# Process innovations in the mining industry and the effects of their implementation presented on the example of longwall milling heads

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*In Poland, the mining industry is one of the branches, in which innovation improvement activities must be undertaken, as it is still a strategic industrial branch. Process innovation is one of the innovation types allowing the improvement of the production process, as well as the improvement of the product quality.*

*In extractive processes, mechanical mining based on hard coal milling in longwall excavations is related to the development of a considerable amount of unneeded fractions, i.e., fine coal and dust. In consequence, it results in a reduction of mined material value, development of dustiness, as well as a hazard of coal dust explosion. Moreover, there is the necessity of efficient spraying system application. The appearance of a larger amount of coarse grade allows reduction of mentioned problems what increases mining efficiency. It is possible when the process of constructional and kinematic milling parameters of worm-type cutting heads is designed properly. The procedure of selection of these parameters proposed in this study supported with experiment executed in industrial conditions allows obtaining the targeted aim, i.e., increase of the amount of coarser fractions in case of mining with use of worm-type milling heads, what constitutes an excellent example of process innovations implemented in the Polish mining industry.*

***Keywords:*** *innovation, process, cutting heads, cutting head designing, coarse grade, longwall shearers*

## Introduction

Hard coal mining is considered as traditional industry boomed in Poland in time of the centrally controlled economic system. From the macro-economical point of view, a drop of the hard coal output is considered as a natural and positive state indicating the development of Polish economy according to Hirsch's theory of the branch lifetime cycle indicating, that in given stage of economy development different branches play a various role in the total state economy. This means that economic growth results in the meaning of branches belonging to the traditional industry is weakened and meaning of branches using advanced technologies growths. Traditional industry is characterized by low market dynamism, and in consequence, innovations occur in a small degree. However, Polish hard coal mining is still a strategic branch of the state industry. With respect to the hard coal output, Poland is placed on the 10-th position in worldwide rankings, and 1-st position in the European Union. Hard coal assures energy safety guaranty actually being major source of the electric energy generation (Midor, 2015), (Kołodziej et al., 2015), (Gembalska-Kwiecień, 2016), (Zasadzień et al., 2015), (Drucker, 1992), (Borowiecki, 2011). Thus action allowing economic reinforcement should be undertaken in order to prolong the lifetime of the mining industry branch in Poland because it is still in the state socioeconomic interest. So innovations are the best tools allowing improvement of the branch competitiveness.

Various types of innovations are described in the literature. International standards referring to the definition and measurement of the innovativeness determined in Oslo Manual 2005 (Działalność innowacyjna, 2014), (Černecký et al., 2015) have been considered in this study. Product, process, as well as organizational and marketing innovations, are distinguished in this manual. With respect to the subject matter of this study, authors paid particular attention to process innovations considered as changes of used production methods, as well as changes of the manner of hunting customers of the product or service. The process innovations are aimed at reduction of the unit costs of the product or delivery and improvement of the product quality. They can comprise an implementation of suitable changes in the scope of the hardware and software, as well as changes related with procedures and techniques used in the provision of services.

Authors of the present study presented an example of process innovation aided with experiment conducted in industrial conditions, comprising application of suitably selected (for concrete conditions) construction and kinematic parameters of worm-type milling heads causing reduction of process energy consumption, reduction of dustiness and appearance of the winning with greater amount of coarser grade, what considerably influences the product price. Taking it under consideration, the authors presented an example of innovation. Method of the selection of parameters both of milling heads and milling process is aimed to tailoring them to concrete working conditions, i.e., properties of mined rock body and parameters of the longwall shearer.

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Research methods described in the study are based on quantitative examinations and research techniques. Research methods comprise observation and data analysis, such as desk research. Observation and experimental methods were applied in part referring to the application of the innovation.

## Process innovations in Polish mining branch

Analyzing innovative action of industrial plants of the branch comprising hard coal and brown coal excavation according to classification Polish Classification of Activities (PKD) in the period 2008-2014, which is shown in Fig. 1, we can observe that innovative activity of Polish mining plants in the analyzed period was kept at the level of 45%, that means that every second plant did not introduce any innovative changes with respect to product quality, work organization or marketing. It is definitely an unprofitable situation for a branch being in difficulty with low profitability. It also results from Fig. 1 that in case of innovatively active companies this activity was mostly directed for process innovations, comprising among the others implementation of new, improved production methods. However, the rest of the innovation groups, the innovations were realized in small percent by companies belonging to the extractive branch.

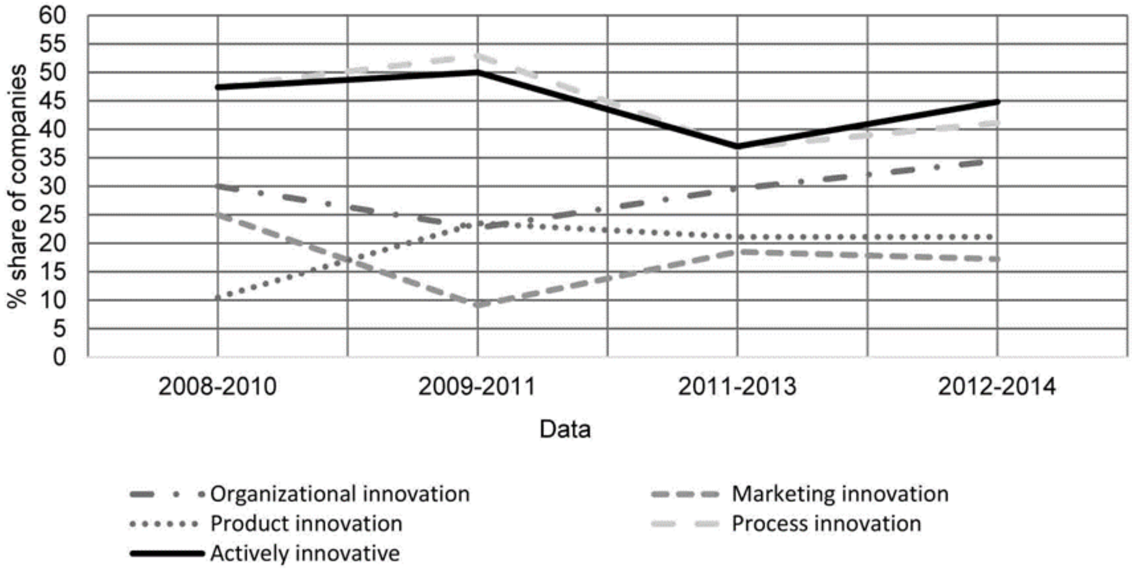


*Fig. 1. Innovative actions of Companies – PKD.*

Because process innovations very often are implemented simultaneously with product innovations, with respect to direct their mutual bonding, the participation of these two types of innovations is presented in Table 1. Analyzing data from this table, we can note that if the innovative activity is implemented, it is directed onto process innovations.

*Tab. 1. The innovative activity of Companies belonging to PKD. Hard and brown coal extraction - product and process innovations.*

| | **Total** | **New, or considerably improved products** | | **New, or considerably improved processes** |
|---|---|---|---|---|
| | | **Total** | **New for market** | |
| | **in % of all Companies** | | | |
| **Period 2008-2010** | 47.4 | 10.5 | - | 47.4 |
| **Period 2009-2011** | 52.9 | 23.5 | 5.9 | 52.9 |
| **Period 2011-2013** | 36.8 | 21.1 | 5.3 | 36.8 |
| **Period 2012-2014** | 47.3 | 21.1 | 10.5 | 42.1 |

Source: *own elaboration on the basis of* (Roczniki branżowe, 2005-2015)

Based on Fig. 1, one can conclude that Companies from the extractive branch are innovatively active first of all in the process field, whereas in other areas this activity is kept on a low level. It is also confirmed by data from Table 2, in which inputs for the innovative activity of companies from mining branch are presented.

Statistical data comprising innovation investments, with respect to their destination can be grouped into four basic areas (Franik, 2015; Nauka, technika, 2014; Midor et al., 2017):

Group A – research and development activity (B+R),

Group B – knowledge buy from external sources and software,

Group C – investment for machines and technical devices, Group D – personnel training and marketing, or crucial improvements of products.

*Tab. 2. Investments for innovative activity - hard and brown coal extraction in a million (mln) PLN in the period 2006-2014.*

| **Year** | **Investments for innovative activity in the scope of product and process innovations in mln PLN** | | | | | |
|---|---|---|---|---|---|---|
| | **Total** | **Research and development activity (B+R) Group A** | **Knowledge buy from external sources and software Group B** | **Investments Group C: Buildings and installations and lands** | **Investments Group C: Machines, technical devices, tools, and transport means** | **Personnel training, marketing related with new or considerably improved products Group D** |
| **2006** | 187,3 | 7,4 | 0,9 | 34 | 137,4 | 0,2 |
| **2007** | 226,8 | 5,4 | 0,3 | 85,3 | 113,3 | 0,6 |
| **2008** | 193,4 | 7,8 | 0,2 | 72,9 | 108,8 | 0,7 |
| **2009** | * | * | * | * | * | * |
| **2010** | 64,8 | 10,4 | 0,0 | 7,8 | 40,9 | no data |
| **2011** | * | 9,3 | 4,6 | 11,5 | * | * |
| **2012** | 67,0 | 13,2 | * | * | * | 0,2 |
| **2013** | 85,9 | 19,6 | * | 2,3 | 63,6 | * |
| **2014** | 80,5 | 5,4 | * | 1,5 | 63,3 | * |

* it means that the data can not be published with respect to the statistical secret - public statistics act.
Source: *own elaboration on the basis* (Roczniki branżowe, 2005-2015)

As results from analysis of data in Table 2, investments in machines and technical devices purchase have the greatest part in four groups of investments spent for innovative activities. Since the year 2006, their part in total investments is kept on a very high level when investment spent on machines and technical devices amounted for 73.3% of total investment spent on innovations. This situation was changed in the period 2007 to 2008. In this period, investment spent on buildings and grounds considerably increased, however in the year 2010 came back to high investment spent on machines and technical devices. In general, we can state that group C related with investment inputs constitutes the main direction of innovations in companies of the mining branch, what is related with process innovations. Example of introducing process innovation in the Polish mining industry will be discussed in the next part of the present study.

## Method of longwall milling heads selection as an example of the process innovation

Longwall excavation commonly known as longwall is equipped with a set of machines and technical devices forming the so-called longwall system. Depending on the type of mining machine is used (shearer, plow) the system is called as shearer system or plow system. Longwall systems are commonly used for hard coal, brown coal, rock salt, and potash chloride exploitation. Actually, longwall shearers are the most commonly used, plow shearers are used rarely, although works on implementation of modern longwall systems in thin coal beds are conducted (Biały, 2014; Bołoz, 2013; Bołoz, 2018; Brodny, 2011). Except for the longwall shearer, the longwall system consists of mechanical longwall support, longwall scraper conveyor and chain conveyor, which transports the winning stream onto band conveyor (Krauze, 2000).

Longwall shearers are equipped with two worm-type milling heads, which realize processes of cutting and loading. These elements are in direct contact with mined rock body. The milling process is realized by milling tools, and loading is realized by worm vanes (Wydro, 2015).

Parameters of the cutting head influencing milling quality can be divided into the following groups:

- design parameters and resulting pick system, as well as the type of cutting tools,
- shearer operation parameters (kinematic and energy performance).

Both groups of parameters influence shearer load, the durability of the mining machine and winning grade, as well as dustiness. Parameters influencing the quality of loading process can be divided into the following groups:

- shearer design parameters and resulting shape of loading instruments,
- shearer operation parameters (kinematic and energy performance).

Also, in this case, both groups of parameters influence shearer load, the durability of the mining machine, winning grade and dustiness.

Parameters of machines of the shearer system should be selected in such manner that for definite excavation and mining and geological conditions, targeted $V_d$ and winning grade (grain-size) were reached. That is why the application of the shearer in longwall excavations requires:

- determination of rules of machines and devices selection, with respect to conditions and hazards,
- determination of the coal properties in a coal seam in question,

- analysis of coal seam and longwall excavation parameters (length *l*, height *h*, longwall coasting area, dip),
- determination of required daily output $V_d$,
- determination of design, kinematic and energy parameters of the longwall shearer system,
- design of worm-type milling heads,
- assessment of the possibility of obtaining coarse coal grades.

Realization of mentioned tasks allows decision if the shearer or plow system can be operated in the given coal seam, as well as what parameters are required to obtain targeted daily output and satisfactory winning grain-size.

The mined material consists of grains of different granulation, which is classified in the enrichment process. In consequence mining plants offer coal of different grade (bricks, chestnut coal, pea coal, pea coal, fine coal) in different price depending on the coal grain-size and quality. In this classification, fine coal is the cheapest, and the most expensive is coal brick. Thus it is important to obtain from given excavation the winning consisting of the possibly great amount of coal grains with a diameter exceeding 8 mm, with a possibly small amount of fine coal (Krauze et al., 2016).

Obtaining of coal of coarse granulation should be analyzed both in technical and economical aspect. The technical aspect is related to mining and enriching power consumption, and it is related to coarser winning. Bigger coal grain-size is accompanied with smaller dustiness, what also is an advantageous feature (Krauze et al., 2016).

From the other side, economical aspect favors coarser coal grain-sizes because their price is considerably higher than the price of the fine coal. Coarser coal grade also generates low exploitation and transport costs. Thus one should consider if obtaining coal of courser grain-size from given excavation is possible, as well as what conditions and requirements must be satisfied. In the case of excavation equipped with full set of machines the problem comprises design of dedicated milling heads, as well as the determination of kinematic parameters of the shearer and its cutting head.

Proper cooperation of longwall system machines forces their compatibility, what is a condition sine qua non of obtaining targeted efficiency. However, generation of assumed daily output is not equivalent to optimal selection of these machines. Each element of the longwall system is characterized by a definite range of parameters, for which operation of the whole system is proper. That is why, in practice, there is at least one machine constituting the weakest element of the system, thus in definite operation conditions it reduces daily output (Krauze, 2000), for example with respect to conveyor efficiency, loading performance of cutting head (Wydro, 2015) or time of the section re-arrangement. That is why the determination of proper and optimal parameters of these machines, including conditions occurring in the machine operations place is needed.

Having in mind the upper conclusions we may suggest that for an assumed output level, accepted exploitation technology, and its parameters, the milling longwall shearer should possess the following design and kinematic parameters:

- advance rate-regulated from zero to maximal value, which should not exceed the smallest rate resulting from the cooperation of the longwall system machines,
- cutting height range soul be bigger than the longwall height *H* resulting from the coal bed thickness,
- two cutting heads of web *Z* (usually 0,8 m ÷ 1,1 m) and diameter $D_s$ (recommended $D_s \approx 2/3\ H$).

Value of the assumed daily output and the longwall parameters allow determination of the support and longwall conveyor parameters. Thus we can also select proper parameters of the worm-type cutting heads. Method of the selection of design, kinematic and energy parameters of machines and devices of the longwall shearer system has been elaborated in the Department of Mining and transport Machines of the AGH University of Science and Technology. On the basis of this method, a suitable computer program allowing the determination of these parameters has been elaborated (Krauze et al., 2016).

The starting point of the selection of cutting head parameters is coal workability measured by mining capacity *A*, side crushing angle $\psi$, compressive strength $R_c$ and compactness factor *f*. Compactness factor *f* is determined according to Protodiakonow's jr method (cracking method). Coal beds geological structure is also determined.

Method of determination of coal mining capacity *A* has also been elaborated in the Department of Mining and Transport Machines of the AGH University of Science and Technology, and it comprises measurement of milling resistances directly in longwall face during execution of rectilinear cuts (Krauze et al., 2016). The measurement cuts are made on an aligned surface with use of 2 cm wide model pick, which is moved along the face of the coal longwall. From the measurement of pressures occurring during cutting with use of a model pick on the depth of 2 cm, after suitable handling of the measurement signal, mean value of cutting force *P* is obtained. In result of these tests, mining capacity factor *A* and angle of side crushing $\psi$ are obtained.

The ratio of mean cutting force $P$ and measured cutting depth $g_s$ is defined as mining capacity factor $A$, and it may be calculated from the following relation:

$$A = \frac{P}{g_s}\left[\frac{\mathrm{N}}{\mathrm{cm}}\right] => P = A \cdot g_s \ [\mathrm{N}] \quad (1)$$

where:

$P$–mean value of cutting force, $N$

$g_s$–cutting depth, cm

This factor is comparable for various coal beds, and the bigger the value it has, the more difficult is the bed mining capacity. In order to determine coal compactness (compact/weakly-cohesive), in parallel with the measurement of the mining capacity factor, the angle of side crushing is determined.

$$\psi = arctg\left(\frac{b_s - b}{2g_s}\right) [°] \quad (2)$$

where:

$b_s$ – cut width

$b$ – cutting pick edge width.

According to classification CMG KOMAG, coal of angle in question smaller than 60° is classified and strongly-cohesive coal, whereas coals having this angle bigger than 60° are classified as weakly-cohesive ones. On the basis of the mining capacity factor $A$ and angle of side coal crushing $\psi$, taking under consideration classification of Polish coals also elaborated by CMG KOMAG, we are able to determine type and category of tested coal.

On the basis of parameters $A$, $\psi$, $R_c$ and $f$ we can determine coal mining capacity and its brittleness. On this base cutting method (milling, plowing), type of cutting picks and their arrangement in cutting head and kinematic parameters are selected, and the possibility of obtaining bigger amount of coarse material is assessed (Biały 2016), (Krauze et al., 2016). It should be noted, that worm-type cutting heads and picks used should be selected not only with respect to their design but also the high quality of their manufacturing, as well as compatibility of real parameters with those assumed in the design phase of the project in question (Krauze et al., 2015).

Properties of the tested rock body determined during executed examinations allow such selection of the cutting head parameters that improvement of the coal grade is possible, including reduction of dustiness and cutting process power consumption. In particular, selection of cutting scale (distance between individual cutting lines) and cutting depth (ratio of the shearer advance rate and the rotary speed of the cutting head with taking into consideration number of picks in cutting line), are very important. Both cutting scale and cutting depth directly influence the winning grain-size. It should be noted that obtaining profitable winning granulation and optimization of the power consumption directly influence the proper cutting process.

Pick fastened in its holder is a part of the cutting head (Fig. 2). Thus operational pick angles $\alpha_r$ and pick rake angle $\gamma_r$ depend not only on design pick parameters but also on parameters of its holder, as well as on cutting rate $v_s$ and advance rate $v_p$. Thus we can conclude that for the cutting head of diameter $D_s$, cutting rates $v_s$ and advance rates $v_p$, holder height $H_u$ and holder angle $\delta_u$, the tangential rotary pick of required length $L_n$ and pick angle $2\beta_u$ should be selected. The proper course of the cutting process is conditioned by such selection of these parameters that operational pick rack angle $\alpha_r$ was always positive. Dislocation of the pick holder along the tangential line marked as $b$ is a parameter allowing correction of the operational cutting angles. Because of the tool wear and developed hazards, the maximal linear speed should be controlled and suitably limited. Moreover, the limitation of the shearer movement with respect to cutting depth resulting from the length of picks and their number in cutting line is needed (Krauze, 2000; Bołoz, 2012).

The pick torsion angle $\varphi$ can describe the pick position on the cutting head. For the pick set shown in Fig. 2, angle $\varphi$ has a value of geometrical pick torsion angle $\varphi_g$. Geometrical pick torsion angle is defined as an angle between radius passing the pick edge and radius, which is perpendicular to the holder base. Value of this angle is constant independently on the pick position during cutting. Angle $\varphi_g$ can be calculated from the formula:

$$\varphi_g = arctg\left(\frac{b - b_{u1} \cdot sin(\delta_u) + L_r \cdot cos(\delta_u)}{0{,}5 \cdot D_b + H_n}\right) [°] \quad (3)$$

The diameter of the cutting head $D_s$ can be determined from the relation:

$$D_S = \frac{D_b + 2 \cdot H_n}{cos(\varphi_g)} [°] \quad (4)$$

Whereas the angle of repose $\alpha$ amounts for:

$$\alpha = \delta_u - \beta_u + \varphi_g [°] \quad (5)$$

A pick rake angle $\gamma$equals to:

$$\gamma = 90 - \delta_u - \beta_u + \varphi_g [°] \quad (6)$$

In result of a combination of advance rate $v_p$ and cutting rate $v_s$ the pick rake angle and pick edge range are changed by values of angle $\delta$ according to the following relations:

Operational pick rake angle:

$$\alpha_r = \alpha - \delta [°] \quad (7)$$

Operational pick edge angle:

$$\gamma_r = \gamma + \delta [°] \quad (8)$$

Value of the angle $\delta$ is changed during cutting in function of angle $\varphi$. Value of angle $\delta$ can be calculated from the formula:

$$\delta(\varphi) = arcos\left(\frac{v_s + v_p \cdot cos(\varphi)}{\sqrt{v_s^2 + v_p^2 + 2v_s \cdot v_p \cdot cos(\varphi)}}\right) [°] \quad (9)$$

Value of angle $\delta$ is changed due to pick position during cutting, and it reaches its maximum when the pick passes horizontal axis of the cutting head.

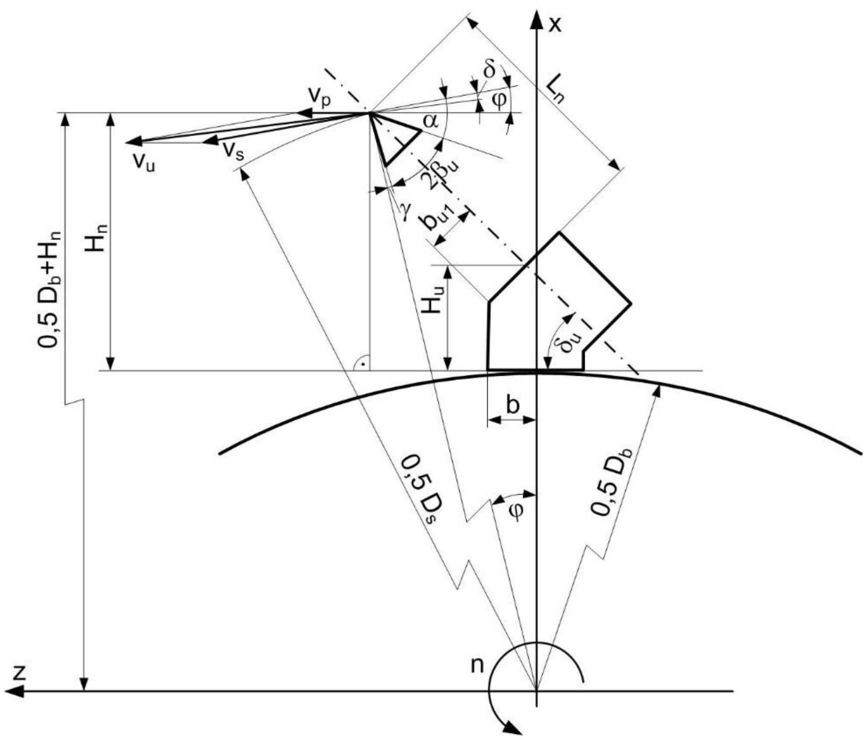


*Fig. 2. Geometrical and kinematic parameters of pick during milling (Bołoz, 2012).*

**Example of the process innovation application within chosen coal longwall**

The assumption of targeted output level from the excavation of defined geometrical parameters, settlement of coal mining capacity and crushing resistance and selection of support, conveyor, shearer and cutting head parameters allow realization of the project of dedicated cutting heads. Consequently, the longwall exploitation with a possibly small dustiness and power consumption, as well with increase of production of coarse coal grades call for empirical verification, which has been executed in one of the longwall excavations of chosen hard coal mining plant in Poland, within coal seam 501 at the exploitation level 830.

Theoretical base presented in the first part of the present study allow selection of worm-type milling heads for head KSW-880 EU/kV in the aspect of obtaining advantages. Thus, for chosen by the mining plant coal longwall of the height $H$ = 3 m, length $L$ = 200 m and longitudinal inclination $\alpha_{pod}$ = 2° and transverse inclination$\alpha_{pop}$ = 3.5°, the procedure of the cutting head selection have been executed. The procedure in question comprises the following activities:

- determination of coal mining capacity in the coal bed on the basis of underground examinations for two parallel cuts (marked as I and II),
- conduction of the analysis of mining and geological conditions, as well as longwall technical equipment in the aspect of obtaining the assumed daily output,
- selection of parameters of the shearer worm-type milling head in order to increase production of coarse coal grades.

Determination of the coal mining capacity requires conduction of suitable tests, and that is why the following activities have been executed:

- measurement of the mining capacity factor $A$ and angle of side crushing $\psi$ for coal occurring in examined coal bed (Fig. 1 and Fig. 3),
- measurement of cohesiveness factor $f$ according to Protodiakonow's method on the basis of samples taken from places of determination of factors $A$ and $\psi$,
- laboratory determination of the coal geological structure.

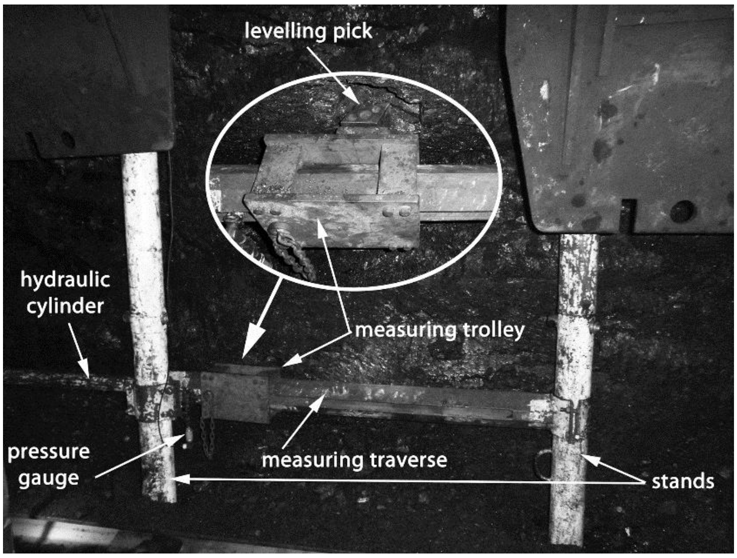


*Fig. 3. Testing stand during examinations*

Results of underground examinations (factor $A$, angle $\psi$, formulas 1 and 2) and results of laboratory tests (factor $f$, coal structure) constituted a base, on which the following conclusions have been drawn (Krauze et al., 2016):

- within the tested coal bed, occurrence of the coal classified to VII ÷ VIII class of mining capacity was proved – cohesive and particularly hardy mined coal (cut I - $A_I$ = 4 045 N/cm, $\psi$ = 18°31', cut II - $A_I$ = 3 790 N/cm, $\psi$ = 38°27', $f$ = 1.76),
- cutting of this coal is possible only with the application of the milling method, with use of tangential-rotary picks,
- coal occurring in tested bed is classified as weakly crushed coal,
- the coal consists of vitrinite, clarite and fusain laminae and a minor amount of inert parts.

The upper conclusions indicate that coal occurring in this coal bed can be mined with use of worm-type milling heads equipped with tangential-rotary picks. Good mining capacity of this coal forces application of small variable scales between milling lines. From the other side, small brittleness indicates high coal resistance to degradation.

Coal occurring within the coal bed in question is classified as steam coal of symbol 32.2 (gas-flame coal). The coal is exploited by the longwall system, transverse, with use of hydraulic support. The shearer works in two-way technology and is equipped with worm-type cutting heads without shielded loaders.

Taking under consideration the longwall height, shearer technical parameters, coal mining capacity and shearer permissible advance rates resulting from cooperation with support and conveyor, as well as on the basis of used procedures, the following parameters of worm-type cutting heads were determined:

- cutting head rotary speed $n$ = 36,2 rpm,
- drum diameter $D_b$ = 1690 mm,
- vane inclination $\alpha_p$ = 23°,
- number of vanes $i_p$ = 4,
- hub diameter $d_p$ = 900 mm,
- vane thickness $b_p \leq$ 50mm,
- disc thickness $b_t \leq$ 80mm,
- the width of the body $B \geq$ 720 mm.

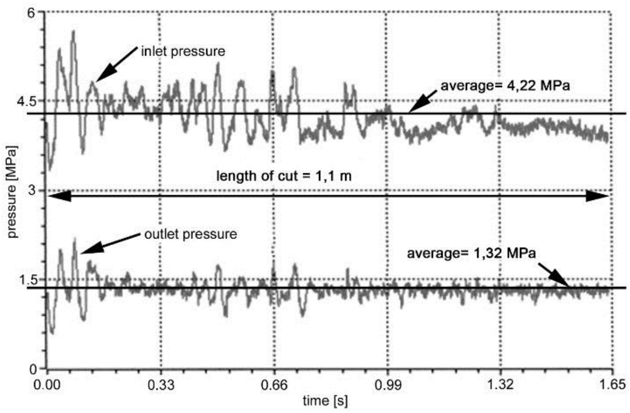


*Fig. 4. Course of measurement signals during coal milling (g = 1.7 cm, $b_s$ = 4.7 cm).*

Pick arrangement with tangential-rotary picks was designed for a cutting head $\phi$2000 x 800. Picks arrangement allowing obtaining changeable scale between milling lines and the moveable cut is characteristic for this cutting system. A small number of picks (disc – 20 pieces, cutting-loading part – 16 pieces) with combination with a changeable scale between milling lines and moveable cut allows obtaining increased part of the coarse coal grade, as well as dustiness reduction if the permissible advance rates are used. It should be noted that the reduction of some picks accompanied by the rock body parameters (mining capacity factor, brittleness factor)will allow the reduction of the power demand of the cutting head motors. Based on relations (3-9), values and courses of changing angle $\delta$ for pick position during the single cut of the shearer, have been determined. Courses of movable pick edge angle $\gamma_r$ and pick rake angle $\alpha_r$ are shown in Fig. 1. These angles change their values, however, pick rake angle must always be positive. If the negative values of pick rake angle occur, crushing instead milling is observed.

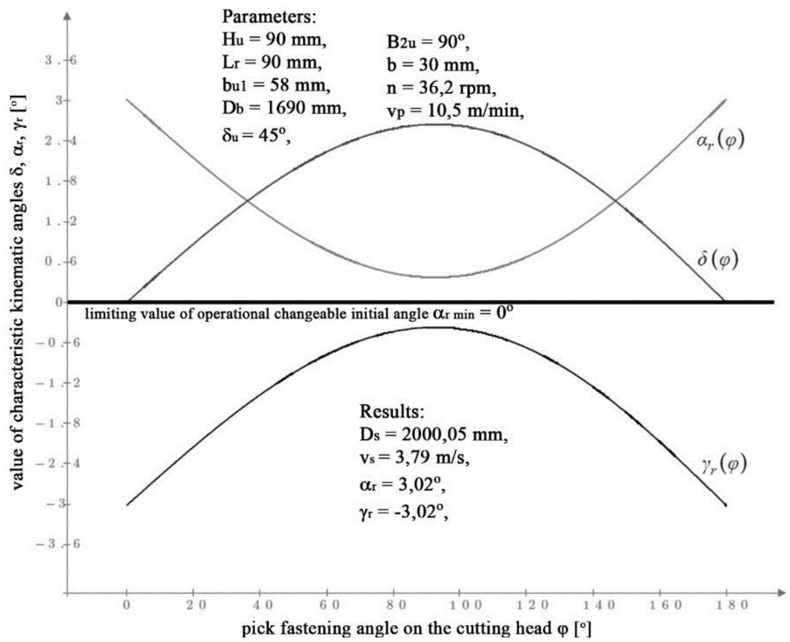


*Fig. 5. Courses of pick edge angles and pick rake angles in function of the pick position of the designed cutting head.*

## Assessment of coal grade and dustiness reduction improvement

Effectivity of the proposed method of the selection of worm-type milling head parameters can be verified by assessment of the winning generated by factory-made milling heads (marked as old) and designed milling heads(marked as new). Thus two-stage analysis of the winning grain-size and analysis of the dustiness both for factory-made milling heads and for the designed milling heads was made. In order to assure the same operational conditions of both milling heads, the measurements were made right before and right after their replacement.

The winning grain-size was measured in the longwall outlet (sieve analysis), where coal samples were manually sieved and classified into fine coal (below 8 mm) and coarse coal (over 8 mm). Winning samples were also taken from these places, and they were exposed to classification in the coal processing plant for sieve mesh ranging from 8 mm to 80 mm.

Dustiness for factory-made and designed milling heads was also measured. The results are presented in Fig. 6. On the basis of data in the diagram shown in Fig. 6, we can conclude that application of the new milling heads reduced dustiness level in the longwall by 36%. Thus we can assume that use of the new milling heads resulted in a reduction of the dustiness, what is considered as the great advantage (Černecký et al., 2015).

Results of the analysis of winning grain-size obtained with the use of new and old milling heads are shown in Fig. 7. The milling heads used so far in this longwall produced winning characterizing with the greatest percentage for grain-size of classes 8÷0, 16÷6, 25÷16. Whereas, the new milling heads produced winning with the greatest percentage of grains over 80 mm, whereas this percentage for grains below 8 mm was the smallest. On the basis of executed tests and obtained results, it was proved that new milling heads satisfy the assumed target, i.e., production of the winning having the most profitable grain-size, what consequently results in smaller dustiness.

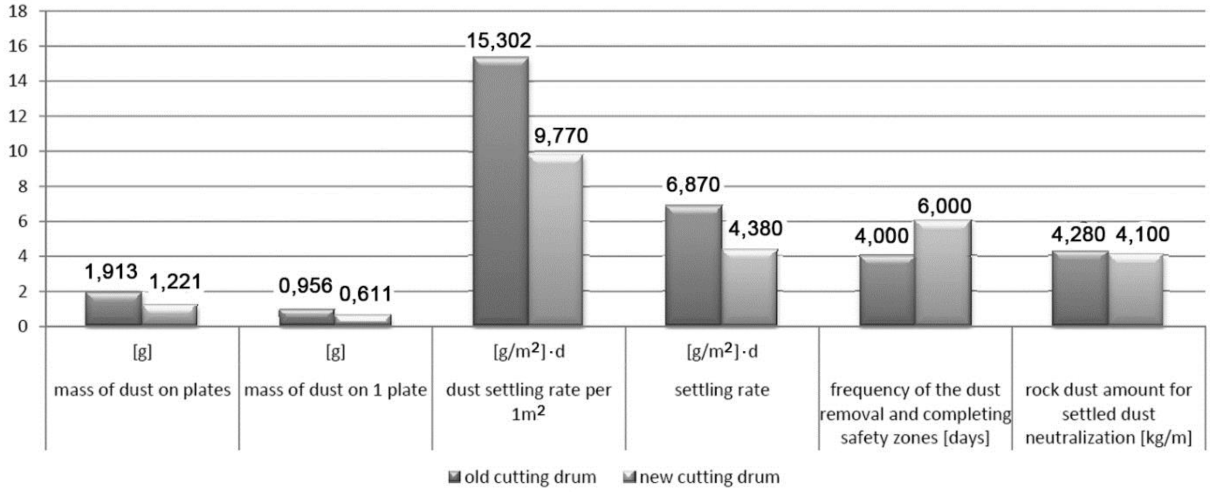


*Fig. 6. Test measurement results obtained for mining with use of factory-made (old) and selected (new) milling heads.*

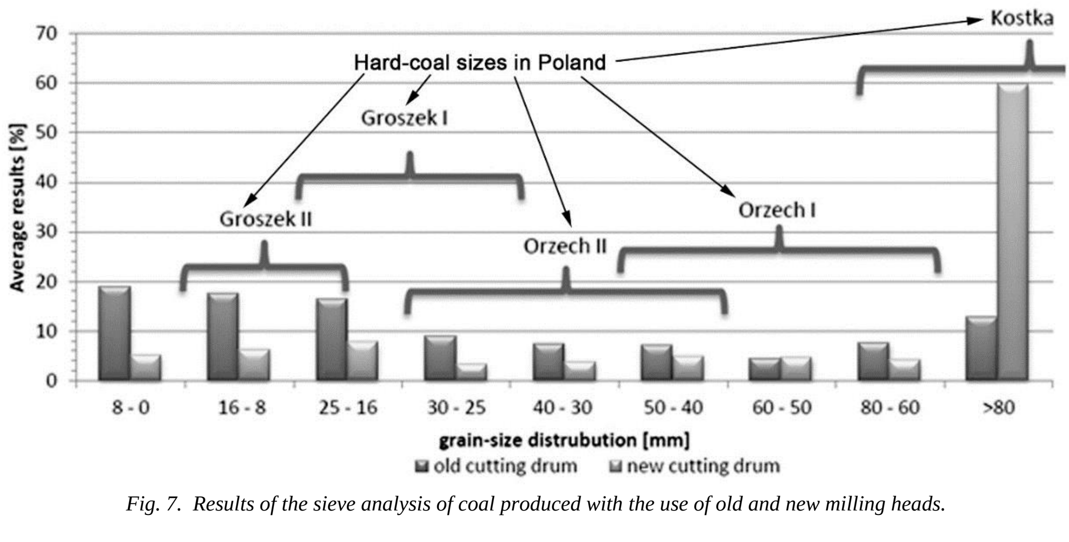


*Fig. 7. Results of the sieve analysis of coal produced with the use of old and new milling heads.*

## Conclusions

Innovative processes have an essential influence on the competitiveness of the domestic economy. In Poland, the expenditures for research works and development amount for only 0,87% Gross Domestic Product (GDP), whereas in the Czech Republic – 1,91%, Germany – 2,85% and in Finland 3,31%. The document named as „Europe 2020" assumes that by the year 2020 the member countries will be investing 3% GDP in research and development activities (HTTP, 2016). In Poland, it is expected that this limit should amount for 1,7% and it is assumed that half of these expenditures will be paid by entrepreneurs. Thus if the Polish domestic mining plants want to survive on the market, they must contribute considerable part in this innovation level of Polish industry (Midor et al., 2015).

Current examination and practice prove that the market is the best verifier of business activity forcing suitable reaction of the company, i.e., it determines the profitability of the innovative programs. Thus market economy forces flexibility and adaptability of given company, an increase of entrepreneurship and ability of adaptation to not only already existing marked changes but also to predicted or expected changes. Thus we can conclude that the activity of the company in a time of the market globalization, and circumstances of a free economy is equal, or even bigger than this what happens in the company itself. The company, which is not intended or not able to tailor to the market and new economic challenges is also not able to develop, in time it loses the ability to satisfy local environment needs and is exposed for collapsing.

The economy of our country is in the specific development phase. For example, current competitive advantages based on monopoly loose their position. Thus developing new advantages based on knowledge and innovativeness is necessary for long distance economic development. Thus the development of innovation activities of companies, including research and development activities, are the major factors of competitiveness (Święcicka, 2012; Tkocz, 2012; Zioło, 2009). These postulates in great extent refer to mining branch and particularly hard coal mining industry which is responsible for state energy safety accompanied by reaching high effectiveness on difficult primary fuel market.

Winning (coal, salt) of increased grain-size is a great challenge both for shearer and cutting head Manufacturers and mining plants. Worm-type cutting heads are commonly considered as typical and standard equipment of longwall shearers. It should be noted that they are considered as main elements responsible for mining and loading process and are characterized with great sensitivity to mining and geological conditions and kinematic parameters. Coarse-grained winning brings a lot of technical and economical advantages for mining plants. The procedure of selection of worm-type milling heads refers both to mining and loading function, and the selection is conducted with respect both to longwall shearer parameters and mining and geological conditions occurring in the longwall excavation. Effect of this procedure depends on its regular application due to new conditions or a new type of the shearer used. Positive empirical verification of the innovation in question will result in considerable economical benefits.

The presented method is applied especially in underground hard coal mines in order to increase grain-size. Nowadays grain size is crucial in terms of a coal price. Additional benefit related to dust reduction enhances working conditions.

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