Earth Pressure Balance TBM – Benny Lau
History of LOVSUNS

LOVAT → CATERPILLAR®

1972 → 2008

2014

420 TBMs Built to Date

Lovsuns Tunneling Canada Ltd.
Different Types of Soft Ground TBMs
What is a EPB TBM?

- One of Two Mechanized Excavation Technique that can be used when Ground is not Self Supporting
- Excavation takes place at full face with full Chamber
- The machine itself provides support during the excavation and protection to the personnel.
- After the excavation, the machine itself carries out the erection of the tunnel liner.

Ground in front of the TBM is supported by the balancing of the pressure inside the excavation chamber with the pressure of the earth outside the chamber.
EPB Principle

In the "Earth Pressure Balance" TBM the excavated material itself is used to support the face of the excavation.

The ground excavated by the cuttinghead is mixed and accumulated under pressure in the muck chamber; it is then extracted in a controlled manner by means of a screw conveyor.

The support or "confinement" of the excavated face is achieved by the contact between the grains of the excavated material and the grains of the working face.

Once the appropriate pressure of confinement is reached in the chamber, the excavation progresses by constant volume. The volume of material extracted from the chamber is equal to the volume of the material excavated at the face.
Calculating EPB Pressure

REQUIRED INFORMATION

▪ DEPTH OF TUNNEL
  » GROUND SURFACE TO TOP OF TUNNEL
  » IF BENEATH WATER THE DEPTH OF THE RIVER OR LAKE ABOVE THE TUNNEL ALIGNMENT

▪ GROUND WATER LEVEL
  » HEIGHT ABOVE TUNNEL
  » PRESENCE OF MULTIPLE WATER TABLES
  » PERCHED WATER
  » ARTESIAN WATER

▪ TYPE OF SOIL
  » CLAY TO BOULDERS
  » SOIL PARAMETERS – COHESION, ANGLE OF FRICTION ETC.

▪ DIAMETER OF TUNNEL
EPB Principle – Balance Pressure

Water Pressure \( (P_W) \)

Ground Pressure \( (P_E) \)

TBM Pressure \( (P_{TBM}) \)

\[
(P_{TBM} = P_W + P_E)
\]
EPB Principle – Over Pressure

\[ P_{TBM} > P_W + P_E \]
EPB Principle – Insufficient Pressure

\[ P_{TBM} < P_W + P_E \]
The Importance of Control Volume Excavation

If too little muck is excavated from the chamber (i.e. screw is slow and propulsion is fast) = increase in EPB pressure and possible outcomes of either heave or a blow out (when EPB pressure is lost to the surface)

If too much muck is excavated from the chamber (i.e. screw is fast and propulsion is slow) = decrease in EPB pressure and a possible outcome of settlement or even a sink hole
Settlement / EPB Control

Control EPB Pressure in the Cuttinghead Chamber during excavation.

Continuous Grouting of Tail Void as TBM advances.

Control of spoil quantity in relation to TBM advance to Prevent over excavation.

Ground Conditioning System to modify soil for EPB operation in any ground.

Maintain pressure in the Cuttinghead Chamber during Segment Erection and Stoppages.

- Continuous advance under extreme sensitive areas
- Maintain material motion/pressure in the Cuttinghead Chamber
- Propulsion Cylinder Automatic Extension
- Ground mix Injection to compensate for volume loss

Maintain Pressure over the length of the shield

- Injection of grout mix into annulus to fill void
EPB Control and Operation

Information Input:
- EPB Sensors
- Screw Conveyor Speed and Torque
- Propulsion Cylinder Advance Rate
- Thrust

Control:
- Advance Rate
- Muck Extraction Rate

PLC Control
- Preset Limits for EPB Sensor Readings
EPB Control

- EPB Sensors
- Screw Conveyor Speed
- Screw Conveyor Torque
- Propulsion Extension Rate
- Propulsion Thrust
- Operator Inputs

PLC

Inputs
- Information to HMI Screen
- Propulsion Speed Adjustment
- Alarms and Warnings
- Data Logging System
- Screw Conveyor Speed Adjustment

Outputs
Main Components of an EPB TBM
Cuttinghead

Soft Ground Cuttingheads: Unstable Ground - Closed Mode Excavation

Cuttinghead Features

- Includes ripper housings only
- May include face isolation doors
- Center nose cone or fish plate at center
- Typically used for Clays, Silts and flowing geology
- Large percentage opening ~ 30%
- Rotary Fluid Joint & Injection Ports
- Copy Cutter

Tool Configurations

Center: Fish Plate (Nose Cone)
Face: Rippers & Spades
Gauge: Rippers & kenrocs

Face Isolation Door
EPB Cuttinghead – Flood Doors
Tool Configurations

Center: Fish Plate
Face: Twin Disc Cutters, Rippers & Scrapers
Gauge: Twin Disc Cutters, Rippers & Scrapers

Cuttinghead Features

- Includes housing for disc cutters
- Rippers are installed with adaptor boxes
- Option of full face of disc cutters
- Fish Plate at center interchangeable with disc cutters
- May include face isolation doors
- Large percentage opening ~ 30%
- Rotary Fluid Joint & Injection Ports
- Copy Cutter

Mixed Ground Cuttingheads:
Stable/Unstable Ground – Open/Closed Mode Excavation
Rippers
- Used in Soft ground
- Three styles for everything from clay, limestone, and abrasive gravels
- Main tool for EPB type TBMs.
Disc Cutters

- Single tip and Twin tip type disc cutters used for mixed ground conditions containing boulders & hard rock.
- Different disc cutter tip spacing are used to cut the rock efficiently.
- 12.0”, 15.5”, 17” and 19” Single tip, Twin tip and Center cutters with replaceable rings.
- Current Production has introduced a proprietary steel for the ring material.
Scrapers

- Used as collection tools
- Scraper Profile sits below the Ripper & Disc Cutting Profile to prevent scrapers from excavating
- Various styles have been used (i.e. bottom bolting, face clamp, cross bolted)
Copy Cutters

- Used to increase the nominal over-cut on soft & mixed faced cuttingheads
- Typically used to help negotiate curves
- Can be integrated into the PLC to cut particular patterns (i.e. top only, left or right, etc.)
Main Drive

MAIN DRIVE COMPONENTS

▪ Main Bearing
  – Triple Roller Design (Most Common)
  – Internal or External Design

▪ Motor
  – Variable Frequency Electric Drive
  – Hydraulic Drive

▪ Gearbox
  – Planetary Type
  – 2 or 3 Stage
  – Water Cooled
  – Integral Pinions

▪ Seals
  – Single/Double Lip
  – Endless Type (no joints)

▪ Motorplate
  – Houses main bearing and gearboxes
Main Drive System

Gearbox c/w Pinion
Electric Motor
Main Bearing
Motorplate Structure
Envelope
Merkel Seals
Cover & Spacer Rings
Hydraulic vs. VFD Main Drive

**VFD ADVANTAGES:**
- More efficient – lower power consumption
- Improved working environment
  - Noise reduction
  - Less heat generation
  - Cleaner (reduced oil leaks)
- Less maintenance of electric motor vs. hydraulic motor
- No risk of hydraulic oil contamination
- Reduced cooling water requirement
- Fewer consumables (ie. hydraulic oil, filters, etc.)
- Less manifolds and valve blocks required in Stationary Shell
- Higher break-out torque available
- Quick site start-up time, more modular (ideally plug and play)
- Torque monitoring on each drive unit

**HYDRAULIC ADVANTAGES:**
- Soft system – spike loads are cushioned
- Troubleshooting can be performed by less skilled technicians where as PLC Techs are required for VFDs
- Torque limiter not required

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Main Drive Sealing System

PURPOSE
To protect the main bearing and the drive against contamination.

PRESSURISED OIL SEALING SYSTEMS
High pressure (EPB) applications up to 6.5 bar
EPB Sensors

Optional 2 EPB Cells on top of Forward Shell

2 No. EPB Cells Inside Screw Conveyors

6 No. EPB Cells Inside Cuttinghead Chamber
Airlock
Airlock

AIRLOCK - INTEGRAL

AIRLOCK - BINOCULAR
Segment Erector

RADIO REMOTE CONTROL
- Heavy duty joystick control
- Color display for cylinder selection and pressure indication
- Dead man switch
- All 6 DOF control
- Emergency stop

ROTOR HOSE TRACK - ("NO MECHANICAL ROTARY UNION")

AXIAL HOSE TRACK

6 NO. POWERED DEGREES OF FREEDOM (DOF) CONTROL

VACUUM PAD AND TANK

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Trailing Shield

- Structure
- Invert gROUT flap
- Passive articulation lug
- Torque linkage
- Grout line
- Grease line
- Brushes tail seal
Tail Seal Grease Injection Distribution

• Tail Seal Grease is injected into each chamber through an array of distribution pipes

• Qty is dependent on diameter of TBM
Grout Injection
SEGMENT vs. TAIL

GROUTING THROUGH SEGMENT

GROUTING THROUGH TRAILING SHIELD
Grout Injection System

Grouting via Trailing Shield

Mortar Grout

Two Component Grout
Grout Injection - Pumps

Peristaltic Pumps

Piston Pumps
Multi-stage Screw Conveyor

Primary and secondary drives

Two independent auger sections, each capable of variable speeds

Multiple injection ports for lubrication and ground conditioning

Length of screw (30m) to allow for pressure dissipation, maintaining of clean working area for segment erection and to bring discharge point behind airlock structure

Emergency closure system
Screw Conveyor c/w Muck Pump
Boulder Catcher
Screw With Muck Pump + Boulder Catcher
Ground Conditioning

When a ground type does not have the ideal characteristics of fluidity and plasticity, ground conditioning can be used to modified & improve its ability to transmit the confinement pressure.
Automatic Face Control System
Rapid Replacement Bentonite Injection System

EPB SENSOR
Monitors Cuttinghead Chamber Pressure

PLC CONTROL SYSTEM
Reads information from EPB Sensor and sends command to Bentonite Tank

PRESSURIZED BENTONITE TANK
Receives command from PLC and injects bentonite into Cuttinghead Chamber
Operator Control Console
TBM Data Logging System

**System** | **Parameters**
--- | ---
Cutterhead | Speed, Torque, Direction, Hours, Flood Door Opening
Articulation | Extension, Cylinder Pressure, Total Thrust, Center of Thrust/Offset
Propulsion | Extension, Cylinder Pressure, Total Thrust, Center of Thrust/Offset
Main Drive | Main Bearing Lube Flow, Sealing Systems Flow and Pressures
Forward Shell | Chamber Earth Pressures
Screw | Speed, Torque, Earth Pressures, Guillotine Gate Position
Conveyor | Excavation Rate, Excavated Material Totalizer
Trailing Belt | Chamber Earth Pressures
Conveyor | Excavation Rate, Excavated Material Totalizer
Ground Conditioning | System Output Totals, Injection Pressures and Flow Rates
Grout System | Injection Pressures and Accumulated Volumes, Rate
Environmental | Methane and Toxic Gases
Hydraulic Systems | Oil Temperatures, System Pressures
Electrical Systems | Motor Current Loads, TBM Power Monitoring (kVA, kW, PF, Amps and Volts)

Notes:
1. This package can operate "standalone", as delivered
2. Connection of Client Workstations rely on the infrastructure provided by the client.
TBM Guidance System - TACS

acs Guidance System
System Overview

Surface Computer

Laser Theodolite
Laser Beam

Reference Object

Tunnel Boring Machine (TBM)
Target Unit (Video Target)

Propulsion Cylinders
Tail Articulation Cylinders
Steering Articulation Cylinders

Industrial Computer

Modern Converter
UPS

Switching Box
Power Supply

TBM Control Computer (SPS/PLC)

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TBM Guidance System - TACS

Visualization of TBM Position

The software shows the geological profile of the tunnel.
Breakthrough Technology

EARTH PRESSURE BALANCE

- 2.0m to 15m diameter
- Soft Ground and Mixed Geology
- Pressures up to 8 bar
- Multi-sectional Screw Conveyors
- Variable Frequency Electric Drives
- Ground Conditioning Systems
- Multipoint Backfill Grout Injection
- Direct Muck Pumping to Surface
- Peripheral Drive Screw Conveyors
Thank You!