Revision of the CEN Standards for Tunnelling Machinery

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1. Introduction

There are four CEN standards for tunnelling machinery safety covered by CEN/TC 151 “Construction equipment and building material machines - Safety”:

1) EN 815:1996+A2:2008 – Safety of unshielded tunnel boring machines and rodless shaft boring machines for rock - Safety requirements,
2) EN 12110:2002+A1:2008 – Tunnelling machines - Air locks - Safety requirements,
3) EN 12111:2002+A1:2009 - Tunnelling machines - Road headers, continuous miners and impact rippers - Safety requirements,

The CEN standardization process is divided into the steps proposal, acceptance, drafting, CEN enquiry, adoption by weighted formal vote and publication. Before the standard development process can be started, a new work item proposal for a European Standard shall be proposed by any interested party.

After acceptance of the new work item, the standard development process begins with the drafting of a text by a working group of a Technical Committee e.g. WG 4 of CEN/TC151. On completion of drafting the text is sent to the national standardization bodies of all CEN member nations for “CEN enquiry”— the first stage of consultation. Simultaneously the text is assessed for conformity with the relevant European Directive by a “CEN Consultant”. These are followed by comment resolution within the WG, after which the text goes back to all CEN member nations for formal vote. Assuming the weighted vote is positive the “harmonised” standard is submitted to the publication process and will be listed in the Official Journal of the EU after completion. Working group members are nominated by CEN member nations from within their national committees which consist of manufacturers, users, regulators and all other interested parties.

The four above mentioned standards were first drafted from 1989 onwards and published between 1996 and 2005. All four standards were harmonized under the “old” Machinery Directive 98/37/EC. With the revision of the “old” Machinery Directive and the coming into force of the “new” Machinery Directive 2006/42/EC at the end of 2009, all 4 standards had to be updated to reflect the essential safety requirements of this directive.

According to the CEN procedures all 4 standards underwent simple amendment to ensure that the essential safety requirements of the “new” directive were covered. The amendments were published before the end of 2009. All 4 standards have already been listed in the Official Journal of the EU which gives the presumption of conformity to the “new” Machinery Directive.
2006/42/EC. Nevertheless, the responsible committee CEN/TC151/ WG 4 considered that in addition to the simple amendments to align the standards with Machinery Directive 2006/42/EC, it was appropriate to undertake a full revision of the standards to address technological changes.

Whilst EN 12110 and EN 12111 were revised to incorporate the necessary technological changes, CEN/TC151/WG 4 decided that there were now sufficient similarities between unshielded and shielded tunnel boring machines that EN 815 and EN 12336 should be both revised and combined into a single standard with the title “Tunnelling machinery — Safety requirements”.

A corresponding CEN work item was created and the 36 months period for standard development started as from 2009-10-08. All revised standards (EN 12110, EN 12111 and EN 815/12336) are intended for CEN enquiry in 2010. Assuming positive votes by the European members of CEN, all standards should be published in 2012.

2. Tunnelling machinery – Safety requirements, Combination of EN 815 and EN 12336

2.1 Background

At present there are two existing European standards for safety requirements of machines for fully mechanized tunnel excavation (see above). When EN 815 (first published in 1996) and EN 12336 (finally published in 2005 after a long history of development) were being drafted, the idea behind the two standards was that the major differences between tunnelling machines for rock and for soft ground conditions necessitated separate standards. In light of practical experience with the application of the two standards and the ongoing rapid development of mechanized tunnelling equipment, as well as an increasing demand for dual mode or hybrid machines, it became obvious that to differentiate between rock and soft ground machines for safety related issues did not provide any advantages. The majority of basic functional and design aspects such as cutterhead access, walkways or fire protection are similar for both machine types. In addition the combination of existing standards into a single new text presented the best option to include new elements and harmonize the common requirements thus assuring equal levels of machinery safety in the future and also enabled the standard as far as possible to cover future technological developments in mechanized tunnelling.

2.2 Major aspects and changes

The future combined standard now covers all classical TBM types.
- Shielded machines for closed and open mode operation (figure 1, left)
- Unshielded machines (figure 1, middle)
- Micro tunnelling machines (figure 1, right)
- Reaming machines
- Shaft boring machines

![Figure 1: typical TBM types, picture: draft standard](image-url)
A micro tunnelling machine is not defined by a specific size or diameter but as a remotely controlled machine designed for non man entry operation except for maintenance purposes when out of service. All other machines are assumed to allow or require regular man entry during operation and maintenance.

Chamber access for cutterhead maintenance or inspection is definitely one of the critical activities in mechanized tunnelling in open as well as in closed mode conditions. Any solutions reducing the required frequency of interventions are preferable, however it has to be anticipated that for the near future no “maintenance free” solution will be available on the market. Therefore provisions for safe cutterhead access and maintenance are considered to be of the highest priority.

Where possible and for all cutterheads larger than 4.5m in diameter, the cutterhead shall be so designed that replacement of cutters can be done without entering the area in front of the cutterhead (i.e. back loading cutters, see figure 2). When the cutterhead has been stopped, any drift away from that position, for whatever reason other than action on the control devices shall be prevented. This should also take into account the permissible inclination for which the machine has been designed. Access to the excavation chamber or the area where contact with the cutterhead can occur shall only be possible after the cutterhead has been brought to a complete standstill. Access openings shall be protected with interlocked doors or guards. When opened, the interlock cuts off the main power supply to the cutterhead motors. A control station for cutterhead maintenance allowing the re-establishment of power for creep and jog operation shall be provided directly behind the cutterhead. This also applies to other equipment in the excavation chamber, such as rock crusher, agitator wheels or belt conveyor. During work in the excavation chamber or in front of the cutterhead, safe egress shall be maintained at all time.

Figure 2: cutter maintenance on a hard rock back-loading cutterhead, picture: Herrenknecht

The erection of the segmental lining elements within the shield tail is a permanent operation in mechanized shield tunnelling. Attempts have been made at automation but manual work and control of the process still provides higher production.

Vacuum erectors have become state of the art for the majority of machines. Therefore the standard gives clear requirements for the basic safety factors. The safety factor against pull-off and sliding force shall be a minimum of 1.5 taking into account the maximum load. Where additional mechanical devices such as shear pins are not provided the minimum safety factor shall be not less than 2.5. The maximum altitude at which the equipment shall be used, shall also be taken into account when using vacuum pads.

For unshielded tunnel boring machines, equipment for the installation of appropriate rock support is considered to be an integral part of the machine, however the type and installation area of the rock support elements shall be determined by the user of the equipment.
Tunnels and underground areas are normally considered to be confined space work environments. The restrictions on available working space provide one of the biggest challenges for the design of tunnelling machinery while still maintaining a safe and ergonomic work place. Naturally large machines provide more options but in many aspects the working conditions in tunnelling machinery are still far removed from the conditions of typical above ground industrial work areas. Defining minimum requirements for walkways and access openings presented one of the most difficult subjects for agreement within CEN/TC151 WG4. The existing standards define the absolute minimum dimensions for all machines. However it was agreed that the new combined standard should set less restrictive geometrical limits for access on larger diameter machines and restrict the minimum acceptable dimensions to the small diameter machines only. It was also concluded that the available internal diameter (→ segmental lining inside diameter for shielded machines or diameter within the planned rock support for unshielded machines) should be used as the key dimension. For potential non circular tunnels the corresponding cross sectional free area may instead be considered.

The standard presents no fixed minimum internal diameter as lower limit for man accessible machinery, however the minimum walkway dimensions present such limits based on the individual layout and design. In general, but especially for small diameters, considerations for safe escape or rescue in case of emergency (→ rescue by stretchers and wearing of breathing apparatus by rescue personnel) has to be taken into account. Maximum distance to “safe areas” or tunnel length should be considered as well on an individual project basis.

Table 1 summarizes the minimum dimensions for walkways and access openings. A walkway is defined as “part of the access system that permits walking or moving between locations of a tunnelling machinery” and an access opening as “opening within tunnelling machinery through which a man can pass to access servicing points”. The minimum geometrical requirements for walkways and access openings ask for a minimum rectangular window for walkways or a minimum cross sectional dimension for access openings, both of them within a minimum cross sectional area.

<table>
<thead>
<tr>
<th></th>
<th>internal diameter</th>
<th>&gt; 6,0m</th>
<th>&gt; 3,5m ≤ 6,0m</th>
<th>&gt; 2,0m ≤ 3,5m</th>
<th>≤ 2,0m</th>
</tr>
</thead>
<tbody>
<tr>
<td>walkways</td>
<td>minimum cross sectional area</td>
<td>1,2m²</td>
<td>0,8m²</td>
<td>0,6m²</td>
<td>0,5m²</td>
</tr>
<tr>
<td></td>
<td>minimum rectangular clear body opening within the minimum cross sectional area</td>
<td>height: 1,9m</td>
<td>height: 1,4m</td>
<td>height: 1,0m</td>
<td>height: 0,7m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>width: 0,6m</td>
<td>width: 0,6m</td>
<td>width: 0,45m</td>
<td>width: 0,45m</td>
</tr>
<tr>
<td></td>
<td>for a maximum length of 4 m reduced minimum rectangular clear body opening within the minimum cross sectional area</td>
<td>not applicable</td>
<td>height: 1,0m</td>
<td>height: 0,7m</td>
<td>not applicable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>width: 0,6m</td>
<td>width: 0,45m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>access openings</td>
<td>minimum cross sectional area</td>
<td>0,35m²</td>
<td>0,25m²</td>
<td>0,2m²</td>
<td>0,2m²</td>
</tr>
<tr>
<td></td>
<td>minimum cross sectional dimension within the minimum cross sectional area</td>
<td>0,45m</td>
<td>0,45m</td>
<td>0,45m</td>
<td>0,45m</td>
</tr>
</tbody>
</table>

*Table 1: – Minimum walkway and access opening dimensions for different internal diameters*
It is understood that whenever reasonably possible walkway and access opening dimensions should be increased for ergonomic reasons to avoid physical stress and fatigue. In addition to the minimum requirements of the standard it also has to be realized that a well designed and ergonomic system for personnel circulation within the machinery creates better productivity as well as additional safety.

In an underground environment fire presents one of the significant hazards. Tunnelling machinery shall therefore be designed to avoid fire risks, shall be fitted with a fire detection system and shall be equipped with fixed fire extinguishing systems, covering the places where there is a risk of fire according to the fire risk assessment. At the rear end of the towed back-up equipment a water curtain shall be installed.

An explosion protected atmospheric monitoring system capable of detecting oxygen deficiency and flammable gases shall be installed.

The provision of a rescue chamber within tunnelling machinery is not general International or European practice at the present time, but more the result of a project-specific risk analysis. Where shown to be necessary the provision of a chamber is a requirement within the tender documents. The future safety standard for tunnelling machinery does not require the use of a rescue chamber in general and leaves the decision still with the specific project related risk analysis. However in a normative annex the standard will provide clear minimum requirements for rescue chambers.

The chamber capacity should be sufficient for a full crew plus two persons. A minimum headroom of 1,6m, 0,75m²/person of floor area and 1,5m³/person of volume shall be provided. A safe air supply to the chamber for a minimum of 24h shall be installed (40 l/min per person). A battery power supply capable of powering the chamber facilities (communication, lighting and flashing lights) for a minimum of 24h shall be installed.

3. Tunnelling machines – Airlocks – Safety requirements, Revision of EN 12110

3.1 Background

European standard EN 12110 was first harmonized in October 2002 and was mainly based on the experience of the tunnelling community along with a few national regulations which were very poor in regard to air lock requirements. The German Federal Ministry of Economics and Labor strongly favoured a revision of the standard to address non conformity with EU directives and the need to adopt state of the art requirements.

Minor changes have already been added by EN 12110 A1 (2008) to make this standard compliant with "new" Machinery Directive 2006/42/EC.

By consulting with experts in compressed air work and in requirements for pressure vessels for human occupancy (PVHOs) as well as with medical experts the air lock standard drafting group prepared a revised standard that in its final version incorporates state of the art requirements and the experience gained during recent years.

The drafting group have made great efforts to address different interests, such as human factors, economics and feasibility.

3.2 Detailed changes

The scope of EN 12110 covers air locks attached to tunnelling machines and bulkheads for use in tunnels under air pressure. No limit regarding pressure (depth) has been specified hence this standard is applicable to 5 bar (g) i.e. 50 m water depth.

Discussions about the hazards associated with airlocks ended with vibration, noise and electromagnetic compatibility being identified as non significant hazards. The list of significant hazards covered by the standard has been updated accordingly.
The design of the pressure vessels and pressure resisting parts is now harmonized with the European Pressure Equipment Directive 97/23/EC.

For fire protection requirements under hyperbaric conditions the drafting group had access to extensive expertise. Extinguishing systems inside air locks as well as fire fighting and emergency provisions at the control stand have become mandatory. A note in the standard explains that criteria for fire extinguishing systems can be taken from NFPA 99 or DIN 13256-3 which will be soon replaced by a European standard.

Requirements for electrical equipment and the emergency provisions for power supply and lighting are now better structured. The intensity requirements for the internal lighting have been changed from 100 lux to 120 lux and meet now international limits. Furthermore the requirement for an emergency pressure control device has been added giving the possibility to control the pressure from the inside of the air lock.

Dimensions of air locks are not comparable to those for medical treatment chambers because during normal operation only healthy people enter an air lock. Even though site personnel require less space than for treatment, consideration was given to the comfort of those in the chamber during decompression. Therefore the dimensions in EN 12110 are based on requirements for “large operators”. Consideration was given to the ergonomic layout of the chamber which has to be able to accommodate people undergoing decompression in a comfortable way with their legs stretched to an angle of 30° to the vertical even in air locks with a non-circular cross section (see figure 3).

![Figure 3: Non-circular air lock, 1,5m headroom with "large operator", picture: Herrenknecht](image)

To make surveillance by the lock attendant much easier and increase safety, the size of windows in the chamber has been enlarged to a diameter of at least 150 mm.

Temperature limits have been adjusted and only water heating systems are allowed.

The noise requirement is harmonized with the “new” Machinery Directive. If the noise exposure level inside or outside an air lock exceeds 80 dB (A) the manufacturer has to describe measures to be taken to keep the noise level under this limit.

Good air quality is necessary for safe operation of an air lock. That is why the standard refers to EN 12021 “Respiratory protective devices - Compressed air for breathing apparatus” in which requirements for breathing air are quoted. EN 12021 will soon be extended to other breathing gases such as Nitrox, Heliox and Trimix.

An oxygen breathing system which can also be used for other breathing mixtures with more than 23% oxygen is now common equipment in air locks to give safer and shorter decompression of
compressed air workers. The main safety issues for breathing systems are laid down as well as for the oxygen supply and monitoring. Oxygen alarm levels have been adjusted to 19% and 23%.

Last but not least, material locks and combined locks (for personnel and material) remain within the scope of the standard with only slight changes to the requirements for them.

4. Tunnelling machines – Road headers, continuous miners and impact rippers – Safety requirements, Revision of EN 12111

4.1 Background

EN 12111 presently covers roadheaders, continuous miners and impact rippers. Roadheaders and continuous miners are used in tunnelling but are more commonly found in mining applications. According to EN 12111, impact rippers consist of a hydraulic hammer mounted on a crawler chassis. EN 12111 was published as a harmonized standard in 2002. A corrigendum was issued in 2004 and an amendment to EN 12111 has recently been published to meet the requirements of Directive 2006/42/EC.

The CEN machinery consultant in his assessment of the draft amendment was highly critical of a number of aspects of the existing standard and only gave a positive assessment of the amendment on the understanding that a full revision of the standard would be undertaken as quickly as possible thereafter. That is underway and at the time of writing this paper the text of the revised standard is ready to go for CEN enquiry.

Following agreement between CEN/TCs 151 and 196 when they were first established, the standard deals only with machines for use in non-gassy environments. The requirements for explosion protection of such machines are dealt with by CEN/TC196.

4.2 Detailed changes

A number of changes have been proposed for the revised standard but none are considered radical. Many of the changes reflect the requirements in more recently harmonized standards for earthmoving or underground machinery which address safety-related issues not found in the existing standard. Some additional requirements to meet the extended range of essential safety requirements in Directive 2006/42/EC are also included.

The most obvious change is probably in the title of the revised standard. The title and the scope of the current standard indicate that “impact rippers” are included. From the definitions and appendices, an “impact ripper” appears to be a hydraulic impact hammer mounted on a crawler excavator. However, somewhat bizarrely, requirements for the hammer are specifically excluded from the standard and there is no explicit statement that the crawler excavator to which the hammer is attached should be covered by EN 474 series standards. The inclusion of “impact rippers” in the standard would therefore appear to offer no value. It was therefore decided to alter the scope to reflect machines currently available. Roadheaders and continuous miners remain within scope as before. Impact rippers have been removed. However cutterhead attachments for excavators have become much more common and impact hammers are used underground. Both have been added to the scope. Since cutterheads and hammers are intended to be attachments to hydraulic excavators, not all requirements of EN 12111 apply but those which do are clearly identified.

Roadheaders as shown in figure 4 and continuous miners are often dual powered machines. A diesel engine is used for travel to and from the face but electric power supplied through a trailing cable from the machine and connected to a fixed underground installation is used whilst at the face. The standard requires the machine manufacturer to provide a main switch box somewhere on the trailing cable between the machine and the tunnel electrical supply. The switch box determines the point of transfer of responsibility for safety, between the machine manufacturer and the supplier of electrical power.
Improved access on machines for operating and maintenance activities is a major aid to safety. Accordingly more rigorous requirements for access have been set. The revised text also sets out a number of requirements to make maintenance safer. For example, as a matter of design principle it has to be possible to undertake routine maintenance from ground level.

Dust is perhaps the single most significant health hazard created by roadheaders and continuous miners. By the nature of these machines they are intended to operate in the softer rocks which are usually high in silica content. Because of the health risks from silica inhalation, considerably more emphasis has been placed on dust control, primarily by reduction in dust produced, supported by improved dust suppression. These requirements apply to attachments also.

As an aid to operational safety of the machines, better lighting for the machine and the working environment around the machine has been specified. Stability is no longer considered to be a significant hazard for these machines due to their weight, low centre of gravity and size of their track base. Requirements for remote operation along with automatic profiling and guidance systems have been included to reflect current developments in these machines. A requirement for a fixed fire extinguishing system has been introduced. This is in keeping with the level of protection in other standards for underground machinery within the ambit of TC 151/WG4. Requirements for fuel and fluid storage are taken from more recently harmonized standards for crawler machinery.

Directive 2006/46/EC extends the scope of essential safety requirements to cover aspects of machine usage such as towing, lifting and transport. Requirements in respect of these topics are included in the revised EN 12111.

5. Conclusions

After major revision and update of the current CEN standards for tunnelling by WG4, the point has been reached where the standards are ready for CEN enquiry. This is an important intermediate step towards full harmonization. The target to include and reflect the latest developments of what is still a fast developing technology for mechanized tunnelling including the use of compressed air has been achieved. Wherever possible foreseeable future development has been considered as well. There may be still suggestions for changes or modifications arising from the CEN enquiry before final publication, but the basic content should remain. As has already been the case with the present CEN tunnelling standards, the revised version may very well be considered as a guideline far outside the CEN area.

Acknowledgements
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