Efficiency optimization of plow systems through the precise planning of new and comprehensive enhancement of operating longwalls

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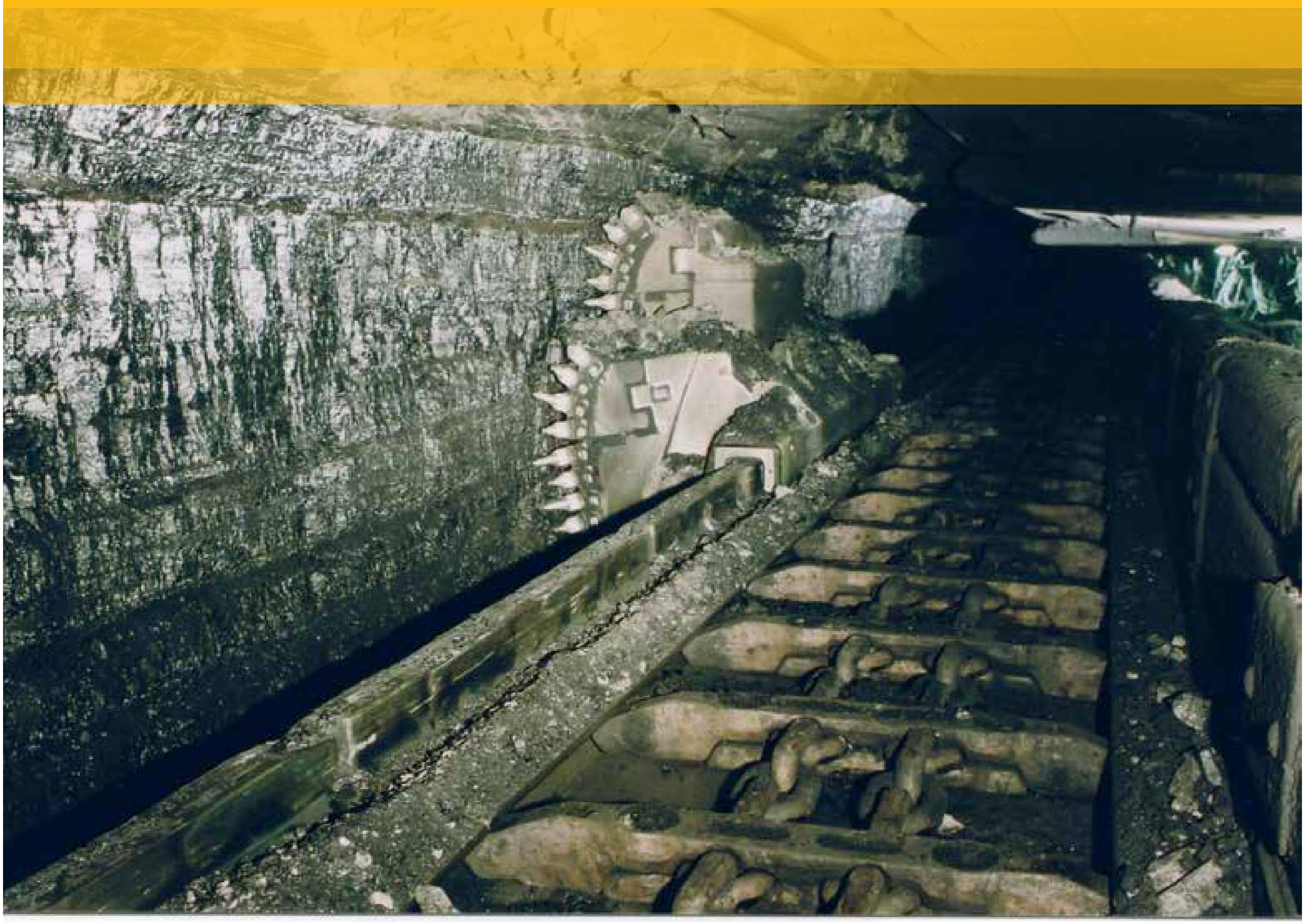

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Abstract

Plow technology has reemerged and increased in importance in recent years, as many operators worldwide searched for an effective technology for extraction of thin and medium-thickness coal seams. Plow systems have significantly improved recently, resulting in higher production from plow faces. Nevertheless, there is an appreciable potential for further performance increase by the means of optimal technical, procedural and organizational improvements. One very important factor for the achievement of planned production rates is a correct plow face design. On the other hand, a performance improvement is possible in many cases without significant changes of the longwall system, instead simply requiring consistent analysis and effective realization of conclusions. The main message of this paper is that production can be strongly increased—even doubled—by paying careful attention to the correct design and optimal operation of a plow face.

KEYWORDS

Plow longwall operation, proper design, operational procedural and organizational factors, performance improvement and efficiency increase.

1. Introduction

Plow longwall systems have been working for more than seventy years. In that time, thousands of plow faces were in operation worldwide. The technical layout of plows has changed dramatically since the first years. The rated power increased by 10 to 12 times, the equipment became decisively more powerful and—most importantly—computer-based systems were implemented to control plows, allowing their full automation. There is a clear correlation between these factors and the performance of plow faces, clearly identifiable by analyzing the respective numbers from the last four decades. On the other hand, the total running time of plow systems has generally moved within a specific range over the years, proving to be difficult to increase. This paper concentrates on technical, operational, procedural and organizational factors aimed at maximizing performance, as in most cases there are numerous opportunities to increase production significantly without changing the overall system configuration.

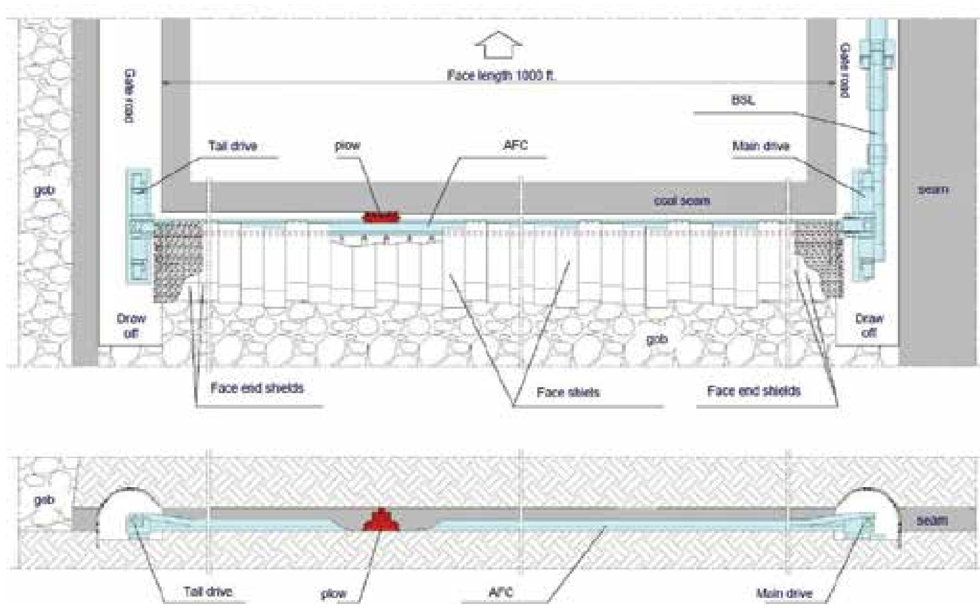
2. Planning of a Plow System

2.1 TECHNICAL LAYOUT OF A PROJECTED FACE

The technical layout of a longwall has a crucial influence on its future performance. In this phase, an in-depth analysis of all data, and information, influencing factors for all the important areas is critical.

In general terms, the equipment selection for a planned face depends on the required production in connection with the all-important mining, geological and logistical factors, as well as the disposable financial means. It is vital to select the face equipment in a coordinated way in order to reach the highest production and to avoid bottlenecks, which could hamper production. Choosing the right equipment has to be carried out thoroughly, as potential mistakes during the design phase can only be mitigated later through immense effort, if at all. In the case of plow faces the most important equipment features that count are:

- Installed power and speeds of plow and AFC
- Plow body type and height range
- AFC width and spill plate height
- Discharge type
- Height range and support density of shield support
- Type of automation and control system
- Power supply
- Conveyance method for extracted material



Exemplary plow face layout

Modern plow systems use gearboxes with overload protection for both the plow and the AFC. The overload protection secures the chains against forces resulting from rotational energy stored in turning motor rotors. For that purpose, multi-disk clutches are used to limit the carried torque.

Another important element of modern plow systems is the use of variable frequency drives (VFDs). These drives contribute the following properties:

- Protection against electric network overloads
- Unlimited number of start-ups of asynchronous motors
- Infinite speed setting ranging from 20-120% of nominal speed
- Equal load shearing between two drives

2. Planning of a Plow System

2.2 ECONOMIC EFFICIENCY OF THE PLANNED FACE

While planning for new equipment, the lowest capital cost possible is frequently the pivotal criterion. While designing a new plow face, the cost-effectiveness of applied equipment should be a subject of in-depth analysis. In this phase, analysis of all initial capital expenses for different options should be carried out. Furthermore, operational, repair, maintenance and overhauling costs for the complete service life of the equipment should be identified and calculated. Last but not least, the overall production rate and total tonnage considered over the whole operating life for the options in question should be thoroughly examined and collected.

With these numbers in hand, the lowest cost for one ton of saleable coal should be the determining criterion for optimal selection.

2.3 SAFETY ASPECTS

While planning a new face, all necessary safety aspects have to be consciously considered. In order to optimize the future operation, the technical and procedural design aspects should be harmonized with safety-related conditions. Restrictions related to strata pressure, rock burst, fire, methane and water hazards can have a strong negative influence on face performance.

Plow system with dust suppression system ("water curtain")

3. Enhancement of Running Faces — Operating Factors

3.1 PLOW FACE SHAPE

Plow faces are most commonly operated in a bow shape, where the face in the middle is more advanced than at the drives by 1–2 percent of the face length as a rule of thumb. This advance in mid-face is motivated by multiple factors:

- Allows effective horizon control along the face
- Increases avoidance of roof fall-outs
- Enables easy adjustment of differences in distance between gate-roads along a panel

The bow should not be bigger than 2 percent of the face length, or else higher-than-normal forces on the chains cause an increase of power consumption for the plow and AFC, resulting in higher wear on all movable parts.

Plow at face end (tail drive)

The AFC should be kept untwisted along the face. A horizontal seesaw AFC run increases frictional resistance of the plow's chain or the AFC's chain assembly.

Vertical undulations should be followed; although in case of very sharp synclines and anti-clines, a smoothing through the floor and/or roof cut can help to increase the radius of AFC vertical bends. Sharp AFC bends close to drives, especially to the main drive, should be avoided, as they strongly increase power consumption and wear.

3.2 PRE-TENSION OF CHAIN DRIVEN FACE EQUIPMENT

For the proper functionality of a plow and AFC, the chains of both devices need a correct pre-tension. Too low a pre-tension can lead to excess chain slack and result in breakages. On the contrary, too high a pre-tension causes high power consumption as well as high wear and—in the worst cases— a chain breakage.

The manufacturers of plows and armored face conveyors deliver values of optimal chain pre-tension for their products, calculated for given conditions such as rated power, chain speed, face length and type of chain(s). Nevertheless, as a rule of thumb the chain has its optimal pre-tension when the greatest allowable amount of chain slack occurs during the highest load.

AFC and plow chain

3. Enhancement of Running Faces — Operating Factors

3.3 OPERATION OF OVERLOAD PROTECTION DEVICES

Every comprehensive face system has its overload protection. Both the plow and AFC have overcurrent protection for their electric motors and protection against excessive torques on drives. Hydraulically driven devices like shields are protected against too high a pressure. The settings for those protection systems are vital for proper operation and protection of the equipment. As the working conditions can change over the course of a panel, these settings have to be frequently checked and adjusted accordingly.

The periodic check of overload protection settings is the best pre-condition for long operating life of the equipment. For that reason, the most important settings should be registered by control systems for a troubleshooting analysis.

3.4 HEIGHT OF THE PLOW BODY

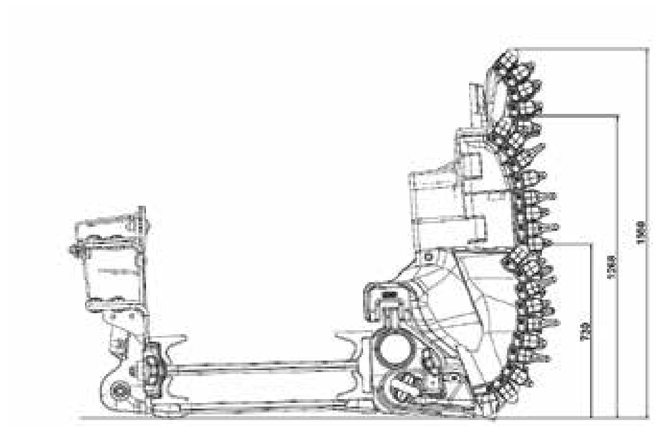
Contemporary Cat plow bodies have an adjustable height. The main height adjustment is carried out by adding or removing intermediate extension blocks to the plow body. The height of a single intermediate extension block amounts to 250 mm. Intermediate blocks can easily be stacked, allowing height adjustment over a wide range. The continuously adjustable middle bit column can be used for the fine setting of the plow body height. The adjustable bit column can be extended by 300 mm.

Plow body height amounts to 60-80 percent of the face height in most cases. The top layer of coal seam left at the roof falls down after a number of plow cuts. This method of plow operation delivers a number of advantages, such as:

- The highest attainable webs
- Low wear of plow body guidance parts because of small lever arm
- No cutting of the roof by top bits
- No danger of potential collisions with canopies

As coal gets harder, cutting at full face height can prove necessary; as growing coal hardness can cause the parting of the seam at the roof to deteriorate in many cases. In this situation, the plow height is the same as the face height, with all of the disadvantages connected to that type of operation.

As a general rule, the height of a plow body should be kept as low as the circumstances in the face allow it to be.



Exemplary plow body height options

3. Enhancement of Running Faces — Operating Factors

3.5 BIT CONFIGURATION

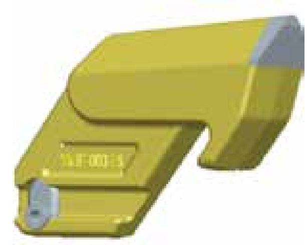
Bits used on today's plow bodies are divided into several categories:

- Carving bits short
- Carving bits long
- Bottom bits
- Top bits

The carving bits are narrower than the bottom or top bits. For hard seams or for seams with dirt bands, the plow body is normally equipped with all short carving bits apart from the lowest and highest bit holders, where bottom and top bits are used accordingly. In case of weaker seams, short and long carving bits are staggered on a plow body. This configuration delivers higher stability in the vertical run of the plow body and lumpier coal.

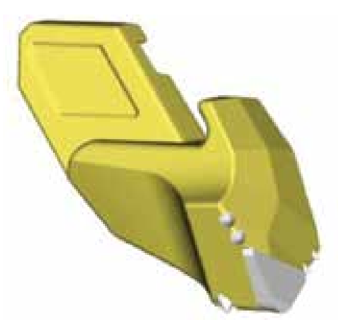
Carving bit, short

Carving bit, long



Top bit

Bottom bit, left side



Bottom bit, right side

3. Enhancement of Running Faces — Operating Factors

3.6 HORIZON CONTROL

Proper navigation of a plow system along the coal seam is one of most important activities on a plow face. There are two complementary mechanisms for height control.

- Vertical position of the bottom bit on the plow body. There are four different positions on every plow body: two for diving, one neutral and one for climbing. The setting of the bottom bit position has an influence on the complete face length.
- Position and angle of plow guidance and AFC pans along the face by means of horizon control (called also outrigger steering) mechanism. Hydraulic cylinders placed on the gob side of pans allow operators to set guidance inclination toward the coal face, causing the plow to dive or climb.

Outrigger steering cylinder for horizon control

On a hard floor, horizon control requires no action. Once a neutral position of bottom bits and outrigger steering cylinders has been found, the plow system will glide automatically along the seam-floor layer.

The situation is more complicated in case of a weak floor. Efficient horizon control on a weak floor demands skill from the workforce. When starting a face on a new seam, miners need to first learn the behavior of the AFC under new conditions and find the optimal settings by trial and error. The horizon control is one of most difficult operations on plow faces, as the outrigger steering is very sensitive and changes in settings can only be observed by the next shift. Therefore, the workers who made the changes cannot observe the results of those changes, which complicates the learning process. For that reason, moderate adjustments to outrigger steering settings are recommended for an inexperienced workforce.

3.7 AVOIDANCE OF BOTTLENECKS

In order to optimize the use of longwall equipment, all elements of the face and coal clearance have to be harmonized. Otherwise, less capable elements of a longwall system will present a weak link in the production chain. As a result, the overall performance of a longwall decreases.

It is important in the design phase to consider all influencing factors resulting from:

- Geology — properties of the seam and adjoining rock
- Strata pressure — roof support in gate-roads and in the face
- Ventilation — air supply, methane occurrence
- Energy supply — electric energy, compressed air, hydraulic emulsion, water
- Logistics — conveying of coal, material transportation, personnel movement
- Control system efficiency and functionality

4. Enhancement of Running Faces — Procedural Factors

4.1 OPTIMAL PLOW AND AFC SPEED SELECTION

Plow and AFC speeds have to be considered very precisely, as they are crucial to the performance of a plow face. When selecting speeds, a number of influencing factors have to be analyzed.

- Achievable plow cutting performance and according coal stream on AFC
- Available cross section of all conveyors
- Admissible torques of gearboxes
- Maximum permissible chain forces
- Maximum utilization degrees

Every longwall is unique in some way, so there is no universal procedure that ensures optimal plow performance. The most common procedure used in recent years is the “overtaking procedure” with 3 m/s speed of the plow and 1 m/s speed of the AFC. At a proportion of both speeds equal to three, the coal stream coming from the face is basically constant while plowing with long passes. The AFC is covered partially by threefold layers of load. If the required cross section of the conveyors is smaller, the speed proportion will be smaller than three.

In case of very weak coal and high faces the so-called “combination procedure” is used. At this procedure, the plow is moving on the pass to the tail drive with a speed comparable to the AFC speed, and on the pass to the head drive, i.e. while traveling in the same direction as the AFC, is moving with half speed. There are no multiple layers of load on the AFC at this procedure and thereby the coal stream is relatively low, allowing usage of conveyors with a small cross-section or operation with very high webs at wide AFCs.

4. Enhancement of Running Faces — Procedural Factors

4.2 LONG PASSES OR SECTIONAL PLOWING

In the early decades of plow face operation, extraction was carried out using a method called "sectional plowing". In this procedure, reciprocating plow movements in a certain section of the face were piloted by miners distributed in that area. After the face was advanced as far as intended, the roof support was advanced in this face section and the piloting team moved to next one. Typically, a face was divided in several sections. This type of operation was also used in face areas with roof fall-outs or faults, in order to better control the face.

In recent years, a method of plowing from one drive to another was systematically implemented. This type of operation was enabled mostly due to implementation of effective automation. With improving control systems in plow longwalls, long passes are more and more frequently applied, as they provide decisively higher performance at the face.

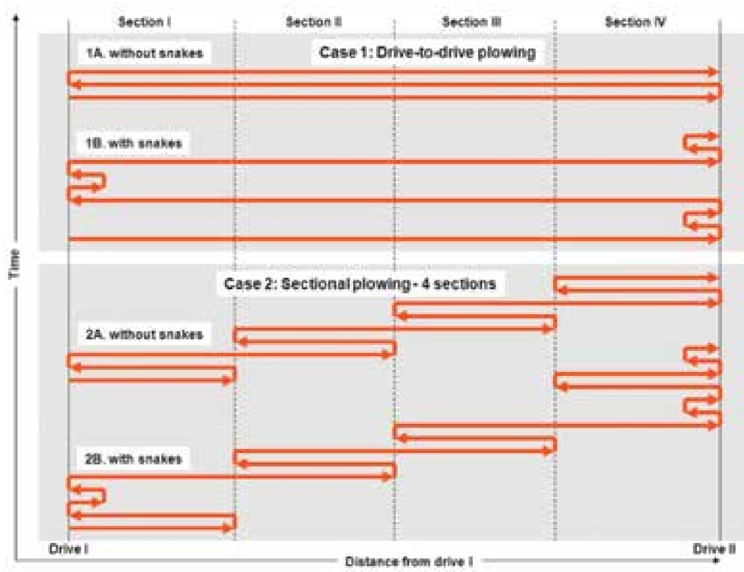


FIGURE 1. *Plowing in long passes vs. sectional plowing.*

4.3 DOUBLE WEB OR DOUBLE CUT

There are two methods of cutting face-end areas before moving back to the other drive.

- Cutting the face-end twice with single web
- Cutting the face-end only once with double web

Cutting the single-web cutting is used in hard seams where a double cut is difficult or impossible because of power consumption requirements and the resultant high chain forces. Cutting a face-end twice requires moving at a low speed over long distances and more frequent changes of direction, and thus more frequent switching of plow motors. These effects provoke a reduction of the procedural utilization degree and thereby cause a reduction in face performance.

If the seam hardness allows cutting with double web at face-ends, the procedural utilization factor and its related face performance increases by 10 to 20 percent.

To summarize: Double-web cutting at face-ends is preferred if technical circumstances allow the usage of this procedure.

4. Enhancement of Running Faces — Procedural Factors

4.4 PROCEDURAL UTILIZATION DEGREE AND FACE PERFORMANCE

The procedural utilization degree (PUD) describes a production diminishment caused by time and space losses related to uninterrupted plow extraction with full web within the running time of a plow system. In other words, PUD describes the efficiency of plowing. PUD is directly proportional to daily face production, so if the PUD increases from 40 to 80 percent, the daily gross production of the face doubles.

PUD depends on the number and duration of plow moves with lower-than-nominal speeds, number of short production breaks and the length of face sections plowed with a smaller-than nominal web. In order to reach the highest possible PUD, the following recommendations should be implemented:

- Plow exclusively in long passes from one drive to the other
- Plow with double web at face-ends if circumstances allow it
- Keep the breaks between direction changes as short as possible
- Accelerate the plow body in the shortest technically feasible time
- Switch to low speed while approaching the opposite side of the face as late as possible, with consideration for the necessary safety distance

One of the most important and measurable values describing the magnitude of PUD is the number of direction changes—also known as switchovers— in a time unit during the plow running time. Figure 2 shows the range of PUD as a function of switchover frequency in an hour.

Generally speaking, the longer the face and the lower the nominal plow speed is, the higher the PUD will be. The highest PUD can be reached while plowing in long passes with double web at face-ends, while using short switching times and decreasing the plow speed in a short distance when approaching a drive.

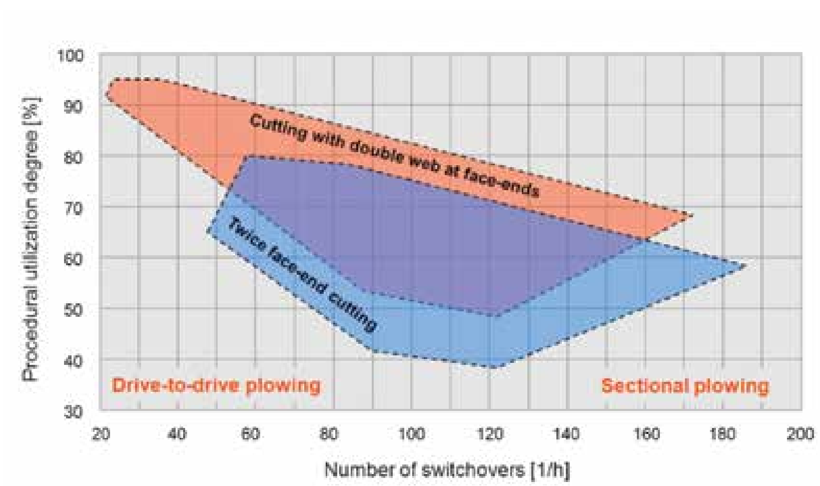


FIGURE 2. ***PUD as a function of switchover frequency.***

5. Enhancement of Running Faces — Organizational Factors

5.1 OPTIMIZATION OF WORKS

Good organization of works and discipline in plow faces is crucial in order to reach satisfactory performance. Frequent interruptions of work can be found at almost any longwall face. The most common reasons for those breaks are:

- Load congestion at conveyors
- Switching on the emergency brake
- Interruptions in power supply
- Overloads of plow or AFC
- Material transportation
- Works at face-ends

Many breaks can be avoided by having a good organization of work in and around the face and employing a disciplined work force. A wide knowledge of the activities in the working time is crucial when attempting to optimize operational sequences. That is why it is vital to observe the operation and analyze the breaks in order to identify the most frequent and time-consuming interruption of work.

5.2 EDUCATION, TRAINING AND MOTIVATION

An educated workforce is crucial for achieving higher production levels. Money and time used for vocational education and intermediate training proves to be a very good investment. The complexity of contemporary plow systems requires in-depth knowledge of equipment control. The majority of devices and machines working in plow systems are controlled by microprocessor-based units with a wide variety of functions, which have to be well known to the workforce in order to reach sufficient operating efficiency. On the contrary, faulty operation caused by a lack of necessary knowledge can lead to serious damage and performance deterioration.

Some operators require a specific level of education for certain jobs. For instance, plow operators need a university degree at one of successful mining companies. This very high requirement results in high performance.

Another important attribute for a plow workforce is its motivation. Experience proves that good, motivated workers contribute decisively to more efficient and higher production. In particular, it is important to use positive individual and group motivation, initiating efforts to improve their own personality and achieve better results at work. Adequate motivation, facilitating identification of workers with their workplace and occupation, is a condition “sine qua non” for high performance. To obtain high motivation of the crew, management must be highly motivated and properly trained.

5. Enhancement of Running Faces — Organizational Factors

5.3 EQUIPMENT MAINTENANCE

In order to avoid damage resulting in production losses and high repair costs and to keep the face equipment operational, continuous maintenance is required. The equipment working in underground longwalls today is highly sophisticated. This property— in connection with the dynamic type of operation and very harsh conditions underground—creates high requirements on regular equipment maintenance. A relatively small and uncomplicated action carried out in time can often help to avoid serious problems and consequent losses.

Maintenance in the plow face

Typical examples include gearboxes, where a regular check of oil quality and necessary changes of oil and oil filters allow proper operation and ensures a avoidance of damages and long service life.

Another important subject of maintenance is the hydraulic high-pressure supply system. A proper hydraulic medium with sufficient concentration and filtration—and without dangerous minerals or organic contaminations—is crucial for efficient and faultless functionality of a hydraulic face system. Deterioration of hydraulic emulsion quality can cause extensive damage to components, which can hamper the operation, decreasing face performance. As these damages can be widespread, the necessary repairs are expensive and time-consuming. For that reason, a frequent and detailed inspection of emulsion quality and check of hydraulic equipment is an important pre-condition for faultless face operation. Correct maintenance means saving a lot of money.

Good maintenance requires a high level of "technical culture". This is one of the more difficult topics to cover when implementing a modern technology. If resources are sufficient, purchase and implementation can be realized in a relatively short period. The more complicated task is the change of workforce attitude to new technologies. This is what the term “technical culture” means. In order to change that attitude, a constant “technical indoctrination” over long time periods is required.

It is important at this point to mention the implementation of condition monitoring at modern longwall systems as a part of preventive maintenance. This condition monitoring should include online monitoring of the most important longwall machinery. Condition monitoring covers constant surveillance of all the main parameters, including vibration monitoring. Such a system means slightly higher capital expenses for operators, but allows much deeper analysis of machinery health, which helps avoid surprising damage and significantly elongates the machine's life cycle.

5. Enhancement of Running Faces — Organizational Factors

5.4 PLOW CONTROL SYSTEMS

The control system is one of the most important components determining the magnitude of plow face performance. Modern plows are controlled either from a cabin located in the energy train underground or in a special control room on the surface. The majority of plow faces worldwide have control cabins underground. In Germany, all plow faces have been controlled from the surface for many years.

FIGURE 3. ***Surface control center at a German mine***

As data transfer distance is not important anymore thanks to modern fiber optics, it can be assumed that future plow control systems will be carried out from surface centers. A control center at the surface has wider functionality than a narrow cabin underground. In contrast to the underground cabin, where the space for control devices is limited, in surface control centers all important information is presented directly on several monitors without any need to switch between applications.

The control center plays an important role in achieving high production. The dispatcher's duty—in addition to the effective control of all plow system devices—is to react as quickly as possible in case of any unscheduled breaks. In order to act effectively, the dispatcher has to have direct access to all relevant monitoring systems, including power supply, pump stations for high pressure medium as well as for cooling and spraying water, conveyors with bunkers and shaft, ventilation and methane control, material transport, etc. Having all this information at a glance allows quick reactions in case of a stoppage. Considering that, in the case of high performance plow faces, a one-minute break means a loss of 15 to 30 tons, the importance of a quick reaction in unusual situations becomes obvious.

5.5 TIME UTILIZATION DEGREE AND FACE PERFORMANCE

The time utilization degree (TUD) is a proportion of total daily plow running time to daily face operating time, expressed in percent. A certain part of a working day in a face is used for scheduled maintenance or other activities that are necessary for proper operation but require a stop in production. Furthermore, an increase of production within the running time is difficult and expensive to achieve; increasing the plow's uptime is much easier and does not require significant investments. But it does require good organization and work discipline.

The operating time of an average plow face accounts for 18 to 22 hours a day. A part of that time is necessary for process-indispensable operations. The residual time can be theoretically used for production. Unfortunately, based upon available statistics less than half of that time is used for active production. The rest is lost for various reasons that are frequently trivial.

The longer the total daily running time of a face, the higher its production. Improvement of organization is the easiest way to increase TUD and, therefore, increase production.

6. Conclusions

Plow systems have significantly improved over more than seventy years of operation worldwide. The size and installed power increased dramatically, and control systems were implemented and improved, allowing full automation in some applications.

Comprehensive planning of a plow face from several important perspectives is an important pre-condition for reaching desired production volume. Potential mistakes at this stage can seriously hamper future operation, and fixing them later can be costly or even impossible.

When designing a new plow face, the cost-effectiveness of applied equipment should be subject to in-depth analysis. The initial capital costs are not the correct indicator for the equipment selection. Instead, focus on the rolling costs of one ton of saleable coal calculated over the whole life span of the equipment. Simply put, buying cheap is expensive in the long run.

An effective enhancement of running longwalls has to be regarded from the operational/technical, procedural and organizational points of view.

Important operational aspects that influence on performance of plow faces include the shape of the face, the optimal setting of plow body height and bit set, the proper operation of horizon control and avoidance of bottlenecks.

The combination of AFC and plow speeds is one of most important procedural factors influencing performance. Furthermore, the method of cutting the face-ends and the length and frequency of plow moves along the face is critical for optimal performance. All those factors affect the procedural utilization degree, used as an indicator of plow face operational efficiency.

The proper organization of a plow face plays an important role in reaching the highest production volume. In order to reach that level, a running analysis of production processes is necessary. Good organization requires a high level of miners' education with periodic training. Effective control of the plow face and successful maintenance of the equipment present further relevant issues for achieving high performance. The quality of organization in a face is expressed by its time utilization degree.

The maximization of TUD and PUD means achieving a high effective running time. The highest possible daily running time is the most important key to success.

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