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LABORATORY AND UNDERGROUND TESTS OF CUTTING HEADS WITH DISC CUTTERS

BADANIA FREZUJĄCEGO ORGANU ŚLIMAKOWEGO WYPOSAŻONEGO W NARZĘDZIA DYSKOWE

Brief description of the construction process of cutting head equipped with disc cutters, including laboratory and underground testing procedure, have been presented in this study. Realization of laboratory tests allowed assessment of the cutting head operation, including elimination of the construction imperfections. Finally, the cutting head with discs was designed. After suitable laboratory tests, the cutting head was qualified for underground tests. The underground tests allowed assessment of the cutting head operation, including directives for the disc cutters application.

Keywords: Disc cutter, longwall shearer, worm mining head, laboratory and underground tests, measuring, dustiness

W niniejszym artykule opisano proces tworzenia frezującego organu ślimakowego wyposażonego w narzędzia dyskowe oraz procedurę badań stanowiskowych i ruchowych (dołowych). W pierwszej części przedstawiono i opisano poszczególne wersje organów ślimakowych, wyposażonych w narzędzia dyskowe, które były przedmiotem badań. W następnym rozdziale opisano budowę specjalnego stanowiska laboratoryjnego do badania frezujących organów urabiających, będącego na wyposażeniu katedry Maszyn Górniczych, Przeróbczych i Transportowych. Przedstawiono plan i metodykę oraz przebieg badań stanowiskowych. Badania przeprowadzono jako porównawcze dla organu z narzędziami dyskowymi oraz z nożami styczno-obrotowymi. W trakcie badań mierzono moment oporu urabiania, siły oddziaływania organu w kierunku posuwu i zawrębiania oraz wartość zapylenia dla zadanych parametrów pracy. Realizacja badań stanowiskowych umożliwiła ocenę pracy przedmiotowych organów oraz konieczność usunięcia niedociągnięć konstrukcyjnych. Końcowym efektem tych prac było opracowanie organu z dyskami, który po pozytywnym przejściu badań stanowiskowych przeznaczony został do prób ruchowych (badania dołowe), w wybranej kopalni węgla kamiennego, w ścianie węglowej. Badania przeprowadzono na kombajnie węglowym KSW-460NZ, na którym na lewym ramieniu zabudowano

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organ z narzędziami dyskowymi a na prawym pozostawiono standardowy organ z nożami styczno-obrotowymi. W czasie prób prowadzono obserwację pracy kombajnu oraz mierzono i rejestrowano jego obciążenie. Różnice parametrów konstrukcyjnych badanych organów oraz parametrów kinematycznych nie pozwoliły na bezpośrednie ich porównanie, jednak można stwierdzić, że badany prototypowy organ wyposażony w narzędzia dyskowe może być zarekomendowany do pracy w wyrobiskach ścianowych. Realizacja badań dołowych umożliwiła ocenę tego organu oraz opracowanie wytycznych do stosowania narzędzi dyskowych na organach urabiających kombajnów węglowych.

Słowa kluczowe: narzędzie dyskowe, kombajn ścianowy, ślimakowy organ urabiający, badania laboratoryjne i dołowe, pomiary, zapylenie

1. Introduction

Assessment of the cutting head equipped with disc cutters has been made in the test stand, which was designed and built especially for this purpose. Two cutting heads with disc cutters (Fig. 1) were designed for coal mining within the longwall mining of selected coal mine. Complicated geological-mining conditions, particularly folded floor, resulted in fast wear of discs, including fast wear of bolts and holders. The damaged elements are shown in figures 2 and 3.

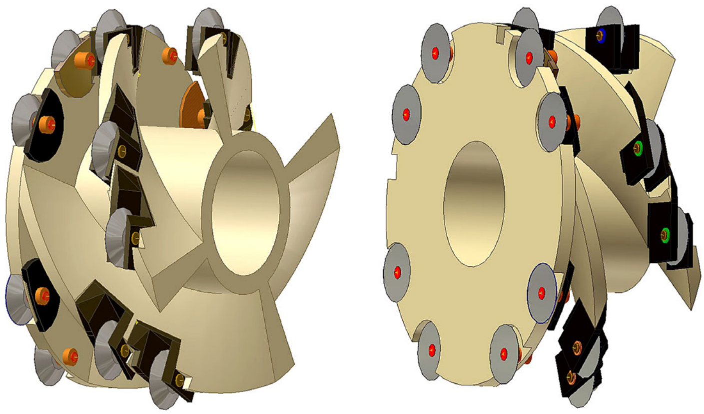

Fig. 1. Worm disc cutter equipped with discs (version I)

For this purpose, the disc system was modified in such manner, that the cutting head could work during the floor dinting. In case of this cutting head (version II), shown in Fig. 4, the construction of holders of discs located on cutting disc and its planes was modified. Moreover, the number of disc cutters was changed from 18 pieces (version I) into 36 pieces (version II), and disc cutters of the diameter 160 mm with different bit angles were used.

Fig. 2. Destroyed disc pins on cutting disc

Fig. 3. Crushed disc cutting edge

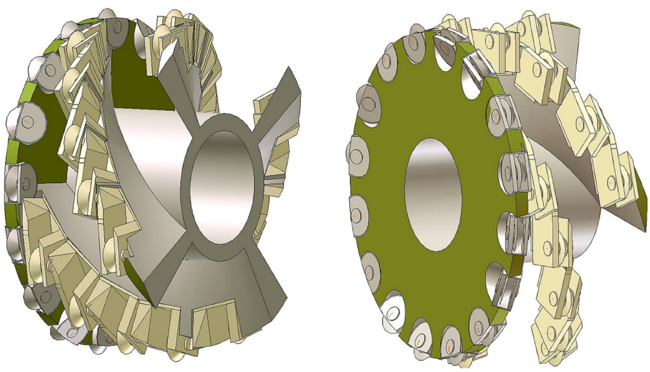

Fig. 4. Worm-type cutter equipped with discs (version II)

Construction of the cutting head in version II and potential user suggestions decided that the operational tests were executed not in underground conditions but in laboratory conditions at test stands in the Department of Mining, Processing and Transport Machines of the AGH University of Science and Technology in Cracow – Poland. The examinations were aimed at the assessment of the cutting head operation with respect to observed constructional imperfections, including their elimination in version used in underground tests. However, technological and operational difficulties forced resignation from one of the cutting lines in tested cutting head, in order to achieve proper connection between disc holders and cutter blades. That is why the version II of the cutting head was equipped with 32 discs and it was marked as version III. The view of this version is shown in Fig. 5.

Fig. 5. Worm-type cutter on test stand

Tests of the cutting head in version III and their results caused further modernization of the cutting head construction. Innovations proposed for this construction (version IV) considered installing new discs at the ends of blades, allowing floor dinting. The cutting head in this version was tested again, and the possibility of underground tests was proved.

Underground tests were conducted in natural conditions, i.e. mined longwall mining, where the cutting head with discs was installed on longwall shearer KSW-460NZ. The mentioned cutting head was operated under such conditions until the wall liquidation, and then in was relocated into another wall within the same seam. In this period, shearer load was measured and the cutting head operation was assessed.

2. Laboratory stand tests of the cutting head equipped with disc cutters

Cutting head ∅1520 × 800 mm equipped with disc cutters was used in the examinations, which in initial version (version III) was equipped with 32 discs (16 pieces on cutting disc and 16 pieces on blades). Shape of the blades and direction of their advance allowed cutting head operation with over-rotation (Fig. 5). Version III was designed in result of elimination of the last row of discs designed in case of version II (change of graduations between the cutting lines).

Just operation of the cutting head with tangential-rotary picks can be the reference point for the estimation of cutting head with disc cutters. That is why, typical worm-type cutting head ∅1400 × 750 mm with 18 picks on the cutting disc and 21 picks on the blades (shown in Fig. 6) was used for the examination.

2.1. Plan and laboratory stand testing procedure

The laboratory stand tests were aimed at the assessment of the operation of worm-type cutting head with disc cutters, as well as at comparison of this process with operation of the cutting head with tangential-rotary picks, including implementation of eventual construction changes. That is why the following testing conditions of the laboratory test were assumed (Kotwica, 1998):

- Cutting of the artificial rock sample of isotropic properties,
- Assuming uniform and realistic parameters of the cutting process,
- Measurement of chosen physical parameters during cutting,
- Visual assessment of the cutting head operation and construction.

The following parameters were used for the process assessment:

- Cutting resistance torque M_o, kNm,
- Cutting head reaction force in advance direction P_u, kN,
- Cutting head reaction force in slotting direction P_w, kN,
- Respirabile and total dustiness value, mg/dcm^3,

The parameters were determined (measured) in the same conditions, i.e. the same value of:

- Advance rate v_p, m/min,
- Cutting head rotations n, rpm,
- Properties of the cut body (artificial rock) measured as compression strength R_c, MPa,

Visual assessment of elements of the cutting head should determine the cutting head wear. Measurement, monitoring and

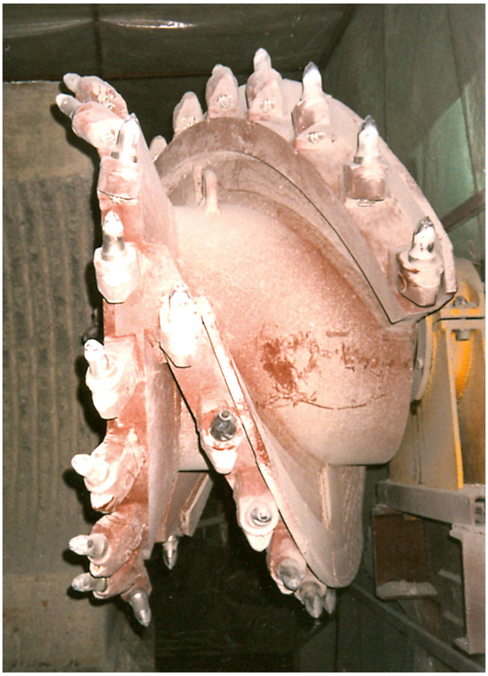

Fig. 6. Worm-type cutter with tangential-rotary picks (CX-18/30/38/50/165/ZH)

handling of the measured values of signals (M_o, P_u, P_w, dustiness) in function of variable parameters (v_p, n, R_c) as well as the cutting head condition (wear) allows assessment of the operation of the worm-type cutting head with disc cutters. Results of the tests were very useful for implementation of the cutting head construction changes.

2.2. Laboratory testing stand

Laboratory stand used for testing the cutting heads, located in the Department of Mining, Processing and Transport Machines of the AGH University of Science and Technology in Cracow-Poland, consists of the following two subassemblies: cutting head drive (d.c. electric motor, mechanical gear, shaft with bearing and the cutting head holder) and advance system of the tested block (longitudinal and transverse pipe guides, advance hydraulic cylinders, hydraulic system, and table for the rock sample cutting). Rotations of the cutting head forced by its drive, and rectilinear motion of the rock sample allow the cutting process realization both during full web operation (normal operation) and during slotting (Kotwica & Maziarz, 2004).

Sample of the natural or artificial mineral was placed on the advance mechanism table. In case of examination of the cutting head construction quality, cutting of artificial rock is recommended, which possess isotropic properties. In each of the cases, a sample of maximal dimensions: length 2010 mm, width 1000 mm and height 2000 mm could be anchored on the table.

Fig. 7. Control cabinet and hydraulic feeder of the rock block advance mechanism with pressure transducers

Hydraulic advance mechanism allows relocation of the table with sample with advance rate v_{pu} up to 9,23 m/min during cutting, and v_{pz} do 4,55 m/min during slotting. The machine control system and rotation control system of the cutting head, as well as hydraulic feed mechanism of the rock block advance is shown in Fig. 7. However, d.c. motor of power N = 140 kW and rotation n = 1340 rpm driving the cutting head, via mechanical gear of ratio i = 32, forces rotation from zero to 42 rpm. The motor with mechanical gear and torque meter is shown in Fig. 8. The measuring system being integral part of the test stand comprises:

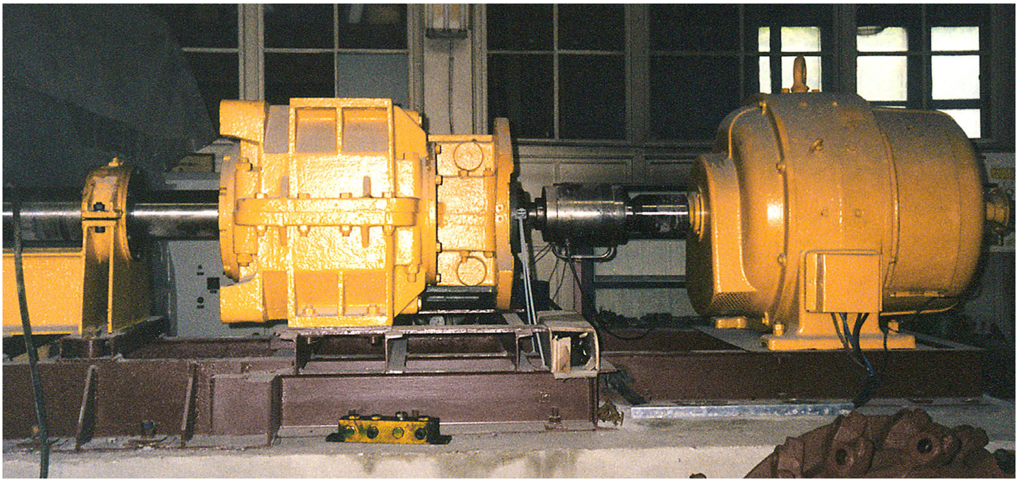

Fig. 8. Cutting head driving unit: d.c. motor, torque meter, mechanical gear and cutting head shaft

- Torque meter installed between electric motor and mechanical gear,
- Pressure converter at inlet and outlet of longitudinal advance hydraulic cylinder (cutting) and transverse advance hydraulic cylinder (slotting),
- Dustiness gauge CIP-10 (No. 345 – respirabile dustiness, No. 78 – total dustiness),
- Monitoring device.

Constructional, kinetic and energetic parameters of the test stand and measuring system allow examination of the mining with use of disc cutting heads, particularly worm-type cutting heads.

2.3. Test stand examinations of mining with use of disc cutters and tangential-rotary pick cutters

The first tests were conducted for cutting cement-sandstone block having compressive strength R_c = 6,8 MPa, using disc cutter in version III. Cutting resistance torque, inlet and outlet pressure and dustiness were measured during the block cutting with full web, with advance rate v_{pu} = 0,56 m/min and rotation n = 20 and 32 rpm. About 1.5 m of the cement-sandstone block has been cut using mentioned kinematical cutting parameters (v_{pu} and n). The cutting process was stopped in the moment when the rock sample was broken.

The second rock sample was made of a cement-basalt grid mixture, having compressive strength R_c = 13,73 MPa, after 30 days fixing time. The sample was first cut with use of disc cutter applying parameters v_{pu} = 0,56 rpm and n = 32 rpm, and the measured values were registered. Then, with use of tangential-rotary pick cutting head, the former procedure was repeated. However, in this case, such parameters of the cutting process (v_{pu}, n) were found, that the cutting head operation stoppage was not possible. Finally, it has been proved, that continuous cutting was possible only at v_{pu} = 0,103 rpm and n = 42 rpm.

During cutting with use of disc cutters or tangential-rotary pick cutters the mentioned above values were measured and registered, as well as technical condition of the heads was controlled. Collected data were then handled and analyzed.

2.4. Laboratory data handling

Registered signals of measured values obtained both for disc cutters and tangential-rotary pick cutters have been handled in order to determine parameters characterizing the cutting process. Value of total and respirabile and total dustiness were determined on the basis of the mass of dust collected in two dust-measuring devices of the type CIP. The calculations were executed according to the procedure described in the device manual. The obtained results were gathered in Table 1. The determined dustiness values were calculated for total time of the cutting head operation, in given day, for different values of parameters v_p and n.

TABLE 1

Values of the dustiness during cutting with disc cutters and cutters with tangential-rotary picks measured with dustiness gauge CIP-10 (N0. 345 – respirabile, N0. 78 – total)

Cutter type / sample strength	**Dustiness, mg/dcm^3**	
	Respirabile	**Total**
Discs, R_c = 6,8 MPa	0,0410	0,5113
Discs, R_c = 13,73 MPa	0,0589	0,8015
Tangential-rotary picks, R_c = 13,73 MPa	0,2330	1,3220
Tangential-rotary picks, R_c = 13,73 MPa	0,3800	2,7370

In case of the other measured values, the signals were handled using standard software ESAM-3000. Mean value, minimal value, maximal value and standard deviation, as well as variability factors defined as the ratio of standard deviation and mean value, including amplitude-frequency characteristics (Krauze et al., *Zastosowanie...*), have been determined for each signal of the measured value.

The procedure described above aimed at the signals handling allowed defining the required parameters needed for the description of the rock block cutting process with use of disc and pick tangential-rotary cutting heads. The results are gathered in Tables 2 and 3. Values of cutting resistance torque M_o, longitudinal advance force P_u (cutting), transverse force P_z (slotting) and variability coefficients of these values are gathered in Table 2. It should be noted that values of forces P_u and P_z were determined from the difference of force acting on hydraulic cylinder piston surfaces – longitudinal and transverse advance (supply pressure × lower piston surface – run off pressure × over piston surface). Whereas, values of the torque amplitude and run-off pressure of the longitudinal advance hydraulic cylinder (cutting) and corresponding frequency values, are gathered in Table 3.

TABLE 2

Values of the torque M_o, force P_u and force P_z versus their variability coefficients

No	**Cutter type**	**Event No.**	**Cutter rotation *n*, rpm**	**Advance rate v_p, m/min**	**Torque M_o, kNm**	**Torque variability factor, w_{zo}**	**Advance force in cutting direction P_u, kN**	**Advance variability factof, w_{zu}**	**Advance force acting in slotting direction P_z, kN**	**Advance force variability coefficient, w_{zw}**
1	2	3	4	5	6	7	8	9	10	11
1	Discs R_c = 6,8 MPa	5/2	32	0,56	31,68	0,3774	149,4	0,0550	8,910	0,2263
2		7/2	20		37,12	0,2645	164,8	0,0429	–0,352	0,4649
3		9/2	32		31,68	0,3426	139,2	0,1030	1,650	2,0667
4		11/2			31,68	0,2759	158,6	0,0321	1,380	4,6287
5	Discs R_c = 13,73 MPa	5/2	32	0,56	32,32	0,5648	171,5	0,0614	–0,930	0,0938
6		7/2			32,00	0,5608	158,4	0,0509	–0,578	0,2727
7		9/2			32,96	0,5636	172,8	0,0236	12,416	0,0610
8	Tangential-rotary picks R_c = 13,73 MPa	7/2	32	0,56*	28,80	0,6539	43,4	0,3258	6,133	1,5000
9		9/2		0,26*	49,92	0,3149	57,6	0,2233	–0,905	3,7200
10		11/1	42		48,96	0,3137	50,0	0,2761	–0,540	1,0500
11		13/1		0,103	16,00	1,0200	14,9	0,4034	–6,384	0,2000
12	Tangential-rotary picks R_c = 13,73 MPa	3/2	32	0,103	16,64	0,9808	20,1	0,5088	2,790	2,0333
13		5/1	42		13,76	1,2791	22,0	0,2460	1,395	0,5789
14		7/1			16,64	1,3654	20,9	0,5932	1,232	0,7222

* – cutter stoppage

TABLE 3

Frequency versus amplitude for torque M_o and force P_u

No	Cutter type	Event No.	Cutter rotation n, rpm	Advance rate v_p, m/min	Torque frequency f, Hz	Torque amplitude, kNm	Frequency of force supply f, Hz	Amplitude of force pressure supply P_u, MPa
1	2	3	4	5	6	7	8	9
1	Discs R_c = 6,8 MPa	5/2	32	0,56	10,010	0,2296	0,122	0,3259
2		7/2	20		10,864	0,1136	0,061	0,1973
3		9/2	32		10,498	0,2711	0,122	1,4390
4		11/2			10,498	0,1707	0,488	0,1806
5	Discs R_c = 13,73 MPa	5/2	32	0,56	10,009	0,4329	1,953	0,5614
6		7/2			9,764	0,4262	0,244	0,4762
7		9/2			9,276	0,3864	1,526	0,1177
8	Tangential-rotary picks R_c = 13,73 MPa	7/2	32	0,56*	6,103	0,1292	0,244	0,3010
9		9/2		0,26*	17,332	0,1688	0,122	0,2766
10		11/1	42		17,576	0,2641	0,122	0,8970
11		13/1		0,103	17,820	0,2528	17,891	0,2006
12	Tangential-rotary picks R_c = 13,73 MPa	3/2	32	0,103	4,638	0,1440	0,122	0,3137
13		5/1	42		11,229	0,2077	0,122	0,3819
14		7/1			10,985	0,3038	0,122	0,4788
* – cutter stappage								

2.5. Analysis of the laboratory tests

The collected testing data concerning assessment of the cutting head with discs and picks can be divided into visual observations and results of data obtained from measured signals handling.

Observations of the disc cutter operation during cutting the cement-sandstone block having compressive strength R_c = 6,8 MPa proved small amount of dust and big amount of coarse-grained winning (Table 1). Numerous traces of a contact between cutting head blades and the rock body (Fig. 9) have been proved, what indicates that the spaces between cutting lines were too big. In case of this artificial rock body used in examinations, the spaces should be reduced to such value that contact between the cutting blades and rock body was eliminated.

Fig. 9. Disc cutter on test stand with traces of the contact between blades and rock body

During cutting the cement-sand-stone block with the same cutting head, traces of the contact between the cutting head and the rock body have been observed, but only on the first cutting line. Spacing between cutting lines was too big only near the cutting disc, what indicates big angle of the side crushing of the rock body having compressive strength R_c = 13,73 MPa. Dustiness during the tests was slightly higher than in the previous case.

Very high dustiness (Table 1) being kept long after the test occurred during cutting the cement-basalt block (R_c = 13,73 MPa) with use of tangential-rotary pick head. However, it was observed that the dustiness values are different, depending of the used advance rate (the same order of magnitude). The differences are bigger because higher advance rates were used during measurements.

Based on the above observations and dustiness values we can state that the disc cutter caused lower dustiness, and the winning was coarser grained. However, in order to eliminate contact between head blades and cut rock body, special correction of the disc system was necessary, particularly of cutting disc and blade tops.

Value of mining resistance torque M_o, variability coefficient of the torque w_{zo} (Table 2) and the highest amplitude and frequency at which it occurs (Table 3), favors the disc option. It is easy to note that the torque for disc cutter head is almost three times smaller (v_p = 0,5 m/min) than the torque of head with picks (v_p = 0,103 m/min). Torque variability measured with the coefficient w_{zo} is also smaller. That is why in case of executed tests and cutting heads used we can state that the disc head was working better than the head with tangential-rotary picks. It is also proved with the frequency value and torque amplitude, which was determined from amplitude-frequency characteristics.

Taking under consideration the forces of the cutting head acting in transverse direction P_z no considerable differences are observed with reference to longitudinal movement (cutting) when the cutting head is working at full web (Table 2), both in case of mean diameters and variability coefficients. Force P_z has similar (comparable) mean values and it also changes direction of acting, both in case of disc heads and heads with picks. That is why operation of these cutting heads can be assessed equally without pointing out which of the cutting heads is better.

However, values of the force acting in direction of longitudinal advance P_u (cutting) are bigger in case of the head with disc cutters, and coefficients w_{zu} are similar (Table 2). Similar situation is observed for frequency and amplitude of the supply pressure (Table 3). That is why during operation with use of disc cutter we should expect considerable increase of the advance force P_u although variability of this force should be comparable with operation with use of tangential-rotary pick cutting heads. When cement-basalt block was cut, the advance force P_u for disc cutter was 7,5 times bigger than in case of the tangential-rotary pick cutting head. The executed examinations of the cutting head equipped with disc cutters brought the following conclusions:

- Disc cutter generates small amount of dust during mineral material cutting,
- Cutting resistance torque is also smaller, almost three times smaller in case of cement-basalt block,
- Advance resistance force is bigger for disc cutter, in this situation 7,5 times bigger,
- Variability coefficients of the cutting resistance torque and forces P_z and P_u have comparable values, what proves similar dynamics of the cutter operation,
- Constructional modifications, which eliminate contact of cutter blades with the rock body and protect the blades during floor dinting, should be implemented,
- When the constructional innovations are implemented, testing procedure used for the cutter made in version III should be repeated.

Based on the tests of the disc cutters (version III), constructional modifications, which eliminated contact between head blades and the rock body, were implemented. The mentioned constructional modifications comprised new positioning of discs on the cutting disc, as well as adding of one more cutting line. These modifications allowed reduction of the spacing pitch between the last discs on the cutting disc and the first blades. Four additional holders protecting the blade endings against contact with the rock body during roof or floor dinting were installed on the blade endings. The cutting head prepared for the tests (version IV) is shown in Fig. 10.

Implementation of these modifications allowed repetition of the stand tests according to the procedure used before. The tests were aimed at elimination of the constructional defects eventually observed during operation of the cutting head in former version (version III), as well as estimation of the tested cutting head operation (version IV). When the tests have been completed, no contact between disc (blades) and the rock body was proved.

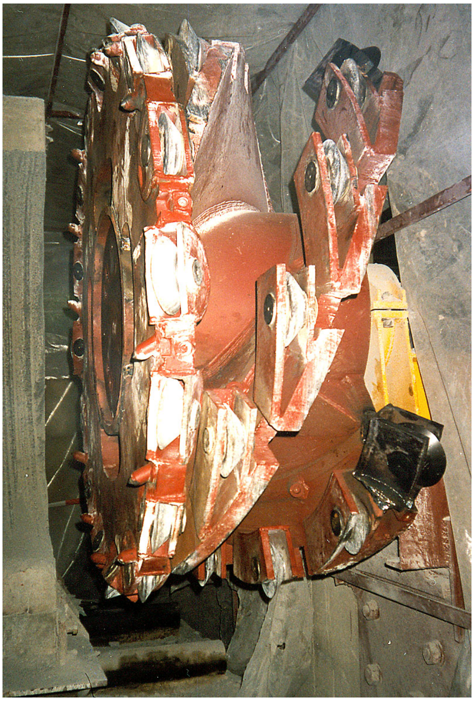

Fig. 10. Worm-type cutter (version IV) on the test stand

Dustiness measurements made during the whole testing cycle (five sections), although slightly higher than in previous tests (respirabile 0,091 mg/m^3, total 1,149 mg/m^3), are in any case lower than in case of cutting head with picks. Dustiness increase should be explained by the fact that two different advance rates have been used for the same cutting head rotation (n = 32 rpm). At first, for two measuring sections the rate was higher (v_p = 0,469 m/min), and for next three sections it was comparable with advance rate of the cutting head with picks. (v_p = 0,167 rpm). Application of two advance rates resulted from the necessity of the same operation conditions both of disc cutter and cutting head with picks.

Mean value of the torque M_o from two measurements (advance rate v_p = 0,469 m/min) amounted for 38,08 kNm (w_{zo} = 0,5572). However, advance force P_u in cutting direction amounted for 165,3 kN (w_{zu} = 0,045), and force P_z in slotting direction amounted for 0,9165 kN (w_{zw} = 0,4028). For lower advance rate (v_p = 0,167 m/min) values of measured parameters were as follow:

M_o = 29,3 kNm (w_{zo} = 0,9479)
P_u = 126,8 kN (w_{zu} = 0,1689)
P_z = 4,71 kN (w_{zw} = 1,7562)

As we compare the obtained results with the data listed in Table 2 we can easily observe that introduction of additional cutting line, although slightly, increased value of the torque and force P_u, whereas variability of load (w_z) was kept on the same level.

3. Underground tests of the worm-type disc cutter

In result of executed test stand examinations, a new cutting head construction marked as version IV, has been designed. Its construction characterized with the same parameters as the previous versions (diameter 1600 mm, web 800 mm) but it was equipped with only three blades and new disc arrangement (15 discs ∅180 mm on main disc, 21 discs ∅180 mm on blades).

The described cutting head is shown in Fig. 11. It was exposed to the same testing procedure as the former versions, i.e. test stand examinations have been executed in order to estimate possibilities of underground tests execution and comparison of the new construction with the former ones. Underground tests and shearer load measurements have been made in a selected mine and longwall. The longwall 1,4÷1,6 m high, localized within the seam 324/3 mined longitudinal-transverse fall of roof mining (Krauze et al.) was selected to the underground tests.

Fig. 11. Worm-type cutter (∅1600 × 800 mm) equipped with discs (∅180 × 40 mm) in the longwall

Worm-type cutting head (∅1600 × 800 mm) was installed on the left arm of the shearer KSW-460NZ, whereas, cutting head with tangential-rotary picks ∅1360 × 750 mm was installed on the right arm of the shearer. The cutting head was operated on the longwall 433 until its liquidation, i.e. two months. During this period, one used disc was replaced on the blade and 53 tangential-rotary picks were replaced on the other cutting head. The shearer operators did not observe essential differences between operation of the shearer with cutting head with picks, or one disc cutter and the other cutter with picks. However it was noted that the disc cutter was loading better and this cutter should be installed on the next longwall with shearer KSW-460NZ. It should be pointed out that problems related with winning loading occurring earlier during operation with use of cutting head with picks caused output reduction and other difficulties with the longwall handling. However, the reason of this problem is probably related mainly with small diameter of cutting head with picks amounting for 1400 mm, although advantages of the disc cutters were earlier announced by coal mines „Zofiówka" and „Piekary".

Longer time of realization of underground tests with use of disc cutters allowed execution of measurements of the shearer load during its normal operation. Obviously, based on the underground tests, cutting factor A (2000 N/cm), angle of side crushing ψ (38°), cohesiveness factor f (1,97) and coal structure (Krauze, 2000), have been determined much earlier. The mentioned parameters describe coal properties in the longwall, mainly its workability.

3.1. Measurement of the shearer load

During realization of the underground tests (Fig. 12), where operation of shearer KSW-460NZ with one disc cutter and one cutter with picks was observed (Fig. 13), measurement of the shearer load has been made. The measurements were executed for the following purposes:

- Proving possibility of assessment of the operation of shearer with disc cutter in underground conditions,
- Getting opinion of the potential user,
- Verification of the laboratory and underground tests.

Fig. 12. Cutter ∅1600 × 800 mm with discs installed on the left arm of shearer KSW460NZ

Fig. 13. Cutter ∅1360 × 750 mm with discs installed on right arm of the shearer KSW460NZ

Thus elaboration of the shearer testing program and preparation of the shearer and the longwall for this aim was necessary. It was assumed that the shearer load would be determined on the basis of:

- Power consumption of the electric motor driving the disc cutter installed on the left arm,
- Power consumption of the electric motor driving cutting head with picks installed on the right arm,
- Power consumption of the electric advance motor,
- Value of the force acting in left arm hydraulic cylinder (disc cutter),
- Value of the force acting in right arm hydraulic cylinder (cutter with picks),
- Value of the torque in left hydraulic advance motor,
- Value of the torque in right hydraulic advance motor.
- Power consumption of the electric advance motor,
- Value of force acting in left arm hydraulic cylinder (disc cutter),
- Value of force acting in right arm hydraulic cylinder (cutting head with picks),
- Value of the torque on left hydraulic advance motor,
- Value of the torque on right hydraulic advance motor.

The values listed above will be measured directly via measurement of electric power consumption, or indirectly, via pressure measurement (forces, torques). List of transducers used in the measurements is cited in Table 4.

Preparation of the shearer for measurements and installation of suitable transducers, including connection with register, allowed execution of the tests in question. Starting the shearer being operated in full web (normal operation) and checking the measurement system allowed execution of the test series, where at the beginning the disc cutter was used as the frontal cutter and the cutting head with picks was used as the rear cutter. Then, after change of the shearer movement direction, cutting head with picks was used as the frontal cutter, and disc cutter was used as the rear cutter. Obviously in both cases, during the shearer operation, signals of measured values and additionally shearer advance rate (timer) were recorded. Single measuring cycle comprised:

- Setting the shearer in full web mode,
- Activation of the cutting heads and hydraulic system,
- Checking of the measurement system operation,
- Activation of the advance system and shearer rate setting,
- Shearer load recorded on the distance of minimum 30 meters (20 sections).

Additionally, as was mentioned before, in order to determine the mean advance rate, time of the shearer movement was measured at the distance of a single segment of the longwal transporter with use of the timer.

TABLE 4

Measurement transducers used in longwall shearer load measurements

No.	Physical value / signal name	Sensor / measurement transducer
1	Pressure in right advance motor – terminal 1 (right arm with disc cutter)	Pressure transducer MBS-32, 0÷40 MPa, Danfoss
2	Pressure in right advance motor – terminal 2 (right arm with cutter with picks)	Pressure transducer MBS-32, 0÷40 MPa, Danfoss
3	Pressure in under piston chamber of right arm hydraulic cylinder (cutter with picks)	Pressure transducer ADZ-SML, 0÷100 MPa, WOBIT
4	Pressure in over piston chamber of right arm hydraulic cylinder (cutter with picks)	Pressure transducer ADZ-SML, 0÷100 MPa, WOBIT
5	Pressure in left advance motor – terminal 1 (left arm with disc cutter)	Pressure transducer MBS-32, 0÷40 MPa, Danfoss
6	Pressure in left advance motor – terminal 2 (left arm with disc cutter)	Pressure transducer MBS-32, 0÷40 MPa, Danfoss
7	Pressure in under piston chamber of the left arm hydraulic cylinder (disc cutter)	Pressure transducer ADZ-SML, 0÷100 MPa, WOBIT
8	Pressure in over piston chamber of the left arm hydraulic cylinder (disc cutter)	Pressure transducer ADZ-SML, 0÷100 MPa, WOBIT
9	Electric power of right cutter motor (cutter with picks)	Current transformers HF 3B 400/5A, Power transducer PP73 M5×09B o KWS-1045
10	Electric power of the left cutter motor (disc cutter)	Current transformers HF 3B 400/5A, Power transducer PP73 M5×09B o KWS-1045
11	Electric power of the advance motor (hydraulic advance)	Current transformers HF 3B 400/5A, Power transducer PP73 M5×09B o KWS-1045

3.2. Testing results handling and analysis

Measurements of the shearer load during its operation allowed recording of the signal values measured in function of the cutter type (disc cutters, cutters with tangential-rotary picks), cutting condition and operational advance rate. Values of the measured signals were stored in the PC memory and then they were handled in order to determine mean, minimal and maximal value of the signal and its variability coefficient, for given measuring segment.

Examples of time courses of the power consumption signal by the motor driving the frontal disc cutter (green color – upper course) and rear cutter with picks N_n (red color – middle course) and advance motor N_p (blue color – lower course), are shown in Fig. 14. The presented signal courses were recorded in time when the shearer was moving with operational advance rate amounting for 7 m/min. The frontal disc cutter of the diameter 1,6 m and web of 0,8 m was cutting with its whole diameter the 1,6 m high longwal. At this time, the rear cutter was only loading the winning, if such was left on the floor (shearer without loader). However, during the movement in opposite direction, the frontal cutter with picks of diameter 1,36 m and web of 0,75 m was also cutting on its whole diameter, but it was

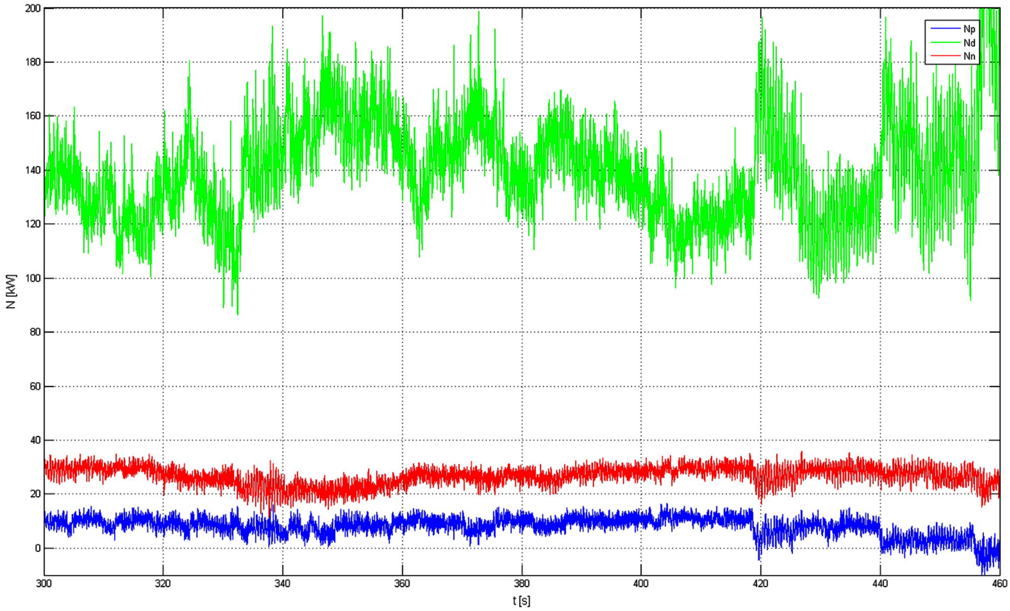

Fig. 14. Power consumption courses via frontal disc cutter N_d and rear advance drive of the shearer KSW-460NZ in longwall No. 433 KWK „Bolesław Śmiały Mine" (v_p = 7 m/min)

leaving coal shelf of thickness amounting for 0,2 m, which had to be cut by the rear disc cutter, and additionally the web should be widened with about 0,05 m.

One longer cut at the advance rate of 7 m/min was made for the shearer with frontal disc cutter. However, in a case of the fontal cutting head with picks, two measurements have been made with targeted rate of v_p = 7 m/min. However both in case of the measurement I and measurement II, maximal advance rate was 4 m/min. It resulted from the fact that the frontal cutting head with picks was practically not able to load the winning. The winning accumulated on the floor was spilled over the shearer, and until the winning was not loaded, it was filling up the space between floor, roof and shearer. That is why in order to avoid winning spillage the advance rate was not exceeding value of 4 m/min. Obviously, such phenomenon was not observed in case of operation with use of frontal disc cutter.

On the basis of registered signals of the measured values, mean, minimal and maximal value of the power consumption and corresponding variability factors have been determined. The determined values were listed for frontal disc cutter and rear cutting head with picks – see Table 5. Data for the adverse case are listed in Table 6.

Values of torques of the left and right motor of the hydraulic advance drive for the measurement section, with the frontal disc cutter and rear cutting head with discs, are listed in Table 7. However, for a case with frontal cutting head with picks and rear disc cutter, the torque values are gathered in Table 8.

Values of forces acting in hydraulic cylinders during rising and lowering the left and right arm for shearer working with frontal disc cutter and rear cutter with picks are listed in Table 9. For opposite situation, when the frontal cutter was armed with picks and the rear cutter was armed with discs, the values of these forces are gathered in Table 10.

TABLE 5

Determined values of power consumption by motors driving frontal disc cutter and rear cutter with picks and advance motor (v_p = 7 m/min)

Physical value	**Frontal cutter with discs**	**Rear cutter with picks**	**Advance**
Mean power, kW	139,7	26,7	10,3
Minimal power, kW	86,2	11,4	8,1
Maximal power, kW	200,1	35,9	16,6
Power variability coefficient	0,13	0,12	0,42

TABLE 6

Determined values of power consumption by motors driving frontal cutter with picks and rear disc cutter and advance motor (v_p = 4 m/min)

Physical value	**Frontal cutter with discs**		**Rear cutter with discs**		**Advance**	
	Measure-ment I	**Measure-ment II**	**Measure-ment I**	**Measure-ment II**	**Measure-ment I**	**Measure-ment II**
Mean power, kW	24,5	23,4	56,2	48,5	4,8	5,2
Minimal power, kW	2,8	10,9	33,6	35,3	1,7	0,6
Maximal power, kW	36,3	33,0	107,1	74,9	13,7	11,5
Power variability coefficient	0,17	0,17	0,18	0,12	0,34	0,25

TABLE 7

Determined values of the torque of right and left motor of hydraulic advance drive of the shearer KSW-460NZ with frontal disc cutter and rear cutter with picks (v_p = 7 m/min)

Physical value	**Right motor**	**Left motor**
Mean torque, kNm	1,079	1,058
Minimal torque, kNm	0,502	0,467
Maximal torque, kNm	1,731	1,712
Torque variability factor	0,17	0,19

TABLE 8

Determined values of the torque of right and left motor of hydraulic advance drive of the shearer KSW-460NZ with frontal cutter with picks and rear disc cutter (v_p = 4 m/min)

Physical value	Measurement I		Measurement II	
	Right motor	Left motor	Right motor	Left motor
Mean torque, kNm	0,846	0,841	0,919	0,921
Minimal torque, kNm	0,483	0,471	0,670	0,660
Maximal torque, kNm	0,233	1,259	1,184	1,185
Torque variability factor	0,13	0,13	0,08	0,08

TABLE 9

Determined values of force acting in hydraulic cylinder of right and left arm of the shearer KSW-460NZ with frontal disc cutter and rear cutter with picks (v_p = 7 m/min)

Physical value	Right hydraulic cylinder	Left hydraulic cylinder
Mean force, kN	189,8	145,3
Minimal force, kN	64,6	30,7
Maximal force, kN	322,1	332,3
Force variability factor	0,13	0,31

TABLE 10

Determined values of force acting in hydraulic cylinder of the right and left arm of the shearer KSW-460NZ with frontal cutter with picks and rear disc cutter (v_p = 4 m/min)

Physical value	Measurement I		Measurement II	
	Right hydraulic cylinder	Left hydraulic cylinder	Right hydraulic cylinder	Left hydraulic cylinder
Mean force, kN	120,2	316,9	114,1	364,0
Minimal force, kN	5,3	235,1	–32,7	255,8
Maximal force, kN	208,0	375,5	278,7	405,4
Force variability factor	0,27	0,09	0,43	0,06

Considering a case when the shearer was mining the coal body at full web, and the frontal cutter was armed with discs (over-rotation), whereas the rear cutter was armed with picks (under-rotation), but the cutters had different diameters (disc cutter – 1,6 m, cutter with picks – 1,36 m) and different webs (disc cutter – 0,8 m, cutter with picks – 0,75 m), it have been noted that the frontal cutter was more loaded and it consumed more of the power. The rear cutter, if operated properly, should not cut but only load, if necessary. It is distinctly seen while mean values of the power consumption gathered in Table 3 are compared, and also on the basis of visual observation of the operated shearer and cutter.

In opposite case, when the frontal cutter is equipped with tangential-rotary picks and the rear with discs, the cutters load should be similar to that previously described. However, because of the different diameters and webs (disc cutter was cutting coal shelf and it widened the web), as well as because of lack of loading with use of cutter with picks, the rear cutter armed with discs was more loaded. The power consumed by cutter with picks comprised about 50% of the power consumed by the disc cutter. Only this can explain the higher power consumption of the disc cutter, as well as it explains lack of compatibility of the test stand results, where the torque of cutting resistance was considerably higher than in case of the cutter with picks.

Similar situation can be observed if the values of power consumed by electric motor of the hydraulic advance drive, where power ratio is similar (as was proved earlier), are compared. However, in this case we should take under consideration first of all big advance rate difference, what allows defining the advance power for the frontal cutter with picks at $v_p = 7$ m/min. In such case, the power should amount for about 9 kW, and it differs only with 1 kW from the power consumed by the advance, when the frontal cutter is armed with discs.

Thus it is difficult to assess, only on the basis of the power consumption, which case, and which cutter, is better or worse. Comparison of variability factors of the power consumption is not helpful. The factors indicate that they are comparable and they do not point out, which cutting head, pick cutters or disc cutters, introduce bigger dynamics of the shearer.

Only analysis of the torque on hydraulic advance motors allows conclusion, what was earlier observed during laboratory stand tests, that the advance resistances are smaller in case of operation with the frontal disc cutter. In opposite situation, the advance resistances grow up because rear cutter must additionally cut the coal shelf, widen the web and load the whole winning onto conveyor. In this case we can state that the cutter with discs is more advantageous, particularly if the loading function is concerned. Values of forces acting in hydraulic cylinders of the left and right arm indicate that lower load is generated with the cutter with over-rotation, independently on installed cutter type.

In general we can state that the executed tests unequivocally indicated, which of the cutters used is more advantageous, although discussed before advantages of disc cutters have been proved both in underground tests and executed measurements. We can only suggest that the tests should be repeated in the future for the same constructional parameters of both cutters.

4. Final conclusions

The executed test stand examinations of the disc cutter and obtained results allowed realization of underground tests in conditions of the coal mine longwall. Obviously, the cutter in question should be considered as a prototype and its operation should be carefully observed. The underground tests results allow further modification of both cutters and cutting tool holders.

At present, based on the mentioned examinations, we can recommend disc cutters for coal mining in longwall systems, including corresponding chosen constructional parameters of the disc cutters. Constructional parameters of the smooth disc comprise the following elements: disc diameter D, pick edge angle α and radius of the pick rounding r. However, disc system can be described with: spacing between cutting lines t, number of cutting lines, number of discs and distribution of slices. Kinematic parameters related with mining with use of disc cutters comprise: advance rate v_p, cutting rate v_s and direction of the cutter rotation. The mentioned parameters decide about value of forces acting during the cutter operation, including energy consumption of the mining process. At the same time, these forces (cutting resistances) decide about disc wearing intensity. Selecting suitable material for disc cutters should be predicted. The material should possess high hardness, high shock resistance and high abrasion resistance (stage I, II).

Based on the discussed information and accessible literature information the following constructional parameters of smooth disc are recommended:

- diameter D – 140÷250 (350) mm,
- pick edge angle α – 20÷90°,
- rounding radius r – 1÷2 mm,
- cutting line spacing t not greater than ten fold of the cutting depth g,
- hardness – 30÷45 HRC.

The other parameters should be selected as for the shearer with cutter with picks (Krauze et al., *Zastosowanie...*).

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