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Rexroth
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Drive & Control profile

Engineering on the cutting edge:

Tunnel boring machines enjoy long lives with redesign and problem solving

Tunnel boring machines (TBMs) are too great an investment to sit idle after one job, which is why Dan Nowak, president of Construction & Tunneling Services, Inc. (CTS), Kent, WA, strives to keep machines active and in high-performance service long after the initial project for which they were designed and manufactured.

CTS, an established designer and supplier of mechanical excavation equipment for the construction and mining communities, draws upon over 300 years of combined experience in underground excavation machinery and seeks challenging applications to develop new and unique technologies. This is the short story of how CTS has kept two TBMs over 25 years old in service with the help of the Industrial Hydraulics and Electric Drives and Controls business units of Bosch Rexroth Corporation and Rexroth distributor and integrator Hydradyne, Inc.

New hydraulics from Rexroth helped CTS more than double the overall torque available on its tunnel boring machines.

Making the way

A TBM is a circular cutting head for excavating a tunnel so the rock removed is reduced to hand-sized chips by continuous rotation of a group of cutting tools thrust against the rock surface. The cutterhead rotates slowly revolution per minute, typically 4 to 10 RPM, and the cutters mounted on the face of the TBM break the rock into chips, which fall and are collected by a number of buckets that rotate with the cutter head. The buckets lift the chips onto a conveyor belt system for discharge into the final transportation system out of the tunnel.

The cutterhead is forced against the rock by a series of high-pressure hydraulic cylinders that push from either an anchoring member gripped to the recently cut tunnel or push from lining elements that are installed throughout the excavated tunnel. All TBMs must be able to grip the walls of the tunnel as the cutter head advances, or they must have the ability to push off the previously installed ground support in order to develop the force required to cut the face. After the TBM makes a forward push of usually four to five feet, the anchoring system of the TBM is pulled back up to the TBM body and cutterhead where it is reset and

another cutting push begins. TBM excavation does not disturb the surrounding rock while cutting, and in most cases it creates a smooth wall.

There are always challenges underground in a confined space with different material formations, yet on average, over a 3,500-meter-long drive, an average advance rate of 30 to 40 meters per 24-hour day would be considered usual. World record daily advances of up to 200 meters per day have been achieved under ideal circumstances. This doesn't seem like much in the age of the automobile, but try it with a shovel and dynamite some time.

According to Nowak, the size of the tunnel and the geological conditions of the rock determine the type and the configuration of TBM that is used. All hard rock TBMs have a circular cutting head with rolling disc cutters to break the rock into small chips. When conditions ahead are worrisome, TBMs are equipped with drill-through ports for probing ahead of the excavated face to test for water or gas and to provide the opportunity to grout the rock back to a cohesive formation. The main design differences of TBMs are determined by the type of rock to be excavated. Non-cohesive and faulted formations generally require support as soon as the excavation is made to prevent fall in, while competent hard rock usually does not require support and may only require an occasional rock bolt to maintain the integrity of the tunnel. After the excavation, most tunnels receive a man-made lining to seal and preserve the tunnel. The type of lining will vary depending on the tunnel's final use.

Opportunity knocks again

Specialty underground contractor Traylor Bros., Inc., of Evansville, Indiana, has excavated over 40 miles of hard rock tunnels using TBMs and has been instrumental in design improvements for TBMs and cutter tools. In 1978 the Robbins Company designed and built TBM 213-190, a gripping machine for Traylor Brothers to excavate a storm water retention tunnel in Chicago. The machine's drive system and disc cutter array was the highest capacity ever developed at the time and provided impressive boring rates during the 12,950-meter long project in dolomitic limestones.

Upon completion of the Chicago project the machine was sent to the contractor's yard for storage, until 12 years later, in 1993, a second opportunity came along. Traylor Brothers, in a joint venture with Frontier-Kemper Constructors, also based in Evansville, won a contract for the Red Line Metro project owned by the Los Angeles County Metropolitan Transport Authority. The Red Line Metro project comprised the construction of twin subway tunnels each 12,500 meters long, which traverse the Santa Monica Mountains near the famous Hollywood sign. The final tunnel was a cast in place concrete lining of 5.44-meter diameter. Two machines with a bore diameter of 6.3 meters were needed for the job, which contained ground conditions significantly different from the Chicago project. Mixed materials were expected, requiring constant ring steel support with wire mat lagging, face control, and reduced ground disturbance from dead weight loading and gripping forces. The TBM 213-190 was a suitable diameter, as was another TBM beam machine manufactured in 1976 that had been in storage since completing its last project in 1987.

CTS engineering and remanufacturing of the two existing TBMs included resizing with new cutterheads and shields, modification from electric to hydraulic drive for variable speed and higher torque, addition of a larger diameter and higher capacity main bearing, ring beam erector and expander for continuous ground support installation, multiple drill installation for advance probing and grouting and ZED guidance system.

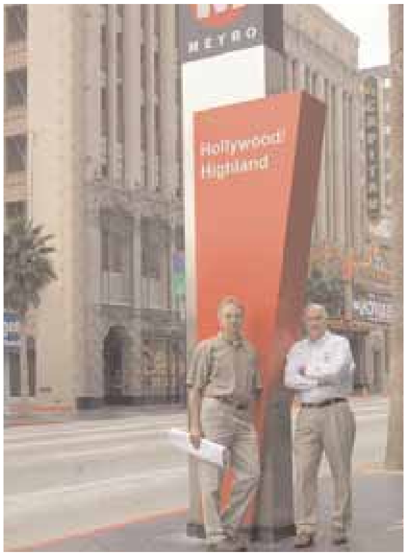
“A review of the changes made to the cutterhead speed over the course of the modifications does not reveal significant changes,” says Nowak. “Originally, the machine was two fixed speeds with an upper speed of 5.66 RPM. The final modified machine was a variable speed of 0 to 5.5 RPM. What is hidden behind the speed values is the overall operating torque available, increased from 2,010 kNm to 5,020 kNm. This increase, combined with the option to operate at any speed within the range, made the drive modification a critical upgrade for the anticipated ground conditions.”

Nowak also noted the change to a variable speed with much higher torque capabilities was achieved by eliminating the fixed-speed electric motors in favor of a hydraulic drive design and increased capacity pinion and main drive gear. The hydraulic drive featured eight Rexroth 6V355 motors and five Rexroth 7V355 pumps in a semi-closed loop configuration with a boosted inlet. Variable speed was achieved by stroke control of both the motors and the pumps. Total maximum flows of 55 l/sec were possible. Reverse flows that resulted in reverse rotation of the cutterhead were achieved using a bank of Rexroth size 80 logic cartridges arranged in a control manifold.

The gearing changes required induction hardened teeth with asymmetric crowned pinions that accommodate structural deflections and maintain line-to-line contact along the gear face. Individual teeth were designed for 450 kNm loads. This custom gear profiling was obtained from Lohmann & Stolterfoht, a division of Bosch Rexroth that has its factory in Germany.

The changes to the main drives were the most significant factors in updating the two machines. The main bearing dimensional envelopes were reworked, taking advantage of main-bearing technology of the 1990s, which could produce significantly higher capacity bearings using asymmetric rolling elements. Both systems’ capacities were raised to match thrust level requirements of the disc cutters, which increased from an 18-metric-ton disc in the 1970s to a 25-metric-ton disc in the 1990s.

The job was not without surprises. The first reach of these tunnels traversed soft rock, originally thought to have an average compressive strength of up to 6.8 MPa. Instead, tunnel excavation encountered a soil-like material,



sometimes plastic, with 1.4 MPa strength in places. Other materials included squeezing shales, sandstones, conglomerates, and granodiorites. The tunnel machines labored through these conditions using the modifications that had been provided to full advantage. After the first, most difficult reach, tunnelers encountered porous sandstone where they were periodically interrupted by programmed grouting of watercourses designed to sustain the seasonal springs above. After penetrating a wide fault, known on the job as the "seismic section," excavation continued. The permanent tunnel lining, cast of concrete, was then placed.

Notes Nowak: "On this project, CTS was able to take advantage of the range of technical product the Bosch Rexroth line offers. Hydraulic components consisting pumps, motors, and valves were integrated with custom gearing and specialty hydraulic cylinders to provide the bulk of the critical pieces that the tunnel machine requires to operate at its peak.

"Our experience with this job re-affirmed what we have known from previous work with the Bosch Rexroth group. They make good products that fit in major areas of machinery design, they understand how these parts perform and where they should be applied for best results. I don't think you will find an operating tunnel machine that doesn't have a Bosch Rexroth part of it.

"The opinion of both the operating contractor and the CTS staff at the end of the job was that without the variable-speed features offered by the Rexroth hydraulics and the higher torque capacity that was permitted with the Lohmann gearing, the project would not have had such a mechanical success."

And again

After completing the Red Line Metro project in 1997, work came calling again in 1999, when a joint venture of Traylor Brothers and Jay-Dee Contractors, known as Traylor-Jay Dee, received a contract for a 7.2-meter-diameter by 1,985-meter-long drive in the city of Detroit. The Detroit River Outfall No. 2 Project, owned by the City of Detroit Water & Sewage Department, was considerably different from the California project as it extended a sewer outfall system under a river through discharge diffusers. Tunnelers anticipated large volumes of water contaminated with hydrogen sulfide requiring extensive probing and grouting of fractured material sections. The machine was to install final lining during its excavation cycle and ultimately be removed from the dead-end tunnel after its drive.

Early in the planning stages, Traylor-Jay Dee and CTS designers realized the potential of using the heart of what was the TBM 213-190 and building the additional structures and systems. The previous modifications to the drive system paid off again, as the new machine configuration was able to use the existing core system in its entirety. Other parts that were resurrected for the project include the inner cutterhead structure, the trailing gear with modifications for segment and back-fill grout systems ventilation fans and electrical and hydraulic components. New structures were designed and manufactured for the shield, propulsion system, erector and segment handling system and the drilling arrangement.

CTS modifications to the TBM involved altering the machine into a single shield with a 7.2-meter cutting diameter and a multi-deck backup system for muck train haulage. Features considered essential to success included a variable-speed hydraulic drive, articulated cutterhead, roll control with skewed propel, twin probe drills on a multi-degree of freedom arms, high-capacity rear change cutters and ZED guidance system. The TBM is unique in that it is a fully shielded machine being used for hard rock mining. This design was specified to allow a bolted, gasketed segmental liner to be installed in the tail shield and backfilled concurrent with mining. The segmental liner is required to reduce the quantity of hydrogen sulfide latent ground water that can enter the tunnel.

The conversion of the machine from a standard rock main beam style to a full shield was a major change to the machine's propulsion arrangement. The shield configuration required a complete circumferential arrangement of cylinders to set hold the lining while it is erected and a complete ring is finished. The arrangement also offers a thrust center that can be varied to suit steering requirements. These cylinders were purchased through Hydradyne, a Rexroth distributor and integrator, and were produced in their Netherlands factory.

"Two features of the Hydradyne/Rexroth solution appealed to us," recalls Nowak. "First, a CIMS internal measuring head allowed us to provide real-time stroke information to the operator with a minimum of external equipment. The alternatives are a magnetic wand slave cylinder or a distance-measuring source that required a target. Our strokes were long and our space was restricted. The CIMS is simple and does not occupy much space to perform its function. Second, the ground conditions were infused with hydrogen sulfides, which, in addition to toxic gas issues, are very corrosive in a water mix. Typically, chrome rods of cylinders are somewhat porous and the propel cylinders have their rods exposed for most of their operating life. Our concerns with these issues led to the selection of Hydradyne as the supplier of the Rexroth cylinders. We considered their exclusive Ceremax rod coating option as a method to increase the operating life of the components."

So far, the main entrance shaft has been excavated and concreted using a top-down method to its final depth. Six riser shafts and two access shafts have been drilled and lined to final depth, and a 7.6-meter-diameter by 24.4-meter-long horseshoe starter tunnel has been excavated using a top heading and bench approach. To date, the TBM has advanced a total of 740 meters. The last 450 meters has been through fractured rock requiring substantial amounts of pre-excavation grouting. Current discharge from the tunnel is over 70 liters per minute. Completion is slated for August 2004.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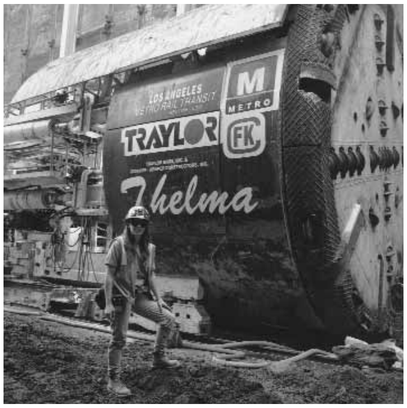

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FORM CTS TraylorBros 2004 (0504)

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