Operational Experiences of Automated Plow Systems in Tiefa, China

Dr. David Xianguang Tang

Plow/AFC System Sales Manager
Caterpillar Global Mining Greater China & Korea
Caterpillar (China) Investment Co., Ltd.

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1. Introduction

Tiefa Coal Mining (Group) Co., Ltd. is a state-owned coal producing company located at Diaob-ingshan City, Liaoning Province, in the northeast of P. R. China. It has eight mines operating in its three coal fields with a total field area of 618.43 KM^2 and total proven coal reserves of 2.3 billion tons, 26% of which is in low seams. It is expanding its coal production by purchasing coal reserves in Inner Mongolia and establishing a joint-venture mine in Shanxi province, which has high-quality coking coal in low seam reserves. Tiefa has a number of concerns regarding how to handle these low seam reserves. First of all, using traditional mining methods such as drilling and blasting is less productive and less safe. Second, halting production in these low seams would result in the waste of these reserves, because it will be very difficult to recover them in the future if the thick seams beneath them are mined first using the current longwall method—which is not allowed by Chinese central government. Third, the service life of some of its coal mines will be shortened considerably because their thick seam reserves have been mined out. Take the Xioaqing Mine for example: it would be closed very soon if low seam reserves are not mined, and its three thousand employees would lose their jobs.

An automated plow system provided Tiefa with a solution for mining its low seam reserves. In 2000, the first automated plow system was imported from DBT (now a part of Caterpillar) and successfully used at the Xiaoqing Mine. Since then, Tiefa has invested heavily to import five automated plow systems, the fifth of which was delivered in early 2013 and put to work at the joint venture mine at Shanxi province.

2. Tiefa Approach to Automated Plow System

Plow systems have been in use in China for a very long time. As early as 1964, some Chinese mining equipment manufacturers started developing plow equipment together with coal mines and research institutes, and were able to supply multiple types of plow equipment in the late 1990s.

In 1980, two sets of Westfalia Becorit 8/30 plows were imported and employed at Qishan Mine and Jiahe Mine, both belonging to Xuzhou Coal Mining Company, Jianshu Province. In 1993, one set of Halbach & Braun KHS-2 compact plows was put into operation at the Da-tong One Mine of Songzao Coal Mining Company, Sichuan Province. However, they were equipped with low installed horsepower motors and were not automated and therefore could not achieve high productivity.

In 1997, Tiefa began to consider applying an automated plow system after learning of successful operations in the USA and Germany. A feasibility study group comprised of Tiefa, a research institute and a local shield supplier conducted intensive investigations to evaluate the feasibility of importing and applying the most technologically advanced system available in the Tiefa mines. The group concluded that the DBT automated plow system would be an ideal candidate for Tiefa's low seams in terms of technology and quality. After further evaluations and discussions, it was agreed to use roof supports—including face end roof supports—supplied by a local manufacturer equipped with a DBT PM4 electro-hydraulic control system, advancing rams and hydraulic valves. In addition, it was decided that one PM4 E/H control unit should control three roof supports instead of only one. This came to be known as the "Tiefa Model," and it was adopted on other DBT automated plow systems imported to China.

The contract for importing the first automated plow system was signed in December of 1999. Thereafter, three more systems were purchased *(Table 1)*. Another system was ordered for the joint venture mine at Shanxi Province and was delivered in early 2013. All five systems were based on the "Tiefa Model," but this does not mean that each system is a simple repeat of the previous systems. Based on the experiences gained in utilizing previous systems and the available cutting-edge technology, improvements were made for each new system, mainly in the following aspects:

A) LOCAL SHIELDS

Both face end shields and face shield came from local suppliers in order to reduce the equipment investment. The interfaces between the local shields and the imported ram cylinders (with reed rod, outrigger steering cylinders, E/H control units, valve blocks, and pressure sensors) are always the key topics during design liaison meetings and the prototype tests conducted at the workshops of local shield suppliers to ensure better performance of each system.

- **Face end shields**

  The face end shields are employed at both main gate end and tail gate end to protect the miners and to push the plow and AFC drives and BSL. All face end shields have four legs. The width of the Tiefa 1 face end shields is 1880 mm, with a support resistance of 9900 kN, which was later proven to be too heavy and large. Starting with the Tiefa 2 system, 6200 kN became the standard support resistance for the face end supports. The support density can reach more than 0.64 MPa while the contact pressure at base is 1.8 MPa. The hydraulic stroke is 600 mm. The face end shields of Tiefa 1 are manually controlled, while those of Tiefa 2 and 3 were upgraded to PM4 E/H controlled. Instead of PM4, the 12- function PMC-R was ordered for Tiefa 4.

2. Tiefa Approach to Automated Plow System

- **Face shield**

  The face shields for all four systems have two double telescopic legs. The contact pressure at base was reduced from 2.5 MPa on the Tiefa 1 to 1.77 MPa on the Tiefa 2 and 3, and further to 1.33 on the Tiefa 4 to suit a soft floor. The auto-controlled water spray was added on the AFC spill plates for the Tiefa 3. On the Tiefa 4, the water spray nozzles were moved to the canopies of the face shield and controlled by PMC-R. The functions of the E/H control were increased from 4 on the Tiefa 1 to 6 on the Tiefa 2 and 3, and further to 12 on the Tiefa 4. The shield closed height is always the most difficult part in the design and manufacture of low seam shields. The closed height of the Tiefa 1 shields is 900 mm. It was lowered to 800 mm for the Tiefa 2 and 3, and further to 600 mm for the Tiefa 4. This height is expected to be reduced to 550 mm on the upcoming Tiefa 5 for the joint venture mine in Shanxi with the support resistance being 4400 kN.

B) AFC

The installed power was increased from 2x315 kW to 2x400 kW. Accordingly, the face length was increased from 200 m to 245 m. Cross-frame drive frames were adopted on the Tiefa 2 and 3 for the better performance in flat seams.

C) PLOW

The installed power was increased from 2x315 kW to 2x400 kW. Meanwhile, the plow body speed increased from 0.88/1.76 m/s to 0.96/1.92 m/s. The GH9-38Ve/5.7N plow body—with a minimum height lower than that of GH9-38Ve/5.7—was ordered for the Tiefa 4 to prepare for the lower seams.

D) PLOW CHAIN PROTECTION

S-15-LK plow gearboxes were installed on the Tiefa 1 and 2. Their mechanical chain protection was difficult to calibrate and did not perform well. As a result, plow chain breakages occurred from time to time. P-30 UEL gearboxes with IKM were used as a substitute on the Tiefa 3 and 4 and achieved a better result. The Tiefa 2 was also upgraded to IKM. P-30 UEL gearboxes with PMC-D/V will be included in the Tiefa 5.

2. Tiefa Approach to Automated Plow System

TABLE 1. *Configurations of automated plow systems of Tiefa*

System		Tiefa 1	Tiefa 2	Tiefa 3	Tiefa 4
Face Length (m)		207	215	230	245
Face end shield	Model	ZZ9900/17/30	ZT6200/18/32D	ZT6200/18/32D	ZT6200/18/32D
	Legs	4	4	4	4
	Height (mm)	1700~3000	1800~3200	1820~3200	1800~3200
	Width (mm)	1880~2130	1420~1590	14400~1610	1420~1590
	Shield center (mm)	2000	1500	1500	1500
	Pump pressure (Mpa)	31.5	31.5	31.5	31.5
	Support resistance (kN)	9900	6200	6200	6200
Face shield	Model	ZY6400/09/20D	ZY5200/08/18D	ZY5200/08/18D	ZY4800/06/16.5D
	Legs	2	2	2	2
	Height (mm)	900~1800	800~1800	800~1800	600~1525
	Width (mm)	1440~1600	1440~1600	1440~1600	1440~1600
	Shield center (mm)	1500	1500	1500	1500
	Pump pressure (Mpa)	31.5	31.5	31.5	31.5
	Support resistance (kN)	6400	5200	5200	4800
AFC	Model	PF2.30/732	PF3/822	PF3/822	PF3/822
	Installed power (kW)	2x315	2x400	2x400	2x400
	Discharge	Overhead	Cross-frame	Cross-frame	Overhead
Plow body	Model	GH9-34Ve/4.7	GH9-38Ve/5.7	GH9-38Ve/5.7	GH9-38Ve/5.7N
	Height (mm)	800~1675	880~1645	880~1645	800~1585
	Installed power (kW)	2x160/315	2x200/400	2x200/400	2x200/400
	Speed (m/s)	0.88/1.76	0.88/1.76	0.96/1.92	0.96/1.92
Electrical	Control unit	Central control	Central control	Central control	Central control
	Plow chain protection	Mechanical	Mechanical	IKM	IKM
	Shield control	PM4	PM4	PM4	PMC-R

3. Performance of Automated Plow Systems

The first automated plow system was put into operation at Xiaoqing Mine in early 2001. Through 2009, nineteen panels had been finished using the four plow systems at the three Tiefa mines *(Table 2)*.

TABLE 2. ***Faces mined by the automated plow systems***

	Plow System	Mine Name	Face Name	Face length (m)	Mining height (m)
1	Tiefa 1	Xiaoqing	W1E-703	200/150	1.34
2	Tiefa 1	Xiaoqing	W1W-712	200	1.46
3	Tiefa 1	Xiaoqing	W1E-702	200	1.34
4	Tiefa 1	Xiaonan	W3-409	165	1.7
5	Tiefa 1	Xiaoqing	W1E-701	200/150	1.35
6	Tiefa 1	Daming	E1S-704	196	1.5
7	Tiefa 1	Daming	E1S-703	200	1.7
8	Tiefa 1	Daming	E1S-705	200	1.6
9	Tiefa 1	Daming	E1S-702	200	1.6
10	Tiefa 1	Daming	E1S-702	155	1.7
11	Tiefa 2	Xiaonan	W3-410	215	1.8
12	Tiefa 2	Xiaoqing	W2-704	215/170	1.67
13	Tiefa 2	Xiaoqing	W2-705	225	1.5
14	Tiefa 2	Xiaoqing	W2-708	215	1.5
15	Tiefa 2	Xiaoqing	S1W-701	215	1.7
16	Tiefa 2	Xiaoqing	W1E-705	220	1.2
17	Tiefa 3	Xiaoqing	W2-719	230	1.8
18	Tiefa 3	Xiaoqing	W1E-704	230	1.3
19	Tiefa 4	Xiaoqing	W2-713	207	1.4

3. Performance of Automated Plow Systems

As a typical automated plow application in Tiefa described below, Panel W3-409 of Xiaonan Mine was successfully mined using the Tiefa 1 plow system from October 2002 to February 2003.

- **MINING CONDITIONS:**

  Panel width: 165 m

  Panel length: 924 m

  Avg seam thickness: 1.7 m

  Coal hardness: f=2~3

  Face inclination: 3 ~10 degrees

  Friable roof: mudstone, avg 0.4 m

  Immediate roof: fine sandstone, sandstone, avg 8.4 m

  Friable floor: mudstone, avg 0.1 m

  Immediate floor: sandstone, avg 2.9 m

  Overburden depth: 407~507 m

  Total panel reserves: 580,000 tons

- **LONGWALL EQUIPMENT:**

  Plow system: Tiefa 1 *(see Table 1)*

  BSL: SZZ764/200

  Crusher: PEM650x1000

- **SELECTED CUTTING DEPTH:**

  Head to tail: 30 mm

  Tail to head: 50 mm

- **OUTPUTS**

  Avg daily output: 4852 tons

  Best daily output: 6658 tons

  Avg monthly output: 142,200 tons

  Best monthly output: 145,600 tons

3. Performance of Automated Plow Systems

Xiaonan's experiences show that, under certain conditions, a shearer longwall can also come relatively close to that performance. However, the automated plow longwall enjoyed obvious economic benefits beside the improvement in safety and working environment. First of all, it used less manpower *(Table 3 and 4)* due to its automation, and thus its manpower efficiency was improved from 90.5 tons/man-shift to 140.1 tons/man-shift. Second, the total direct operation costs of the panel (consumable & wear parts, labor, materials, grease and equipment rental) were reduced by 2.2 million Chinese Yuan. Third, if a shearer had been used for this face, 600 mm roof/floor rock would have to have been cut in order to make enough space for the operators travelling along the face, which would have increased rock content in coal by 15%. The better quality coal produced by the plow increased profits by 12 million Chinese Yuan.

TABLE 3. ***Manpower Organization Shearer Longwall***

JOB TITLE	SHIFT				
	Maintenance	Production 1	Production 2	Production 3	Subtotal
Foreman	1	1	1	1	4
Shift head	1	1	1	1	4
Shearer operator		2	2	2	6
Shield operator		3	3	3	9
Face end worker		4	4	4	12
Electrician	5	1	1	1	8
Mechanic	10				10
Backup		3	3	3	9
Total	**17**	**15**	**15**	**15**	**62**

TABLE 4. ***Manpower Organizational Plow Longwall***

JOB TITLE	SHIFT				
	Maintenance	Production 1	Production 2	Production 3	Subtotal
Foreman	1	1	1	1	4
Shift head	1	1	1	1	4
MCU operator		2	2	2	6
Face end worker		4	4	4	12
Electrician	4	1	1	1	7
Mechanic	7				7
Backup		2	2	2	6
Total	**13**	**11**	**11**	**11**	**46**

4. Gate Entries, Setup Room and Recovery Room

A) GATE ENTRIES

Compared to a shearer longwall, a plow longwall requires wider head & tail gate entries because all drives are in the gate entries. However, the wider entries are more difficult to support and maintain. To solve this problem, Tiefa has tried every means to make the entries wide enough to meet the requirements of the plow systems. Take Panel W3-409 of Xiaonan for ex-ample: The dimensions of its rectangular head gate entry were 5.6 m x 2.5 m, while the dimensions of its rectangular tail entry were 5.0 m x 2.5 m. Seven Φ22 mm x 2200 mm fully grouted resin bolts per row, 800 mm apart and 800 mm between rows, plus two Φ15.5 mm x 5300 mm (pattern 2000 mm x 2400 mm) cable bolts were used to support the roof of the head gate entry. In the tail gate entry, five Φ22 mm x 2200 mm fully grouted resin bolts per row, 900 mm apart and 900 mm between rows, plus two Φ15.5 mm x 5300 mm (pattern 2000 mm x 2400 mm) cable bolts were used for the roof. In both the head and tail gate entries, Φ22 mm x 2000 mm resin bolts (pattern 800 mm x 800 mm) plus 80 mm x 120 mm mesh were installed on each rib side *(Fig. 1 and 2)*. The capacities of the roof bolt, cable bolt, and rib bolt were required larger than 120 kN, 180 kN and 50 kN, respectively.

This design effectively controlled the entry deformation and thus ensured the success of the plow longwall.

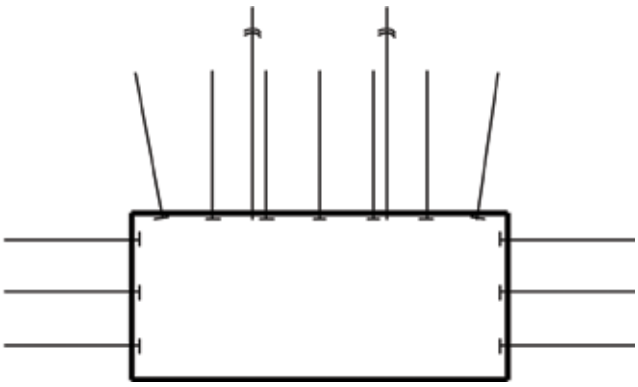

FIGURE 1. ***Head gate entry of plow panel***

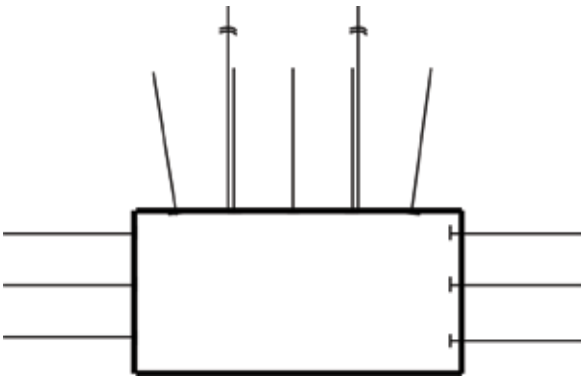

FIGURE 2. ***Tail gate entry of plow panel***

4. Gate Entries, Setup Room and Recovery Room

B) SETUP ROOM

The dimensions of a setup room must meet the requirements of the transportation and lifting of the face shields during face installation. In Tiefa's practice, a plow setup room was normally 7.0 m wide and 2.3~2.4 m high and developed along the floor. Roof rock needed to be cut in order to reach the required height. To make sure the shields contact the roof well and enter the seam smoothly, a 1.9 m wide roof was developed on the face side, inclined toward the face. Nine Φ22 mm x 2200 mm fully grouted resin bolts per row, 800 mm apart and 800 mm between rows, plus two Φ15.5 mm x 5300 mm (pattern 2000 mm x 2400 mm) cable bolts were used for roof support. Two Φ22 mm x 2200 mm bolts were installed on the face side rib and the gob side rib *(Fig. 3).*

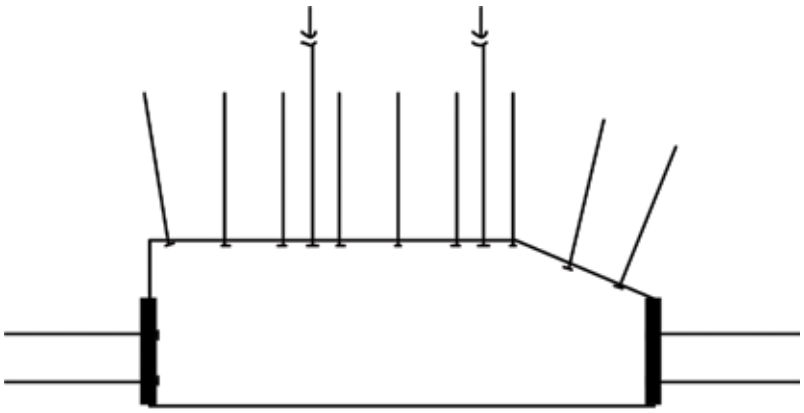

FIGURE 3. ***Setup room for plow longwall***

5. Conclusions

Cat automated plow systems helped Tiefa to achieve significant benefits. First of all, millions of tons in low seam reserves have been recovered. Second, the service life of the mines has been significantly extended. Assuming the total production capacity of Tiefa remains 20 million tons per year in the future, 620 million tons of low seam reserves will increase the service life of Tiefa's coal field by 31 years. Third, the working environment and safety of Tiefa miners have been improved considerably by automated operation.

Chinese experiences show that even though a shearer longwall can come close to the performance of a plow under certain conditions, the automated plow longwall enjoys obvious economic benefits beside the improvement in safety and working environment. It uses less manpower due to its automation, delivering higher efficiency, and has significantly lower operating costs. Furthermore, plows produce much cleaner output, as operation of shearers requires an additional roof/floor cut of several hundred millimeters.

Low seam reserves account for 20% of the total coal reserves in China. But the coal produced from these low seams contributes only 10% of the total production of China because of the low efficiency of low-seam mining without suitable equipment. Encouraged by Tiefa's successful experiences using Cat automated plow systems, six Chinese coal companies have imported Cat plows of their own; meaning there are now 11 Cat plow systems operating in China. More potential end users are discussing with Caterpillar in order to apply Cat automated plow systems—including the more powerful GH1600—to their low-seam mining.

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