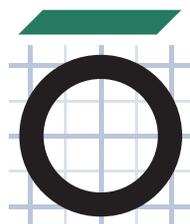


ITATECH GUIDELINES ON REBUILDS OF MACHINERY FOR MECHANIZED TUNNEL EXCAVATION

ITAttech Activity Group Excavation

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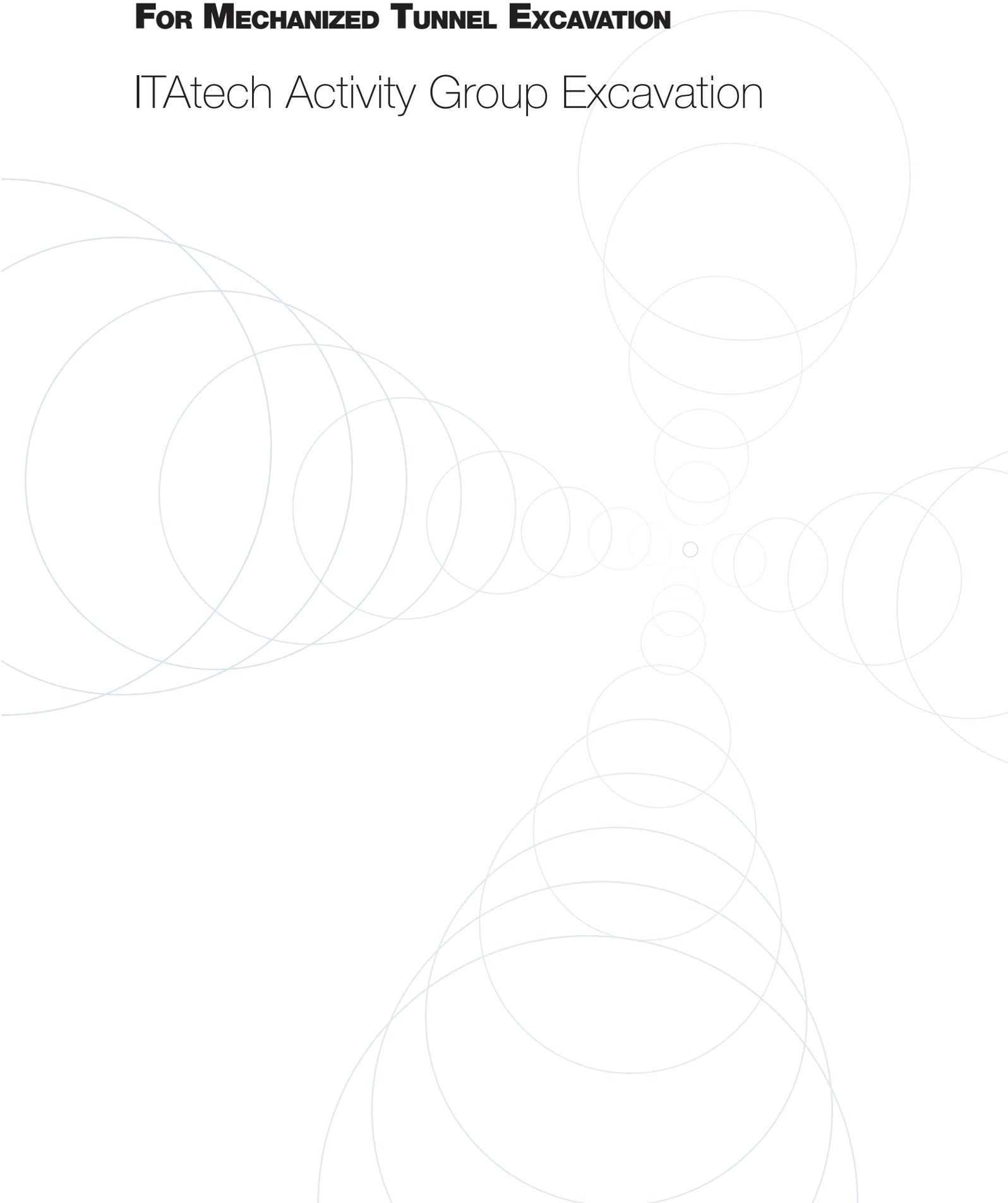
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1 >> FOREWORD, BACKGROUND, SCOPE

1.1 FOREWORD

The use of previously used and rebuilt equipment is quite a common practice in underground construction. For environmental (reduction of carbon footprint) as well as economic or schedule reasons the multiple use of equipment can be considered a reliable and safe solution.

The purpose of this ITAttech Guideline is to establish definitions and minimum requirements for rebuilding pre-used tunnelling machinery, as defined in section 1.3, that can be used for contract or rebuild scope specifications, by the project owner or contractor.

1.2 BACKGROUND

To date, there is no specific guidance available for the tunnelling industry to establish minimum quality requirements for rebuilding pre-used tunnelling machinery.

To achieve an adapted level of quality and scope for the requirements of the intended future use of tunnelling machinery rebuilds, two rebuild levels and their minimum requirements are established:

- **Remanufacturing** as defined in section 2.2
- **Refurbishment** as defined in section 2.3

Note : The selection of the appropriate excavation and support system or TBM type for a tunnel project is primarily influenced by the anticipated ground and groundwater conditions. The intended use of the tunnelling machinery is agreed between the rebuilder and the user taking into account information on predicted ground conditions provided by the user (e.g. Geotechnical Baseline Report).

1.3 SCOPE

The guideline covers shielded and unshielded Tunnel Boring Machines (TBMs) and their backup structures along with non-man-accessible Micro Tunnelling Machines (MTBMs), including associated equipment (e.g. towed California switches,

booster pump stations, above ground power packs, control containers or jacking frames).

Were the country of the intended future use of rebuilt tunnelling machinery is different to the country of previous use care has to be taken for compliance with national standards and regulations of the location of intended future use.

Note : In the absence of relevant standards applicable in the county of intended future use EN 12110 and EN 16191 may be used for guidance.

The requirements set out in this guideline may be applied to complete machines, individual subassemblies or components of machines.

Note : In many cases only individual parts or subassemblies (e.g. main drive) of contractor-owned tunnelling machinery are shipped to the rebuilder for refurbishment or remanufacturing based on a specified and agreed scope of work.

General requirements are given for hydraulic -, electric -, pneumatic face pressure regulation - and soil conditioning systems.

Decompression chambers, pressure vessels, refuge chambers and crane systems are not within the scope of this guideline. For clarity, the requalification of such components has to comply with the national standards and regulations of the country of intended future use.

Note : General guidance on refuge chambers can be found in ITA Report No 14, "Guidelines for the provision of refuge chambers in tunnels under construction".

2 >> REBUILT LEVELS FOR TOTAL SYSTEMS OR SUBASSEMBLIES

Depending on the requirements of the individual future project (e.g. tunnel length, anticipated duration of use or geological conditions) different options for tunnelling machinery specifications are available.

Machinery can be specified to be all new or rebuilt tunnelling machinery, which could be an alternative, with corresponding benefits for environment, economy and schedule.

In light of the intended future use it may not always be necessary to specify the highest and therefore most expensive level of rebuild. For that reason, two levels of the rebuild process are established, going back to different stages of the product life cycle (Figure 1).

The two levels of rebuild :

- Remanufacturing (higher level establishing a full new live cycle for the product)
- Refurbishment (lower level extending the useful life of the product)

The minimum requirements for each of these two rebuild levels are given within the guideline. Individual manufacturers or rebuilders may offer additional measures to achieve a specific warranty.

2.1 APPLICATION OF THE DIFFERENT REBUILD LEVELS

During the project development process, the minimum requirements for the tunnelling machinery are established to assure a safe and reliable excavation process. In many cases the allowance for the use of rebuilt tunnelling machinery with its associated benefits for environment, economy and schedule can be a viable option, whereas the rebuild level is depending on the specific project requirements.

- Remanufacturing is typically applicable for future projects or applications where full component lifetime and a “state-of-the-art” set of requirements for the machinery exist. Systems or sub-assemblies are employed at a different future project in the original configuration or with modifications.
- Refurbishment is typically applicable for future projects or applications without special challenges that can employ machinery that successfully completed a project with at least comparable requirements. Systems or sub-assemblies are employed at a comparable future project in their predominantly original configuration.

2.1.1 Mixed application of the different rebuild levels

Both, the remanufacturing or refurbishment level can be applied to different subassemblies within the same machinery rebuild depending on the project specific requirements and associated potential technical, schedule and economic risks. A future project with a short tunnel length in very abrasive ground conditions may for example require the higher level remanufacturing requirements for cutterhead and screw conveyor while the lower level refurbishment requirements for gantry structures or hydraulic power packs can be sufficient.

2.1.2 Combined configurations

Common practice in the industry is also to combine the allowance for the use of remanufactured tunnelling machinery with the requirement of new condition for clearly specified sub-assemblies or components of a TBM or MTBM. This may be the result of an assessment of the predicted geological conditions or an operation risk analysis.

Note : The term “new” means components are of new manufacture and have never previously been used. This can also include new components of older manufacture taken from the spare part stock of previous projects. For new components from stock that are subject to aging (e.g. seals, hydraulic hoses etc.) the remaining life span should be a minimum of two times the anticipated future project duration.

In many cases the components or sub-assemblies with such “mandatory new” requirement are defined by the project owner, designer or the buyer. Also TBM suppliers may offer such combined options for projects allowing rebuilt tunnelling machinery.

Typically major or core components of TBMs or MTBMs (e.g. main drive, bearing and seal systems, shield structure etc.), or ground condition related components (e.g. cutterhead, rock support installation etc.) are specified as new and specifically built for the project in a list of “mandatory new” components, as listed in

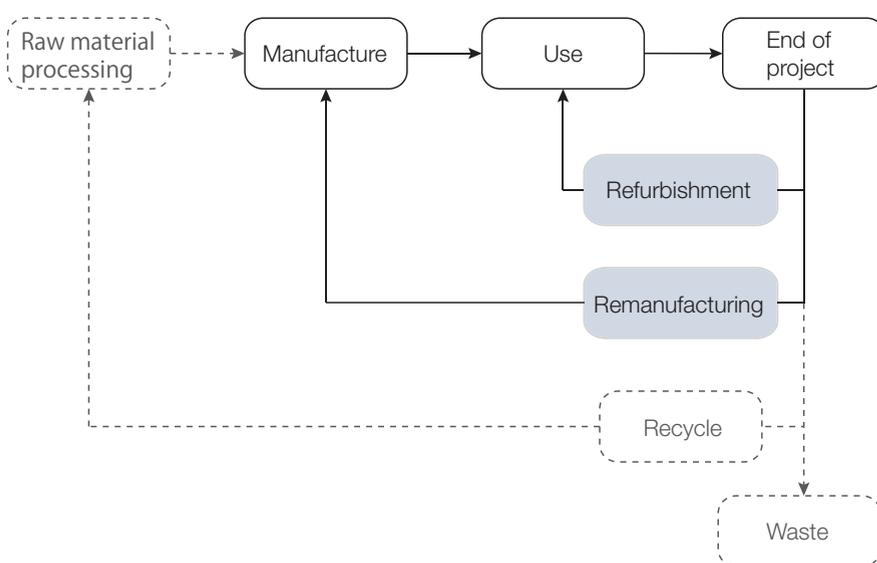


Figure 1: Part of the full life cycle process covered by this guideline (solid line, black)

2 >> REBUILT LEVELS FOR TOTAL SYSTEMS OR SUBASSEMBLIES

the contract specifications or supply offer for a machine.

Such combined configurations are typically applicable for “high profile” projects where extended component lifetime is needed and a special set of requirements for the machinery exists.

2.2 REMANUFACTURING

The basic philosophy behind the remanufacturing process is to establish a full new life cycle for the product with sufficient life to complete the intended future project.

2.2.1 The remanufacturing process

The general remanufacturing process consists of five major process steps (Figure 2) accompanied by a pre-defined Quality Assurance / Control procedure. The remanufacturing process is in most aspects, similar to the original process of first manufacturing.

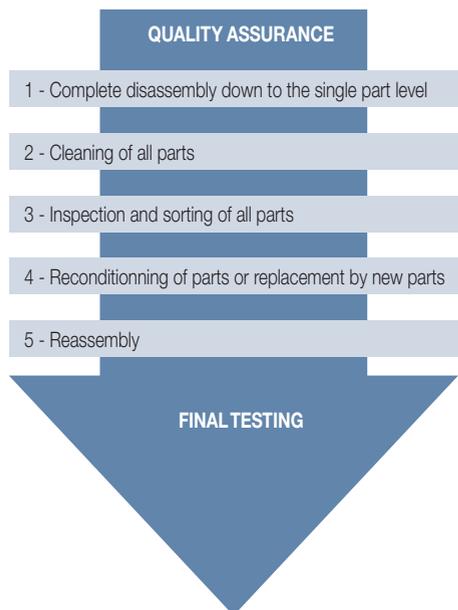


Figure 2: Remanufacturing process steps

Step 1: Disassembly goes down to the single part level in the sense of a single part definition during the original first assembly. The disassembly process includes scrapping parts that are apparently not reusable as well

as separation of components that are generally not reused such as seals.

Step 2 : Cleaning includes removal of muck/soil/debris, de-greasing, draining of fluids, de-rusting as well as removing of old paint.

Note : Depending on the previous use of the tunnelling machinery additional measures may be required for disassembly and cleaning (e.g. previous use in ground conditions containing asbestos)

Step 3 : Inspection of single parts depends on the nature of the part and is either a purely visual inspection or an inspection by dimensional measurement or other testing (e.g. crack testing methods, electrical test, pressure loss or leakage test etc.). The sorting of parts into reusable, able to be reconditioned or not reusable as a result of the inspection has to be based on predetermined and documented criteria.

Step 4 : Reconditioning of parts may involve similar or identical manufacturing steps to those applied during manufacture of the new part. Upgrades or improvements to more recent technical solutions as well as structural reinforcement may be part of the process including replacement of individual parts by new ones.

Step 5 : The reassembly process is identical to the process of original first assembly including using the same procedures and tools. The final testing after reassembly follows the identical procedure, test criteria and documentation requirements as after the original first assembly.



Figure 3: Segment erector after remanufacturing ready for final assembly in the TBM

2.3 REFURBISHMENT

The refurbishment is considered to be a “full maintenance” and “repair or replace defective functions or parts” procedure, followed by a final functional test including full test documentation as per original build.

The basic philosophy behind the refurbishment process is to extend the useful life of the product.



Figure 4 : Gripper TBM after refurbishment ready to be used for the Erstfeld contract of the Gotthard tunnel after completing the Amsteg section of the Gotthard tunnel

3 >> GENERAL REQUIREMENTS

Hydraulic, electric and pneumatic systems for face pressure control as well as soil conditioning systems for EPBs are considered to be of major importance for a reliable and safe function of the tunnelling machinery.

3.1 HYDRAULIC SYSTEMS

	REFURBISHMENT	REMANUFACTURING
Hydraulic fluids	New	New
Filter cartridges	Visual inspection	New
Hoses	Visual inspection Replacement when exceeding lifetime limit or damaged	New
Piping	Visual inspection, cleaning	New
Oil reservoirs	Visual inspection, cleaning	Disassembly, cleaning, new seals, reassembly
Hydraulic cylinders	Visual inspection, pressure test	Disassembly, new seals, new wear parts, reassembly, pressure test
Hydraulic motors > 150 cm ³ displacement volume	Visual inspection, functional test	Disassembly, new seals, new wear parts, reassembly, bench test
Hydraulic motors < 150 cm ³ displacement volume	Visual inspection, functional test	Visual inspection, bench test
Hydraulic pumps > 100 cm ³ displacement volume	Visual inspection, functional test	Disassembly, new seals, new wear parts, reassembly, bench test
hydraulic pumps < 100 cm ³ displacement volume	Visual inspection, functional test	Visual inspection, bench test
Valves, valve banks	Visual inspection, functional test	Disassembly, new seals, new wear parts, reassembly, bench test

3.2 ELECTRICAL SYSTEMS

	REFURBISHMENT	REMANUFACTURING
Cables > 1000 V	Visual inspection, insulation test	Visual inspection, insulation test
Cables < 1000 V	Visual inspection, insulation test	Visual inspection, insulation test
Cable drums > 1000 V	Visual inspection	Disassembly, cleaning, reassembly, electrical test
High voltage switchgear	Visual inspection	Disassembly, cleaning, reassembly, electrical test
Low voltage switchgear	Visual inspection	Disassembly, cleaning, reassembly, electrical test
Transformers	Disassembly, cleaning, reassembly, electrical test	Disassembly, cleaning, reassembly, electrical test
Electrical motors	Visual inspection, electrical test	Disassembly, new bearings, reassembly, electrical test
PLC hardware	Functional test	Replace obsolete parts, functional test
PLC software	Functional test	New, newest update
Sensors	Visual inspection, functional test	Visual inspection, functional test
Safety related parts	Functional test	New, functional test

3 >> GENERAL REQUIREMENTS

3.3 PNEUMATIC SYSTEMS FOR FACE PRESSURE REGULATION

For Slurry-TBMs, the compressed air regulation system for the air bubble is an integral part of the excavation and face support process. Its capacity and status is of importance for the full functionality and control of the excavation process.

	REFURBISHMENT	REMANUFACTURING
Differential pressure regulator	Visual inspection , functional test	Disassembly, new seals, new wear parts, reassembly, bench test
Pressure transducer	Visual inspection , functional test	Visual inspection, functional test
Pressure reducer / pressure regulator / flow regulator	Visual inspection , functional test	Disassembly, new seals, new wear parts, reassembly, bench test
Pneumatic compact controller	Visual inspection , functional test	Visual inspection, functional test
Pneumatic control valves	Visual inspection , functional test	Disassembly, new seals, new wear parts, reassembly, bench test

3.4 SOIL CONDITIONING SYSTEMS FOR EPB-TBMS (EARTH PRESSURE BALANCE TBMS)

For EPB-TBMs, the installed soil conditioning system is an integral part of the excavation and face support process. Its capacity and the status is of importance for the full functionality and control of the excavation process.

The layout and dimensioning of a soil conditioning system is depending on the anticipated ground conditions of the intended future use. Its suitability has to be checked by the rebuilder.

	REFURBISHMENT	REMANUFACTURING
Water supply system	Visual inspection, new wear parts, functional test	Disassembly, new seals, new wear parts, reassembly, functional test
Air supply system	Visual inspection, new wear parts, functional test	Disassembly, new seals, new wear parts, reassembly, functional test
Conditioning materials supply system	Visual inspection, cleaning, new wear parts	Disassembly, new pumps, controls and piping; reassembly; functional test
Foam generators	Visual inspection, cleaning, new wear parts	New

4 >> SPECIFIC REQUIREMENTS FOR TBMs AND MICRO-TBMs

The specific requirements set out in Sections 4.1 to 4.6 shall be respected for both, the remanufacturing as well as for the refurbishment level.

4.1 SHIELD STRUCTURES AND PARTS OF MACHINERY ACTING AS TEMPORARY GROUND SUPPORT

Shield structures and parts of machinery (e.g. roof support structures) acting as temporary ground support during tunnelling operations must be checked by calculation (e.g. FEA) for their ability to withstand the loads imposed by the ground and groundwater for the intended future use taking into account information on future tunnel alignment and ground / groundwater conditions as provided by the user.

Specific test and reconditioning plans and procedures for shield structure accompanied by a written documentation are mandatory minimum requirements.

4.2 GROUND SUPPORT INSTALLATION

For unshielded tunnel boring machines where equipment for rock support installation is provided, the existing type and installation area of the rock support elements must be checked to ensure it is in accordance with the intended future use.

For shielded tunnel boring machines with precast segment installation capability the shield to lining interface (arrangement, stroke and pad size of thrust cylinders) as well as the handling capacities and ergonomics of the segment installation equipment must be checked to be in accordance with the intended future use and segment design.

4.3 MAIN BEARING

The main bearing of a TBM is a high value core component of TBM or MTBM with a long lead time for replacement. Typical design life of a TBM main bearing is 10.000 hours or more based on assumed loadings established from the anticipated operational conditions of the intended TBM use.

However, due to the fact that the majority of main bearings do not approach the limit of

their design life in their first application, multiple use of a main bearing is acceptable given the following requirements :

- The operating hours of the main bearing have not yet reached an estimated 50% of the original design life of the bearing.
- A new lifetime calculation, that takes into account the “as experienced” load conditions and hours of operation in previous use taken from the TBM data recording system and in addition to that, the anticipated load conditions of the intended future use confirms the usability for the estimated hours of future use operation
- A full main bearing inspection and reconditioning as required by the original bearing manufacturer or an equally qualified organization confirms the “ready to use” condition.

The minimum requirements for main bearing inspection are :

- Measurement of axial and radial bearing clearance
- Total dismantling of the main bearing and cleaning of all parts
- Visual inspection of all main bearing elements (raceways, rollers, cages, bolting threads and bull gear if an integrated part of the bearing)
- Crack testing of all raceways and bull gear if an integrated part of the main bearing
- Documentation of results and recommendation of required remedial measures if any

As a minimum all seals (lip seals, O-rings) have to be replaced when reassembling the main bearing. Care has to be taken for appropriate corrosion protection.

Note : A feasible option for main bearing reconditioning is regrinding of the raceways and the installation of new rollers. As a maximum value, 0.5mm is typically considered to be the limit for grind depth. The readjustment of the correct bearing clearance is part of the reconditioning process. Such operations have to be done by a qualified bearing manufacturer and preferably by the original bearing manufacturer.

4.4 CUTTERHEAD, EXCAVATION TOOLS AND MUCK HANDLING EQUIPMENT

Parts and sub-assemblies of TBMs that are primary elements of the TBM – ground interaction, excavation and primary muck transport are highly project specific elements with an exposure to abrasive wear. Therefore such elements are less suitable for multiple uses on different projects.

- Excavation tools are considered to be consumable wear parts and should be replaced by new for tunnelling machinery rebuilds (refurbishment and remanufacturing), unless a specific OEM rebuild procedure is applied, as it is common practice for disc cutters.
- Cutterhead structures are subject to abrasive wear and high loads affecting the base structure itself as well as the excavation tool sockets which typically are integrated into the base structure. Specific test and reconditioning plans and procedures for the cutterhead structure accompanied by a written documentation are mandatory minimum requirements. Fixed wear protection elements should be replaced depending on their condition and considering the intended future use or in any case when 50% of the wear limit has been reached. In addition the design of cutterhead structures is strongly related to the anticipated ground conditions of the specific project. Ground related design considerations such as excavation tool types and arrangement, disc cutter size and spacing, opening ratio, muck flow, distribution of conditioning or flushing ports all have a major influence on the overall structure. Therefore cutterhead reuse has to be justified by a qualified comparison of the ground conditions of previous use and the intended future use.
- Elements for primary muck processing and transportation such as stone crushers, screw conveyors, TBM belt conveyors or shield slurry piping systems are subject to abrasive wear. Specific test and reconditioning plans and procedures for the individual structures accompanied by a written documentation are mandatory minimum requirements. Fixed wear protection elements should be replaced depending on their condition and considering

4 >> SPECIFIC REQUIREMENTS FOR TBMs AND MICRO-TBMs

the intended future use or in any case when 50% of the wear limit has been reached. Replaceable wear protection elements or crushing tools are considered consumable wear parts and should be replaced by new elements for all tunnelling machinery rebuilds.

4.5 MACHINERY MODIFICATIONS AND PLC CONTROLS

The extent of changes made to the original tunnelling machinery, together with its provenance can result in new legal obligations on the owner, user or organization undertaking such work.

Functional modifications or full replacements of subassemblies as well as modification to the PLC programming must comply with the national standards and regulations of the country of intended future use (e.g. Machinery Directive 2006/42/EC for use in the EU).

4.6 DOCUMENTATION

In addition to the QA/QC documentation accompanying the rebuild and testing process for structures and major components as described in chapter 4.1 to 4.5 documentation must be provided about the previous service life history or previous projects.

The instruction handbook of the original tunnelling machinery must be amended or modified to fully reflect the upgrades or modifications executed as part of the rebuild process.

5 >> QUALIFICATION OF REBUILDER, WARRANTY

5.1 QUALIFICATION OF REBUILDER

For complex machinery for the use in tunnel excavation the rebuild process does need a high level of competence. Besides the mechanical and electrical aspects, operational safety may be affected (see Section 4.5).

- Remanufacturing and refurbishment as defined in Sections 2.2 and 2.3 under the full responsibility or with major support of the Original Equipment Manufacturer (OEM) is the preferred solution. This configuration assures that the original manufacturer know how as well as the entire set of original design and manufacturing documents, schematics, calculations including control software and PLC programming is available for the rebuild process.
- Remanufacturing and refurbishment as defined in Sections 2.2 and 2.3 by equally experienced alternative manufacturer from the same industry is an acceptable solution as long as adequate technical documentation including control software and PLC programming for the tunnelling machinery is made accessible to the rebuilder.
- Refurbishment as defined in Section 2.3 by other organizations experienced and qualified in the handling and reconditioning of heavy construction machinery is an acceptable solution as long as adequate technical documentation including control software and PLC programming for the tunnelling machinery is made accessible to the rebuilder.

5.2 WARRANTY

Depending on the organization performing or supporting the rebuild process, different levels of warranty for the intended future use of the tunnelling machinery are common practice in the industry. Typically these conditions are subject to individual negotiation within the rebuild or supply contract.

Warranties for tunnelling machinery rebuilds by the OEM can reach comparable conditions to new equipment.

6 >> REFERENCES

- EN 16191 “Tunnelling machinery – Safety requirements”
- EN 12110 “Tunnelling machines - Air locks - Safety requirements”
- ISO 4413 “Hydraulic fluid power - General rules and safety requirements for systems and their components”
- ISO 4414 “Pneumatic fluid power - General rules and safety requirements for systems and their components”
- EN 60204 “Safety of machinery - Electrical equipment of machines”
- IEC 62309 “Dependability of product containing reused parts – Requirements for functionality and test”
- ISO 16714 “Earth-moving Machinery – Recyclability and recoverability – Terminology and calculation method”
- Rolf Steinhilper: “Remanufacturing”, 1998, Fraunhofer IRB Verlag, Stuttgart
- ITAtech Report No 1 “Guidelines on standard indication of load cases for calculating of rating life (L10) of TBM main bearings”
- ITA Report No 14 “Guidelines for the provision of refuge chambers in tunnels under construction”



