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Unique cutting heads equipped with tips for mining frozen rocks and minerals

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Abstract
Cutting heads are the cutting elements of many working machines. Although they have been used successfully for several decades in the mining, road, or construction sectors, new solutions and designs are still being developed. Today's most common cutting heads in the mining industry are the cutting drums of longwall shearers and the cutting heads of roadheaders. Cutting heads are also used in continuous miners, shaft boring machinery, and many other, less common machines. Cutting heads vary in design, shape, diameter, and width as well as in the type and arrangement of cutting tools. As a result, they can be equipped with many picks, the number of which ranges from a dozen to more than two hundred. There are numerous studies devoted to the cutting heads of longwall shearers, roadheaders, and continuous miners; hence, this article is concerned only with unique cutting heads equipped with cutting tools. It discusses the problem of determining essential properties of the mined rock, including the cuttability index and the breakout angle. Examples of original cutting heads have been presented. The cutting heads used for shaft excavations have been described: one designed for extracting salt and the other for mining frozen rocks. A cutting head to be used in open-pit mining and a similar one for cutting the floor in an underground mine have also been presented, as well as a special cutting head, which, unlike typical cutting heads, is not circular in cross-section but oval in shape, so it has a steplessly adjustable cutting height, suitable for uneven seam profiles. The cutting head with a variable cutting height allows for more efficient exploitation of thin mineral seams with variable thickness. The cutting heads under consideration have been designed for specific operating conditions and machines, and most have been implemented in real-world conditions.

Keywords
cutting head, cutting drum, design of cutting heads, rock mining, variable height cutting head, mechanised rock cutting, shaft excavation, floor excavation.

Introduction

Cutting heads are the cutting elements of many working machines. Although they have been used successfully for several decades in the mining, road, or construction sectors, new solutions and designs are still being developed. Today's most common cutting heads in the mining industry are the cutting drums of longwall shearers, equipped with conical picks, designed for the extraction of hard coal and associated rock (Krauze, 2000; Bołoz & Castañeda, 2018; Biały, 2024). The second group of cutting heads is intended for roadheaders and continuous miners, equipped with conical picks designed to drive headings and extract minerals in room-and-pillar systems (Kotwica & Klich, 2011). The cutting heads are also used in machines such as shaft boring machines, open-pit shearers, surface miners, floor miners, and many other machines (Bołoz & Kalukiewicz, 2020; Bołoz, 2013; Bołoz, 2018a; Bołoz, 2018b; Bołoz, 2025, Kovanic et al 2021).

Cutting heads vary in design, diameter, shape, width, type, and arrangement of cutting tools. Cutting heads can therefore be equipped with many picks, the number of which ranges from a dozen to more than two hundred. The construction and design of cutting heads for extracting hard coal and associated rock with longwall shearers and roadheaders is described in the literature (Jonak, 2002; Kotwica & Klich, 2011; Krauze, 2000; Biały, 2005; Rożenek, 2019; Siegmund, 2021; Krauze et al., 2009; Biały et al., 2024).

The primary function of the cutting head is to excavate the rock to obtain spoil, to drive excavations, or to level or enlarge the existing ones. However, it is essential to note the second function of many cutting heads, i.e., loading the spoil. They primarily load longwall shearer cutting drums (Krauze, 2000; Wydro, 2011; Wydro, 2015; Wydro, 2020). However, the cutting heads of continuous miners, surface and floor miners, i.e., cutting heads characterised by a considerable length compared to their diameter, are also designed to move the spoil over considerable distances, to the centre of the cutting drum, where a means of transport, such as a conveyor, is located. Hence, these cutting drums are also engaged in the loading process. The short drums of machines such as roadheaders have small vanes or appropriately placed pick holders that load the spoil towards the shovel plate.

The diameter of a longwall shearer cutting drum ranges widely from 380 mm for thin seams (Bołoz, 2018a) to the typical 1,200 mm - 2,200 mm (Grenevia SA FAMUR, 2025) and up to 3,500 mm (Joy, 2025b). On the other hand, their width (web) is usually in the range 800 mm ÷ 1,200 mm. The cutting heads of roadheaders are made in the shape of a body of revolution. Similar cutting head solutions are also used as a cutting adaptor for various machines, including excavators. Unlike the others, such cutting heads are driven by hydraulic motors. Similar solutions are used as adaptors for scalers (roof scale machines) for underground mining, such as Mine Master's Roof Scaler 2,3D (Mine Master, 2025), or a dinting loader, such as the solution developed at AGH for the ŁBT 700-EH loader (Krauze & Kotwica, 2009). The single cutting heads of such machines range from approximately 700 mm to 1,500 mm in diameter and approximately 700 mm in width, with an overall width ranging between 1,200 mm and 17,000 mm (Jonak, 2002; Kotwica & Klich, 2011). The cutting head of continuous miners ranges in diameter from approximately 740 mm to 1,480 mm, and in width from 2,900 mm to 6,000 mm (Jonak, 2002; Biały et al., 2024). The cutting heads of the most popular cutting machines are depicted in **Chyba! Nenašiel sa žiaden zdroj odkazov.** (Bołoz, 2025).

Fig. 1. Examples of cutting heads:

a). The SL 1000 longwall shearer from Eickhoff (Eickhoff, 2025), *b). The MT521 roadheader from Sandvik (Sandvik Mining Equipment, Parts & Services, 2025)* *c). The Komatsu 14CM15 continuous miner (Joy, 2025a)*

Roadheader cutting heads equipped with conical picks are commonly used to cut various rocks. Alternatively, cutting heads with disc tools can be found. The disc tools roll over the surface to be mined with a high normal force and destroy the rock by static pressure, like indenters. Tunnel boring machines (TBMs) are equipped only with disc tools (Bołoz, 2019, 2020a; Bołoz et al., 2020; Bołoz & Kalukiewicz, 2020; Kotwica & Małkowski, 2019; Krauze et al., 2015; Techgong, 2024). For longwall shearers, disks were applied only for testing in prototype coal-cutting drum solutions (Krauze, 2000). However, undercutting has recently been applied in many machine solutions, among others, in the process of rock chipping by shearing. Rear undercutting can also be applied in the case of conical picks (Bołoz & Kalukiewicz, 2020; Dewangan & Chattopadhyaya, 2016; Kotwica, 2018). A unique cutting head to be fitted on heavy equipment with disc tools has been developed at AGH. This cutting head utilizes the undercutting method, resulting from a complex tool trajectory (Gospodarczyk et al., 2013; Mendyka, 2016).

Materials and methods

The properties of rocks are numerically described by many characteristics, utilising dozens of physical and mechanical parameters. Among the physical properties are, for example, density, porosity, and absorbability, with apparent density (with pores) being the most commonly determined. Mechanical properties include friction angles, cohesion, cutting workability, hardness, abrasion and abrasiveness, and tensile, compressive, or bending strength (Kopas et al, 2017a; Kopas et al, 2017b). The most important mechanical properties of rocks are uniaxial compressive strength, cutting workability, and abrasiveness (Hobler, 1977).

According to the International Society for Rock Mechanics, rocks with strengths between 50 MPa and 100 MPa are strong, 100 MPa to 250 MPa are very strong, while those above 250 MPa are extremely strong (Vogt, 2016). In its mining tool catalogues, Sandvik provides overlapping strength ranges: rocks up to 30 MPa are considered weak, 20 MPa to 50 MPa are medium, 40 MPa to 80 MPa are strong, and above 70 MPa are extremely strong (Sandvik Mining Equipment, Parts & Services, 2025). Poland has adopted a similar rock classification based on uniaxial compressive strength (Biały et al., 2023).

While uniaxial compressive strength is insufficient for selecting a tool or estimating cutting resistance, it is most commonly determined and readily available for many rocks. In contrast, workability is a parameter that quantifies a rock's resistance to cutting by a tool. The workability of a rock is determined by two parameters: the cuttability index A and the breakout angle ψ. It is determined empirically by measuring the cutting force during the measuring cut on a special test rig installed in situ. The test rig allows cutting the rock with a defined depth, width, and length. A diagram of this test rig is shown in Fig. 2a.

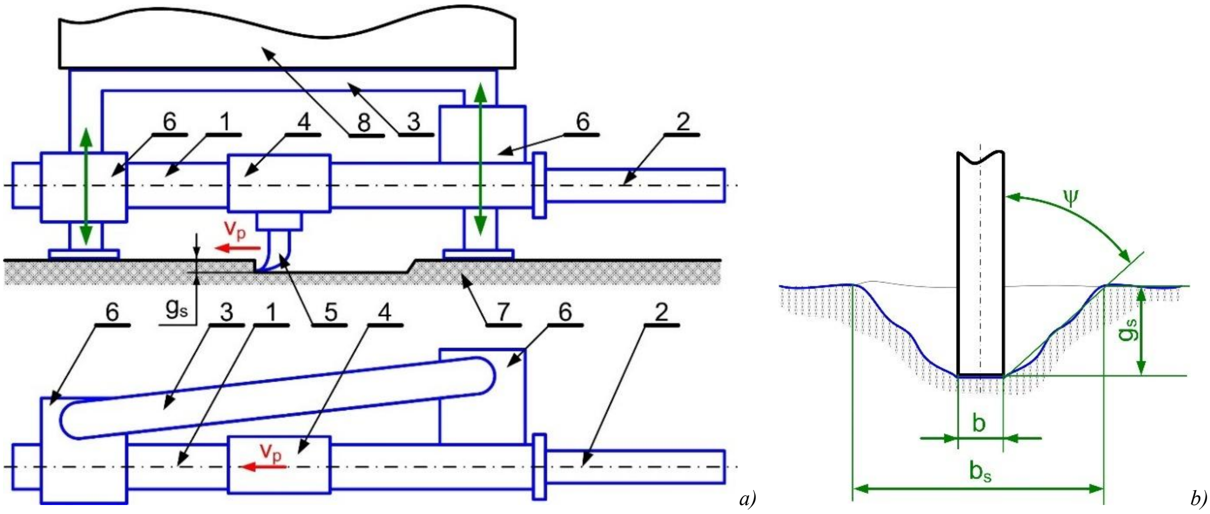


Fig. 2. Determination of rock workability (Bołoz, 2025):
a). schematic of the test rig mounted on the frame: 1 - crossbar, 2 - hydraulic cylinder, 3 - frame, 4 - carriage, 5 - levelling or measuring picks, 6 - adapter, 7 - unmined rock, 8 - frame clamp
b). diagram for determining the breakout angle of the rock

A hydraulic cylinder is responsible for the linear movement of the carriage with cutting picks. During cutting, the inlet and outlet pressures of the hydraulic cylinder are recorded. After the cut, the actual depth (g_s) and width of the cut (b_s), marked in Fig. 2b, are measured. The values of the cutting force and cut depth make it possible to determine the cuttability index, which is proportional to the cutting force and inversely proportional to the depth of the cut. Simultaneously with the measurement of the cuttability index, the lateral breakout angle ψ is determined, which determines the structure of the rock with regard to whether it is compact or brittle.

The greater the numerical value of the cuttability index A, the more difficult the workability of the material in question. At the same time, the smaller the breakout angle *ψ*, the more compact the mineral is. Based on the cuttability index A and the breakout angle ψ, the rock category can be determined and a suitable mining technique selected for the rock casing. This method determines the workability of coal and other rocks to be mechanically mined (Bołoz, 2020b). The rock category is determined according to the classification of rocks developed by ITG KOMAG, but other classifications are also used in practice (Biały, 2005).

The presented method of determining workability is one of many known methods; among others, it is worth mentioning the method using the Sikora, Potępski, or POS-1 device. The latest method of determining workability is based on the use of the POU-BW/01-WAP device (Biały, 2014; Biały, 2015). The subject literature provides a detailed review of methods and equipment for determining relevant properties of rocks, especially workability (Biały et al., 2023). The above-mentioned device allows cutting according to the real trajectory of the picks. Both devices for determining the cuttability index and the breakout angle are illustrated in Fig. 3.

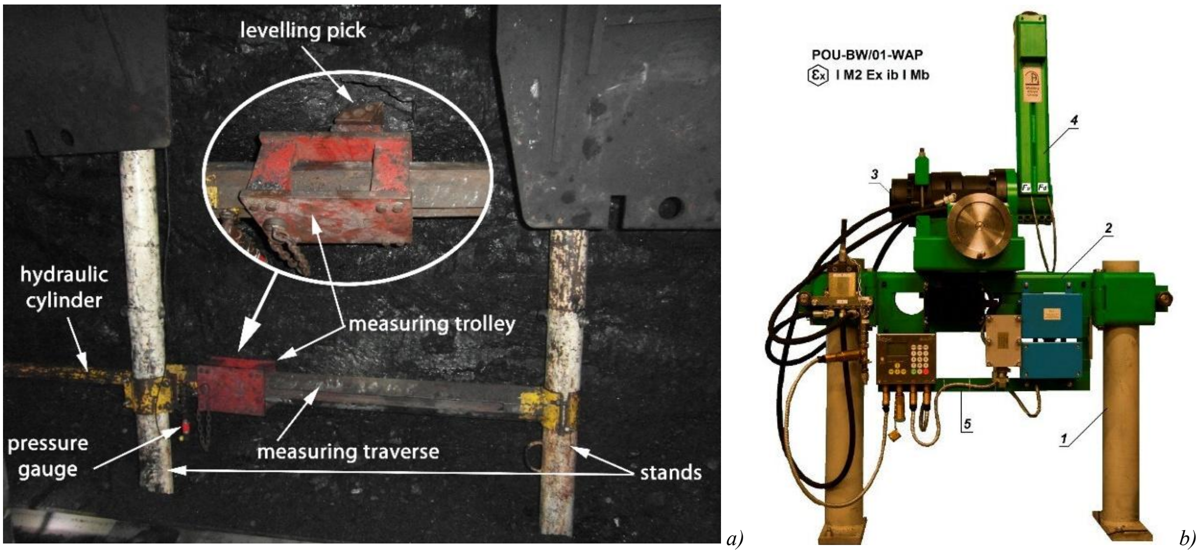


Fig. 3. Devices for determining rock workability in situ:
a). AGH device (Bołoz & Midor, 2018), b). POU-BW/01-WAP device (Biały, 2014)

An adequately designed cutting head with an appropriate tool system, using the assumed kinematic parameters, should ensure the lowest energy consumption of the process, high productivity, and low dust and fragmentation of the mined material (Jonak, 1998; Sikora et al., 2000; Bołoz, 2025). This article presents selected cutting heads for specific operating conditions. When designing a cutting head for mining a specific rock, the first stage is always to determine the rock's properties, followed by selecting the geometrical and kinematic parameters of the cutting head, the pick holder, and the tools.

Spatial cutting head for mining rock salt in shafts

A unique spatial cutting drum was designed for the mechanical excavation of a ventilation shaft in one of KGHM's mines. The shaft, designated SW-4, with a diameter of up to 9,200 mm, was excavated using a KDS-2 shaft shearer with the shaft brine-freezing method. The KDS-2 shaft boring machine was designed to modify the KWB-6 longwall shearer, enabling it to cut rocks with a strength of up to 35 MPa. A characteristic feature of the machine was the vertical axis of rotation of the cutting drum. The shaft boring machine was a part of the shaft complex. During excavation of the SW-4 shaft at depths of 1,020 m to 1,190 m, mining was carried out in a rock salt dome. Consequently, a new shaft cutting head solution had to be developed to allow efficient mining with the machine used (Krauze et al., 2012a; Krauze et al., 2012b). The salt-cutting head was the second cutting head developed for this shaft. The first one was a barrel cutting head (without vanes) equipped with conical picks, which made it possible to carry out the slotting process in half the time achieved with the previously applied solution. Moreover, due to its use, the resulting side wall was perfectly even (Fig. 4) (Krauze et al., 2010).

Although rock salt does not have a high compressive strength, it has a high cutting resistance under load, i.e., during cutting. It was necessary to determine the properties of the salt found in the SW-4 shaft. During the cutting drum design phase, the bottom of the shaft did not reach the level of the salt dome, making in situ testing impossible; therefore, tests were carried out on a supplied piece of salt from another site within the same dome. The cuttability index laboratory tests revealed that the workability of the salt was very high, especially compared with the coal for which the KWB-6 longwall shearer was designed. At the same time, the breakout angle indicated that the tested salt was workable, allowing for larger cutting spacing. Tests of uniaxial compressive strength showed that the salt was in this respect comparable to very difficult-to-machine coal seams (Krauze et al., 2013).

a) b)

Fig. 4. Cutting head ϕ1225 x 840 (Bołoz, 2025):
a). picture of the cutting head working in the shaft, b). Effect of mining on the shaft side wall

A special ϕ1340 mm × 750 mm spatial cutting head was designed in compliance with the requirements arising from the shearer used and the results of salt testing. The characteristic feature of this cutting head is the use of two discs and crossbars instead of the typical vanes or drum. The design was based on the idea described in a patented AGH-developed solution (Krauze, Wydro, et al., 2014). The 3D model of the cutting drum and its body in their original state is shown in Fig. 5, while the finished cutting heads on the shaft surface and during salt mining are depicted in Fig. 6.

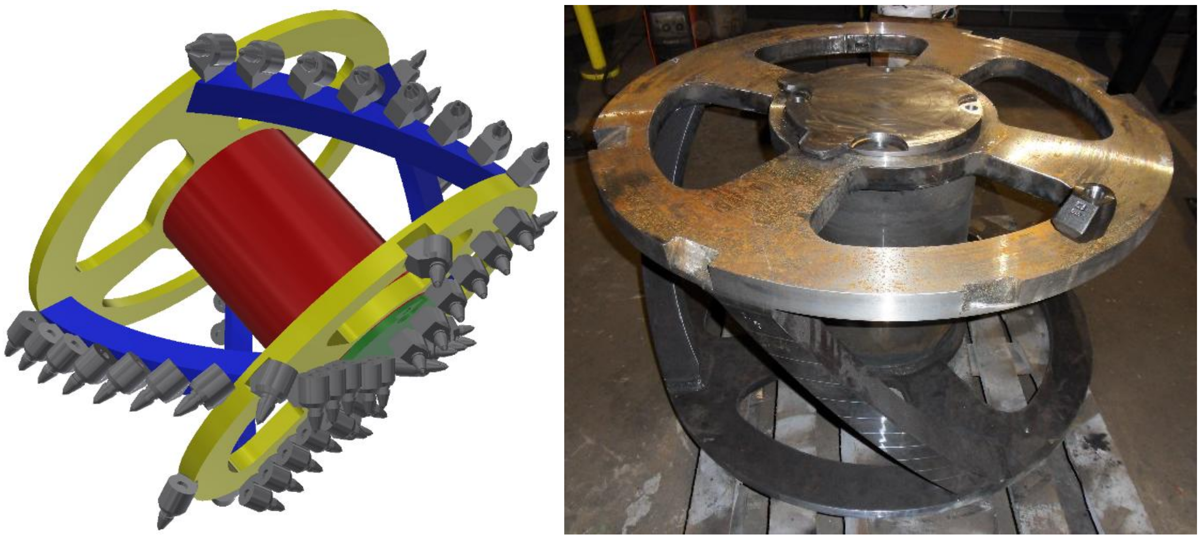
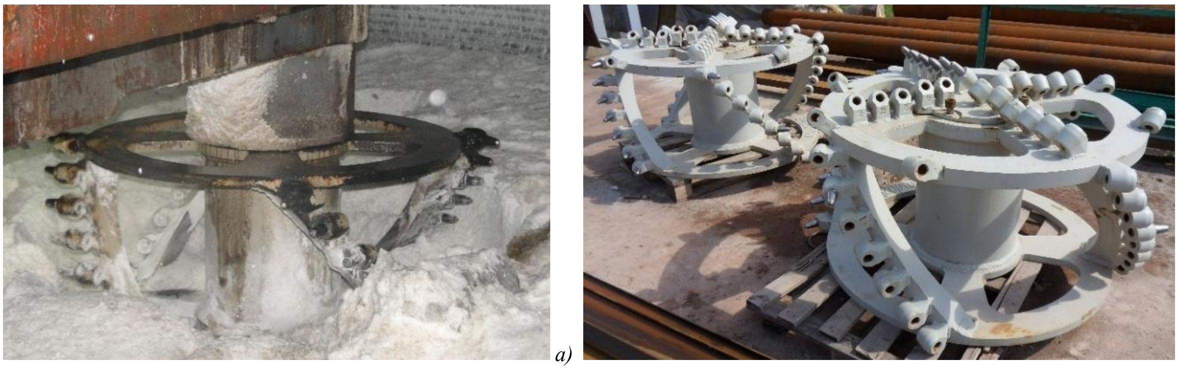


Fig. 5. 3D model of the cutting head and its body during production (Bołoz, 2025)

The cutting head with two discs and four crossbars was equipped with a total of 58 picks with a working part length of L_r = 62 mm and a tip angle of $2\beta_u$ = 75°. On the crossbars, 28 picks with a spacing of 80 mm were located. There were eight picks on the disc and 22 on the end face. This solution was possible because the cutting drum did not have to perform the loading function, and the salt could flow freely into the cutting head's body and onto the floor. By increasing the volume of the cutting head, this spatial design reduced the recirculation of salt, thus reducing the resistance of the process. The cutting head met expectations and allowed the SW-4 shaft to pass through the salt dome, resulting in an excavation 7.2 m in diameter.

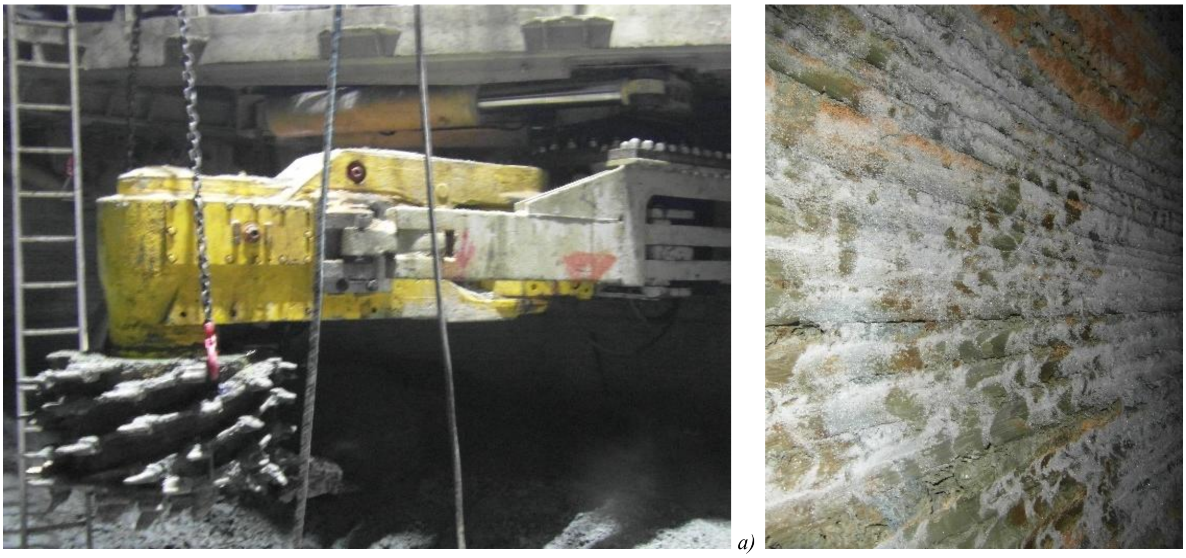


a) b)

Fig. 6. Spatial cutting head for salt:
a). during salt excavation in the SW-4 shaft (Bołoz, 2025), b). on the surface of the shaft

Shaft spatial cutting head for frozen rocks

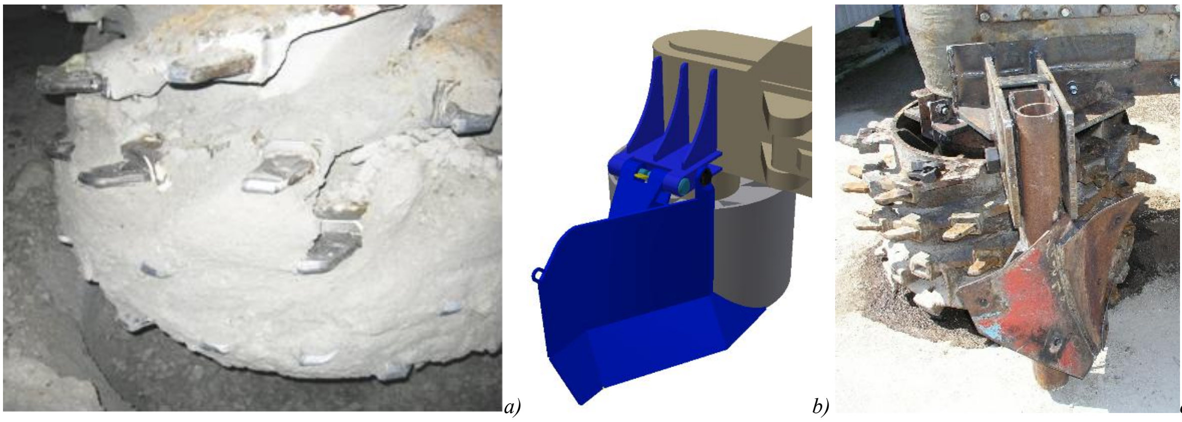
Shaft GG-1, also for one of KGHM's mines, was excavated using the KDS-2 machine mentioned earlier. Similar to the previous one, shaft GG-1 was excavated using the brine freezing method. Fig. 7 shows the KDS-2 shearer with the original cutting drum with vanes equipped with radial picks, and the frozen rock after cutting.



a) b)

Fig. 7. Excavation of shaft GG-1 (Bołoz, 2025):
a). KDS-2 machine, b). side wall with visible frost made with the cutting head

Previous experiences with excavating the shaft by mechanical methods showed that it was necessary to use special cutting heads, selected precisely for this type of rock, as this had a beneficial effect on the progress of the work (Fabich et al., 2018). In addition, in the case under analysis, the excavated material accumulated and got stuck due to its recirculation in the cutting head (Fig. 8a). An ad hoc solution to the problem was to pivot a specially designed, prototyped, and tested loader for the duration of the shovelling process (Fig. 8b and c). The loader was effective, but could only work after the cutting head had been slotted. Therefore, a new, unique spatial cutting head solution was developed to increase cutting efficiency (Krauze, Bołoz, et al., 2014).



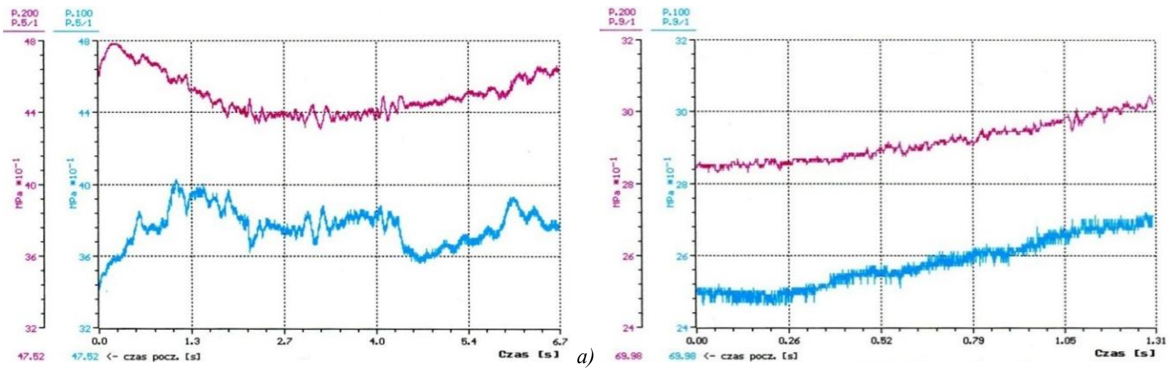
a) b) c)

Fig. 8. Cutting head of the KDS-2 machine (Krauze et al., 2010):
a). encased in mined rock, b). special loader design, c). special loader prototype

The design of the new cutting head was based on earlier experience implementing the two previous solutions, especially the spatial cutting head for excavating salt rock. The design process started with the determination of the properties of the rock by performing in situ workability tests, which were complicated due to the specific test site, as illustrated in Fig. 9.

Fig. 9. Test rig prepared for workability testing in the GG-1 shaft and the cut (Bołoz, 2025)

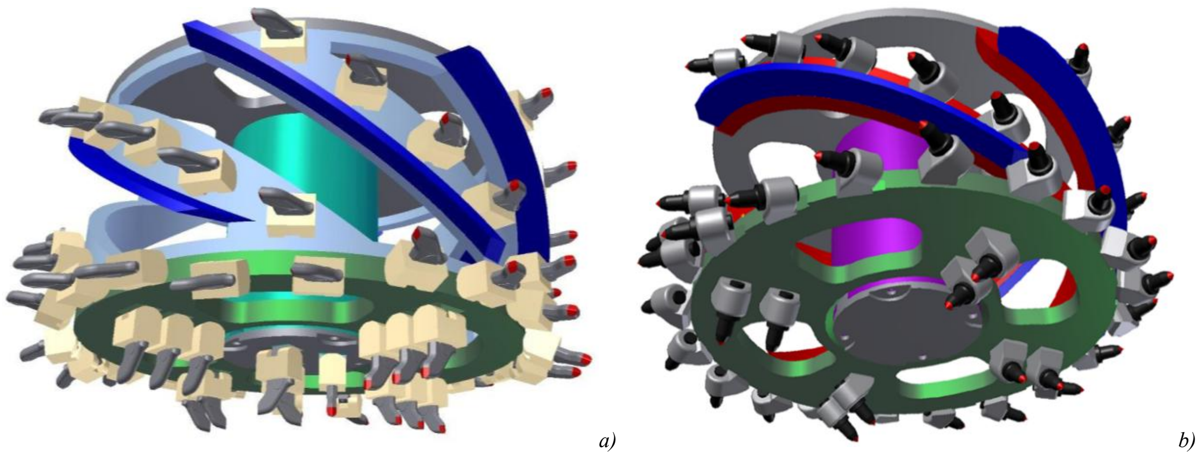
Testing was carried out at a depth of 23 m. Two parallel test cuts were made in the claystone layer, the temperature of which was -3 °C. The obtained values of inlet and outlet pressures are included in the graphs in Fig. 10. Based on the obtained results and the performed calculations, the cuttability index and the breakout angle were determined for cuts I and II: A_I = 1,295 N/cm and ψ_I = 9° 01' and A_{II} = 994 N/cm and ψ_{II} = 11° 42', respectively. The tested mineral was classified as compact and moderately workable.



a) b)

Fig. 10. Pressure waveforms recorded during testing and performance (Bołoz, 2025):
a). measuring cut I; b). measuring cut II

Based on the test results and the specific features of the shearer, four 1,300 mm × 650 mm cutting heads were designed, equipped with radial (Fig. 11a) and conical picks (Fig. 11b). As regards the salt, the cutting function was separated from the loading function, and vanes were replaced by crossbars (Frankovsky et al., 2020). Due to user requirements, including radial picks, the design was developed for the cutting head shown in Fig. 11a.



a) b)

Fig. 11. 3D model of the spatial cutting drums (Bołoz, 2025):
a). equipped with radial picks; b). equipped with conical picks

The designed cutting head had three picks along the cutting line, with a cutting spacing of 50 mm on the cylindrical part and 40 mm on the end face. The pick holder with a cylindrical underside allowed it to be pivoted on the disc. The cutting head was equipped with 68 radial picks, 30 of which were distributed on the cylindrical part (6 crossbars), 20 on the disc, and 18 on the end face.

One of the user's requirements was to ensure that the pick holders could be changed efficiently when worn out; hence, a unique technical solution was designed. It involved placing each holder in a correct position and at a right angle using two slotted spring-type straight pins. The body of the cutting head had precision-made holes into which the holder was fitted. A set of jigs was designed to make the holes in the pick holders. Fig. 12 shows the cutting head at its production stage.

Fig. 12. Spatial cutting head with picks fixed according to the author's solution (Bołoz, 2025)

Depending on their location on the cutting head, mounting holes must be made in the holders at a specific angle. Making such holes in the pick holder at a specific angle requires it to be mounted in a jig, which can then be placed on the drilling machine table (Fig. 13). A set of three jigs has been designed, each allowing holes to be drilled at two different angles (0° and 10°, 13° and 15°, 25° and 35°).

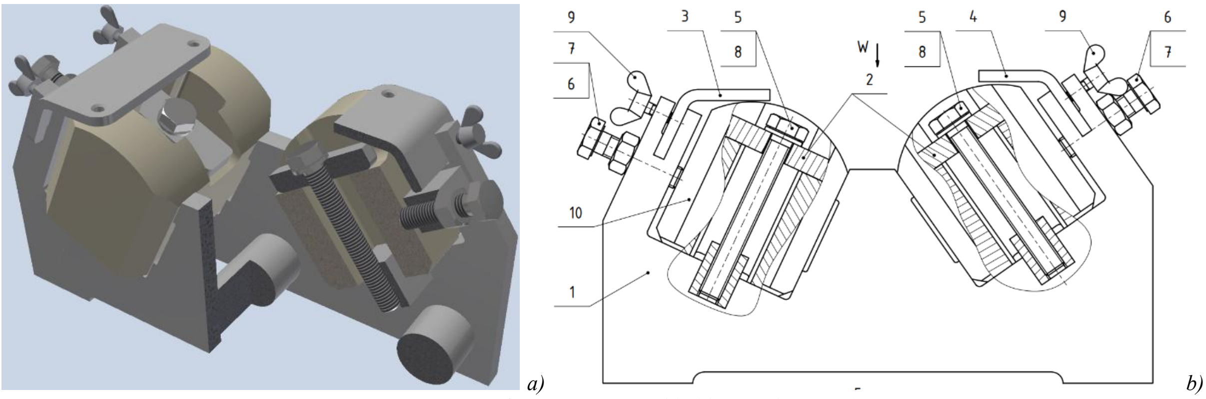


Fig. 13. 25-35 jig for positioning tool holders (Bołoz, 2025):
a). 3D model with a cross-section; b). technical drawing

Other cutting heads

Listed below are other unique cutting heads solutions of technical interest that have been completed at the patent or design stage. One example is the cutting head of a longwall shearer, which has crosspieces in addition to the vanes, similar to the spatial cutting head described earlier. The vanes perform the loading function, whereas the crossbars, which are inversely positioned, make it possible to change the order in which the picks cut the rock. The pick that initiates the cutting process is closest to the free surface, significantly reducing cutting resistance. Each subsequent pick makes a semi-open cut. Such a cutting drum is the subject of a patent (Krauze, Wydro, et al., 2014; Bołoz, 2025).

Another interesting solution is a cutting drum for mining chalk marls, which is mounted on the machine (skidder, bulldozer) and allows abandoning mining operations with explosives. In the case in question, an alternative method of extracting marls was sought due to the proximity of the buildings and problems involved in the extraction of marls with the available skidders. To develop such a solution, the workability of the chalk marls was determined in situ and on a test rig (Fig. 14). Analysis of the rock's properties indicated that it could be effectively mined with the cutting head in question (Bołoz & Krauze, 2018).

Fig. 14. Photographs of chalk marls subjected to workability tests in the mine (Bołoz, 2025)

It was proposed to equip a heavy TD-40 crawler dozer tractor with a cutting head, as conceptually illustrated.

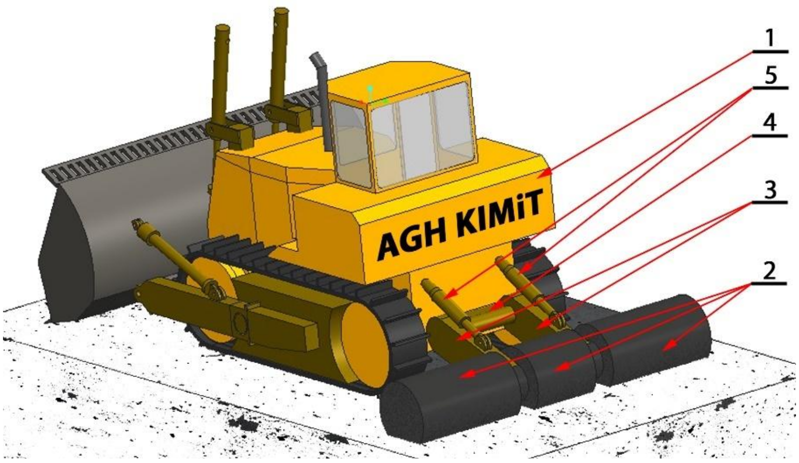


Fig. 15. Concept of the cutting head for the TD-40 tractor (Bołoz & Krauze, 2018):
1 - TD-40 tractor, 2 - cutting head assembly, 3 - arm assembly, 4 - adapter, 5 - lifting cylinders

A similar use of the cutting head has been proposed for roadway maintenance in a copper mine. A special cutting head, equipped with an internal drive, was developed to level the bottom and create drainage channels with the use of an additional removable cutting disc. Based on the analysis and conceptual work, it was found that the cutting head could be applied to the crawler dozer. A schematic of such a solution and proposals for a sprinkler system have been shown in Fig. 16.

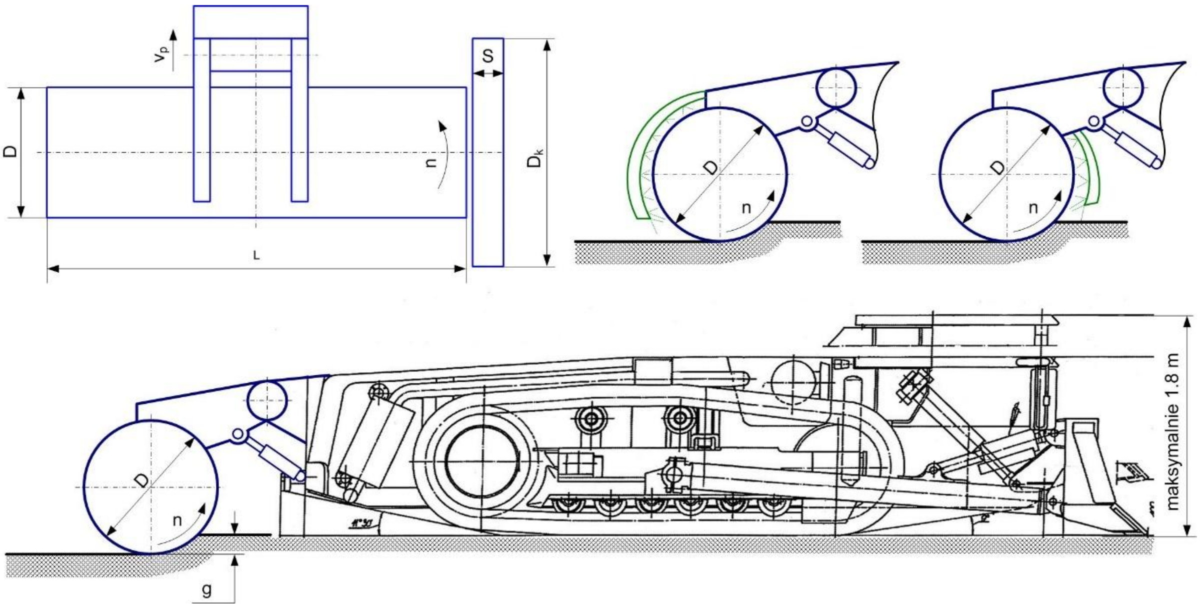


Fig. 16. Concept of a cutting head to maintain the technical condition of the road bottom in a copper mine (Bołoz, 2025): a. Diagram of the cutting head, b. proposals for sprinkler systems, c. cutting head installed behind a crawler dozer

The next cutting head is unique because it enables cutting at variable seam thicknesses. Coal-bearing sedimentary rocks have been shaped by geological processes into layers of varying thickness and at different inclinations. Such mining conditions necessitate the construction of machines with variable mining heights (like longwall shearers). The solutions most commonly applied in longwall shearers are those equipped with two cutting drums, at least one of which is mounted on a ranging arm. This makes it possible to change the mining height by changing the position of the rear arm with the cutting drum. If only one cutting head is required, there is a problem of changing the mining height (Bołoz, 2018a). The solution to this technical problem is a cutting head enabling mining deposits of variable thickness with a machine equipped with a single cutting head. The presented solution is covered by patent protection (Krauze & Bołoz, 2019; Bołoz, 2025).

This cutting head, unlike typical cylindrical ones, is characterised by an oval outline. Chains with tool holders and picks are moved by rails along the hull contour (Fig. 17). A change in the angular position of the cutting head causes a change in the cutting height.

The cutting head depicted in Fig. 17 (1), made of an oval hull, is attached to the cutting machine (2). The hull's surface is equipped with guides with chains (3) moving in articulated segments. Attached to some of the segments are tool holders (5), which hold the conical picks (6). A chain wheel (7) drives the chains inside the cutting head (3). The chain wheel is attached to a drive shaft (8) extending from the hull (2). The drive shaft (8) transmits torque from the motor (9) through a gearbox (10). The cutting head (1) is attached to the hull (2) of the machine by an angle adjuster (11). The drive shaft (8) operates in the angular corrector hollow (11) (Fig. 17b). The angle corrector (11) is connected via a helical gear (12) to the hydraulic rotary actuator (13). The hydraulic rotary actuator (13), by rotating the angle adjuster (11), changes the angular position of the cutting head (1) in the range from 0° to 90°. The cutting head has the minimum height H_{min} for angle $\alpha_h = 0°$; as the angle α_h increases, the cutting height also rises, reaching maximum H_{max} for $\alpha_h = 90°$. The common axis of the shaft (8) and the angle adjuster (11) is located on the body (1) at a constant distance from the floor H_o, which does not depend on the angle α_h. This makes it possible to change the mining height without correcting the distance of the shaft axis from the floor. Alternatively, the motor (9) of the chain wheel (7), together with a special gear (14), can be built into the cutting head (1) instead of in the machine body (2), so that the hydraulic rotary actuator (13) can be directly connected to the angle adjuster (11). This adjuster does not have to be hollow (Fig. 17c).

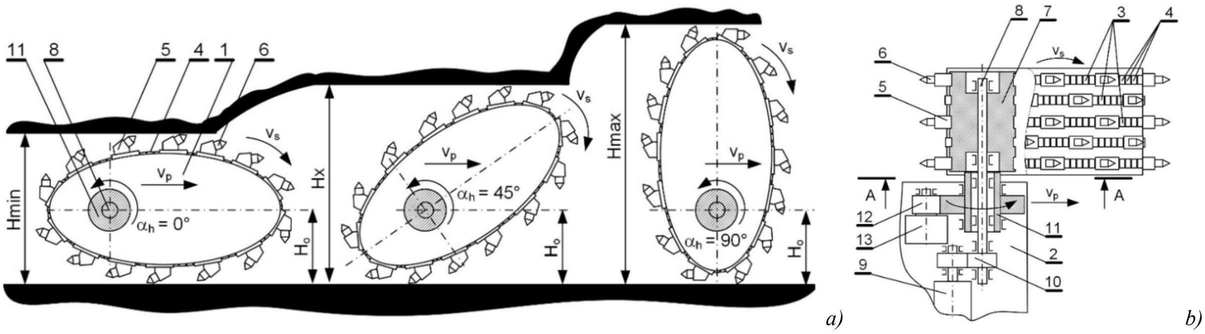


Fig. 17. Schematic of the oval cutting head:
a). idea of changing the mining height, b). cutting head with an external height adjustment drive

To verify the solution's assumptions, a preliminary design for such a cutting head was developed, accounting for the typical properties of hard coal. The cutting head was designed for mining thin seams ranging from 1.0 m to 1.5 m (Fig. 18). Strength calculations demonstrated the feasibility of designing such a cutting head using available technology and components (Frankovský et al., 2022).

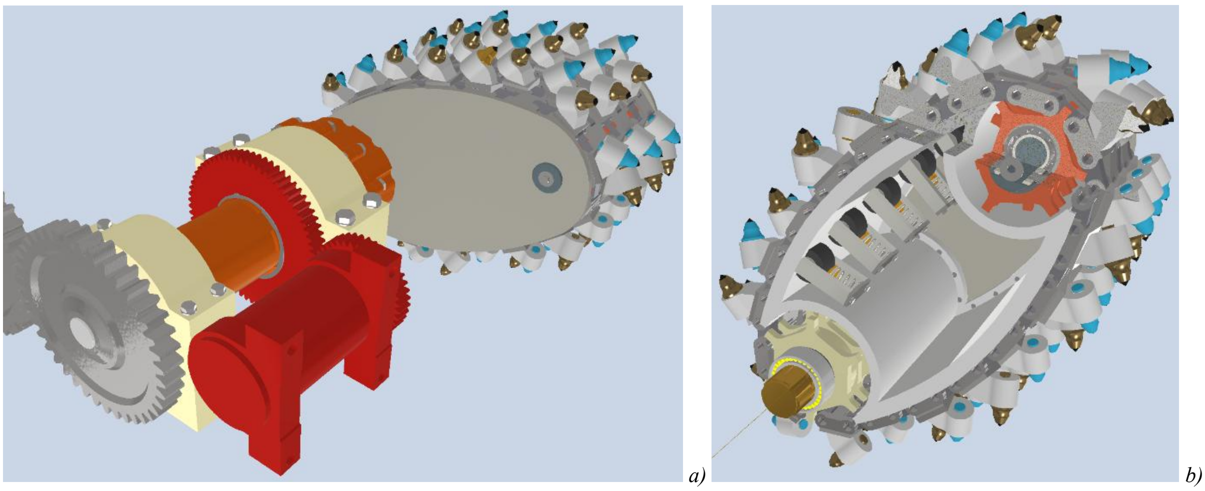


Fig. 18. Oval cutting head with a position angle correction system (Bołoz, 2025):
a). general view, b). inside structure of the cutting head

Conclusions

The high demand for certain minerals, along with the constant effort to increase mining efficiency and reduce mining costs, drives the ongoing development of mechanical rock mining. Mechanical mining involves using a mining tool that acts on the rock mass. The most common type of mining is based on the use of cutting heads. The cutting process carried out by many mining machines requires the correct selection of cutting heads, tooling systems, tool holders, tools, as well as the kinematic parameters of the machine and the cutting heads. The correct selection of these components enables the cutting process to proceed. However, it should be noted that the design of the cutting head requires experience and knowledge of the physical-mechanical properties of the rock being mined. The literature provides recommendations for selecting geometric parameters of cutting heads for specific conditions. However, they apply to the most popular machines, i.e., longwall shearers and roadheaders. The article presents selected cutting heads equipped with picks, for example, those designed to work in the shaft complex during the excavation of two shafts at KGHM. These cutting heads were characterised by an unusual spatial design, in which the picks with holders were located on crossbars rather than on the vanes. The open design prevented the recirculation of excavated material, thereby increasing mining efficiency. One of the heads equipped with conical picks was designed for cutting a rock salt dome. The other, equipped with radial picks, was intended for mining claystone and other rocks. These cutting heads were commissioned by the industry and put into operation. The article also mentions some technically interesting solutions, such as cutting heads for mining the floor or variable-height tools.

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