TBM Design for Long Distance Tunnels:
How to Keep Hard Rock TBMs boring for 15 km or More

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THE ROBBINS COMPANY
LONG DISTANCE TBMs
TBMs for 15 km or More

INTRODUCTION

+ Challenges of Tunneling at Long Distances
+ Resulting Aspects of TBM Design
  – Cutterhead & Cutters
  – Main Bearing & Seals
  – Lubrication
  – Drive System
  – Continuous Conveyors
+ Importance of Proper Operation & Maintenance
+ New Developments: Difficult Ground Solutions (DGS)
+ Conclusions
CHALLENGES OF
LONG-DISTANCE
TUNNELS
CHALLENGES OF LONG-DISTANCE TUNNELS

BRIEF BACKGROUND

LONG TUNNELS

+ TBMs are capable of being used on multiple tunnels spanning decades and 50 km or more
+ TBMs have been used on single-drive tunnels of at least 27 km
+ More long tunnels are on the horizon for mega-infrastructure including rail and water tunnels
CHALLENGES OF LONG-DISTANCE TUNNELS

CHALLENGES:

LONG TUNNELS

+ Long tunnels are more likely to run into challenging geology, such as fault zones, water inflows, and more
+ Logistics of muck removal and materials/crew transport
+ Ventilation
+ Machine wear and tear: regular maintenance becomes all the more important
Aspects of TBM Design FOR LONG DISTANCES
Cutterhead design
CUTTERHEAD DESIGN

STRENGTH OF STEEL

+ Heavy steel structure for hard rock conditions
+ Full penetration welds are recommended for the cutterhead structure to battle fatigue loading and vibration
+ Rigorous weld inspections and FEA stress analysis checks can then be made for vulnerabilities in the cutterhead structure
TBM DESIGN FOR LONG DISTANCES

CUTTERHEAD DESIGN

WEAR PLATING

+ Hard ox plates can be used in less abrasive rock
+ Chromium carbide plates used for very abrasive ground, and can be made replaceable
+ Plates can cover entire face, periphery, and back of the cutterhead
During operation, deflector plates on the cutterhead can bulldoze rock away from the leading edge of disc cutters, minimizing the impact of loose rock on cutters that might otherwise cause chipping or spalling.

Adequately-sized muck buckets are also a crucial component to allow for a smooth flow of muck, along with the right quantity and location on the cutterhead.

Durable, replaceable bucket lips are of key importance in these high-wear areas.
Main Bearing and lubrication
MAIN BEARING DESIGN & LIFE

MAIN BEARING & LUBRICATION

+ Large diameter 3-axis main bearings, with the largest possible bearing to tunnel diameter ratio have larger dynamic capacity
+ They are capable of withstanding more load impacts and giving longer bearing life
+ Dry sump lubrication is a critical way of keeping the main bearing cavity clean by filtering and recycling the oil at a constant rate
As the ratio falls below 0.6, Main Bearing life is reduced.
Seal Design for Long Distances

+ Hardened wear bands are essential
+ Many other manufacturers don’t use wear bands, and so as the TBM operates, it wears a groove into the seal lip contact zone
+ Sacrificial wear bands can be switched out or replaced, making repairs easier
+ Seals can be inspected and changed without removal of the cutterhead
Main Bearing & Seals

Seal Design

Changing the Wear Bands

- The seal carrier and jacking screws can be moved to relocate the wear band
- Procedure for replacement requires a bondable seal
- To change the wear bands the seal must be opened and bonded in place
- We are currently developing techniques for open-ended seals
Other

Important

Features
**GEAR BOXES & DRIVE MOTORS**

**ADVANCEMENTS**

**TWO-SPEED GEARBOXES**

- Sturdy, water-cooled gear boxes last in long stretches of tunnel without failure
- Two-speed gearboxes offer two modes of operation: low speed/high torque for difficult ground such as fault zones and high speed/low torque for typical hard rock conditions

<table>
<thead>
<tr>
<th>Cutterhead Speed (RPM)</th>
<th>Cutterhead Torque (kNm)</th>
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<tbody>
<tr>
<td>0</td>
<td>Low Speed</td>
</tr>
<tr>
<td>2</td>
<td>Exceptional Low Speed</td>
</tr>
<tr>
<td>4</td>
<td>Low Speed</td>
</tr>
<tr>
<td>6</td>
<td>Exceptional Low Speed</td>
</tr>
<tr>
<td>8</td>
<td>High Speed</td>
</tr>
<tr>
<td>10</td>
<td>Exceptional High Speed</td>
</tr>
</tbody>
</table>

- Diagram showing the relationship between cutterhead speed and torque for different speed settings.
- Chart indicates how torque decreases with increasing speed.
- Low speed (green line) and high speed (yellow line) show minimal change in torque, whereas exceptional low speed (gray line) and high speed (brown line) show significant variation.
MUCK REMOVAL

OVERSIZED MACHINE CONVEYOR

+ Conveyor systems are based on cutterhead size—must be large enough to keep up with machine
+ Larger bearings allow for larger belts, which make removal of cuttings faster and increases TBM advance rate
+ Robbins belt conveyors oversized by 2x to accommodate uneven piles of muck falling on the conveyor belt from within the cutterhead
+ Wear plating added to inside of muck chute
MUCK REMOVAL

EFFICIENT & FAST
CONTINUOUS CONVEYORS

+ Use of continuous conveyors limits downtime when compared to the downtime experienced when a locomotive and muck cars are used.
+ As a tunnel gets longer, the time to transport muck cars in and out of the tunnel becomes less and less efficient.
+ Continuous conveyors for long distances must be designed with robust transfer points to allow for a soft landing of the muck in order to reduce wear and tear.
+ A good maintenance system including muck scrapers to keep the belt clean and flashings to prevent spillage and belt wear & tear is also of critical importance.
OVERALL

EFFICIENT & FAST

OVERSIZED COMPONENTS

+ For 7 to 8 m diameter machines, the average advance rate is 700 to 750 m per month
+ This includes downtime, so the meters bored per month are in reality much higher—1,000 to 1,200 m per month
+ At such high rates everything must be oversized and subsystems must be designed to achieve high performance
IMPORTANCE OF PROPER OPERATION, MAINTENANCE & SUPPORT
THE BASIC TENETS OF PROPER OPERATION & MAINTENANCE

Consistency is Key

+ Training of the crew for the very wide range of conditions that may be encountered in a long tunnel is needed
+ Planned cutter inspections are a regular part of maintenance, which is recommended daily
+ Checking of oil levels, and all fluids, greases and hydraulics, is also of primary importance
+ Daily logs are recommended for monitoring of all major systems on the TBM
+ Routine maintenance checks at the daily, monthly, semi-monthly, and annual level
+ Depending on the tunnel length, other maintenance may be needed. Gear boxes, for example, may be designed for long tunnels but if the tunnel length exceeds the design life then replacement should be planned
NEW CONCEPTS FOR LONG DISTANCES
DIFFICULT GROUND SOLUTIONS
DIFFICULT GROUND SOLUTIONS

BENEFITS IN DIFFICULT GROUND

+ The longer the tunnel, the greater the chance of encountering adverse conditions
+ Developed based on real experiences in the field
+ Data collection while probing makes ground investigation strategically usable
+ Particularly suitable for shielded hard rock and Crossover/Dual Mode TBMs
+ A comprehensive solution to be installed based on anticipated adverse ground conditions
+ Tunneling efficiency dependent on having a detailed, accurate geotechnical report
+ Reduces risk to Contractors when a challenge is encountered:
  + Squeezing ground
  + Fault zones
  + Water inflows
  + Mixed face conditions
  + Blocky rock
Rapid Advance Shield Design for difficult ground entails a number of features to effectively excavate in squeezing conditions:

+ Shorter shield design
+ Stepped/tapered shields
+ Convergence measuring system
+ Peripheral shield lubrication
+ Hydraulic shield breakout system
DIFFICULT GROUND SOLUTIONS

FEATURE

COLLAPSE DETECTION

+ Purpose – Identifies ground when it has started to collapse onto the forward shield of the TBM by detecting weight build-up
+ Temposonic cylinder to measure distance from shield to ground
+ Read distance measurement from operator’s screen
DIFFICULT GROUND SOLUTIONS

FEATURE

FACE INSPECTION CAMERA

+ Purpose – To see the cut face in front of the TBM
+ Allows understanding of ground stability
+ Uses pre-positioned ports that pass through the back of the cutterhead
Monitoring of probe drilling results is critical. These results can be integrated into the data collection system so the TBM can be operated more effectively. Probe drilling can be done in advance of the face, with multiple probe holes drilled in faulted areas. Drills are at a 7º angle relative to tunnel alignment. Drill ports can be located 360º around the shield. Grouting can be done for ground consolidation from the probe hole, or additional holes.
DIFFICULT GROUND SOLUTIONS

FEATURE

MEASUREMENT WHILE DRILLING (MWD) & OTHER SYSTEMS

+ MWD system and TBM data interprets geological model
  + Understanding the rock mass results in improved general performance
  + Documentation of the existing rock formation improves performance going forward
+ Amberg TSP System
  + One or more shot lines w/small explosive charges
  + Four receivers
+ Geoelectrical BEAM System
  + Whole cutterhead or single cutting tools can act as measuring electrode
DIFFICULT GROUND SOLUTIONS

FEATURE
WATER INRUSH CONTROL

+ In the event of a large inrush of water, a guillotine gate on the muck chute can effectively seal off the muck chamber
+ Keeps the crew safe and the machine from becoming flooded out
+ Additional inflatable seals can close the gap between the telescopic and outer shields of a Double Shield TBM
+ “Passive” water protection as the TBM is stopped in place for crews to perform grouting/other procedures
CASE STUDY
LIAONING NOW
LIAONING NOW

PROJECT BACKGROUND

• Six 8.53 Robbins machines for an eight-machine project in China; each machine is boring an average of 15 km
• First machines in country to use back-loading 20-inch disc cutters
• First project in China to use multiple Main Beam TBMs from varied suppliers (Robbins and two other companies)
• Each TBM is trailed with a Robbins continuous conveyor system

One of the six Robbins TBMs on site
Fractured ground has necessitated the McNally ground support system and shotcrete for worker and machine protection (50% of tunnel)
High cutter wear required the switch to Robbins robust cutters at several tunnel sites
Muck removal has been streamlined by use of continuous conveyor systems
PROJECT CASE STUDIES

LIAONING NOW

MCNALLY SUPPORT SYSTEM

The system, used exclusively on Robbins TBMs, extrudes steel slats as it advances, providing a safe tunnel lining for workers and TBM parts.
Liaoning NOW Project - Advance
All 8.5 m diameter Main Beam Hard Rock TBMs
All boring in Granite, Gneiss, and Schist

*=Tunneling Completed
Meters/Month & m³/Cutter Disc

**Left:** Average monthly boring meters

- **T1 EU:** 322
- **T1 Non-EU:** 613
- **T2 EU:** 467
- **T3 Non-EU:** 567
- **T4 Non-EU:** 588
- **T5 Non-EU:** 635
- **T6 Non-EU:** 555
- **T6 Other:** 563
- **T8 TRC:** 452

**Right:** Cubic meters per cutter disc ring consumed

- **T1 EU:** 140
- **T1 Non-EU:** 199
- **T2 EU:** 199
- **T3 Non-EU:** 199
- **T4 Non-EU:** 199
- **T5 Non-EU:** 199
- **T6 Non-EU:** 199
- **T6 Other:** 199
- **T8 TRC:** 199

*Note: The figures represent the average values for the respective categories.*
Average Monthly Performance: 19-inch vs. 20-inch

19-inch cutter average monthly performance: 445.71
20-inch cutter average monthly performance: 546.16
LESSONS LEARNED

+ The difference that quality components such as cutters and conveyors can make on overall project success and ultimately, project cost
  • Higher upfront cost
  • Less maintenance
  • Better durability
+ Importance of ground support for good results and improved safety
CONCLUSIONS

TBMS ARE WELL-SUITED FOR LONG DISTANCES WHEN PROPERLY MAINTAINED

+ Intelligent, robust machines designed for purpose, combined with a rigorous maintenance program performed on a regular basis, are the fundamental tenets of building TBMs for long distance tunnels in hard rock.

+ With today’s technology and skilled workers, there is no reason why TBMs can’t excavate longer tunnels in excess of 25 km, and last over multiple projects and decades of use.