# POSSIBILITIES OF HARD ROCKS MINING IN THE ASPECT OF ENERGY CONSUMPTION AND DURABILITY OF MINING TOOLS

**KRZYSZTOF KOTWICA [1]**

**Abstract:** The article in the first part presents problems associated with mechanical mining of hard rocks using cutting tools, mainly tangential-rotary picks. This applies especially to the rapid wear of this type of tool. Several solutions have been proposed to increase their time life, as well as an alternative solution for tangential-rotary picks. Mechanical mining methods using symmetrical and asymmetrical disk tools were presented. Advantages and disadvantages of these methods in relation to cutting tools were described, and energy consumption of the mining process was compared using both types of mining tools. Perspective directions of development of methods for mechanical mining of hard rocks, limiting energy consumption of the mining process and wear of mining tools, have been presented.

**Keywords:** hard rock mining, mining tools, durability, wear, energy consumption,

## 1. MECHANICAL MINING OF HARD ROCK WITH CUTTING TOOLS

Currently, in underground mines, one of the most used methods of hard rocks mining, in the process of row minerals excavation and drilling of exploratory and opening-out headings or tunnels is the mechanical method. It is very often performed in rocks with very unfavorable parameters. This applies above all to the high strength of the rock massive on uniaxial compression, which in many cases exceeds 120 MPa and its structure. Increasingly, it encounters rocks that have a homogeneous structure. The most used machines in underground mines are roadheaders, continuous miners and shearers. They make it possible to obtain large mining capacity or drilling speed, but also generates several hazards or restrictions, depending of used mining tools. In the case of these machines, cutting tools are used, mainly tangential-rotary picks but also radial picks (Fig. 1).

[1]*Ph.D., Eng., AGH Professor, AGH University of Science and Technology, Krakow, kotwica@agh.edu.pl*

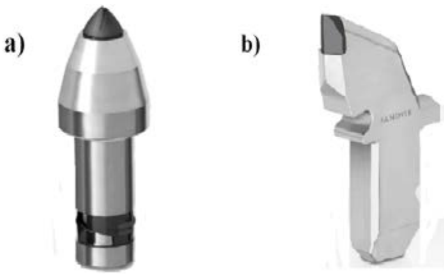


**Fig.1** Types of cutting tools used in mining: a) rotary-tangential pick, b) radial pick

Tangential-rotary picks, thanks to their design and the method of fixing, there can rotate in tool holders. These tools are more predisposed to mining rocks, even very hard ones, but they need to maintain proper parameters of their work. However, the disadvantage of the method of mining rocks by cutting or milling is the generation of dust and limitation of the use of this method, associated with the upper limit of rock strength to uniaxial compression or high compactness of these rocks. In connection with the high abrasiveness of such rocks, this results in excessive wear of cutting picks and a decrease in drilling speed. Excessive wear of the tool edge also leads to increased dustiness and the risk of explosion of mine gases, mainly methane, as a result of frictional sparking (Fig. 2). This problem occurs especially with radial picks.

Even the use of rotary-tangential pick reduces this problem only to a small extent. Work is underway to develop more durable cutting tools, however, even new-generation rotary-tangential pick are not always able to provide the required mining parameters. When mining hard rocks, the increased wear of tools and the generated dust hazards and gas explosion often result that the process of rock mining is economical unprofessionally. It is strictly connected with limiting or disappearing of pick turnovers in the holder. It causes very unregular wear or even destroying of the pick.

**Fig.2** View of frictional sparking, dustiness during cutting of a rock sample with a rotary-tangential pick and wear of pick wedge

Pick wear is significant for the efficiency of the cutting process. If the size of tool wear is bigger, it generated more number of small particles of output.

When cutting is done with a blunted pick (Fig. 3), the rock indentation zone occurs both in front of and underneath the pick. Crushing must occur before the pick as the contact area between the tool face and the rock increases. The crushed rock (area 1) is forced sideways or upwards, but due to the pressure from the tool face, it carries a small layer (2) of crushed rock residue. At the same time, under the contact surface of the tool with the rock, a zone of compressed, crushed rock (3) is formed. The zone size is directly proportional to the size of this surface, which is greater the more the tool wear increases.

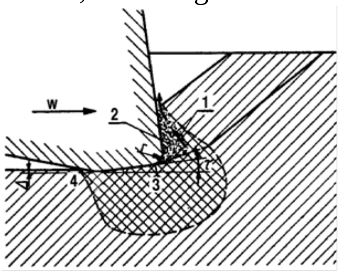


**Fig.3.** Cutting with a blunted radial pick

The degree of the tool's wear is very important. Studies have shown that pick The degree of the tool's wear is very important. Studies have shown that pick blunting is a very significant factor in specific power consumption, in relation to the volume of the excavated rock. Figure 4 shows the relationship between the power consumption N and the specific power consumption coefficient $K_u$ as a function of the longwall shearer's advance rate vp for four radial picks blunting values Sp in millimeters. Comparing to the brand-new pick, the pick blunted up to 19.6 mm the power consumption $K_u$ is more than double. The charts show that as the advance rate $v_p$ grows, causing an increase in the cutting depth, the impact of pick blunting becomes significantly stronger. The bigger blunted surface increases heat dissipation and, by extension, increased tool heating, and a sparking tendency.

The rock mining process depends largely on the excavated rock workability. Rock workability is a property describing a rock's resistance to mining understood as the separation of a piece of the rock from the solid. The measure of workability is the so-called specific mining energy – that is, the amount of energy required to remove a unit of a rock's volume. Based on observations and the analysis of the rock mining process, a general theory of mechanical rock mining was formulated. In this theory it posit that the so-called indentation zone plays the key role in the process of rock disintegration.

But cutting-based methods are not appropriate for rocks that are difficult and very difficult to excavate, including especially those that contain silicon. Such rocks require the use of large cutting forces.

The parallel movement of the pick and the related friction between the rock and the pick surface cause pick blunting and wear, resulting in an instant increase in cutting resistance. It causes also the decreasing of output grains. In the cases of large wear of cutting tool, output grains are comparable to dust.

The primary purpose of rock mining is to separate from the rock solid the largest possible rock pieces using as little energy as possible. Rock mining is measured using the specific energy $E_w$.

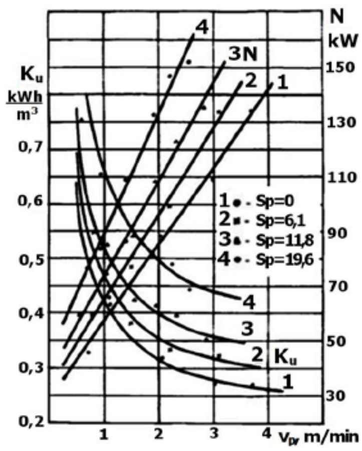


**Fig.4** The impact of the radial pick blunting $S_p$ on the power consumption *N* and the specific power consumption coefficient $K_u$ as a function of the shearer's advance rate

$$E_w = \frac{E_u}{V} \tag{1}$$

where:

$E_u$ – energy supplied to excavate the rock, J.

$V$ – volume of the excavated rock, $m^3$.

Thus, the specific energy expressed as (1) is the energy required to excavate a unit of a rock's volume. The lower the specific energy, the more efficient the process. It seems reasonable to assume that in an efficient process, the supplied energy E will be proportional to the newly created surface ($\sim d^2$, where d is the linear dimension of the newly created rock grain). The volume of the removed rock piece V will be proportional to its linear dimensions raised to the power of three (~d;). Thus:

$$E_w \sim \frac{1}{d} \tag{2}$$

Hence, the specific mining energy is reversely proportional to the dimensions of the removed rock piece. This means that as the grain dimensions increase, the energy required to excavate a unit of the rock's volume decreases. The energy required to break the rock – for instance, through high-energy impacts – is proportional to 1/d.

It so can assume that to obtain of specific mining energy value, small and very even wear of cutting tools is needed. Bellow alternative tool solution for rotary-tangential pick and holder for them, are described. Both solutions enabling and increasing the turnovers of the tool, thus limiting tool wear.

## 2. NEW SOLUTION OF CUTTING TOOL AND HOLDER

The new solution of special cutting tools, which can replace traditional tangential-rotary picks was developed in AGH UST. These tools are adapted to attach in standard holders which are commonly used for hard rock cutting, whereas design solution of the working part is different than for the standard tangential rotary picks. The new pick is shown in Figure 5. The cutting segment is bell or crown-shaped, and the working part is armed at the circumference with eight cone-shaped sintered carbide inserts. Such design solution should allow loosening rock fragments as a result of point pressures exerted by individual sintered carbide inserts. Moreover, non-uniform load of individual carbide inserts should cause increase the tool rotary speed in the holder. After manufacturing of the new tool prototype, preliminary tests at a special laboratory stand were carried out.

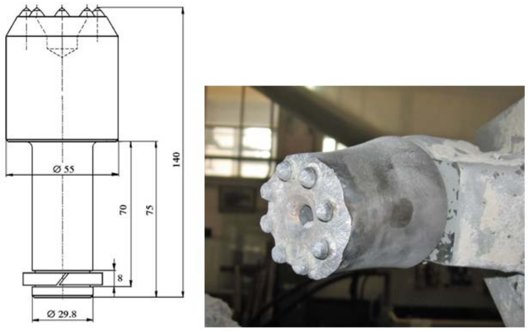


**Fig.5** Scheme of the new type of the crown pick and view of new crown pick with 8 carbide inserts with diameter 8 mm after the test

The results of preliminary researches have been satisfactory. Significant rotations and very small wear of new tool were observed. Figure 5 presents the view of this crown pick after sample mining on the total distance of 1200 m. At the same cutting distance, working part of standard rotary-tangential pick was practically total destroyed.

New type of the tool has been applied in the roadheader mining head. The mining head, equipped with new crown picks, was tested in limestone opencast mine (Fig. 6). Working conditions were comparable to the standard mining head with tangential rotary picks operation regime. There were no problems with the head work. During 5 hours of work, a comparable quantity of output (to a standard mining head) was excavated. The difference was only in dimensions of the grain size of the output. The output was homogeneous and fine. No major signs of wear of new tools were observed. The view of one of the new picks after the tests is shown in Figure 6. In order to confirm the effectiveness of these tools, however, research in real conditions in an underground mine is required.

The increased and uneven wear of tangential rotary picks results mainly from reduction or even block of tool rotation in the holder. One of the main causes for this situation is deterioration of cooperation conditions of the tool shank surface and the inner surface of the holder sleeve due to elements of dust and small grains of output penetrating both. It increases resistance of the tool rotation in the holder. In order to solve this problem, a team of researchers from AGH UST undertook attempts to ensure the rotation of the shanks of tangential rotary picks in holders by the change of dry or semi dry friction state to mixed or half liquid. It was suggested to force lubrication of cooperating surfaces of the holder sleeve and the tool shank.

The solution of modernized holder for standard rotary tangential picks with forced lubrication is presented in Figure 7.

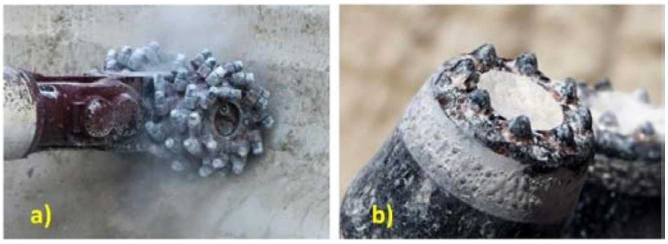


**Fig.6** View of the mining head with new crown picks: a) – during the tests in limestone opencast mine, b) – new crown picks after the tests

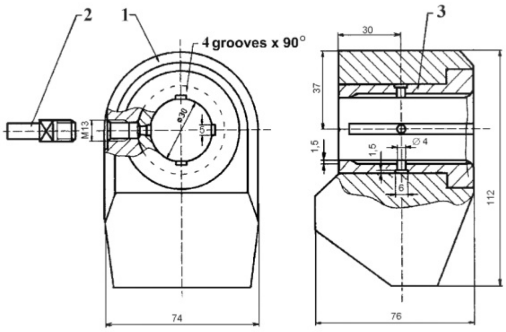


**Fig.7** Modernized, lubricated holder of standard tangential rotary picks: 1 – tool holder, 2 – supply tubing barb, 3 – sleeve

In this solution lubricant (low-grade emulsion or clean water) is supplied under pressure through the hole of the tubing barb 2 to four grooves in the sleeve 3, mounted in the tool holder 1. Using the new solution of lubricated holder, initial laboratory tests were carried out. The test stand allowed to cut the concrete sample on its side surface, with stable mining parameters, such as depth, cutting pitch and speed, and angles defined by the mining mode. The tests were performed as comparative ones for the new solution of holder, and the standard holder.

The number of tool rotations per 1 minute was measured for determined cutting conditions. Cutting of the sample was performed at its whole height. The lubricated holder was supplied with 1,5% oil-water emulsion during part of the trials and with clean water during the rest. In both cases the value of feed pressure was p=1,5 MPa. The influence of tools mounting method and the conditions of cutting process on the number of picks revolutions is shown in the diagram in the Figure 8. The tests showed that in the case of lubricated holders, even at small value of side deflection angle of the tool, it rotates in its holder. Both in the case when the holder was fed by emulsion or clean water, the pick and holder surfaces have been clean and free from impurities. Figure 9 shows view of the tool edge and holder surfaces after tests of rock sample cutting at the distance of app. 1000 m, with clean water supplying to the holder.

Holder lubrication caused desirable, regular and relatively very small wear of the tool's edges. Lubrication of the holder with low-grade emulsion caused even higher, by more than 25 – 30%, reduction of wear.

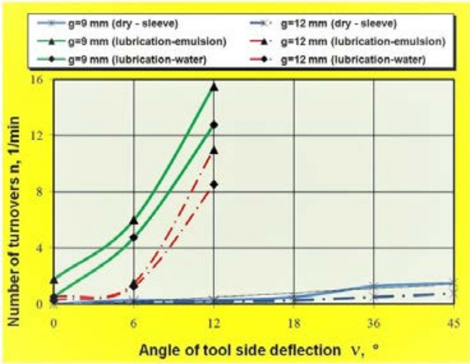


**Fig.8** Influence of the tool side deflection angle υ on the number of its rotations in the function of cutting depth and type of holder

**Fig. 9** View of the tool edge and holder surface after tests of rock sample cutting at the length of about 1000 m, with holder water feed

The positive results of the tests lead to designing and manufacturing of special mining head with lubricated holders for roadheader. Tests performed in one of coal underground mines fully confirmed the usefulness of the proposed solution. Tools mounted in new holders were used two times longer in comparison for tools mounted in standard one. Also, the tool wear was very regular.

## 3. MECHANICAL MINING USING DISK TOOLS

The second of the most used methods in mechanical mining of hard rocks is mining by means of static crushing, carried out with the help of wheel tools called disks. Disk tools used for this mining method can be symmetrical or asymmetric. This method consists in pushing the disc edge into a rock massive with the normal force perpendicular to its surface. As a result of this force, the uniaxial compressive strength of the rock is locally exceeded, rock massive is crushed and disk penetrates the depth g (Fig. 10). Rotary assembly in the holder allows the disk to rotate around the axis. The ability to rotate the tool in the head reduces the friction forces, which reduces energy loss and generates less toll edge wear and dustiness, compared to cutting tools. It also greatly facilitates the removal of heat emitted on the edge of the disk and ensures very long durability of the tool. Smooth single blade disk tool can work without visible wear even up to few kilometers of roadway or tunnel advance. In comparison cutting tool lifetime is not more than several cubic meter of output per piece.

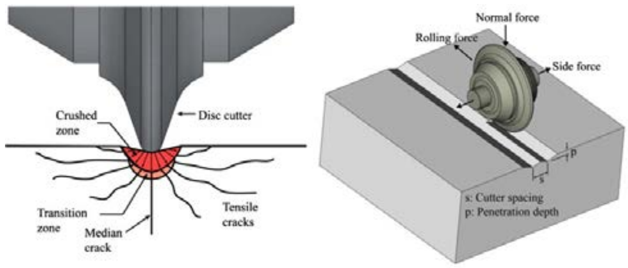


**Fig.10** The work principle of a single symmetric disk

The disadvantage of mining by static crushing is the need to ensure a high pressure force of the tool, even to 300 kN. The occurrence of large values of pressure and reaction forces causes large mass (up to 3,500 Mg) and dimensions of the machine (the length up to 400 meters). This results in the limited use of this type of machinery for the drilling of excavations with a very large runnout.

A clear drawback of the static crumpling method is necessity to provide large pressure forces to the disks. Asymmetrical disk is applied also in the undercutting method. The principle of this method is mining a rock by it cutting off towards a free space. A disk tool affects the rock tangentially to the surface of the mined body, similarly as for cutting tools, but the difference is that here it uses the disk rolling movement which efficiently eliminates sliding friction in favor of rolling friction. Figure 11 presents a diagram of this method. Application of disk tools in that way lowers energy consumption and pressure force. It allows designing mining machines with respectively lower energy demands and lower requirements concerning stability than in case of machines equipped with classical disks.

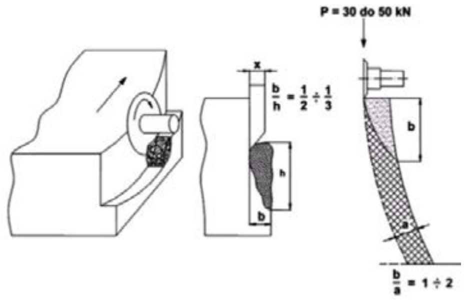


**Fig.11** Diagram of the undercutting method mining principle

In the case of this method there are strongly varying lateral forces on the edges of disk tools. This is the reason for the difficulty in properly taking over the reaction on the disk tool holders and their bearing. The view of the Wirth machine used undercutting method and the effects of its work is shown in Figure 12. It can be observed large grains of output. Currently these types of machines are produced by Aker Wirth for Rio Tinto Company.

## 3. SUMMARY

The mining of compact rocks with roadheaders equipped with milling mining heads seems to be currently the most popular method. But it method causes large wear of cutting tools.

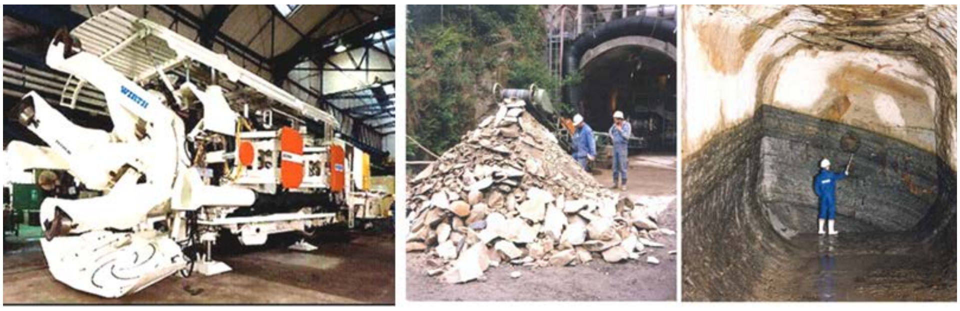

**Fig. 12.** View of the Wirth machine used undercutting method and the effects of its work

Symmetric disk tools with a diameter of 400 - 500 mm, working with static crumpling, mounted on the mining heads of TBM machine, have very high durability but in this case very high value of pressure force require huge dimensions, weight and costs of the whole machine. The undercutting method using non-symmetrical disk tools, mounted on swing arms, offer also promising results. The new Aker Wirth machine are able to mine excavations in compact rocks with reduced energy consumption of the mining process and high granulation of the output. There were the concepts of use on the mining heads mini-asymmetrical disks, in which the basic idea was to use the disk as a chipping tool. Thanks to this, energy consumption and the value of the pressure force are smaller, which gives the possibility of constructing a mining machine with lower energy parameters.

The idea of the undercutting method was used in AGH UST, in order to design an innovative construction of mining head, equipped with mini asymmetrical disk tools. On the basis of results of own tests of rocks mining with asymmetrical disk tools (of diameter 160 - 170 mm), the tests to devise a new conception of a mining head were started. In this design motion of tools will be forced and will cause mining of a rock body with tools along complex movement trajectory. It allows crossing of mining lines of individual disk tools and facilitates mining compact rocks through breaking off rock furrows. It should lower energy consumption of the process. Disk tools were mounted on separate plates that could rotate on the mining head body and are propelled independently from it. The works were performed in cooperation with the REMAG Company. The view of spatial model of mining head and view of roadheader with new mining head ready for tests is presented in Figure 13.

The tests were performed on artificial large size concrete block of uniaxial compressive strength up to 80 MPa prepared at REMAG Company. The tests results allowed to choose most convenient parameters of mining head work. The best effects of the work – large graining of the output, low engine load, and limited vibrations were obtained for the head body rotations at counterclockwise direction of value 20 rpm, and the plates rotations at clockwise direction of value 60 rpm.

Currently attempts to use mini disk tools (up to 180 mm in diameter) on the roadheaders mining heads offer promising results. However, the biggest drawback is durability. During the tests, disk tools made of different materials and by various methods were used. They were made of tool steel, Hadfield or low-alloyed cast steel and ADI spheroidal cast iron. In the case of most tools after short (one hour) work numerous edge breaks as well as cracking and breakage of the part of tools were noticed. It was the biggest problem during the tests. The implementation of these tools, for example, using the forging method and the appropriate heat treatment can give good results.

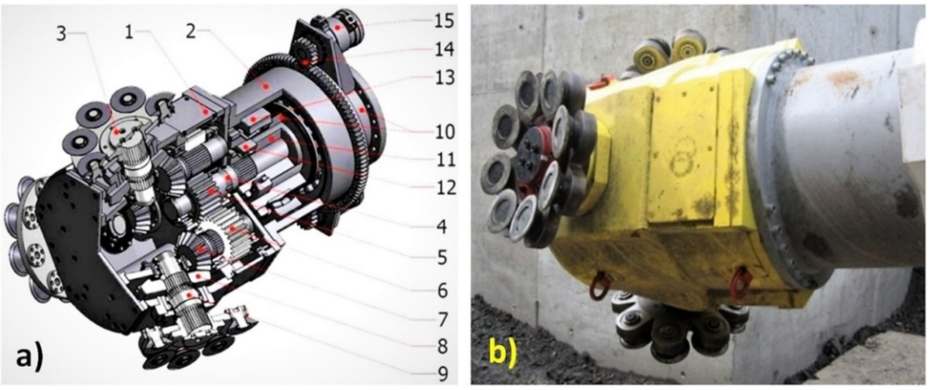


**Fig.13** The new mining head solution with disc tool of complex trajectory: a) spatial model, b) view of roadheader mining head ready for field tests

1 – main gear, 2 – auxiliary gear, 3 – disc plate, 4 – input shaft, 5 – central gear wheel, 6 – orbital gear wheel, 7 – pinion, 8 – face gear, 9 – output shaft, 10 – support, 11 – connector, 12,13 – bearings, 14 – body gear, 15 – hydraulic engine

## REFERENCES


**[1].** **Gospodarczyk P., Kotwica K, Kalukiewicz A., Łapa D.,** *Noże koronowe – narzędzia nowej generacji do urabiania skał zwięzłych*. Maszyny Górnicze nr 4/2006, Gliwice, 2006, (in Polish);

**[2].** **Gospodarczyk P., Kotwica K., Stopka G.,** *A new generation mining head with head with disc tool of complex trajectory.* Archives of Mining Sciences, vol. 58, issue 4, 2013;

**[3].** **Klich A., Gospodarczyk P., Kalukiewicz A., Kotwica K., Krauze K., Pawlik K., Reś J.,** *Niekonwencjonalne techniki urabiania skał.* Wydawnictwo Śląsk, Katowice 1998 (in Polish);

**[4].** **Kotwica K.,** *Atypical and innovative tool, holder and mining head designer for roadheaders used to tunnel and gallery drilling in hard rock.* Tunneling and Underground Space Technology no.8, 2018;

**[5].** **Kotwica K at all,** *Wybrane problemy urabiania, transportu i przeróbki skał trudnourabialnych, Part 1, 2 and 3.* Wydawnictwa AGH Kraków. 2016, 2017, 2018; (in Polish)

**[6].** **Kotwica K., Maziarz M.,** *Impact of the Mounting of Tangential Rotary Tools on their Proper Operation*. Archives of Mining Sciences. Vol. 49, 2004;

**[7].** **Kotwica K.,** *Hard rock mining – cutting or disk tools*. Innovative Mining Technologies. IOP Conf. Series: Materials Science and Engineering, vol.545. DOI:10.1088/1757-899X/545/1/012019. 2019;

**[8].** **Kotwica K.,** *The influence of water assistance on the character and degree of wear of cutting tools applied in roadheaders.* Archives of Mining Sciences. *vol. 56, iss. 3.* 2011;

**[9].** **Matyja S.,** *Badania wpływu prędkości skrawania i posuwu na obciążenie kombajnu bębnowego.* Mechanizacja i Automatyzacja Górnictwa, no 2/51, 1973 (in Polish);

**[10].** **Weber W.,** *Drążenie chodników przy pomocy techniki tylnego wycinania. Maszyna firmy Wirth-HDRK "Continuous Mining Machine".* Symposium: "Drążenie chodników w górnictwie węgla kamiennego". Siemianowice Śl., 1994 (in Polish);