

China's First AC Powered Walking Dragline

in Coal Mining

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Abstract

The following paper describes the introduction and operation of the world's most advanced dragline to the Hei Dai Gou Open Pit Mine of the Shenhua Group Zhungeer Energy Co. Ltd in Inner Mongolia, China. This represents a major step forward in surface mining in China and in the growth and expansion of the Hei Dai Gou Open Pit Mine. The advanced gearless hoist and drag features, operating characteristics and application of the 90m³ (117.7 cubic yard) Bucyrus 8750 dragline is presented by Bucyrus and Shenhua in a joint paper covering not only the machine but the integration into one of China's largest surface coal mining operations.

China's First AC Powered Walking Dragline in Coal Mining

Hei Dai Gou Mine

Hei Dai Gou Mine is one of China's largest open pit mines belonging to Shenhua Zhungeer Energy Co. Ltd, and is one of Zhungeer's main mines. Zhungeer itself is one of the state's key projects stemming from the 8th Five-Year Plan (covering the period from 1991-95) and formal production began in 1999.

Situated in the central Zhungeer Coalfield in Inner Mongolia (Figure 1), it is conveniently located about 10 kilometers (6 miles) from Shenhua Zhungeer Energy head quarters in Xuejiawan, 150km (94 miles) south of Hohhot and 150km (94 miles) south west of the city of



Ordos. It is connected to these locations by relatively good highways. It can also be reached directly via the Dazhun electrified railway and a conventional railway linking it to Hohhot is under construction.

Figure 1. Hei Dai Gou mine location.

Hei Dai Gou open mine (Figure 2) has a planned mining area of 42 square kilometers with recoverable coal reserves amounting to 1.5 billion tonnes and an initial design capacity of 12 million tonnes which has risen considerably. The coal quality is ideal for power generation

containing low sulphur (<0.5) and low phosphorus (<0.05). In its first few years of production, output grew by 1.5 million tonnes annually. It yielded over 10 million tonnes in 2002, which pushed it into the Chinese category of super-large surface mines (yielding 10 million tonnes annually). It reached full production in 2003 with the crude coal output amounting to 14 million tonnes.

Hei Dai Gou has continued to increase and improve its production capacity, in 2004, it yielded 17 million tonnes of raw coal and in 2006 yielded 20 million tonnes, which made it one of the largest open mines in China. Finally, in 2007, coal output reached 26 million tonnes and Hei Dai Gou became the number one surface coal mine in China. This coal not only provided sufficient supply for surrounding power stations, but additional coal was also shipped into southern China.



Figure 2. Hei Dai Gou Open Pit Mine

Mining Operations

Hei Dai Gou Open Pit Mine has applied a number of integrated mining technologies in the overburden removal process, for the upper loess layer averaging 49 meters (160 feet) thick; it uses four bucket wheel excavators with conveyors running around the pit to the dump areas.

For the middle rock layer averaging 56 meters (184 feet), it uses electric mining shovels loading into mining trucks and the 8750 walking dragline in a cast-blast/direct spoil application. For the bottom coal layer averaging 28.8 meters (95 feet), it again uses electric mining shovels loading into mining trucks which discharge into semi-mobile crushing stations and belt conveyors. Advanced mining equipment has been imported from the United States, Germany, Japan, the United Kingdom and Canada. Main surface equipment includes four sets of Bucket Wheel Systems from Krupp (Germany), Six 32m³ (42 cubic yard) Bucyrus 395B Excavators and one P&H 2800 mining shovel. In addition, there are four domestically built 10m³ (13 cubic yard) capacity shovels as well as a 20m³ (26.15 cubic yard) and 35m³ (45.77cubic yard) model manufactured in China. Truck fleets from domestic production are in operation and Komatsu models 630E and 730E range in capacity from 154 mt to 185mt (170 – 205t) . In addition, there are four domestic built 10m³ (13 cubic yard) capacity shovels as well as a 20m³ (26 cubic yard) and 35m³ (46 cubic yard) model manufactured in China.

Environmental Policies

Shenhua Group has been highly motivated in the area of the environmental impact of its mining operations, the Hei Dai Gou mine is located on the Ordos Plateau, and this is a region suffering from serious drought and soil erosion with numerous sandstorms developing during the year where temperatures can range from –35 degrees Celsius to plus 38 degrees Celsius. When the project began, surrounding regions were extremely dry, covered in sparse vegetation which was

being eroded further by harsh winds and creeping desertification. The mine immediately began a program of reforestation. It has so far reclaimed an area of 3.5 million square meters with a greenery coverage rate of 45%. The land reclamation rate is 12 times the national average. For its efforts, the mine has been named a “National Advanced Enterprise for Environmental Protection” and “Advanced Afforestation Enterprise of Coal System.”

Hei Dai Gou Expansion

Hei Dai Gou Mine has embarked upon significant new expansion plans which have included introducing new technologies to China such as controlled cast blasting and the introduction for the first time in China of overburden removal with the use of a large walking dragline.

Additional equipment has included large electric powered rotary blast hole drills with angle hole drilling for cast blasting and new dozer fleets of Komatsu D475 model units for additional dozing of cast material and dragline bench preparation. As the mine becomes more familiar with this new stripping method and the efficiencies improve the mine anticipates further increases in production capacities and the use of cast blasting will achieve up to 33-35% of material to be moved directly in the pit without the use of trucks.

China Growth

The importance of coal in China's economic growth is significant, with 2007 production of 2.53 billion tonnes of coal it is estimated that China produces 34% of the total world coal production and since 2004 has seen 13% annual growth.

China dependence on coal is well known with 66% of the current energy mix as the country tries to diversify its energy portfolio with major investments in hydroelectric, wind power and other energy forms.

Limited oil resources and the high cost of diesel fuel has helped provide impetus in China to look for less fuel intensive ways to mine for coal, this coupled with the supply difficulties for large mining vehicle tires have spurred interest in China in not only large electric powered walking draglines capable of moving material directly to its resting place but also crushing and conveying in either mobile or semi mobile forms to lower the dependency on large truck fleets.

Draglines - the early years

In the years prior to 2002 Shenhua and Zhungeer mining experts visited many operations around the world to benchmark their activities and learn new techniques as they evolved in the mining industry. Countries that were frequently hosting such visits were the United States and Australia where few mines if any operated in surface coal without a combination of dragline and shovel truck methods to mine coal at the lowest cost per tonne possible. It became clear to many in key mining positions that if China was to continue its rapid development as a world class player alongside other notables such as Peabody, BHP Billington, Rio Tinto and others there would be need to be serious consideration of this mining approach. The above outlined mining conditions at Hei Dai Gou mine and the general climatic conditions made the Powder River Basin of Gillette Wyoming and the Lignite areas in North Dakota a popular visit site to view the use of draglines together with other areas where cast blasting in mining was growing in popularity.

After much investigation and close co-operation with key mine design institutes in China detailed technical reviews were held with major suppliers and tenders were issued for a Large Walking Dragline of 90m³ (117.7 cubic yard) capacity operating at a working radius of 100m. Bucyrus was awarded the honor to supply this first large dragline in China and the first of its size in Asia outside of Australia.

Birth of the World's Most Advanced Dragline

In 1912 Bucyrus introduced electric power for the first time to the walking dragline and the mining world, although somewhat crude at the time many basic operating principals used in dragline technology have survived the test of time. The basic motions of the dragline's digging actions, Hoist, Drag, Swing and Propel, and the basic mechanical design of an upper frame with machinery, mast or tri-structure arrangement, boom and base or tub all have proven effective and therefore have changed very little.

In 1922 Bucyrus introduced a boom point arrangement on its model Heyworth - Newman Excavator, with a fore and aft sheave arrangement, productivity enhancements were hoped for but never fully materialized and other problems arose, today the modification has been tried again using today's advanced software and computing capability with limited results and added complexity to a few machines trying the system.

In 1977 Bucyrus introduced two major developments to the dragline world with the development of two modular draglines and for the first time AC drive to replace the traditional Ward Leonard DC drives used to electrically power draglines. These two models, the 380W and 680W (12-19 cu meter) (15.7-24.85 cubic yard) were originally designed for rapid move between projects eliminating the long erection and teardown cycles inherent with large walking draglines.

In 1997 Bucyrus acquired the assets of Marion Power Shovel Company to combine what had been the two leading worldwide manufacturer's of draglines into the most advanced manufacturer and developer in dragline technology. Thus began both a process of integration of the engineering expertise as well as the rationalization of two competing product lines and the development plans already in process or in the planning stages.

As the year 2000 approached and the product lines became confirmed drive system technology research and development that had been underway for a number of years moved to the forefront in the quest to significantly improve the current technology in use at that time and prepare these very capital intensive products for the next generation of mining.

Wave of the Future

In 1980 Bucyrus together with its Electrical Drive System partner, Siemens pioneered the use of AC drives on its Electric Mining Shovels, today all of Bucyrus Mining Shovels are powered by full AC drive systems and electrical performance has steadily improved to an unmatched level today compared to any DC drive technology available. With the trend away from DC motors and generators in all areas of the mining industry and the high performance of its 680W there had been on going reviews to move the very largest draglines up to 100 cubic meter (130.78 cubic yard) capacity into the world of AC power.

Key factors in the drive to introduce AC technology on the largest draglines were relatively straight forward and evidenced in all the gains experienced on the latest Bucyrus Mining shovel technologies using AC IGBT (Integrated Gate Bipolar Transistor) inverters:

- Elimination of Motor Generator Sets, Motor Brush and commutator maintenance and repair costs and downtime
- Increased motor life
- Enhanced Machine Performance in Speed and Torque
- Lower Drive System energy costs
- Improved Electrical System control and monitoring
- Reduced Control complexity and ease of trouble shooting.

Although the introduction of AC drive to the larger draglines had been under review for some years it was in effect the introduction of the AC IGBT AFE (Active Front End) inverter technology by Siemens for large horsepower drives that paved the way for the final stages of development and introduction with Bucyrus into the dragline market. The AC benefits are clear and represent the technology for the largest mining machines that will operate for the next 40 years or more.

One Step Beyond

With the application of AC technology to large draglines and the opportunity to replace multiple Motor Generator Sets Bucyrus Engineers opened up to other potential system improvements and such talks led down a path which resulted in the decision to move toward eliminating multiple motors and gearboxes with the first application of gearless technology on a large walking dragline. While certainly a new approach to draglines the technology was in fact mature having been used for many years in different applications since the early 80's:

- Bucket Chain Excavators

- Mine Winders

- Conveyors

- Cement Mills/ Grinding Mills

Of particular appeal when looking at the use of large Synchronous motors for such an application was the very low motor speed requirements of less than 35RPM and the inherent longevity of such drives, further more there would be no motor bearings as the Hoist and Drag rotors would be supported by the drums themselves under a direct drive arrangement.

As one can imagine the proposal by Bucyrus engineers to eliminate multiple hoist and drag gearboxes with all the associated shafts, cases, gears, pinions etc was a highly controversial proposal for a manufacturing company whose core competency is in this area and that was set to initiate a major expansion and renovation of its facilities. The management of Bucyrus however recognized the major benefits it would deliver to its customers and clearly weighed these against the future technology trends that would set the path for the future and maintain Bucyrus leading position in the dragline market.

Along with the above mentioned advantages of course was the further elimination of all lubrication on the hoist and drag functions, a typical 90-100m³ dragline using 60,000 liters of lubricant over a 20 year life of ownership alone.

Higher efficiencies result in a nearly 20% gain for AC gearless drives with an associated 20% lower energy cost, large savings in many of today's energy dependent countries (Table 1).

Existing Geared DC Drives		AC Gearless Drive	
■ Input Transformer	0.98	Input Transformer	0.98
■ MG Set Motor	0.93	AFE / Inverter	0.98
■ DC Generator	0.92	AC Integral Motor	0.93
■ DC Motor	0.92		
■ Existing Gearing	0.96		
TOTAL Efficiency	0.74	TOTAL Efficiency	0.89

Table 1. AC gearless drives prove more efficient

Performance

Along with the improvements in efficiency came substantially improved performance with reduced bucket filling times, higher hoisting speeds and better control and matching of lowering and payout speeds. In the periods of initial operation at Hei Dai Gou mine operating specialists have seen the machine reach production levels of up to 5000 BCM per hour and average production rates of 4000 BCM per hour during the early months of operation.

Machine Layout

Figure 3 provides an overall layout of the major components of the Bucyrus 8750 gearless hoist and drag (or Direct Drive Dragline: D3) showing the simplified layout with two large AC Synchronous motors for hoist and drag functions with motor capacities of 9600kw (13,000 HP). With this particular machine configuration of 90m³ (117.7 cubic yard) bucket capacity at 100m operating radius the deck layout comprises six 932kw (1250HP) motors with planetary drives and four 1150HP motors for the conventional propel gearboxes.

At the forward left hand area of the machinery house a lubrication room which is heated and insulated houses all lubrication tanks and equipment, on the right rear is the Electrical control room area housing all the IGBT Active Front End Rectifiers (AFEs) and the water cooled IGBT inverters cabinets together with all the associated electrical control and drive system components and equipment. Three main drive power transformers are mounted to the outer rear of the machine in a protected enclosure, main input power to the machine being at 22KV.

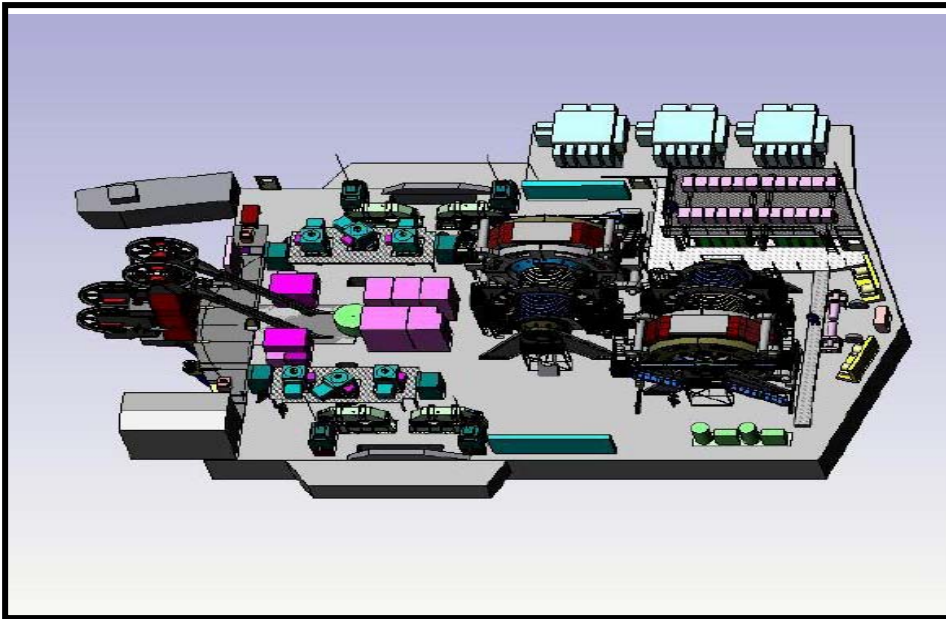


Figure 3. Machinery Layout 8750 Dragline with Gearless Hoist/Drag

Figure 4 highlights the Hoist and Drag functions showing the Low Speed AC Synchronous Motor, the mounting of the drum directly to the motor without gearing and Figure 5 the cross sectional view showing the motor poles mounted to the extended drum barrel and the main drum bearings which support the Rotor and drum assemblies.

In the center of the hoist or drag drum is a large caliper disc drum brake used for braking and holding of the hoist and drag functions when needed, this arrangement replaces a multitude of motor disc brakes on non gearless machines and with the slow speed of the hoist and drag drums should provide excellent braking capacity with long life. Early operational experience actually proved the brake system capability to be more than required and testing was carried out to reduce the number of caliper units and thus better match the braking system to the machine needs.

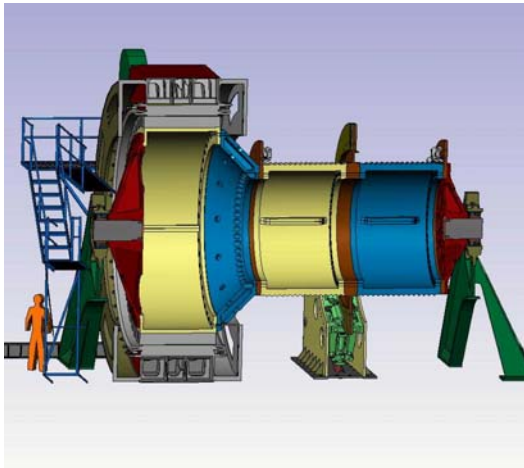


Figure 4. Synchronous Motor, Drum and Brake Assembly

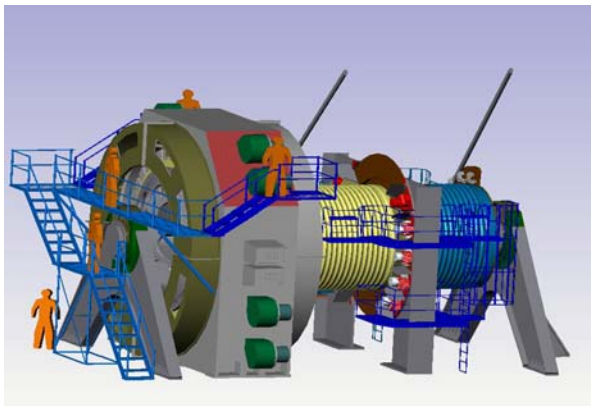


Figure 5. Cross section Showing Motor Poles, Extended Drum and Bearing Assemblies

Hoist/Drag Motors

Both hoist and drag main AC Synchronous Motors were fully assembled by Siemens' major motor plant in Berlin, Germany. Each motor is comprised of a stator and rotor with a combined weight of 260 tons. The stator stands 8m (26 feet) in height and was designed and manufactured in four sections for ease of disassembly, if required. It shipped preassembled into two sections for installation during the dragline's erection at site (See Figure 6). The rotor consists of 36 motor poles mounted to a drum extension. The operating life of these types of motors which operate at relatively low RPM rates is expected to exceed more than 150,000 operating hours.

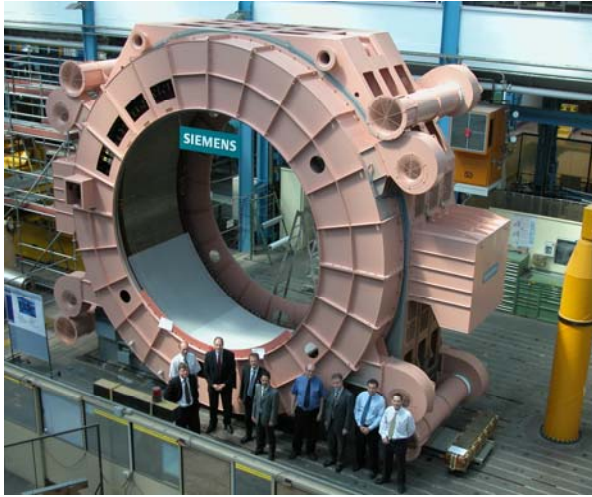


Figure 6. AC Synchronous Motor assembled in Germany

During the design phase of the entire assembly of the motor and drum system extensive 3D modeling and finite element analysis was performed by both Bucyrus and Siemens design teams but also audited by outside structural components (See Figure 7). During the early start up period of the dragline engineers traveled to China to install strain gauges and testing equipment to confirm and make any required adjustments based upon both theoretical case loads compared to the actual loading during full operation.

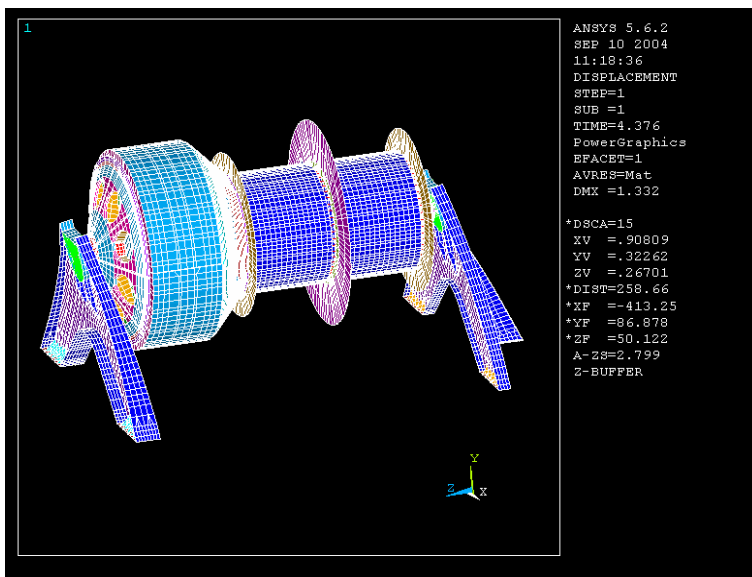


Figure 7. Finite Element Analysis and 3-D Modeling

Inverter Technology

Over 20 years of application of AC drive technology in Bucyrus Mining Shovels and smaller capacity Draglines paved the way for the successful application of AC drives on large walking draglines, finally achieving a long term goal of both partners' technology strategies. In particular, the introduction in the late 90's of IGBT inverters (Integrated Gate Bipolar Transistor) on Bucyrus Mining Shovels led the way to the capability to control AC drives with the highest efficiency and performance needed to control both speed and torque over the full motor capacity range.

The technology used is common today for both Bucyrus Excavators as well as large mining trucks with up to 400 tons payload capability. The same inverters (See Figure 8) are used for both the Active Front End (AFEs) and Inverters are completely interchangeable requiring



Figure 8. Siemens Water Cooled Inverter/AFE

limited parts stock requirements, with reliable 21st century digital electronics the machine has enhanced diagnostics and on board trouble shooting aids.

Recognizing the machine's eventual location in Inner Mongolia and the technological advances of the machine both Bucyrus and Zhungeer

Energy recognized the importance of monitoring the system as effectively as possible.

Arrangements have been made to incorporate "Access Direct" on board the machine to enable engineers as far away as the US or in Germany to access and monitor the machine as needed once the necessary communication equipment is installed.

Shipment and Erection

In late 2005 shipment of components and parts for the erection of the dragline at Hei Dai Gou mine began in earnest, China Shenhua Energy specialists were involved in careful planning for the arrival of several large shipments of major components, parts and materials to erect the machine. Since many of the ship loads were too large for containerization special arrangements had to be made to move such overweight and oversize loads from the port of Xingiang across country to Inner Mongolia. Often trucks were ready at the dock for custom clearance and direct shipment to site, extreme loads required special vehicles with multiple axles and special beds for overcoming transportation restrictions.

To erect the machine Shenhua Zhungeer Energy contracted the service of Fuxin Company who had previously erected a number of mining shovels and other equipment at the mine site in prior years. Bucyrus on its part dispatched additional Factory erection managers to assist in the machine erection since this would be the first exposure of this type of machine to the Chinese Mining Industry and in recognition of the likely challenges the parties would face together.

In the early structural phases the learning curve involved in completing the assembly and weld out of structures such as the dragline base, revolving frame, tri-structure and boom progressed as expected at a slower rate than in typical erections in mature markets but in time the contractor and the dedicated team of Shenhua Zhungeer Energy project engineers became quite proficient as the project advanced.

The project was not without its problems prior to final start up in late 2007, the explosion in equipment demand of the mining industry after commodity markets and economies rose putting considerable strain on material supplies, especially special castings and component supplies. Two key large casting components ran into process problems which required redesign and

delayed shipment. Shenhua Zhungeer Energy project engineers, its contractor and Bucyrus worked closely together to attempt to minimize the overall impact of such situations recognizing that this was the first such undertaking in China.

Application at Hei Dai Gou Mine

The Hei Dai Gou mine sits at an elevation of 1100m and experiences annual temperature ranges of -34 degrees Celsius to plus 39 degrees Celsius. In this relatively dry area of Inner Mongolia annual rainfall is from only 231mm to 460mm, the area frequently experiences dust storms and winds of up to 23m/s.

Figure 9 is a general overview of the dragline pit in the early phases of its initial set up. The mine has been operated as a bucket wheel/shovel truck mine since its initial operation, the introduction of this 90m³ (117.7 cubic yard) dragline is a major step forward for the mine and presents its own challenges. Shenhua Zhungeer Energy mining engineers, production and maintenance engineers are in a period of adjustment as they move towards planning a more intensive mining program and developing an understanding of the most efficient ways to use the machine.

Other changes in their mine process has been the introduction of the first cast blasting in China with dragline benches as much as 55m (180 feet). Engineers worked closely with Orica from Australia in the implementation and planning of the blasting program. Currently the mine is successfully casting 33% - 35% of the dragline bench material. Komatsu 475 Dozers are then used to push and level the 8750 walking dragline bench for the next stage in mining. The 8750 then moves the remaining material to the spoil side of the pit. General length of the dragline cut is currently 2200m (1.4 miles) with a cut width of 80m (260 feet). The pit layout incorporates a central coal haulage ramp for removal of the coal which is carried out using smaller electric

mining shovels, the coal is 20 to 32m (65-105 feet) thick and must be taken in two lifts with a coal dip of several degrees.

Moving ahead of the dragline the top 40m-60m (130-200 feet) of overburden (loess) is excavated by the four Bucket Wheels and conveyed around the pit to the mined out areas. Following the initial cut by the wheel excavators up to 30m (100 feet) of sandstone and mudstone rock is blasted and removed by 35m³ (45.8 cubic yard) Electric Mining Shovels and trucks. The remaining 40-45m (130-150 feet) of rock is finally handled by the dragline above the coal seam.

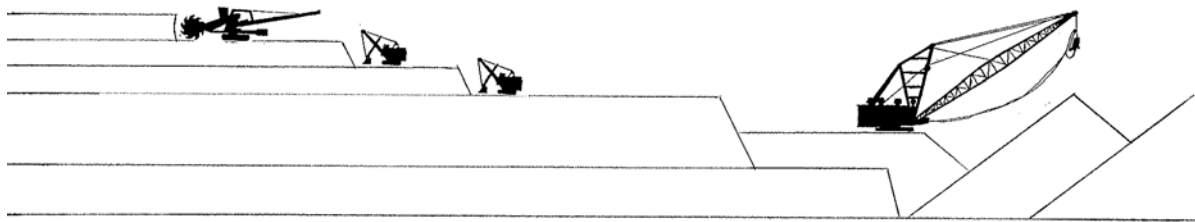


Figure 9. General Cross section of mine plan for Hei Dai Gou Mine.

Integration in to Hei Dai Gou Mine

Clearly numerous changes have been required in the mine and production planning areas of Zhungeer Energy, although this is the first application of a dragline in China the mine has successfully developed its revised pit layout to accommodate these major changes in mine application. Mine personnel are developing the knowledge and skills required to operate a successful dragline mine operation. This process has involved continuous technical training and

practical operating skills to operate the dragline at similar levels of existing operations in other more mature markets. Bucyrus and Zhungeer Energy personnel along with management have worked closely together to overcome a number of challenges during the completion of the project. Today with much of the initial integration work behind them Shenhua Group Zhungeer Energy Co. Ltd. is poised for the next phase of mine development as the operating efficiencies continue to improve.

While coal will continue to be the main source of energy in this rapidly developing economy, both underground and surface mines continue to develop their mining operations with particular emphasis on new and advanced approaches. The Hei Dai Gou mine has taken a major step forward in its development by acquiring the first dragline in China; other mines around the world are watching closely the introduction of this and other new technologies. There are a number of potential dragline mining operations in Inner Mongolia and other provinces as the expansion in surface mined coal develops. The entire Chinese mine industry is obviously watching closely the developments at Hei Dai Gou Mine.