Equipment/machinery failure rate
in hard coal mines

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INTRODUCTION

The task of each organization (enterprise) is to create rules and principles according to which a specific order can be achieved. These rules and principles should have a reasonable scope for both detail and flexibility, as the organization (enterprise) has to be constantly adapted to changing operating conditions. This applies in particular to the maintenance department as a special division within the company. The activities carried out within this department in most manufacturing companies consist in solving various problems arising from the production process. This applies in particular to the control of rational use and effective operation, in order to maintain or increase the possibility of generating specific profits by the equipment (machinery), (and consequently by the enterprise). Through the improvement of operation effectiveness, which in practice translates into the increase (prolongation) of equipment (machines) usability, limitation of failures and downtimes, as well as proper organization and implementation of maintenance and repair works, it is possible to maintain continuity of production, increase efficiency and improve the quality of manufactured products and reduce operating costs of equipment (machines), and thus reduce production and product costs (Maruszewska E.W., Tkocz-Wolny, 2004).

In the Polish coal mining industry, the exploitation of coal seams is carried out with longwall systems using mining machines operating on the cutting principle. Therefore, one of the important areas of mines' activity is proper operation of equipment (machinery). This activity should involve, among others, the control of rational, safe and effective use and maintenance of equipment (machines) in the operation process (Krauze, K., 2009; Loska, A., 2011).

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MAINTENANCE OF THE MINING OPERATIONS IN THE MINE

In the hard coal mining process, monitoring of mining equipment (machines) and analysis of failure rates in the equipment and machines involved in the process are of great importance.

The main element in this process is the so-called mining sequence, in which the following stages can be specified (Fig. 1), (Biały, W., Bobkowski, G., 2005; Biały, W., 2010):

- mining process,
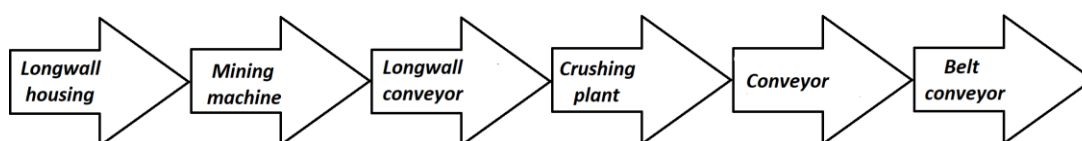- horizontal transport,
- vertical transport.

Fig. 1 Components of the mining operation

Currently, in the world mining industry, in underground hard coal mines, the mining process is carried out using two types of mining machines: harvester or plane.

Horizontal transport, i.e. removal of the excavated material from the coal wall, is carried out with two types of conveyors: armoured face conveyor and belt conveyor. Vertical transport, on the other hand, is carried out with the use of shaft devices (skips).

The mining process – horizontal transport – vertical transport – is by nature a serial system. Therefore, any failure of any link in the system causes the shutdown of its other elements.

Horizontal transport is an element which significantly determines the production results of mine. Conveyors must transport the output from the longwall to the shaft equipment in a strictly defined time. Therefore, very high demands are placed on the equipment in terms of operational reliability.

USE OF QUALITY MANAGEMENT TOOL TO ASSESS FAILURE RATES

One of the traditional quality management tools – the Pareto-Lorenza diagram was used to assess the failure rate of mining equipment (machines).

The Pareto-Lorenz diagram is a tool that enables ordering the factors influencing the studied phenomenon. Using this graphical image it is possible to present both the relative and absolute distribution of error types, problems and their causes (Fig. 2) (Krzemień, E., 2003; Wolniak, R., Skotnicka, B., 2007).

Table 1 presents data concerning the causes of failures, the accumulated percentage number of individual devices (machines), times of failures that occurred for particular elements of the mining complex, percentage number of failures and the accumulated percentage number of failures (wykaz awarii 2009, 2010).
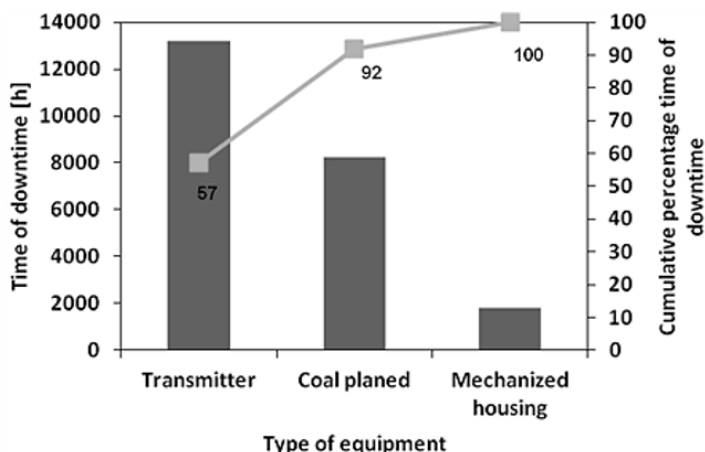
Fig. 2 Pareto-Lorenz diagram for the wall under analysis

Table 1 Mining machinery failures

Type of equipment	Cumulative percentage number of elements *SPIE*	Number of failures *IA*	Percentage number of failures *PIA*	Cumulative percentage number of failures *SPIA*
Conveyor	33.33	13204	57	57
Mining machine	66.66	8215	35	92
Mechanized housing	100	1822	8	100

BASICS OF MACHINE/EQUIPMENT DIAGNOSTICS

Diagnostics is responsible for tests and evaluation of technical condition in machines/equipment. The word "diagnostics" is derived from the Greek "diagnosticos", which means the ability to recognize. Diagnosis is called "the process of evaluating the technical condition of a device, machine or entire system." All routine operations, such as auscultation and external inspection of the equipment, control and analysis of the operating parameters, measurements and inspection of device parts during maintenance or repair, constitute elements of the diagnosis process.

Technical diagnostics is a field of knowledge covering the entirety of theoretical and practical issues concerning identification and evaluation of current, past and future conditions of a technical object, taking into account its surroundings. The purpose of technical diagnostics is to inspect and evaluate the condition of technical object (or process) in a strictly defined period, for the purpose of its comparison with the model state and determining the suitability or unfitness of technical object (or the process flow) and to determine the causes of existing state, as well as to make a forecast of possible future states of the object.

Continuous monitoring

Monitoring means regular qualitative and quantitative measurements or observations of a phenomenon. Investigation involves analysis and assessment of the condition in order to observe its changes.

The simplified operation principle consists in recording the signal, transmission, then appropriate processing and displaying the results on a computer monitor screen. Online fault management (i.e. early detection of problems and taking

appropriate actions to isolate and eliminate them), provides messages describing active connections and the status of equipment used. These systems are designed to be used in strategic devices for the plant or hard-to-reach devices, where the safety of users is threatened. These systems allow reliability and maintenance staff to focus on diagnosing and correcting problems without the need to collect data in a monitored environment.

Continuous monitoring is clearly associated with protection, security, but also with viewing, measuring and collecting information on various topics. It is a common term used in almost all fields of science, from astronomy to construction. Generally speaking, it is a regular observation or measurement of a specific phenomenon for an indefinite period of time.

Continuous monitoring is widely used in many branches of production (including hard coal mining), document processing, electronic products, logistics, product safety, atmospheric air and water monitoring, trade and practically in every area of life.

Ad hoc monitoring – comparative

Ad hoc monitoring, resulting from the momentary need, satisfactory at a given moment, means qualitative and quantitative measurements, organoleptic observations of the phenomenon. Investigation consists in simplification of the procedure, immediate release and performance of an analysis, as well as assessment of the observation state of occurring changes. The idea comes down to the principle – two images in one, e.g. two measurement charts (previous and new) and objective evaluation of the measurement difference. It enables to observe two samples simultaneously (e.g. two measurement charts, two thermograms, two photos, etc.) and to observe the changes taking place. The source of data (information) on the condition of machine/equipment parameters are portable devices for monitoring the condition of the machine recorded in the monitored machine in fixed or moving measurement points. The simplified operation principle consists in recording signal data, appropriate processing and displaying the results on a monitor screen of measuring instrument.

The concept of time in diagnostics

The condition of operational equipment may change over time. A change in the object's state entails a change in the value of state attributes, which is most often caused by the progressing process of the object's wear. Thus, observation of momentary changes in the values of machine's state attributes over time or related state symptoms may lead to identification of the current machine's condition. In order to solve such a precise diagnostic task, it is advisable to assume that the time in which the momentary values of signal characteristics (diagnostic symptom) were estimated is different, while the time in which changes in the state of tested object were observed is different. It also results from the fact that the estimation ranges of momentary values for signal characteristics are measured most often in fractions of seconds, while changes

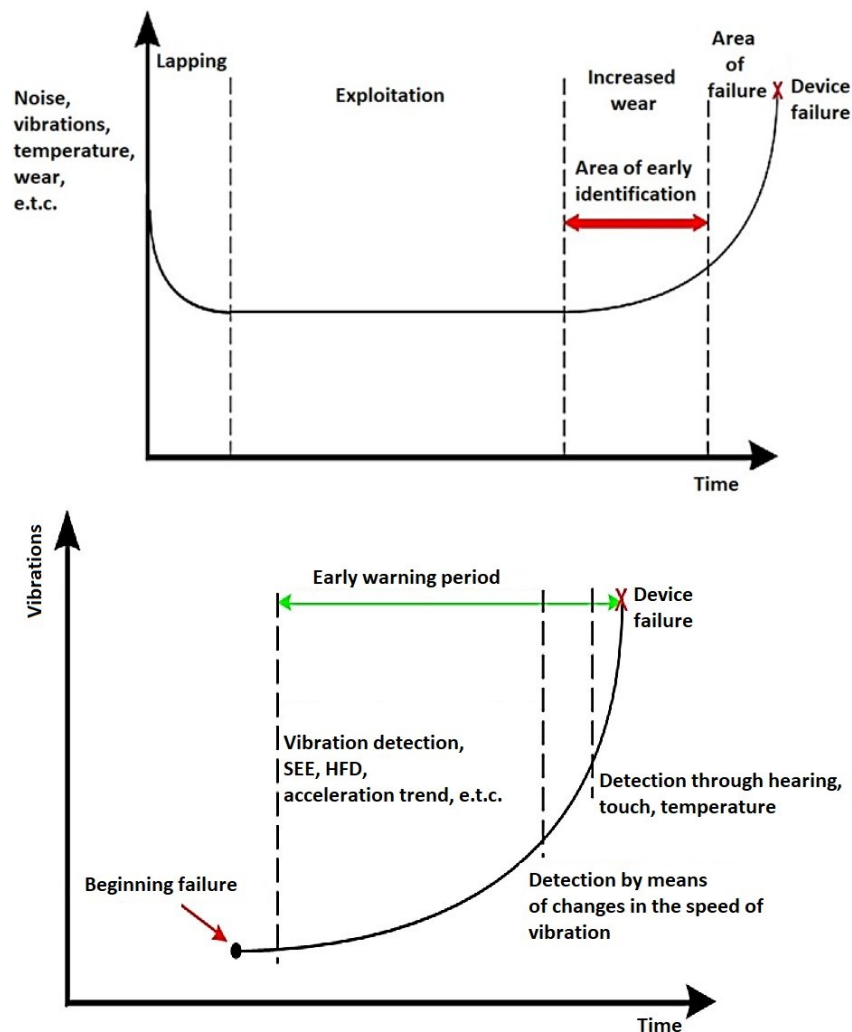in the operation of machines may occur in calendar time units. The described situation was shown in Figure 3.

Fig. 3 Bathtub curve of wearing and end of operation, as well as the final phase of curve and fault identification capability

When analyzing Figure 3, it can be seen that the observation of a trend in wear cycle, the so-called bathtub curve, on which we can observe the progressing course of wear over time, in the first area of reaching the beginning of operation, reaches a significant wearing out. This wear is gradually reduced as the parts run in gradually until the current wear is reached. When the final phase of shutdown area is reached, wear is gradually increased again until it grows rapidly. This area is characterized by aging processes, material degradation, and the intensity of failure increases significantly. In order to objectively determine the technical condition, it is possible to use various methods of technical diagnostics, which will allow the detection of newly emerging failures or even damages before they appear on the material surface. The resulting failure emits a high-frequency signal that can be intercepted using adequate diagnostic methods. These methods enable to pay attention to failures and problems very quickly.

Vibroacoustic diagnostics

Vibroacoustic diagnostics is based on the assessment of the condition of a technical object on the basis of observations of vibration-acoustic residual processes, i.e.: vibrations, noise, pulsation, generated during the operation of this object. As it results from the classification of basic technical diagnostic methods (Korbiel, T., et al., 2016), vibroacoustic diagnostics is classified as instrumental – indirect methods. It follows that the aim of vibroacoustic diagnostics (apart from the primary objective, which is to assess the machine condition) is to develop appropriate methods, means and diagnostic procedures (algorithms) that answer the questions:

- what to measure, what process and why,
- how to measure, what process parameter and why this one,
- what to measure, which sensors and accessories to use, how to process signals,
- how to conclude, how to define border states and preventive actions.

METHODOLOGY OF TESTS FOR SELECTED MINING UNDERGROUND EQUIPMENT

Diversity of mining equipment enables the use of uniform diagnostic procedures in the assessment of its technical condition. The conditions in which mining equipment is operated also significantly reduce the use of research methods. Measurement locations in mining plants are very difficult due to the explosion hazard, dust and humidity. High dustiness, humidity and dimensions of the excavations cause difficult access to the equipment. For this reason, the offer of measuring instruments is limited. In addition, measuring equipment must meet the specific requirements for equipment used in mines. An equally important issue is the conditions of measurement – difficult technical conditions, variety of devices and the non-stationary operation mode require the development of dedicated research methodology. The equipment that can be used for underground tests should be easy to transport, easy to use and resistant to external conditions. It is also necessary that the measurement is always carried out in the same conditions in order to prevent any significant changes in the conditions. Therefore, it is important for the correct combination of measured values that the measurements (if technically possible) are always carried out under the same operating conditions.

For the purpose of measuring devices, the measurement points in kinematic diagrams of devices near the bearing nodes must be determined and numbered accordingly. Measurements should be conducted in three directions: (X Y Z) axially, horizontally, perpendicularly (vertically). During measurements it is very important that the measuring instrument is correctly positioned in relation to the housing (always perpendicular) – it is also necessary to avoid surfaces covered with grease, unloaded bearing zones and places of luminaires division and material losses.

At the marked measuring points, the measurement should always be carried out in the same place – each measurement is carried out twice at the same point. If the measurements have similar values, the higher value is entered into the measurement chart, and if the measurements differ significantly, the third measurement is carried out for verification purposes. These places are cleaned before each measurement, and these points are mapped in the diagram and test register. The number and arrangement of measuring points is determined individually for each type of device, based on a kinematic diagram. In order to identify the peak vibration values, a measuring table is created. In the search for reference values of measured parameters, every device after inspection or repair is tested for control purposes. Measurements are differentiated according to the type of equipment, as well as where and under what conditions it operates. The values obtained from the measurements are the basis for evaluation of the equipment and forecasts as to its further use or repair.

VERIFICATION OF THE METHOD UNDER REAL CONDITIONS

The proposed algorithm has been implemented in one of the hard coal mines. The observation of the technical condition of underground mining equipment was based, among others, on periodical measurements of vibration parameters at selected points on the machine. Measurements were conducted with a vibration pen (Fig. 4).

Fig. 4 Pen plus CMVP 50 of SKF company – vibration pen

In order to monitor the technical condition, the model of measurement chart was used. The measurement chart contains information with the numbers of measurement points, which are indicated on the device. The presented methodology was used to determine the maximum levels of the average vibration velocity, defined as pre-fault level [10]. An exemplary fragment of the arrangement of measurement points on the lower drive of discharge conveyor R-850 Ryfam was shown in Figure 5, while the measurement chart for the conveyor was shown in Table 2.
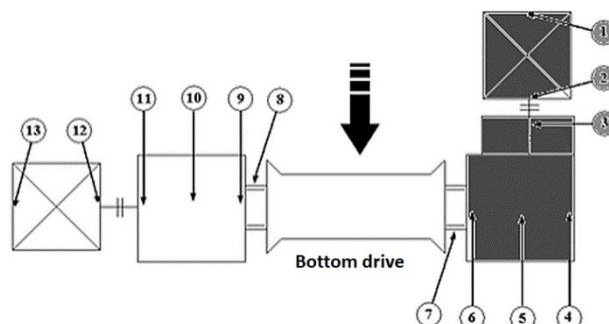

Fig. 5 Arrangement of the measuring points on the conveyor

Table 2 Measurement chart for armoured face conveyor

Measuring location	Measurement orientation	Measuring point number		
		1	**2**	**3**
No. 1	↓	3.1	2.0	2.3
	→	3.1	1.7	2.2
	⊗	2.2	-	-
	↑	**1.51**	**0.46**	**2.00**
No. 2	↓	3.2	2.3	2.4
	→	3.1	2.2	2.4
	⊗	2.5	-	-
	↑	**1.60**	**1.82**	**6.00**
No. 3	↓	3.0	2.1	2.3
	→	2.7	2.0	2.3
	⊗	2.3	-	-
	↑	**1.76**	**1.84**	**4.90**
No. 4	↓	3.1	2.1	2.4
	→	2.7	2.2	2.3
	⊗	2.3	-	-
	↑	**1.85**	**1.92**	**5.90**
No. 5	↓	3.7	4.1	7.5
	→	3.2	4.0	7.3
	⊗	3.2	4.0	7.3
	↑	**3.30**	**5.00**	**9.10**
No. 6	↓	3.7	4.1	7.5
	→	3.2	4.0	7.3
	⊗	3.0	-	-
	↑	**3.4**	**15.20**	**34.20**
No. 7	↓	3.9	4.3	44.5
	→	3.5	4.1	37.0
	⊗	3.5	-	-
	↑	**5.8**	**19.70**	**37.40**
No. 8	↓	3.9		
	→	3.5		
	⊗	3.5		
	↑	**7.8**	**19.70**	**37.40**
No. 9	↓	3.8		
	→	3.3		
	⊗	3.7		
	↑	**10.4**		
No. 10	↓	4.1		
	→	3.7		
	⊗	3.9		
	↑	**15.5**		

For collected data, a diagram of changes in rms value of vibration velocity (designation in Table 2 ↑) has been prepared. This diagram corresponds to the assumptions of fatigue degradation of the machine (Fig. 6).

The analysis was also carried out taking into account 3 and 4 historical measurements. In this case N = 4 or N = 5. The value of exponent and the expected value were presented in Figures 7 and 8.

On the basis of conducted sample analyses it results that for a measurement for which the effective value of vibration velocity was 5.9 mm/s, the exponent slightly exceeded value 1. Subsequent measurement caused the exponent to exceed 3.5, which clearly indicates that the pre-fault phase had begun. The expected value also increased rapidly, confirming this hypothesis. This information indicated the pre-fault condition of the conveyor drive.
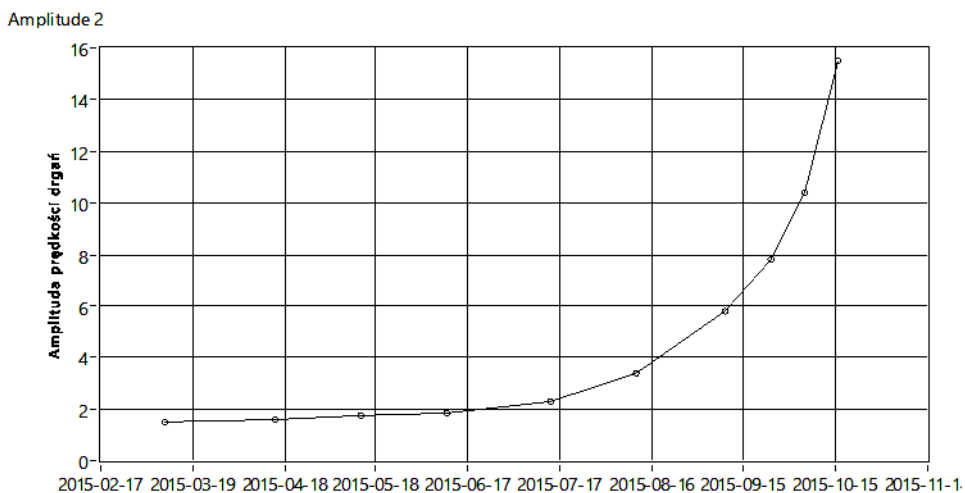
Amplitude 2

Fig. 6 The course of average vibration velocity value for 1 measuring point
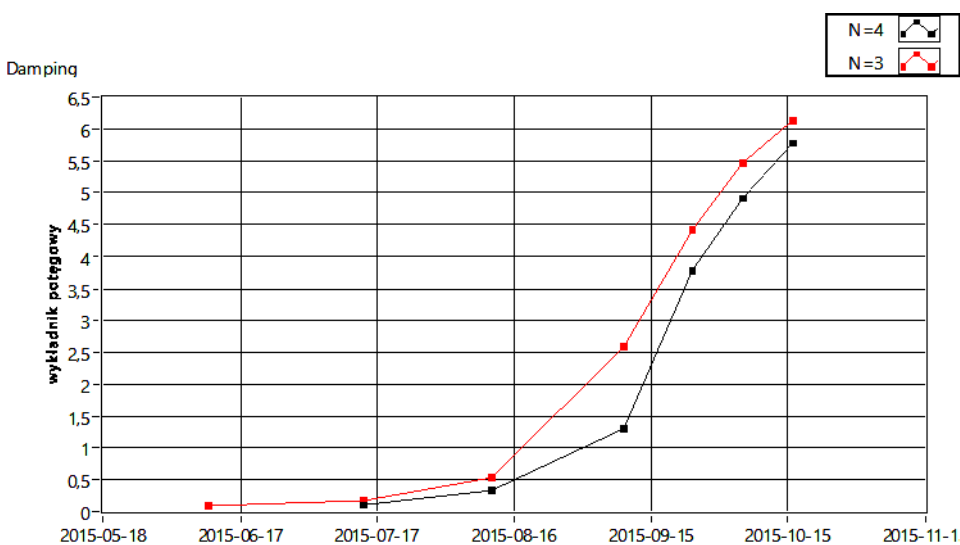
Damping
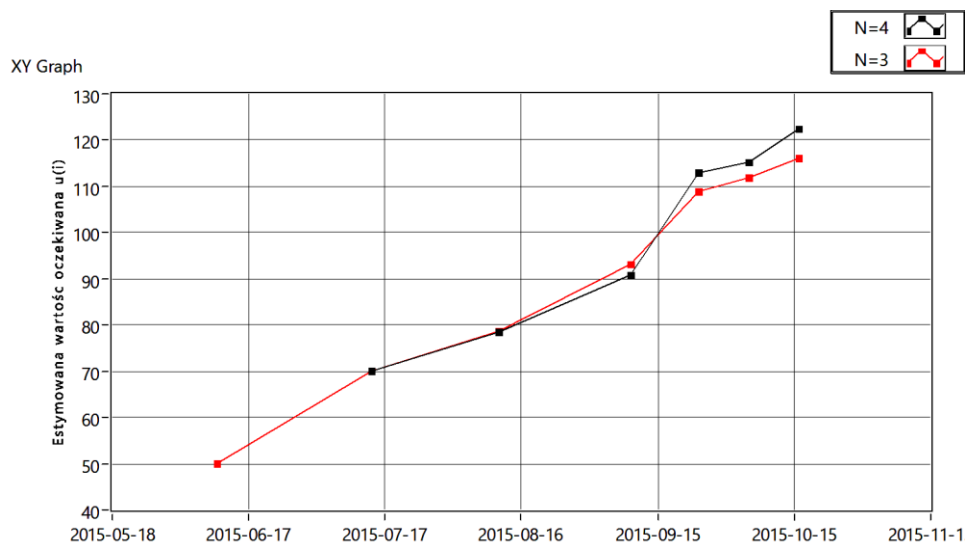

Fig. 7 Diagram of exponent

XY Graph

Fig. 8 Diagram of expected value

As a consequence, its technical condition was monitored and its technological preparation for repair was intensified. The conveyor operated in this state for

two more weeks, after which it was shut down. Its repair unequivocally confirmed the observed damage.

CONCLUSION

In order to eliminate the failure of technological lines in the mining plant, it was decided to implement a monitoring system for early fault detection of machinery and equipment in the mine. Due to very limited technical and financial resources, it was decided that the knowledge of diagnosticians will be used in combination with effective devices for diagnosing the condition of equipment. Hence, very easy to use, small size equipment was selected. An additional argument in favor of choosing these equipment was the opinion of tested, similar equipment in another mining plant. The above arguments were followed by the use of Vibration Pen Cmvp50-En. With the help of this meter it is possible to effectively analyze machine vibrations.

The Pen Plus vibratory pen (Fig. 4) is a simple, compact and small device that can be used for diagnostics in harsh mining conditions and effectively detects equipment/machine failures.

Persons monitoring and controlling the operation of armoured face conveyor, belt conveyors and mining machines should take special care of the technical condition of these equipment and try to prevent the occurrence of failures. In addition, the top management of the mine should verify the principles of selecting people for sensitive positions in accordance with generally accepted principles of human resources management (Kołodziej, S., 2004). Improper principles of selecting people for particular workstations may translate into reduction (or increase) of failure rates.

It is necessary to analyze the causes of failures and the consequences for mines, which are the result of failures of those equipment (machines) which have the greatest impact on downtime of the mining process, i.e. haulage equipment (armoured face and belt conveyors).

This analysis should show whether the reasons for failure were caused by:

• human factor (errors in operation, maintenance, service),
• caused by the equipment (design, manufacturing errors),
• other which do not result from the abovementioned criteria, e.g. particularly difficult working conditions.

After the above mentioned analysis, it should be indicated which actions should be taken by persons operating these equipment (conveyors) to minimize downtime, and which have a significant impact on the economic results achieved by the mine.

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REFERENCES

Biały W., Bobkowski G.: (2005). Możliwości wykorzystania narzędzi komputerowych w gospodarce remontowej kopalń węgla kamiennego. Mechanizacja i Automatyzacja Górnictwa. Katowice, 4. (s. 42-51).

Biały W.: (2010). Awaryjność górniczych urządzeń technicznych w procesie wydobywczym. Rozdział 6. Monografia pod redakcją K. Krauze „Problemy Bezpieczeństwa w Budowie i Eksploatacji Maszyn i Urządzeń Górnictwa Podziemnego". Centrum Badań i Dozoru Górnictwa Podziemnego Sp. z o. o. Lędziny. (s. 73-85).

Krzemień E.: (2003). Zintegrowane zarządzanie – aspekty towaroznawcze: jakość, środowisko, technologia, bezpieczeństwo. Wydawnictwo „Śląsk" Katowice.

Wolniak R., Skotnicka B.: (2007). Metody i narzędzia zarządzania jakością – teoria i praktyka. Wydawnictwo Politechniki Śląskiej Gliwice.

Maruszewska E., Tkocz-Wolny K.: (2004). Rachunkowość w podejmowaniu decyzji inwestycyjnych w zakresie środków trwałych. Zeszyty Naukowe Politechniki Śląskiej Organizacja i Zarządzanie, nr 22, Gliwice.

Wykaz awarii ściany wydobywczej w latach 2009, 2010. Materiały niepublikowane.

Krauze K.: (2009). Problemy bezpieczeństwa w budowie i eksploatacji maszyn i urządzeń górnictwa podziemnego. Monografia. Wydawca Centrum Badań i Dozoru Górnictwa Podziemnego Sp. z o. o., Lędziny. ISBN 83-922183-9-6.

Kołodziej S.: (2004). Wykorzystanie badań ankietowych do wspomagania zarządzania zasobami ludzkimi. Zeszyty Naukowe Politechniki Śląskiej, seria: Organizacja i Zarządzanie, z. 22, Gliwice.

Loska A.: (2011). Selected organizational aspects of maintenance organization modeling. Management Systems in Production Engineering. z. 4, Gliwice. ISSN 2083-5280.

T Korbiel, W Biały, S Czerwiński.: (2016). Ocena stanu technicznego maszyn górniczych w oparciu o kryterium Weibulla. Systemy Wspomagania w Inżynierii Produkcji, s. 639-654

Abstract.
The main task of the maintenance services in hard coal mines is to ensure continuous operation of the equipment (machines). The measurable effect of these actions should be the reduction of maintenance costs of equipment (machinery) and thus the reduction of production costs – coal mining. The paper presents an issue of failure rate of technical measures applied in the mining process. In order to ensure greater efficiency and productivity, it is necessary to find the causes of the most frequent failures in this process and effectively counteract them. As a result of these activities, the production availability of machines/equipment involved in the mining process will increase. This will to a large extent ensure failure-free and uninterrupted progress, increase productivity and improve the quality of manufactured products, as well as reduce the operating costs of equipment (machines), and thus reduce production and product costs. This effect should consist mainly in the control of rational, safe and effective use and operation of equipment (machines) in the exploitation process. An algorithm implemented in one of the hard coal mines was presented. The technical condition of underground mining equipment was observed by periodical measurements of vibration parameters at selected points on the machine – measurements were conducted with a vibration pen. The aim of this research is to improve the reliability of technological process of a mining plant through its failure-free operation. In order to achieve this objective, i.e. the efficiency of a mining company, it is necessary to reduce its costs. The action that leads to this aim is a proper assessment of the technical condition with regard to the equipment used in technological process.

Keywords: mining machinery/equipment, failures, vibration pen, measurements