

doi:10.2478/mape-2021-0025

Date of submission to the Editor: 05/2021  
Date of acceptance by the Editor: 07/2021

MAPE 2021, volume 4, issue 1, pp. 281-289

**Witold Biały**

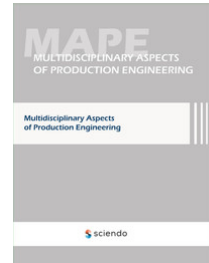
ORCID ID: 0000-0003-2313-0230  
Silesian University of Technology, **Poland**

**Jiri Fries**

ORCID ID: 0000-0001-9776-6878  
VSB-Technical University of Ostrava, **Czech Republic**

**Greg Galecki**

Missouri University of Science and Technology, **USA**



## INTRODUCTION

The POU-BW/01-WAP device offers a possibility to measure the cutting forces applied to knives during the mining process. The resistance extensometry method ensures that the cutting forces can be measured with sufficient accuracy as it enables accurate strain measurement. In practice it consists of measuring elongations on the body surface under the influence of known external forces. The measurement principle consists of determining a measuring segment of original length  $L$ , called the measuring base, measured in the desired direction, and then measuring the increase in its length  $\frac{\lambda}{L}$  under the influence of external forces. For a uniform deformation state, the quotient determines the specific elongation

$$\varepsilon = \frac{\lambda}{L} \tag{1}$$

Knowing the elastic constant of material under test and the result of measurement of specific elongation, it is possible, using Hooke's law, to calculate the values of stress occurring in the material, and through it other mechanical quantities, such as force, bending moment, pressure, etc.

If the tests are to be carried out under normal operating conditions, it is best to use the resistance strain method, which uses strain gauges classified as electrical strain gauges. This method provides the possibility of making multi-point measurements with remote recording of results, or with their direct transfer to a recording device (memory, computer). Such a measuring system has a very low inertia, which allows measurements of quickly changing quantities.

The electrical strain gauge method is based on the property of a metal wire to change its electrical resistance due to changes in its cross-section and length, induced by deformation, as a result of external force.

Resistance strain gauges take the form of a series of wires properly adhered to a substrate and attached to the test surface with a special adhesive. Currently, foil resistance strain gauges are commonly used, where the resistance grid is made of thin metal foil between two layers of plastic foil. Electrical wires are connected to the ends of strain gauge leads, connecting the strain gauge to the measuring system. The measuring system consists of a power source, a strain gauge bridge with measuring and compensation strain gauge (its task is to compensate the influence of side factors, mainly temperature), measuring amplifier, increasing the signal to a value suitable for the recording device. The measuring strain gauge is one of the branches of the bridge, in the other branches of which there are reference elements (resistances). The state when no current flows in the diagonal branch of the bridge is called the equilibrium state, and the relationships between the parameters of individual branches in equilibrium are called the equilibrium conditions.

Measurement bridges are divided into balanced and unbalanced. In the case of a balanced bridge, the measurement consists in bringing the bridge to equilibrium state by changing the values of reference elements and calculating – from the equilibrium conditions – the parameters of tested element. For an unbalanced bridge being previously in equilibrium, the voltage (in the diagonal branch of the bridge) is measured, which arises as a result of changes in resistance of strain gauge attached to the tested element, which is also one of the branches of that bridge.

The main problem in conducting measurements using the resistance extensometry method is to find a place for attaching strain gauges on the tested element in such a way that the interpretation of obtained measurement results is easy and unambiguous.

### **FORCES IN THE CUTTING PROCESS**

The mining process that takes place under natural conditions using a specific technology is a complex process (Biały 2002, 2011, 2013, 1013a, 2014, 2015, Krauze & Kotwica, 2007, Myszkowski & Paschedag, 2008, Krauze et al. 2015, Bołoz 2018). Most often this process differs significantly from the adopted model. Due to the fact that tangential-rotary knives are most commonly used in modern longwall drum shearers (Fig. 1), the most serious problem was to design the measuring element of the device in such a way that the measurement is possible at all (Biały 2013b, 2014a). Strain gauges should be arranged to allow direct measurement of these forces.



**Fig. 1 Tangential-rotary knife used in the head of POU-BW/01-WAP device**

In fact, the tangential-rotary knives have the ability to rotate in their holders, which makes it impossible to attach strain gauges directly to them in such a way as to receive a signal. A solution has been proposed that enables the forces to be measured in a simple way and then, thanks to the known geometrical parameters of the device, allows the load parameters, e.g. in a form of forces (force moments), to be calculated using elementary equations. It is also important to be able to statistically process the results of any number of measurements, each of which is a record of the load course of a given cutter in real time.

During mining, a force acts on the shearer's knife (Fig. 1), which is divided into the following components (Fig. 2) (Biały 2005, 2009):

$F_s$  – cutting force,

$F_d$  – pressure force applied to the mining a body of coal,

$F_b$  – lateral force (thrust).

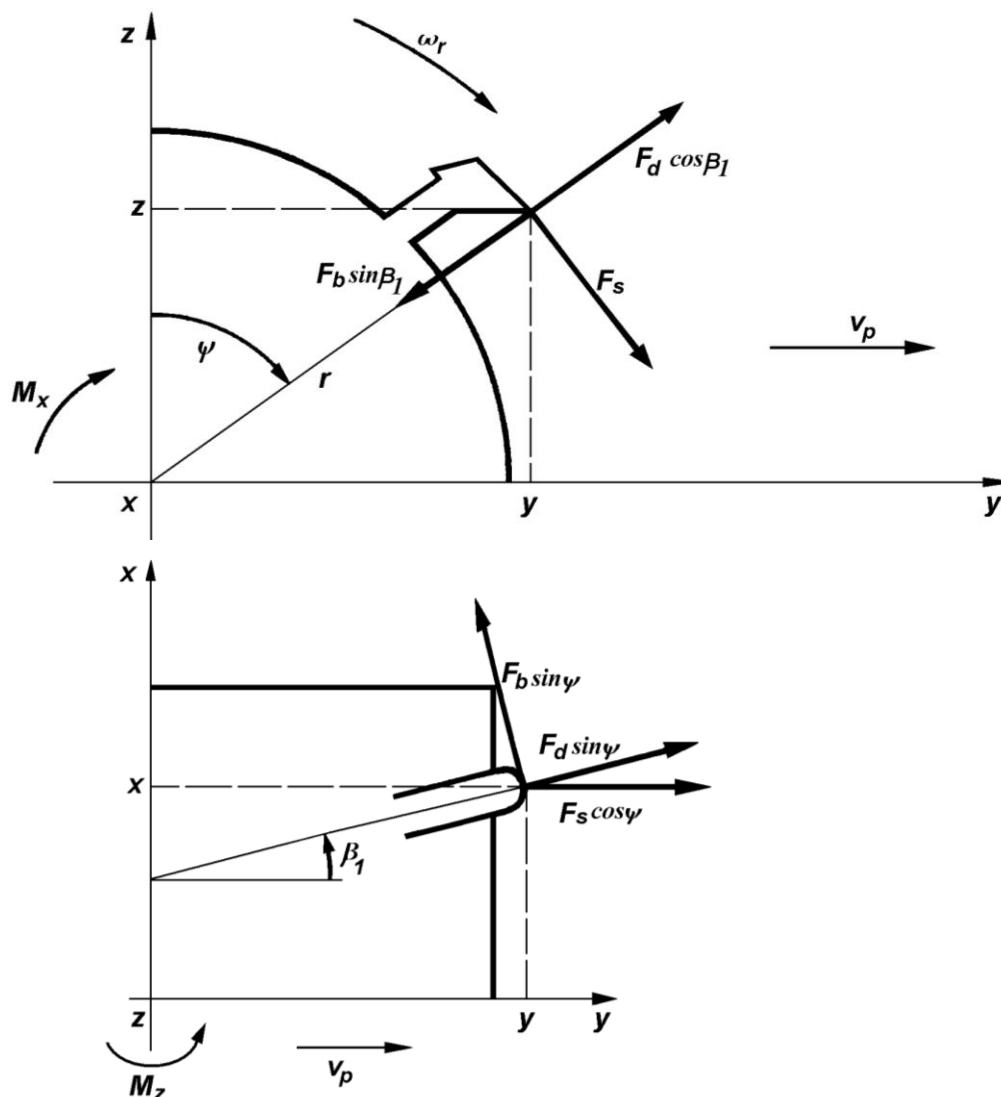


Fig. 2 Force components in the mining process

In the POU-BW/01-WAP device, the measuring head (Fig. 3), has been constructed in such a way that it allows to measure simultaneously two of three forces occurring during the cutting process: cutting force  $F_s$  (Fig. 4) and pressure force applied to the mining a body of coal  $F_d$  (Fig. 5).

The value of cutting force  $F_s$  is measured from the force moment that bends the holder in which the knife is fixed. While the knife pressure force  $F_d$ , is measured by the knife pressure on the body base, also by means of strain gauges.



Fig. 3 Measuring head body with measuring blade



Fig. 4 Sensor for measuring the cutting force  $F_s$

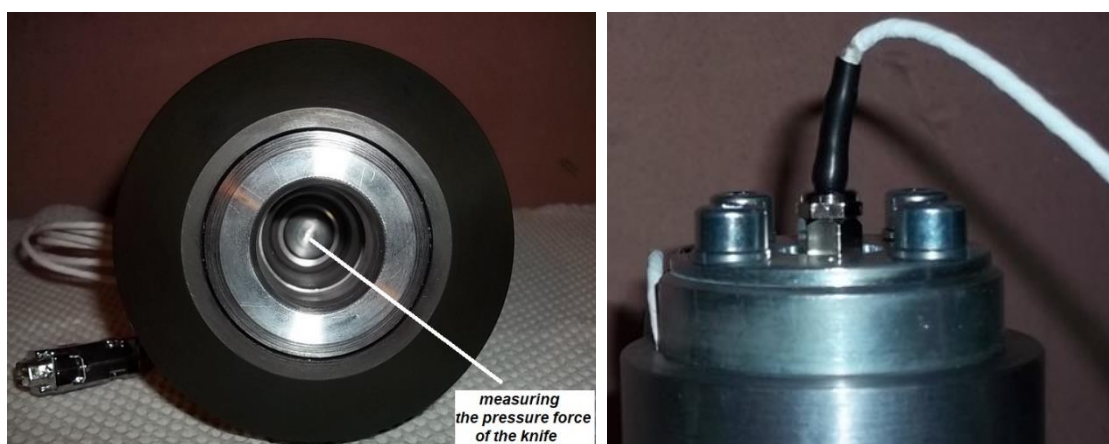


Fig. 5 Knife force sensor applied to the unmined coal  $F_d$

The strain gauges were adhered in such a way that their base was in accordance with the direction of the greatest stresses (Fig. 6, 7), at the same time as the greatest change in the length of measurement element (bending).

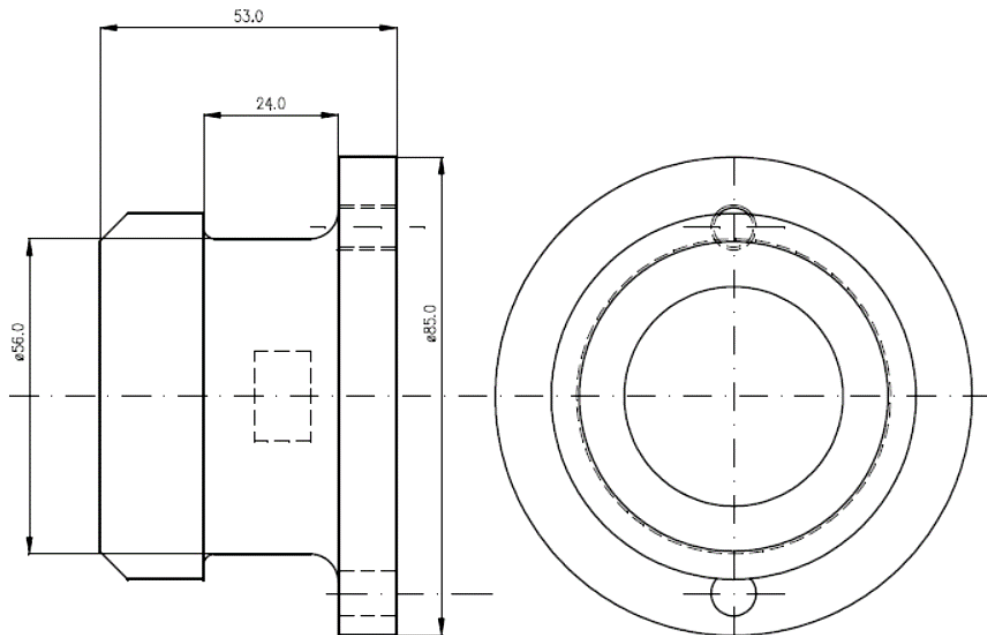


Fig. 6 Place of strain gauges adhesion for measurement of the cutting force  $F_s$

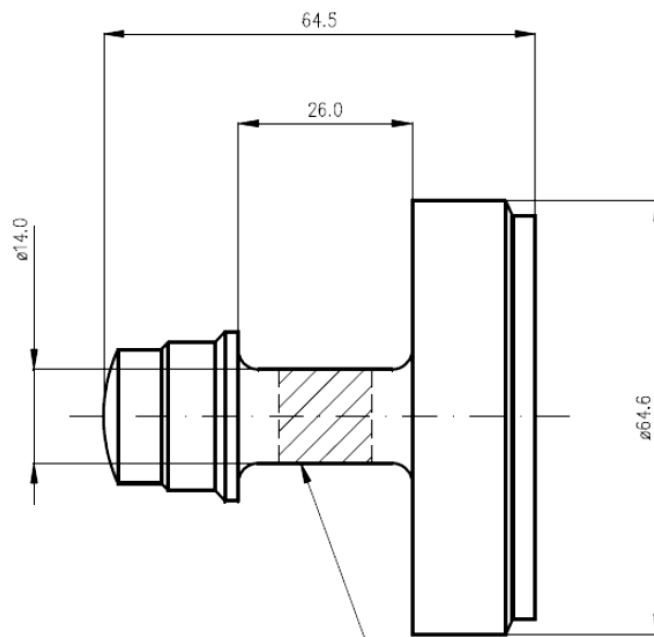


Fig. 7 Place of strain gauges adhesion for measurement of the pressure force  $F_d$

Compensating strain gauges are adhered across from the active ones, i.e. in the direction of minimum stress. This configuration provides the greatest bridge deviation from equilibrium as the stress changes in a measuring element. On the other hand, attaching the compensating strain gauge in the same place as the active one causes that they are at the same temperature and the

temperature-induced changes in their resistance are the same. Whereas in a bridge they interact in the opposite way, i.e. they compensate each other.

Separation of the cutting force component  $F_s$  is obtained using the compensation method, by adding and subtracting the results (in each case) from the bridge located on the bended side (Fig. 6). The knife pressure force  $F_d$  is obtained from the strain gauge bridge located in the lower part of cutting head, where compression occurs (Fig. 7).

The cutting head of POU-BW-01-WAP device was calibrated for known loads on the test stand. Therefore, it is assured that the results obtained are reliable. Moreover, since the device is equipped with force and pressure sensors, it is possible to determine the cutting forces from two independent measurement sources, and thus verify the obtained measurement results – cutting force ( $F_s$ ) and knife pressure force ( $F_d$ ).

The cutting head with strain gauge bridges for measurement and recording of two forces involved in the coal cutting process is shown in Figure 8.

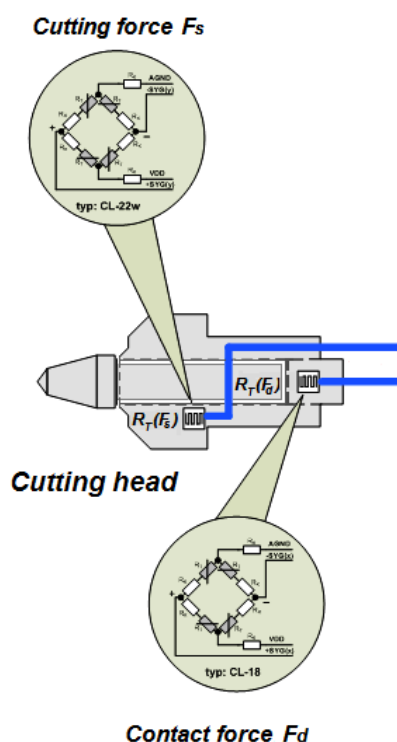


Fig. 8 POU-BW/01-WAP cutting head with strain gauge bridges

The blade used in the cutting head is a tangential-rotary knife. This knife has the ability to rotate freely during the cutting tests.

## ANALYSIS OF AW-PSSW COAL CUTTING FORCE MEASUREMENT RESULTS

The AW-PSSW program (Fig. 9) allows visualization and analysis of collected information from the Coal Cutting Force Measurement system (Documentation,

2012, 2012a). On the monitor screen, there are three values that can be read directly: cutting force  $F_s$ , pressure force  $F_d$  and pressure value.

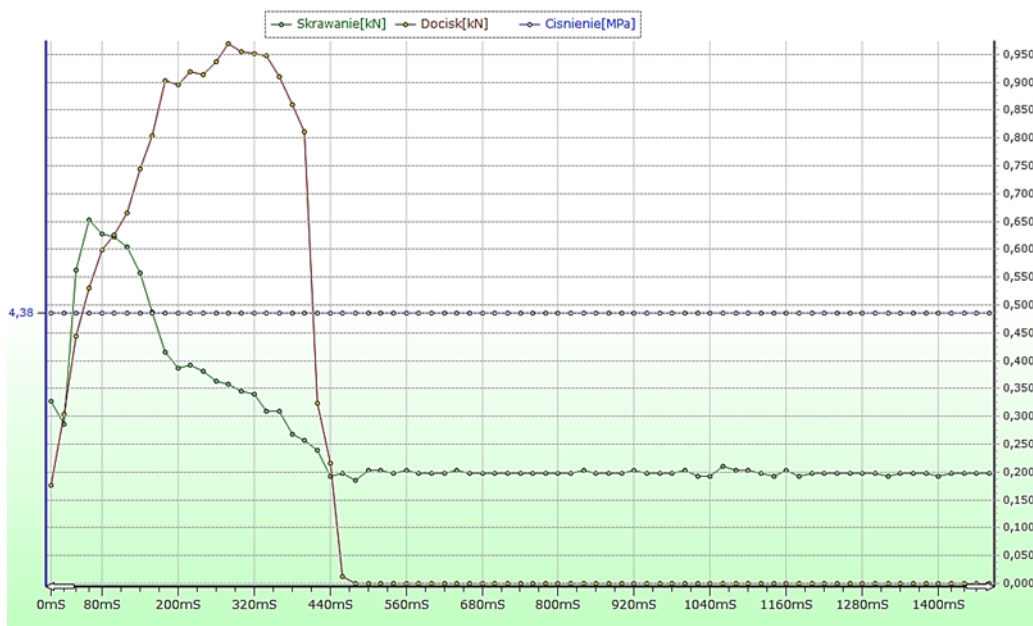


Fig. 9 Graphical layout of the AW-PSSW program

The main program options include:

- browsing of collected files in the form of entries arranged in a table,
- conversion of DAT files to a spreadsheet,
- data visualization in the form of graphs,
- data analysis using histogram and outcome statistics,
- measurement printout,
- measurement export to a text file.

The program requires a PC with Windows XP and Microsoft .NET Framework 3.5 installed for proper operation.

## CONCLUSION

In order to correctly select or predict the shearer loader power in real geological-mining conditions, it is necessary to know the force components involved in this process. For this purpose, the POU-BW/01-WAP device is used, which allows the measurement and recording of two force components involved in this process ( $F_s$  and  $F_d$ ).

It is the only device in the world with which it is possible to determine the two force components involved in the machining process. Determination of force components involved in the cutting process, is possible by using two independent measuring blocks, which is a strain gauge force sensors: cutting ( $F_s$ ) and knife pressure ( $F_d$ ). In order to register these forces, a real mining knife used in longwall shearer drums was applied – i.e. tangential-rotary.

Knowing the force value required for the cutting operation, it is possible to determine two parameters: workability index A, or energy workability index AE.



The workability index A is defined as the ratio of average force ( $F_{sr}$ ) to depth of cut ( $g$ ):

$$A = \frac{F_{sr}}{g} \left[ \frac{kN}{m} \right] \quad (2)$$

While the energy workability index AE is defined as follows:

$$AE = \frac{F_{sr} \cdot l}{Q} \left[ \frac{MJ}{m^3} \right] \quad (3)$$

where:

$F_{sr}$  – average cutting force per cutting length,

$l$  – length of the cutting groove,

$Q$  – volume of mined coal (rock).

This device uses the most modern solutions in terms of construction as well as measurement and recording of measured values. The POU-BW/01-WAP device can be used in real conditions (mining plants) as it has ATEX certificate that allows operation in potentially explosive atmospheres – according to the 94/9/EC directive.

## ACKNOWLEDGMENTS

*The article was written in support of BK-273/ROZ3/2021 (13/030/BK\_21/0065) research under the title "Department of Production Engineering' resources development for carrying out activities in the areas related to the Silesian University of Technology Priority Research Areas".*

## REFERENCES

- Biały W. (2002). The side-crumble angle  $\psi$  of coal and the energy consumption of the mining process as a function of the vertical component  $\sigma_z$  of exploitation pressure. Polska Akademia Nauk, Archiwum Górnictwa tom 47 nr 3. pp. 361-384.
- Biały W. (2005) Empiryczne prognozowanie mocy ścianowych kombajnów bębnowych. Wydawnictwo Politechniki Śląskiej. Seria: Górnictwo z. 262 Gliwice.
- Biały W. (2009) Volba dobývacích kombajnů na základě výzkumů rozpojitelnosti uhlí. VŠB-Technická univerzita Ostrava, Fakulta strojní, Ostrava 2009.
- Biały W. (2011). The selection of optimal method determining mechanical properties of coal layers. Management Systems in Production Engineering no. 2 ISSN 2299-0461. pp. 26-30.
- Biały W. (2013). Innowacyjne narzędzia do wyznaczania właściwości mechanicznych węgla. Przegląd Górniczy nr 6. Katowice. ISSN 0033-26X. pp. 17-26.
- Biały W. (2013a). New devices used in determining and assessing mechanical characteristics of coal. 13<sup>th</sup> SGEM GeoConference on Science and Technologies In Geology, Exploration and Mining, SGEM2013 Conference Proceedings, ISBN 978-954-91818-7-6/ISSN 1314-2704 June 16-22.2013. Vol. 1. pp. 547-554.
- Biały W. (2013b) Sposób pomiaru sił na głowicy urabiającej przyrządu POU-BW/01-WAP. Rozdział 8. Problemy bezpieczeństwa w budowie i eksploatacji maszyn i urządzeń górnictwa podziemnego. Monografia red. Krauze K. Centrum Badań i Dozoru Górnictwa Podziemnego Sp. z o.o. Łędziny 2013.
- Biały W. (2014). Coal cutting force measurment systems – (CCFM). 14<sup>th</sup> SGEM GeoConference on Science and Technologies In Geology, Exploration and Mining, SGEM2014 Conference Proceedings, June 17-26, 2014, Vol. III, BULGARIA ISBN 978-619-7105-09-4/ISSN 1314-2704. pp. 91-98.



- Biały W. (2014a) Zasoby węgla kamiennego. Urabialność pokładów węglowych. Wydawnictwo PA NOVA SA. Gliwice 2014.
- Biały W. (2015). „Innovative solutions applied in tools for determining coal mechanical properties” Management Systems in Production Engineering vol. 4(20). Gliwice. ISSN 2299-0461. pp. 202-209. DOI: 10.12914/MSPE-02-04-2015
- Bołoz Ł. (2018). Model tests of longwall shearer with string feed system, Archives of Mining Sciences, vol. 63 no. 1, pp. 61-74, DOI 10.24425/118885.
- Krauze K., Kotwica K. (2007). Selection and Underground Tests of the Rotary Tangential Cutting Picks used in Cutting Heads of the Longwall and Roadway Miners. Polska Akademia Nauk, Archiwum Górnictwa tom 52 nr 2. pp. 195-217.
- Krauze K., Bołoz Ł., Wydro T. (2015). Parametric factors for the tangential-rotary picks quality assessment, Archives of Mining Sciences, vol. 60, no. 1, DOI: 10.1515/amsc-2015-0018,
- Myszkowski M., Paschedag U. (2008). Longwall mining In seams of medium thickness – comparison between shearer and plow. 21<sup>st</sup>. World Mining Congress. Kraków. Dokumentacja Techniczno-Ruchowa POU-BW/01-WAP, (2012). Welding Alloys Polska sp. z o.o. Gliwice.
- Dokumentacja Techniczno-Ruchowa (2012a). Urządzenie do Pomiaru Siły Skrawania Węgla. ITI EMAG. Katowice.

**Abstract:** The paper presents a method for measuring and recording the forces involved in the coal cutting process. Moreover, a method for visualization of all forces involved in the cutting process was described. In the following part, the construction and principle of operation of a device for determination of forces involved in the cutting process (coal mining), referred to by the author as POU-BW/01-WAP, are presented. Resistance extensometry was used to measure the forces. This is the only device in the world that determines two of three force components that take part in the cutting process. For this purpose, two independent measuring blocks were used, which are strain gauges of force: cutting ( $F_s$ ) and knife pressure ( $F_d$ ). In order to register these forces, a real mining knife used in longwall shearer drums was applied – i.e. tangential-rotary. The equipment has the ATEX certificate allowing for operation in real conditions as a device intended for use in potentially explosive atmospheres – in accordance with the directive 94/9/EC. It has received many awards at world fairs for inventions and innovative solutions.

**Keywords:** workability, cutting forces, measurement, recording, strain gauges