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THE SELECTION OF OPTIMAL METHOD DETERMINING MECHANICAL PROPERTIES OF COAL LAYERS

WYBÓR OPTYMALNEJ METODY BADANIA WŁAŚCIWOŚCI MECHANICZNYCH POKŁADÓW WĘGLA

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Abstract:
The article presents selected methods and ways of mining resistance as well as mineability index determination with the use of different instruments. The principles of their operation and the way of mining resistance measurement as well as their usefulness in planning of cutting mining machines selection (longwall tumble heading machines) in given mining-geological conditions are discussed. Their advantages and disadvantages are presented and a method presenting actual mode of longwall tumble heading machines' action is proposed. The results obtained with the use of this method should be taken as representative in the selection of cutting mining machines.

Key words: *coal properties, analysis, the optimal method*

Słowa kluczowe: *właściwości węgla, analiza, metoda optymalna*

INTRODUCTION

Coal mining - still a strategic branch of industry in Poland (especially in the Upper Silesia) is characterized by complex and specific problems in application and use of technical equipment. These problems already occur during design, construction and production of machines used in coal layers' mining and cumulate during the use of these installations.

One of the most important technical tasks in coal mining, not only in Poland, is a proper selection of machines (device) that will consider specific (uncomparable to other branches of industry) exploitation conditions. This problem especially regards proper selection of mining machines and their operating conditions. The most representative for this group of machines is a longwall cutting tumble heading machine. The problem of proper matching of the heading machine to specific longwall regarding the peculiarity of the process is extremely important considering the increasing concentration of the mining.

The most important factors significantly influencing the decision taking in this matter are:

– mining-geological conditions of the excavated seam,
– coal mining method,
– unmined coal properties.

One of the most important factors determining the possibility of application of specific mining machine in given mining conditions and reaching formerly established production results at minimal costs (economic results) is mineability of the coal i.e. longwall's properties [1].

In order to estimate proper operation of the mining machines and accordance of the mining process different factors are used which more or less characterize the machine's utility.

The energy consumption, as a ratio between the force (work) necessary to the loosening (i.e. mining) of the coal from the rock mass and the volume of the mined coal, is one of the basic factors characterizing the proper application of a specific device to given operating conditions [2, 3, 8, 9]. Proper machine assortment to specific conditions is based upon the estimation of energy consumption of the tumble heading machine in the real digging process and function of rock mass properties (mineability).

AN OVERVIEW AND ANALYSIS OF THE WORLD MOST IMPORTANT METHODS OF MINEABILITY TESTING

The estimation of rock mass properties that will determine the coal's mineability with cutting tumble heading machines requires the introduction of the experimental methods that will determine both the whole sum of the mined material (coal) resistance during loosening of its parts from the rock mass and coal's mineability. In the mining process destruction of the seam's coherence occurs resulting in the change in volume and shape of the mined coal. Coal mining and breaking-up process is related to dynamic force action therefore the way of mineability estimation must relate on the mode of the mining machine's action and should consider the fact that such properties of the coal influence the mineability of the coal in the specific area [1, 3, 7, 10]:

– sort of the coal material (type of coal),
– stress state in the working area of the mining device,
– variability of the cutting force value within the thickness range of the seam,

- occurrence and situation of decreased coherence layers,
- interlayers.

Various methods of coal's mineability estimation, determined and interpreted miscellaneously, are used in the mining industry worldwide to improve mining mechanization. These factors (there are plenty of them) [1, 5] present mechanical properties of the mined seam miscellaneously could be, according to the author, divided into following groups:

1. laboratory methods of coal mineability estimation,
2. seam drilling parameters registration,
3. brittleness measurement,
4. knife's or group of knives' cutting force measurement,

This article analyses methods of the widest use in selection and placement of longwall cutting mining machines.

The first group contains:

- mineability index „f" estimation method. Protodiakonov's coal specimens' stamping (BN-77/8704-12). The estimation rule is based on stamping of a given quantity of coal, coal interlayers or adjacent rocks in given conditions which is followed by estimation of obtained, smaller than 0.5 mm, coal bricks' volume. This way the mineability index f is calculated.
- mineability index „U" energetic estimation method,
- compression resistance of coal Rc (BN-75/8704-07). Laboratory method of estimation of single axial (one way) compression resistance is based upon cylinder- or cubicoid-shaped specimen's loading with increasing force until the moment of resistant destruction. The, so called, specimen's slenderness as well as friction between the specimen and pressure-inducing planes have vital influence on test result. It is suggested that during experiments with coal specimens of irregular shape a sheet of paper between the specimen and pressure-inducing planes should be inserted in order to determine the real area of contact and to take this area into account when compression resistance would be estimated. The resistance calculated this way is usually twice larger than resistance calculated on regular shape specimens.

The SDM device assisted, mostly used in Russia, belongs to second group of methods. In this method the mineability index is estimated based upon the output torque value during hole drilling in the longwall heading. Due to differences in character and direction of measuring cuts made with SDM device and cutting mining machines the results obtained with this method do not allow to estimate the mineability resistance of tumble heading machines.

One of the most popular methods of coal mineability, and indirectly the mineability index estimation is the one elaborated in Mitsui Miike Machinery Co., Ltd [5]. Coal specimens for analyses are taken from measurement points of the longwall head. In every measurement point two coal specimens are taken from the same stratigraphic intersection. Next, the specimens are crushed and placed in a special box over the steel board where, after sudden opening of the bottom of the box, they fall down on the steel plate disintegrating. Based upon partition of grain classes determined percentage of given classes and relation index are estimated. Grindability marked as FD is calculated as difference between summarized percentage and the sum of percentage product of given classes and relation indexes. This method represents the unmined coal properties but there is no exact correlation between the cutting mining machines' mode of action and the mineability. This method does not take such factors into account as: stress state in the working area of the mining machine, variability in the cutting force value within the range of the seam's thickness, occurrence and situation of decreased coherence planes and interlayers.

Measurement of cutting knife's force (or group's of knives – fourth group) is performed with the use of special device:

- PKS, DKS, Lubimov's (Russia) [1, 5]. All presented instruments are characterized by complexity of their construction; labor consuming measurements performance and need of special niche or hole preparation. Mining resistance measurements can only be performed parallel to the floor level, which does not represent the tumble heading machine mode of action.
- DMT developed in Deutsche Montan Technologie in Essen (Germany) [5], a device used mainly for wedgehead localization. The idea of the measurement is based on the model cutting knife's, placed on wedgehead's toolhead, force registration during 2 cm cut performance. Therefore this method should not be applied in tumble heading machines' localization due to their different mode of action.
- IN-SEAM TESTER (USA) [5] operates based upon extensometric measurements of forces pressing the cutting knife. The measurements performed with this instrument are labor consuming but the results quite exactly represent the mined rock mass properties.
- CERCHAR (France) [5]. One of the stages of the method developed in Cerchar Center in cooperation with Mining School in Paris is a single knife cutting force measurement in laboratory conditions. Cutting force measurements were performed on mining heads' models reduced with factor 1:6, then 1:1, followed by actual objects in Lorraine Coal Basin mines. Measurement of components of the forces bearing on the mined rock was performed as follows: tangent component called cutting force Fs and normal Fd called pressure force. Based upon these measurements the cutting force was calculated which characterizes the coal's mineability.
- ZP-1 (Czech) [1]. This method is based on the measurement of tentative knife's cutting force in a given excavation place followed by coal's mineability estimation with mineability factor B. ZP-1's mode of action represents the coal plough's therefore the obtained results are useful only in wedgeheads' situation. The instrument's inability to perform vertical cuts does not allow certificating tumble heading machines with this method.

COMMON MINEABILITY MEASUREMENT METHODS IN POLAND

A common, cutting resistance estimating device in Poland is POS-1 [1, 9] developed in CMG „KOMAG" (fig. 1).

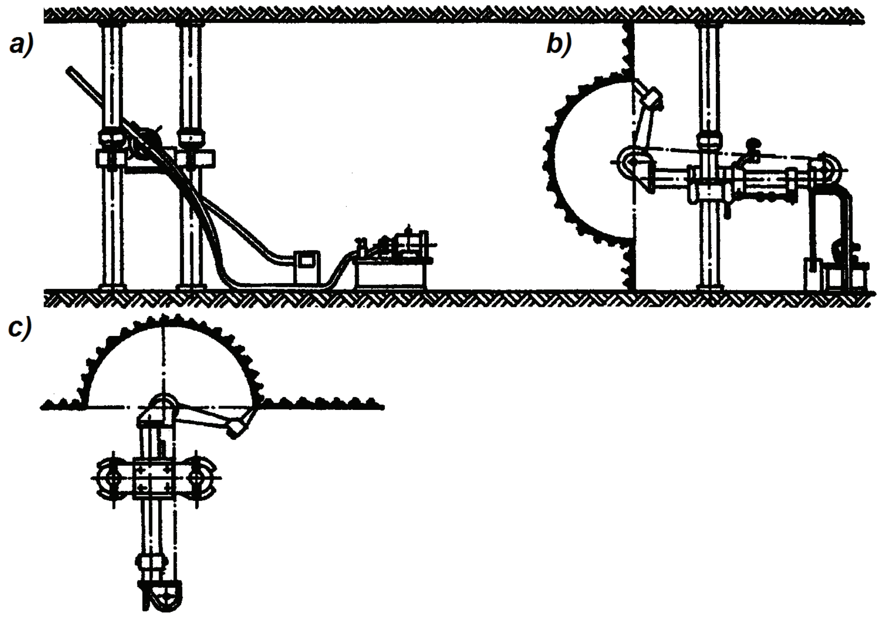

Fig. 1. POS-1 device to mining resistance estimation (mineability index Ay):
a) oblique,
b) normal to the floor (vertical),
c) parallel to the floor (horizontal)
Rys. 1. Przyrząd POS-1 do wyznaczania wskaźnika urabialności Ay (oporów urabiania):
a) skośnie,
b) w płaszczyźnie prostopadłej do spągu,
c) w płaszczyźnie równoległej do spągu

Mineability index estimated with this device as a proportion of a mean cutting force and thickness (deepness) of the cut is marked A. Considering the actual shape of a measuring cut (as well as the side-crumble angle Ψ) this index is marked A_Ψ [4] – and its value as follows:

$$A_\psi = \frac{P_{śr}}{g\left(1+\frac{g}{b}tg\psi\right)}\left[\frac{kN}{cm}\right] \quad (1)$$

A_Ψ value estimated with this device leads to coal classification based on the mineability hardness. The mining technique of this device represents the knives' of the tumble heading machines mode of action imaging the real tools' installed on the ripping heads work where the main mining direction and turn are the same. More, POS-1 makes measuring cuts taking both in laboratory and real conditions possible. This gives way to the measurements in any direction and turn; the possibility of making thick cuts as well as with blade of geometry identical or similar to the knives installed on the ripping heads (radial, tangent, tangent-rotatory) and considers all the possible components of the stress state.

The other, also quite popular way of coal mineability statement in Poland is the estimation of uniaxial (unidirectional) compression resistance. The analysis of various Rc estimation methods (ad. 2) has proven that results differ depending on the shape of the tested specimen (regular or any given).

In experiments performed in CMG „KOMAG" [6] an ultrasound way of Rc value estimation instead of traditional mode was proposed. The measurements were performed on the test bed (fig. 2) according to Laboratory Rule NZ-OBRTG-21.

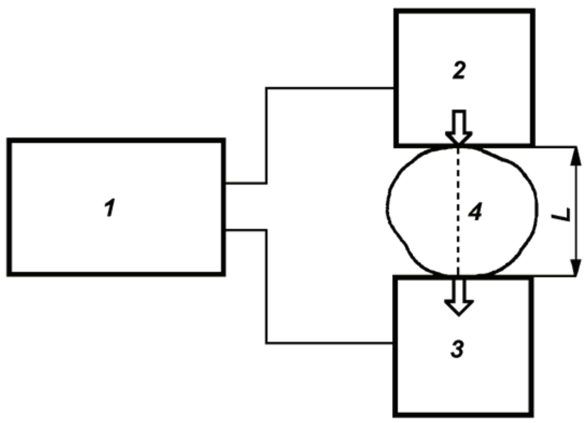

Fig. 2. Scheme of the test stand for ultrasound wave passage through rock specimens velocity measurements
Rys. 2 Schemat ideowy stanowiska do pomiarów prędkości przechodzenia fali ultradźwiękowej przez węgiel

Sensor 1 recording the wave transition time is connected to a pair of ultrasound heads: sending 2 and receiving 3 by concentric cables. The sending head emits ultrasound wave with a frequency 0.04 MHz, which passes through the tested specimen and is collected by receiving head. The passage time through a given specimen tp [4] is measured with adequacy to 0.1 s, while the passage path L is measured with adequacy to 0.1 mm in a direction normal to coal lamination. Velocity VL is calculated from the following relationship [5, 6]

Compression resistance is determined assuming that:
where:

ρ – specimen's apparent density kg/m^3,
V_L – longitudinal wave velocity m/s,
V_T – transverse wave velocity m/s.

Considering that acoustic module H has been defined as a product

$$V_L = \frac{L}{t_p}\left[\frac{m}{s}\right] \quad (2)$$

with assumption that, longitudinal and transverse wave

$$R_c = f(\rho, V_L, V_T) \quad (3)$$

velocity ratio is almost constant (varying inconsiderably), the acoustic module as well as uniaxial compression resistance Rc may be, according to [5, 6] defined as:
where:

M – deposit constant MPa^2,
N – deposit constant MPa.

$$H = \rho \times V_L \times V_T\ [MPa] \quad (4)$$

CRITERIA OF OPTIMAL METHOD SELECTION

In order to estimate coal bed properties in the mining process with mechanized tumble heading machines following variables have to be previously estimated:

$$R_c = \frac{M}{N - H}\ [MPa] \quad (5)$$

- mineability index,
- side-crumble angle,
- cutting force unevenness index,
- knife's geometry and shape influence,
- stress and deformation state in the mining machine's working area.

The method of rock mass mining resistance estimation characterized by mineability index should consider coal bed properties (described in Paragraph 2), as well as allow to:

- present the actual character of mining machine's operation,
- perform thick cuts,
- perform cuts in all possible stress and deformation states,
- perform measuring cuts in any mining direction and turn,
- perform cuts with real knife or with similar geometry in order to neglect the knife's geometry influence on the results,
- perform measuring cuts in laboratory conditions as well as "in situ".

Properly estimated mineability index with acquisition of optimal calculation method should allow to:

- estimate the energy consumption of the mining process (and simultaneously prognosticate the mining machines' power),
- machine certification.

SELECTION OF OPTIMAL METHOD

Two of described mineability resistance estimation methods presenting the mechanical properties of mined seam satisfy the criteria stated in Paragraph 4, i.e. the method developed in CMG „KOMAG" and CERCHAR method.

Coal mineability index A_ψ estimation method [4] (considering the real shape of the measuring cut groove intersection) with the use of POS-1 device is widely described in various publications [1, 5]. Despite several faults (labour-consuming measurement taking, special specimen preparation, equaling cuts' performance) it is a reliable method because based upon mining resistance measurements followed by mineability index A_ψ and side-crumble angle ψ estimation with the use of POS-1 device the cutting machines in given walls are properly placed and very good production results are obtained. This refers both to the longwall mined with wedgehead as well as tumble heading machine reaching high day output (in case of the heading machine mean day output exceeded 7000 tons).

Then, the CERCHAR method can be useful in energy consumption of the digging process estimation especially during mining machines' design to given mining-geological conditions after several describing and estimating coal deposition conditions factors' consideration. The main advantage of this method are the simplifications and facility of calculations as well as the fact that basic necessary parameters are determined during estimation of coal longwall mechanical properties values (cutting force F, side-crumble angle ψ and uniaxial compression resistance R_c).

The fast and exact method of Rc value determination is acoustic module method [6] which is determined by ultrasound wave passage through the specimen velocity measurement, developed and used in CMG „KOMAG". During acoustic module determination for a given kind of rock compression resistance Rc can be also estimated as a relation H = f(R_c) as a linear dependence [6] (fig. 3).

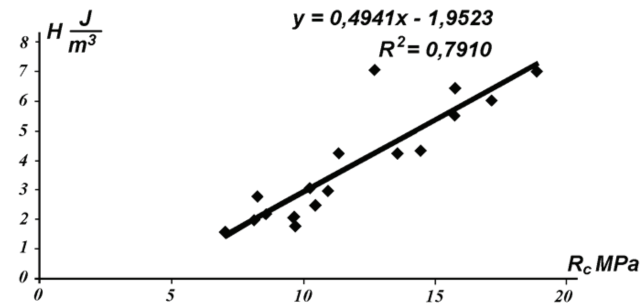

Fig. 3. Regression function H=f(Rc)
Rys. 3 Liniowa funkcja regresji H = f(R_c)

SUMMARY

Factors characterizing the machines' functionality were taken to determine their usefulness and to estimate the rock mass mining process.

The basic factor describing the mining power demand in given mining-geological conditions is energy consumption, defined as relationship between the force (work) necessary for coal loosening and its volume.

Energy consumption may be determined in actual tumble heading machines operating conditions or upon theoretical calculations. Energy consumption determined in actual conditions considers all complex operating conditions and can be determined via measurements only. The so-called theoretical energy consumption is calculated from given factors characterizing the mined coal's properties. If the factors, which lead to theoretical energy consumption calculation, characterize the mined coal's properties and the mining machine's mode of action in the most actual way the more exact prognosis of power demand necessary for effective mining (in given mining-geological conditions) can be made.

So far the experimental results obtained in IMG of Silesian Technical University, CMG „KOMAG" and worldwide, have proven the sense of energy consumption of the dig-

ging process estimation as a basic factor of proper selection of the tumble heading machine in given mining-geological conditions (leading to high productivity). In order to obtain maximum information about machine-longwall system and energy consumption of the digging process, it is necessary to estimate the power consumption with simultaneous certain parameters value, giving us the univocal mechanical characteristics of the rock mass (mining resistance characterized by mineability index A_ψ, side-crumble angle ψ and uniaxial compression resistance R_c).

The estimation of energy consumption of the longwall tumble heading machine digging process in actual conditions and correlation with mechanical properties of the mined wall (characterized by mineability index A_ψ, side-crumble angle ψ and compression resistance R_c) will allow the proper selection of the machines to given mining-geological conditions and then may be useful in prognostics of certain machine elements and the machine's itself durability leading to optimal economic effect.

Based upon the analysis the CERCHAR method with parameters describing the mechanical properties of the rock mass may be also useful in Poland. Parameters necessary to apply this method in Poland are estimated: cutting force value P and side crumble angle y are estimated with the POS-1 device while the compression resistance R_c is estimated with the indirect method from the function $H = f(R_c)$ (fig. 3).

Initial comparisons of heading machine power in real measurements and theoretical calculations with CERCHAR method varied significantly. The reason for his difference may be the coal compression resistance value Rc which was not determined experimentally but from Protodiakonov's index.

Therefore, in order to determine the energy consumption of the digging process with CERCHAR method the parameters influencing the final results need to be estimated precisely.

Uniaxial compression resistance Rc estimated with indirect method with the use of ultrasound wave velocity measurement as a function of acoustic module is an exact method with representative results. The mineability index A_ψ estimated with this indirect method as a function $A_\psi = f(R_c)$ does not take into account all the factors which significantly influence its value (ad. 2). More, the index estimated with this method does not take into account the real intersection of measuring cut groove therefore we obtain increased values of A_ψ index.

CONCLUSIONS

1. Based upon the analysis of known and used methods of mining resistance estimation A index seems to be the most relevant. It presents both the way and properties of mined coal mass. It also characterizes the actual mode of longwall tumble heading machines action. Production effects prove the adequacy of the results obtained with this method in given mining-geological conditions based on parameters estimated with POS-1 device.

2. Uniaxial coal compression resistance R_c estimated with indirect method using the acoustic module H (a symptom of R_c) exactly presents this function. This method allows to estimate the Rc value on irregular specimens, which is a great advantage in comparison to laboratory methods which are characterized by expensive and labor-consuming preparation especially of regular specimens.

3. CERCHAR method application to estimate the necessary power of the longwall tumble heading machine is possible in Polish conditions (all the parameters necessary to apply this method are estimated in Poland).

REFERENCES

[1] Biały W.: Analiza metod badania urabialności węgla. Przegląd Górniczy. Nr 4,2002.
[2] Biały W.: Wpływ usytuowania płaszczyzn osłabionej spójności na warunki skrawania oraz energochłonność procesu urabiania. I Międzynarodowa Konferencja „TECHNIKI URABIANIA 2001". Kraków-Krynica 2001.
[3] Biały W.: Estimation of the value of energy consumption in the digging process based upon the measurements of cutting power of a single knife. Międzynarodowa Konferencja "DIAGO 2001". Ostrava 2001.
[4] Biały W.: Wskaźnik urabialności węgla (skał) w funkcji składowej pionowej stanu naprężenia sz przy uwzględnieniu kierunku i zwrotu urabiania. VIII Konferencja Naukowo-Techniczna „Górnictwo surowców skalnych w gospodarce u progu XXI wieku". Górnictwo Odkrywkowe z. 5, 2001.
[5] Biały W.: Volba dobývacích kombajnů na základě výzkumů rozpojitelnosti uhlí.VŠB-Technická univerzita Ostrava Fakulta strojní. Ostrava 2009.
[6] Chrzan T.: Moduł akustyczny – względny wskaźnik energochłonności procesu niszczenia spoistości ośrodka skalnego. Górnictwo i Geologia. Wrocław 1992.
[7] Jonak J.: Urabianie skał głowicami wielonarzędziowymi. Wydawnictwo „Śląsk". Katowice 2001.
[8] Krauze K.: Teoria procesu roboczego frezujących organów ślimakowych w skałach średniozwięzłych. Monografie i Rozprawy nr 36, Wydawnictwa AGH, Kraków 1995.
[9] Krauze K.: Urabianie skał kombajnami ścianowymi. „Śląsk" sp. z o.o. Wydawnictwo Naukowe. Katowice 2000.
[10] Sikora W., Skoczyński W.: Wpływ wzmożonych ciśnień górotworu na urabialność węgli. Zeszyty Naukowe Politechniki Śląskiej Górnictwo z.145, 1988.

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