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The effect of experimental research on the durability and reliability of mining equipment

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Abstract
Due to special conditions of functioning of machinery and devices used in coal mining, the process of its selection is important and should comprise variability of working conditions. A short review of methods of assessment of coal workability used as yet was done and the results were divided into groups. Significance of measurements and assessment of mechanical characteristics (including workability) is proven by worldwide in scientific centres by numerous elaborated methods of its assessment. In the article new devices used in determining and assessing mechanical characteristics of coal that significantly influence durability and reliability of mining machinery were described.

Introduction

The reliability of machines and equipment is shaped at all stages of their existence – design, production, operation. If all possible influences are to be taken into account at the stage of designing (of a machine or equipment), the designer's knowledge should reach the highest possible level. Hence, it is very important (as early as at the stage of designing) to undertake steps aiming to rationally shape the reliability of machines and equipment. The properties related to machines' reliability which were modelled during the design stage are realised at the production stage. One should also remember to apply an appropriate manufacturing technology, which also exerts an impact on the required reliability. On the other hand, during the machines' operation, special attention should be paid to elements and assemblies which are so-called „weak links" in the reliability structure. All these elements are exposed to unfavourable influences; hence, shaping their optimal reliability by technological methods (and not only) becomes particularly important.

Also the conditions of a machine's work are extremely important. For this reason, before a machine or equipment is installed in specific conditions, appropriate investigations should be carried out and measurements need to be taken in order to confirm (or exclude) a possibility of improper use, which influences the service life and reliability of equipment.

Since the 1980s a group of ISO 9000 standards has been in existence in the global industry. The standards define the entirety of steps to be undertaken so as to ensure, supervise, shape and document the reliability of machines, equipment and manufacturing processes.

The problem related to proper maintenance and, in consequence, reliability of machines, is present also in Polish mining industry, where the machines' failure rate is relatively high [1].

A necessity to ensure an adequate reliability of mining machines results also from the fact that these machines influence the occupational safety and hygiene, as well as the environment in which they function (hard coal-mines).

Ensuring a better quality of products and, in consequence, an enhanced durability and reliability of machines, requires modern technical and organisational means to be used in each of the aspects, i.e. technical or functional parameters.

Ensuring a high quality of products (mining machines or equipment) at lower costs than competitors, as well as application of new production

technologies are basic requirements for competing on the market. Both the environment of enterprises and enterprises themselves are forced to function in an increasingly dynamic way and be oriented to the future, which increases uncertainty and risk in the decision-making process.

This justifies the necessity to evaluate decisions, the selection of proposed technical and technological solutions and to take into consideration various criteria of their evaluation. Taking a decision – from among many possibilities – requires the use of advanced tools for the collection and processing of data, which is next transformed into knowledge used to analyse the production processes [2, 3, 4].

In Polish hard coal mining industry, coal deposits are exploited mainly by means of longwall systems, using mining machines which work like cutting equipment. For this reason, one of major areas of coal mines' activity is a proper selection and use of machines necessary to ensure the continuity of the production process. This activity should among others involve control over rational and effective use and maintenance of machines in the process of exploitation.

Hence, experimental research reproducing the character of a machine's work is a very important element in the process of mining machines' design and construction. Such investigations are aimed at exploring the highest possible number of parameters and their influence on the work of a machine (its elements), which in turn has an impact on the machine's service life and reliability in difficult geological and mining conditions.

Selected methods of coal and rock workability measurement

The importance of the measurement and evaluation of coal (rock) workability is confirmed by the number of methods of its measurement that have been developed in various centres around the world.

Workability measurements were taken chiefly for the needs of coal mining (underground).

The methods of coal (rock) workability evaluation fall into four basic groups, namely [5]:

I laboratory methods,
II recording of drilling resistance,
III measurements of grindability,
IV measurement of the forces of cutting with a single knife or a group of knives.

The first three methods are often burdened with a considerable error, resulting mainly form the fact that the character of a mining machine is not reproduced.

The fourth group includes methods in which instruments (devices) reproducing the real or similar character of a mining machine's work have been applied. Moreover, in this group of instruments it can distinguish devices reproducing the character of work performed by cutter-loaders or plows.

Devices whose character of work illustrates the character of plow's work include among others:

- ZP-1 (Czech Republic),
- DMT (Germany).

In Czech Republic the workability index B is defined as a ratio of average cutting force ($F_{śr}$) on the measurement knife to the depth of the cut (g):

$$B = F_{sr} / g \quad \text{[kN/cm]}$$

DMT is widely applied for determining the plow's work conditions – proper location. The measurement principle consists in recording the cutting force while making a 2-cm deep measurement cut with a standard knife placed on the measurement head. As opposed to research conducted in Poland, the classification of coal beds takes into consideration only the averaged value of force (F_S) applied to the measurement knife, as the depth of the cut is assumed to be constant [6]. Based on the adopted methodology and conducted investigations, a classification dividing coal beds into four groups has been developed (Table 1).

Table 1. Classification of coal by DMT

The class	The average value of force [kN]	The degree of difficulties excavating
1	$F_s < 1.5$	well excavating
2	$1.5 < F_s < 2.0$	normally excavating
3	$2.0 < F_s < 2.5$	difficult to excavating
4	$2.5 < F_s$	very difficult to excavating

On the other hand, devices whose character of work reflects the character of a cutter-loader's work include among others such instruments as:

- DKS, SDM (Russia),
- POS-1 (Poland).

In these devices the index of workability A is defined as a ratio of average cutting force ($F_{śr}$) on the measuring knife to the depth of the cut (g):

$$A = F_{sr} / g \quad \text{[kN/cm]}$$

Moreover, in Poland another workability index has been introduced – A_ψ, which takes into consideration the side-crumble angle ψ and equals [7, 8]:

$$A_\psi = \frac{F_{sr}}{g\left(1 + \frac{g}{b} tg\psi\right)} \quad \text{[kN/cm]}$$

where: b – the width of the cutting tool edge.

The conducted investigations and the obtained results served as a basis for modifying the classification of Polish coals into three categories, depending on the side-crumble angle ψ and the value of workability index A (Table 2), which are closely related to each other [7, 8].

Moreover, the above mentioned devices provide a possibility of taking measurements not only in laboratory conditions, but also under „in situ" conditions. Investigations conducted in underground conditions reflect the state of stress and deformation occurring in real geological and mining conditions.

Table 2. The division coal beds in the class by the difficulty of excavating

Index workability A [kN/cm]	The angle of the side crumble ψ [°]			The degree of difficulties excavating
	$\psi > 70°$	$40° < \psi \leq 70°$	$\psi \leq 40°$	
$A \leq 1.80$	I	–	–	easily workable
$1.81 < A \leq 3.00$	–	II	–	average workable
$A > 3.01$	–	–	III	difficult to workable
	brittle W_k	hard W_t	very hard W_{bt}	

Another noteworthy research was carried out at the Technical University of Istanbul, which has a positive recommendation of the International Rock Mechanics Association as a standard for laboratory measurement of workability. In these investigations workability is described by means of *SE* index, which is calculated as a ratio of the force applied to the cutting knife over the length of the cut (*FN*) to the volume of broken rock (*Q*) [9].

$$SE = \frac{FN}{Q} \quad [\mathrm{MJ/m^3}]$$

The index value has a considerable impact on the power, efficiency and durability of mining equipment. It can be therefore concluded that this parameter has a decisive influence on the service life, installed power and dimensions of a mining machine and, in consequence, influences the costs of purchase and maintenance.

For this reason, coal workability measurement allows an optimal selection of mining machines' operational parameters and can be one of decisive factors that enables evaluating the effective exploitation of a particular plot or coal bed. This problem concerns coal mining by means of both a cutter-loader or a plow.

Instruments for determining the index of workability

Instrument reproducing the work of a plow

The device for measuring the cutting forces which reproduces the character of a coal plow's work was constructed in GIG (Central Mining Institute) in Katowice [11, 13]. It enables a uniform and stable feed-in of the measurement knife to the coal solid, ensures high accuracy of the coal solid preparation over a length of 1m and makes it possible to perform precise cuts and take measurements of parameters necessary to determine the rock workability index. The device enables making cuts with two turns – a measurement of coal resistance to cutting in deposits having a thickness of 0.6–2.0 m, making a minimum of 10 measurement cuts with one mounting of the device at one height, without a necessity to move it, which is a pre-condition for the accuracy of measurements. The device is easy to install and use, which translates into low maintenance costs.

The device for determining the cutting index of coal consists of four elements (Fig. 1):

1. guide *1* mounted on hydraulic props *2*,
2. carriage *3* driven by hydraulic motor *4*,
3. chain wheels *5* and chain *9*,
4. feed-in assembly *6*.

Guide *1* with carriage *3* equipped with a holder for mounting a levelling knife (head) *7* or a cutting-measuring knife *8*, driven by hydraulic motor *4*, is fixed to hydraulic props *2* (Fig.1). The drive is transmitted by means of chain *9*, fastened on chain wheels *5*. The device is equipped with a feed-in assembly *6*, which consists of two consoles connected with the hydraulic props by means of clamping rings *10*.

The cutting forces are measured in four stages. Before proceeding to measure the cutting forces, it is necessary to level the coal solid surface – stage 1. This is performed by means of a levelling head equipped with a furnished hydraulic motor *7*. The next step (stage II) is to install a levelling head and equip it with scanner *11* in order to scan the levelled surface. The next stage (III) involves furnishing a head with a cutting-measuring knife *8* in order to take a measurement by recording the resistance to cutting. After the measurements have been taken, the cutting-measuring head is dismantled and the scanning head is installed again in order to scan the obtained groove (stage IV). On the basis of the recorded values of resistance to cutting (forces) and the computed volume of mined rock, its workability index is calculated. In order to make subsequent measuring grooves at the same height, the pre-

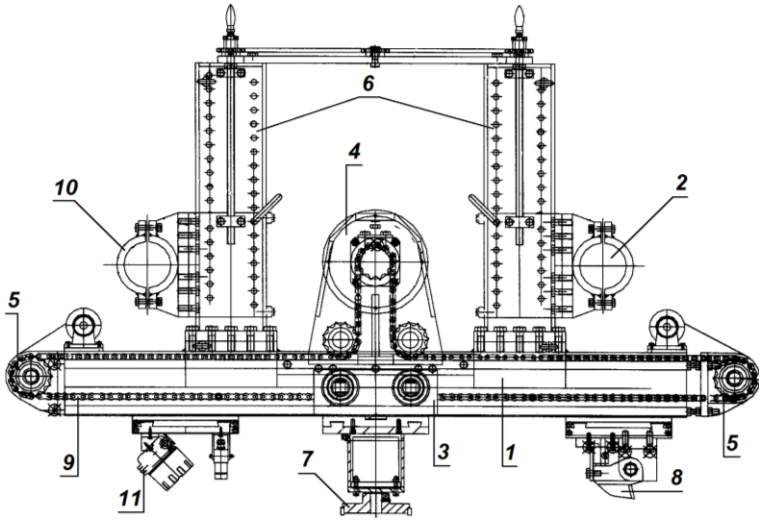

Fig. 1. The GIG device for measuring the cutting forces

sented procedure should be repeated. The adopted methodology of measurements assumes that minimum three measuring grooves on one level in a coal bed are made.

Instrument reproducing the work of a cutter-loader

The POU-BW/01-WAP device, installed and ready for work, has been presented in figure 2 [12].

It consists of three basic elements (Fig. 2):

– carrying beam to be installed on props SHC/SHI *1*;
– support with actuator's carriage *2*;
– arm with measuring knife *3*.

The POU-BW/01-WAP device for determining the workability of coal enables making the cuts in a vertical plane (perpendicular to the roof and floor) with two turns. This instrument reproduces the real character of a drum cutter-loader's work, as the measurement cut has a changeable direction of cutting, starting approximately with a horizontal direction, through a vertical one, and finishing with a horizontal direction, which however has an opposite turn at the end. Moreover, the POU-BW/01-WAP instrument (Fig. 2) enables the measurement knife to be moved closer to the coal solid by means of support *2*, which is fixed on frame *1*. The support's construction ensures high accuracy of coal

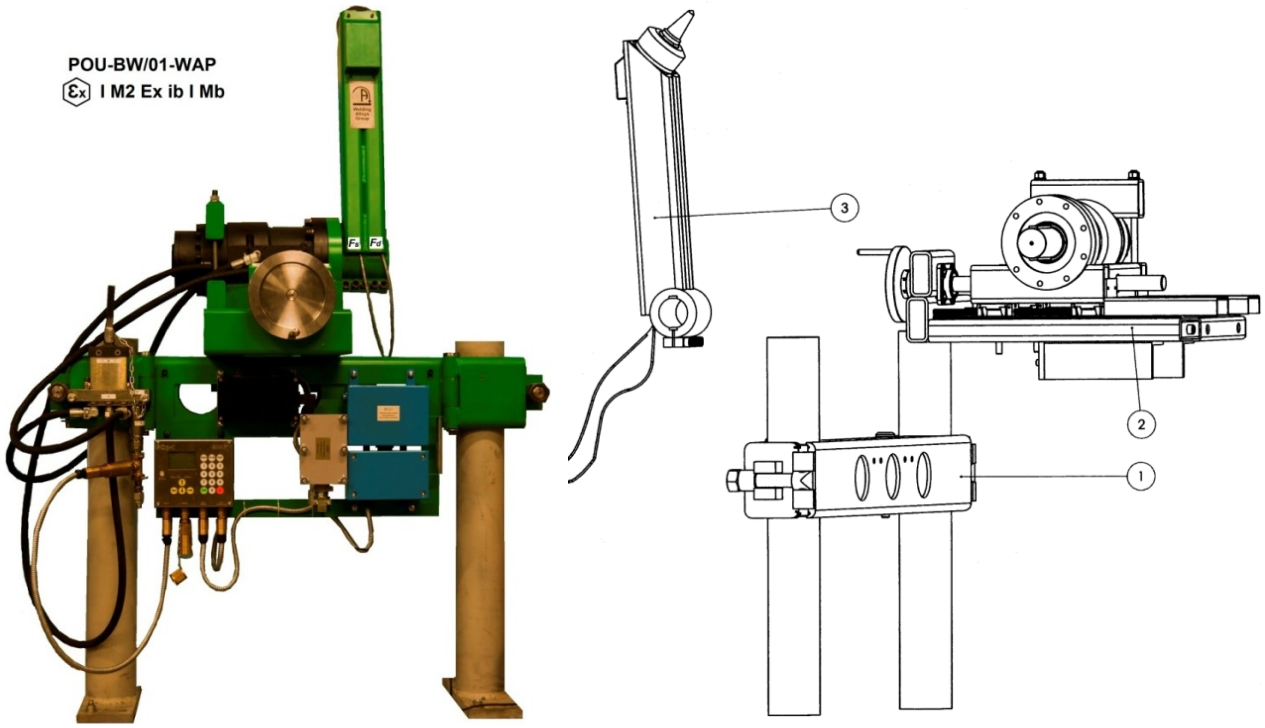

Fig. 2. The POU-BW/01-WAP device

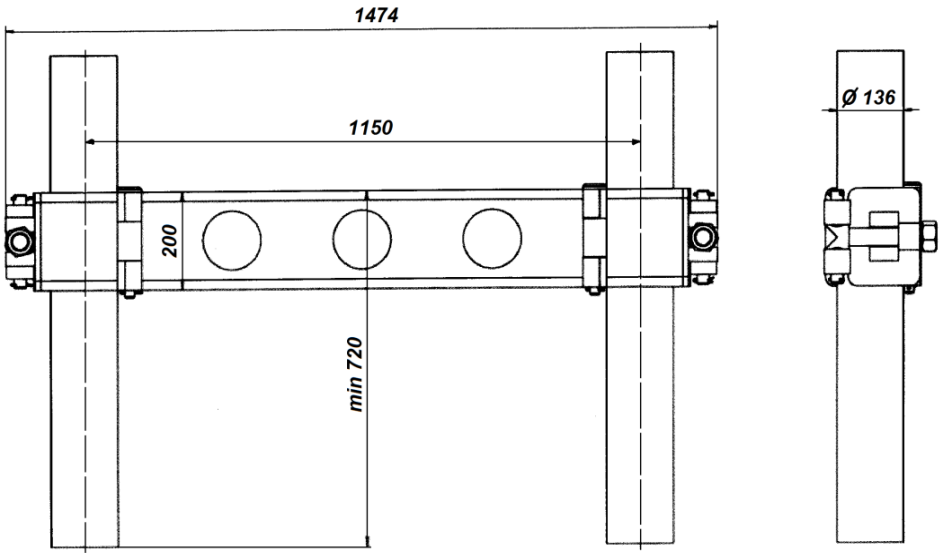

Fig. 3. Balancer carrier beam device

solid preparation and a similarly high precision of the performed cuts and measurements of parameters necessary to determine coal workability index. A real knife that is installed in drum cutter-loaders (tangential-rotary) has been applied in the instrument as a measuring knife, thanks to which there is no need to take into consideration the influence of the knife's geometry on measurement results. In the previously applied devices the measurement's knife geometry was similar to that of real knives, which entailed the necessity of taking into account the influence of the knife's geometry on the cutting force value in measurement results.

The device is adapted to be mounted on two SHI/SHC props. After the props have been initially aligned, the carrying beam must be fixed at a height of minimum 720 mm away from the base to its upper surface (Fig. 3), with the frontal area directed towards the coal bed (side wall) and mounting openings directed upwards. After initial aligning and levelling, the beam should be screwed with two bolts M36.

The support with the actuator's carriage is fixed to the upper part of the beam (Fig. 4) by means of M16×40 screws in one of possible positions – the actuator's shaft should be located on the right side. The choice of the support's position is optional and depends on the conditions at the place where measurements are taken. It is possible to mount the support in one of two positions left/right and front/back by using appropriate holes in the beam and the support (Fig. 3).

The last element of the device is the arm, the end of which is equipped with a measurement knife (Fig. 5). The arm's knife should be directed towards the mined bed (side wall).

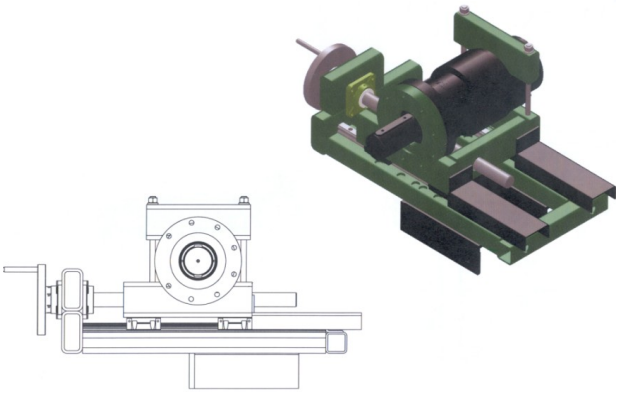

Fig. 4. Suport the trolley and actuator

After the support has been initially positioned, it is necessary to precisely adjust the distances by means of a knob equipped with a scale (Fig. 5). The knob enables forward movement of the carriage, as well as its withdrawal. One full turn of the knob shifts the support by 7 mm – one division on the scale means a 1-mm shift.

Fig. 5. Measuring arm with a knife

When the mechanical elements have been assembled, the hydraulic system is connected and the supply from the water-oil main in the mine is connected to sockets and the control unit (the device can also be supplied from a pump).

The system is equipped with a pressure regulator, the aim of which is to prevent the pressure value from exceeding the admissible level (21 MPa for the device), which may occur in the mine's main. The current value of pressure can be checked by means of a manometer attached to the device.

After measurements have been taken, the recorded results are further processed by means of a special software, which is an integral part of the device.

After assembling the whole instrument, a place for taking measurements should be prepared. In order to do that, a vertical longitudinal cavity should be made in the coal bed in which the measurement cutting knife will work. A cavity is made by mounting a levelling knife on the arm and performing a few cycles of work. After each pass of the knife, it should be withdrawn to the upper position and next the whole carriage should be shifted away from the coal bed by 1–2 cm by means of the knob. After preparing the cavity, it is necessary to mount the cutting knife and start up the measurement system. The next step is to switch on the device and perform a cutting procedure. The forces acting on the knife will be recorded. After each cutting cycle performed with the measurement knife, the cavity should be levelled by means of a levelling knife.

Coal resistance to cutting can be measured in coal beds having a thickness of 0.75 to 6.0 m. The POU-BW/01-WAP instrument enables a maximum of 15 measurement cuts to be made with one mounting of the device at one height, without a necessity to shift the hydraulic props, which guarantees high accuracy of measurements. The measurement data coordinates are recorded by recording devices within an accuracy of 1mm. Due to a small number of elements, the device is easy to assemble, simple to use and cheap to maintain.

As the device is equipped with force sensors and a pressure sensor, it is possible to determine the cutting forces from two independent measurement forces, which allows verifying the obtained results of measurements – the cutting force and the knife feed force. Moreover, owing to the pressure sensor, it is possible to determine an instantaneous cutting force of coal rock (the rock surrounding a coal bed).

Conclusions

One of important areas of mines' activity is the proper use of machines, which among others should involve proper control over a rational and effective use of machines in the exploitation process [10]. The improvement of machines operation contributes to a reduction of failures and allows better organisation of maintenance department work, increasing the participation of planned activities, such as: maintenance works, periodical inspections and current repairs [14]. Finally, it influences the quality of maintenance teams work and their better co-operation with mining departments employees.

The previously conducted research and analyses indicate that the value of this index has a considerable impact on the power, efficiency, as well as durability and reliability of mining machines' work. It can also be concluded that this parameter exerts a decisive influence on energy consumption, installed power and dimensions of a mining machine, and, in consequence, affects the costs of purchase and maintenance. High powers installed on mining machines contribute to their larger dimensions and increase climatic hazards, cause disorders in air flow, methane risk or, finally, a necessity to make headings with larger cross-sections.

The efficiency of a longwall working depends directly on properly selected machines and equipment of the longwall system. A properly selected longwall system must take into consideration the geological and mining conditions of the mined longwall.

For this reason, coal workability measurement will allow an optimal selection of mining machines' exploitation parameters and can become one of decisive factors for evaluating the possibility of effective exploitation of a particular plot or a coal bed. This problem concerns coal mining by means of both a plow or a cutter-loader.

The results of measurements can be used to determine the grade of coal and, in consequence, the projected power of a longwall drum cutter-loader working in particular geological and mining conditions.

The devices, which were developed in Poland over the last two years, were noticed and awarded for their innovative solutions.

During the International Exhibition of Innovation, held annually in November in Brussels, they won the following prizes:

- GIG device in 2011 – GOLD MEDAL;
- POU-BW/01-WAP device in 2012 – SILVER MEDAL, whereas in February 2013, during XX Exhibition of Inventions in Warsaw, it received a DIPLOMA granted by the Minister of Science and Higher Education.

The devices presented in this article have been based on hi-tech solutions in terms of construction, as well as measurements and the recording of measured values.

They have an ATEX **I M2 Ex ib I Mb** certificate, allowing their work in real conditions (mining plants) as a device intended for use in potentially explosive atmospheres – in accordance with Directive 94/9/EC.


DIPLOMA

BRUSSELS Eureka!

THE BELGIAN AND INTERNATIONAL TRADE FAIR FOR TECHNOLOGICAL INNOVATION

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Witold Bialy, Jaroslaw Brodny, Wladyslaw Konopko, Zbigniew Lubosik, Marek Plonka, Stanislaw Prusek, Sylwester Rajwa, Wlodzimierz Sikora, Marian Turek, Andrzej Walentek, Aleksander Wrana

for the innovation

Instrument for determination of machinability of coal and rock

Gold medal

THE PRESIDENT OF THE INTERNATIONAL JURY

THE PRESIDENT

Brussels, 19th November 2011


DIPLOMA

BRUSSELS Eureka!

THE BELGIAN AND INTERNATIONAL TRADE FAIR FOR TECHNOLOGICAL INNOVATION

TO

Politechnika Slaska, Wydzial Organizacji i Zarzadzania; Instytut Inzynierii Produkcji

Witold Bialy, Marek Marczak

for the innovation

Instrument determining workability of coal or rock enclosing the coal deposit – POU-BW/01-WAP.

Silver medal

THE PRESIDENT OF THE INTERNATIONAL JURY

THE PRESIDENT

Brussels, 17th November 2012


MINISTER
NAUKI I SZKOLNICTWA WYŻSZEGO

DYPLOM

dla

Instytutu Inżynierii Produkcji Wydziału Organizacji i Zarządzania Politechniki Śląskiej

za projekt pod nazwą

Przyrząd określający urabialność węgla lub skał otaczających złoże węglowe – POU-BW/01-WAP

Twórcy:

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References

1. SKOTNICKA-ZASADZIEŃ B., BIAŁY W.: An analysis of possibilities to use a Pareto chart for evaluating mining machines' failure frequency. Eksploatacja i Niezawodność, Maintenance and Reliability, 3, 2011, 51–55.
2. GAWLIK J., KIEŁBUS A., MOTYKA S.: Poradnik dla Beneficjentów Ostatecznych. Opracowanie wieloparametrowego systemu monitoringu i oceny efektywności wdrażania Regionalnej Strategii Innowacji Województwa Małopolskiego i innowacyjnych projektów, będących jej składowymi. Sekcja Poligrafii Politechniki Krakowskiej, Kraków 2007.
3. LOSKA A.: Remarks about modelling of maintenance processes with the use of scenario techniques. Eksploatacja i Niezawodność. Maintenance and Reliability 2(14), 2012, 92–98.
4. MARUSZEWSKA E.: Implementation of Enterprise Resource Planning system and change in accountant's role – Polish perspective. Management Systems in Production Engineering 2(6), 2012, 3–7.
5. BIAŁY W.: Wybrane metody badania urabialności węgla. Eksploatacja i Niezawodność, Maintenance and Reliability 5, 2001, 36–40.
6. MYSZKOWSKI M., PASCHEDAG U.: Longwall mining in seams of medium thickness – comparison between shearer and plow. 21st Word Mining Congress. Kraków 2008.

7. BIAŁY W.: Empiryczne prognozowanie mocy ścianowych kombajnów bębnowych. Zeszyty Naukowe Politechniki Śląskiej, seria Górnictwo, z. 262. Wydawnictwo Politechniki Śląskiej, Gliwice 2005.
8. BIAŁY W.: Volba dobývacích kombajnů na základě výzkumů rozpojitelnosti uhlí. VŠB-Technická univerzita Ostrava, Fakulta strojní Ostrava 2009.
9. ESKIKAYA S., BILGIN N., OZDEMIR L.: Development of rapid excavation technologies for the Turkish mining and tunneling industries. NATO TU Excavation SfS Program project report. Mining Engineering Departament. Istanbul Technical University 2000.
10. PETER F.: Rethinking Pareto analysis maintenance applications of logarithmic scatterplots. Journal of Quality i Maintenance Engineering, 4(7), 2001, 252–263.
11. PRUSEK S., RAJWA S., WRANA A., WALENTEK A.: Ocena skrawalności pokładów węgla i skał otaczających w warunkach dołowych z wykorzystaniem przyrządu opracowanego w GIG. Nowe spojrzenie na technikę i technologię eksploatacji cienkich pokładów węgla kamiennego, 24–26.11.2011, LW Bogdanka SA, 123–131.
12. Dokumentacja Techniczno-Ruchowa Przyrządu POU-BW/01-WAP. Gliwice 2012.
13. PRUSEK S., RAJWA S., WRANA A., WALENTEK A.: Wykorzystanie nowoczesnych technik pomiarowych do oceny parametru skrawalności węgla i skał w warunkach in situ. Prace Naukowe GIG „Górnictwo i Środowisko" Kwartalnik nr 1/1/2011, 302–307. Główny Instytut Górnictwa, Katowice 2011.
14. MIDOR K., SZCZĘŚNIAK B., ZASADZIEŃ M.: The methods of studying the satisfaction of production department with traffic maintanence department's work – the ouline of research method. Scientific Journals Maritime University of Szczecin 24(96), 2010, 53–58.