The Next Generation of TBMs for Mining Applications

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ABSTRACT

TBMs have been used in mining in decades past, but their use has been limited and sporadic, due to both perceived and actual application difficulties. With new technology and mounting success stories, this is changing. For both coal and metallurgical mining, deep ore bodies require long access tunnels, and an efficient and economical method of reaching those deposits.

Today, mining engineers are considering TBMs as part of the overall mine development plan. Planned TBM mine drifts are not only longer, but have more complicated trajectories. Mine development TBMs will have to cope with varying geology, potential for high water inflows, steep gradients, and high temperatures. TBM systems are being planned to cope with such difficulties. TBM systems will be considered and increasingly deployed for mine development, even if commodity prices remain low. TBMs can satisfy the need for increased productivity, better life of mine infrastructure, and safety.

This paper will review the historical use of TBMs in mining, and will discuss the 2015 status of TBMs in mining, and the special requirements and adaptable features needed in order to make efficient TBMs a reality in mines worldwide.

HISTORICAL USE OF TBMS IN MINING APPLICATIONS

The successful hard rock TBM was invented in 1954. Over the next decades, TBMs have been used in many mining applications:

- Mine access drifts in several Spanish mines
- White Pine Copper Mine, USA
- Selby Coal mine drift, UK
- Coal slopes in Appalachia, USA
- German coal mines accdess drifts, several mines
- Magma Copper San Manuel, USA
- Cape Bretton Undersea Coal Slopes, Canada
- Stillwater Mines, USA

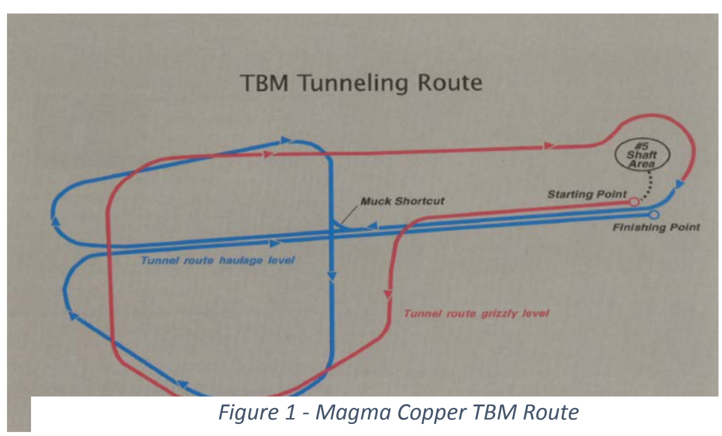

Figure 1 - Magma Copper TBM Route

In spite of these many applications and apparent successes, use of TBMs in mining applications has been sporadic. The percentage of underground excavations for both mine development and production drifts remains very small in comparison to the total length driven by drill and blast and all other methods. An interesting note is that the mining industry has embraced the use of raise drills for shafts and raises in mines. They use TBM rock cutting techniques and are in routine use in the mines. However, they are more compact, easier to deploy, lower capital cost, and more standardized than current TBMs.

CURRENT PROJECT UPDATE: STILLWATER MINES

Stillwater Mines, located in Montana, provides 4% of the global platinum supply and 9% of the global palladium supply. Stillwater Mining Company (SMC) has used conventional mining methods such as ramp and fill, captive cut and fill, and sub-level stoping to access a 28 mile long reef ore body near Yellowstone National Park. Since 1988, SMC has used four TBMs to drive mine drifts at this mine complex. SMC's Blitz Project is currently utilizing an 18"2" Robbins Main Beam TBM to develop 2 miles of the ore body reef. This TBM is outfitted with two roof drills, a probe drill with 360 degree grouting capability, and three core drills. 6 exploratory core drill holes are planned for every 500 feet of TBM advance.

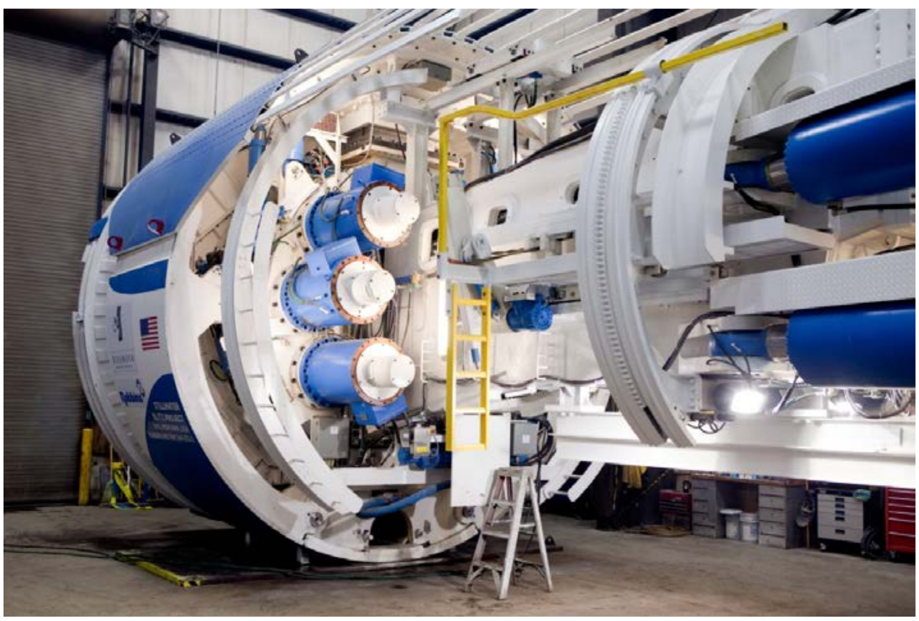

Figure 2 - Robbins 18' 2" Stillwater Mines TBM

As of October 2015, the 18'2" TBM has reached 9,013 feet with another 14,400 feet remaining. SMC has navigated through challenging ground conditions with small block sizes and highly altered joints. The TBM will bore through two more major faults with probing data showing water pressure less than 300 PSI and flow rates of less than 200 GPM. Crews are percussion probing on intervals to advance the machine and utilizing colloidal grout mixers and high pressure piston pumps to grout to refusal.

Figure 3 - Probe Drilling on Stillwater Mines TBM

CURRENT PROJECT UPDATE: GROSVENOR COAL SLOPES

Grosvenor Coal Mine, located north of Brisbane, Australia, is expected to produce 5 million tonnes of metallurgical coal per year for 26 years of operation, starting in 2016. Two decline tunnels are required for mine access to the coal seam; the conveyor drift (880m @ 16.7% decline) and the man and material drift (1000m @ 12.5% decline). For these tunnels, an Ø8.0m Robbins Dual Mode TBM was selected. The Grosvenor TBM is capable of boring through soft ground, mixed face, and hard rock conditions which required dual mode features. More importantly, it was designed to operate safely in the coal mine environment and manage the presence of methane gas with EPB mode, a double screw conveyor, and compliance to ERZ and NERZ requirements. In addition, the TBM was required to build two consecutive blind tunnels and designed for quick disassembly and remobilization for the next drift.

After an OFTA assembly above ground, the TBM was walked into a starter tunnel and began boring the first of two drifts on December 20, 2013. After completion of the first 880m blind tunnel, the TBM was rolled out back to the surface where it could be transported to the site of the second drift. Transport was done via special flat trucks keeping as much of the TBM and backup assembled together as possible.

Figure 4 - Grosvenor TBM Transport

The second drift was started on November 7 2014 and holed through on February 9, 2015. The greatest achievement at Grosvenor is the substantial improvement of health and safety conditions for workers and the high quality of the final product in terms of stability, durability and zero maintenance compared to any other bolts and mesh system.

Figure 5 – Completed Grosvenor Tunnel with Roadbed and Mine Piping Installed

FUTURE COAL SLOPES

Due to world economic conditions, environmental concerns, and an abundance of natural gas and other alternate energy sources in many parts of the world, the demand and price for thermal and metallurgical coal has dropped significantly in recent years. In spite of the success at Grosvenor Coal Mine, there have been no other TBM driven coal drifts since. However, interest remains high in several coal producing regions of the world. Alternative fuels are not always available or economical in many parts of the world, particularly in developing regions where energy demands are soaring. And metallurgical coal will still remain necessary for steel making.

Recently, Robbins has done much application engineering and preliminary TBM design for driving coal slopes in many parts of the world. The Grosvenor coal seams were at about 160 meters deep, so the slopes were only about 1000m long to reach the seam. Most of coal seams in other locations are much deeper. While this doesn't change the basic technique of developing the slopes with a TBM, it does increase the complexity of supply logistics to the machine, ground support, water pumping and ventilation. Since the TBM can reach drift development rates even up to ten times that achieved with roadheaders or other conventional mining techniques, The TBM should have even greater value for developing longer drifts.

Due to long technical and economic study times that are seem typical for mine planning, and the long delivery time of a purpose built TBM, it is important evaluate the benefit of TBMs early in the mine planning cycle. Otherwise, the decision to use a TBM can come too late in the planning cycle, and conventional equipment will be favored because it “takes too long to get a TBM on site and underground working”. In several situations, we have been requested to investigate mobilizing a TBM rapidly via a drift that has been started by roadheader or conventional excavation. The pace of excavation with the conventional equipment is too slow. Consideration to use a TBM comes later in the project, in order to get back to schedule. The illustration below shows mobilization of a TBM via a drift that had been started by roadheader. The TBM must be brought in and mobilized quickly in order to regain the schedule.

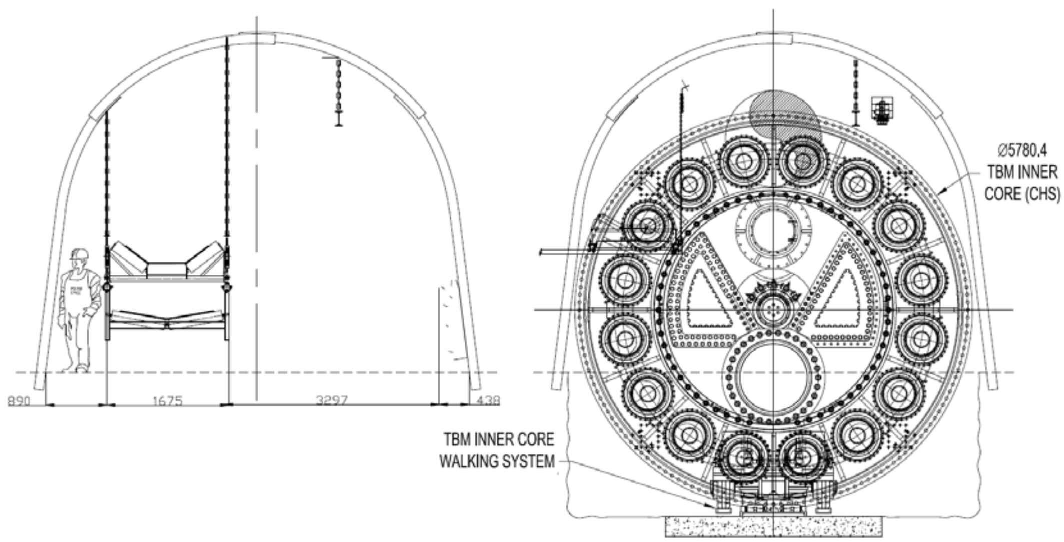

Figure 6 - Invert Excavated to Allow Assembly of TBM

In several applications, the mine plan is to drive down to the coal seam with the TBM, then follow the seam with the TBM to drive the development drift “in seam”. This creates problems of separating the coal from the rock, when it is transported to the surface. Mining in seam increases the danger of encountering gas, or the danger of coal dust or coal ignition from sparks or heat created by the TBM. Gas monitoring, tool materials, and tool operating velocities are critical considerations. Effective extraction ventilation or controlling the face conditions by flooding with inert gas or foams must be carefully implemented.

When driving in seam roof control can become more difficult due to the coal/rock interface. Often, cross cuts will be needed from the in seam development tunnel. Provisions for cross cuts must be carefully considered, including the effect on roof control at the cut.

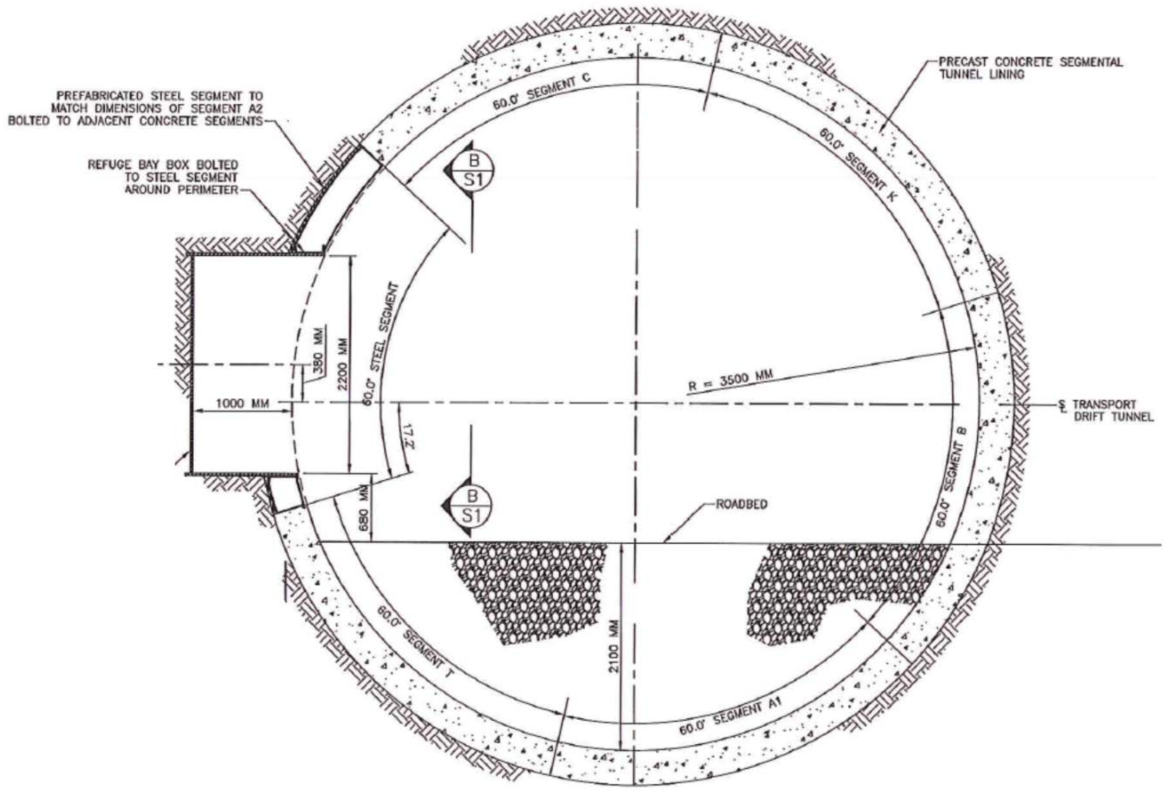

Figure 7 – Preparation for Refuge Bay or Cross Cut

Coal mine operations and equipment requirements are dictated by statutory regulations. Many different National standards and regulations, and even sometimes Regional, regulations exist. These are legal requirements in each region. The requirements can vary greatly from country to country, and even by region. This greatly increases the difficulty of providing a TBM that is compliant with the regulations in a given region. In Queensland, for instance, the need for flame proof equipment on the TBM is determined by definition of a so called ERZ/NERZ boundary (see figure 4). The ERZ zone is an Explosion Risk Zone. All electrical equipment in the ERZ must be flameproof, while equipment in the NERZ zone can be standard industrial IP55 rated equipment. This boundary is determined after risk analysis by a panel of experts. The electrical risks, environment, ventilation, and many other factors are carefully considered to define the risk. Absolutely vigilant gas monitoring and gas dilution were always part of the operating program.

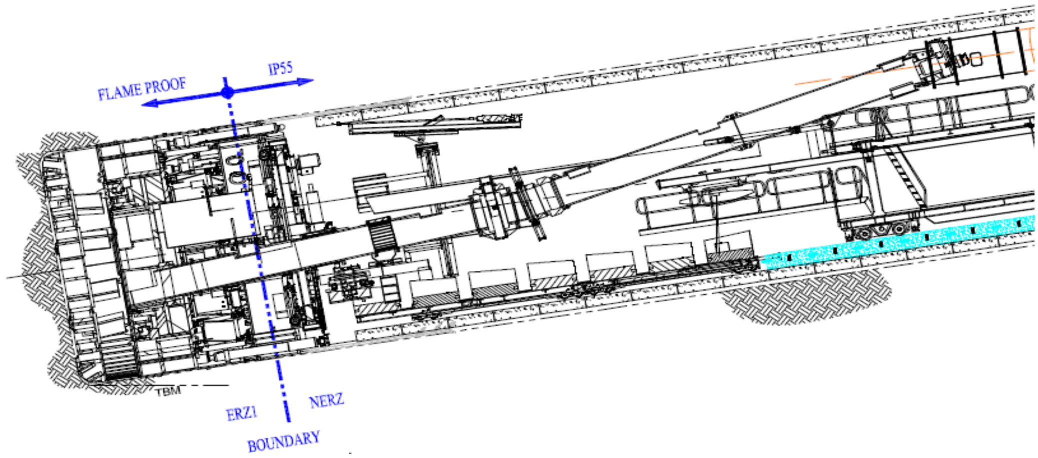

Figure 8 - Grosvenor TBM ERZ & NERZ Zones

In the USA, coal mining is regulated by the government agency MSHA. In essence, any piece of electrically operated machinery that goes underground in a coal mine environment must be "permissible", i.e., entirely flameproof. There are other regulations regarding the power transformers and the maximum voltage. The maximum voltage for a TBM is limited by MSHA regulations to 4160 VAC. A greater voltage level is necessary for practical power supply to a high power TBM, which will mine a significant distance from the portal or shaft. Such regulations are important and have saved many miners' lives. However, the use of a TBM can greatly increase the safety of mine development. Mining regulations should be considered according to the unique operation of the TBM equipment, so that TBMs can be used in a safe and practical way for coal mine development. An international standard, with special provisions made for any serious local conditions that may affect safe operation, would be of great benefit to the industry.

MINE ACCESS TUNNELS, DIFFICULT GROUND CONDITIONS

El Teniente is a very large copper mine in Chile. Two parallel access tunnels, 10 km long each, were planned to provide access to a new working area of the mine. Development of this new section is critical to the future operation of this mine operations. One tunnel is for bus traffic which would be used to bring the labor force into the mine. The other tunnel is for the main conveyor belt which transports ore out of the mine.

The tunnels encounter various rock conditions and depth of cover, to a maximum depth of 1500 meters. Contractors could tender the tunnel excavation by either drill and blast, or the TBM method. The successful contractor choose to use drill and blast excavation. Using drill and blast, the contractor could perform the excavation from several faces simultaneously. And it was thought that drill and blast would allow more versatile and less risky excavation in the areas of difficult ground. In fact, when the D+B headings reached the difficult ground, the work became very slow and problematic. Due to the high depth of cover and high in situ stresses, rock bursting often occurred. This required careful working and very heavy ground support, even in the face that would be excavated in the next round. In an effort to allow the ground to destress before excavation continued, long waiting periods were routine between rounds. Due to very slow progress, the contractor asked Robbins to study deployment of a TBM to complete the tunnels. There are serious risks to using TBMs in such difficult ground conditions. However, a TBM with special ground support provisions successfully completed the Olmos tunnel in similar, difficult conditions. Robbins proposed a TBM with the slat roof support system, efficient mesh and rock bolt installation, and shotcrete if necessary. Special personnel protection shields were designed to protect personnel from rock bursts and other bad ground conditions. The TBM could be deployed rapidly via the existing D+B tunnels. This TBM seemed to offer rapid excavation rates and good safety provisions in the difficult ground conditions. However, the tunnels were already nearly half done when the TBM study started. Due to the long decision making process and the fact that several faces were being worked by D+B, the TBM was not ordered. In retrospect, if it had been considered from the early planning stages, the overall tunneling schedule would most likely be significantly improved.

TBMs have been used on several projects recently in difficult ground conditions. One school of thought has been that such challenging jobs are better left to D+B. The thought is that conventional excavation can be more versatile and allow different techniques to be employed in difficult ground. However, recent TBMs have been equipped with versatile system for such difficult conditions. Although the TBM may progress slower in such difficult conditions, the overall rate is much greater due to the superior TBM advance rates in more "normal" conditions.

Figure 9 - McNally System with Ring Beams and Slat Supports

LONG ACCESS TUNNELS, CONTINUOUS CONVEYORS

Most TBMs for mine access tunnels will need to be used with continuous conveyor systems for mucking. Usually, the TBM must bore downwards to reach the ore deposit. Most access tunnels start at the surface, then bore at the steepest decline that is practical to reach the depth of the deposit. For tunnels that will be used for high capacity belt conveyors for mine production, the grade is usually limited to about 1 in 6 (9.5 degrees, depending on the material to be transported, water, etc.) Some conveyors can be steeper, up to 15 degrees maximum, although gradient is usually limited to reduce the risk. Rubber tired or special rail bound systems could be considered for mucking out on such gradients. However, such systems can generally not keep up with the advance capacity of a TBM. So a continuous conveyor system is generally used with the TBM for such applications.

Often, mine access tunnels are done conventionally as spiral ramp roads or a zig-zag ramps to get down to the ore. These tunnels often have very sharp curve radii, so it is common to plan even TBM driven tunnels with curves. Continuous conveyor systems for TBM mucking have become highly developed and can negotiate many curves. However, curved conveyor belt systems consume a lot of power since the guide rollers that guide the belt in the curve cause some resistance on the belt edges. Tunnels with a combination of steep gradient and sharp curves are a challenge for the continuous conveyor. Hauling the material up the slope and the guide roller drag both consume much power. However, for high power conveyor systems, steel cord belt is preferred over fabric belts, since the steel cord belts can be used with much higher tensions and power. This can eliminate the need for conveyor booster drives at intervals within the tunnel. However, steel cord belt is stiffer and cannot negotiate sharper radius curves without troughing problems.

The tunnel plan shown below was designed with steep grades and sharp directional changes at the knee points. This could be possible if conventional excavation is used, but is not practical for TBM and tunnel conveyor. The overlaid curves allow the TBM and conveyor to be used in a practical way. If important points underground must be intersected at the kneed points, the tunnel trajectory can be adjusted slightly so the curves intersect the planned knee points.

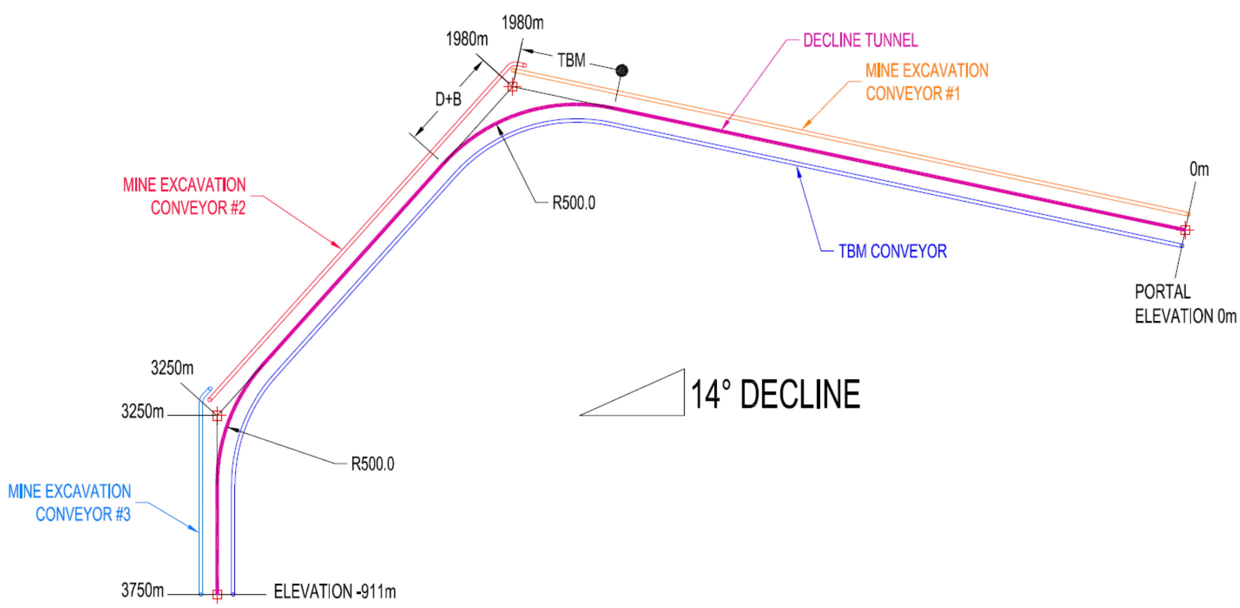

Figure 10 - Tunnel Plan Overview

ACCESS TUNNELS, MINE PRODUCTION CONVEYORS

Conveyors used for tunnel construction need generally have shorter operating hours due to the relatively short tunnel construction period. Production conveyors for mines may need to run near continuously for decades. Therefore, if the tunnel will be used for the mine production conveyor, it could be advisable to design the tunnel trajectory with more generous curves. Then the production conveyor will not be taxed. Or, the knee points can be created by a combination of TBM mining and short conventional mining. In this case, the tunnel would be excavated with a curved conveyor, but the final production conveyor would be installed as straight belt “flight” sections, with transfer points at the knee points. See figure 9 for this technique.

Some mine tunnels for the mine production conveyor can be very long, even to reach a remote port or load out facility. Such tunnels can increase the operating efficiency of the mine, or even make the mine feasible if it is located in an environmentally sensitive area. The bulk materials are removed “out of sight, out of mind”. Such high capacity conveyors can have belt widths of up to 2000-2500mm in some cases, and have much higher capacity than what is needed for TBM excavation. Mining is a time sensitive and capital intensive operation, so the quicker is generally “better”. It is tempting to install the permanent mine production conveyor during the tunnel excavation phase to bring the conveyor on line quicker. The feasibility depends on the size and configuration of the production conveyor, in relation to the tunnel size. If the conveyor size is too large in proportion, it may be better to install the production conveyor as a follow on operation. However, it could be feasible to install hangers or some other preparatory work during tunnel excavation.

LONG ACCESS TUNNELS, ENTIRE MINE DEVELOPMENT

An operating precious metals mine is considering a very long tunnel to provide access to four different ore bodies, which have been defined by exploration drilling. See illustration below. The tunnel has been designed with a portal entry near the existing surface infrastructure of the mine. The trajectory of the tunnel is with a -15% decline to get down to the existing haulage level in the mine. The tunnel continues at near level grade, then descends again to get to a deeper level near one of the ore bodies. The trajectory has been designed with various curves to place the tunnel in best proximity to the ore bodies and existing mine infrastructure. As shown, the entire length of tunnel is 27 km long. At the deepest point, the tunnel reaches about 920 meters below surface. This tunnel is expected to be entirely with in rock of fairly competent quality over most of the length. The TBM must be retracted several times to perform “Wye” intersections, and to retrieve the TBM at the end of the tunnel. For this reason, a Main Beam type TBM has been favored for the job. This very long tunnel trajectory has several complications that have been addressed.

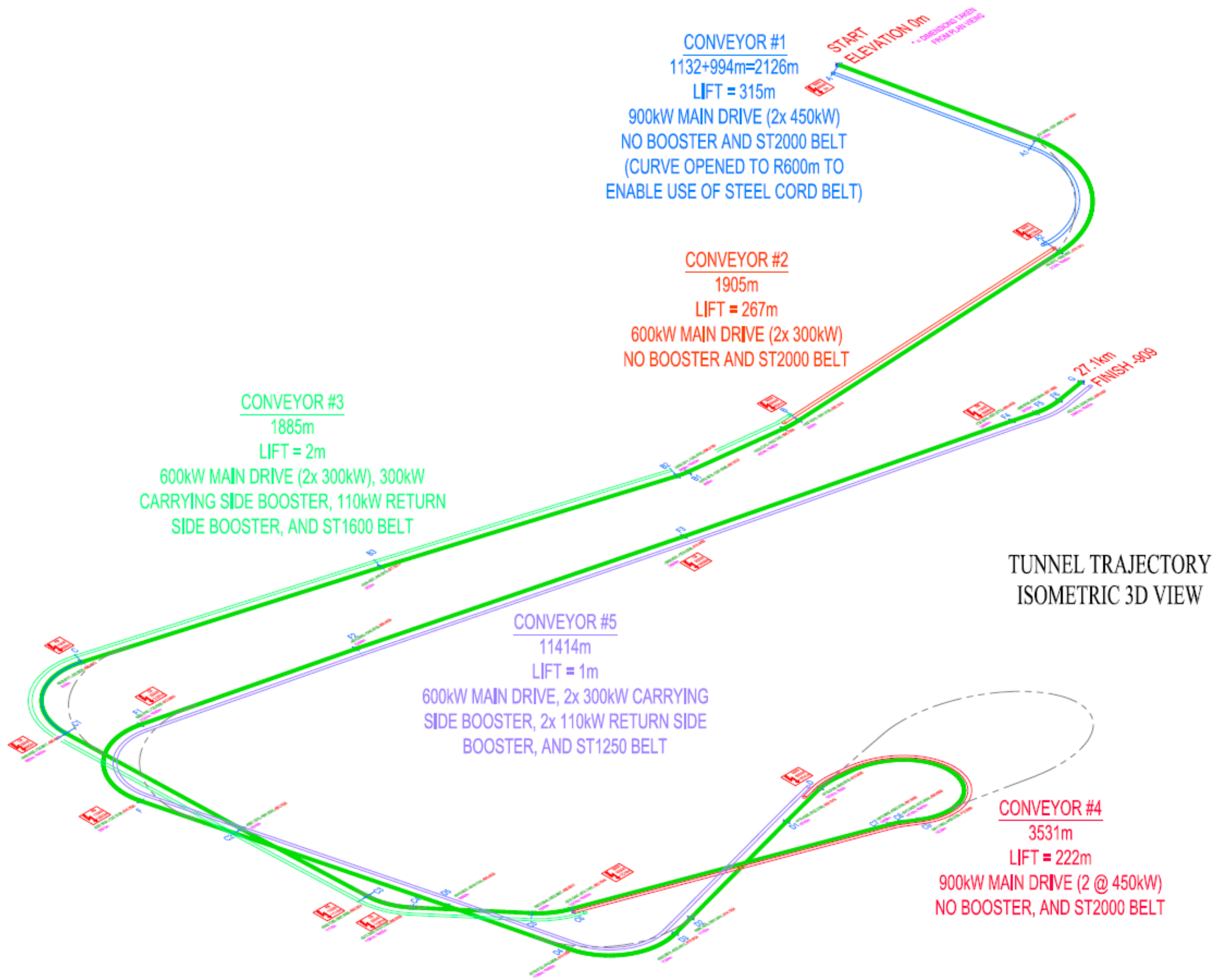

Figure 11 - Tunnel Trajectory

Since the tunnel trajectory is with steep gradients, and significant curves, this presents a challenge for conveyor design. The curve design was increased from R400m to R600m to allow higher tensile rated belt to be used. Even with the high tension belt, five separate flights of conveyors would be needed to provide haulage for the full 27 km of tunnel. The five conveyor flights are shown on the illustration. Several booster drives are needed within the tunnel. These are designed to fit within the tunnel confines, with minimum slashing to provide passage room for the mine vehicles. The booster drives are modular and can be mounted quickly. Total power of the conveyor system is about 3900 kW.

Most of the ground conditions are expected to be fairly good. However, some poor ground conditions have been encountered by the conventional excavations in this mine. And several faults are expected. With such a long tunnel, many unexpected conditions may be encountered. Therefore, the TBM will be equipped with all the best support systems: efficient probe and roof drills, mesh handlers, ring beam erectors, and shotcrete spraying installations.

High temperature geothermal water has been encountered within this mine. Due to this, the high installed power of the equipment, and the ventilation challenges at this length and depth, temperature control must be carefully considered so a reasonable working environment can be maintained. Probe drilling and grouting will be used as much as possible to cut off the ground water. This is a significant source of heat if liberated. If the water does come into the tunnel, it will be routed to an enclosed channel in the invert to prevent radiant heating into the tunnel. Often, cooling plants are installed on board the TBM Backup system to cool the air that is delivered to the working areas. These cooling machines liberate some heat themselves as they are high powered electrical equipment. And they place an increased demand on the TBM electrical system. Centralized chilling plants are more typical in the mines. This is planned for the long TBM drive. Chilled water or brine is cooled by a chiller located outside of the tunnel. The chilled liquid is pumped to the TBM via insulated pipes, and through heat exchangers on the backup.

A flat roadway is needed by this mine, and by most other mines. While machines that produce non-circular cross sections have been developed, the most efficient way to bore rock is with a full face circular TBM. The flat roadway is created at the machine backup. This can be either by installing precast segments, or by pouring a concrete roadway in place, with a specially designed backup system following. A channel in the roadway concrete is used to carry off the groundwater.

Since the tunnel is so long and critical to the mine development, high speed excavation is desirable. We have proposed the best High Power TBM and high capacity conveyor system. This technology comes from the civil construction sector, but would be adapted to the mining environment as necessary.
At the present time, the mine is finishing final design assessments and economic studies.

CONCLUSIONS

The mining industry has been deeply affected by the current situation with low commodity prices and reduced demand. However, the world will continue to consume energy and mineral resources. Ever more efficient, safer methods of mining are necessary for a mine to be a successful business. TBMs can excavate at advanced rates and with great safety. However, TBMs are capital intensive and have long delivery times. In order to be successfully implemented with full advantages, TBMs should be considered early on in the mine planning.

Very special mining TBMs can be conceived, designed and commissioned. However, the most successful TBM applications in mining have been with TBM technology that is well proven in the civil sector, but specially adapted to the needs of the mine.