Longwall Mining in Seams of Medium Thickness

Comparison of Plow and Shearer Performance under Comparable Conditions

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1 Importance of coal

Today, coal plays a vital role in power generation. This role is set to continue in decades to come, whether we like it or not. Coal currently fuels 40% of the world's electricity generation, and will continue to do so for many years.

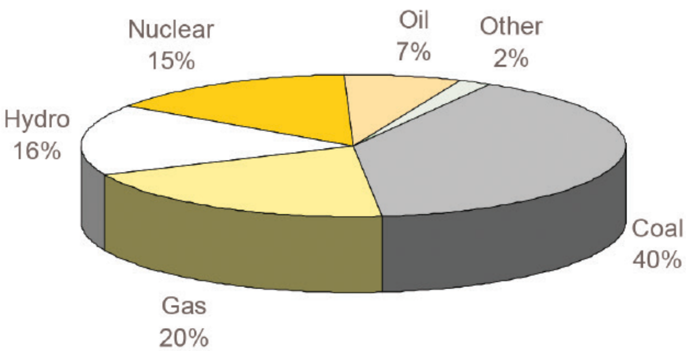


Fig. 1: Total World Electricity Generation by fuel in 2005 [46]

Coal reserves are available in nearly every country, with recoverable reserves in around 70 countries. At current production levels, proven coal reserves are estimated to last 147 years [46], while other sources say it could be 200 years or more [14]. In contrast, proven oil and gas reserves are equivalent to around 41 and 63 years, respectively, at current production levels. According to numerous sources, "proven reserves" of uranium will only last some 50 years at current consumption levels. Additionally, nuclear energy is limited by its economics and concerns about the treatment of nuclear waste. Hydro energy appears to be reaching its upper limit [5]. Implementing a renewable source of energy generation (today approximately 2%) is vital, but may take a long time and cannot seriously change the statistic from Fig. 1 within the next decades. Thus, according to International Energy Agency (IEA), demand for coal in 2050 should be greater than it is today.

In the face of environmental issues like global warming and air pollution, the efficiency of energy generation from coal needs to be significantly upgraded. Under the fair assumption that coal will remain a primary fuel in power generation and a vital player in a balanced energy mix for the future, the following steps seem to be necessary:

1. The net efficiency of coal-fired power plants has to further improve; and there must be development in the creation of ultra-supercritical steam conditions

2. The more environmentally friendly gasification of coal should gradually replace combustion

3. Flue gas treatment, which can already achieve virtually any level of emissions cleanup, needs to be more widely established

4. CO_2 capture and storage need to be implemented on a large scale

The previously mentioned measures will, unfortunately, temporarily increase the operational costs of power production. Nevertheless, they are indispensable, because in the long term they will allow generation of clean energy from coal.

2 Underground mining in low seams

Mining of low seams will be more important in the future because thick seams have been mined intensely in the past. Therefore, there are numerous reserves of high-quality coal remaining in thin seams. Fig. 2 presents the distribution of reserves as the function of seam thickness in the German Ruhr District [7]. According to that statistic, approximately 80% of deposits are in seams lower than 1.5 m (59 in). Mineable reserves located less than 1,500 m (4,921 ft) below surface in seams between 0.6 m (2 ft) and 1.5 m (59 in) make up 60% of all black coal deposits.

The situation is similar in other important mining countries. In the USA, the trend toward increased underground output from thinner coal seams (less than 1,675 mm [66 in]) is anticipated to accelerate during the next five years [44]. Seams with a thickness lower than 1.3 m (are estimated to contain up to 25% of all coal in China.

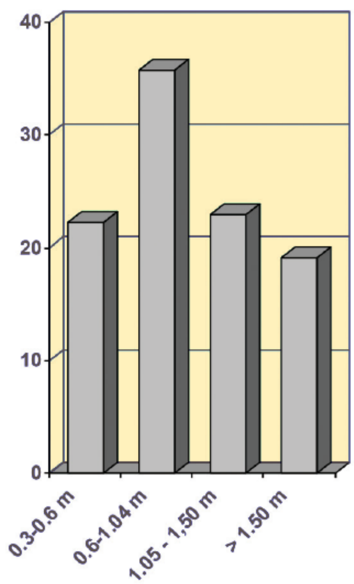


Fig. 2: Distribution of black coal reserves in the Ruhr-District

Efficient extraction technologies are necessary in order to mine those reserves with economic reliability. Thin seams can be mined in different ways. Today, there are two primary underground extraction methods in use:

- Room-and-Pillar
- Longwall

Room-and-pillar technology is commonly used in the USA. In the room-and-pillar method, rooms are cut into the coal seam leaving a series of pillars, or columns of coal to help support the mine roof and control the flow of air. Generally, rooms are 6 m to 10 m (19.7 ft to 32.8 ft) wide and the pillars up to 30 m (98.4 ft) wide. As mining advances, a grid-like pattern of rooms and pillars forms. There are two types of room-and-pillar mining: conventional mining and continuous mining

Conventional mining is the oldest method used today. In conventional mining, the coal seam is cut, drilled, blasted and then loaded into cars. In continuous mining, a machine known as a continuous miner cuts the coal from the mining face and deposits it directly into a haulage vehicle; an efficient technique that obviates the need for drilling and blasting.

Room-and-pillar mining in low seams is generally less efficient than longwall mining because as much as 50% of coal is lost.

There are two main longwall extraction systems: shearer and plow. Both systems have been used in the German underground hard coal mining industry for many years. In past decades, there were periods of dominance for both extraction technologies. Between the 1950s and 1980s, plows clearly dominated the German coal-mining industry. In the first half of the 1990s, shearers became more capable and thus more important. Since then, shearers have outbalanced plows. This situation lasted over a decade, but now the industry is turning back toward plow technology. In the near future, plow systems will again constitute the majority in German longwall mines [11].

Today, there are many common misconceptions regarding the capabilities of plow technology. In many countries, there is a widespread opinion that plows are less productive than shearers based on experiences with outdated technology. This objective analysis, based upon all available data and a comprehensive comparison between the two systems, should help provide a scientific answer for a common question in medium and low coal seams: shearer or plow?

3 Comparison: Plow versus Shearer

In the past, there were attempts to find a common denominator that allowed these two techniques to be directly compared. In most cases, this only resulted in a partial comparison. Most often, some similar technical facets of both shearers and plows were compared, and sometimes the technology involved in each type of machine was considered, but there was never a true holistic analysis. However, a comprehensive comparison between two different technologies makes sense only if it's part of an integral analysis that takes into account all important technical, procedural and economic aspects of longwall mining.

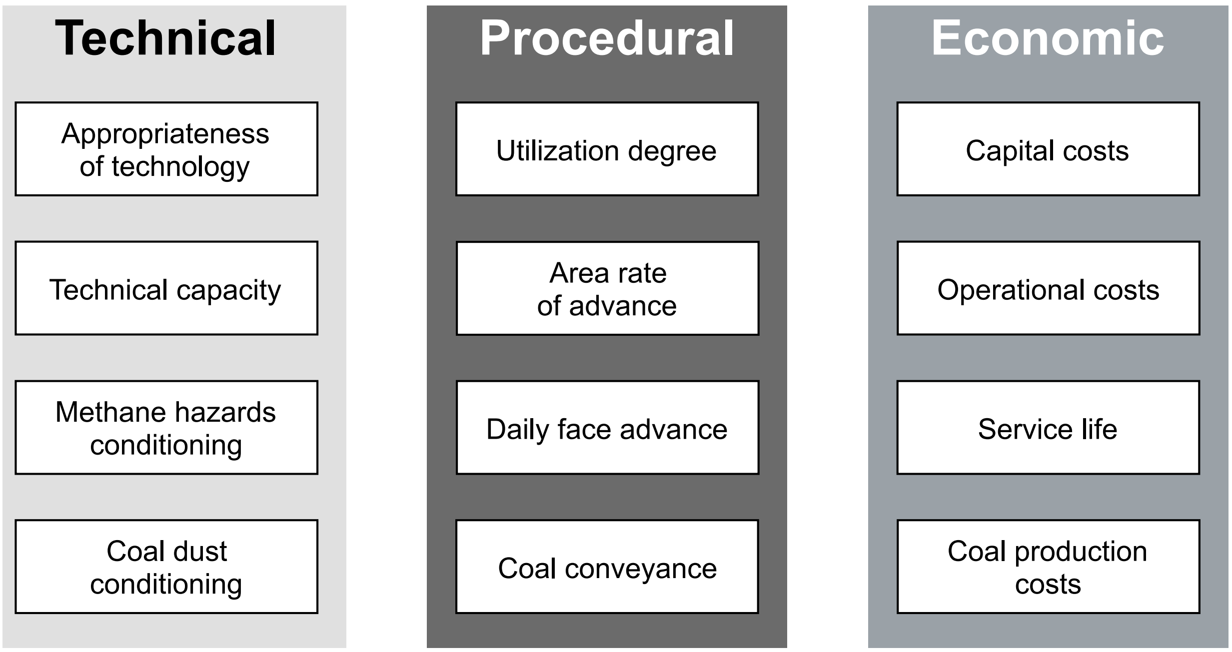


Fig. 3: Levels of comparison for the shearer and plow technologies

The following text presents the results of a wide study comparing plows and shearers on multiple levels.

4 Procedural aspects

When considering technological (procedural) aspects, there are two factors of major importance to the performance of a longwall: the Time Utilization Degree (TUD) and the Procedural Utilization Degree (PUD). Organizational and technological efficiency are measured using the Area Rate of Advance and Daily Face Advance, which are related to TUD and PUD. Access to a constant stream of coal also plays an important role in some applications.

4.1 Types of procedures in longwall faces

There are a variety of available cutting sequence procedures for both shearers and plows. These depend on:

- Speed of the shearer or plow in pass to the tail and to the main gate
- Cutting depth of the shearer or plow in pass to the tail and to the main gate
- Speed of the AFC during the shearer's or plow's pass to the tail or to the main gate

These procedures are commonly divided by product type.

For a shearer

- Bi-directional cutting – The shearer cuts coal in both directions, with two sumping operations at the face resulting in a complete cycle.
- Uni-directional cutting – The shearer cuts the coal only in one direction. On the return trip, the floor is cleaned and there is only one sumping operation.
- Half-web cutting – The shearer cuts full-web only at the face ends, and in the face it cuts a half web in order to avoid sumping operation.
- Half/partial opening cutting – The shearer cuts a full web in one direction, taking the top coal with one drum and the bottom coal with the other drum; and it sumps at mid face.

Shearers usually cut either full- or half-web. The volume stream of extracted material (coal) is, in most cases, regulated by setting a required shearer haulage speed.

For a plow

- Conventional procedure – The plow travels in both directions, moving slower than the AFC, with relatively high cutting depths.
- Combination procedure – The plow travels to the tail gate as fast as the AFC and to the main gate slower than the AFC.
- Overtaking procedure – The plow travels in both directions faster than the AFC with relatively low cutting depths.

Plows always cut the full height of the face in both directions. In weak coal, though, the height of the plow body is usually lower than the face height. The volume stream of extracted material can be regulated by setting the required plow speed and/or cutting depth. The cutting depth is usually different in each direction in order to achieve the optimal procedure. When the situation allows, the operation can be carried out without sumping by using the double-cut procedure on both face ends.

4.2 Utilization degrees

There are two utilization degrees related to the organizational and technological aspects:

- Time utilization degree
- Procedural utilization degree

The whole circle shown in Fig. 4 represents the total working time of the crew on the face. This time can refer to a single shift or, in most cases, to a working day. Theoretically, this is the time when the face could be in operation.

1. Time utilization degree (TUD)

$$\eta_T = \frac{t_{EE} + t_{PL}}{t_{DT} + t_{EE} + t_{PL}}$$

2. Procedural utilization degree (PUD)

$$\eta_P = \frac{t_{EE}}{t_{EE} + t_{PL}}$$

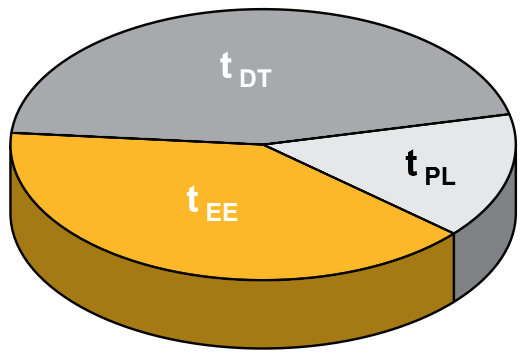


Fig. 4: Utilization degrees in longwalls

Where:

t_{EE} – effective extraction time [min/d]

t_{DT} – breaks, downtime [min/d]

t_{PL} – procedural losses [min/d]

η_T – time utilization degree [-]

η_P – procedural utilization degree [-]

4.2.1 Time utilization degree

The TUD, also called "availability," shows the proportion of cumulative running time of a shearer/plow to the working time in a shift or day. For practical purposes, TUD expressed in a percentage is determined by the following formula:

$$\eta_T = \frac{t_{RT}}{t_{OT}} * 100 \qquad (1)$$

where:

t_{RT} – total daily running time of a shearer or plow [min/d],

t_{OT} – daily working time [min/d],

η_T – time utilization degree [%].

Apart from the scheduled maintenance time or some special non-productive activities, the rest of the time when the crew is present at the face could potentially be used for effective mining. These situations rarely occur. In practical terms, there are some breaks in the production. Those breaks can be caused by:

- Internal factors like operations requiring standstills, oversize load stoppages, methane shutdowns, equipment damages, accidents, etc.
- External factors including, but not limited to, haulage stoppages, breaks in electric or hydraulic energy supply, communication disturbances, etc.

TUD can vary drastically. On average, TUD in longwalls ranges between 40% and 70% [18], [36], [39]. The lowest average TUD reported was 30% [39], the highest TUD reaches more than 90% [26], [29].

In German coal mines, the TUD in an average shearer face was slightly higher than an average plow face. This effect was connected to mining activities at the junction between the longwall face and gate road. Since a plow needs less time than a shearer for a full cycle, various time-consuming works had been causing production breaks. This tendency cannot be confirmed while analyzing the best high-performance shearer and plow faces, where a significant difference between shearers and plows could not be found.

4.2.2 Procedural utilization degree

Procedural utilization degree, also called “machine utilization,” describes the extent of production equipment exploitation in the face. PUD specifies an equivalent fragment of the machinery running time while a shearer or plow is working with a nominal cutting depth at a nominal speed.

The selection of a correct procedure plays an essential role in the performance optimization of underground longwalls. This is vital both for shearer and plow faces.

Both shearers and plows only work a part of their total running time with nominal cutting depth and speed. In the residual time, they are working either with lower speed and/or lower cutting depth or idling in situations like:

- Cutting 50% of the cutting depth in the half-web cutting procedure
- Loading coal during a return trip in the uni-directional procedure
- Acceleration at the beginning of a pass toward another gate end
- Slowing down while arriving at the gate
- Running without cutting (standing) after a direction change
- Sumping
- Lowering/raising of ranging arms, rotating of cowls

The procedural loses can be divided into:

- Losses resulting from deceleration
- Losses connected to lower cutting depth

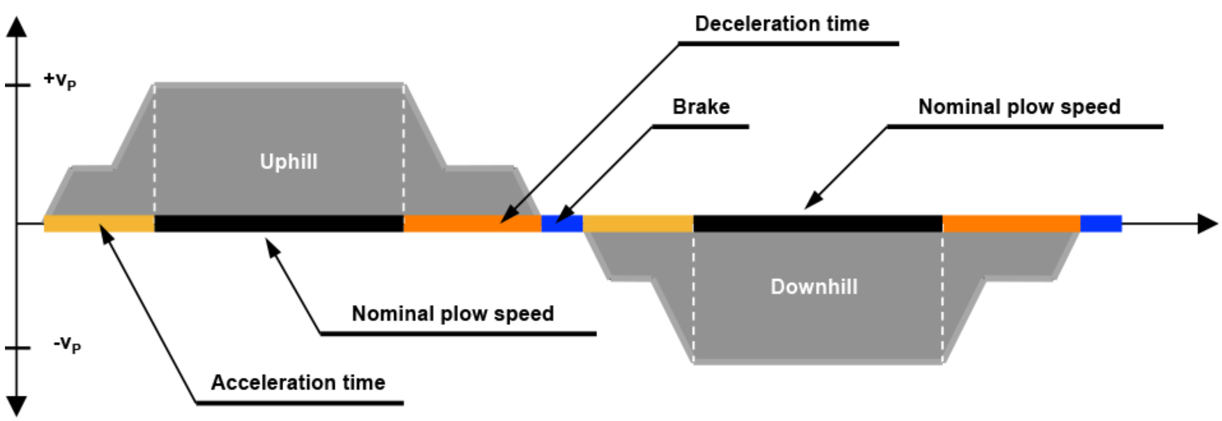


Fig. 5: Losses resulting from a speed reduction

Fig. 5 shows the mechanism of time losses in situations when extraction is running at a less-than nominal speed or during procedural breaks. A shearer or plow needs some time after turning on to accelerate before reaching its nominal speed. Plows using pole-changeable motors switch first to primary speed and, after a couple of seconds, change to their nominal (secondary) speed. Even after the machine reaches nominal speed, it slows down often. While approaching the face ends, the speed is first reduced to the primary stage for a short period, then it is further decreased until stopped. After a short break in the case of plows or a longer period of time for shearers (while the operator swings the drums and cowls), the machine begins to move in the opposite direction.

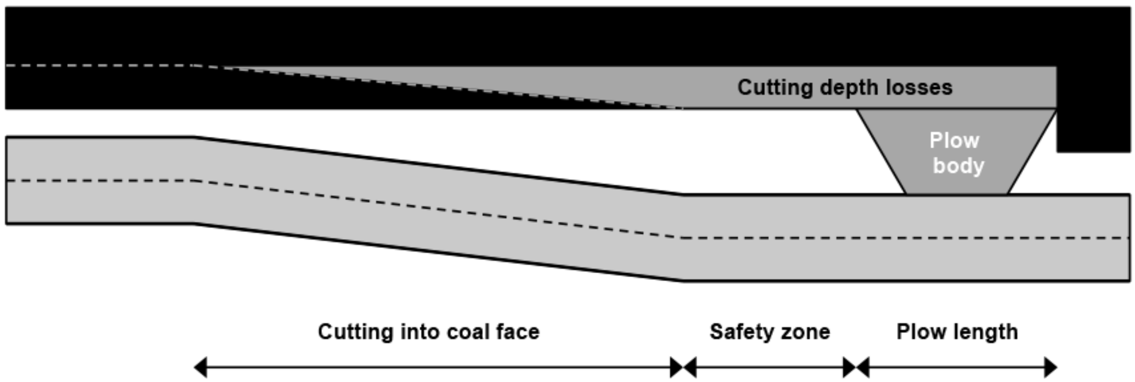


Fig. 6: Losses resulting from a reduction of cutting depth

Fig. 6 presents the origin of cutting depth losses. The AFC push is carried out first, following a certain distance behind a shearer or plow. During a direction change in the face, the shearer or plow does not cut the face within this distance. Afterward, the cut along the length of the snake is theoretically only half a web on average. Only behind the end of the snake zone will the machine start to hit its nominal cutting depth again. This situation repeats after every directional change.

The reductions in reversing losses of a nominally achievable cutting depth are a part of this category. The cutback of 50% of the cutting depth during a half-web procedure or a return run at zero cutting depth during the uni-directional procedure rank among web losses.

Both types of time losses are related to the hypothetical extraction time at nominal speed and web, and constitute the procedural utilization degree. Thus, PUD can never reach 100%, even in the best possible situation, for either shearers or plows. The reason for this is that both machines need to reverse running directions at the face ends.

In practical terms, PUD can easily be determined if the total daily running time of the shearer or plow and daily advance are known. With consideration of the nominal cutting speed and depth, the following formula can be used:

$$\eta_P = \frac{l_F * l_A}{\Delta_W * v_E * t_D * 60} * 100 \qquad (2)$$

where:

l_F – face length [m],

l_A – daily face advance [m/d],

Δ_W – nominal cutting depth (web) [m]

v_E – nominal cutting velocity [m/s]

t_D – total daily running time of plow or shearer [min/d]

η_P – procedural utilization degree (PUD) [%]

PUD varies strongly for both shearer and plow faces. The following PUDs are based on past experience:

- For shearers: between 20% and 75% [16], [17], [26], [38],
- For plows: between 40% and 95% [23], [24], [30].

According to the above statistic, PUD is generally higher for plow faces than those with shearers. In the case of shearers, the lowest PUDs occur during bi-directional cutting and the highest PUD comes from half-web procedures X[4X], X[26X], X[35X]. For plows, the lowest PUD arises in the case of sectional plowing. The highest PUD can be achieved by plowing from face-end to face-end while double-cutting the face ends. Like the shearer during a half-web procedure, the plow avoids double-reversing in the face, maximizing PUD.

4.3 Area rate of advance

The area rate of advance is an important factor when measuring the performance of a longwall. This indicator describes a floor or a roof area exposed over a time unit. The area rate of advance can be based upon running or operational time and is usually presented in m²/min. The area rate of advance is determined by following formula:

$$\dot{A} = \Delta_W * v_E * \eta_P * 60 = \frac{l_E * l_A}{t_D} \qquad (3)$$

where:

$\dot{A}$ – area rate of advance [m²/min].

Adapted from German experiences and statistics, the area rate of advance based on running time is generally higher in plow faces than it is in shearer faces. In a comprehensive study carried out on 75 German longwall faces over four years, the area rate of advance in plow faces was 58% higher than in shearer faces [37].

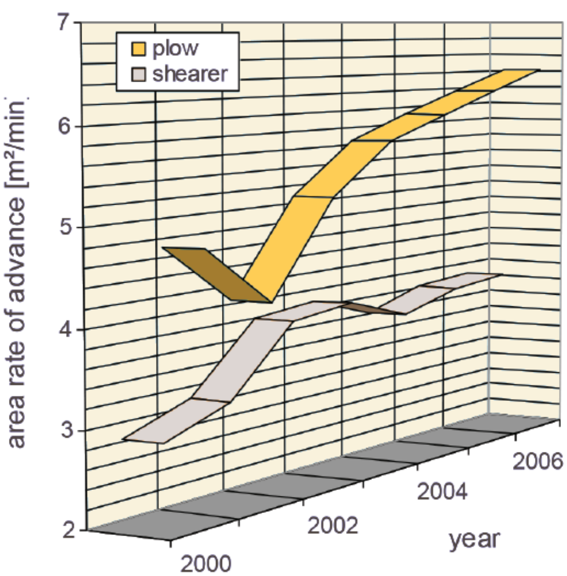


Fig. 7: Average area rate of advance in German shearer and plow longwalls [1]

This tendency can be observed in recent years [42]. Fig. 7 shows the development of area rate of advance for shearer and plow faces in the last decade in German longwalls in the Ruhr-Region.

[1] *Source: DSK AG*

4.4 Daily face advance

The comparison of the daily face advance in German shearer and plow longwalls generally favors plow faces. Plow faces on average have a 20% to 40% higher daily face advance.

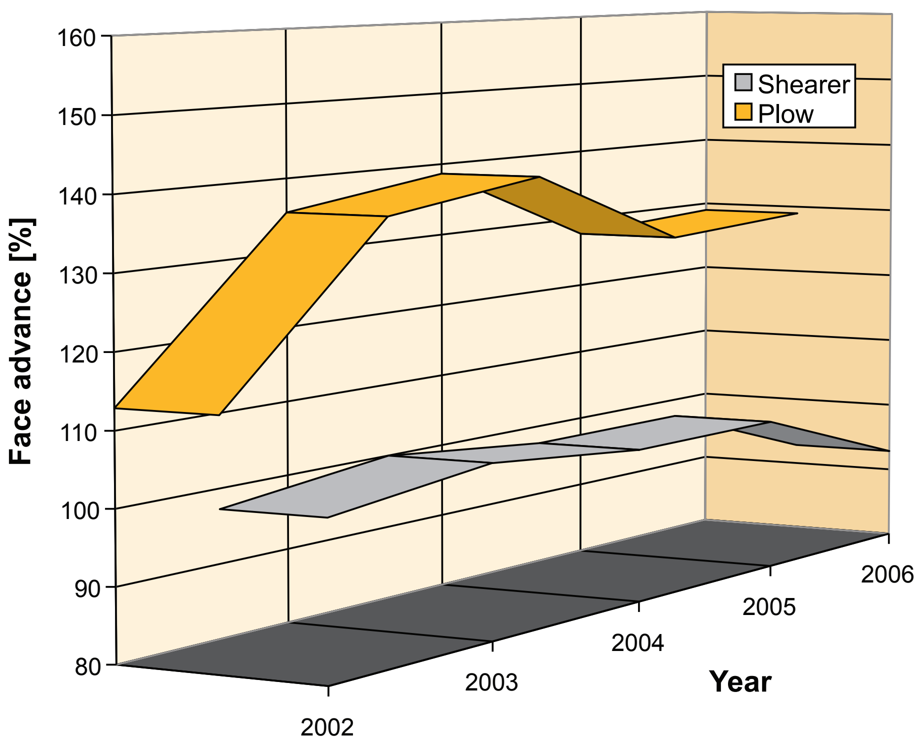


Fig. 8: Average daily advance of shearer and plow longwalls in Germany [2]

Fig. 8 shows the development of the average daily face advance in the German coal-mining industry in the years between 2002 and 2006.

[2] *Source: DSK AG*

4.5 Coal conveyance

The volume stream coming out of a face plays a vital role in circumstances where the operational capacity of connected haulage infrastructure is limited. Such a situation can occur if a number of coal streams (e.g. from different faces) are flowing together on one conveyor belt. Any load peaks can cause an overloading of that conveyor. This type of restriction has occurred frequently in the past in the German coal mining industry.

The volume stream coming from a face depends mostly on the procedure chosen for that face. Shearer faces usually generate irregular volume streams. The shearer traveling from main to tail is loading a relatively thin layer of coal on the AFC because of the high difference in speed between shearer and AFC and a restriction caused by limited space under the shearer. On the contrary, during the trip from tail to main gate the load layer is much higher. In the case of uni-directional procedures, periods with high load are interlaced with periods where the AFC is almost empty.

In the case of plow faces, the volume stream is also dependent on the procedure. When using the combination procedure, a constant volume stream can be achieved using a selection of cutting depths for both cutting directions. For the overtaking procedure, a constant volume stream can be obtained if the plow is running from drive to drive with the same cutting depth and a plow speed of three times that of the AFC velocity. In the case of sectional plowing, an irregular load stream will occur.

5 Technical aspects

The technical aspects of both longwall extraction techniques concentrate on their applicability and main features for use in underground longwall mining.

5.1 Technical applicability

Technical applicability is an important issue when selecting an extraction method. This includes consideration of a number of relevant geological (inclusive tectonic and stratigraphical) and operational conditions.

		Shearer	Plow
1. Seam thickness		1.5 m up to 6.0 m+	0.6 m up to 2.3 m
2. Coal hardness		Both types of coal extraction systems are comparable*	
3. Inclination	Face	Up to 20°	Up to 45°
	Panel	Uphill up to 20°, downhill up to 20°	Uphill up to 45°, downhill up to 20°
4. Mining through faults		Both types of coal extraction systems are comparable*	
5. Undulations		Plow can negotiate seam undulations much easier than a shearer	
6. Immediate roof		Friable roof can easily lead to roof falls	Smaller cutting depth allows safe operation even under friable roof
7. Immediate floor		The applicability of both systems is comparable (shearer shields use a base lift, plow shields use a special feature called elephant step to work in soft floor)	
8. Raw coal size		Shearer produces more fine particles	Plow produces more large lumps
9. Entry dimensions		Tail drive located inside the face	Plow normally requires wider tail entry
10. Automation		Shearers not fully automated yet	Cat plow systems are full Automation-capable and used worldwide

Fig. 9: Important factors regarding the technical applicability of shearers and plows

The topics stated in Fig. 9 are detailed and discussed in the sections below.

[3] Application of the GH1600 plow system with 1.6 MW installed power
[4] Doesn't apply for a plow system with only one drive placed on the main gate

5.1.1 Seam thickness

Shearers are commonly used in seam thicknesses as low as 1.5 m (59 in) and as high as, or even higher than, 6.0 m (236 in). In the past, there were many attempts to use shearers cost-effectively in seams lower than 1.5 m (59 in). Most of those attempts were unsuccessful in terms of efficiency and cost-effectiveness. The relatively low installed power, difficulties with operation in narrowed space and bad loading properties were the main reasons. In many cases, shearers operated at cutting heights higher than the seam thickness, so they were cutting additional floor and/or roof, increasing rock content and production costs. In seams with variable thickness, shearers can easily adapt their cutting height.

Plows work in seams from 0.6 to 2.3 m (23.6 to 90.5 in), although plows were used in Germany in seams up to 3 m (118 in). Generally, seams below 1.0 m (39.3 in), use baseplate plows. In thicker seams, gliding plows are more effective. Because of their lower height, plows are able to mine in-seam to extract coal without cutting adjoining rock. Seams with variable thickness are not a problem for plows as long as the seams have a good parting on the roof or the layer of top coal can be brought down by the canopies. Plow body height can easily be adjusted if required.

5.1.2 Coal hardness

Shearers can operate in both weak and hard coal seams. With increasing hardness of coal, the specific extraction energy (the amount of energy necessary to extract and load of 1 m^3 of coal) also increases, reducing the performance of shearers.

Plows were used more frequently on soft coal in the past. The main reasons for that issue were low installed power and difficulty utilizing that power. The situation has vastly improved over the last ten years because of the following developments:

- An implementation of reliable working microprocessors brought a breakthrough for plows. An incremental plowing system now allows operators to set a cutting depth with high precision and eliminate previously frequent blockages.
- Chain breakages have been greatly reduced by the implementation of effective overload protection systems.
- Available power of plow systems has steadily increased. Today's plow systems have up to 1.6 MW (2,145 hp) installed cutting power.
- Variable frequency drive (VFD) motors allow infinite speed adjustment; together with AFC motors of the same kind, they allow the optimization of plow longwalls.

Due to these developments, modern plow systems are able to extract the same hard coal that shearers do.

5.1.3 Face inclination

Shearers can operate in faces with longitudinal and transversal inclinations up to 20°. Only specially designed shearers are able to work in higher longitudinally inclined faces.

Plows are able to work in faces with longitudinal inclination up to 45° and transversal inclination by 45°at up-dip and 20° at dip face. Faces up to 60° longitudinal inclination have been mined by plows before.

5.1.4 Mining through faults

Shearers are able to cut hard rock by reducing haulage speed. However, the shearer's specific extraction energy becomes inevitably higher and large quantities of fine coal and dust are created.

Plows, in the past, have had difficulties crossing geological faults. This was due to a non-adjustable cutting depth and limited plow speed adjustment. The plow speed could only be reduced to either 50% or 33%. The setting of a defined smaller web was, in practical terms, almost impossible.

A modern plow system equipped with incremental plowing and variable frequency drives with a significantly higher installed power is able to set (reduce) both web and speed to a required level. This means that modern plows can cross faults as effectively as shearers do. For example, at Ibbenbüren Mine in Germany, a plow system was cutting rock at 60 MPa UCS on full height over a long distance while crossing a fault with a significant vertical step [1].

5.1.5 Undulations

Shearers are much longer than plow bodies and their AFC pans can bend vertically up to ±3°. For that reason, shearers have difficulty negotiating undulations.

Plow bodies are shorter and plow guides attached to the AFC pans are able to bend vertically up to ±6°, meaning that plows can handle face undulations much more easily than shearers [32].

Fig. 10: Saddle on a plow system

5.1.6 Intermediate roof

Shearers can operate easily only if the roof is strong enough to span one open web cut.

Plows are better suited to control the roof by reducing the shield advancing web if the roof is friable in front of the shield canopy tip [32].

5.1.7 Intermediate floor

Shearer faces operate better under hard floor conditions. If the floor is weak, more attention needs to be paid to height control while extracting the face. Regarding the supports, problems associated with a soft floor can be handled by a base-lift device on the shield.

Plows run smoothly on hard floors and are sensitive during height control if the floor is weak. This problem is solved by the adjustable height control system, provided the face crew is trained and has the necessary experience. Modern shield supports in plow faces use the "elephant step" (i.e. lifting one of the bases) during advancing in the case of a weak floor.

5.1.8 Raw coal size

Shearers crush and mill the coal and adjoining rock during extraction, which is inevitably connected to the principle of shearing extraction. Thus, the mined coal is pulverized in comparison to plows [20].

Plows cutting with a relatively high web and small velocity achieve larger-sized yield [32], leading to lower processing costs later.

5.1.9 Entry dimensions

Shearers and plows with comparable performance require similar-sized entries. Normally, the minimum entry width is 4-5 m (157.5-196.9 in) and the minimum entry height is around 2 m (78.7 in).

Plow faces are normally equipped with a tail drive for both the AFC and plow, which is located in the tail entry. The gate dimensions are thus determined by the size of the drives. However, developments are underway to operate the plow with only one large drive at the main gate.

5.1.10 Automation

Shearers have recently begun to use a technique called memory cut in order to adapt the position of the ranging arms to local situations in the face. Still, even very modern shearers need constant assistance. Haulage speed is limited, as the operators need to walk with the shearer. It is expected that shearers will also require assistance in the future, even if technical developments move forward.

Plows today are capable of working with complete autonomy. In some mines, crews are not even permitted to stay at the face during production; the plow is running unmanned using a remote control from the surface without any assistance at the face. In many coal mines around the world, plow faces have been running automatically for some time.

5.2 Technical capacity

Technical capacity of shearers and plows working under specific conditions in underground seams depends mostly on the following factors:

- Hardness of coal
- Installed power
- Haulage speed
- Face height
- Cutting depth (web)

The hardness of coal is described differently in relation to shearers than it is with regard to plows. In the case of shearers worldwide, the usual parameter is uniaxial compressive strength (UCS). The following scale can be found in the literature [32]:

- Soft coal – UCS < 10 MPa
- Medium coal – 10 MPa < UCS < 20 MPa
- Hard coal – UCS > 20 MPa

When measuring coal hardness for plow faces, the most recognized scale was developed by the German Research Institute DMT GmbH. The so-called "plowability" of coal is described by an average cutting force Fs of a single plow bit in kN. This cutting force is determined during "in-situ" measurement with a special device [24], [28]. According to that criteria, they developed the following plowability categories:

- Good plowable – F_S < 1.5 kN
- Normal plowable – 1.5 kN < F_S < 2.0 kN
- Hard plowable – 2.0 kN < F_S < 2.5 kN
- Very hard plowable – 2.5 kN < F_S

The correlation between UCS and Fs is weak because, during linear cutting, the mechanical properties of coal are only partially responsible for the dimension of cutting forces. A medium plowability force includes provisions for bedding and joint faces that are present in every humic coal seam, and also takes into consideration the influence of strata pressure.

Installed power of both shearers and plows has increased steadily over the decades, although in the 1990s shearers began to develop faster than plows. In 2002, with the design of the powerful GH42 plow system, plow technology caught up with shearers. Today, shearers with height between 1.5 to 2.0 m (59.1 to 78.7 in), as a general rule, have a total installed power of up to 1.2 MW (1,609 hp).

Modern shearers can cut coal with velocities up to 40 m/min (131.2 ft/min). Today, plows move with speeds between 2 and 3.6 m/s (78.7 to 141.7 in).

The disputable area, where both systems are applicable, is placed between 1.5 and 2.3 m (59.1 to 90.6 in) face height. Below that range, plow systems are definitely the only cost-effective option for a longwall. Today, only shearers are used in seam heights above 2.3 m (90.6 in).

Shearers cut with a web between 0.8 and 1.2 m (31.5 to 47.2 in). The cutting depth of plows, depending on coal hardness, installed power, speed and face height varies between 5 and 25 cm (2 to 9.8 in).

All five of those parameters are connected to the performance of a shearer or plow, which is measured by the amount of energy necessary to extract and load one unit of volume or mass. This energy is called specific energy and is expressed in MJ/m³ (Fig. 11).

The specific energy of shearers varies between 0.7 and almost 10 MJ/m³, although in a variety of cases it does not exceed 5 MJ/m³ [10], [26], [32], [45]. Plow systems are characterized by a specific energy ranging from 1.0 to nearly 10 MJ/m³, but in most plow faces the specific energy does not go beyond 5 MJ/m³, either.

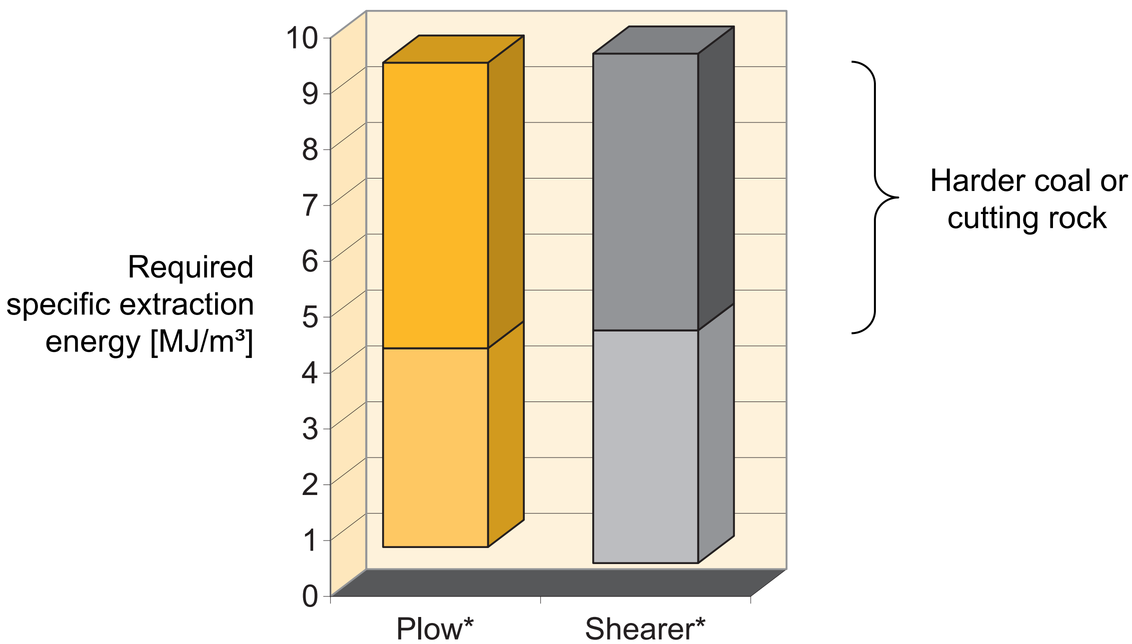


Fig. 11: Specific energy of shearers and plows

In seams with soft coal, the specific energy is on the lower end of the ranges described above. Based upon those numbers, it can be stated that the specific energy for both extraction systems is comparable. An explanation for that fact can be found in two places:

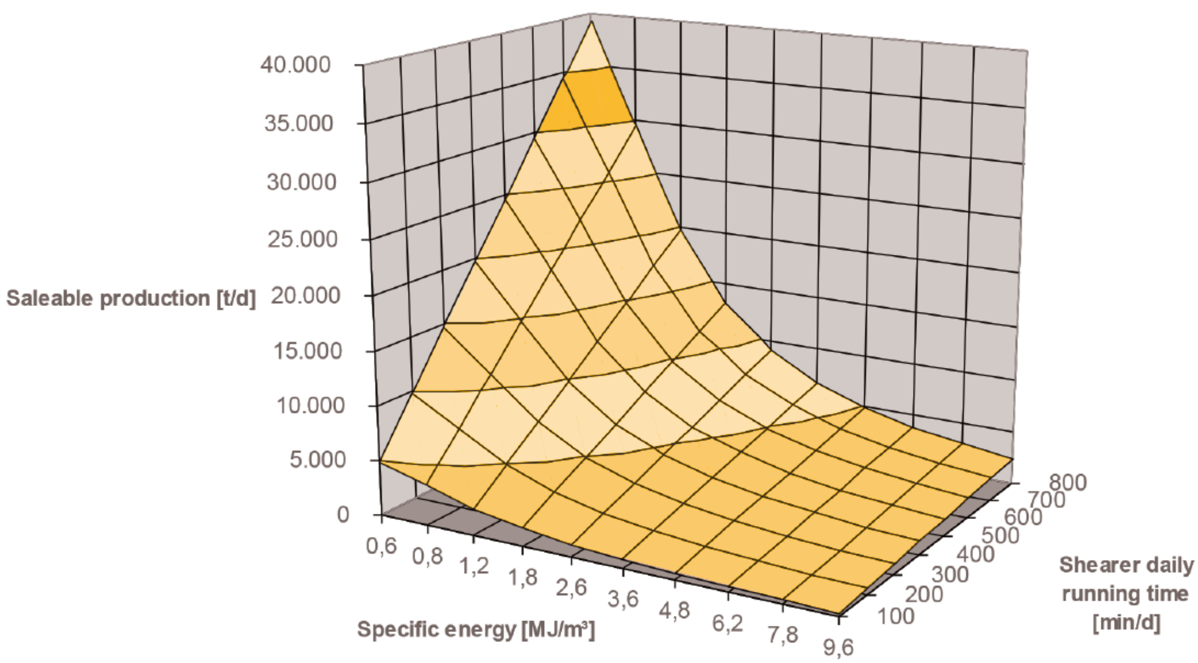
- Process of coal extraction – Plows cut coal with a bigger web and lower cutting velocity. Thus, plows extract coal more effectively by achieving bigger coal sizing. On the contrary, shearers mill the coal through lower web and higher speed on bits, which is more energy-consuming.
- Energy transfer efficiency – The proportion of energy for cutting and loading to the absorbed electric energy is higher in case of shearers, as plows use a portion of their energy converting rotational force into longitudinal motion and for moving the masses of the chain and plow body.

To summarize: In the case of shearers, their lower cutting efficiency is compensated by a better energy transmission in comparison to the plow. This gives them a similar specific energy under comparable conditions.

The diagram in Fig. 12 presents the theoretical performance of a shearer in a medium coal seam. The saleable daily production is presented as the function of specific energy and daily running time. The calculation is based upon an algorithm presented by RWTH [26], with consideration of the following assumptions:

- Face length 300 m (984 ft)
- Seam thickness (equal face height) 1.8 m (70.9 in)
- Seam density 1.5 t/m³
- Shearer cutting power 2 x 500 kW (2 x 670.5 hp)
- Technical efficiency 85%
- Drum diameter 1.4 m (55.1 in)
- Half-web procedure with 0.4 m (15.7 in) cutting depth
- Shearer haulage according to specific energy X[26X]
- PUD 60%

Fig. 12: Shearer face production referred to specific energy and daily running time



The parameters of the shearer were chosen to compliment the chosen face height. At that height, a suitable drum diameter and a reasonable installed power for cutter motors were assumed.

The diagram in Fig. 13 presents the theoretical output from a plow system in a medium coal seam. The saleable daily production is presented as the function of seam cutability and plow daily running time. The calculation is based upon an algorithm of DMT [25], [28], under consideration of following assumptions:

- Face length 300 m (984 ft)
- Seam thickness (equal face height) 1.8 m (70.9 in)
- Seam density 1.5 t/m³
- Plow installed power 2 x 800 kW (1,072.8 hp)
- Technical drive efficiency 80%
- Plow speed 3 m/s (118 in/s)
- Double-cut overtaking procedure
- Cutting depth according to the coal hardness X[25X]
- PUD 75%

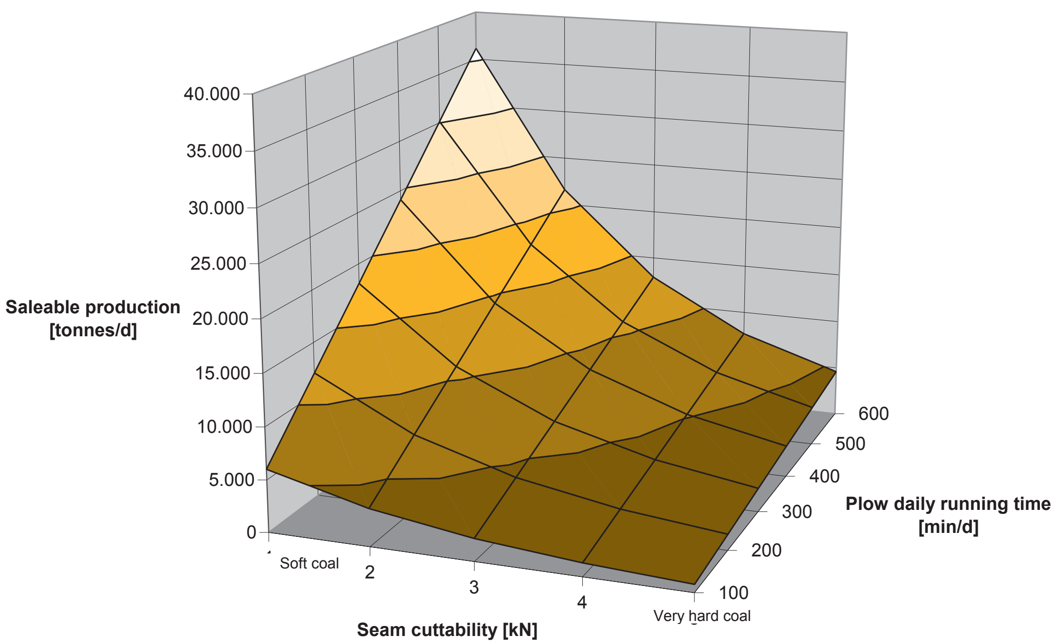


Fig. 13: Plow face production referred to specific energy and daily running time

Both calculations are based upon praxis-related algorithms considering realistic field-tested parameters. The asserted PUD input numbers are higher-than-average values, distinguishing excellent faces for both the shearer and plow. In both cases, cutting of coal at full height has been assumed.

The comparison of both diagrams displays higher performance from a plow for that face height at the same running time. This fact should be explained by the higher specific power on the plow system, which is able to fully utilize its installed power.

The diagram in Fig. 14 presents specific installed power for modern plows and shearers working in low and medium coal seams. The term “specific” denotes that the installed power of a shearer or plow is expressed per unit of the face height.

$$\bar{P}_S = \frac{\sum P_{Inst}}{h_L} \tag{4}$$

where:

$\sum P_{Inst}$ – total installed power of shearer or plow [kW],

h_L – longwall height [m].

The diagram in Fig. 14 shows the specific power installed on a shearer or plow versus face thickness. Presented curves are calculated according to the formula (4) for following machinery:

- Shearers with 600 kW (804 hp), 1000 kW (1,341 hp), 1200 kW (1,609 hp), 1500 kW (2,012 hp) and 1800 kW (2,414 hp)
- Plow systems with 800 kW (1,072 hp) and 1600 kW (2,145 hp)

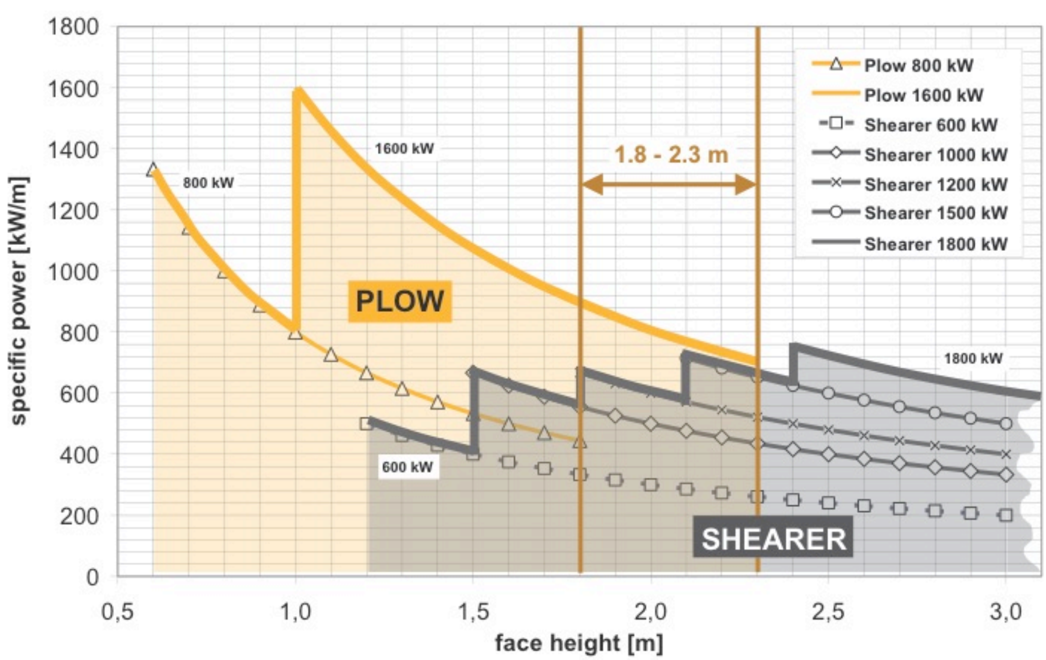


Fig. 14: Specific shearer or plow power rating vs. face height

The diagram clearly presents that, in the range between 1.5 and 2.2 m (59.1 to 86.6 in), the 1600 kW (2,145 hp) plows have a higher specific power than shearers. Beyond that, shearers take the lead.

To summarize: Power and in-seam mining are both positive attributes for plow technology in low and medium seams today. In contrast, some people have unfair opinions of plow technology based on improper interpretations or outdated information [6].

5.3 Methane hazards

Shearers work at lower speeds and larger cutting depths, so the volume stream of crushed coal from the face is much more concentrated on one place than it is when using a plow. Additionally, as previously stated, shearers crush and mill the coal vigorously, releasing more methane from a unit of extracted coal in a short time. Therefore, a higher level of local methane concentration is more probable in a shearer operation. Unfortunately, there are no known (at least to the authors) publications about direct comparison tests, so consideration and comparison of methane emission in shearer and plow faces is only theoretical.

5.4 Coal dust hazards

Shearers create a lot of fine coal dust concentrated in a relatively small area [20]. This is basically caused by the same factors as their higher methane production. Coal is crushed and milled by the rotating drum and the coal dust is blown into the surrounding atmosphere. The quantity and quality of dust depends on the type of extracted coal and on a number of shearer parameters like drum diameter, type, number and distribution of bits, rotational speed of the drum, and shearer haulage speed [45]. In order to suppress the distribution of dust into the atmosphere, shearers rely on sophisticated spray systems. In most cases, the nozzles are placed directly on the drums. Water spray booms attached to the shearer are also frequently used to assist in dust suppression.

In contrast, a plow produces more large coal lumps and less airborne dust. The percentage of large lumps increases and the airborne dust reduces as the plowing depth increases. The airborne dust produced by the plow is more uniformly distributed in the air along the face [34], [45].

While cutting the face, the plow body always pushes a heap of crushed coal in front of it. With this type of system, the plow bits on the body are always cutting under a covering of coal, which suppresses dust propagation [24]. In plow faces, spraying systems are usually located under the shield canopies and sometimes in the spill plates of the AFC. The plow control system activates the nozzles just seconds before the arrival of the plow body and deactivates seconds after the plow passes.

6 Economic aspects

Economic factors are just as important as the technical and procedural aspects discussed in previous chapters. Every comparison of different techniques, technologies or procedures has to be informed by a financial analysis. In the past, many countries subsidized their coal mining industries, so economic factors had a lower priority in equipment selection. Today, however, such a situation is unimaginable; so the production costs play the most important role. A comparison between longwall mining with shearers and plows can be comprehensive and complete only if all costs are considered and precisely analyzed.

6.1 Capital costs

Longwall mining is decisively more effective, but also much more expensive than room-and-pillar systems. Face equipment consists of extraction machinery, i.e. a shearer or plow, an armored face conveyor (AFC), and a roof support system.

6.1.1 Roof support

The most expensive part of every longwall is the roof support, which is composed of an array of shields. One shield presents a cost factor of many tens of thousands of Euros or dollars. Roof support costs are directly proportional to face length. The longer the face is, the more shields need to be used. In general, there are minor design distinctions between shields for plow and shearer faces. The most important differences can be described as follows:

- Shearer shields have rigid bases, plow shields have split bases.
- Shearer shields are equipped with base lift cylinders, plow shields are not.
- Shearer shields have much longer canopies (nearly 20 – 30% longer).
- Shearer shield canopies are equipped with front cantilevers, plow shields are not.
- Plow shields (even when fully automated) may operate with a control device on every third shield. The adjacent shields are controlled by the control unit placed on the middle shield.

Shields for a shearer face are slightly more expensive than plow shields for comparable geological conditions.

6.1.2 Extraction machine

The costs of a longwall cutting machine such as a shearer or plow system are much lower than expenses for a roof support. Generally, they only cost 10% to 20% as much as the roof support system.

A modern shearer is a highly complicated machine. In addition to a vast number of steel parts, a shearer has many mechanical, hydraulic, electric, and highly sophisticated electronic parts. The price for a shearer is almost irrespective to the face length.

The costs for a plow system depend (to a certain extent) on the length of the face.

A plow system consists of:

- Plow body
- Plow guidance attached (welded) to the AFC pans
- Plow chain of 38 or 42 mm (1.5 or 1.7 in) thickness and twice the length of the face
- Two drives, consisting of plow box, gear box and motor

In the past, plow systems used pole-changeable asynchronous motors. This type of motor has only two different speeds: low and high. Generally, high speed is two or three times higher than low speed. Since the beginning of this decade, VFD motors are frequently used on plow systems. This type of motor allows a continuously variable setting of speed and is more expensive than the asynchronous motor.

As a general rule, the costs for a shearer are roughly similar to those of a plow system under comparable face conditions, although the price for the most capable plows can be slightly higher.

6.1.3 Face conveyor

AFC costs depend almost entirely on the face's length and height. Longer faces need more pans, longer chain assemblies and thus more power. More power means larger drives and larger supply units. Higher faces require wider pans in order to accommodate extracted coal.

The differences between shearer and plow AFCs are fairly distinct. Drive frames for a plow system are more complicated because the plow drives are attached to the frame on the opposite side of the AFC drives. The pans for both systems are comparable, but spill plates have some differences. Additional elements for a shearer AFC are the components of the haulage system. Additional parts for a plow AFC are cylinders for the height control, which is called outrigger steering. Those cylinders are usually placed on every second pan in the face, though sometimes one is placed on every pan.

AFC costs for a shearer face are slightly higher than they are for a plow face.

6.1.4 Face auxiliary equipment

Face equipment needs a number of auxiliary pieces like transformers, switches, control and communication devices, pumps, etc. These devices are mostly the same whether the face uses a shearer or a plow. The differences occur only with regard to the extraction machine. A plow system needs an additional switch for the energy supply of its drives, while a shearer normally has its own switch on board.

6.1.5 Total face equipment costs

The table in Fig. 15 shows a general relative comparison of capital costs for a comparable shearer and plow face. The face equipment was subdivided into:

- Extraction machine type: A shearer is an integral device, but a plow system has a fragmented structure with plow guidance attached to the AFC containing chains and two (or one) drives placed at face ends and attached to frames
- AFC being relatively similar in both cases
- Electric and hydraulic equipment is slightly different in both cases
- Shields of the roof support: Differences between shields for shearer and plow faces are described in section 6.1.1.

Component	**Shearer face** Seam height 3 m Face length 300 m Capacity 3,500 tonnes/h***	**High-powered* plow face** Seam height 2 m Face length 300 m Capacity 3,500 tonnes/h
1. Extraction machine	Comparable	Comparable
2. AFC system	Less expensive	More expensive**
3. Electric equipment and services	Comparable	Comparable
4. Shield supports	Support resistance 100 t/sqm, more expensive	Support resistance 75 t/sqm, less expensive
Total	Plow is probably slightly more expensive	

Fig. 15: Comparison of main capital costs for a shearer and a plow face

The composition of main longwall components presented in Fig. 15 shows a comparability of capital expenses for a shearer and a plow face.

[5] *Including plow drives, plow guidance, chain and plow body*

6.2 Equipment lifetime

Modern shearers are very sophisticated. A shearer consists of a frame and, in most cases, two ranging arms with drums. Shearers have a number of motors, gearboxes and pumps, as well as electric, hydraulic and control equipment. Altogether, a contemporary shearer is a hybrid of different technologies. This complex machine is continuously exposed to damaging factors during production, like vibrations, mechanical loading, varying temperature, moisture, aggressive water, dust, etc. In spite of the robust design, such circumstances inevitably cause frequent damage and corresponding repairs and overhauls. Shearers have many wearing parts like bits, cutting drums, trapping shoes, etc. Generally, due to the high wear and frequent replacement of parts, the life of a shearer mining coal is approximately 10 million to 20 million tons.

The situation is different for plows. A plow body, which moves along the face, cutting and loading coal, consists only of steel parts. There are no rotating parts like motors, gearboxes or pumps, all of which can be easily damaged. Although the plow is complex in design, it is really just a hunk of steel that is resistant to mechanical forces and other destructive factors. Even though the plow body moves a few times faster than a shearer and is a subject to higher forces, its robustness makes it much less vulnerable. The wear parts of a plow system are the bits, gliding parts of the plow body, chain and sprockets. The wear parts will need to be periodically replaced and the plow guidance and plow body will need to be overhauled through welding. The lifespan of plow can reach 35 million tons, depending on working conditions.

Longwall equipment has to be maintained. Periodical overhauls are to be planned and repairs need to be considered and budgeted. These periods of repair and overhaul, along with the costs associated with them, are based on previous experiences. While planning a new longwall operation, funds for those operations have to be allocated. Based upon the authors' experiences, the average costs and overhaul periods are described below.

Shearer – Repair costs for a shearer, within the course of a longwall panel, lie between 10% and 30% of the original purchase price. Similar expenses need to be planned for an overhaul of the shearer. As a rule, the overhaul is carried out after the conclusion of a longwall panel. On average, some four to eight overhauls are performed over the lifetime of a shearer.

Plow system – A plow system working under comparable conditions requires similar overhaul periods, though the average overhaul expenses are slightly lower. The total number of overhauls during the life of a plow is similar to that of a shearer.

6.3 Operating costs

The sum of all expenses involved in setting up and maintaining the longwall is the "operating cost" of the face. The following list accounts for most of the operating costs:

- Salaries, wages
- Materials and consumables
- Spare parts
- Energy
- Depreciation, depletion, amortization
- Insurances
- Rents

In order to compare shearers with plows, operating costs also have to be matched. For the purpose of making that comparison as objective as possible, both longwall systems need to operate under comparable conditions. In the case of different conditions, an adequate sample must be taken to produce accurate results.

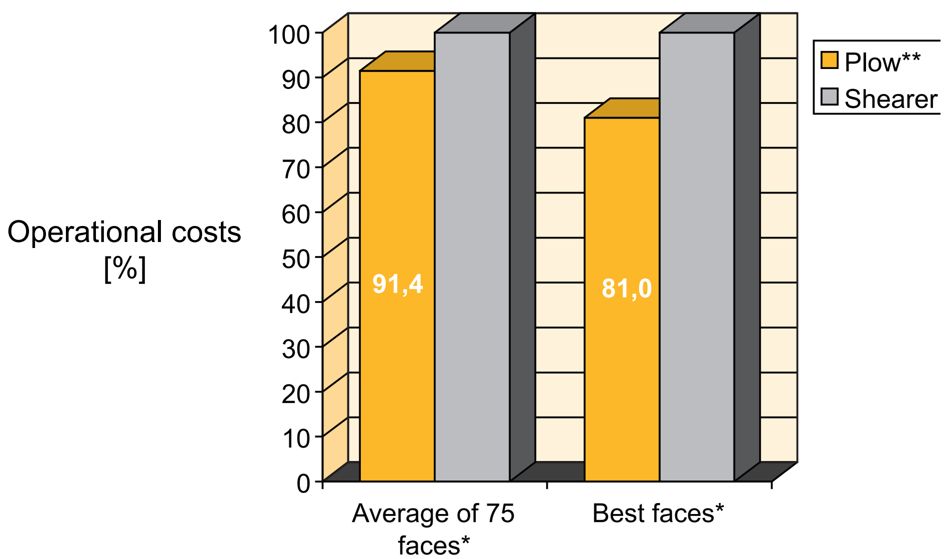


Fig. 16: Comparison of operating costs for shearer and plow faces in Germany

There was a study done in Germany, where numerous shearer and plows are in use, that included comprehensive analysis of operating costs, among other factors. Over a period of four years, there were 75 longwalls analyzed. They consisted of 18 shearer and 57 plow faces [9], [37]. The analysis spanned all faces and focused specifically on the most efficient longwalls. Fig. 16. shows the results of that analysis.

In both cases, operating costs of plow faces were lower than those of shearer faces. In the case of all faces, the difference amounted to 8.6%. The comparison of the best longwalls of both groups was even more specific. In this group, the discrepancy between operating costs of plow and shearer longwalls was almost 20%.

6.4 Coal production costs

The final mine cost, which is associated with producing a unit of saleable coal, is a very important factor that can show how well a mine or coal company has performed during a certain period of time. The total production costs per ton include all previously mentioned parameters, all of which are linked to a certain extent. The higher the technical capacities and procedural degrees are, the lower the cost of production will be. On the other hand, the lower the capital and operating costs are, the cheaper it is to mine one ton of coal.

This elaboration was focused solely on the cost of longwall mining. In most cases, mines have expenses beyond those directly related to the longwall itself. Those costs are usually insignificant depending on the type of longwall, so they were not discussed here. However, they do need to be considered in the final calculation, as they influence the final price of coal production.

Real mining industry production costs for a shearer and a plow face working under comparable conditions are difficult to obtain, as every mine is different, but with comparable capital costs and lower operating costs, the plow is clearly a more cost-effective longwall system.

7 Summary and conclusions

Today, coal fuels 40% of the world's electricity generation. This percentage is expected to last for the next several decades. Coal reserves are considerably more abundant than oil or gas reserves, so coal will maintain an important role throughout the future. A large part of the remaining coal reserves are located in seams smaller than 2 m (78.7 in). Underground longwall extraction of coal between the height of 1.5 and 2.3 m (59.1 to 90.6 in) can be done with a shearer or a plow. In this study, authors tried to conduct a comprehensive comparison of both longwall extraction methods by having a closer look at relevant aspects.

In order to compare the performance of shearer and plow faces in medium coal seams, the authors carried out a comprehensive consideration of the technical, procedural and financial aspects of longwall mining.

A. Shearers are characterized by a better rate of energy transmission, but a lower extraction efficiency than plows. With that said, the specific energy needed for the extraction of a coal unit under similar face conditions is comparable for both types.

B. Within the range of up to 2.1-2.3 m (82.7 to 90.6 in), modern plow systems are equipped with higher specific power (installed power relative to face height) than shearers.

C. The average shearer face has a higher time utilization degree (TUD) than an average plow face, but on high-performance faces the TUD for both extraction methods is roughly the same. TUD in normal situations ranges from 40% to 70%, but the best faces have achieved as much as 90%.

D. Plows are earmarked by a higher procedural utilization degree (PUD) than shearers. The best plow faces can reach a PUD of up to 95%, while the most effective shearer faces top out at 75%.

E. Production costs depend on face performance, as well as capital and operating costs. In general terms, it can be stated that, for a seam thickness ranging between 1.5 and 2.3 m (59.1 to 90.6 in), modern shearer and plow faces show comparable capital expenditures, but operating costs for plows are lower. Thus, the production costs of plow faces are lower than those of shearer faces.

Longwall face performance is a function of all five factors presented above.

Performance = f (A, B, C, D, E)

Having lower capital and operating costs and efficient production numbers will yield lower total production costs.

Taking a high-performance shearer system and plow system into consideration, the following conclusions have been drawn:

- Below a 1.8 m (70.9 in) face height, the plow system is the better choice
- Between 1.8 m and 2.3 m (70.9 to 90.6 in), the choice depends on the longwall's specific geological and mining conditions
- In longwalls taller than 2.3 m (90.6 in), shearers become the most suitable extraction technique

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