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THE EVOLUTION OF MECHANIZED EXCAVATING SYSTEMS IN LGOM MINES CONDITIONS

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Abstract: This paper details the experiences of national copper ore mining associated with mechanized rock excavating systems. In particular, the machines used, technological solutions, efficiencies, and problems related to their implementation to underground copper mining conditions on Fore-Sudetic Monocline are discussed. Beginning from the experiences of „Konrad" mine in the Old Copper Basin where cutter-loaders type WŁE-50S were used - and ending with the ongoing tests with the Caterpillar ACT longwall shearer in the „Polkowice-Sieroszowice" mine. The implementation of mechanical excavation systems in KGHM's mines has not reached a successful level thus far, but the results achieved during the previous attempts are promising. The roadheaders used while excavating the mining drifts achieved very good results considering the given mining-organizational conditions.

Keywords: mechanized excavating system, longwall shearer, roadheader

1. INTRODUCTION

Currently, the flat copper ore exploitation in underground copper mines of KGHM Polska Miedź S.A. is typically achieved through the use of blasting technology. This requires the use of a technological system based on self-propelling machines. Maintaining the extensive service facilities needed to provide regular inspections and current repairs to these machines also incurs a significant increase of the unit cost of

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mining. The use of tire vehicles for mining works allows for the excavation of mining galleries with a minimum height of 1.8 m of opening that increases the dilution of copper ore and enforces location of gangues within the goafs due to dimensions of the mining machines. The constraining mining conditions, increasing depth of the deposit, and difficult geomechanical and climactic conditions, highlight the need to search out new technologies for mining works, particularly regarding thin deposits with a thickness of less than 1.5 m. With the emergence of the possibility of hard rock excavating using mechanized mining systems for rocks with a compressive strength greater than 120 MPa, new technological solutions based on roadheaders and longwall shearers have been considered. The implementation of mechanical excavation systems in KGHM's mines has not reached a successful level to this point. Several attempts have indicated that due to high geomechanical hazard (roof falls and high deformations of surrounding rocks) and the presence of hard rocks in deposits – the use of proposed roadheaders and longwall shearers haven't proved advantageous over traditional blasting based techniques. This indicates that mechanized excavating technologies should be still improved and upgraded to achieve maximum efficiency.

2. MECHANIZATION OF WORKS IN THE OLD COPPER BASIN

The start of production at the „Konrad" mine, located in Iwiny, began using simple and relatively inefficient devices. The mining faces and drifts at the initial phase were equipped with compressed air-powered trough conveyors. Along the entire length of the longwall, blasting holes with a length of 1.2 m were drilled. After blasting the longwall, output was loaded manually onto a conveyor using shovels. Between 1953-1961 the longwall works were equipped with haulage devices, which did not allow for the mechanical loading of ore. In 1955, loading the output was carried out using a pneumatic overhead loader. In the same year, the „Konrad" mine began implementation of an electrical drive called NRE-20, which led to the 1957 introduction of electric overhead loaders EPM-1. These types of drives were commonly used for run-of-mine haulage from the longwall workings until 1961. In 1962, within the framework of further mechanization of loading process, apart from armor conveyors „Śląsk", cutter-loaders type WŁE-50S was implemented. In 1963, the inclined workings were equipped with belt conveyors with a reinforced tip (PTP-650), allowing for partial mechanical loading of copper ore. In 1965, in these types of excavations, armored conveyors types „Grot" were introduced for loading and hauling. Until 1967, armor conveyors and cutter-loaders - type WŁE-50S - were the only equipment of the longwall workings of „Konrad" mine. In 1967, the scraper loaders were implemented for loading and hauling (fig. 1). They eliminated the manual loading process and allowed for a fully mechanized loading process, allowing a significant increase in the average length of burden. However, exploitation of the deposit was carried out using a blasting technique until the end of the mine life. (Paździora, 1999).

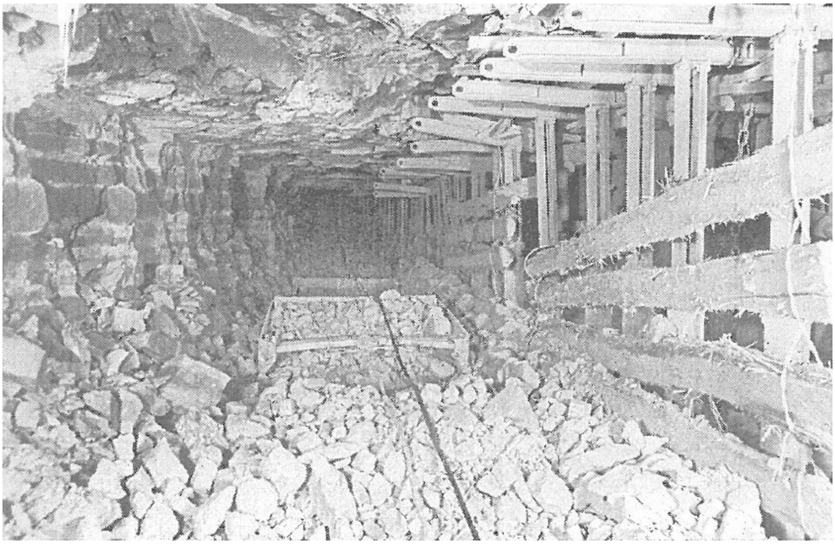


Fig. 1. Hauling of the output from the longwall by the use of a scraper loader (Paździora, 1999)

3. THE FIRST ATTEMPTS OF MECHANICAL EXCAVATING SYSTEMS IN LGOM MINES

The first attempts of a mechanical excavation of the rocks within the LGOM mines took place in 1991, in the „Polkowice-Sieroszowice" mine. The development workings in the rock salt deposit were excavated using an AM-50 Voest Alpine road-header. As a result of underground tests, it was found that the cutting head drive power was insufficient and the weight of the roadheader was too small to overcome resistance arising from the excavation of the mining face. Until present time, the mine workings located in rock salt deposit are being excavated using a AM-85P Voest Al-pine and ATM-105IC Sandvik roadheaders - additionally, since the concession for the industrial exploitation of the rock salt has been granted, prototype MB-770 Sandvik roadheader was applied. The first attempts of mechanical excavation of the copper ore took place in 1995 in the „Polkowice-Sieroszowice" mine using an E-169 roadheader manufactured by Paurat. During these tests, the used roadheader was excavating the full burden of mine workings with an average compressive strength of 35-230 MPa. On the cutting head, with a diameter of 570-1,200 mm with 100 kW drive, 42 cutting knives from sintered carbides were installed. During the tests a maximum efficiency of 17 Mg/h was achieved. Each excavation test lasted between 40-80 minutes. In this time, on average, 7 cutting knives were replaced. Finally, there was no further cooperation with Paurat Company in the application of mining roadheaders (Ziętkowski and Teodorski, 2011).

The roadheader was applied again in 2005 in the „Lubin" mine during the excavation of the inclined drifts AW-13/14/15 in the „Lubin Main" region. Inclined drift was carried out under very difficult geological-mining conditions. The stratigraphic 95 m throw made the exploitation process even more difficult. Excavating the mining drifts AW-13/14/15 was associated with the performance of the 2,500 m length of mine workings within Zechstein and Rotliegend gangues. The application of commonly used roof bolting supports was excluded due to geomechanical conditions and a steel arch yielding support was used. Using the blasting techniques in four shifts system, a daily progress of two burdens, i.e. 5-6 m could be achieved, assuming an uninterrupted technological cycle. In this case, use of the roadheader seemed to be the most advantageous solution. The AM-75 Alpine Miner roadheader version Ex-S manufactured by Voest Alpine (fig. 2) and equipped with two cutting heads, 50 cutting knives each, was chosen. The AM-75 roadheader was supplied with electric motors with a total power of 345 kW, while 200 kW was dedicated to the cutting units. The roadheader was also equipped with two working platforms and a lift, making the manual installation of arch support easier. Excavation of the mining drift started within the grey sandstone with carbonate cements at 42-122 MPa compressive strength. During the winning process, intensive water spraying of the cutting heads was applied. The wearing of cutting knives amounted to approximately 50 pieces per day. At this place, water from the head cooling system was falling down to the floor causing a swelling of the red sandstone. Plasticization of the floor and subsidence of the roadheader required the frequent relocation of the unit and significantly added a limitation to the progress of the work. This problem disappeared when the mining drift passed this zone and the unit started to excavate in softer red sandstone with a low content of clay minerals and less than 30 MPa of compressive strength. In this time, progress of 2 m per shift was achieved. To ensure the continuity of the technological cycle, operation of the following machines was required: 6 haul tracks, 2 spoon loaders, and 2 crawler tractors. The work was carried out in a four-shift system. One shift was intended for service. Excavation of the AW-13 inclined drift was completed in mid-March 2006. Similar to excavating the inclined drifts AS-33/34/35, the entire work was carried out in I, II and III degrees of water hazard. On the last stage of AW-13 inclined drift excavation, the water outflow from the research holes of 600 l/min. was noted. Having observed the increased water inflow caused by tectonic disturbances, the sealing of the rock mass was applied. Operation of the AM-75 roadheader in softer rock mass, while excavating the development drifts, gave satisfactory mining and economical results. During the first stage of work, until June 2007, approximately 1,982 m of mining drifts were completed. The next stage was to excavate L-141/142 inclined drift and lasted from March 2008 until April 2010. In this time 1,503 m of the mining drifts were excavated. The AM-75 Alpine Miner roadheader, due to the material of which the cutting knives were made, the size of the driving power, and insufficient total weight, which is required for appropriate stabilization of the unit while excavating, did not allow for operation in hard and high strength carbonates rocks (Napiórkowski and Tokarczuk, 2007).

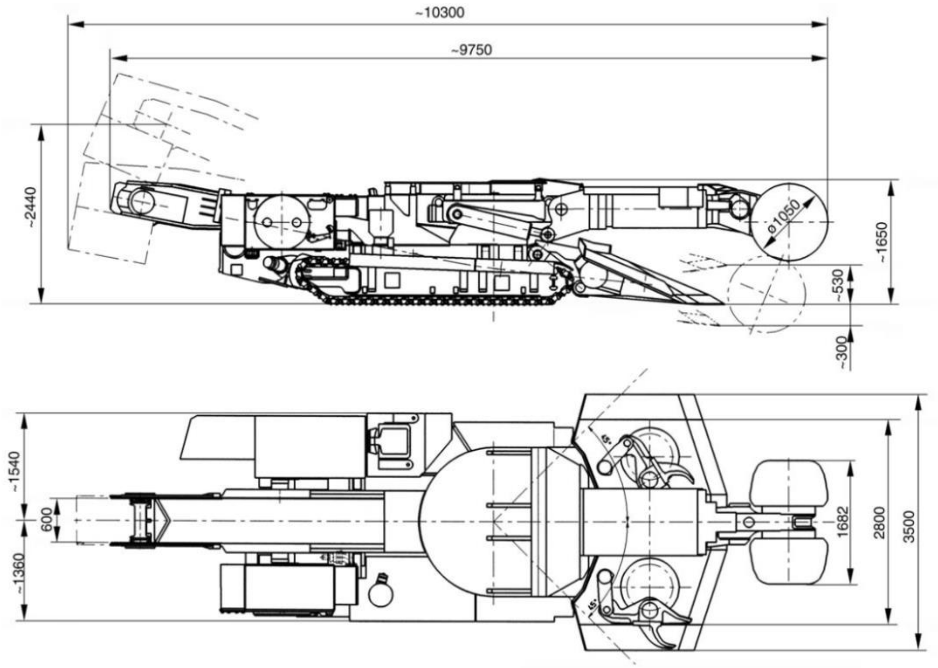
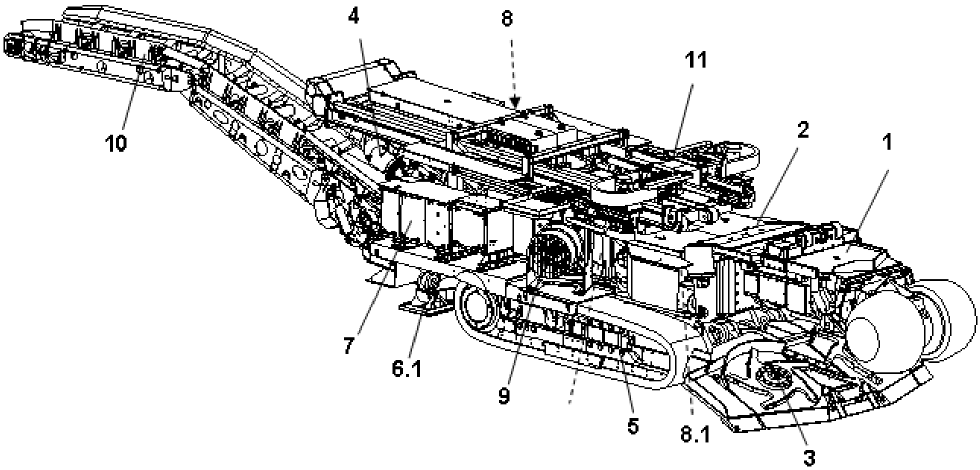


Fig. 2. Scheme of AM-75 Alpine Miner roadheader (Technical datasheet of AM-75)

4. SANDVIK MH-620 ROADHEADER

In 2009, the PeBeKa Lubin Company began the excavation of the development drifts within the „Lubin" mine. The MH-620/024 Sandvik roadheader was used for this purpose (fig. 3). This type of roadheader was designed to excavate the rock mass of rock with a compressive strength of up to 130 MPa and is equipped with a bolting unit and conveyor belt for haulage and loading of the output into the haulage tracks. The working unit consisted of a cutting arm, turret and loading table (fig. 4). The cutting arm consisted of a cutting plinth, which is an engine mount and is connected with a telescopic arm equipped with two shifting cylinders. The cutting arm was installed on the main frame of the roadheader. Additionally, it was supplied with a telescopic mechanism allowing for extension of the cutting head of 650 mm. It enables the excavation without a relocation of the entire roadheader. A 300 kW cutting engine was installed on a telescopic boom and cooled by water spraying. The cutting head is an element that has direct contact with the rock mass and is installed on the end of the gear unit via a spline. They are equipped with 2 x 72 pcs. of slots for a knives with a shank diameter of 38 mm and a cutting edge diameter from the sintered carbides of 22 mm. The loading unit function is to transport the output from under the cutting head on the receiving conveyor. This is a welded construction, hydraulically lifted and moving down. The mobile elements are so called 'loading star' wheels installed on the loading gear 2x36 kW.



1	Cutting arm	7	Electrical system
2	Turret	8	Hydraulic aggregate
3	Loading unit	8.1	Lubricating system
4	Chain conveyor	9	Cooling system
5	Tracked mechanism	10	Belt conveyor
6	Frame	11	Bolting unit
6.1	Back support		

Fig. 3. Scheme of MH-620 Sandvik roadheader (Tkaczuk and Czechowski, 2011)

The task of MH-620 roadheader was to connect the AS-35 inclined mining drift in „Lubin" mine with a C-5/7 inclined drift in the „Polkowice-Sieroszowice" mine. The total length of the planned galleries was 11,820 m and 20m2 of cross-section in the rocks with average uniaxial compression strength of 116.12 MPa. The work began in April of 2009 in the Z-702 behind the P-7 crosscut. Due to difficult geological-mining conditions in the selected place, the roadheader was moved to different, safer locations, primarily due to roof fall hazards. Finally, 257.5 m of mining drifts were excavated. Consequently, the observations made allowed for a determination of productivity parameters. During the excavation of the rock mass, the actual average efficiency was 11 m3/h. Several times, the daily progress of 6 meters with an efficiency of 20 m3/h (as declared by the manufacturer) was reached. Since the possibility of reaching the presented efficiency has been confirmed, implementation of the mechanized excavating systems based on Sandvik MH-620 roadheader in KGHM's mines continued. However, some changes in bolting and loading units were required. A decreased value of average efficiency was due to frequent mechanical failures, current modernizations, movement to other locations, and downtimes caused by an interruption in water and electricity supplies (Młynarczyk and Ziętkowski, 2010).

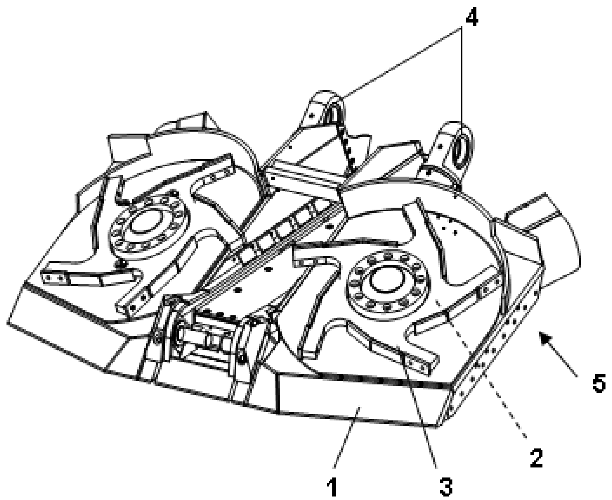


Fig. 4. Loading table of MH-620 Sandvik roadheader (Młynarczyk and Ziętkowski, 2010); 1 – loading table; 2 – loading gear; 3 – loading stars/scrapers; 4 – hydraulic cylinder; 5 – expansion system of loading table

After the first stage of work completion, the width of the working table was increased to 4,900 mm and the range of the hydraulic cylinders were extended. This allowed an increase of the width of the working table to 5,700 mm. However, increased width of the roadheaders' working table did not create a higher efficiency of haulage system due to a lack of changes in other parts of this system, i.e. chain and belt conveyors. Nevertheless, this allowed the elimination of some auxiliary work related to floor cleaning after roadheaders' driving. The operating range of the loading stars was increased. At the same time, some structural changes were made, which consisted of the replacement of the bolting unit. A single-arm tilt-rotary bolting unit with a telescopic boom was also installed.

When all of the modifications and structural modernizations were made, the Sandvik MH-620 roadheader was moved to another location. Having in mind the difficult geological-mining conditions from the previous operation, a central part of the Lubin-Małomice deposit, approximately 3 km west of L-1 shaft was selected. The compressive strength of the rocks from the exploitation gate ranged between 30-110 MPa. The new task consisted of excavating the EW-12 mining drift up to a C-107 inclined drift and then excavating a C-108a inclined drift with C-108a and C-107 diagonal crosscuts. The first attempts with the roadheader in a new location and after modernizations began on the 10th and 11th of June, 2010, and ran for 7 months. The CB-4PCK haulage track was used to transport the copper ore (with a load capacity of 20 Mg and 11.1 m3 of volume). A significant increase of efficiency and progress (from 35.6 m in June to 165.7 m in December) was observed. Disproportions of results were caused by assembly defects, as the roadheader was initially operating with incomplete power, and there was a low level of initial training of the crew and operators. During the observations made by KGHM CUPRUM and the manufacturer of the roadheader between October and November of 2010, the average daily progress of 7.5 m was observed, reaching a maximum level of 9 m and an actual average efficiency of 21.4 m3/h. Satisfactory results were obtained despite many downtimes caused by mechanical failures and mining factors. The final observed efficiency of the roadheader increased to 90% (Ziętkowski and Teodorski, 2011).

After the second stage of roadheaders' operation and subsequent full analysis of the results, some structural changes were made. Based on these conclusions a new version - 600 class - suited to LGOM mining conditions, was designed and manufactured. The main difference between the new and previous version was an installation of an air-conditioned operator's steering cab making the work more ergonomic. Nevertheless, more important structural change consisted in a reduction of the roadheader's size of 100 mm. Currently, MH-620 Sandvik roadheader is successfully operated in the works being carried out by PeBeKa Lubin Company (Nowak, 2012).

5. EXCAVATING THIN DEPOSITS USING AN ARM-1100 ROADHEADER

In 2004, the first attempts to excavate copper ore deposits as a part of the mining process took place in the „Polkowice-Sieroszowice" mine. The Voest Alpine ARM-1100 roadheader, equipped with a cutting head with asymmetric cutting discs located on the perimeter of head's disc was used (fig. 5). It was designed for mechanical excavation of a deposit at 1.1-1.3 m thickness. Excavation of the rock mass consisted of undercutting the rocks with a cutting head in the horizontal movement range of 120˚. The copper ore from one cycle of the cutting head was scraped by blade and then moved by feeder to the further devices of a haulage system. (Szpak, 2008).

As a part of the ARM-1100 operation, mining drift parallel to A-1/6 inclined drift between the A106/6 gallery and P-10 cross-cut of A-1/6 inclined drift was excavated. Attempts of rock mass excavation in the area of the junction of the P-9 cross-cut and A-1/6 inclined drift were carried out. Two mining drifts along the A-1/6 inclined drift with the total length of approximately 560 m where assumed. However, only 44 m of the mining drift was excavated. Excavating of the unmined rocks behind the protective pillar along the A-1/6 inclined drift was also planned. Finally, ca. 170 m of inset within the unmined rocks were excavated (fig. 6).

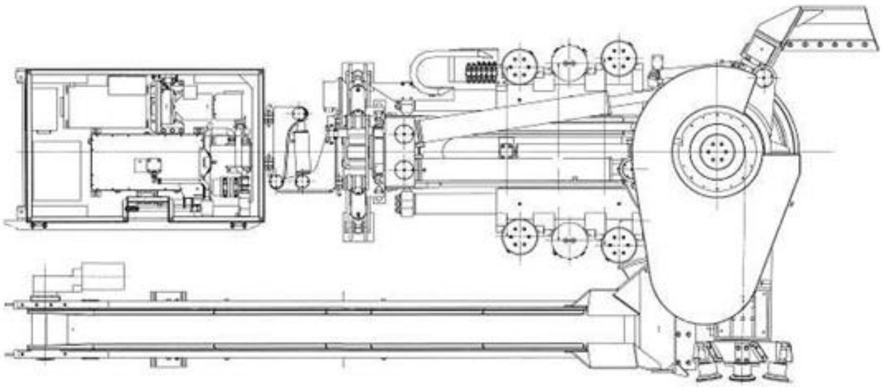


Fig. 5. Scheme of ARM-1100 Voest Alpine roadheader (Gromysz et al., 2005)

Problems arose at the beginning of the mining works, directly after the roadheader was moved from the platform to the floor. Strength of the shale was insufficient for carrying the load from the roadheader's struts, around which the cutting head rotates. Additionally, inadequate machine stabilization on the floor resulted in an increased vibration of the construction while excavating. This problem was resolved by applying an expanded floor prop.

Testing carried out underground indicated the following weaknesses of the ARM-1100 roadheader: time-consuming movement, inefficient system of excavated rock collection from the cutting head's working space, and difficulties of breakdown removal. This had a significant impact on the availability rate of 55.7%. These factors negatively affected the adoption of the proposed solution, but on the other hand, an average efficiency of the excavation by a cutting head of 20 Mg/h (max. 53.6 Mg/h) was achieved. The minimal wear of cutting tools, which excavated 133 m was noted, even though 50 m was preliminarily assumed. The average uniaxial compressive strength of the excavated rocks was 103.1 MPa. Additionally, a sieve analysis of the output was carried out. It showed that 60% of grains had a diameter smaller than 20 mm. The output grined like this would allow for significant savings in subsequent stages of haulage and processing. This justified the necessity to implement a mechanical excavating system using a new generation of roadheaders. The tests results, amount of excavated material, and the surface of exposed roof, however, did not provide sufficient information to clearly identify the mining system that should be implemented for roadheader excavation in LGOM mining conditions (Gromysz et al., 2005).

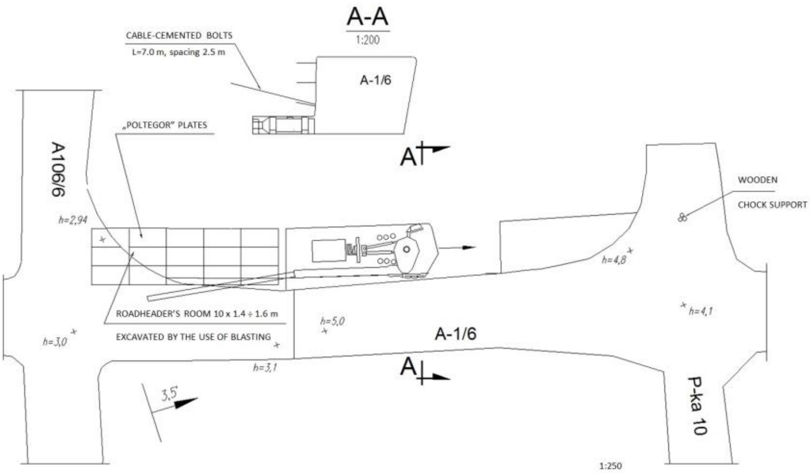


Fig. 6. Location of excavation along the A-1/6 inclined drift by the use of ARM-1100 roadheader (Gromysz et al., 2005)

6. ACT LONGWALL SHEARER

In recent years, the developments in the field of mechanized excavating systems for hard rocks, indicates that exploitation using a longwall mining system may be effective and profitable for thin deposits. In 2007, conceptual studies of the implementation of ACT longwall shearer began (fig. 7). Exploitation of the first A-5/1 longwall face in the „Polkowice-Sieroszowice" mine began in early 2013. It was carried in transverse arrangement out up the rise towards the P-1 cross-cut. Liquidation of the mined out area was conducted by the roof deflection on artificial, irremovable, goaf's pillars, i.e. „Link-N-Lock" wooden chock support. The length of the longwall was 44 m and the distance from the longwall face to the goaf's line approximately 10 m. The discussed mining field was determined by the A-5D and A-5C inclined drifts, where the A-5D was the bottom drift and A-5C the top drift. The longwall was equipped with 23 sets of powered-roof support, including 12 sections with installed anti-falling roof-bars, a plated conveyor and ACT longwall shearer. Haulage of the output was conducted by the bottom drift from the longwall conveyor to the haulage equipment of mining division (Butra and Matusz, 2014).

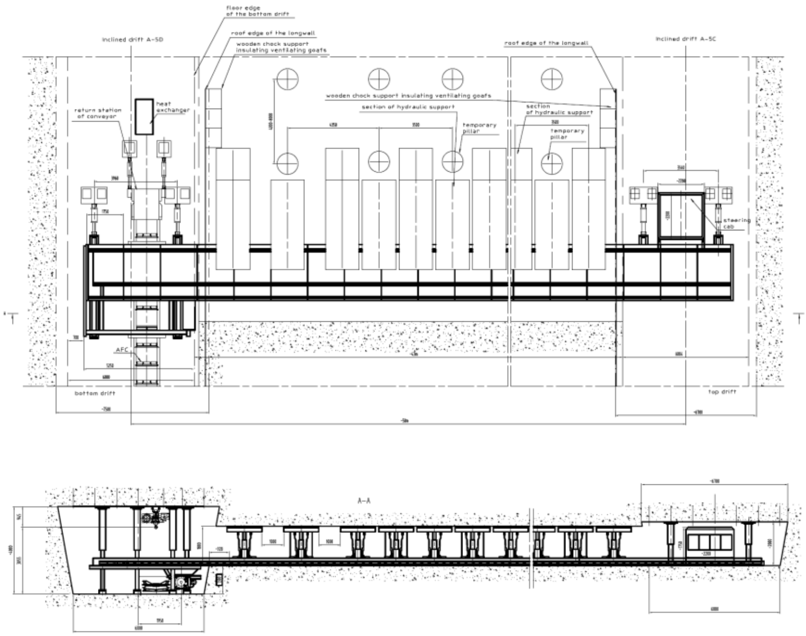


Fig. 7. Scheme of the trial longwall in „Polkowice-Sieroszowice" mine (Butra et al., 2015)

During the excavation within the trial panel, spontaneous roof falls have occurred. The first one occurred on the 27th of August 2013 covering the roof directly behind the sections of powered-roof support. The roof-fall area was located within the goafs. The artificial walls in longwall drifts made by previously mentioned wooden chock support were not destroyed. After the roof fall occurred, spacing of the wooden complex support sets were changed. To reduce the deformation of the longwall drifts and increase the operational safety of the works, two rows of wooden chock support, separating the goaf's zone were applied. A major problem during excavation attempts have been falling rock plates from an unsupported roof to the working space. They are removed prior to protection of the roof by the use of additional prop support.

7. SUMMARY AND CONCLUSIONS

The implementations of mechanical excavation systems in LGOM mining conditions have not reached a successful level so far and are still being tested, although results obtained in the previous attempts are quite promising. The roadheaders used while excavating the mining drifts achieve very good results under the given mining-organizational conditions. The development of mechanical excavating techniques can be a key element of exploitation when the thickness of the deposit is less than 1.5 m. Experiences of ACT longwall shearer implementation allows for the collection of necessary information in order to improve its effectiveness. Excavating the deposits by the use of longwall shearers gives the possibility of the copper ore exploitation from currently technologically inaccessible or unprofitable deposits. Mechanical excavation of the rocks is one of the most important strategic initiatives of KGHM. An improvement of the efficiency of mining works is expected. Furthermore, it has a significant correlation with the conditions of copper mines operation within current and prospective areas of exploitation. Efficiency of the entire mining process depends on efficiency of excavation of the rock mass.

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TECHNICAL DATASHEET OF AM-75 ALPINE MINER.