Problem of Interruptions in Reinforcement Works and Longwall Exploitation

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INTRODUCTION

Strong competition, globalization of the world economy forces companies, especially hard coal mines, to use available technical means more efficiently. In accordance with the PN ISO 9000 standard (PN-EN ISO, 2015), the efficiency is understood as the relation between achieved production results and used resources. Therefore, the concept of efficiency in a complex production process is not unambiguous and such a process is encountered in a mining plant. It is possible to refer to economic and technical efficiency, which is a result of the quality of system use or particular technical means. Technical efficiency determines the extent to which the production and technological capabilities of technical means have been used under given conditions. Economic efficiency, on the other hand, shows the effectiveness of property, human resources and cost management (Kozioł et al., 2010; Kołodziej, 2004; Maruszewska, 2015).

The task of each organization (enterprise) is to create such principles and rules according to which a strictly defined order can be achieved. These principles and rules should have a reasonable scope of both detail and flexibility, as the organization (enterprise) has to be constantly adapted to changing operating conditions.

Production companies – including hard coal mines – in the sphere of efficiency and safety in the technological process, focus their efforts mainly on the preparation of procedures to be undertaken in case of disasters, equipment failures, or removal of their effects. In fact, the prevailing number of downtimes of technical means occurs as a result of failures, human errors, or planned downtimes. In order to achieve high work efficiency, special emphasis should be placed on minimizing or completely eliminating all causes of downtime, which first comes down to a thorough and systematic analysis of individual work stages.

MACHINE SYSTEMS IN MINING

Machine is a device designed to perform useful work at the expense of energy provided or to convert one type of energy into another. In accordance with the European Union (Directive 89/392/EEC), a machine is made up of interlinked

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components, at least one of which is movable. The machine is also an assembly of individual machines connected together in such a way as to operate as a whole. The useful operation of machines is usually reflected in the processing of matter carried out in the working system of the machine (Biały, 2017).
The way the machine operates and the machine control systems should be adapted to the operator. The way in which the machine is operated, the location of its individual assemblies, parts, lighting, position of the employee's body, has a great influence on the accuracy of performed work. Areas of knowledge which describe the relationship between the machine and man are (Doroszewski, 1996-1997):

- Bionics – a field of knowledge from the borderline of technology and biology – a new branch of science was created by combining the efforts of biologists and electronics. Bionics – science dealing with the study of living organisms and biological processes in order to use them as models for the construction of technical devices – etymology: **bio**(logy) + (electro)**nics**.
- Ergonomics – a field of science dealing with principles and methods of adapting devices and tools to the physical and mental characteristics of humans. Ergonomics – a science that studies the relationship between the working conditions and environment and the psychophysical abilities of man – from the Greek: **ergon** – work; **nómos** – law.
- Anthropometry – a branch of anthropology that deals with the dimensions of the human body and the proportions between them – from the Greek: **ánthrōpos** – man; **metreō** – measure.

The underground mining industry uses a wide range of machines, thanks to which there is an increase in extraction, productivity and improvement of work safety conditions.
Through the improvement of mining efficiency, which in practice results in the increase (extension) of technical means, reduction of breakdowns and stoppages, and the proper organization and implementation of operation and maintenance works, it is possible to maintain the continuity of production, increase the efficiency and improvement of the quality of manufactured products, and to reduce the operation costs of technical means, and thus to reduce the production and product costs (Maruszewska, 2015).

LONGWALL REINFORCEMENT PROCESS

Longwall reinforcement – it is a concept related to launching a longwall excavation. Longwall reinforcement consists in inserting a longwall scraper conveyor, mechanized casing, installing extracting machines, making appropriate hydraulic and electrical connections and means of communication into the road (or mining cross-cuts).
Longwall reinforcement is one of the most important elements of the hard coal seams exploitation process. The way to ensure greater effectiveness and efficiency of these works is to find the causes of the most frequent failures and

counteract them in order to increase the production availability of technical means. On the basis of thorough reports and failure analyses, conclusions can be drawn to find (identify) the weaker "links" in the process and facilitate optimization of people work and technical means. This information provide important insights on where to invest and where to make changes. The deliberations, which are the subject of the second part of this paper, concern the course of longwall reinforcement process in a mine, taking into account the important role of technical means used in this process.

The process of longwall reinforcement is generally preparation of excavations, in the shortest possible time, for the mining process – it consists in preparing excavations in mechanical, electrical, mining and hydraulic terms. The scope of reinforcement works also includes the preparation of excavated material removal routes with conveyor belts in the bottom roads. The group of basic machines and equipment used in underground mining plants for the longwall reinforcement are as follows:

- overhead and trailing rails,
- track machines,
- winches,
- power units,
- self-propelled chain hoists,
- impact wrench.

Technical condition of the technical means used in longwall reinforcement and their proper selection for the tasks ensure, to a large extent, failure-free and uninterrupted progress of these works. Therefore, this equipment should meet both high technical and safety requirements. The most important in this respect are equipment failures, which are the reason for the loss of ability to perform useful work. Working conditions, machine age, as well as the knowledge of the operators have a very important impact on the failure rate.

As already mentioned, the process of longwall reinforcement is a very important element of mining process. The failure-free course of longwall reinforcement and the correct performance of reinforcement translates into proper start-up and operation of the longwall, which is inseparable from the economic effects of a mine.

The classification of factors affecting the use of nominal working time can be presented in the form of a flow chart (Figure 1).

Taking into account the factors affecting the use of nominal working time of technical measures, it can be noted that this time is significantly influenced by (Figure 1) (Biały, 2013; Biały, 2014; Biały, 2017):

- the use of machines and equipment within the time frame in which they are operational (fully functional),
- frequency of failure related to reliability,
- duration of the repair and maintenance (preventive) services,
- delays in the repair processes that increase the time of unserviceability.

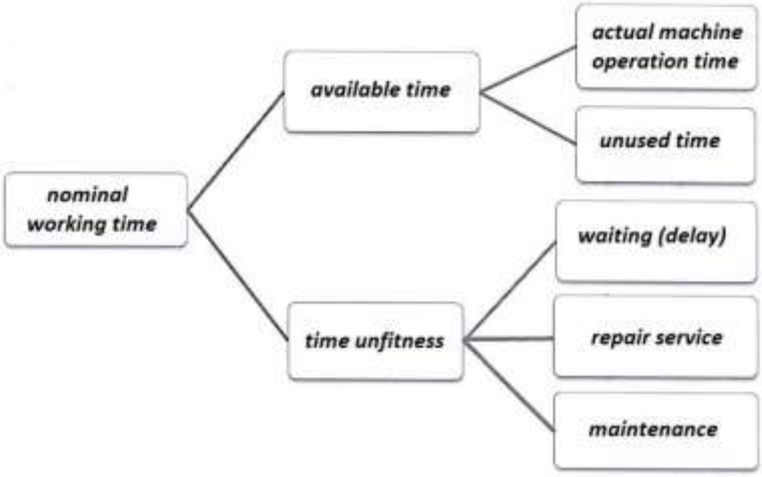

Fig. 1 Use of the nominal machine operating time

Scheduled interruptions that occur during the operation of technical measures result from the use of these measures. Each technical measure is scheduled to have periodic, detailed or shifted inspections according to the schedule provided by the manufacturer. The purpose of these inspections is to investigate the current technical condition and to protect against any damage during the work.

PROBLEM OF INTERRUPTIONS IN LONGWALL REINFORCEMENT

The analysis of the course of longwall reinforcement and the sequence of work and related downtime (scheduled and breakdowns) were carried out for one of the longwalls in a mine owned by JSW SA (Książka raportu, 2017; Raport, 2017). Machines used to transport materials necessary for longwall reinforcement were presented as an example of the operating time of machines for longwall reinforcement. These machines were overhead rails. During the longwall reinforcement, which lasted 57 days, there were 10 stoppages, where 8 were caused by exceeding the permissible values of the machine parameters, and 2 stoppages were caused by a breakdown. In general, the sum of downtimes (10) can (and should) be treated as a time of incapacity – unplanned interruptions. The main reason for the seven interruptions of overhead rail was the exceeding of permissible water temperature, which cools the exhaust fumes of the rail. Therefore, the stoppage lasted until the water temperature reached the appropriate temperature – each time this duration was over 1 hour. In one case, the oil temperature in the overhead rail exceeded, due to the loss of oil. As a result the oil had to be delivered and refilled, which caused a downtime of almost one hour. The other two breakdowns were caused by damage to the hose, which supplies the oil necessary for the operation of the winches. As a result of these events, the tasks that were scheduled to be performed on shift were not performed completely.

The total working time along with interruptions that caused the disturbances in longwall reinforcement was shown in the form of a chart in Figure 2.

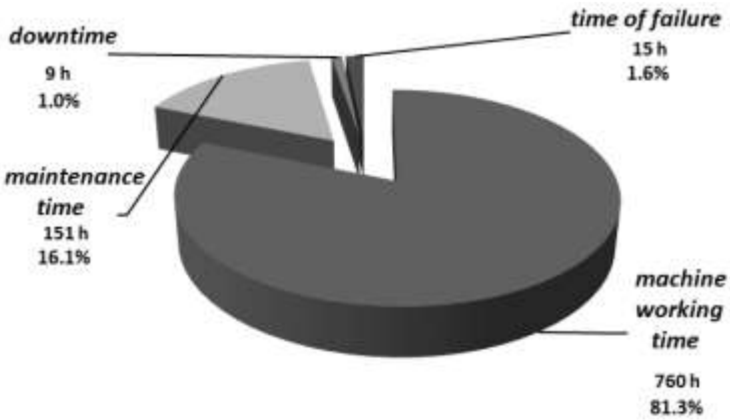

Fig. 2 Effective working and downtime of machines and equipment during longwall reinforcement

Source: own study based on (Książka raportu, 2017; Raport, 2017)

LONGWALL – FAILURE RATE

The economic effects of a longwall are significantly influenced by the selection of an appropriate extracting machine. Selection of extracting machine is related to geological-mining conditions (on which we have no influence), but we have an influence on selection of extracting machine to the existing geological-mining conditions (Biały, 2013; Biały, 2014; Biały, 2014a; Maruszewska & Biały, 2013). The technical efficiency of mining line is of particular importance in hard coal mining, where high costs of fixed assets, large investment outlays related to the equipment of coal face, a large share of fixed costs in the costs of coal mining, even force a high extraction concentration.

In the analyzed longwall, a five-shift system was applied – the first four are mining shifts, while the fifth one is for repair and maintenance. The causes of downtime (failure) of technical means during the exploitation of a longwall were divided into the following (Biały, 2017):

- mining,
- organizational,
- technical.

Moreover, the failure was divided according to: causes, place of failure, duration of failure – this division concerned:

- causes of failure occurrence,
- duration of failure,
- number of failures,
- breakdown sites,
- percentage of failure time when the longwall is ready for operation.

The equipment of longwall has changed during the longwall operation – a different type of shearer was used. Replacement of extracting machines took place for economic reasons. The shearer indicated in this paper as "A shearer" was a new shearer, installed for the first time in longwall (it was not owned by the mine – it was leased). The second shearer (marked as "B shearer") was owned by the mine. It completed the exploitation of a parallel longwall –

previously it worked in three other longwalls. Each of shearers was used in the analysed longwall with the same number of working days – 84.
According to the analysis, the number of failures caused by the shearers has significantly decreased (from 82 – "A shearer" to 42 – "B shearer") – also the duration of breaks resulting from the failures has decreased (6800/4105) (Książka raportu, 2017; Raport, 2017). Thus, the shearer's availability time increased by 4%. It follows that "B shearer", despite the fact that it was used in "three longwalls", performed its function more correctly (it was "correctly selected" for the existing geological-mining conditions). Therefore, it can be concluded that in the case of "A shearer", there was an incorrect selection of the extracting machine to the existing geological-mining conditions. The comparison of working times and downtimes caused by shearer loaders' failures was presented in Table 1.

Table 1 Average daily longwall availability time

Lp.	Parameter	shearer 1	shearer 2	entity
1	Sum of all longwall complex failures	19226/320.4	15785/263.1	min/h
2	Sum of working days	84	84	day
3	Average daily sum of all failures	229/3.9	188/3.1	min/h
4	Average daily available working time	941/15.7	982/16.4	min/h

Source: own study based on (Książka raportu, 2017; Raport, 2017)

The average 24-hour downtime caused by failures for "A shearer" was 48 minutes longer than the average 24-hour downtime for "B shearer". This confirms the statement that the mining machine was not properly selected for geological-mining conditions.
In total, as a result of shearer's failure, the longwall operated longer by 120 shifts, which resulted in "extension" of the longwall operation time by 30 working days.
The presented (very concisely) analysis indicates that the results obtained in the longwall with the use of "B shearer" were much higher. Furthermore, it is possible to determine the losses associated with individual failures as well as to determine the possible production in the longwall under analysis. The possible and actual extraction for two shearers used in the analysed longwall was shown in Table 2.
On the assumption of failure-free operation of the longwall complex, "B shearer" was closer to achieving the assumed extraction plan (5000 Mg/day) (Table 2). Moreover, taking into account the shearer's failure-free operation, achieving the planned extraction of 5000 Mg/day turns out to be impossible in this particular case. In conclusion, regardless of the installed shearer ("A" or "B"), the actual and possible extraction in the analysed longwall was much lower than the assumed 5000 Mg/day.
On the assumption of failure-free operation of the longwall complex, the "B shearer" – 4504 Mg/day, compared to 2954 Mg/day for "A shearer" (Table 2) was closer to achieving the assumed result.

This result was probably affected by the inappropriate selection of extracting machine (Maruszewska & Biały, 2013). It can be concluded that the shearer which was used in this particular longwall was not properly selected. The selection of a shearer was not preceded by a thorough analysis of the existing geological-mining conditions – the shearer available on the mine was used.

Table 2 Actual and possible extraction

Lp.	Parameter	shearer 1	shearer 2	entity
Extraction that includes failures				
1	Total net extraction	199602	317587	Mg
2	Actual working time of the longwall complex	79054	82495	min
3	Total time of all failures	19226	15785	min
4	Failure rate at available time	24	19	%
5	Actual extraction per hour	122	194	Mg/h
Actual daily extraction		2379	3783	Mg/day
Extraction without failure				
6	Total net extraction	248145	378355	Mg
7	Possible extraction per hour	151	231	Mg/h
8	Possible extraction per mining shift	739	1126	Mg/day
9	Loss due to the sum of failures	48543	60769	Mg
10	Loss due to conveyor failure	16556	32794	Mg
11	Possible extraction taking into account conveyor failures	2757	4114	Mg/day
12	Loss due to mining, supports, other failures	176	144	Mg
13	Possible extraction including mining, supports, other failures	2778	4361	Mg/day
14	Loss due to shearer failures	17136	15763	Mg
15	Possible extraction taking into account shearer failure	2750	4317	Mg/day
Possible daily extraction		2954	4504	Mg/day

Source: own study based on (Książka raportu, 2017; Raport, 2017)

Such a selection method of extracting machine very often leads to downtime caused by failures, which translates into economic results achieved by the mine.

ECONOMIC ANALYSIS

The evaluation of economic effects with regard to the analyzed longwall is influenced by the basic values obtained by individual shearers, taking into account unplanned interruptions in operation (failures). Table 3 presents the actual effects obtained, such as:

- actual daily extraction,
- nine face performance,
- unit performance,
- total value of the extraction obtained.

Analyzing Table 3, it can be noted that all the values obtained during the longwall operation of "B shearer" definitely exceed the values obtained with the use of "A shearer". Each of these shearers was operated in the longwall for the same number of working days (84), under comparable geological-mining conditions. "B shearer" achieved an average daily extraction higher by 1404 Mg/day, which represents a 59% increase in extraction (Figure 3, 4).

Table 3 Economic analysis of the studied longwall

Lp.	Parameter	shearer 1	shearer 2	entity
1	Average coal price	240	240	PLN/Mg
2	Actual daily extraction	2379	3783	Mg/day
3	Daily extraction value	571	908	thousands PLN
4	Number of crew members in the longwall	58	58	number of people
5	Mine face performance	41	65	Mg/working day
6	Mine face performance value	10	16	thousands PLN/ working day
7	Number of crew in the mining unit	100	100	Ilość osób
8	Unit performance	24	38	Mg/working day
9	Unit performance value	5.7	9.1	thousands PLN/ working day

Source: own study based on (Książka raportu, 2017; Raport, 2017)

Fig. 3 Actual daily extraction

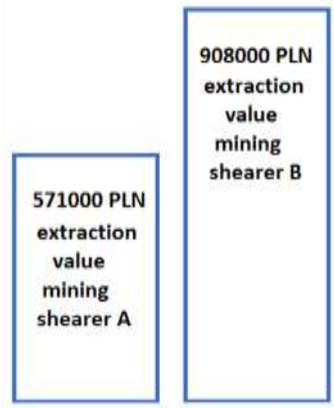

Fig. 4 Extraction value

The above analysis shows how important the correct selection of a mining machine has on the hard coal mining efficiency (and what is related to its economic effects).

CONCLUSION

The problem of maximum use of available machine time is an issue that occurs in practically all branches of industry, hard coal mining is not an isolated case.

Therefore, it is necessary to analyze the causes of failures and their consequences for the mine, which are the result of failures regarding technical means, which have the greatest impact on downtimes.

This analysis should indicate whether the causes of failures resulted from:

- human factor (operational, maintenance, handling faults),
- technical measures (construction and execution errors),
- others that do not result from the previously mentioned criteria, e.g. particularly difficult working conditions.

In hard coal mines, the mining process has the main impact on the efficiency of coal extraction as well as on the economic effects achieved. Technical means, especially the mining machines, constitute an important element of this process. Therefore, it is very important to properly select a shearer to the geological and mining conditions existing in the longwall. This has an impact on the working time and thus on the efficiency achieved.

The conducted analysis of longwall shows that there are quite significant differences in interruptions resulting from failures of various elements of the longwall complex. In the analyzed longwall, the greatest limitation was “A shearer”, which represented 6800 minutes of downtime, i.e. 8.6% of the available time. This resulted in the greatest loss in extraction. After replacing the mining machine with “B shearer”, the downtimes caused by failures were reduced by almost 40%. Hence, the average daily extraction with the use of “shearer 2” was 3783 Mg/day, as compared to 2379 Mg/day with “shearer 1”, representing a 59% increase.

From the analysis of longwall reinforcement it can be stated that:

- downtimes and failures that occur at the stage of longwall reinforcement mainly concern machines transporting heavy equipment elements to the areas where the reinforcement takes place,
- the main reason turned out to be very difficult climatic conditions in the mine – high humidity and air temperature.

Breakdowns of individual machines and equipment cause great losses for the mine, thus it seems justified to propose such actions (Kołodziej, 2004) which would help to reduce the number of potential failures.

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Abstract: This paper presents the problem of technical means failure, used both in longwall reinforcement and in the mining process. Longwall reinforcement – a concept related to launching a longwall mining excavation – is one of the most important elements in the process of hard coal seams exploitation. It consists in introducing all necessary machinery and equipment to the future longwall in order to enable the effective mining process. The efficiency of a longwall excavation as well as works related to the reinforcement of longwalls depends directly on properly selected machines and equipment of the longwall complex. In order to ensure greater effectiveness and efficiency, it is necessary to find the causes of the most frequent failures in these processes and effectively counteract them. These actions result in increased production availability of machines and equipment involved in the mining process. The increase of production availability is significantly influenced by the technical condition of technical means used both in longwall reinforcement and in the mining process, and their proper selection. This will ensure a largely failure-free and uninterrupted progress of works.

Keywords: technical measures, failure, longwall reinforcement, mining process