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Capacity losses factors of fully mechanized longwall complexes

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Abstract:

Between longwall (LW) fully mechanized complex with shearer theoretical capacity (potential) and really achieved capacity sometimes there is a significant difference. In article sources of those differences are described. There are external and internal factors constraining real capacity below LW complex technical potential as local conditions and menaces. Mining technologies and extraction process management and organization are seriously affecting the final result. Differences between potential and achieved LW complex capacity are in fact capacity and capital asset losses. In the article main reasons of those measurable capacity losses are pointed out such as available time losses and incomplete fully mechanized LW technical potential: shearer cutting speed, cutting depth and seam thickness use ratio.

Streszczenie:

Pomiędzy teoretyczną a rzeczywistą wydajnością zmechanizowanego kompleksu ścianowego z kombajnem węglowym bardzo często występują duże różnice. W artykule podjęto próbę wskazania źródeł takich różnic. Są to czynniki zewnętrzne i wewnętrzne ograniczające możliwości wykorzystania potencjału technicznego kompleksu ścianowego w postaci warunków górniczo-geologicznych, a w tym występujących zagrożeń górniczych. Istotny wpływ wywierają także czynniki związane technologią prowadzenia robót górniczych oraz organizacją i zarządzaniem procesem wydobywczym. Jako główne przyczyny, będących w istocie stratami, mierzalnych różnic pomiędzy potencjalną a rzeczywistą wydajnością kombajnowego kompleksu ścianowego wskazano straty dostępnego czasu pracy kompleksu oraz niepełne wykorzystanie potencjału technicznego w postaci prędkości urabiania, głębokości zabioru i wykorzystania miąższości pokładu oraz niektórych przyczyn występowania takich strat.

1. Introduction

Comprehensively mechanized longwalls are potentially the most efficient technology for the implementation of the mining process in the coal extraction [1].

Among the longwall systems of hard coal mining, fully mechanized longwall complexes allow to obtain a daily production of over 50,000 tpd for mining with shearer loaders [2]. An alternative technique for mechanical mining of coal in mechanized longwall systems are coal ploughs [3], but they are much less common due to technical requirements and price (currently 17 comprehensively mechanized plough longwalls are in operation worldwide). Moreover, the plough longwall systems have a limited scope of application due to the maximum cutting height (up to about 2.2 m) and therefore, even in the most favorable conditions, they do not achieve such record results as some longwall systems with shearer loaders. For this reason, the article focuses on mechanized longwall systems with shearer loaders. Although conventional longwall systems (with blasting) and various variants of semi-mechanized longwall [4] systems are still operated in the world, the production level of longwall systems is determined by fully mechanized complexes [5].

2. Mechanized longwall complex – idea, components and their cooperation/compatibility

Regardless of the mechanization degree, the longwall is intended to carry out the basic operations of the extraction process, i.e. [6]:

- coal mining,
- loading coal onto a haulage device (armoured face conveyor - AFC),
- hauling/transporting coal along the face.

In the extraction process implemented in the longwall heading, an additional operation is performed in the form of temporary and ultimate protection of the heading by providing a roof support (temporary and/or ultimate one). The fact that in the first longwall operations (17th century) and the modern ore mining often there wasn't a need to secure the working space of the longwall [1], the operation of temporary and ultimate protection of the heading has been recognized as of an additional/auxiliary nature. The longwall heading is secured by supporting the roof and/or covering the working space of the face. Historically, various technical and technological solutions have been applied in the longwalls:

- traditional longwalls – with hand mining. At the beginning, all operations of the extraction process were carried out manually with simple tools, gradually replaced by manual machines (the impact hammer replaced the pickaxe, the mechanical shovel replaced the manual shovel, and finally the transportation of the output material in boxes or simple cars was replaced the oscillating conveyor and then the belt conveyor).
- Conventional longwalls - with the mining of coal body with explosives (blasting). Starting from performing all operations manually through mechanical drilling of blast holes with hand drills. In order to reduce the labor consumption of blasting works, the cut/breaking in hole (i.e. an additional exposure plane) made by means of blasting works was replaced by the notch performed mechanically (using various types of cutters). Conventional longwalls are associated with the use of armoured conveyors (Upper Silesia, around 1942). Later, chain cutters were additionally used to load the output material onto the armoured conveyor.
- Fully mechanized longwalls – with mechanical mining with the use of coal ploughs and longwall shearers (initially cutting ones, being the development of chain cutters, to modern shearer loaders with ranging arms).

When considering the degree of mechanization of the extraction process in coal longwalls, three basic stages of mechanization can be distinguished:

- **Small (manual) mechanization**, where some operations are mechanized by means of hand-held mechanical tools (impact hammer, drill, mechanical shovel, etc.),
- **Partial mechanization**, where one or several operations is/are mechanized among many operations performed. The first mechanized operation to be mentioned was the transport of the excavated material in the longwall by means of oscillating or belt conveyors applied at the beginning of the 20th century (hence the replacement of Longwall Mining with the term Conveyor Mining in Great Britain at that time). Mechanical mining with cutting shearers appeared in the British mining just before the World War II, the first coal ploughs were implemented in the German mining industry during the World War II. The first mechanized (without hydraulic components) roof supports also appeared in the German coal mining in the first half of the 20th century. At similar time, the first longwall protective roof supports (without hydraulic components) appeared in the mining industry of the former USSR. The individual devices were not functionally coupled to each other at that time.
- **Complex (full) mechanization**, where all extraction process operations in the longwall are mechanized. Contemporary, comprehensively mechanized longwalls are equipped with systems of functionally combined machines and devices. In the Polish conditions, it is difficult to talk about complex mechanization of longwalls due to a large portion of manual operations performed in the area of the AFC drives in the zone of intersections of the face with the gateroads secured by the yield arch supports.

Complex (full) mechanization of the process is a necessary (fundamental) prerequisite for the automation of this process.

A modern mechanized longwall system is composed of several basic elements:

- Cutting machine (shearer or plough),
- Armoured face conveyor,
- Powered roof support,
- Beam stage loader with crusher,
- Hydraulic pump unit supplying the powered roof support,
- Set of electrical devices powering the longwall equipment.

Fig. 1. Fully mechanized longwall complex with coal shearer – general view [own source]

The basic elements of the mechanized longwall complex provide various functions intended for a good operation of the aforementioned components and their mutual correct cooperation, as follows:

- The cutting machine (shearer or plough) is primarily intended to mine coal (to separate it from the unmined coal) and load it onto the armoured face conveyor. An additional function of the cutting machine is to prepare (cut) the space for the other longwall devices for their proper operation. Therefore, sometimes it is necessary to additionally trim/cut rocks in the vicinity of the coal seam (in the floor or in the roof) or to leave the coal in the floor or roof of the longwall. In the case of high longwalls, crushers sometimes are installed on the longwall shearer (from the AFC tail drive) to crush large lumps of coal, especially with the shearer cutting towards the tail drive (in the opposite direction to the AFC running direction).
- Face conveyor (so called armoured or articulated conveyor) is mainly intended to haul the coal mined by the cutting machine along the longwall. The armoured face conveyor also provides the following functions:
  - the armoured face conveyor is a specific keystone/closer (backbone) of the longwall,
  - the mining machine (plough or shearer) moves along the AFC and the powered roof support is attached to it,
  - a movable part of hoses and cables supplying the shearer is led in the cable trays (spill plates),
  - the armoured face conveyor is a mechanical connection of individual powered roof support units/shields (enabling their movement - advancing),
  - the AFC pan route also serves as a structure for leading electrical cables and hydraulic hoses through the longwall, and in the plough longwalls – for leading the pull and return chain of the plough (as in the Mikrus longwall complex),
  - the AFC structure is often also used to attach additional equipment (communication and signaling devices, and emergency stops),

    - the AFC structure enables the stream of transported material to be partially aligned during transport,
    - sometimes, especially in high longwalls, it is necessary to use an additional crusher on the main drive of the armoured face conveyor in order to crush very large lumps of excavated material that could block the transfer from the face conveyor onto the beam stage loader and cause the longwall to stop - production stoppage.
- The powered roof support - its primary function is to protect the working space of the longwall. This is obtained by supporting the roof and/or preventing the caving rocks/debris from falling into the working space of the longwall. In addition, the powered roof support provides the following functions:
    - it's a base for advancing the armoured face conveyor,
    - the advancing ram is intended to advance the armoured face conveyor,
    - the advancing ram is intended to advance the powered roof support units/shields,
    - structural elements of the powered roof support units/shields are base for installing additional yield components – rams (for correction or stabilization of the longwall equipment components),
    - it's a base for installing other longwall equipment, including:
        - hydraulic hoses
        - cables
        - components of the control system (the powered roof support control system included), communication and signalling systems.
- The beam stage loader (BSL) with a crusher (resizer) is intended to unload the output material from the armoured face conveyor, the material whose stream is uneven and containing quite large lumps. The design and construction of the beam stage loader enables to align the stream of output material, and the crusher embedded on it is intended to break large lumps of spoil before loading it onto another conveyor – a belt conveyor, which is characterized by high sensitivity to overloading and/or the presence of oversized lumps of material. Belt conveyors do not tolerate local overloads and large-size lumps, therefore the material from the armoured face conveyor is not discharged/unloaded directly onto the belt conveyor. Additionally, the beam stage loaders are equipped with boot ends enabling the BSL to be moved along the gate, sometimes together with the return station of the belt conveyor.

In the studies of the productivity or efficiency of the mechanized longwall systems, it is also necessary to indicate the elements not being part of this system, but having significant effect on its operating conditions, such as the shape and type of the gates (maingate and tailgate).

3. Factors affecting the actual productivity of the fully mechanized longwall complex.

Seemingly, productivity of the mechanized longwall system depends only on the resulting/ the lowest productivity of the devices the longwall system is composed of. However, as many years of observations show, the real average productivity of longwall complexes is lower than the theoretical technical productivity of an individual longwall complex. This is due to the fact that there are factors that limit this productivity. The main factors that decrease the actual productivity at the longwall system are as follows:

- Local conditions (geo-mining ones included) and menaces/risks,
- Applied technologies of operating the technical system of the longwall and the skills of operators and managers,
- Faulty management and organization of work (Fig.2).

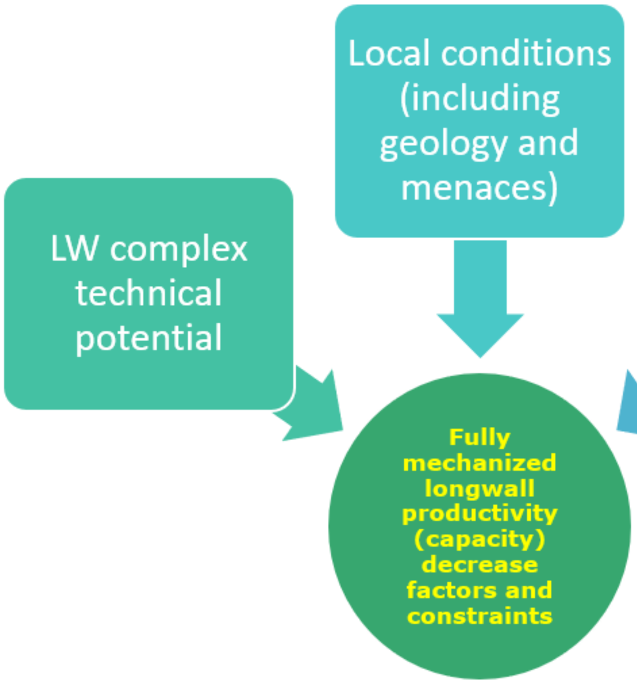

Fig. 2. Main groups of constraints – productivity decrease factor in LW extraction [own source]

As a result of the occurrence of factors (constraints) limiting the productivity/capacity of coal longwalls, their actual productivity/capacity is lower than theoretically possible (Fig.3).

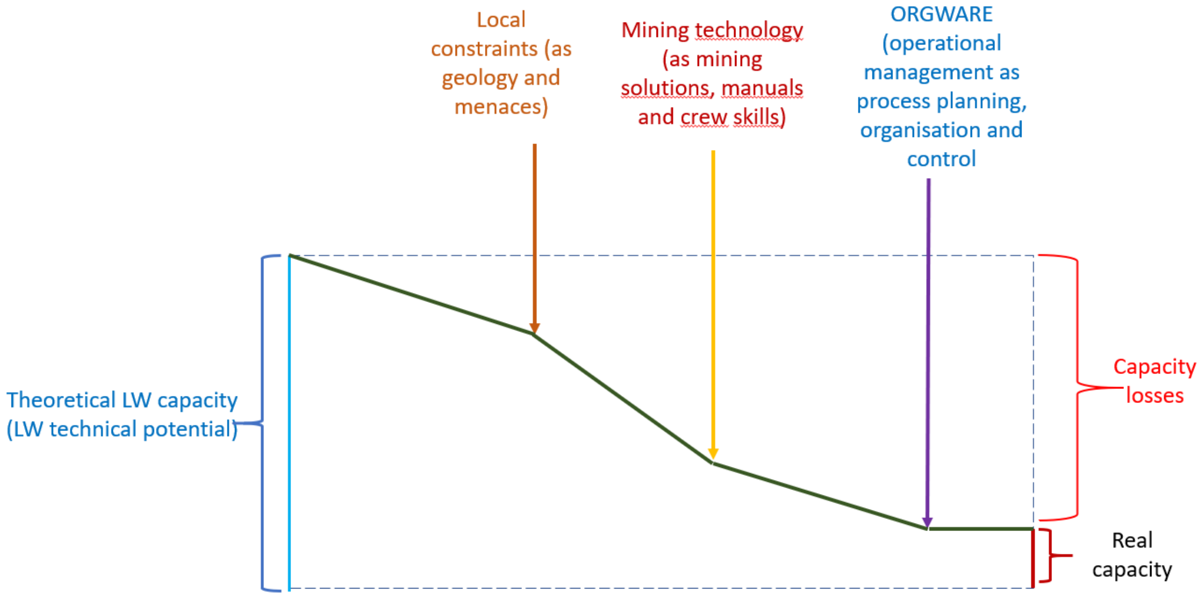

Fig. 3. Theoretical and real LW face capacity and capacity losses [own source]

In the analysis of the reasons of capacity losses, a detailed analysis of the causes of their occurrence and a possibility of eliminating or reducing them is significant.

4. Reasons for occurrence of productivity/capacity losses of longwall systems with shearer loaders.

The above-mentioned general factors decreasing the longwall systems productivity/capacity can be presented in a different way as losses of the theoretical capacity (potential) losses of this technical system (Fig. 4).

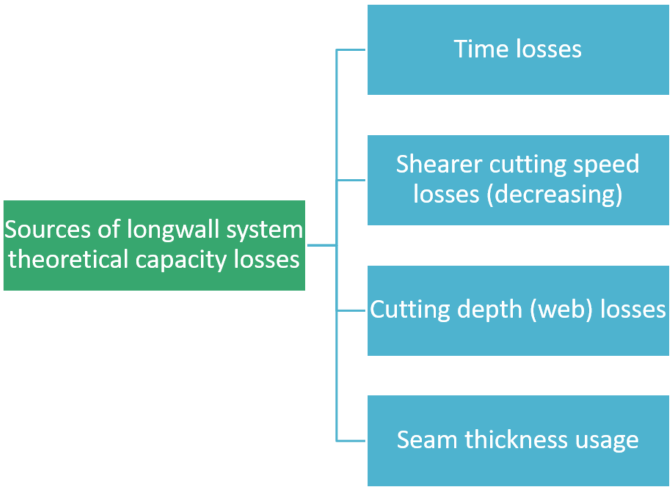

Fig. 4. Main sources/reasons of theoretical shearer longwall complex losses[own source]

All these capacity losses result from the constraints shown in Fig. 3. The research work and analyses carried out by the Author show that the greatest capacity losses of the mechanized longwall complex result from an incomplete use of the available time and the failure to use available speed of the cutting machine - the longwall shearer.

In the Polish coal mining industry, since the introduction of drum longwall shearers into operation, first in partially and then fully mechanized longwalls, studies of the degree of utilization of the technical potential of these shearers have been conducted for many years and a number of KPI - Key Performance Indicators [7] have been defined. The economic transformation in the 1990s meant that the measurements and analyses of these indicators have been gradually abandoned. Nowadays, also in the Polish coal mining industry, the analysis of the operating time of mechanized longwall systems is being restored [8].

4.1. Losses of available cutting time

The use of the available working time of mining machines is a very important element in the search for the productivity of the mining process [9].

For many years, the Polish underground coal mining has been dominated by a mechanized longwall system almost exclusively with longwall shearers, and recently only with caving. After a period of careful research on the use of longwall systems [10] in the form of a system of indicators, such analyses were gradually abandoned, mainly due to the lack of automatic measurement tools. However, advanced tools for monitoring and diagnostics of the operation and condition of longwall systems have appeared [11, 12]. For several years, the measurement the operating time use in the case of the shearer longwall systems has been applied again in the Polish companies extracting hard coal, as one of the components of the of the mining process assessment - KPI (Key Performance Indicator) [8].

Very often, in the Polish hard coal mining industry, the degree of use of longwall shearers in terms of percentage of working time of these machines in the daily time has been applied in the assessments. The low percentage of this time is treated as an assessment of the reliability of mining machines, regardless of their manufacturer. Meanwhile, similarly to the analyses used in the Polish hard coal mining industry in the past, the optimized time structure has been used in the very modern and efficient Australian coal mining, as shown in Fig. 5.

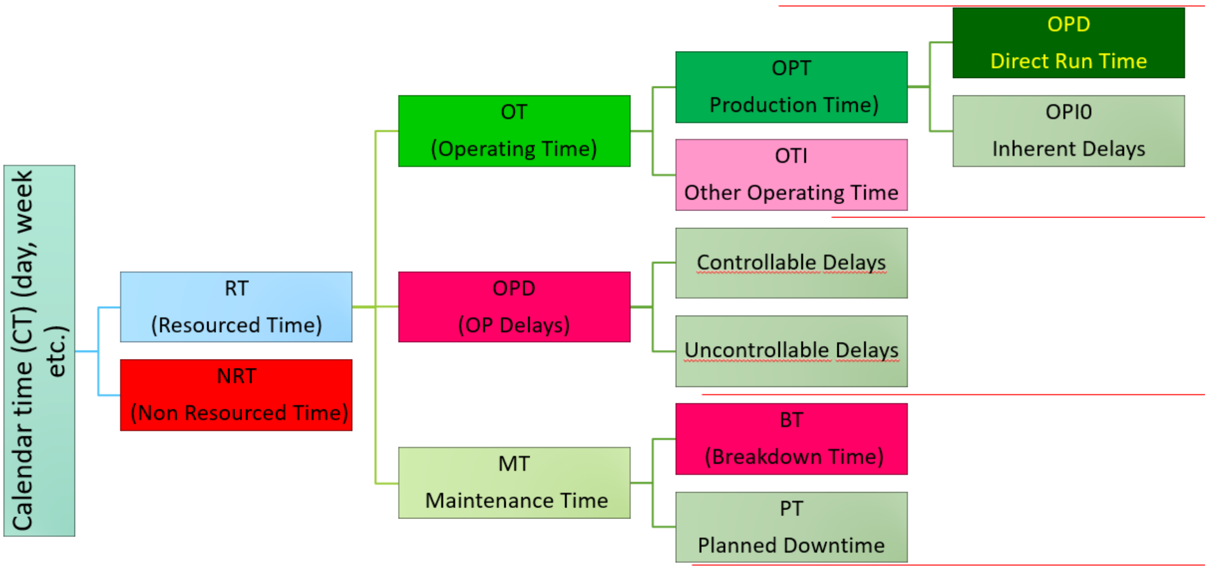

Fig. 5. Calendar time structure in longwall operations [8]

Direct Run Time is the working time of a longwall shearer while it's cutting. Theoretically, it should be aimed at 100% of this time in calendar time, but it is not feasible. It is not possible to eliminate OTI (Other Operating Time) and OPIO (Inherent Delays) completely - you can only try to shorten them. In the conditions of the Polish underground hard coal mines, operations at the longwall ends, that is at the face-gate crossings, are a significant source of time losses, which is a potential chance for a significant improvement in the time use of the longwall complex [13, 14, 15].

A question can be asked whether it is possible to eliminate breakdowns and normal technical maintenance (MT) completely by an appropriate construction and operation of the mechanized longwall system? Certainly, it is necessary to eliminate completely organizational breaks (OPD), the causes of which are outside the longwall complex itself and result from the process organization and management, mining and geological conditions and the technical condition of the technical infrastructure outside the longwall. It is unlikely to eliminate completely organizational interruptions and delays in the mining process, but any time reduction within this scope results in the OPD (Direct Run Time) increase.

4.2. Utilization of nominal speed of the shearer cutting

Observations of the actual cutting speed of shearer loaders in one group of the Polish mines show that the actual speed is lower than the nominally available one. Even an elimination of the periods at the speed "0" m/min from the analysis indicates that the average speed is significantly lower than the nominal speed (Fig. 6).

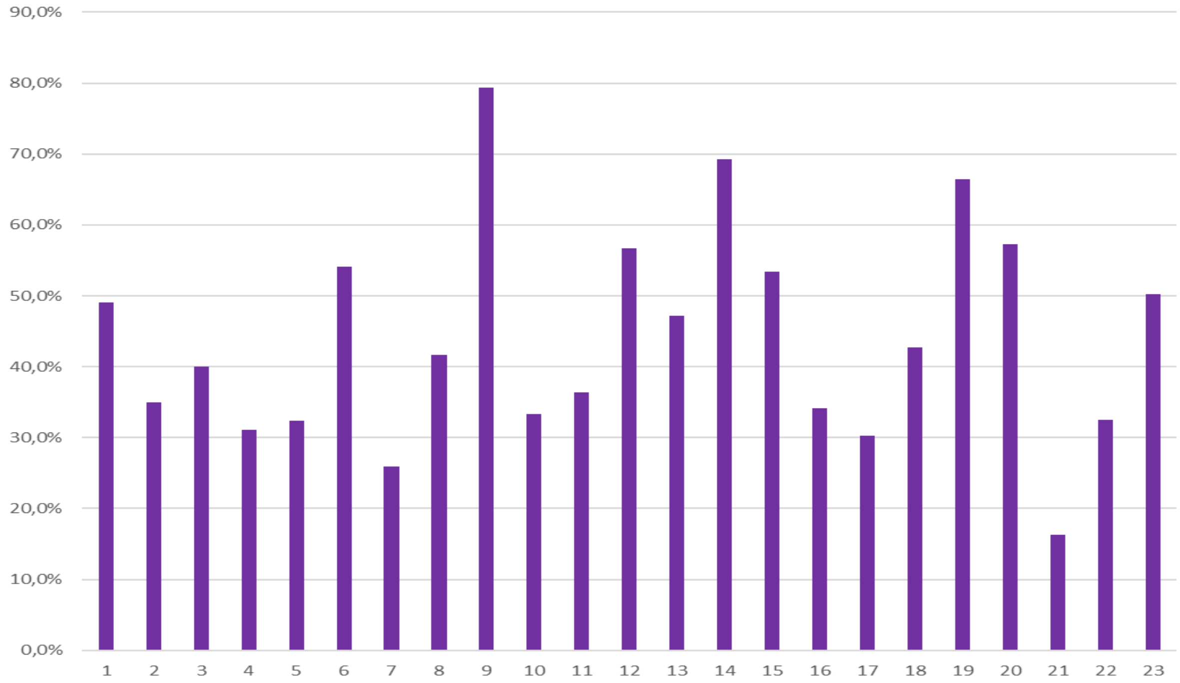

Fig. 6. Utilization of nominal speed of longwall shearers in one of the Polish mining companies in January 2019 – monthly average [own source]

The main constraints/factors limiting the average speed of longwall shearers are:

- Poor technical condition of the longwall equipment which does result in stoppages (e.g. deteriorated condition of the AFC as the runway for the shearer).
- High level of methane hazard requiring a reduction of the shearer cutting speed (for the actual longwall, the cutting speed is a factor significantly affecting the volume of methane emitted) [16].
- A large number of the shearer stops and its bringing to speed due to various reasons.

4.3. Cutting depth (web) losses

Longwall shearers have a constructionally set (nominal) cutting depth to which the stroke of the advancing systems of the powered support units/shields is adapted [17, 18]. However, there are situations when the actually obtained web of the shearer is lower than the nominal one, which is a loss of the longwall capacity. The main reasons for such situations can be as follows:

- Inaccurate loading of the output material and leaving it between the face and the armoured face conveyor, which limits the actual (performed) web of this conveyor
- In the event of errors by the operators of the powered roof support and/or the powered roof support control system, the gate support unit/shield may be positioned non-perpendicularly to the armoured face conveyor and, consequently, the actual advancing web of the longwall may be reduced. Such situations often occur in longwalls with a longitudinal slope exceeding 15°. Additional operations related to correcting the p.r.s.units/shields positioning may also reduce the shearer cutting speed, which is also a source of productivity loss (of the available longwall potential).

The Author's analyses show that the degree of utilization of the shearer nominal web in the longwalls of high productivity/capacity is 100% (and in some cases it is even slightly higher). However, there are cases when the resulting web depth (for a larger number of cycles) differs significantly from the nominal value.

4.4. Use of the seam thickness

Effective use of the seam thickness should mean cutting and loading the entire seam thickness, unfortunately sometimes with rock interlayers occurring in it. Therefore, one should strive to select the mining machine in such a way that it is able to cut the entire available seam thickness. Leaving the unmined coal layer means a waste of not only the available resources, but also of the available technical potential of the longwall system. It happens, however, that the mining machine cuts the rock in the vicinity of the seam as a result of the decrease in the seam thickness, incorrect selection of the mining machine or operator's errors. These are also potential losses resulting in the limitation of the cutting speed and loading the transported mined material with additional ballast which is also decreasing the output material quality. It should be also noted, that in many coal basins there are seams, in the mining of which there is a spontaneous collapse of the direct roof layer, but this phenomenon is independent of the selection of the mining machine or operator's errors [18, 19, 20].

5. Summary

High investment expenditures and operating costs related to an operation of comprehensively mechanized longwalls require their high productivity and an elimination of any losses of the available mining potential, as well as a full use of the available operating time of the longwall complex (understood as the cutting time of the shearer). Potential capabilities of capacity growth exist, for the real longwall complex, in the field of planning, technology and organization of the extraction process.

The observations of the majority of longwalls in operation in Poland show that, even with the existing constraints caused by geo-mining conditions and menaces (hazards), the degree of utilization of the technical potential of the longwall systems is low. The main reasons for the low utilization of the available mining capacity of the mechanized longwall systems lie in the large losses of the available/nominal time (for cutting), including the time lost at the longwall ends. Another noticeable reason is a failure to use the technical capabilities of the longwall system equipment, which may indicate errors in planning and selecting equipment adapted for in-situ conditions.

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