as these works are necessary if the roadways in question are indispensable in the long term and in the technological process of extracting the mineral or to ensure adequate ventilation. The machine built allows costs to be optimized in terms of restoring the correct dimensions of the roadways clamped from the bottom. The replacement of previous methods using explosives or combustion-powered equipment with an electrically driven machine equipped with a spraying device eliminates dust, the release of blasting gases into the mine atmosphere, and removes hazards resulting from blasting under methane hazard conditions.

The designed and manufactured machine offers the possibility of reconstruction in order to adapt it to other working conditions or applications. If there is a need to use a grinding machine with the above-described features in a different working environment, UiK SA has the capabilities and technical means to modify it appropriately or develop a new version of the grinding machine depending on market demand, e.g. with a combustion engine or battery electric drive.

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