High performance remote controlled longwall extraction of low seams exploiting plow systems

M. Myszkowski
Caterpillar Global Mining, Luenen, Germany

ABSTRACT: Nowadays technically efficient and economically effective underground mining systems play a more and more important role worldwide. Longwall mining systems present the most effective extraction method, capable of producing annually several million tones outputs from a single longwall face. The extraction of thick seams is fully occupied by shearers, which work effectively even under difficult geological conditions. In thin seams in contrast plows deliver the highest efficiency. Contemporary plow systems are designed to extract seams with a thickness below one meter up to three meters, capable to stay in a seam without cutting the adjoining rock in the roof or floor. Modern plow systems are remotely controlled either from an entry or the surface. Due to the remote control capability, sophisticated power supply, and unique level of automation the plow systems are capable to work very efficiently and safely. This paper describes some important present plow applications worldwide and anticipates the future development of the plow technology.

KEYWORDS: Low seams, high performance longwall, efficient extraction, remote control.

1 INTRODUCTION

The plow technology for extraction of coal seams has been developed over 70 years in Germany. The first plow was used at the Ibbenbüren Mine, placed in northern North Rhine-Westphalia State, in Western Germany around 1940.

Since that time much more than ten thousand plow faces were operated worldwide. The peak number of plow faces occurred in the mid-sixties of last century, where in Germany alone over 500 plow faces with an average production of some 500 tonnes per day were operational.

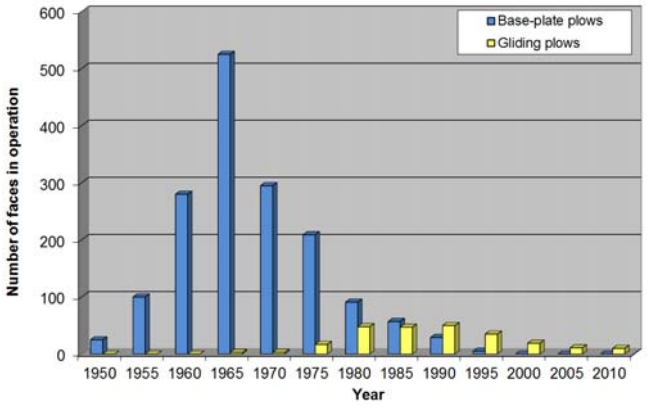

Figure 1. Number of plow faces in Germany between 1950 and 2010

Since that period the average performance increased by 20 to 30 times. Today an average production from modern high performance plow faces from coal seams between 1.2 and 1.7 m exceeds 10,000 t/d. Present automated plow systems are equipped with most advanced technical solutions, allowing the remote control of the complete system from the surface and automatic operation of the plow system.

There are two main reasons for this significant increase of the plow longwall performance:

1. An implementation of high automation levels based upon microprocessor technology.
2. Significant increase of the installed power in plow faces.

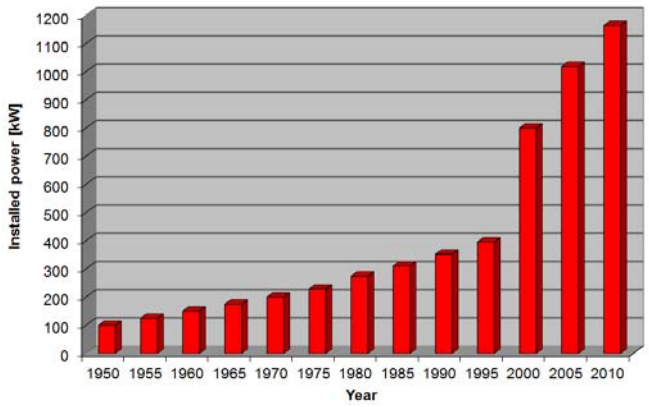

Figure 2. Average installed power on plows in Germany between 1950 and 2010

The diagram in Figure 2 shows, that the average installed power on plow systems in Germany increased significantly till the end of last century. In practical terms the nominal power on asynchronous motors used on plows, doubled within a couple of years.

The following is a number of important high performance GH1600 plow applications from recent years. Furthermore, this paper describes anticipated developments of the plow technology in the near future.

2 FIRST GH 1600 PLOW SYSTEM AT THE PROSPER HANIEL MINE IN GERMANY

The underground hard coal mine, Prosper-Haniel, is located in Bottrop, in the Ruhr District in North Rhine-Westphalia State in the western part of Germany. The history of the Prosper Haniel Mine begins in the nineteenth century. The first mining activities commenced in 1863 with a workforce of 315 miners. Nowadays, Prosper Haniel is the highly competitive mine operated by the RAG Deutsche Steinkohle AG. Prosper Haniel employs about 4,500 miners. The mine produces about 3 million tonnes of high-quality coal annualy. The coal is extracted from four production levels in depths between 700 and 1,300 meters. The underground roadway system amounts to 141 km. The mineable reserves of Prosper Haniel account for around 200 million tonnes.

For the new panel 258 at Prosper Haniel with an average seam height of ca. 1.5 m a plow system was selected. This was a preference to a shearer to avoid the need to cut adjoining rock. Such a rock cut would negatively affect the productivity of the shearer. According to the experiences of the German Mining Industry at a seam height below approx. 1.8 m an automated plow system can achieve definitely a higher productivity than a shearer.

The plow longwall technology was implemented at the Prosper Haniel Mine in 1950s. The first high performance plow GH1600 plow system was applied at the Prosper Haniel Mine in last decade. This first panel with this plow system commenced its operation in September 2003 in the panel 258, located in the coal seam H.

Figure 3. Location of the Prosper Haniel Mine in Germany

Technical data of the plow system operated in the panel 258:

- Face length 400 m
- Roof support Shields DBT Type II
- Machine frame MR65
- Installed plow power 2 x 800 kW VFD / 1k V, 50 Hz
- Plow gearbox P-45 UEL; i = 16:1
- Plow chain 42x137 mm
- Plow speed 3 m/s
- Plow body GH1600-1
- AFC PF4/1132 mm with cross-frame
- AFC chain assembly 2 x 42x146 mm, spacing 6
- AFC gearbox P-65 UEL; i = 39:1
- Installed AFC power 2 x 1000 kW VFD / 1 kV, 50 Hz
- AFC speed 1.2 m/s

For the first time in a plow longwall, two 800 kW variable frequency controlled were used for the plow drives in conjunction with P-45 UEL-R overload protection gearboxes from DBT with a gear ratio of 16:1.

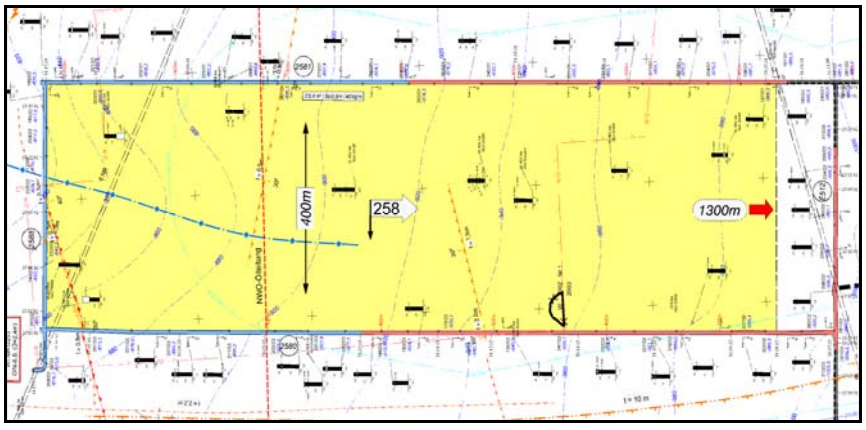

Figure 4. Location of the Prosper Haniel Mine in Germany

The coal seam H is located ca. 1000 m below the surface. The average H seam height amounts to 1.68 m, whereof ca. 0.15 m are the rock layers. The inclination of the panel lay between 22.5 and 27° in the direction of face retreat i.e. the face was working to the dip. The cuttability of the coal seam was estimated for 1.5 kN in the DMT scale. This means that the coal seam was regularly plowable.

The face shields have yield strength of 4,585 kN, a retracted height of 0.8 m and an extended height of 2.1 m. The collapsed and extended height ranges are slightly higher to accommodate and protect the equipment in the gate entry. The length of the face shield amounts to 5.5 m. The weight of the shield is 15 tonnes.

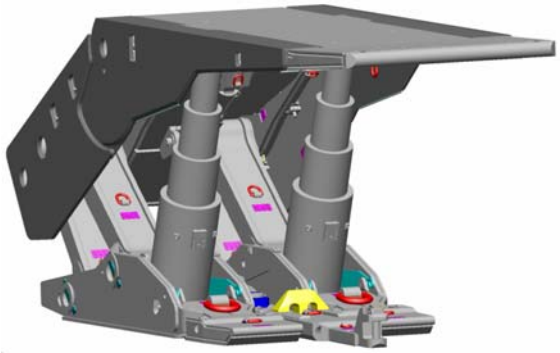

Figure 5. Shield of type DSK Group II – yield 4,585 kN

The new plow guide (at that time it was described as GH 42) was manufactured of highly wear-resistant cast material which contains a high degree of chromium and manganese for higher resistance and lower wear. The stability for the new plow guide was almost twice as high compared to the previous GH 9-38ve plow guide.

The new plow guide consisted of very strong one-piece guiding beams with rounded and separated chain channels. At the joints a circular overlap was designed, working as a seal against fine coal.

Together with the new plow guide, a modified plow pan PF 4 was introduced. The face and the gob side connectors had a breaking force of 3600 kN. In summary a very compact design of plow pans was created.

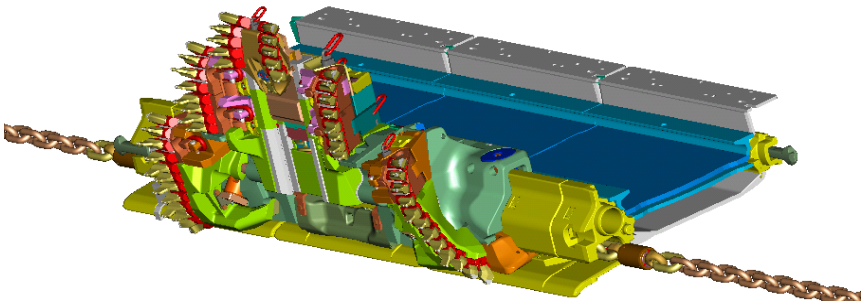

Figure 6. Plow body GH1600-1 applied at the Prosper Haniel Mine

The new plow body GH 1600 (previously also named GH 42) to operate with above described plow guide, was developed from the previous 5.7 plow body. The dimension and the strength of this new plow body were designed for the much higher installed power of 1600 kW (doubled power in comparison to previous plow systems).

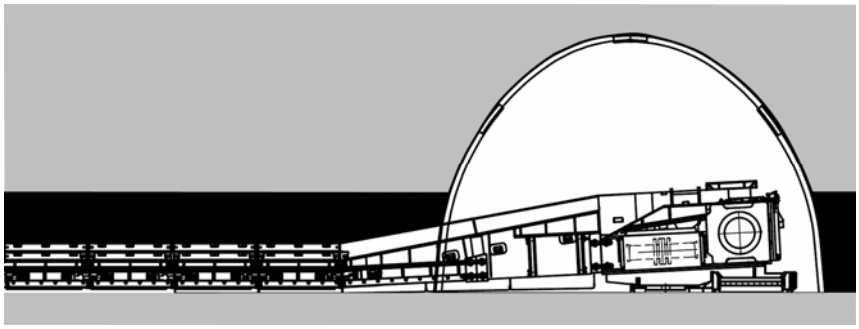

Figure 7. Main drive configuration at the Prosper Haniel Mine

With the new plow body an improved, definitely stronger bit system with a modified geometry (in comparison to former DBT 99 bits) was developed. The bit holders were strongly reinforced, based on the assumption that the bit forces on this new plow body will be much higher than those in the past, where the highest installed power was 800 kW.

Table number 1 presents the average and peak performance achieved in panel 258 at Prosper Haniel mine. This panel was in operation between September 2003 and May 2004.

Table 1. Performance of the first GH1600 plow system at Prosper Haniel

Plow system	Panel	Lengths		Average daily data		Peak daily data	
		Panel	Face	Advance	Output	Advance	Output
1	258	1,300 m	400 m	7.39 m	11,689 t	11.0 m	17,650 t

During that period about 1.2 million tonnes (ROM) had been mined. This corresponds to ca. 1 million ton of clean coal. The GH 1600 plow system operating in panel 258 at Prosper Haniel mine, was at this time, by far the best plow system in operation in all RAG (DSK) longwalls in 2003. At this time only one shearer face with a much higher seam height had better productivity.

3 GH 1600 PLOW SYSTEM AT PINNACLE MINE IN USA

The Pinnacle coal mine belonging now (since December 2015) to Seneca Coal Resources, LLC (previously to Cliffs Natural Resources Inc.) is located in Central Appalachia, Southern West Virginia, near the city of Pineville.

The exploitation of low to medium, volatile metallurgical coal, at this mine is carried out in the Pocahontas No. 3 seam. This seam lies in a depth between 300 and 500 m and shows a middle thickness of 1.1 to 1.4 m, with an average of 1.25 m. All mine activities run in the horizontal deposits, with inclination below 5°.

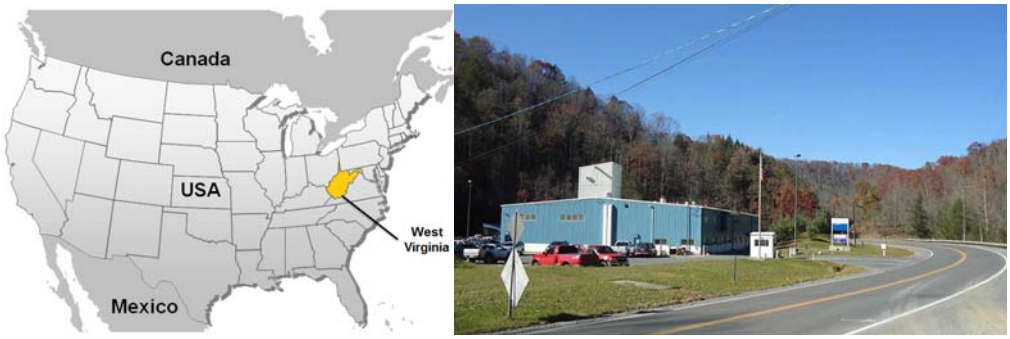

Fig. 8: Location of the Pinnacle Mine in the United States

The Pinnacle mine (in the past named US Steel #50 mine) has used plows since 1977. All faces were operated in the retreat mining system. The entries at Pinnacle have a height of about 1.4 to 1.5 m. Only the main transport and conveyance entries have a height of 2 m (79 in.). Generally, all entries are anchored.

In 1989, Pinnacle mine became the world's first automated longwall without an operator at the face. Westfalia Luenen (predecessor of Caterpillar) delivered to U.S. Steel #50 Mine in 1989 and 1990 two of the following plow systems:

- Face length 250 m
- Roof support 2-leg shields with PM 3 controls; 1.75 m centers
- Installed plow power 2 x 270 kW
- Plow guide 9-34 ve
- Plow chain 30 x 126 mm
- Plow speed 1.54 m/s
- AFC width 900 mm
- Installed AFC power 2 x 270 kW

In 1991 a new plow guide, allowing the use of 38x137 mm chain and installation of up to 2 x 400 kW power was implemented and in 1994 a new AFC drive system CST became operational. In 1995 a new plow body with all parts interchangeable underground was introduced and in 1996 and 1997 the reliable PM 4 shield control system was installed. In 1999 a new plow planetary gearbox UEL with overload protection was implemented, allowing an application of up to 500 kW.

In 1999 a new plow system described below was delivered by DBT:

- Face length 319 m
- Installed plow power 2 x 400 kW with HK 30-2 plow box

- Plow guide 9-38 ve
- Plow chain 38 x 137 mm
- Plow speed 1.98 m/s
- Plow body Type 2.7 - triple body
- AFC PF4/1032 mm with cross-frame
- Installed AFC power 2 x 600 kW
- AFC speed 1.86 m/s

The plows at Pinnacle Mine work with large cutting depths up to 250 mm. Such a large web results in a significant increase in cut product to be loaded. Earlier experiences have shown that a single plow body has difficulties to load such an amount of coal. For that reason a new triple plow body with inside bottom bits has been developed and manufactured, allowing loading of extracted coal at two different points simultaneously. As in the previous model of the plow body all wear parts were exchangeable underground.

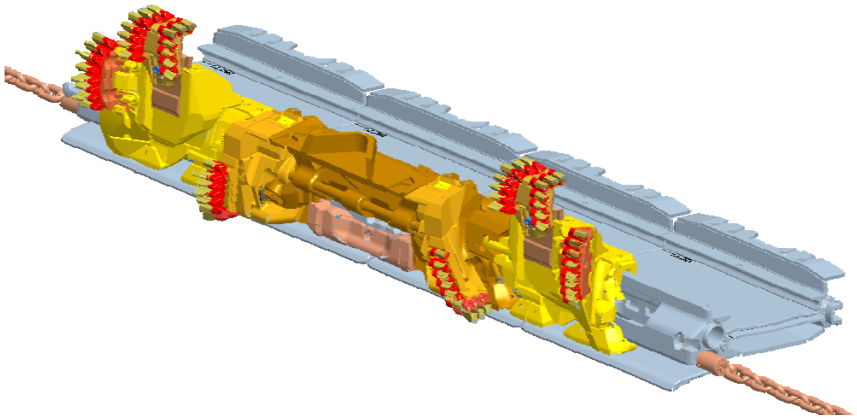

Figure 9. Plow body from the Pinnacle mine.

The drawing in Figure 10 shows the panel 7O in detail with its three-entry system. The face length was 290 m, the panel length was 2,800 m. The seam thickness in panel 7O was 1.4 m and has never been any higher in the past. It is expected to lower again down to approximately 1.2 m for future panels. The underground installation was between February and March 2000, end of March the panel started initial production.

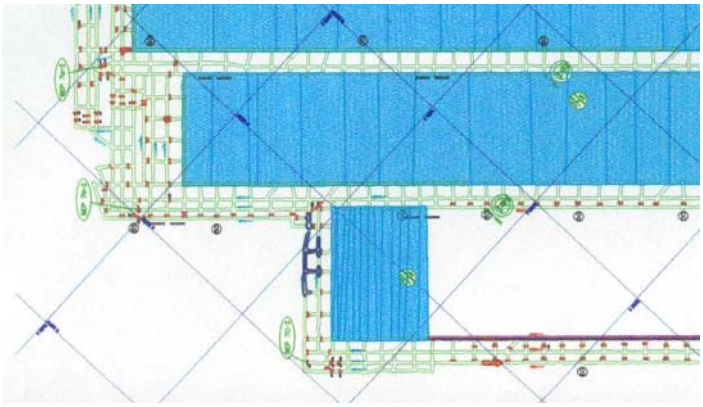

Figure 10. Pinnacle Mine - Typical panel with its three-entry system

This Pinnacle Mine has five shafts, one of which is the inclined main shaft (coal and material transportation). For roadway development three Continuous Miners are being used.

The plow systems at Pinnacle mine have reached in the last decade, a production of up to 1,400 t/h. Based upon an a daily plow run time of 14 - 16 hours (typically) a daily production of over 14,000 to 17,000 t/d of clean coal was produced. The peak production achieved in that face amounts to 22,700 t/d clean coal. After 10 years of very intense mining activities Pinnacle Mine decided to purchase a new longwall system for the Pocahontas seam. In order to select on one hand the most technically reliable and efficient working system and on the other, equipment ensuring the lowest production costs, a comprehensive study of available technologies has been carried out.

The plow system delivered in 2010 to Pinnacle Mine is characterized by following data:

- Face length 300 m
- Shield support CAT 880/1970 2x3181
- Machine frame MR35-1100/1500
- Installed plow power 2 x 300/600 kW / 4,160 V, 60 Hz
- Plow box HK 40-2
- Plow chain 42x137 mm
- Plow speed 1.98 m/s
- Plow body GH1600-2 (triple body)
- AFC type PF4/1132 mm with a cross-frame
- AFC chain assembly 2 x 34x126 mm, spacing 6
- AFC gearbox KP30 CST
- Installed AFC power 2 x 600 kW / 4,160 V, 60 Hz
- AFC speed 2.13 m/s

Figure 11. The new plow system delivered to the Pinnacle Mine in the year 2010

The newest plow system GH1600 for Pinnacle mine has been assembled and extensively tested during the compatibility test, which took place in July 2010 in Houston Pennsylvania. A 50 meters long plow system complete with shields, energy supply and control units was set up, tuned and screened during a couple of weeks. Such action was necessary, as this system incorporated several new technical solutions for the first time.

The GH 1600-2 plow body for the new Pinnacle plow face has similar configuration to the previous one. The plow body consists of two external parts and one intermediate part, where the pulling chain is attached to the plow body over the pulling sledge. The plow body is designed this to deal with high loading requirement, which would be difficult to load on the AFC with a single body. The bottom bits are placed near to the lateral axis in order to improve the behavior of the plow body while crossing undulations.

Figure 12. Operator car at the Pinnacle mine for control of the plow system.

The Pinnacle plow system is operated from a special control room placed in an operator car (see the picture in Figure 12), located in the energy train in the main drive entry. Inside the operator car all necessary computers, control and

communication units, screens and other devices are located. The underground control unit is connected via fiber optics to a control room located in the mine building at the surface.

The plow system consists of two types of shields: face and gate shields. Face shields support the roof where coal is being mined, and gate shields protect the gate ends of the plow system.

The face shields have a collapsed height of 0.88 m and an extended height of 1.97 m. A hydraulic cylinder with diameter of 300 mm provides yield strength of 5,162 kN. The transport length, which is critical to moving a shield around the mine, is 5.64 m and the shield weights 14.7 metric tons.

The gate shields have yield strength of 6,816 kN and a retracted height of 1.14 m and an extended height of 3.05 m. The collapsed and extended height ranges are slightly higher to accommodate and protect the equipment in the gate entry. The length and weight increase substantially to 8.18 m and 23.7 metric tons.

These roof supports have been designed and validated through rigorous testing. The life expectancy will enhance the overall performance and the ultimate payback.

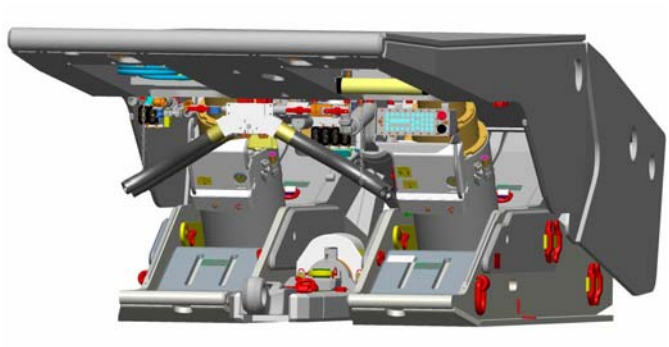

Figure 13. A face shield from the Pinnacle plow system – yield 5,162 kN

The plow system has commenced its service at the Pinnacle mine at the end of 2009 in a relatively short panel. After the move to a new panel the plow system started again in the spring of 2011. In mid-2011 Pinnacle mine was closed for several months by the American Mining Authority MSHA because of CO occurrence and the necessity of remedial measures.

The main drive entry has a width of 7 m and is 2 m high. The tail drive entry has the same height, but it is 1.5 m narrower, i.e. its width is 5.5 m. As both entries have special entry shields with longer canopies to keep the roof above the drives stable, the drives have a relatively low height of ca. 1.6 m.

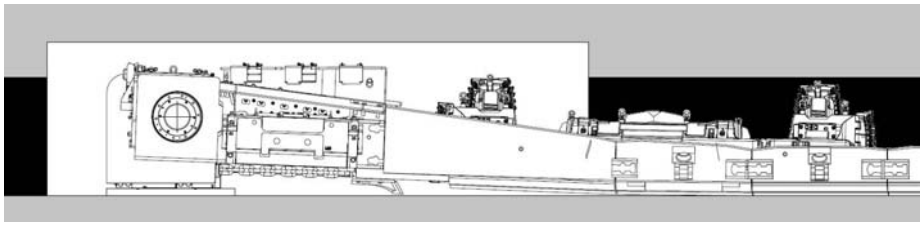

Figure 14. Main drive configuration at the Pinnacle mine.

Currently, Pinnacle Mine and its plow system face are operational again for some two months reaching a production over 10,000 metric tons. The momentary production restrictions are caused by CH4 occurrence. After overcoming those restrictions, the performance of the Pinnacle mine is expected to increase significantly.

Table 2. Performance of plow systems at Pinnacle

Plow system	Panel	Lengths		Average daily data		Peak daily data	
		Panel	Face	Advance	Output	Advance	Output
1	8D	2,000 m	250 m	23.3 m	11,510 t	42.0 m	18,140 t *
2	7O	2,800 m	290 m	12.0 m	15,500 t	37.0 m	22,700 t *
3	9I	2,631 m	298 m	24.2 m	18,834 t	47.9 m	32,411 t

* - Clean coal

Pinnacle coal mine is currently holding the world production record of 32,411 tonnes, mined within 24 hours on 11th of April 2014.

4 PLOW SYSTEMS AT BOGDANKA MINE IN POLAND

The Polish "Bogdanka" Mine belongs to Lubelski Węgiel „Bogdanka" S.A. The Bogdanka mine is located in the south-east Central Coal District, the best explored part of the Lubelskie Coal Basin (LCB) near the Ukrainian and Belarus borders. The CCD itself is situated within the boundaries of Polesie Lubelskie of which only a small portion is part of Lubelska Upland. „Bogdanka" is the only mine extracting hard coal in LCB.

Figure 15. "Bogdanka" Mine in Poland

Lubelski Węgiel „Bogdanka" S.A. is one of the leading producers of hard coal in Poland. The company achieved its leading position in this sector as a result of comprehensive financial operations as well as hard work on constant efficiency improvement of its mining activities over the last 30 years. The coal mined by "Bogdanka" is used mainly for the generation of electric and thermal energy as well as cement production.

The operative coal reserves of Lubelski Węgiel „Bogdanka" S.A. reach about 250 million tonnes. The mining area of LWB S.A. amounts to 57 km². In this area, from among 18 coal seams classified as balance resources and situated under an overburden of between 650 m and 730 m, eight seams with industrial resources have been selected for exploitation.

Lubelski Węgiel „Bogdanka" S.A. consists of three plants: Bogdanka, Nadrybie and Stefanów. The three plants are within in a distance of a few kilometers and have in total 6 shafts and one preparation plant.

Bogdanka started its mining activities in 1975, the first coal from a longwall was mined in 1982. Since that time "Bogdanka" mined over 100 million tonnes of coal. For 30 years "Bogdanka" based their underground mining operations on shearer technology.

During the mining operations conducted to date, the "Bogdanka" Mine has optimized the shearer-based technology of longwall mining to a satisfactory efficiency level and reaches reasonable economic results in seams of more than 1.6 m thickness. In seams of 2.0-2.5 m thickness, the use of shearers allowed it to reach a daily output from one longwall of up to 20,000 tonnes ROM, in lower longwalls with 1.6-2.0 m height the daily output reached up to 15,000 tonnes.

The extraction operations require the constant attendance of shearer operators in the longwall following the machine. According to Bogdanka, the constant presence of operators in a longwall allows an economically reliable mining operation with shearers in seams of at least 1.6 m thickness.

In order to reach those goals, an application of plow technology at "Bogdanka" Mine was decided. The implementation of plows has been recognized as an undertaking of strategic importance to further develop "Bogdanka" and has been consistently carried out for several years. Through the implementation of plows "Bogdanka" expected to reach reliable mining of seams of 1.2 to 1.6 m thickness. The application of this technology should improve the cost effectiveness of mining and on the other hand significantly reduce the amount of rock in the bulk output.

Figure 16. Plow system Bogdanka 1

The first plow longwall at Bogdanka was set-up on the Nadrybie plant in the panel VI of seam 385/2. The length of the longwall was 250 m, whereas the panel length was 1,750 m. The mining operation on that panel commenced on 25 March 2010.

Technical data of the plow system operated in panel 1/VI/385:

- Face length 305 m
- Roof support Shields 950/2,000 mm, props 2x3,619 kN
- Machine frame MR65
- Installed plow power 2 x 210/630 kW / 3.3 kV, 50 Hz
- Plow gearbox P-45 UEL; i = 16:1
- Plow chain 42x137 mm
- Plow speed 3 m/s
- Plow body GH1600-1
- AFC PF4/1032 mm with cross-frame
- AFC chain assembly 2 x 42x146 mm, spacing 6
- AFC gearbox P-45 CST; i = 33:1
- Installed AFC power 2 x 800 kW / 3.3 kV, 50 Hz
- AFC speed 1.52 m/s

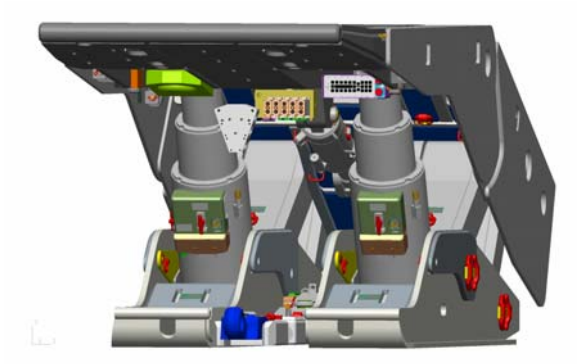

Figure 17. Face shield from the plow system at Bogdanka – yield 6413 kN

The plow longwall1/VI/385 in seam 385/2, the first in the history of Lubelski Węgiel "Bogdanka" S.A, was launched on 23 March 2010. The energy train containing the power supply units and plow system control cabin was situated in the tail drive gate entry.

The first months of mining operation in that longwall were used for training of the proper operation of the automated plow system by the staff. More than one month after launching the system, time used for fine tuning of the plow system's control, automation software and the optimal adjustment parameters to the geological and mining conditions, an output of 6,000 tonnes per day was reached.

Over time the performance achieved by the plow system increased steadily and reached the planned output at the expected level of 10,000 tonnes ROM. per day within three months after start-up. On 25 August 2010, a peak daily output of 16,894 tonnes was achieved. The first panel was completed on 20 October 2010.

The next panel with the first “Bogdanka” plow system was set-up on the Stefanów plant. This panel with the description 7/VII/385 had some important changes in comparison to the first, experimental panel. The face was widened from 250 to 305 m and the panel length was approximately 3 times as long, i.e. 5070 m. The thickness of the seam in this field ranged from 1.2 to 1.6 m. The Longwall 7/VII/385 was launched at the beginning of October 2011.

Another important change was the positioning of the plow control station on the surface. The control station was set-up in a special room in the Stefanów administration building. In comparison to the plow control cabin placed in the energy train in the first panel the control station on Stefanów was additionally equipped with a number of other monitoring systems like ventilation, energy supply, conveying, transportation and other vital mining systems.

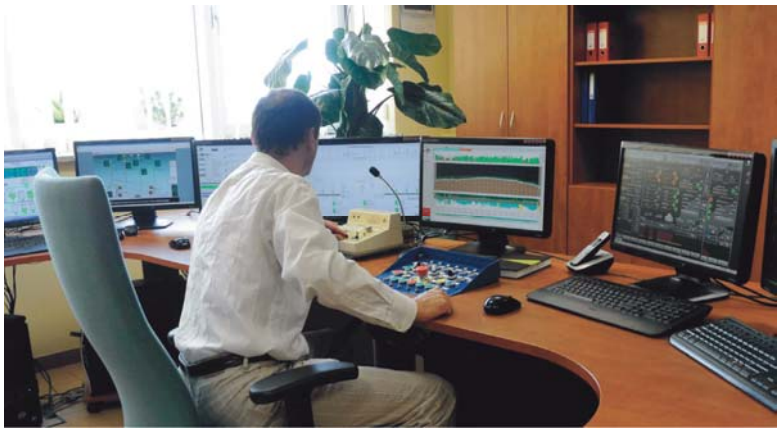

Figure 18. Plow control room on Stefanów

A control center plays an important role in achieving high production. The dispatcher’s duty, along with 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 a direct access to all relevant monitoring systems such as 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 one glance, allows quick reaction in case of a stoppage. Considering that for a high performance plow face, a one minute break means a loss of 15 to 30 tonnes, the importance of a quick reaction for unusual situations becomes obvious.

The plow system in the second panel reached a daily production level of 10,000 to 15,000 tonnes ROM relatively quickly. The daily running time of the plow increased in comparison to the first panel from 6 hours to over 10 hours. This positive development results from the longer face width but also from conclusions drawn by Bogdanka from the first panel and the technical improvements implemented in the second panel.

On 16 February 2012, “Bogdanka” broke the world production record for daily production from a plow-equipped longwall, with an output of 24,900 tonnes of coal from the 7/VII/385 panel. The plow face advanced more than 27 meters that day at a 1.63 m cutting height.

In the second half of 2012, the plow system moved into a part of the panel with very difficult geological conditions. A number of faults, rolls and wash-outs occurred in the course of the face run. For that reason the production dropped below 10,000 tonnes in that period.

The average daily performance for the year 2012 reached 11,721 tonnes. The plow system mined in 2012 a total of 3.43 million tonnes.

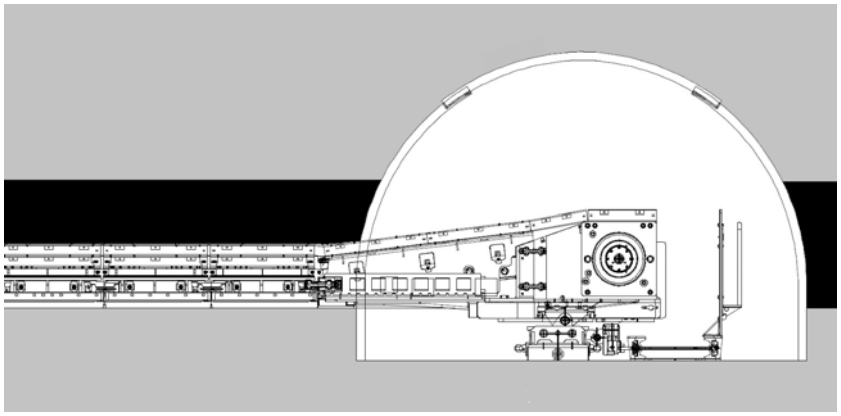

Figure 19. Main drive configuration at the Bogdanka mine.

In the fourth quarter of 2012 a second plow system on the Nadrybie plant has commenced operation.

The new plow system is significantly based on the technical solutions from the original. However, there are many important technical improvements in comparison to the first system at Nadrybie. Among other features the following important differences were implemented:

- The plow uses asynchronous motors with 265/800 kW installed power instead of 210/630 kW motors used on the first system.
- For the powering of the plow and the AFC motors 3.3 kV liquid cooled four-quadrant variable frequency drives (VFD) are applied.
- New, specially developed P45-CST (VM version) instead of P45-UEL gearboxes are used for driving the plow and the AFC.

Figure 20. In the face “Bogdanka” 2

The medium voltage VFDs are confected in a flame proof enclosure utilizing a Pulse Width Modulated (PWM) Current Source Inverter (CSI) for the machine side converter. VFDs of this type, possesses an effective power structure with a current limiting DC link inductor. The CSI VFD works a lot more precise than a Voltage Source Inverter (VSI) with variable frequency drive, delivering a very clean, near sinusoidal current and voltage waveform with total harmonic distortion (THD) below 5%. The CSI VFDs used at “Bogdanka” have regenerative power capabilities, thus they can absorb power flow back from the motor into the power supply. All four VFDs together with a special liquid cooling station are positioned in the energy train on the tailgate side of the plow system. The cooling station is working on all four VFDs, using a closed circuit for the coolant.

The application of VFD brings a significant improvement for the plow and AFC operation. It implements among others the following advantages:

- Application of standard asynchronous motors,
- Distance between motors and powering VFDs up to 4 kilometers,
- Variable speed for AFC and plow in a wide range (0 to 120% of nominal speed),
- Precise torque control of the asynchronous motors,

– Full utilization of installed power on both plow's motors through load shearing,
– Improvement of overload protection for motors and chains,
– Breaking possibilities and thus returning back power to the network,
– Unlimited start-ups of the motors,
– No significant voltage drop during start-ups,
– The usage of "weaker" networks possible.

The parameterization and control of the VFDs is realized from the control system located on the surface.

Figure 21. VFDs of the "Bogdanka" 2 plow system placed in the energy train on tail drive

Another important technical innovation is the very first application of a new CST gearbox. This unit is designed for operation at any rotational speed, at the perpetuation of all previous features of CST drives in worldwide operation. Thus the application of CST drives delivers a very sensitive overload protection for the chains.

The implementation of several new technical solutions by Caterpillar Global Mining and "Bogdanka" in conjunction with a very good organization of skilled and disciplined personnel from "Bogdanka" opens new, wide perspectives for the future of plow systems.

In November 2014 the third GH1600 plow system commenced operation at the Nadrybie plant. The length of the Bogdanka III longwall was 305 m. This system was very similar to the previous one i.e. to the Bogdanka II plow system. This system was equipped with the same type of roof support, plow system, AFC, BSL, crusher and power supply system. The only additional component was the remote controlled, automatic horizon control for the AFC. On every 5th pan an inclination sensor and a remote controlled valves for the outrigger steering cylinders is implemented. This system allows automatic maintenance of the set inclination of the AFC on the complete face length. The Bogdanka III plow system already mined the first panel over approximately one year.

The fourth plow system of type GH 1600 started the operation in May 2015. This system was for the first time implemented at the Bogdanka plant i.e. at the main shafts, where past mining activities took place. The Bogdanka IV plow system has several differences compared to previous two systems. The main alterations are:

– The longwall roof support shields have 360 mm longer canopies.
– The face shields have several smaller modifications.
– The plow has single speed 800 kW motors, identical as the AFC motors.
– The VFDs have a simpler design without bypass circuits.
– There are some differences in the control systems.

The Bogdanka IV system works under significantly more difficult geological conditions. Up till now this plow longwall has mined already over 1,200 m of the panel.

Table 3. Performance of plow systems at Bogdanka

Face	Panel	Lengths		Average daily data		Peak daily data	
		Panel	Face	Advance	Output	Advance	Output
1	1/VI/385	1,750 m	250 m	10.4 m	8,200 t	21.8 m	16,894 t
2	7/VII/385	5,022 m	305 m	12.0 m	11,721 t	27.0 m	24,934 t
3	1/VIII/385	5,015 m	304 m	10.8 m	10,201 t	15.0 m	15,309 t
4	6/VII/385	4,850 m	305 m	10.1 m	10,050 t	13.6 m	13,679 t

This high performance at "Bogdanka" can be achieved because of the following facts:

– "Bogdanka" is one of the most advanced mines worldwide. The performance magnitude and mining efficiency are their most important decision criteria for the selection of mining equipment.
– The work crew of "Bogdanka" is well skilled and motivated, possessing a very high level of technical knowledge.
– The advantages of plow technology are easily visible under such conditions. The procedural utilization degree (PUD), known also as the machine utilization, plays a crucial role here. The highest PUD can be achieved while plowing from face-end to face-end with double web at the face ends. This procedure is used at "Bogdanka". By applying such a procedure the plow system is able to reach a performance 50% higher than a shearer working under comparable conditions. Thus the face performance within the running time is also approximately 50% better than when using a shearer.

5 THE EXISTENT POTENTIALS AND TENDENCY OF FUTURE DEVELOPMENT OF PLOW SYSTEMS

The contemporary plow systems possess strong potentials for a high performance. A GH 1600 plow system equipped with 1600 kW is able to reach a performance of more than 10,000 t/d, even in seams with very hard coal. The diagram below presents theoretical calculation of a performance potential of a GH 1600 plow system as a function of the coal hardness (according to the DMT scale) and of the total daily running time. This calculation was carried out based upon a 300 m long face with working height between 1.5 and 1.8 m.

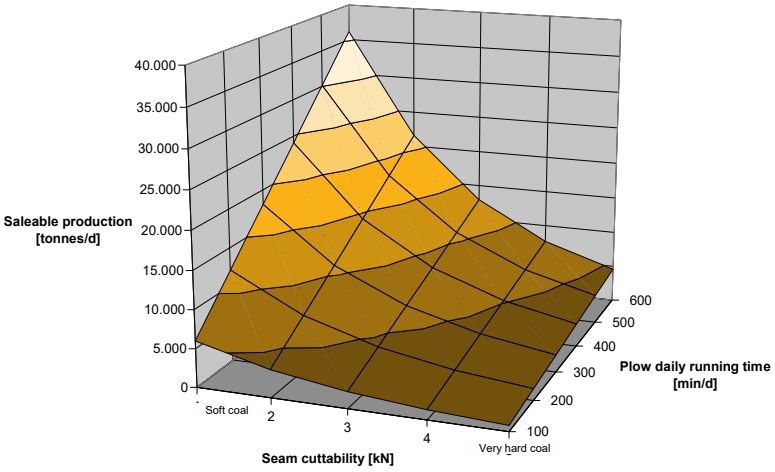

Figure 22. Performance potentials of a GH 1600 plow system.

The performance achieved by the plow systems presented in previous chapters shows the strong correlation between the theoretical calculation and the numbers from the quoted longwalls.

Nowadays economic factors play a more and more important role in decisions about the type and dimension of extraction technology applied in a mine. Because of low coal prices many operators worldwide look for longwall systems with lower investment. In general terms the mid-tier longwall systems are ca. 60 to 75 percent less expensive than the high performance longwall systems. But the initial investment magnitude should not be the decisive factor for a purchase of quoted equipment. High performance extraction systems (also plow systems) are more expensive but they are capable to deliver much higher performance (in case of GH 1600 plow systems approximately twice as high as mid-tier plow systems) and because of better quality to stay operational for much longer periods. Summarizing the above stated facts it can be stated that a high performance plow system is able to reach definitely lower Total Costs of Ownership. It means that a skillful mine operator while considering the mine operations from all necessary (it means technical, procedural, economic and safety) points of view for more than one decade will sooner or later come to the point, that a high quality and high performance plow systems are definitely more affordable.

Further development of future plow systems will be orientated on the following general directions:
– Additional performance increase
– Reduction of number of necessary miners working in a plow face
– Improvement of safety in plow longwalls.

The main driver to reach the above stated goals is the automation. The latest technology developments in this area enables a significant improvement in following areas:

- Communication. The digital copper cable, fiber optic and wireless base communication allows a fast and extensive transfer of data for short and long distances.
- Visual surveillance. An application of modern digital cameras allows a remote control of processes in underground mines.
- Measurement of different physical values. The implementation of new sensors, in many cases diverse types of sensors measuring different physical parameters working as a sensor fusion in order to increase the detection of difficult to detect determinants.
- Full automation of processes. Through the consolidation of all three above stated technical directions in conjunction with the available, very capable computer technology, many sub-processes or even main processes can be operated in the fully automation modus.

Full automation refers to the autonomous control of different machines of a longwall system. Modern plow systems are already now very strongly automated. A further automation of plow systems will definitely take place in next years.

6 REFERENCES

Bittner M., Weiss H-J. 2007. Einsatz schwerer Hobelanlagen – von der Innovation zum Standard. High-Performance Mine Production Symposium Aachen 2007 (in German).

Göge M., Paschedag U. 2005. High-Productive Longwall Mining in Medium and Thin Seams with Automated Plow Systems. Longwall USA, Pittsburgh June 2005.

Kicki, J., Myszkowski, M. 2011. Plow technology – strategic chance for performance improvements in mining. Plow technology – Implementation practice (in Polish). Krakow 2011, ISBN 978-83-62079-02-5.

Myszkowski, M., Bauckmann, S. 2011. Operational experiences with automated plow systems at the Pinnacle Mine in the USA. International Mining Forum, Poland, 2011, CRC Press/Balkema 2011, ISBN10: 0-415-68938-4 and ISBN13: 978.0-415-68938-0.

Myszkowski, M., Paschedag, U 2008. Longwall mining in seams of medium thickness – comparison between shearer and plow. 21st World Mining Congress & Expo 2008.
Central Mining Institute Katowice Poland, ISSN 1643-7608.

Myszkowski, M. 2011. Efficiency optimization of plow systems through the precise planning of new and comprehensive enhancement of operating longwalls. International Mining Forum, Poland, 2011, CRC Press/Balkema 2011, ISBN10: 0-415-68938-4 and ISBN13: 978.0-415-68938-0.

Paschedag, U., Filipiak, A. 2000. High-Performance Longwall Mining in Thin Seams. High-Performance Longwall Operations Colloquium Aachen 2000.

Paschedag, U. 2005: Advanced plow systems. Coal Magazine, Issue 7.

Paschedag U., Göge M. 2005. High-Productive Longwall Mining in Medium and Thin Seams with Automated Plow Systems. Longwall USA, Pittsburgh June 2005.

Stopa, Z. 2011. Experiences of Lubelski Węgiel “Bogdanka” S.A. with the implementation of plow technology. Plow technology – Implementation practice (in Polish). Krakow 2011, ISBN 978-83-62079-02-5.

Stopa, Z. 2011. Plough Technique at LW “Bogdanka” S.A. - Present State and Prospects of Development. International Mining Forum, Poland, CRC Press/Balkema 2011, ISBN10: 0-415-68938-4 and ISBN13: 978.0-415-68938-0.

Voss H-W., Junker M., Bittner M. 2004. First operational experiences with a new high-powered plow system in hard coal. Glückauf Mining reporter 2-2004.