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THE DESIGNING PROCESS AND STAND TESTS OF A NEW SOLUTION OF A MINING HEAD WITH DISC TOOLS OF COMPLEX MOTION TRAJECTORY FOR COMPACT ROCKS MINING

SUMMARY

The article presents a new solution of a mining head with asymmetrical disc tools of a complex motion trajectory for hard rocks mining. The developed and manufactured head is to be an alternative for traditional milling heads used in roadheaders. The basis for the head development was elaborated based on laboratory tests performed in the AGH University of Science and Technology in Krakow. The technical design and the head were implemented in cooperation with the factory of REMAG S.A. in Katowice. The head, mounted on the KR 150 roadheader, underwent field tests. Their results allowed modernisation of the head and its adaptation to further industrial tests in mining plants.

***Keywords**: mining head, hard rock, disc tool, roadheader, stand tests*

PROJEKTOWANIE I BADANIA STANOWISKOWE NOWEGO ROZWIĄZANIA GŁOWICY Z NARZĘDZIAMI DYSKOWYMI O ZŁOŻONEJ TRAJEKTORII RUCHU DO URABIANIA SKAŁ ZWIĘZŁYCH

W artykule przedstawiono nowe rozwiązanie głowicy z narzędziami dyskowymi niesymetrycznymi o złożonej trajektorii ruchu do urabiania skał zwięzłych. Opracowana i wykonana głowica ma być alternatywą dla tradycyjnych głowic frezujących stosowanych w ramionowych kombajnach chodnikowych. Założenia do opracowania głowicy opracowano na podstawie przeprowadzonych w AGH badań laboratoryjnych. Projekt techniczny i głowicę wykonano we współpracy z Zakładami REMAG S.A. w Katowicach. Głowica, zainstalowana na kombajnie chodnikowych KR 150 została poddana próbom poligonowym. Ich wyniki pozwoliły na wykonanie modernizacji głowicy i przystosowanie jej do dalszych prób przemysłowych w zakładach górniczych.

***Słowa kluczowe**: głowica urabiająca, skała zwięzła, narzędzie dyskowe, kombajn chodnikowy, badania stanowiskowe*

1. INTRODUCTION

Drilling of heading and tunnel excavations in hard rocks is currently realized with the use of two methods: a traditional one using explosives placed in formerly made shot holes and a mechanical one. The latter method bases on applying two techniques of rocks mining: milling with the use of radial tools or rotary tangent bits, and so called static crushing with the use of symmetrical disc tools. The first technique of mining by milling is much more common. Static crushing can only be applied at drilling tunnels or excavations of large dimensions due to the necessity to achieve large forces of pressing the tools onto the rock whole, which can be obtained by high mass and dimensions of the machine. There are also other techniques of mechanical mining e.g. the method of back incision, but they are not widely recognized nowadays.

In case of hard rocks mining by milling, mainly arm heading miners are applied. They have many advantages like ability to realize excavations of any section or possibility of selective mining, but their biggest drawback is a decreased effectiveness of mining or even total disability to operate when rocks of high hardness occur in the wall face. It causes a faster process of the cutting picks wear which makes the mining process unprofitable.

That is why a few research centers in the world have tried to apply symmetrical and asymmetrical mini disc cutters on mining heads of roadheaders. Colorado School of Mines, among others, has developed and constructed a solution of a longitudinal head equipped with symmetrical disc tools (Kotwica *et al.* 2008, 2009a, b). In order to decrease values of mining forces, the head uses symmetrical mini discs of 125 mm diameter. However, the solution is currently being tested. The greatest problem is the issue of mini discs bearing which influences the tools life loaded with heavy duty. A view of such a prototype equipped with mini discs is presented in Figure 1.

Disc tools are mounted in chucks directly on the unit casing and their rotation in enforced by rotation of the whole unit. It affects heavy duty of the mining disc tools and low mining effectiveness. That is why, on the basis of analysis of world technique condition, results of conducted researches and own experience, the Department of Mining, Dressing and Transport Machines of the AGH University of Science and Technology in Krakow has attempted to develop a new solution of a unit in which the motion of disc tools

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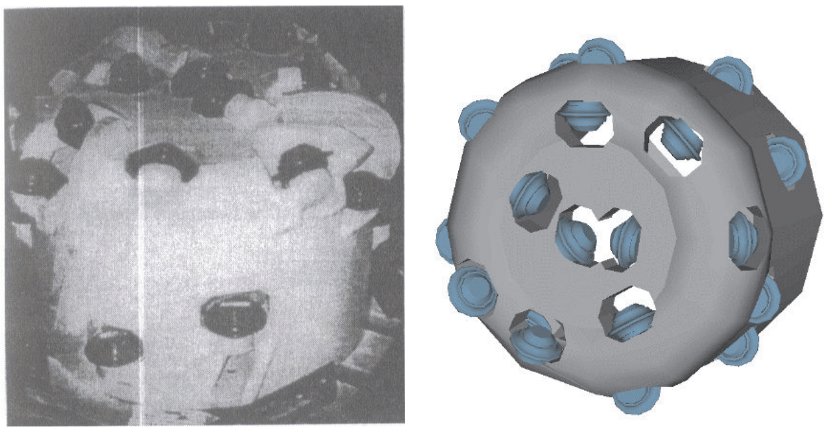

Fig. 1. A design and a view of the prototype mining head of the roadheader equipped with mini discs developed in Colorado School of Mines (Kotwica *et al.* 2008, 2009a, b)

will be forced and it will cause mining of the rock whole with the same tools following a complex trajectory. It will result in crossing of mining lines of particular disc tools and making it easier to mine hard rocks by breaking off rock grooves. It should also decrease energy consumption during the mining process. For this purpose a disc tool should be constructed on separate elements, mounted rotationally on the mining unit casing and powered independently. Such a conception is presented in Figure 2 (Kotwica *et al.* 2008, 2009a, b).

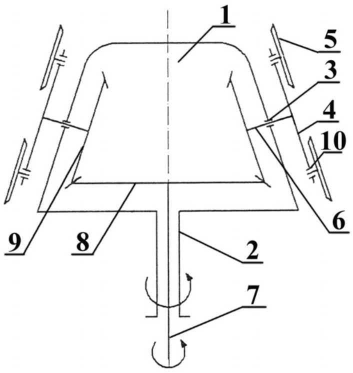

Fig. 2. A conception of a mining unit equipped with disc tools (Kotwica *et al*. 2008, 2009a, b)

According to the conception, the mining head consists of independently powered body with mounted in it and powered discs tools – asymmetrical disc tools. The body of the head (1) is driven by an external shaft. In the body, in seatings (3) drive shafts are mounted (6) with round plates (4) on which asymmetrical disc tools (5) are mounted in bearing seatings (10). The number of the tools should not be lower than 3 and most favourably should be 6. The propulsion on drive shafts (6) is transmitted by an internal drive shaft (7), independent from the external one (2), and a set of bevel gears (8), (9) or alternative ones. In the suggested conception of a mining unit equipped with disc tools, the tools are mounted on round plates (4), parallel to the axis of their rotation.

Assuming application of replaceable round plates (4), it will be possible to mount on them the disc tools of rotation axes located crosswise to the rotary axis of the disc. Such a solution is presented in Figure 3. Both for disc tools of rotary axes placed crosswise to the disc rotation and those with parallel axes, in the conception of the new solution of the unit it is essential to move axes of round plates (4) drive shafts (6) with mining tools (5) by the value *e* so that they do not cross the drive shaft axis (2) of the body head (1). It is also presented in Figure 3. Such eccentric way of placing the disc axes with disc tools should enable easy slotting of the tools into the whole both at horizontal and vertical motion of the unit. The size of the displacement of the disc axis towards the axis of the head body drive shaft should amount at least as much as assumed maximal value of the single disc tool mining depth. It is accepted that it should not exceed 25–30 mm. In order to develop constructional solution of such a unit it is required to know values of basic geometrical and kinematic parameters like: diameter and blade angle of disc tools, deviation angle of the axis on which disc tools are mounted, diameter of the disc and disc tools arrangement, number of revolutions of the mining unit casing, direction of the unit disc and casing revolutions and direction and speed of the mining unit movement.

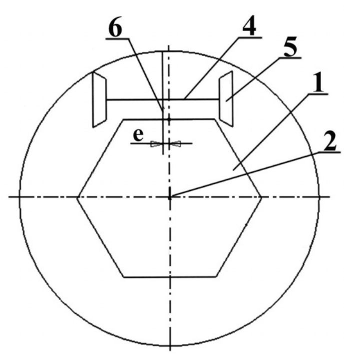

Fig. 3. A conception of a mining unit equipped with disc tools of rotation axes placed crosswise towards the disc rotation axis (Kotwica *et al*. 2009a, b)

Fig. 4. A view of laboratory stand for testing hard rock mining using single round plate with asymmetrical disc tools (Kotwica *et al*. 2008, 2009a, b)

The values cannot be defined on the basis of theoretical calculations and they cannot be assumed based on possessed information and experience. For theoretical calculation it would be necessary to develop a very complex model in which the most difficult problem would be modeling of the mined centre. As for the obtained experience, it is too little to be the base for determining the mentioned parameters values. That is why conducting of the basic research allowing obtaining of full or partial information in the subject seems to be the most reasonable idea. The research were performed on a specially prepared and constructed laboratory stand (Kotwica *et al.* 2008, 2009a, b). The view of this stand is presented in Figure 4.

Below, there were presented principles and guidelines after researches for development of a conception and technical design of new solution of mining head with disc cutters. Elaboration of principles and guidelines was based on the results of preliminary examinations of rocks mining with asymmetrical disc tools conducted in AGH University of Science and Technology in Krakow on laboratory stand.

On the basis of the obtained results the individual parameters were listed below together with ranges of their values for an experimental mining head with asymmetrical disc tools:

– Diameter of asymmetrical disc tools D = 160 mm,
– Disc tool blade angle $\beta = 30–45^{o}$,
– Diameter of round plates with disc tools 600 mm $\leq Du \leq$ 850 mm,
– Diameter of arrangement of disc tools on the round plates 300 mm $\leq Du \leq$ 500 mm,
– Number of disc tools on the round plates $l_d \leq 8$ pieces,
– Revolutions number of the round plates with disc tools $20 \leq n_t \leq 60$ 1/min,
– Speed of movement of the disc with disc tools horizontally, vertically and aside set within the range of 1 mm/s $\leq v_t \leq$ 30 mm/s,
– Torque of the disc with disc tools $M_t \approx$ 2500–3500 Nm.

2. ELABORATION AND IMPLEMENTATION OF A NEW SOLUTION OF A MINING HEAD WITH DISC TOOLS OF COMPLEX MOTION TRAJECTOR

On the basis of assumptions presented above, the development of the design and model of a new solution of a mining head with asymmetrical disc tools of complex motion trajectory began. Due to an access to a fleet of machines and during following research works to particular roadheaders, the development was conducted in cooperation with REMAG S.A. – a leading Polish manufacturer of light and medium arm roadheaders. It was planned to elaborate and adapt the new solution of a head for the model of a medium roadheader – KR 150 produced by REMAG S.A. On the basis of analysis of milling heads used on the machine, it was agreed that the length of the new solution should not exceed 1750 mm, its diameter 859 mm and weight 5 tones.

A preliminary model of the head assumed mounting three plates with disc tools on its body. The casing body will have an ability of rotation independent from plates with disc tools. Kinematic possibilities of the solution were presented in Figure 5. For the need of research tests it was assumed that the new solution of the head will be able to change both the direction and number of the head body and plates with disc tools rotation (Kotwica *et al.* 2008).

According to the above presented assumptions, there was developed a preliminary model of a head with asymmetrical disc tools of a complex motion trajectory. It was presented in Figures 6 and 7. During its development, it was additionally assumed that the drive of the plates with disc tools will be realised by an electric engine of 150 kW power mounted on the roadheader arm, whereas the drive of the head body will be realised by two hydraulic engines HS 0.8.

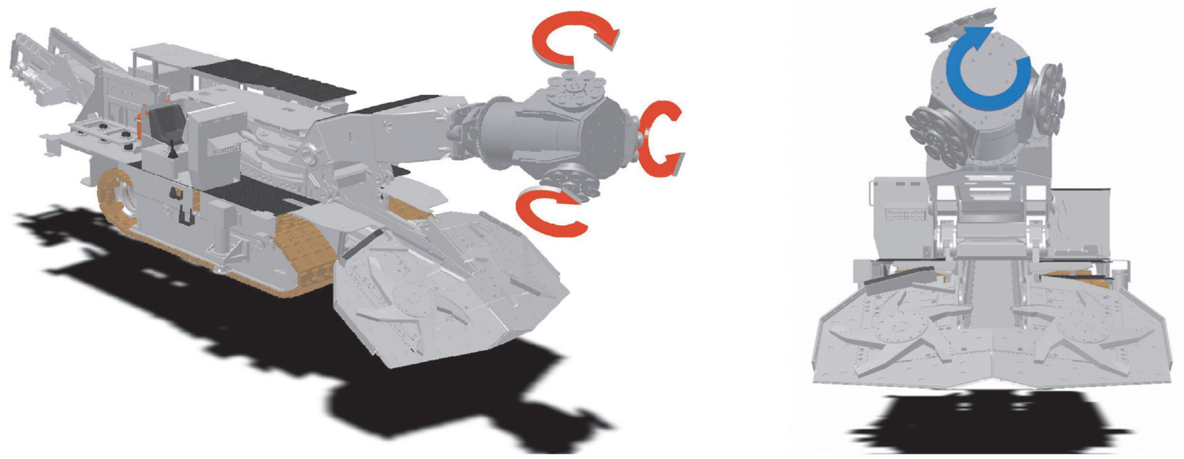

Fig. 5. Kinematic abilities of a new solution of a head with asymmetrical disc tools of a complex motion trajectory mounted on the KR 150 roadheader (Kotwica *et al*. 2009a, b)

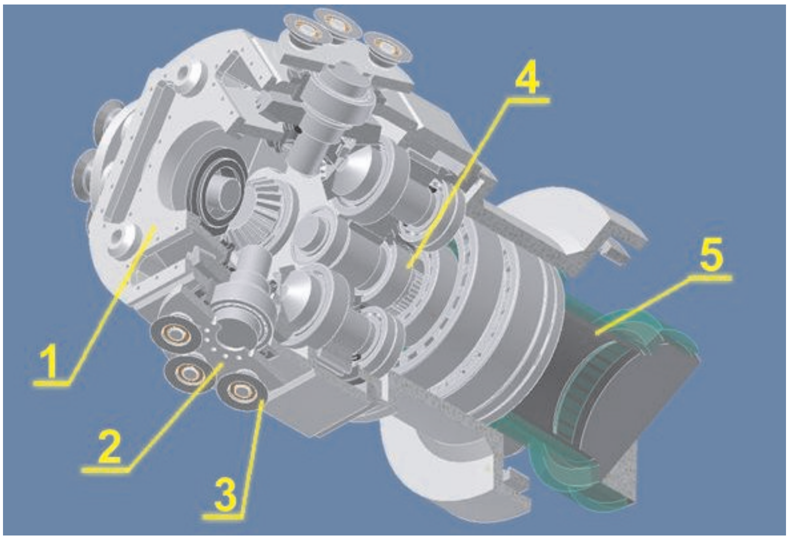

Fig. 6. A preliminary model of a head with asymmetrical disc tools of complex motion trajectory (Kotwica *et al*. 2009a, b)

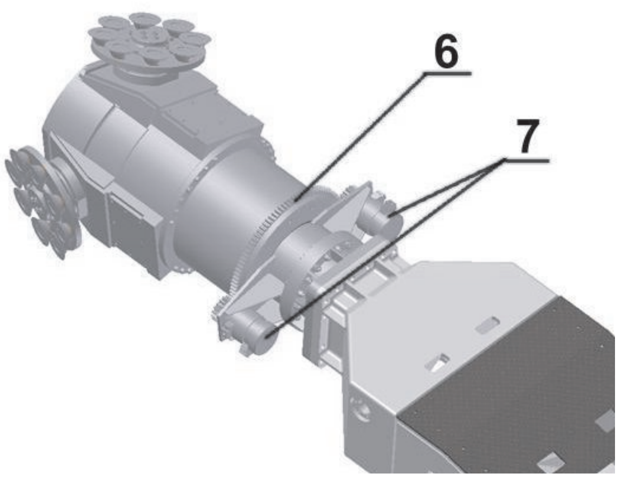

Fig. 7. A preliminary model of a head with asymmetrical disc tools of complex motion trajectory mounted on the arm of the KR 150 roadheader (Kotwica *et al*. 2009a, b)

Following the presented model, the head consists of a body (1) propelled through a cylindrical gear of external meshing (6) by two hydraulic engines HS 0.8 (7). There is a two-stage toothed gear (4), with the first stage of cylindrical mesh and the second of bevel one. The gear is propelled through a central shaft (5) directly connected to the 150 kW electric engine. The gear (4) transmits the drive to the three plates with disc tools (2). Asymmetrical disc tools are mounted on the plates (3).

For such a model there was a simulation conducted using the Inventor 2010 pack to determine setting of the three plates with disc tools on the head body. The simulation was conducted to check depth of mining with single disc tools. Exemplary results were presented in Figure 8. For rotation axes of plates perpendicular to the body surface and crossing in the rotation axis of the body there were achieved disc tools trajectories as presented in Figure 8B. Mining depths did not exceed twenty millimetres and plates with disc tools

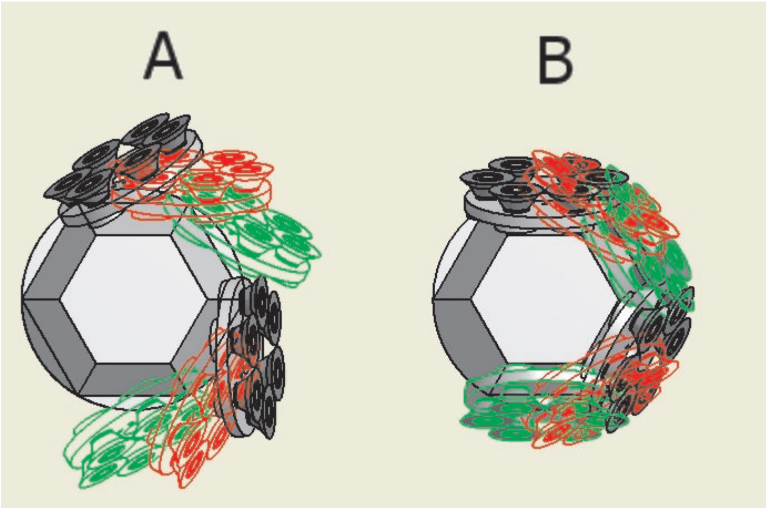

Fig. 8. A kinematic trajectories of cutting tools fixed on the head with asymmetrical disc tools of complex motion trajectory mounted on the arm of the KR 150 roadheader (Kotwica *et al*. 2009a, b)

were brushing against the mined rock. When the rotation axes of plates got inclined and moved eccentrically towards the body rotation, the mining depth increased several times without brushing against the rock. One of such simulations is presented in Figure 8A. The most favourable parameters obtained from the simulations are as follows: angle of the plate inclination -5^{o} and movement of the axis eccentrically towards the body rotation by about 20 mm (Kotwica *et al.* 2008).

It was assumed that the drive engine power transmitted on plates with disc tools will not exceed 50 kW and the engine revolutions will not be higher than 500 per minute. For the data and maximal rotation of the plates reaching up to 200 per minute, there were performed calculations and elaboration of a two-stages cylindrical-bevel gear of total gear ratio about 1 : 2. A model of the gear with marked bearing seatings is presented in Figure 9 (Kotwica *et al.* 2009b).

It was assumed that the gear transmitting rotations on the head body will transmit the power of 2 × 10.6 kW from two engines HS 0.8 at maximal engines revolutions of 250 per minute. For the assumed body rotations reaching up to 40 per minute, there was developed an external toothed cylindrical gear of the ratio 1:6. On the basis of the elaborated models there was created a technical design of a head. It was the base for the head implementation. A simplified assembly picture with overall dimensions marked is presented in Figure 10.

The factory of REMAG S.A. manufactured the head adapted to be mounted on the arm of the KR 150 roadheader. A view of the head ready for field tests is presented in Figure 11.

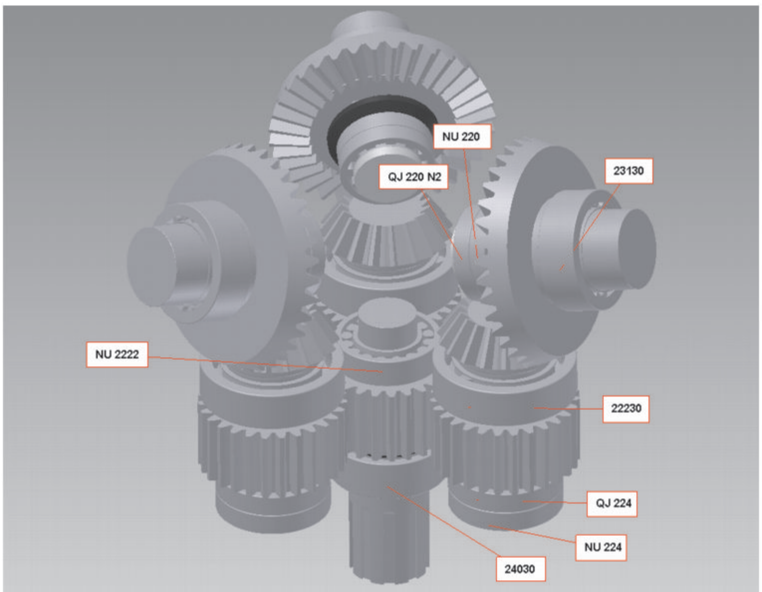

Fig. 9. A model of a two-stages cylindrical-bevel gear of total gear ratio about 1:2 with marked bearing seatings (Kotwica *et al.* 2009b)

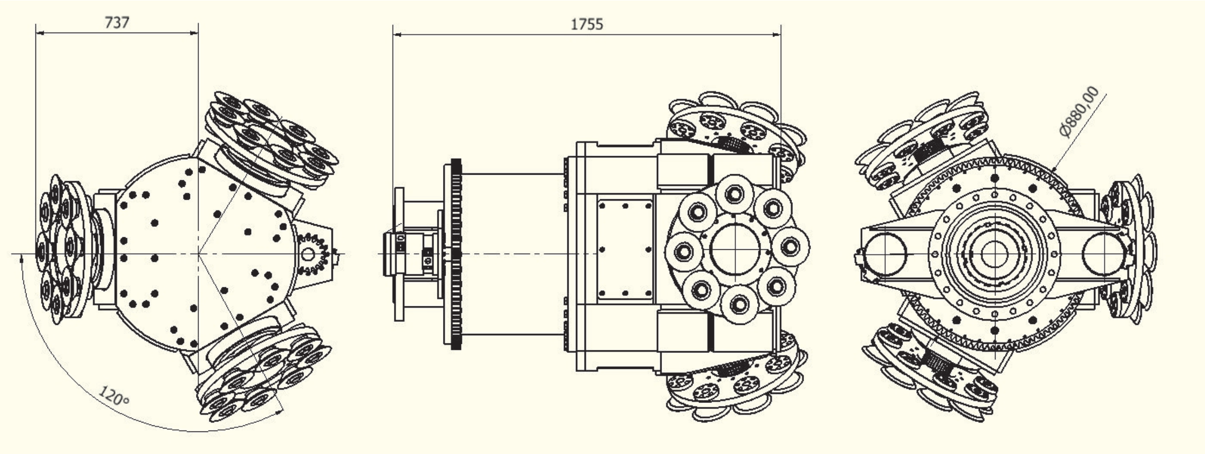

Fig. 10. A simplified assembly picture of a head with asymmetrical disc tools of a complex motion trajectory (Kotwica *et al.* 2009b)

Fig. 11. A view of a head with asymmetrical disc tools of complex motion trajectory on the arm of the KR 150 roadheader, ready for field tests

3. FIELD TESTS OF THE NEW SOLUTION OF A HEAD WITH DISC TOOLS OF COMPLEX MOTION TRAJECTORY

Field tests of the head with asymmetrical disc tools of complex motion trajectory were performed on a research stand prepared within the area of REMAG S.A. It enabled mining of a large-size concrete block of guaranteed one-axis compressive strength about 40 MPa. During tests the electric engine mounted in the arm of the KR 150 roadheader was fed by a frequency converter allowing change of direction and number of revolutions of the engine at its power not exceeding 50 kW. The hydraulic engines HS 0.8 were fed by the roadheader hydraulic generator. It enabled conducting tests at different directions and numbers of revolutions of both the head body and the plates with disc tools. The revolutions change of the head body varied within the range from 10 to 40 rpm, and of the plates with disc tools from 20 to 200 rpm. During mining tests the power consumption of the electric engine was measured as well as the feed pressure of hydraulic engines. Mining effectiveness and the level of disc tools wear were monitored as well as granulation of the obtained winning. A view of the KR 150 roadheader with the new solution of a head with asymmetrical disc tools of complex motion trajectory during one of the conducted mining tests is presented in Figure 12.

The tests started at the head body rotations counterclockwise and clockwise rotations of plates with disc tools. The number of the head body rotations was altered from 10 to 40 rpm and the number of plates with disc tools rotations from 20 to 200 rpm. The new solutions worked for such parameters without any bigger problems. At low values of rotations it was possible to obtain very high graining of the winning, however, accompanied by high vibration of the head. An increase of rotations of plates with disc tools

Fig. 12. A view of the KR 150 roadheader with the new solution of a head with asymmetrical disc tools of complex motion trajectory during one of the field tests

caused limitation of vibrations but it increased dustiness and at maximal rotations even sparking at the contact of tools and a rock. The most favourable operation parameters – high graining, low load for drive engines and vibration limitation – were obtained for the head body rotation of about 20 rpm at the plates rotation of about 60 rpm. A view of the head while mining a rock sample with such parameters is presented in Figure 13 and of the obtained winning and the block surface in Figure 14. No significant signs of disc tools wear were observed. Whereas, a change of rotation direction of the head body or plates with disc tools to the contrary one had a very negative influence on the engines load and both disc tools and plates themselves wear. A view of the plates wear is presented in Figure 15. At the change of direction of both rotations there was an improvement in the head work, but its parameters were less favourable than for the set described formerly. Moreover, it was observed that application of the frequency converter is not a favourable solution for an electric drive engine. It may cause its break down.

Fig. 13. A view of the KR 150 roadheader with the new solution of a head with asymmetrical disc tools of complex motion trajectory during one of the field tests for the most favourable selection of direction and number of rotations of the head body and plates with tools

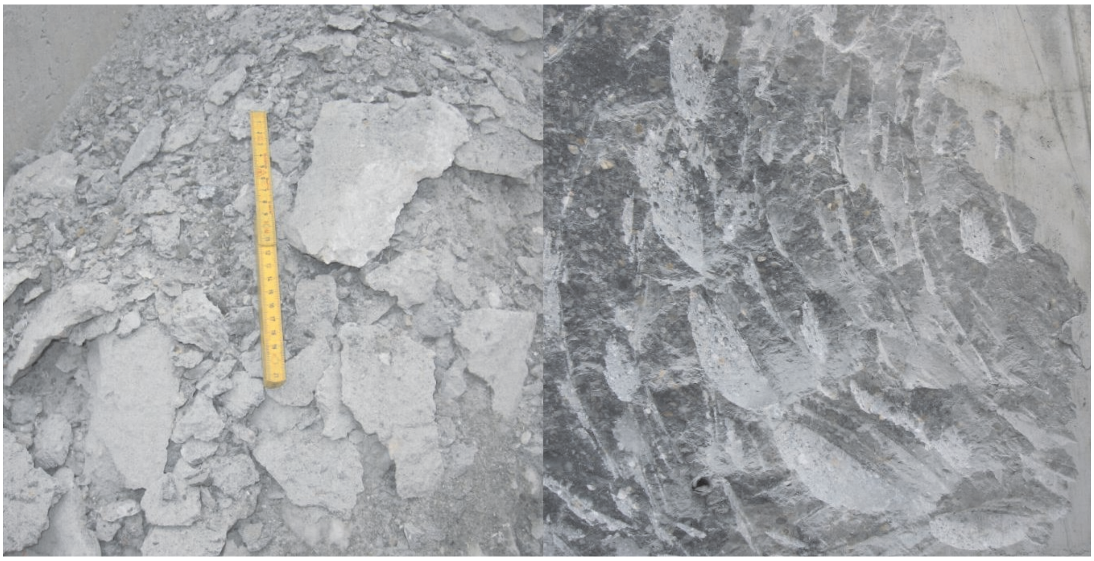

Fig. 14. A view of the winning and the surface of the mined rock block obtained for the most favourable selection of direction and number of rotations of the head body and plates with tools

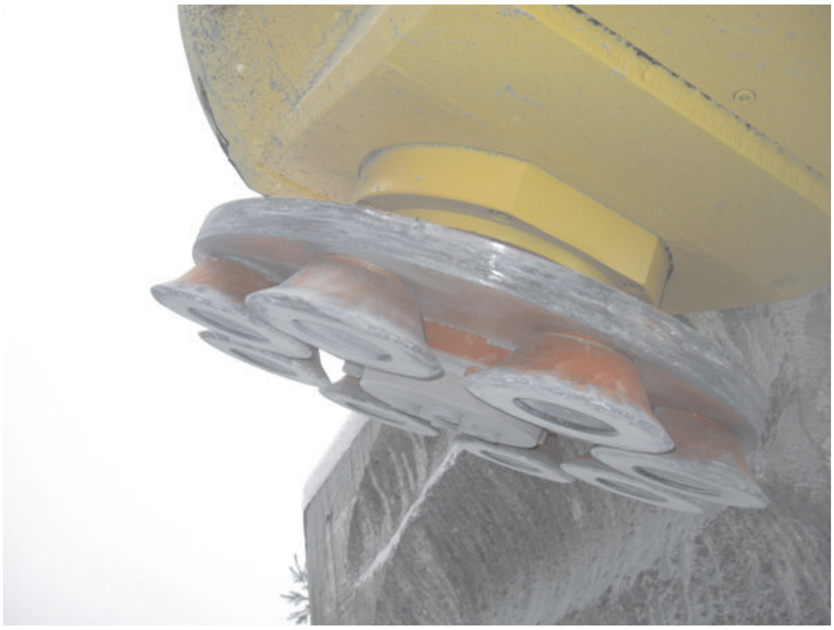

Fig. 15. A view of plates with disc tools wear at counterclockwise direction of the plates rotation

4. MODERNISATION OF THE NEW SOLUTION OF A HEAD WITH DISC TOOLS OF COMPLEX MOTION TRAJECTORY FOR INDUSTRIAL TESTS

Field tests of the new solution of a head with asymmetrical disc tools of complex motion trajectory allowed the statement that the head can effectively mine the rock whole at suitable configuration of direction and number of rotation of the head body and plates with tools. However, in order to increase reliability of the suggested solution some modernisation and introduction of constructional changes of the head got suggested for further industrial tests. They mainly based on application of a hydraulic engine providing parameters ensuring work stability to drive plates with disc tools instead of the electric one.

Another change was a different construction of plates and disc tools to increase their life period and decrease their wear. Instead of a round plate a many-branched plate was suggested. Smooth disc tools were replaced with tools reinforced with sintered carbide rods. A view of the place of mounting the hydraulic engine to drive plates with disc tools is presented in Figure. 16, whereas a view of new pates and disc tools in Figure 17. After assembling the new elements and conducting stand tests, the KR 150 roadheader with the new solution of a head will undergo industrial tests in one of the mining plants.

Fig. 16. A view of mounting the hydraulic engine to drive plates with disc tools in the arm of the KR 150 roadheader

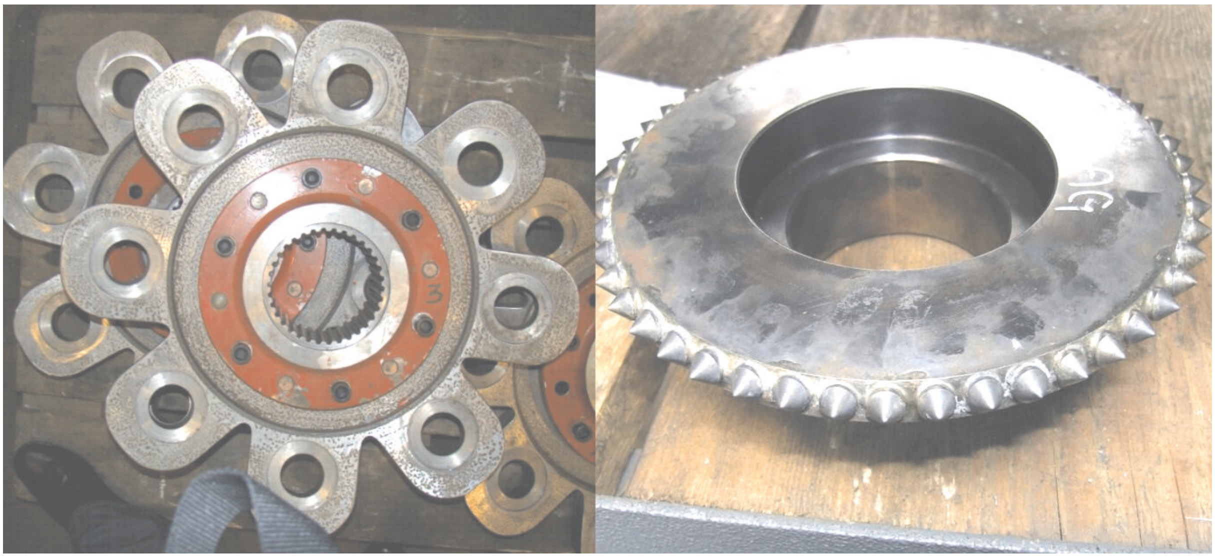

Fig. 17. A view of the new solution of plates for mounting disc tools and disc tools reinforced with sintered carbide rods

5. SUMMARY

The suggested solution of a head with asymmetrical disc tools of complex motion trajectory proved its usefulness while compact rocks mining and can be used as an alternative for milling heads of arm roadheaders. A selection of proper configuration of direction and number of rotations of the head body and plates with tools is necessary to obtain the most favourable parameters of the head operation – high graining of the winning, low load of drive engines and vibration limitation. The head after positive field tests will undergo industrial tests in one of the mining plants.

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