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Quality engineering tools in analysis of failure of longwall mining complex

Downtimes caused by machine failures translate into a loss of effectiveness in the mining process. The main task of maintenance teams in hard coal mines is to ensure the uninterrupted work of the machines used. A measurable effect of these activities should be reducing machine maintenance and, as a consequence, reducing the costs of coal mining; i.e., a mine's operating costs. In the present article, two longwall mining machines have been analyzed: a cutter-loader and a plow. The analysis was based on one of the quality engineering tools – the Pareto–Lorenz diagram. This tool allows for grouping the causes of breakdowns and establishing which of them are the most important and should be removed first. The analysis has demonstrated the significance of machine selection and its adjustment to the existing geological-mining conditions. Improper selection results in increased energy consumption in the mining process, premature wear, or prolonged downtimes caused by breakdowns.

Key words: *longwall mining machines, breakdowns, output, Pareto–Lorenz diagram*

1. INTRODUCTION

In coal mining (both global and Polish), exploitation of coal seams is done with longwall systems using cutting machines that machine the face. Thus, one of the important areas of a mine's activity is the operation of the machinery and equipment necessary for its proper functioning. This activity should include, among others, supervision over the effective and rational use and maintenance of machines and devices in the process of their exploitation [1–4]. At present in Polish (as well as world) mining, two systems are applied: a shearer (Fig. 1) and a plow (Fig. 2). The mining process in both systems is identical; the difference lies in the cutting machine installed (shearer or plow). The other elements of the system remain unchanged.

The efficiency of a properly designed mechanization system and its reliability directly affect the economic result of the company. The technological development in mining as well as the increasing complexity, efficiency, and power of mining machinery and equipment puts ever greater demands on the culture of their use. These devices must meet the conditions of energy efficiency, reliability, high durability, and work safety.

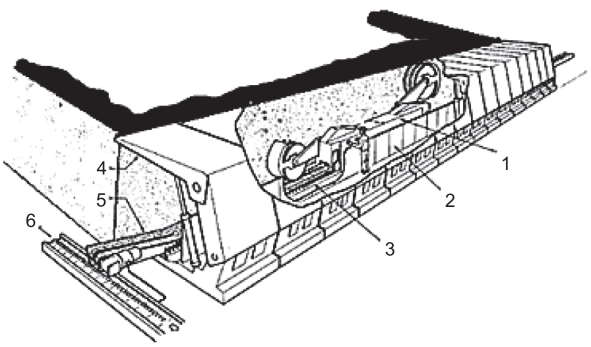

Fig. 1. Longwall shearer system: 1 – shearer, 2 – spill plate, 3 – ladder, 4 – powered roof support, 5 – armored face conveyor, 6 – beam stage loader [1]

Mining machines and equipment are complex technical objects that should be characterized by adequately high durability and reliability of operation over a relatively long period of exploitation. The formation of these features is influenced not only by the very process of their design, construction, and assembly but above all (during the broadly defined process of use) proper attention to their technical condition. The use of technical diagnostics, which allows us to correctly determine the technical condition of machines, guarantees reliability and the high durability of the equipment during operation. Therefore, the main task of mine maintenance services is to ensure the continuity of operation of the machines and equipment operated at a given moment. The consequence of these activities is a reduction of maintenance costs in the machines and equipment, which is associated with a reduction in production costs; that is, the operation of the mining plant. Disruptions in this process generate great losses.

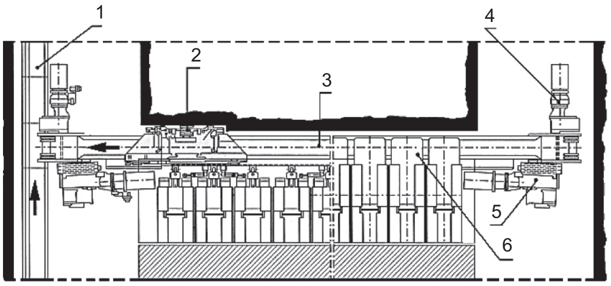

Fig. 2. Longwall plow system: 1 – beam stage loader, 2 – plow, 3 – armored face conveyor, 4 – conveyor drive, 5 – plow drive, 6 – powered roof support [1]

In the present paper, one of the traditional quality management tools – the Pareto–Lorenz diagram – was used to assess the failure rate of mining machines and equipment [4, 5]. This chart allows us to present both the relative and absolute distribution of the types of errors, problems, and reasons for their formation [6].

In the process of extracting minerals, the main element is the mining process line, in which three consecutive stages can be distinguished [1, 4]:

– extraction process,
– horizontal transport,
– vertical transport.

By analyzing the mining process line, it can be seen that it is a serial system – failure of one of the links causes the "disabling" of the other elements on the line (Fig. 3).

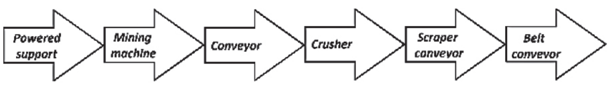

Fig. 3. Components of mining process line

2. MINING PROCESS LINE MAINTENANCE

The maintenance of mining machines and equipment is carried out by services connected to the mine as well as by external companies. In the case of external companies, they are most often the manufacturer of a given machine or device.

Every machine or device installed in a mine is subject to maintenance and repair activities that can be broken down into factors that allow them to be properly located in the repair structure (Fig. 4):

– repairs/maintenance of hydraulic (pneumatic) elements,
– repairs/maintenance of mechanical elements,
– repairs/maintenance of electrical elements.

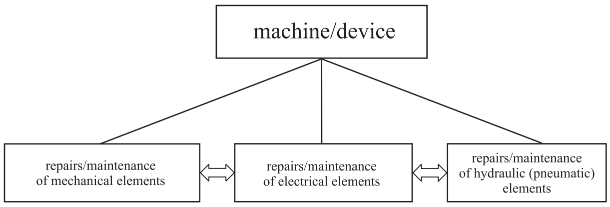

Fig. 4. Block diagram of repair structure

The model currently used for collecting data on the failures of mining machines/equipment in one of the PGG mines is shown in Figure 5.

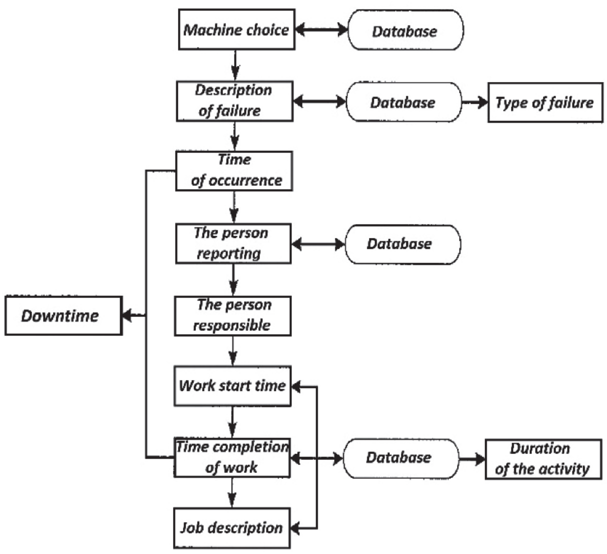

Fig. 5. Diagram of registration of machine/equipment failure at PGG mine

Based on observations, it can be stated that Polish hard coal mines have not developed a uniform management system for managing the maintenance of mining machines as of yet; neither during their operation nor during repairs. The system should include the following [1]:

- observation, registration, and analysis of individual activities;
- scheduling activities;
- a method of gathering information about the machines and equipment;
- a way of establishing the scope of service work between the user and the manufacturer;
- shaping the right competences of employees performing maintenance activities;
- collection and processing of information pertaining to maintenance works.

Quality engineering can be used to monitor and control the machinery/equipment of a longwall mining complex. The use of quality engineering elements in the majority of manufacturing enterprises is aimed at detecting the occurrence of potential defects in the product or production cycle. The use of quality management tools allows for the monitoring of the production cycle, starting from the design phase through production and to the final stage; that is, delivering the finished product to the customer. Quality engineering tools for assessing the effects of failures will significantly reduce losses that are associated with unplanned downtime (breakdowns). Thus, it seems justified to use quality engineering tools in the production (mining) process that will allow for an effective reduction of losses resulting from failures. Therefore, it is suggested to include quality engineering elements in the determination of the causes of failures in the mining process (Fig. 6).

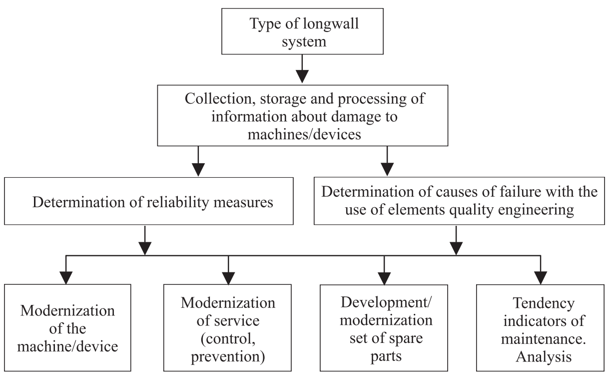

Fig. 6. Quality engineering in determining causes of failure

The practical application of selected elements of quality engineering in the production process (in this case – mining) reduces the losses associated with downtime resulting from machine/equipment breakdowns.

3. QUALITY ENGNEERING AND MACHINE/EQUIPMENT FAILURE RATE

Quality engineering is understood as the shaping, modeling, and implementation of quality systems according to specific standards and norms, quality management, quality system certification methods, accreditation and audit methods, process control, metrology, legal aspects of quality, and methods of total quality management (TQM).

First and foremost, the management staff requires information for effective quality management. The information must be reliable, current, and (above all) true. Quality management is aimed at improving products and/or services – creating and assuring their quality so as to satisfy the customer. It is a comprehensive activity, and various tools and methods help in its implementation.

Quality tools are used to collect and process information, supervise the quality management process, and detect errors, defects, and irregularities in the processes, products, and services. They allow one to visualize the data as well as monitor and diagnose the processes. Thanks to these, the effectiveness of the actions taken can be assessed; they are instruments that allow for the monitoring of activities (processes) throughout the product's life cycle.

Quality management tools are divided into traditional, new, and auxiliary. Traditional tools are called the magnificent seven. They are the most commonly used and fundamental ones. These tools can be used alone but are often used as components of quality management methods. One of the traditional quality management tools is the Pareto–Lorenz diagram [7–9].

The Pareto–Lorenz diagram (also called the ABC method, the law of non-uniformity of distribution, or the law of 20–80) is used to identify and assess the significance of the issues analyzed. It identifies the problems that, despite being the minority as related to the number of all problems (20%), exert a dominant influence on the considered issue (80%).

The procedure for conducting an analysis according to the ABC method consists of the following:

- identification of the types of issues considered (e.g., types of defects);
- determination of the time interval (day, change, year, etc.) for later comparison of the effects of the implemented changes;
- determining the frequency of occurrence of particular categories (e.g., causes, defects);

- classification of categories in descending order by frequency of occurrence, calculation of percentages, and cumulative rates;
- determination of scales on the vertical (most often designated as absolute frequency and cumulative percentage) and horizontal axes (categories);
- plot bars corresponding to the frequency for individual categories (Pareto chart) and the curve for cumulative percentages (Lorenz curve) in order, from the highest to the lowest impact.

When discussing the ABC method, it can be concluded that a small number of causes are responsible for the majority of the issues. Eliminating these 20% significantly improves the final process. The precise identification of the phenomena allows one to effectively avoid non-significant reasons, because the Pareto principle is based on an analysis of the uneven distribution of decisive factors. The Pareto analysis (which results in the creation of a Pareto–Lorenz diagram) allows for the organization and analysis of the previously collected data. It is used when the goal is to counteract the following:

- negative phenomena with the highest frequency of occurrence,
- phenomena incurring the largest costs.

The Pareto–Lorenz diagram is a tool enabling the hierarchization of the factors affecting the studied phenomenon. It is a visual representation, showing both the relative and absolute distribution of the types of errors and problems as well as their causes. It allows for the presentation of data in a column chart with emphasis on the elements that contribute the most to the analyzed problem (Fig. 7).

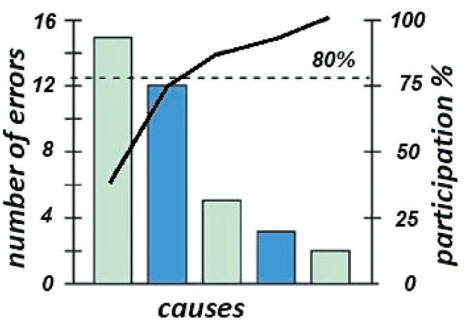

Fig. 7. Pareto–Lorenz diagram

4. PROBLEM ANALYSIS

In the mining industry, the Pareto–Lorenz diagram is used to monitor and control the mining equipment (mining machine, armored face conveyor, belt conveyor, powered roof support) that constitutes an important element of the mining process [2]. In the case of these machines/equipment, it is important to assess the failure rate and reliability as well as to indicate which of the detected reasons causing failure frequency should be eliminated first.

The construction of the Pareto–Lorenz diagram for the control and monitoring of mining machinery/equipment is divided into the following stages:

- collecting information – that is, completing data on the failure rate of mining machines/equipment in the individual stages of the mining process;
- sorting the collected data – assigning particular failures to specific mining machines/equipment such as the mining machine, armored face conveyor, belt conveyor, or powered roof support;
- calculation of cumulative percentages – determination of cumulative percentages for particular highlighted failures;
- drawing a Pareto–Lorenz diagram;
- interpretation of the Pareto–Lorenz diagram.

5. LONGWALL FAILURE RATE

Because the mining process line is the fundamental element affecting the output volume in the process of extracting hard coal (useful minerals) and, thus, the costs associated with this process, the failure rate of this fundamental element was analyzed (plow and shearer) [1, 2, 6, 9]. The failure rates of two longwalls in hard coal mines were analyzed over the entire period of their operation (from their commissioning to the end of their operation). A traditional quality management tool – the Pareto–Lorenz diagram – was used to analyze the failure rate of the longwall plow complex.

The Pareto–Lorenz diagram was constructed according to the following stages:

- data was collected related to the type of failure of the following mining equipment (machines): the mining machine (plow, shearer), conveyors (AFC, belt), and powered roof support;
- individual failures were assigned to specific mining machines (equipment);
- cumulative percentages were calculated (determination of cumulative percentages for particular highlighted failures).

6. LONGWALL PLOW SYSTEM

All breaks in the work on the longwall that occurred over the entire mining period were registered by the relevant departments of the mine [10–12]. The piece of equipment (machine) in which the break occurred was assumed as the point of failure. The failure points were as follows:

- conveyors (AFC, beam stage loader, belt),
- plow,
- powered roof support.

Note: in the case of conveyor belts, only failures in the branch transport have been taken into account, disregarding the main haulage.

Table 1 presents the data on the causes of the failures, cumulative percentage number of the individual machines/equipment, breakdown times that occurred for individual elements of the mining complex, percentage number of failures, and cumulative percentage number of failures [5]. Meanwhile, Figure 8 presents a Pareto–Lorenz diagram showing the failure rate of a longwall plow system in the analyzed mine.

Table 1
Failure rate of longwall plow system

Failure cause	Cumulative percent *SPIE* [%]	Break-down time min. *IA*	Percent number of failures *PIA* [%]	Cumulative number of failures *SPIA* [%]
Conveyors	33.33	13,204	57	57
Coal plow	66.66	8215	35	92
Powered support	100	1822	8	100

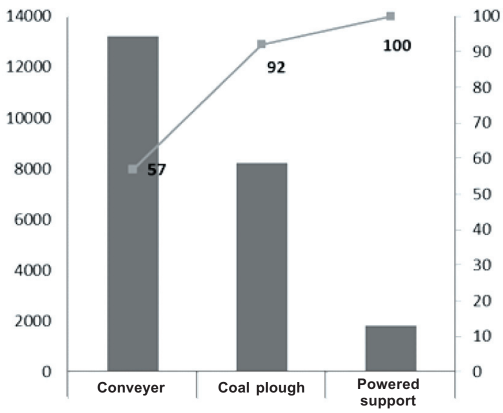

Fig. 8. Pareto–Lorenz diagram for plow longwall analyzed

7. LONGWALL SHEARER SYSTEM

The analysis of the longwall shearer system was carried out using the example of one wall in a mine belonging to PGG S.A. in which a two-armed mining machine was installed.

The working time of the analyzed wall from the start of work to the end of its operation was 92 days. All breaks in the work on the wall that occurred over the entire mining period were registered by the mine's dispatcher. The machine/equipment that caused the break was assumed as the point of failure. The points of failure were as follows:

- shearer,
- conveyors (AFC, beam stage loader, belt),
- crusher,
- roof support,
- other.

The sum of all breaks in the operation of the longwall complex is presented in Table 2 and the Pareto–Lorenz diagram (Fig. 9). Table 2 illustrates the number and time of the breaks in the operation of individual elements in the longwall shearer complex. In terms of the number of breaks, it is clearly visible that the conveyors had the largest failure rate, followed closely by the shearer (Fig. 9). On the other hand, considering the total stoppage time, the sum of the stoppages in the longwall system was affected the most by breaks in the operation of the shearer, followed by the conveyors [10–12].

Table 2
Total stoppage in operation of longwall system

No.	Breaks in operation of element of longwall system	Number of breaks	Total stoppage time (min)	Stoppage time for all breaks [%]	Cumulative stoppage time [%]
1	Cutter-loader	67	6065	47	47
2	Conveyor	70	4920	39	86
3	Mining	14	725	5	91
4	Powered support	19	625	5	96
5	Another	13	500	4	100
Total:			**183**	**12.835**	**100**

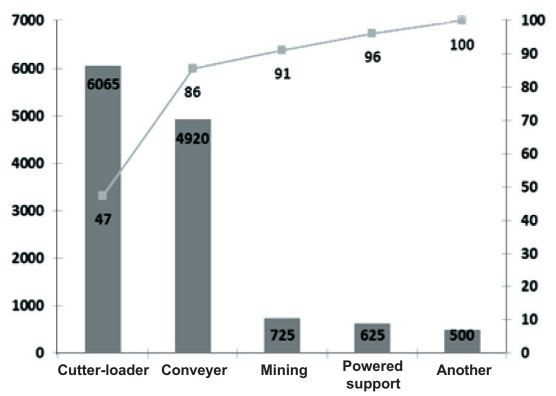

Fig. 9. Pareto–Lorenz diagram for longwall shearer system

Analyzing the Pareto–Lorenz diagram, it can be concluded that the element of the longwall shearer system that caused the most failures was the mining machine (shearer – 47%), followed by the conveyor (39%).

8. CONCLUSIONS

The Pareto–Lorenz diagram allows for an analysis of the causes of failures and the effects of breaks in the operation of machines/equipment with the greatest impact on stoppages in the mining process in mines.

Analysis of these causes should show whether the failures were caused by the following:

– human factor (errors in operation, maintenance, servicing);
– the devices themselves (design, manufacturing defects);
– others that have not been created as a result of the aforementioned factors; e.g., particularly difficult working conditions.

Upon carrying out the aforementioned analysis, it is necessary to indicate the actions to be taken by those persons operating these machines and equipment to minimize the number of breaks in work that have a significant impact on the economic results of the mine.

In each of the mining systems analyzed (plow, shearer), it can be seen that two elements of the mining complex should be subjected to special analysis. The analysis should indicate the main causes of the failure and which methods and measures should be taken to significantly reduce the failure rate of these elements of the mining system.

In the case of a longwall plow system, the largest failure rate was demonstrated by the conveyors, followed by the plow. On the other hand, the element that caused the longest downtimes in the longwall shearer system was the shearer, followed by the conveyors.

An analysis of the Pareto–Lorenz diagram for a longwall plow system indicates that the largest number of failures (92%) are caused by two elements of the mining system; namely, the conveyors (AFC, belt) and plow.

Taking into account the percentage share of these two elements of a mining system, it can be concluded on the basis of the Pareto–Lorenz diagram that a total of 66.7% of the machines/equipment causes as much as 92% of all failures.

Analyzing a longwall shearer system, the shearer is the element that causes the most failures (47%); this is why a thorough analysis of the failure rate of the shearer should be carried out in the next stage.

Persons monitoring and controlling the operation of machines/equipment should take special care of the technical condition of these machines/equipment and try to prevent the occurrence of failures. Failures of individual mining machines (and longwall shearers in particular) cause large losses for a mine, which is why it seems reasonable to propose actions that would help reduce the number of potential breakdowns of these machines. This is why employees connected with operating the machines (equipment) should be frequently trained in the field of operation and exploitation in order to avoid frequent stoppages; in particular, on issues such as the following:

– the purpose, design, and principle of operation as well as the application of a control and diagnostic system;
– principles of operation and installation of system sensors;
– structure, design, and principle of operation of the components and subassemblies;
– methods of installation, commissioning, and operation;
– diagnostics and analysis of the causes of failures and their elimination;
– operating guidelines;
– health and safety requirements.

In this group of failures, the employee is not a direct cause, but he can effectively prevent the emergence of some of these failures. You can reduce removal time by frequent staff training on breakdown recovery. Training connected with the proper maintenance of equipment (machines) should also be carried out, which should contribute to the prolongation of the failure-free operation of the machines.

The failure rate of the mining system (plow and shearer) directly translates into the efficiency and concentration of extraction, which ultimately reflects in the financial result of the mine.

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