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A NEW GENERATION MINING HEAD WITH DISC TOOL OF COMPLEX TRAJECTORY

GŁOWICA URABIAJĄCA NOWEJ GENERACJI Z NARZĘDZIAMI DYSKOWYMI O ZŁOŻONEJ TRAJEKTORII

In Polish underground mining plenty of dog headings are drilled with mechanical methods with the use of arm roadheaders equipped with milling units. Cutting tools applied on the units – rotary tangent bits in unfavourable mining and geological conditions or improper work conditions are affected by an accelerated wear process. It influences the speed and costs of drilling such excavations. The article presents a new and innovative solution of a mining head with asymmetric disc tools of complex trajectory elaborated at the Department of Mining, Dressing and Transport Machines, AGH University of Science and Technology, Krakow as an alternative for standard milling units. Advantages of the applied mining method using so called back incision were described as well as principles of construction and work of the suggested solution of the head. In order to work out a construction of the head prototype it was necessary to determine principles and guidelines based on laboratory tests. A construction of a specially prepared laboratory stand for examination of disc tools of complex trajectory, planned research methodology, course of tests and obtained results were presented. An analysis of the results allowed determining the above listed principles and guidelines for a construction of a prototype head. They were the base to work out, with cooperation of the REMAG Ltd Company in Katowice, a technical project of a new head solution, adapted for mounting on the arm of a medium arm roadheader KR 150. A constructed head underwent tests on a research stand on the REMAG testing area and received positive preliminary tests results.

Keywords: roadheader, mining, hard rock, cutting head

W polskim górnictwie podziemnym bardzo duża liczba wyrobisk korytarzowych drążona jest metodami mechanicznymi z wykorzystaniem ramionowych kombajnów chodnikowych, wyposażonych w organy frezujące. Stosowane na tych organach narzędzia skrawające – noże styczno-obrotowe, w niekorzystnych warunkach górniczo-geologicznych lub przy nieprawidłowych warunkach pracy, ulegają przyspieszonemu zużyciu. Wpływa to na prędkość i koszty drążenia tych wyrobisk. W artykule przedstawiono opracowane w Katedrze MGPiT AGH Kraków nowe i innowacyjne rozwiązanie głowicy urabiającej, z narzędziami dyskowymi niesymetrycznymi o złożonej trajektorii, jako alternatywę dla standardowych organów frezujących. Opisano zalety zastosowanej metody urabiania z wykorzystaniem tzw. tylnego podcinania

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oraz zasadę budowy i pracy zaproponowanego rozwiązania przedmiotowej głowicy. Dla opracowania konstrukcji prototypowego egzemplarza tej głowicy koniecznym było określenie, na podstawie badań laboratoryjnych, założeń i wytycznych. Przedstawiono konstrukcję opracowanego specjalnego stanowiska laboratoryjnego do badania narzędzi dyskowych o złożonej trajektorii, założoną metodykę badawczą, przebieg badań oraz uzyskane wyniki. Analiza tych wyników umożliwiła określenie wyżej wymienionych założeń i wytycznych dla konstrukcji głowicy prototypowej. Na ich podstawie opracowano, we współpracy z Zakładami REMAG S.A. w Katowicach, projekt techniczny nowego rozwiązania głowicy, dostosowanej do zabudowy na ramieniu średniego kombajnu chodnikowego KR 150. Wykonany egzemplarz głowicy został poddany próbom na stanowisku badawczym na poligonie Zakładów REMAG i uzyskał pozytywne wyniki badań wstępnych.

Słowa kluczowe: kombajn chodnikowy, urabianie, skała zwięzła, głowica urabiająca

1. Introduction

Differentiation of physic-mechanical properties of mined centres decides about their division on less or more compact rocks. The properties affect selection of a mining method or type of applied mining tools. A basic criterion connected with the informative side of the mining process is kinematics of the mining unit. The energy aspect of the process relies on transforming energy of a certain type and form into inner energy of a rock causing its destruction, overcoming cohesion forces and consequently obtaining output. Currently, there is a tendency to apply mainly mechanical methods in the process of rocks mining. In the Polish coal mining most opening-out dog headings and preparatory ones are drilled with mechanical methods using arm roadheaders. It is caused by benefits the method features in relation to traditional mining methods with application of explosives. The most important is an ability to perform a few operations at the same time (mining, loading, haulage). The rock structure surrounding the excavation is not weakened or broken which cannot be avoided when applying explosives. Moreover, obtaining a precise profile of the face section facilitates better fitting of the lining to neat lines and as a result the lining transfers lower and more evenly distributed loads and its placing is less work and time consuming which positively influences effectiveness and unitary cost of drilling a dog heading.

Effective application of the methods is mainly connected with gettability of a given rock. A significant criterion of the mechanical mining methods division is the direction of action of the main component of the tool force affecting the rock which leads to its destruction. The direction can be tangent or normal to the surface of the mined rock. The first case refers to cutting and the second one to crushing. Cutting is more commonly used for mining less compact rocks or rocks of natural weakening planes. The range of the pressing zone at a suitable angle of a blade is small and the run of the process makes cracks occur in the weakest places, at maximal use of planes of lower cohesion. It allows obtaining high efficiency of mining.

Mining hard and very hard mineable rocks, especially the ones that contain silicon on their chemical composition, its compounds or derivatives, or inclusions of effusive rocks with application of methods based on cutting does not work. Such rocks require use of high forces of cutting. Parallel application of the cutting bit and friction of the rock and the bit surface connected with it cause fast blunting (increased blunting increases friction) and wear of the bits. New construction solutions of rotary tangent bits currently used on mining units of roadheaders are equipped new generation plates made of multilayer carbides. However, in the above described conditions even they do not ensure effective and economically justified mining of a rock centre (Krauze &

Kotwica, 2007). Also application of systems of inner and outer water sparkling of cutting bits or even high pressure bits support on the mining units of modern roadheaders cannot fully provide even wear of the bits and their proper durability (Kotwica, 2011).

The second most commonly applied method in the process of mechanical mining of compact rocks is mining with static pressure causing rock destruction by its crushing realized by disc tools, usually symmetrical ones. The method relies on driving the disc edge in the rock body at the pressure force Pd perpendicular to its surface. A clear drawback of the method is necessity to provide large force of the tool pressure. Destruction of the rock body takes place when its resistance against uniaxial compression is exceeded. The value of pressure force on one symmetrical disc tool can amount at even 300 kN. In case of a high number of disc tools on a mining unit, it results in large summary values of the pressure force (depending on the unit diameter even up to 25000 kN) and many times higher value of the side sprag force of the miner to provide stability of its work. The mining machine has to transfer reactions from the mining unit and stabilizing sprags. Occurrence of high reaction forces results in high weight (up to 3500 Mg) and size of the machine (length of a miner up to 400 m). It limits the use of such machines to drill excavations of a very high reach where high costs connected with producing and constructing them in the excavation can be justified. There have been attempts to use high pressure support with water jets for the process of rocks mining with disc tools on full section miners to limit the machine weight. The attempt gave positive results but they were not applied on a large scale (Gospodarczyk at al., 2007; Kotwica, 1998).

Whereas, asymmetrical disc tools have been used on mining tools of long wall coal miners to increase output of a large size grade. Conducted industrial tests demonstrated usefulness of such equipment for obtaining higher graining but increased dynamics of mining with the units was the reason that they are not commonly used nowadays (Krauze et al., 2007, 2009).

Asymmetrical disc tools are applied in the technique of mechanical mining not only as crushing devices but also as prising ones. Mining through prising with a disc tool uses typical for rocks much smaller resistance against stretching than uniaxial pressing. The principle of the incision technique is mining a rock by cutting it off towards a free space. A disc tool affects the rock tangentially to the surface of the mined body, similarly as for a cutting tool, but the difference is that it uses the disc rolling movement which efficiently eliminates sliding friction in favour of rolling friction. Fig. 1 presents a diagram of mining with the method of back incision. Application of disc tools in that way lowers energy consumption and pressure force which allows constructing a mining machine of respectively lower energy parameters, lower requirement concerning stability than in case of classical crushing discs operating perpendicularly towards the surface of the mined body (Weber, 1994).

However, in case of the method there occur strongly changeable side forces on disc tools blades. It results from difficulties with proper transfer of reactions on disc tools chucks and their bearing. Explanation of the phenomenon is presented in Fig. 2. In the picture on the left the rock is not chipped off yet, the disc cuts into the rock body, and on the right the rock piece is already chipped off. The disc cuts a new mining path in the rock and is initially pushed way from the working face.

An example and a diagram of machine work that uses the technique worked out and produced by the Wirth company got presented in Fig. 3. The machine features four independently controlled arms, equipped with asymmetrical disc tools that can mine in any way the surface
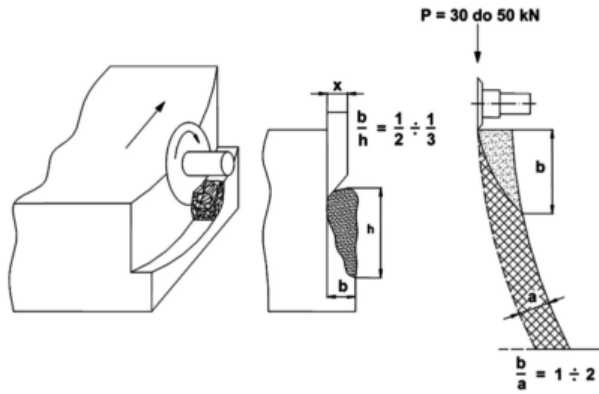
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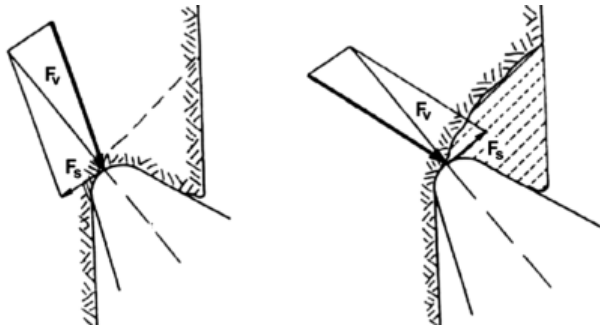Fig. 1. Diagram of the back incision mining method principle

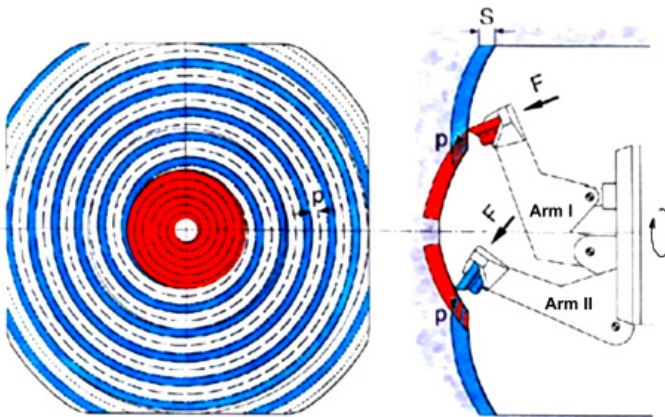Fig. 2. Diagram of forces affecting disc tool

Fig. 3. Diagram of mining working face with a four-arm solution of the Wirth company,
using the back incision technique

of the working face. The machine was applied for drilling excavation of dimensions 4 m × 4 m in relatively hard mineable rocks. The method of back incision, used in the presented machine showed full usability of the suggested solution. Also taking into account energy consumption, promising results were obtained, significantly lower than in case of full section miners and a few times lower than for milling miners. The only drawback is a very complex method of steering individual arms and very high reaction forces.

That is why the idea of the back incision technique was intended to be developed in the Department of Mining, Dressing and Transport Machines, AGH University of Science and Technology, Krakow in order to elaborate an innovative construction of a mining unit equipped with mini asymmetrical disc tools that could be applied in arm roadheaders. The course of implemented works is presented below.

2. A conception of a new solution of a mining unit

Works over preparation of new construction solutions of mining heads and units for arm roadheaders or mining methods allowing effective mining of hard mineable rocks have been conducted for years. One of such solutions was application of a mining unit equipped with discs like e.g. a solution elaborated and tested in the Colorado School of Mines in the US. In order to decrease values of mining forces, mini discs of 125 mm diameters were used. The biggest problem was the solution of discs bearing influencing tools life at their high load. A few solutions of such tools bearings were prepared as well as a technical project of a unit which was the base for a prototype. The results of tests were satisfying, though there is no detailed information on them. Further works over a unit of that type were not continued on a larger scale (Gospodarczyk at al., 2007, 2010).

At first in the Department of Mining, Dressing and Transport Machines, AGH University of Science and Technology, Krakow also an attempt was undertaken to work out a solution of a mining unit equipped with mini disc tools mounted in chucks directly on the unit casing. Due to high load of the disc tools and low effectiveness of mining the solution was given up.

On the basis of an analysis of the world technique condition and results of our own tests of rocks mining with asymmetrical disc tools of diameter up to 160 mm, the Department started tests to elaborate a new conception of a unit in which the motion of tools will be forced and will cause mining of a rock body with tools along complex trajectory. It allows crossing of mining lines of individual disc tools and facilitates mining compact rocks through breaking off rock furrows. It should decrease energy consumption of the process (Gospodarczyk at al., 2007, 2010). Disc tools were mounted on separate plates that could rotate on the mining unit casing and are propelled independently from it. For simplification purposes it can be assumed that the plate in motion acts like as singular disc. Next, subsequent locations of the disc during the body rotation can be determined as shown in Fig. 4.

As the designed head is to operate on an arm roadheader, its shape and dimensions should be close to the solutions of units currently applied in the machines. In the method of back incision, which was intended to be used in the elaborated conception of the unit, mining requires rotary motion of the disc. In order to ensure the motion the rotation axes have to move during work in relation to the unit body. Discs displacement during the unit operation can be obtained locating them on a plate whose rotary movement is enforced. The plates should be mounted to the side surface of the unit body and their rotation axes perpendicularly to the fastening surface.
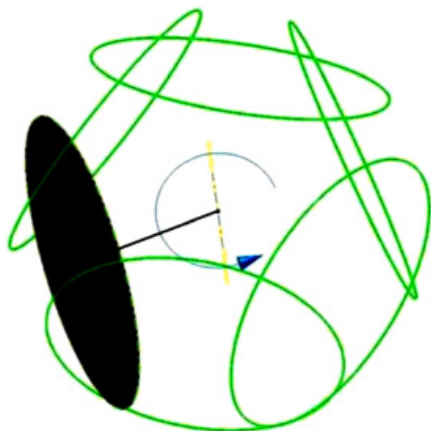
Fig. 4. Diagram of subsequent locations of the disc during the body rotation

Taking that into consideration, there was elaborated a conception of a unit with asymmetrical disc tools of a complex trajectory, mounted on three plates rotating in relation to the unit (Gospodarczyk at al., 2007, 2010). It was presented in Fig. 5. The elaborated mining unit consists of independently propelled body and mounted in it propelled discs with asymmetrical disc tools. The unit body 1 is propelled by an external drive shaft 2. In the body, in seats 3 drive shafts 6 are mounted with plates 4, on which in bearing seats 10 disc tools 5 are installed. The most favourable number of the tools should be 6 to 8 pieces. The drive shafts 6 are propelled by an internal drive shaft 7 independent from the external drive shaft 2 and a set of bevel gears 8 and 9 or alternative ones. In the conception of the new solution it is very important to ensure dislocation of the drive shafts axes 6 of the plates 4 with mining tools 5 by the value e so that they do not cross the axis of the head body 1 drive shaft 2. The eccentric location of the plates axes with tools should enable their easy slotting into the rock body at the unit motion both vertical and horizontal one. The solution is protected by patent law.
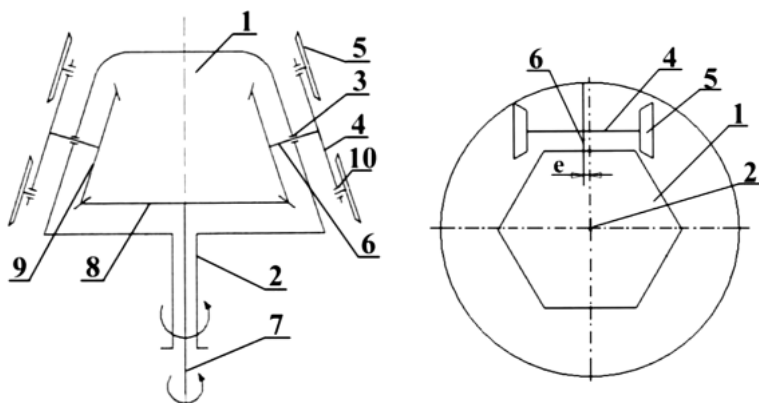

Fig. 5. Conception of a unit equipped with disc tools of a complex motion trajectory

Trajectory of discs motion can change depending on inclination of the plane in which the plate rotates in relation to the body rotation axis. A result of a simulation performed in the Inventor program for four angles of the plate plane inclination 0°, 10°, 20° and 30° was shown in Fig. 6. The simulation was performed not just for one plate but for all three of them that were mounted on the head body. It can be noticed that at higher values of inclination of the plane in which the plate rotates in relation to the body rotation axis, the mining zone moves towards the unit face which facilitates slotting. Fig. 6 shows only trajectories of displacing disc tools on rotating plates. Whereas, Fig. 7 presents an exemplary result of a simulation of displacement of plates with disc tools during a rotation of the head body (Gospodarczyk at al., 2010). Such a simulation was also performed to check depth of mining with single disc tools. For the simulation apart from a change of inclination angle of the plane in which the plate rotates in relation to the body rotation axis, also the value of the eccentric e by which the axes of the plates with discs were moved towards the body rotation was changed.

Inclination 0°   **Inclination** 10°
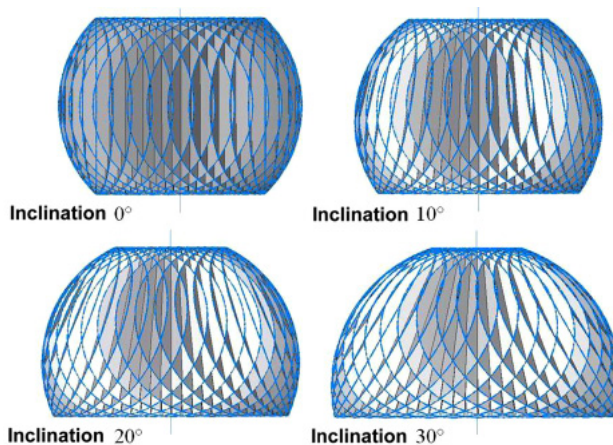
Inclination 20°   **Inclination** 30°

Fig. 6. Result of a simulation of discs blades motion trajectory depending on the inclination angle of the plane in which the plate rotates in relation to the body rotation axis
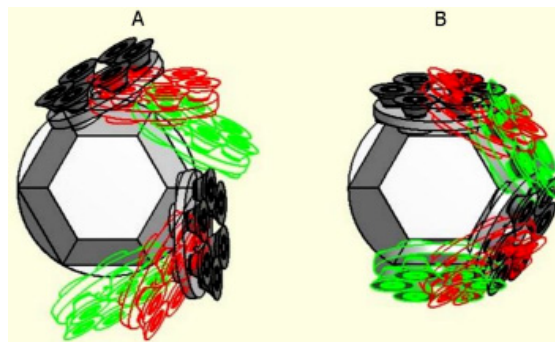

A   B

Fig. 7. Result of simulation of plates with disc tools displacement depending on the plate plane inclination angle and eccentric movement of the plates rotation axis

Fig. 7B. presents trajectories of disc tools obtained for axis of plates rotation perpendicular to the body surface and crossing in the axis of the body rotation. Mining depths did not exceed a dozen or so millimetres and the plates with disc tools rubbed the mined rock. When inclining the plates rotation axes and moving them eccentrically towards the body rotation a several times deeper mining was obtained without plates rubbing the rock. A view of such a simulation is presented in Fig. 7A. The most favourable parameters from the performed simulation are as follows: the plate axis inclination angle 15° and eccentric movement of axis towards the body rotation by about 20 mm.

Therefore, the values were accepted as the most beneficial ones in the further part of the model of the mining head. Moreover, it should allowed to locate the gear inside the body keeping a favourable shape of the head. Assuming that the designed head is to operate on an arm roadheader, its shape and dimensions should be close to solutions of units presently used on the machines. It was also necessary to determine values of many other parameters essential for proper designing the new head solution such as e.g. a number and direction of rotation of plates with tools, required value of torques for plates and the unit body, etc. Estimating the values through theoretical simulation was very complicated or in some cases even impossible, that is why stand tests of mining compact rocks with disc tools on a specially constructed lab stand were suggested. Results of the works are presented below.

3. A lab stand for testing disc tools of complex trajectory and the assumed research methodology

Lab tests of the mining process were planned to be performed only for one plate with asymmetrical disc tools of diameter 160 mm and blade angle 40°. The maximal diameter of the plate was defined at 450 mm, the number of disc tools at 6 pieces and their distribution on a diameter equal or lower than 350 mm. The required torque on the plate for the configuration was assessed at minimum 3000 Nm on the basis of the previously conducted tests on another lab stand. Assuming that the number of rotations of the plate can reach up to 60 rpm, their control is to be smooth and there must be a possibility to change direction of the rotations, it was decided that the power system should be equipped with a hydraulic engine with a toothed gear. The plate with tools must be able to move in three directions, mutually perpendicular, at changing, smoothly controlled velocity of the movement. Moreover, there must be a possibility to install an artificial rock sample for the mining process on the stand (Gospodarczyk at al., 2007, 2011).

Taking into consideration all the above presented principles, a lab stand was designed and implemented for examining the process of mining compact rocks with disc tools of complex trajectory. A model of the stand is to be found in Fig. 8 (Gospodarczyk at al., 2007).

The basic element of the stand is its frame welded of channel section C 3000. In its front part a construction of boarding for an artificial rock sample of dimensions 1650 mm × 1000 m × 1200 and volume of almost 2.0 m^3 was installed. Between the base plate and the rear part of the frame were built in two pipe slides on which the base with rotary plate will be moved forward and backward with a hydraulic actuator. On the base rotary plate there is welded a construction of the arm support on which the arm is mounted on a joint. The head is slipped into the front part of the arm and fixed with screws. The plate with disc tools is mounted to the head and it is propelled by a power unit installed on the other side of the head. The unit comprises hydraulic
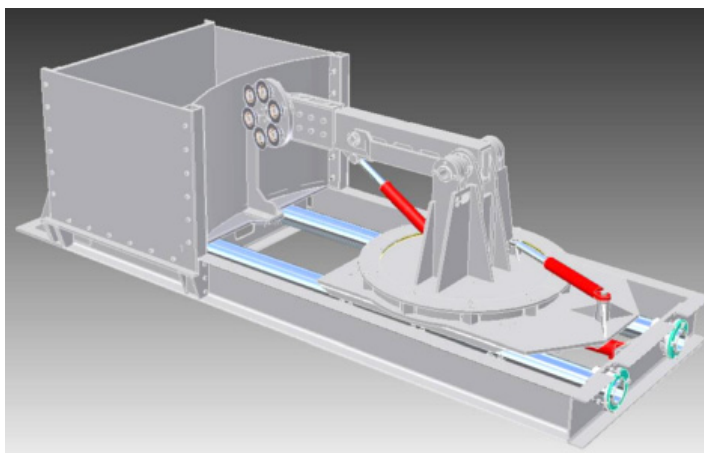
Fig. 8. A spatial model of a lab stand for testing mining process of compact rocks
with disc tools of complex trajectory

engine of OMTS 250 type made by the Sauer Danfoss company together with integrated planetary gear of RR5/OMC type.

Movement of the arm with the plate with disc tools is realised horizontally by rotation of the actuator of the base of rotary plate. The vertical arm movement is realised by rotation of hydraulic actuator mounted by its cylinder do the base and by its piston to the arm construction. At the suggested solution of the arm and actuators realising its movement horizontally and vertically, kinematic parameters of the plate and disc tools were determined. They are presented in Fig. 9. The plate features an ability to move forward and backward at the length of 1000 mm. In case of side movements is can turn by 32° angle to the left or right, whereas in case of vertical movement it can lower by 17° angle and rise by 12° angle. It allows mining the rock sample at its whole face surface at depth comparable to the length of the sample.

Additionally, for the elaborated spatial model of the lab stand there were also performed load simulations using the Finite Elements Method modelling the stand construction in the Ansys Design Space pack. Due to limited possibilities, the simulation was performed as static one without modelling the mined rock centre. The simulation was not intended to reflect the real state during mining but determination whether there are units of weaker resistance in the stand construction that can get damaged during work at nominal load. It was assumed that one of the disc tools is fixed at the depth of 15 mm in a brittle-elastic centre, whereas hydraulic actuators generated force constraints o maximal possible values. Also a simultaneous combination of three possible movements on the stand was assumed, forward movement, rising and arm rotation. The material planned for the stand implementation was an alloy steel 18G2A for the most extreme work conditions that in reality are not likely to appear, no symptoms of increased load of the material were observed.

The stand was fed and controlled from a special hydraulic aggregate allowing free and smooth setting of both the value of pressure and energy expenditure and change of the plate with disc tools rotation direction. The aggregate parameters enabled to obtain the number of rotations of the plate with disc tools within the range from 0 to 65 rpm.
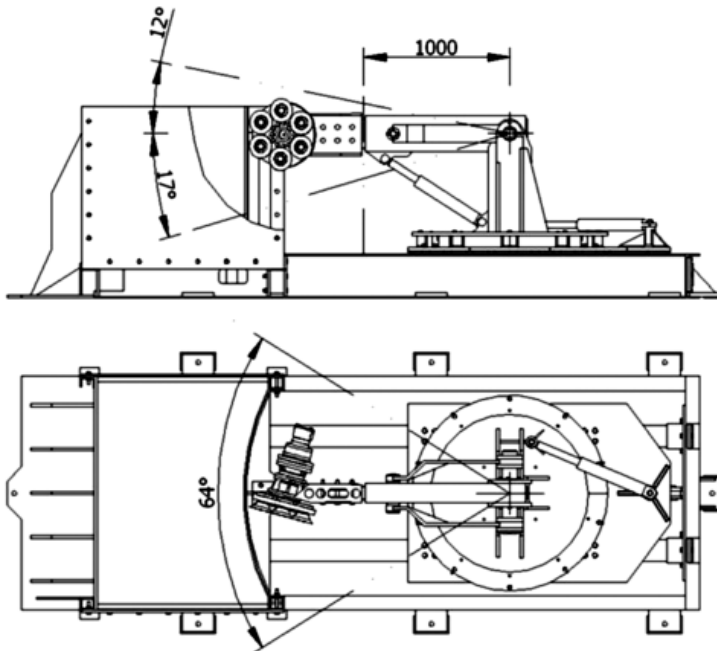
Fig. 9. Lab stand for testing the mining process of compact rocks with disc tools of complex trajectory with marked kinematic abilities

Whereas, for individual hydraulic actuators the following velocity values of the plate with disc tools movement: forward and backward from 0 to 7.2 cm/s, vertically from 0 to 8.9 cm/s, horizontally from 0 to 6.4 cm/s. All the values are within the required range for a research stand.

In case of the conducted tests it was required not only to perform observations connected with mining process with disc tools of complex trajectory but also determining approximate moments affecting the plates with disc tools and forces from individual movements of the plate. In order to do so, in the system supplying individual hydraulic receivers were installed pressure transducers made by Danfoss of MBS 33-3411-1AB08 type, registering pressure values at both the feed and downflow. Additionally, the actuators rising the arm and rotating the support construction were equipped with induction sensors of movement PT allowing defining velocity of the plate with disc tools. Distribution of the sensors and a diagram of the slotted line are presented in Fig. 10.

It was planned to perform tests comprising at least four changing parameters: direction and number of rotations of the plate with disc tools (overshot and undershot rotations and at least three ranges of rotation velocity 40, 50, and 60 1/m), mining pitch (from 10 mm to 40 mm), cutting depth (at least three values of cutting depth from 6 to 20 mm). For the above listed parameters it was assumed to perform cuts moving the plate horizontally and then the rock sample verti-cally (Gospodarczyk at al., 2011a). A diagram of mining the rock in both planes is presented in Figs. 11 and 12. Depending on mining direction (left or right) and vertical mining of the sample from left or right edge, the disc tool attacks the rock body with its flat or inclined surface. The aim of the tests was assessment of the mining process with a disc plate depending on the taken slide movement and direction of the disc plate rotations.
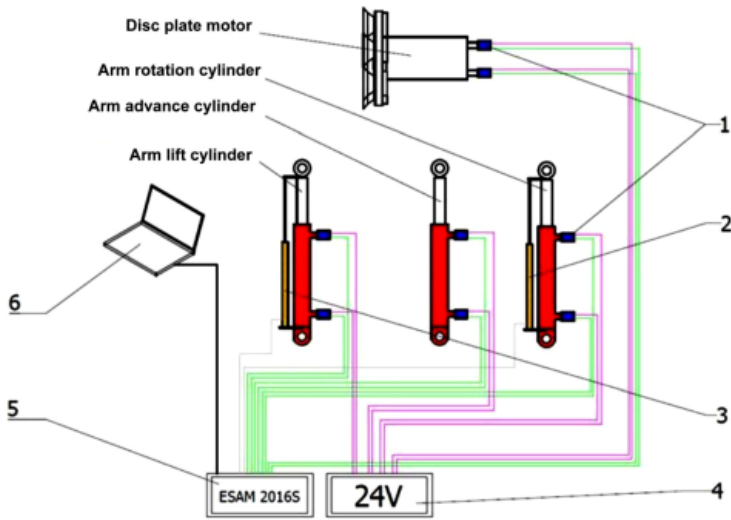
Fig. 10. Diagram of slotted line and distribution of sensors
1 – pressure transducer MBS32, 2 – movement sensor PT300, 3 – movement sensor PT500,
4 – feeder, 5 – measurement card ESAM 2016S, 6 – measurement computer
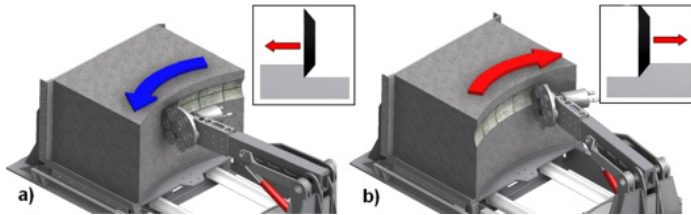

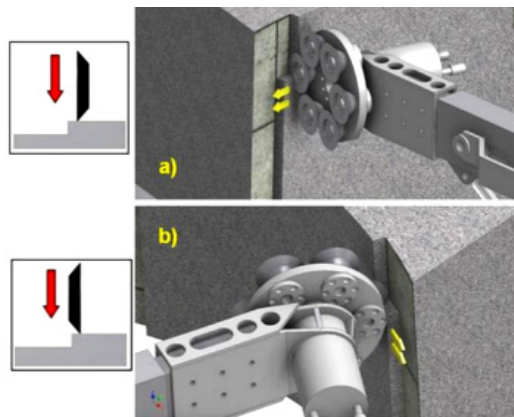Fig. 11. Diagram of horizontal mining of the samples: a) to the left, b) to the right

Fig. 12. Diagram of vertical mining of the sample: a) from left edge, b) from right edge

For selected tests a grain analysis of the winning was planned using sets of screens of 1 and 10 mm mesh sizes. The first test was conducted on a concrete sample of uniaxial compression resistance of 26 MPa. Some mining tests were repeated on natural rock samples embedded in a concrete block. Sandstone blocks featuring uniaxial compression resistance $Rc = 73$ MPa and a granite block of $Rc = 253$ MPa were used for the tests.

4. The course and analysis of the stand tests results

Mining tests in a horizontal plane were all conducted on a concrete block. Realisation of the research started with pilot tests during which the sample face was properly equalized. The depth varied from 0 to 10 mm, whereas the plate rate of rotation was 40 to 60 rpm. At the speed of 60 rpm a significantly lower amplitude of the construction vibrations was observed which considerably improved work conditions of the disc plate. Overshot direction of the disc plate motion was applied to minimize vibrations of the construction stand (Gospodarczyk at al., 2011a). A view of the cut after one of the mining tests in the horizontal plane was shown in Fig. 13.

Fig. 13. A view of the cut after one of the mining tests in the horizontal plane

After the sample surface got equalized and the value of rotational speed was determined, the main tests started which included passes of the disc plate on the full width of the sample. The cutting depths were within the range from 6 to 15 mm implementing passes on the full length of the sample bend (1630 mm) horizontally left and right alternately. At the move of the plate to the left side of the block, a significantly lower dynamics of the mining process was observed which resulted from attacking the sample with the flat surface of the disc. A view of registered courses of component forces values (pressure Pd, cutting Ps and side Pb) during mining to the left and right at cutting depth g 10 mm was presented in Fig. 14 (Gospodarczyk at al., 2011a).

The main part of the research included mining tests in a vertical plane that were implemented firstly on the concrete block and then on natural sandstone and granite blocks embedded in a concrete block. A view of embedded sandstone and granite blocks is shown in Fig. 15.
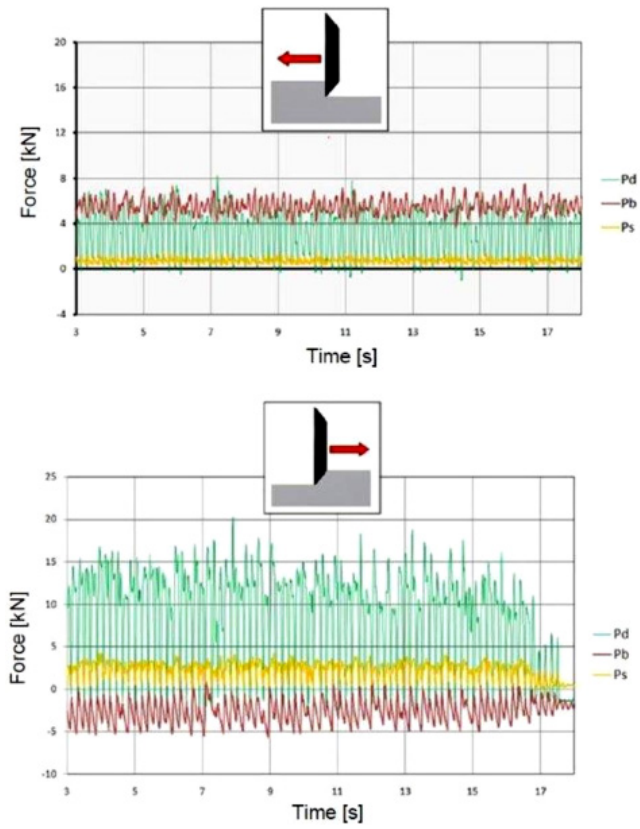
Fig. 14. Courses of values of pressure Pd, cutting Ps and side Pb forces during mining to the left
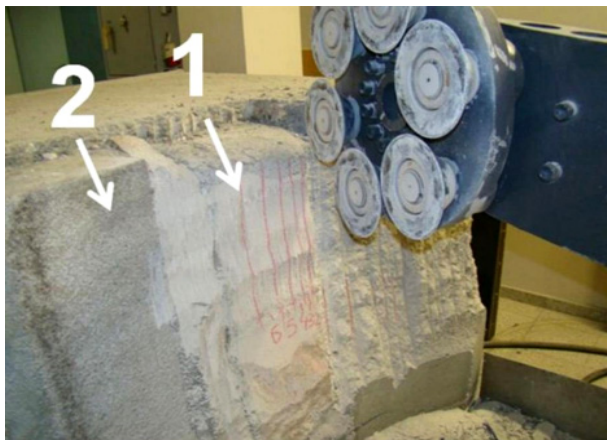and right at cutting depth of $g = 10$ mm

Fig. 15. Sandstone (1) and granite (2) blocks embedded in concrete

Tests of vertical mining started with mining the concrete block. Firstly, the stand arm was moved to its extreme left position and at the depth of 10 mm the first opening cut was performed. Then, half-open cuts were done for pitches 20 mm, 30 mm and 40 mm (Gospodarczyk at al., 2011).

In the next series of tests the cutting depth was increased to 15 mm, repeating values of applied cutting pitches from the previous series. For both series it was noticed that for the pitch $t = 40$ mm full spalling of the cut groove does not take place and at the depth $g = 15$ mm strong reactions occur leading to the construction vibrations that disturb the mining process.

Another set of tests was performed from the right side of the sample so that the cut spalling took place as a result of the conic surface of the disc action. The tests were conducted at depth of $g = 15$ and 20 mm at cutting pitches $t = 20$, 30 and 40 mm. It was observed that for each case of mining full spalling of the cut took place. Therefore, additional tests were performed for $g = 25$ mm and pitches $t = 20$, 30 and 60 mm. For the first two values of pitches full spalling of the cut occurred. For the pitch $t = 60$ mm the cut groove was not fully spalled so further increasing of the cutting pitch value was given up. Mean values of component forces calculated during left and right mining of the block at depth $g = 15$ mm are presented in Fig. 16 (Gospodarczyk at al., 2011a).
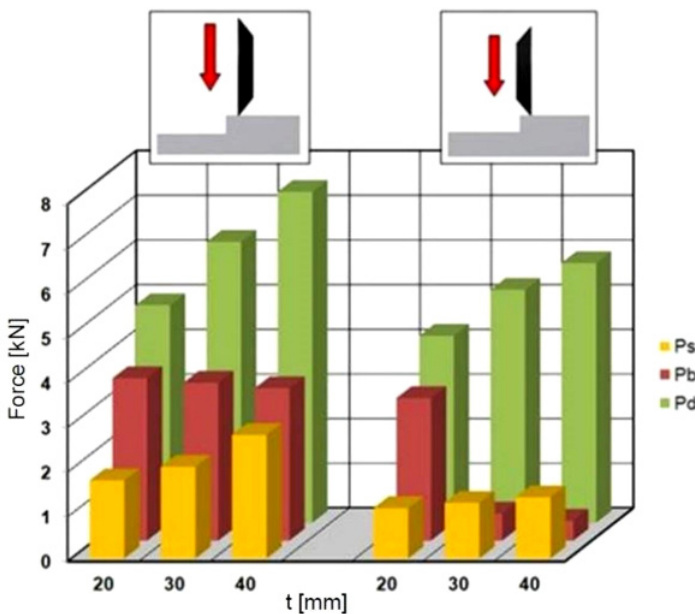

Fig. 16. Mean values of the pressure Pd, cutting Ps and side Pb forces during mining from the left and right side of the block at cutting depth $g = 15$ mm

Measurements of the obtained winning allowed conclusion that as a result of vertical mining the dominant fraction are grains several times bigger that grains obtained during horizontal mining which is presented in Fig. 17 (Gospodarczyk at al., 2011a). It mainly refers to the case when mining took place through spalling of the cut groove with a conic surface of the disc (vertical mining from the right side of the block).

Fig. 17. Graining of the winning obtained during horizontal (left) and vertical (right) mining

Due to relatively low volume of the sample, during mining the sandstone and granite it was decided to apply a constant cutting depth and performing cuts only from the right. As a result of preliminary tests, the cutting depth was set for sandstone at $g = 40$ mm at the pitch $t = 30, 40, 50$ and 60 mm and for granite $g = 25$ mm at $t = 10, 20$ and 30 mm. Observations done during the experiment allowed to find out a significant decrease of the mining process dynamics in comparison to tests of concrete mining (Gospodarczyk at al., 2011a). The surface of the sandstone body uncovered as a result of mining was relatively regular which meant smooth chipping off the rock (Fig. 18). A good effect was also noticed for the form of the obtained winning with granulation considerably increased when compared to the one obtained in previous tests.
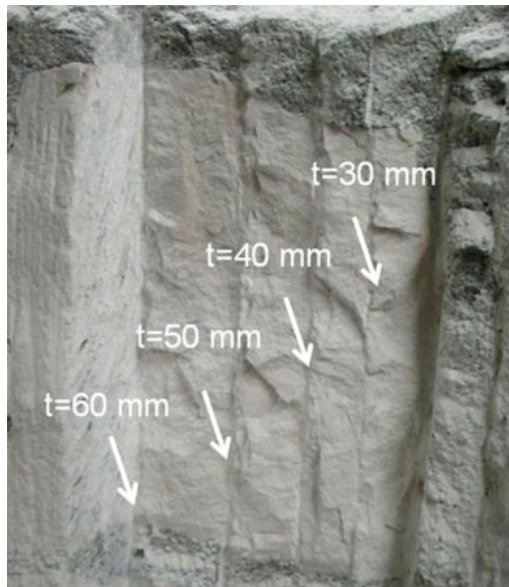

Fig. 18. A view of the sandstone block surface after completing the mining tests

Vertical mining from the right edge of the sample allowed obtaining higher values of depth and cutting pitch at full spalling of the cut groove. The obtained results clearly illustrate influences of mining parameters on values of component forces of mining resistance. Pressure force reached significantly highest values during the tests. An increase of the pressure force value was caused by an increase of cutting depth and pitch. The value of cutting force changed mainly because of an increase of cutting depth and was little sensitive to the change of cutting pitch (especially for sandstone). A high changeability was presented by the side force. In case of mining the concrete sample, the highest values of the side force were connected with a low value of cutting pitch so they accompanied full spalling of the cut groove. Presentation of mean values of mining forces for tests of mining concrete and natural rocks in which the highest values of cutting depth and pitch were obtained in shown on a diagram in Fig. 19 (Gospodarczyk at al., 2011a).
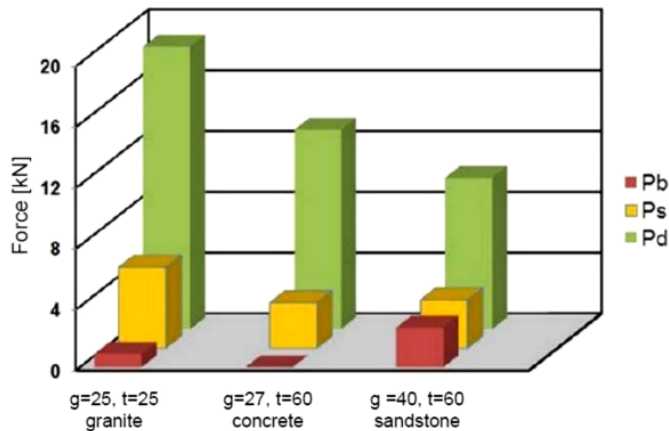

Fig. 19. Mean values of mining forces for maximal values of cutting depth
and pitch during mining different rock samples

On the basis of an analysis of the obtained lab tests results, the following principles were selected for further designing works over the prototype head with disc tools of complex trajectory (Gospodarczyk at al., 2007, 2011b):
- Diameter of disc tools – $D = 160$ mm,
- Disc tool blade angle $b = 30 – 45°$,
- Diameter of plates with disc tools 700 mm $\leq Du \leq 850$ mm,
- Diameter of discs distribution of the plates – 550 mm $\leq Dn \leq 650$ mm,
- Number of disc tools on the plates $l_d \leq 8$ pieces,
- Revolutions number of plates with disc tools – $60 \leq n_t \leq 100$ rpm,
- Number of plates with disc tools – 3,
- Revolutions number of the body on which the plates are mounted – $20 \leq n_k \leq 30$ rpm,
- Torque of the disc with disc tools – $M_t \approx$ minimum 4000 Nm, suggested 5000 Nm,
- Total value of the moment to propel the plates with disc tools – minimum 8000 Nm, suggested 10000 Nm.

The above presented values were estimated taking into consideration, in comparison to the results obtained in lab stand tests, an increased diameter of the plates with disc tools by at least 50%, predicted higher strength of the mined rock at the level of at least 100 MPa, and target mining depth at minimum 25 mm) and the fact that during mining there are at least two plates with disc tools in contact with the rock body at the same time.

5. A design of the new head solution

On the basis of the above presented principles, elaboration of the design and model of the new head solution with disc tools of complex trajectory started. The works were performed with cooperation with the REMAG Ltd company – the leading Polish producer of light and medium arm roadheaders. It was planned to work out and adapt the new head solution for a medium road-header KR150 manufactured by REMAG. On the basis of an analysis of milling heads used on the miner it was assumed that length of the new solution should not exceed 1750 mm, its diameter 859 mm and weight 5 tonnes. The elaborated initial model of the head comprised mounting three plates with disc tools on its body. The casing body will have an ability of independent rotation in relation to plates with disc tools. Kinematic capabilities of the new head solution are presented in Fig. 20 (Gospodarczyk at al., 2010, 2011a).
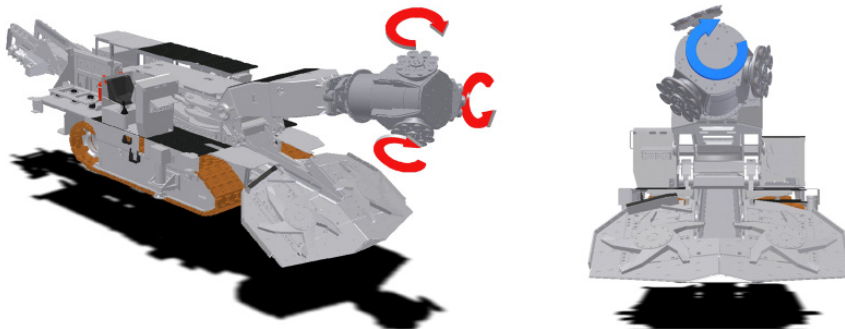

Fig. 20. Kinematic capabilities of the new head solution mounted on the roadheader KR 150

It was assumed that drives for both motions should be separate to enable independent control of the value of their rotational speed. The head body will be propelled by a hollow shaft, whereas the drive of the plates with disc tools will be realised by an external shaft through a gear placed inside the body. The method of drive transmission is shown on a diagram in Fig. 21. The gear solution allows displacement of the plates rotation axle in relation to the axle of the whole unit rotation. In this option the driving wheel 2 propelled by shaft 1 cooperates with wheels 3 mounted on common shafts with wheels 4 from which the torque is transmitted to conic wheels 5 propelling individual plates.

On the basis of the above diagram, an initial model of a head with asymmetrical disc tools of complex trajectory was elaborated (Fig. 22). While preparing the solution, it was additionally assumed that the drive of plates with disc tools will be realised from an electrical engine of
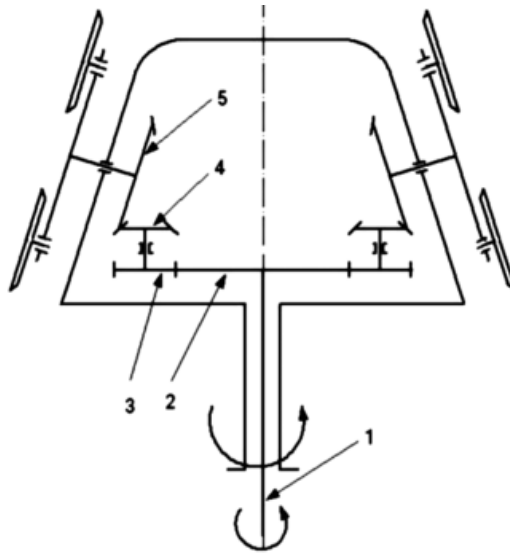
Fig. 21. Optional solution of inner double bevel cylindrical gear for drive transmission
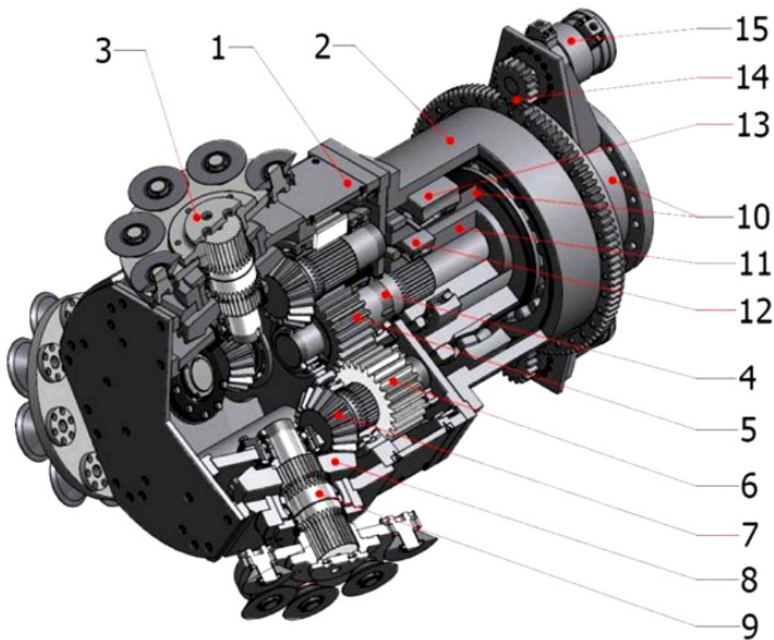on plates with disc tools

Fig. 22. Model of the new head solution with disc tool of complex trajectory.
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

150 kW power mounted on the miner arm, whereas the drive of the head body will be realised by two hydraulic engines HS 0.8.

It was planned that the power from the engine propelling the plates will not exceed 50 kW ant its revolutions will not be higher than 500 rpm. For the data and maximal rotations of plates reaching 200 rpm a two-step cylindrical-bevel gear of summary ration about 1 : 2 was worked out. It was assumed that the gear transmitting rotations onto the head body will transmit power of 2×80 kW from two engines HS 0.8, at maximal engines rotation 250 rpm. For the planned body rotations reaching 30 rpm, an external cylindrical gear was of ratio 1 : 6 was elaborated (Gospodarczyk at al., 2011b).

On the basis of the elaborated model, a technical design of the head was implemented enabling to make it in metal. The head for mounting on the KR150 miner and initial field tests was manufactured by REMAG Ltd. Its view before the field test is shown in Fig. 23.

Fig. 23. A view of the KR150 miner arm with a head with disc tools of complex trajectory before field tests

6. Preliminary examinations of the prototype head solution

Preliminary field tests of the head with asymmetrical disc tools of complex trajectory were conducted on a test stand prepared at REMAG Ltd. It was possible to mine a large-size concrete block of uniaxial resistance of about 40 MPa. During the first stage of initial tests, a change of the head body rotations was planned within the range from 10 to 30 rpm and for the plates with disc tools from 20 to 200 rpm. Mining effectiveness and the level of the tools wear were checked as well as granulation of the obtained winning. A view of the KR150 miner with the new solution during one of the conducted mining tests was shown in Fig. 24 (Gospodarczyk at al., 2010, 2011b).

The tests started at the head body rotations at counter clockwise direction and rotations of plates with disc tools at clockwise direction. Disc tools were mounted on the plates with the flat side out. The new head solution worked for the parameters without serious reservations. At lower values of rotations very large graining was obtained, however it was accompanied by high vibrations of the head.

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Fig. 24. A view of the KR150 miner with the new head solution with asymmetrical disc tools
during one of the field tests

An increase of rotations of plates with disc tools caused lowering the vibrations but it increased dustiness and at maximal rotations there even occurred sparking at the contact of the tools and the rock. The best effects of the work – large graining of the winning, low engines load and limited vibrations were obtained for the head body rotations of ca 20 rpm at the plates rotations value of ca 60 rpm. A view of the obtained winning and a typical surface of the block is shown in Fig. 25 (Gospodarczyk at al., 2010, 2011b). No considerable symptoms of the disc tools wear
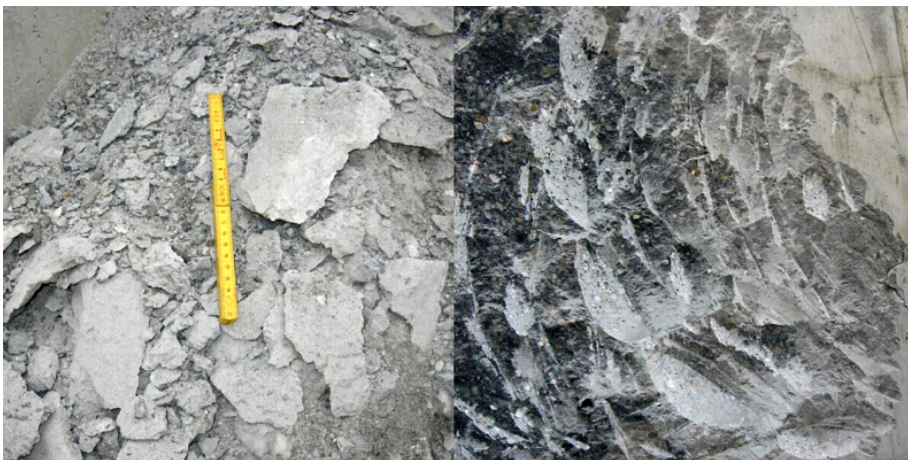

Fig. 25. A view of the winning and the surface of the mined rock block obtained for the most favourable set of
direction and revolutions number of the head body and plates with tools

were noticed. Whereas, a change of direction of the head body or plates with disc tools rotation onto the opposite one had a highly negativeinluence on the engines load and disc tools and the plates themselves wear (Gospodarczyk at al., 2010, 2011b).

Similar results were obtained when changing arrangement of the disc tools on the plates. Both for alternate setting and for contrary mounting, with flat side towards the plates, the winning was very fine and the vibrations significantly higher. Moreover, typical for the previous test, crossing tracks of individual disc tools were not found. A view of the plate with disc tools after one of such tests in shown in Fig. 26.

Fig. 26. A view of wear marks on the plate side surface and disc tools

After changing the mounting of the disc tools to the first one, mining tests of the block surface for different directions of slotting were performed, at the number of plates with disc tools rotations at ca 70 rpm and clockwise direction, and rotations of the head body ca 20 rpm and opposite direction. The values were changed within a little range keeping the relation of the plates with disc tools rotations number to the number of the head body rotations within the range of 3 to 3.3. It was found that the most favourable direction of slotting and mining for this configuration of rotations is the horizontal one from right to left from the depth of 0 to maximum. The maximal depth should not exceed 15 – 20 cm for the suggested head solution. It is also possible to mine vertically from left to right at lowered speed of the head movement. However, face slotting was more difficult as well as mining from top to the bottom (Gospodarczyk at al., 2010, 2011b).

7. Conclusions and final remarks

The suggested solution of the head with asymmetrical disc tools of complex trajectory demonstrated its usefulness during mining compact rocks and it can be applied as an alternative for

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milling heads of arm roadheaders. In order to obtain the most favourable parameters of the head work – large graining of the winning, low load of the driving engines and limited vibrations, it is necessary to select proper configuration of the direction and number of rotations for the head body and plates with tools. However, it seems sensible to perform further tests both field and industrial ones to elaborate the most favourable construction of the head and technology of its work during drilling dog headings.

In order to increase reliability of the elaborated solution, some constructional changes of the head were suggested for further tests. First of all, replacing the electrical engine propelling the disc plates by a hydraulic engine of parameters ensuring work stability. Another change was suggesting a new construction of plates and disc tools to lower their wear. Instead of a round plate, a branched plate was suggested as well as replacing smooth disc tools with tools with padded edges. One more change included implementing plates and disc tools chucks that could enable their mounting at different angles in relation to the plates rotation axle. After introducing the above listed changes to the head construction, subsequent field tests will be conducted to verify usability of the modifications and their influence on mining effectiveness.

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