CE-MARKING OF THE ELECTRIC BREAKER HAMMER AND PRODUCT SAFETY REQUIREMENTS FOR THE U.S. AND CANADIAN MARKETS

Lappeenranta–Lahti University of Technology LUT

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ABSTRACT

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CE-Marking of the electric breaker hammer and product safety requirements for the U.S. and Canadian markets.

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The purpose of this research is to identify the relevant EU directives and regulations that apply to an electric breaker hammer when it's undergoing CE marking process. As the electric breaker hammer is a new type of product, relevant standards are identified to ensure machine safety and demonstrate compliance with directives.

As the company that has designed the hammer is intending to export the hammer to the U.S. market and Canadian market in the future, the differences between machine safety requirements of these markets and European Economic Area in the case of the electric breaker hammer are investigated. Legislative bodies, standardization organizations and standards that were evaluated to be important in North American markets are also introduced briefly.

The process of CE-marking the electric breaker hammer is introduced through a case study. And finally differences between different markets are briefly discussed.

The study found relevant EU-directives and standards for CE-marking of the machine and gave practical advice for CE-marking process through harmonized standards. It also managed to highlight key differences between European Economic Area and North American markets that were under the scope of research.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

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Konetekniikka

Juho Ukkola

Sähköisen rikotusvasaran CE-merkitseminen ja tuoteturvallisuusvaatimukset Yhdysvaltojen ja Kanadan markkinoilla.

Konetekniikan diplomityö

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Tämän tutkimuksen tarkoituksena on tunnistaa EU:n direktiivit ja asetukset, joita sovelletaan sähkökäyttöiseen rikotusvasaraan, kun sille tehdään CE-merkintäprosessi. Koska sähköinen rikotusvasara on uudenlainen tuote, asiaankuuluvat standardit tulee löytää koneen turvallisuuden varmistamiseksi ja direktiivien noudattamisen osoittamiseksi.

Koska koneen suunnitellut yritys aikoo tulevaisuudessa viedä vasaraa Yhdysvaltojen ja Kanadan markkinoille, tutkitaan näiden markkinoiden ja Euroopan talousalueen koneturvallisuusvaatimusten välisiä eroja sähkökäyttöisen rikotusvasaran tapauksessa. Lainsäädäntöelimet, standardointijärjestöt ja standardit, joiden arvioitiin olevan tärkeitä Pohjois-Amerikan markkinoilla, esitellään myös lyhyesti.

Sähkökäyttöisen rikotusvasaran CE-merkintäprosessi esitellään tapaustutkimuksen avulla. Lopuksi käsitellään lyhyesti eri markkinoiden välisiä eroja.

Tutkimuksessa löydettiin koneen CE-merkinnän kannalta merkitykselliset EU-direktiivit ja standardit ja annettiin käytännön neuvoja CE-merkintäprosessia varten yhdenmukaistettujen standardien avulla. Tutkimuksessa onnistuttiin myös korostamaan kohteena olleiden Euroopan talousalueen ja Pohjois-Amerikan markkinoiden keskeisiä eroja.

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I am grateful for all the friends I made during my studies in Lappeenranta. Friends, Koneenrakennuskilta and PoWi offered a good balance for studying and working over the past six years.

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Hollola, May 23, 2022

Juho Ukkola

ABBREVIATIONS

ANSI	American National Standards Institute
ASSP	American Society of Safety Professionals
CCF	Common Cause Failure
CCOHS	Canadian Centre for Occupational Health and Safety
CE	European Conformity
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CFR	Code of Federal Regulations
CISPR	International Special Committee on Radio Interference
DCavg	Average Diagnostics Coverage
DoC	Declaration of Conformity
EEA	European Economic Area
EEE	Electrical and Electronic Equipment
EMC	Electromagnetic Compatibility
EMCD	Electromagnetic Compatibility Directive
EN	European Norm
ETSI	European Telecommunications Standards Institute
IEC	International Electrotechnical Commission
ISED	Innovation, Science and Economic Development Canada
ISO	The International Organization for Standardization
LVD	Low Voltage Directive
MSHA	Mining Safety and Health Administration

MTTFd	Mean Time To Dangerous Failure
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
NRTL	Nationally Recognized Testing Laboratory
OSHA	Occupational Safety and Health Administration
PED	Pressure Equipment Directive
PELV	Protective Extra-Low Voltage
PL	Performance Level
PLr	Required Performance Level
PS	Maximum allowable pressure. Design Pressure
QMS	Quality Management System
RoHS	Restriction of Hazardous Substances
SCC	Standards Council of Canada
SRP/SC	Safety Related Parts of Control Systems
TS	Maximum/minimum allowable temperature, Design temperature
UL	Underwriters Laboratories

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1. Introduction

This research work is done for a start-up company Lekatech Oy, which has developed an electric breaker hammer to replace conventional hydraulic breaker hammer. At the start of this thesis the product has passed technology proof of concept stage and is in prototype phase. The machine is intended to be sold first in European Economic Area and later in the U.S. and Canada.

Now it is important to move the focus from proof of concept, to prototype machine that meets safety requirements in these areas and can be used as a pilot machine in actual operating environment. Making these changes during the design of pilot machine is important, not only for safety reasons, but also for financial reasons.

The machine can be used with an excavator or with a mechanized scaling or breaking machine. In this research these will be referenced as carrier vehicles. Figure 1 and Figure 2 below show two examples how the electric breaker hammer setup could be installed in different cases.

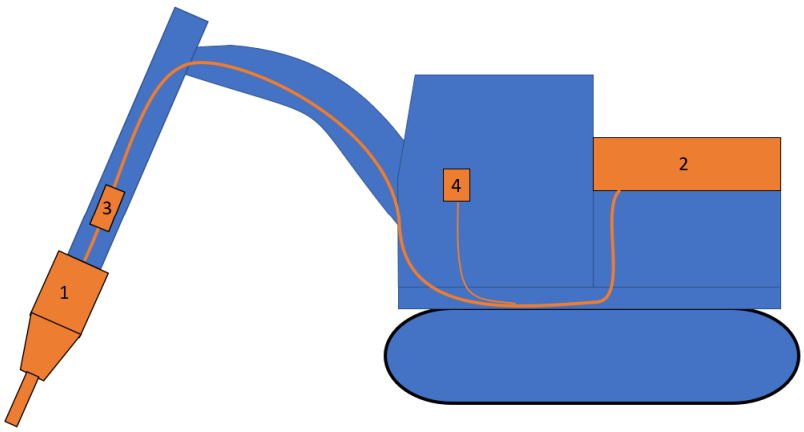

Figure 1. An excavator with an electric breaker hammer.

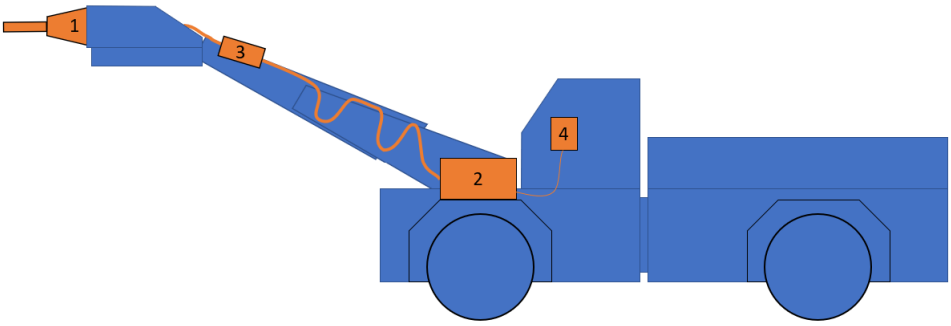

Figure 2. A mechanized scaling machine with an electric breaker hammer.

In figures Figure 1 and Figure 2 can be seen installation locations of subassemblies. Subassemblies of the product are numbered as:

1. Hammer.
2. Auxiliary unit.
3. Connector at boom.
4. User interface in the cabin.

From now-on in this research full assembly than contains all subassemblies is referred as the machine.

1.1. Research problem and questions

The product that is coming to market needs to meet safety criteria and requirements set in directives and standards. Currently the company doesn't have full knowledge about all directives and standards an electric breaker hammer needs to comply with. The prototype was made to fulfil safety that was required for proof-of-concept prototype testing. As the product is new technology, there is no previous research about it.

The research problem is: How to ensure electric breaker hammer's compliance with requirements set for European Economic Area and product safety for North American markets?

Sub-questions to answer to the research problem are:

- What directives, norms, and standards are important for electric breaker hammer in the EEA, and what should be taken into consideration?
- How to implement requirements in practice for the product?
- What documentation is required for declaration of conformity?
- How machine safety requirements differ in the US and Canada in comparison to EEA?

1.2. Limitations

The electric breaker hammer is a new product, and it doesn't have product type specific standard in EN or ISO standards. If product type specific standard for this kind of machine is drafted, it may overrule some parts of more generic standards that are referred in this work. Additionally, electric breaker hammer falls under multiple different directives and regulations. These may vary depending on the environment where the hammer is being used, and what kind of machinery it is attached to.

1.3. Objective

The target of the master's thesis is to have a look into requirements of CE-marking in Europe and certification process in North America. Goals based on research problem are:

- Well documented and written instructions how electric breaker hammers compliance is ensured now and in the future.
- Instructions how to create required documentation for declaration of conformity.
- How to implement new information to product development process, so the product meets requirements in the future.

2. Research methods

Following research methods were used:

- Theoretical research focusing on books, guides, and published material about CE-marking and required safety practices in the North American market. Focus being on machinery and machine properties that are the same as electric breaker hammers.
- Empirical research that is mainly qualitative research. It is done at Lekatech premises focusing on the electric breaker hammer.
- Interviews of designers of the previous prototype and documentation. Focusing on what directives and standards were taken into consideration when designing the hammer and during the assembly.

The research was done as literature review of directives, regulations and norms that apply to European Economic Area (EEA), the United States of America and Canada. Initial information about these was gained through books that focus on applying safety practices to machinery, guidance given by colleagues who designed prototype product, and from company's business partners that work in the field where electric breaker hammer would be used. Additionally, organizations that are working on ensuring product safety were consulted. Initial contacts, online databases about directives, regulations, and standards were used to draft framework for requirements for the pilot product.

3. Directives and standards for EAA, the U.S. and Canada

This chapter looks into directives, regulations and standards in the scope of this research. The EEA (European Economic Area) is covered in detail. North American markets The United States of America and Canada are covered on more general level.

3.1. Directives in EEA

In EEA (European Economic Area) the manufacturer of a machine has responsibility to ensure their products comply with health and safety requirements if the machine is put out to the market. (2006/42/EC, 157/25)

Directives that should be investigated when producing a machine that uses electricity are:

- The machine directive, 2006/42/EC
    - Consolidated version published 26/07/2019
- The low voltage directive (LVD), 2006/95/EC
    - Current version: 2014/35/EU
- The electromagnetic compatibility (EMC) directive, 2004/108/EC
    - Current version: 2014/30/EU

(Siirilä, 2008, p. 28.)

Other directives that may be relevant in case of electric breaker hammer are Pressure equipment directive (PED), 2014/68/EU, since the hammer has a pressurized chamber. Directive relating to the noise emission in environment by equipment, 2000/14/EC, since the machine may be used in urban environment. Additionally, Ecodesign requirements for energy-related products, 2009/125/EC, may apply. (European Commission, 2016, p. 14)

Also, UN regulation R100.02 for wheeled electric vehicles should be applied due customer request. While breaker hammer is not an electric vehicle, it may be attached to fully electric carrier vehicle, and it needs to comply with isolation resistance guidelines set for the vehicle.

There is also a system of standards to complement directives and regulations. In Europe these are EN standards or international EN ISO standards. These standards are grouped to three types, A, B, and C. Type A is top level, which is generic standards for machinery, these are often applicable to all machines. Type B is for specific feature or safety devices. And type C is for specific type of machine or group of machines. (Siirilä, 2008, p. 33.)

Main benefit of following standards is that they provide a way to assess conformity by following defined rules instead of having to prove conformity by other means. The 'Blue Guide' on the implementation of EU products rules says following when assessing conformity of product with essential requirements:

- "Standards are of voluntary application.
- 'Harmonised standards' are 'European standards' adopted, upon a request made by the Commission for the application of Union harmonisation legislation.
- Harmonised standards provide a presumption of conformity with the essential requirements they aim to cover." (European Commission, 2016, p. 41.)

3.1.1. The machine directive, 2006/42/EC

According to the machine directive, machines that are sold in EEA must comply with safety requirements that are set for machinery. The guidelines only cover essential health and safety aspects for generic applications. More in-depth instructions are given in harmonized standards and those should be used when possible. Some machinery is excluded from the directive and risk assessment should follow guidelines given in different directive. The electric breaker hammer is a machine that falls under the machine directive. (2006/42/EC, 2006, p. 25.)

About harmonized standard types and using them for presumptions of conformity with the machine directive Commission implementing decision (EU) 2019/436 says following:

> "(2) There are three types of harmonised standards conferring a presumption of conformity with Directive 2006/42/EC.
>
> (3) A-type standards specify basic concepts, terminology and design principles applicable to all categories of machinery. Application of such standards alone, although providing an essential framework for the correct application of the Directive 2006/42/EC, is not sufficient to ensure conformity with the relevant essential health and safety requirements of Directive 2006/42/EC and therefore does not give a full presumption of conformity.
>
> (4) B-type standards deal with specific aspects of machinery safety or specific types of safeguard that can be used across a wide range of categories of machinery. Application of the specifications of B-type standards confers a presumption of conformity with the essential health and safety requirements of Directive 2006/42/EC that they cover when a C-type standard or the manufacturer's risk assessment shows that a technical solution specified by the B-type standard is adequate for the particular category or model of machinery concerned. Application of B-type standards that give specifications for safety components that are independently placed on the market confers a presumption of conformity for the safety components concerned and for the essential health and safety requirements covered by the standards.
>
> (5) C-type standards provide specifications for a given category of machinery. The different types of machinery belonging to the category covered by a C-type standard have a similar intended use and present similar hazards. C-type standards may refer to A-type or B-type standards, indicating which of the specifications of the A-type or B-type standard are applicable to the category of machinery concerned. When, for a given aspect of machinery safety, a C-type standard deviates from the specifications of an A or B-type standard, the specifications of the C-type standard take precedence over the specifications of the A-type or B-type standard. Application of the specifications of a C-type standard on the basis of the manufacturers' risk assessment confers a presumption of conformity with the essential health and safety requirements of Directive 2006/42/EC covered by the standard. Certain C-type standards are organised as a series of several parts, Part 1 of the standard giving general specifications applicable to a family of machinery and other parts of the standard giving specifications for specific categories of machinery belonging to the family, supplementing or modifying the general specifications of Part 1. For C-type standards organised in this way, the presumption of conformity with the essential health and safety requirements of Directive 2006/42/EC is conferred by application of the general Part 1 of the standard together with the relevant specific part of the standard." (2019/436 EU, 2019.)

In short, the quoted part says that machine's compliance with machine directive cannot be demonstrated by using only A-type standards. With B-type standards it is possible if the manufacturer's risk assessment shows that technical solutions used are adequate. And C-type standards would be the ideal for demonstrating compliance with required health and safety requirements that the machine directive sets. (2019/436 EU, 2019.) As C-type standards don't exist for electric breaker hammer, type B standards shall be used for demonstrating conformity.

The directive lists some essential health and safety requirements of general application and adds some more detailed requirements for specific categories. It also gives permission to use a machinery that doesn't have CE marking at special occasions, such as exhibitions, if people are informed that machine is not going to be put to market as is. (2006/42/EC, 2006, p. 25.)

The directive's scope includes multiple different types of products:

- Machinery
- Interchangeable equipment
- Safety components
- Lifting accessories
- Chains, ropes and webbing
- Removable mechanical transmission devices
- Partly completed machinery

(2006/42/EC, 2006, p. 26.)

From these categories, most interesting in case of the electric breaker hammer are machinery, interchangeable equipment, and partly completed machinery, as definitions of these are the closest to the nature of the electric breaker hammer. According to the European Commission's Guide to application of the Machinery Directive 2006/42/EC the electric breaker hammer would be defined as interchangeable equipment, as it is intended to be used with machinery that is already in service, or interchangeable part of machine that is about to be put to service:

> ". . . after the putting into service of machinery or of a tractor . . .
>
> Interchangeable equipment is equipment that is designed and constructed in order to be assembled with machinery after the basic machinery has been put into service. Equipment that is assembled with machinery by the manufacturer when the machinery is placed on the market and that is not intended to be changed by the user is not considered as interchangeable equipment but is considered as part of the machinery. One or more items of interchangeable equipment may be supplied by the machinery manufacturer together with the basic machinery or by another manufacturer. In either case, each item of interchangeable equipment shall be considered as a separate product and must be accompanied by a separate EC Declaration of Conformity, bear the CE marking and be supplied with its own instructions.
>
> . . . is assembled with that machinery or tractor by the operator himself . . .
>
> The fact that interchangeable equipment is intended to be assembled with the machinery implies that the combination of the basic machinery and the interchangeable equipment functions as an integral whole. Equipment that is used with the machinery but not assembled with it is not to be considered as interchangeable equipment. Equipment that requires significant modifications to the "parent machine" by the user when adding and removing the item or it is not designed to be removed or added on a routine basis, is not regarded as "interchangeable equipment"." (European Commission, 2019, pp. 41-42.)

According to the guide, the interchangeable equipment must be provided with instructions about types of machinery it can be mounted to. And these combinations of machinery and the interchangeable equipment must be safely assembled and used. (European Commission, 2019, p. 42.) Apart from these requirements, interchangeable equipment, and all other types of machinery within the scope of the directive, fall under broad term 'machinery' and shall follow requirements set for machinery. Only exception to this is partly completed machinery which has its own procedure for conformity assessment. (European Commission, 2019, p. 32.)

For machinery there are six steps that need to be taken before it is placed on the market or put into service. Actions required at each step vary depending on the machine and hazards it causes. If hazards are present, standards related to those hazards can overrule things stated in machine directive. These steps can be stated as:

- Ensure that machine satisfies relevant health and safety requirements.

- Prepare a technical file and making sure it is available for ten years.
- Provide the necessary instructions and information about the machine.
- Take required steps for assessing conformity.
- Prepare the EC declaration of conformity.
- Affix the CE marking to the machine.

(2006/42/EC, 2006, p. 29.)

To ensure satisfying relevant health and safety requirements, there is iterative five step process for risk assessment and reduction. It starts by determining the limits of machinery and including potential misuse of machinery where it can be foreseeable. Then identifying hazards generated by machinery within those set limits. Estimating risks caused by those hazards and evaluating potential frequency of the risk and possible injuries and danger to health. Perform risk evaluation based on previous step and determine whether risk reduction is required. And finally eliminate hazards or reduce risks these hazards cause by applying protective measures. (2006/42/EC, 2006, p. 35.)

Eliminating and reducing risks should be done as far as possible. If a risk cannot be eliminated, protective measures should take place. If residual risks are present, people who can be at risk should be informed about the risk and personal protective equipment should be required. (2006/42/EC, 2006, p. 36.) More detailed explanations for the essential health and safety requirements are listed in the machine directive's annex I.

When assessing conformity, there are different paths that can be followed. These paths follow different annexes of the machine directive and can be seen below in the Figure 3

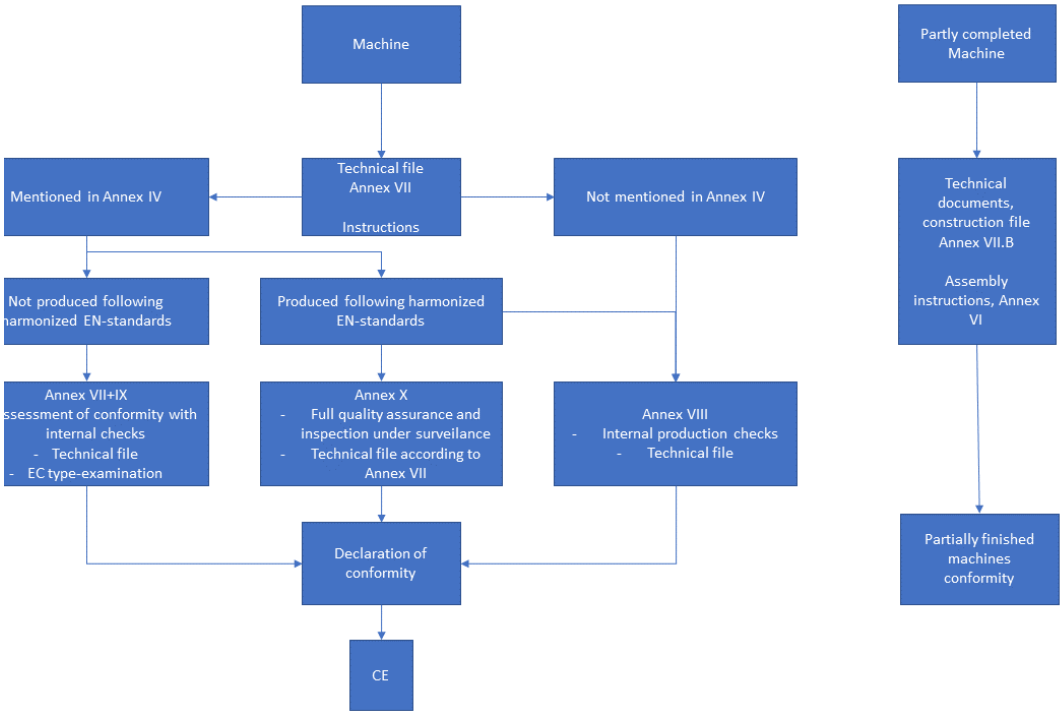

Figure 3 Assessing conformity. (2006/42/EC, 2006).

Figure 3 shows that all the machines are required to have a technical file that is made according to annex VII of the directive. In short, technical file contains:

- General description of the machine.
- Drawings that explain functionality of machinery. Drawings, calculations, test results and certificates required to check conformity.
- Risk assessment documentation, health and safety requirements, and how protective measurements are implemented.
- Standards that are implemented, indicating health and safety aspects covered in the standards.
- Test results and technical reports.
- A copy of instructions for the machinery
- A copy of EC declaration of conformity of machinery.

Full contents of the technical file can be seen in Appendix 6.

3.1.2. The low voltage directive (LVD), 2014/35/EU

The low voltage directive covers electrical equipment designed to alternating current rating between 50 and 1000 volts and direct current between 75 and 1500 volts. If the product uses multiple different voltages, and the highest voltage rating falls within the voltages mentioned, the LVD should be used. In this case, voltage rating means either the highest input or highest output voltage. Inside the machine voltages may exceed these limits. (2014/35/EU, 2014, p. 360; European Commission, 2018, p. 19.)

LVD follows the safety principles of Machine directive. And according to e-mail from Seppo Niemi, from Finnish Safety and Chemicals Agency (Tukes), it doesn't need to be mentioned in documentation as requirements for a machine following LVD falls under Machine directive. (Niemi, 2021). The same is mentioned in European Commission's LVD guide. The LVD guide also clarifies the machine directives exclusion of electric motors. Based on the guide, electrical motors that are incorporated with gear boxes, generators and alternators are not considered to be machines. Therefore, those electric motors should follow LVD. (European Commission, 2018, pp. 79-81.) Electric breaker hammer has linear electric motor that is inbuilt part of a machine, therefore it differs from these examples and doesn't follow LVD.

3.1.3. Pressure equipment directive (PED), 2014/68/EU

In general pressure equipment directive applies to designing, manufacturing and conformity assessments of pressure equipment and assemblies of pressure equipment that have maximum allowable design pressure (PS) that is over 0,5 bar. (2014/68/EU, 2014, p. 176).

Some pressure equipment is excluded from the directive. For example, when the machine directive applies to the machine and pressure equipment is integrated part of the machine,

the pressure equipment directive isn't applied. (2014/68/EU, 2014, p. 177). Also, according to Niemi from Tukes, if the machine directive is applicable and followed, requirements for CE marking fall under the machine directive and PED is not necessary. (Niemi, 2021).

At this point of research, it is likely that the pressurized part will be integrated to the machine and PED won't be applicable since the part can't be used separately as pressure equipment and it will follow machine directive. But if it's not integral part, following will apply to the pressure equipment.

Technical requirements pressure equipment depends on whether the pressure vessel's contents are gas or liquid at maximum design temperature and at normal atmospheric pressure. Also, factors that need to be taken into consideration is if the pressure vessel is fired or heated, and if pressure equipment is piping. Below in the Figure 4 is a chart that gives guidelines for designing unfired pressure vessels and finding correct inspection method. It's worth noting that, in the standard, contents of pressure vessel are called fluids even if it contains gasses that are under pressure. (2014/68/EU, 2014, pp. 182-184.)

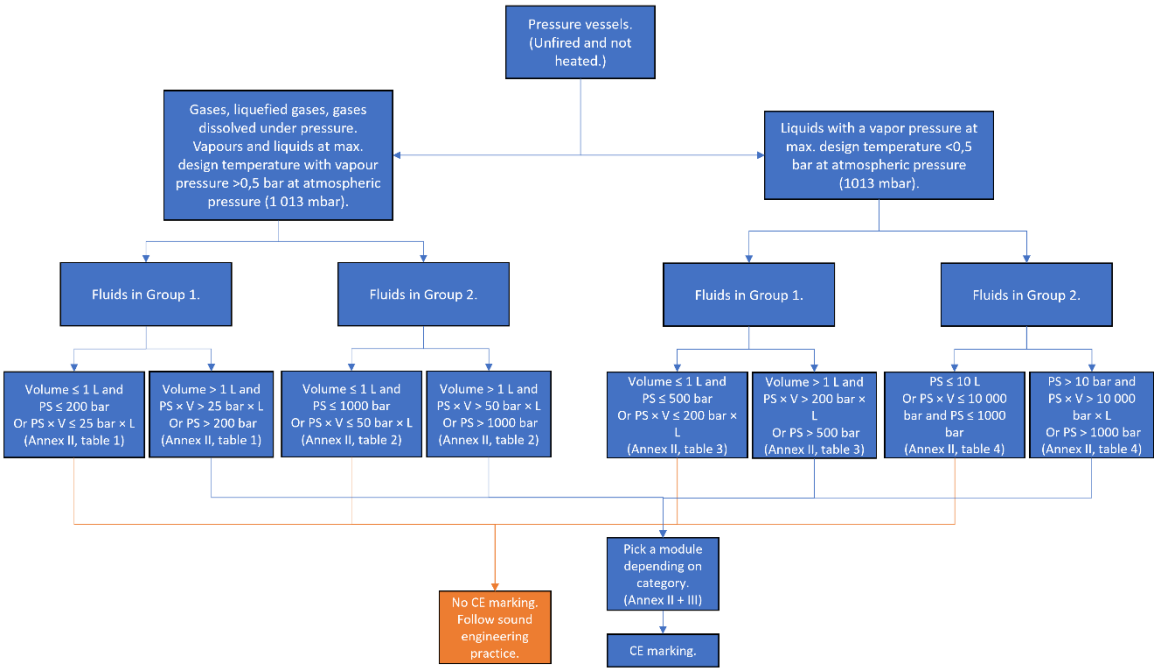

Figure 4 Unfired pressure vessels. Groups, categories, and potential CE marking, if no exceptions apply.

In the Figure 4 is flowchart to support design of unfired pressure vessels in most cases, some exceptions may apply in case of unstable gasses, portable extinguishers or breathing apparatus bottles. The first step is selecting wether the pressure vessel contains gas or liquid. Then selecting which group the gas or liquid falls under. Group 1 contains substances that are considered to be dangerous, oxidising, acidic, flammable, explosive, etc. Group 2 covers everything that doesn't fall under group 1. (2014/68/EU, 2014, pp. 182-183, 192-193.)

After group selection, the category is chosen based on pressure and volume of pressure vessel. Below is an example figure about category selection for pressure vessels containing group 2 gasses. (2014/68/EU, 2014, p. 215.)

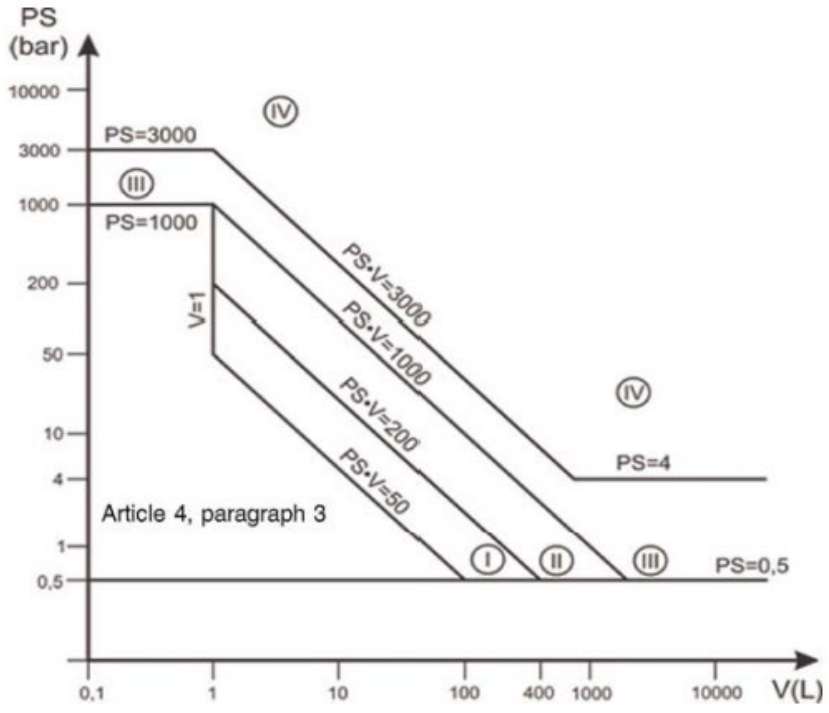

Figure 5 Pressure equipment classes for pressure vessels containing group 2 gasses. (2014/68/EU, 2014, p. 215).

From Figure 5 can be seen that if volume is equal, or less than 1 litre and pressure is 1000 bar or less, or product of pressure and volume stays below 50 bar*L. If the pressure vessel

doesn’t reach any pressure vessel classes and it doesn’t need CE marking and it must be designed and manufactured following sound engineering practices. (2014/68/EU, 2014, p. 177.)

If it goes outside of that range, the pressure vessel needs to follow the requirements for the category it falls into. And it must be designed, manufactured, and inspected according to instructions given in module that matches the category. These modules are explained in detail in the Annex 3 of the standard. Some modules overlap multiple pressure categories, and some are better suited for one off product and some for serial production. If there are multiple modules available in the category, only one needs to be selected. (2014/68/EU, 2014, p. 183.) After following instructions given in required module, the EU declaration conformity is drafted, and CE marking is affixed. (2014/68/EU, 2014).

3.1.4. The electromagnetic compatibility directive (EMCD), 2014/30/EU

The goal of the EMC directive is to ensure that the electromagnetic disturbance generated by the machine doesn’t exceed the amount that can cause disturbance to radio, telecommunication, or other equipment. And at the same time, the machine must have enough immunity against disturbances so it can operate in the environment it’s intended to operate in. (2014/30/EU, 2014, p. 97). The directive also specifies that it doesn’t ensure the safety of the machine, as safety aspects fall under other union legislation. The directive only focuses to electromagnetic compatibility. (2014/30/EU, 2014, p. 80.) In the directive machine is called apparatus, but for uniformity of the text, in this research it will be called machine.

The first step is defining if the machine falls into the scope of the directive. Below in the Figure 6 is flowchart that provides same information as article 2 of the directive and the first flowchart in European commission’s Guide for the EMCD. (2014/30/EU, 2014, pp. 83-84; European Commission, 2018, p. 9).

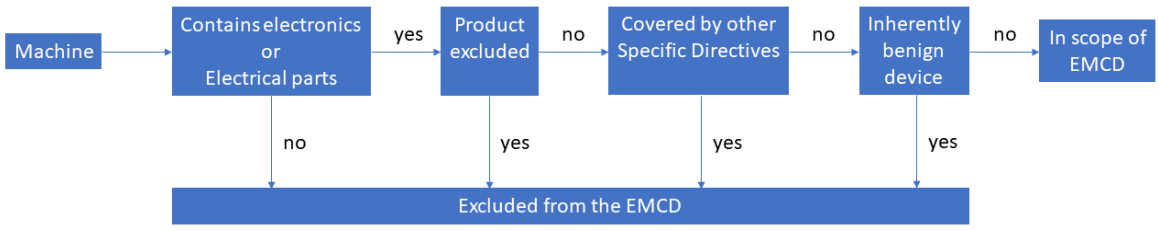

Figure 6 EMCD scope.

The Figure 6 above shows the process of defining weather the machine is in the scope of the directive. More details about each step in the Figure 6 is available in the directive. If the machine is defined to be within the scope, it shall meet the essential requirements set in the directive. (2014/30/EU, 2014, p. 86).

> "1. General requirements
>
> Equipment shall be so designed and manufactured, having regard to the state of the art, as to ensure that:
>
> (a) the electromagnetic disturbance generated does not exceed the level above which radio and telecommunications equipment or other equipment cannot operate as intended;
>
> (b) it has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use." (2014/30/EU, 2014, p. 97.)

Above can be seen definition of essential requirements in general cases. If the installation of machine would be fixed installation, it would have different requirements. (2014/30/EU, 2014, p. 97).

About inherently benign device, that is mentioned in the Figure 6, the section 2.2.d of the standard says following:

> "(d) equipment the inherent nature of the physical characteristics of which is such that:
>
> (i) it is incapable of generating or contributing to electromagnetic emissions which exceed a level allowing radio and telecommunication equipment and other equipment to operate as intended; and

> (ii) it operates without unacceptable degradation in the presence of the electromagnetic disturbance normally consequent upon its intended use" (2014/30/EU, 2014, p. 84.)

EMC guide gives examples of parts that can fall under description above. Following electronic parts that may be used in the machine, as fitting under the definition of the inherently benign:

> "– Cables and cabling, cables accessories, considered separately;
>
> – Induction motors without electronic circuits;
>
> – Protection equipment which only produces transitory disturbances of short duration during the clearing of a short circuit fault or an abnormal situation in a circuit and which do not include active electronic components, such as fuses and circuit breakers without active electronic parts or active components;" (European Commission, 2018, pp. 17-18.)

About cables the EMC guide has extra note about considering installation method and characteristics of cables when considering EMC performance. Knowing which parts of the machine are benign is useful when deciding which tests should be done for machinery, since benign components/sub-assemblies are excluded from the scope. (European Commission, 2018, p. 23.)

EMC assessment process of a machine is described in flow chart in European Commission's document Guide for EMCD. This can be seen in below in Figure 7.

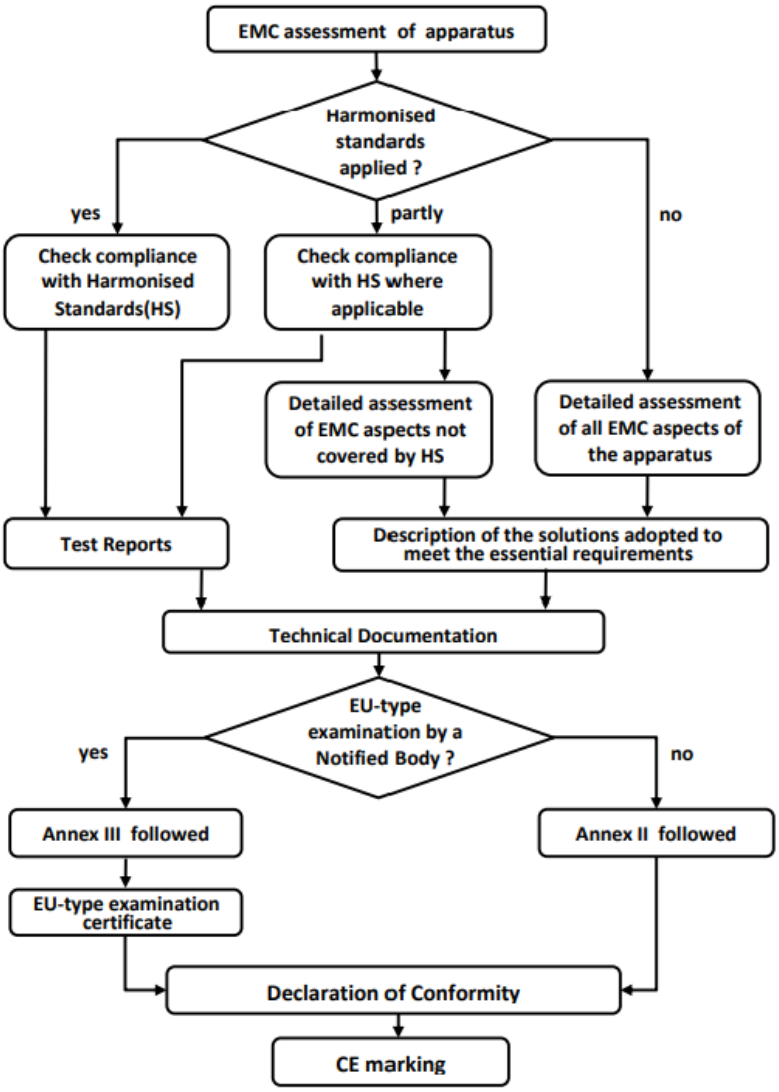

Figure 7 EMCD assessment of machine, declaring conformity and affixing CE marking. (European Commission, 2018, p. 28).

In the Figure 7 the first step is assessing risks under normal operating conditions, to be able to cover all electromagnetic phenomena that is relevant to the machine. Then selecting whether harmonized standards can be applied and used. Or if detailed assessment of all EMC aspects of the machine should be drafted. The third option is combination of these two if compliance can be partially assessed through harmonized standards. If harmonized standards are used for compliance check, test reports about testing according to standards shall be drafted. It is also important to notice that EMC assessment is on manufacturers responsibility, even if third party EMC test laboratory is used. (European Commission, 2018, pp. 29-30.)

Final step before declaration of conformity is deciding if EU-type examination by notified body is used. If it is used, a notified body of manufacturers decision will inspect the documentation of the machine and give certification about inspection. Then the manufacturer needs to ensure good manufacturing practices, affix CE marking and draft EU declaration of conformity. The alternative method is following instructions in annex II of the directive, doing the EMC assessment without a notified body, drafting technical documentation, ensuring good manufacturing practices, affixing CE marking, and drafting the EU declaration of conformity. (2014/30/EU, 2014, pp. 98-101.)

If the manufacturer has different machine designs in product family, and designs are similar, the EMC assessment can be done based on the worst case. This way other products in the product family can get EMC assessment without testing each individual configuration separately. If the assessment is done based on the worst case, it needs to be mentioned in the technical documentation. (European Commission, 2018, p. 31.)

3.1.5. The outdoor noise directive, 2000/14/EC

The outdoor noise directive aims to reduce outdoor equipment's noise emission levels to protect the health and wellbeing of citizens and protect the environment. Based on the directive, information about noise created by equipment should be provided to public. (2000/14/EC, 2000, p. 1.) In practice the directive means that equipment used outdoors must have marking about guaranteed sound power level. Additionally, the marking about sound level is requirement for CE marking. (2000/14/EC, 2000, p. 3).

The directive lists various equipment that need to comply with the directive and have markings about noise level. Electric breaker hammers are not listed, but since hydraulic breaker hammer is listed it can be assumed that electric breaker hammer needs to comply with same rules. The directive mentions that hydraulic breaker hammers will be tested according to *Basic noise emission standard EN ISO 3744:1995*. Additionally, the directive

gives detailed explanation how the hydraulic breaker hammer should be mounted to the carrier vehicle, what kind of tool should be used and what hydraulic power input and oil flow should be used (2000/14/EC, 2000, pp. 43-45). In case of electric breaker hammer some of these can be the same, for example tool and test block that are described in directive. Also mounting practices and hammer stability requirements would be the same, meaning that the hammer must not exceed the maximum weight limit set for the carrier vehicle, and the hammer should be held firmly in place and in upright position during the testing. Detailed instructions for testing in case of hydraulic breaker hammer can be seen in Appendix 9-Appendix 11. Altered test method for electric breaker hammer is described in chapter 4.1.6.3.

3.1.6. Ecodesign directive, 2009/125/EC

Ecodesign directive's purpose is to reduce environmental impact of products by improving energy efficiency, since electricity demand is projected to grow in next 20 to 30 years. The directive is aiming to lay down requirements for energy-related products and ensure free movement of such products. (2009/125/EC, 2012, p. 11.) According to the directive these goals can be reached by improving energy and resource efficiency, providing information for consumers how they can use the product in most sustainable way and informing them about ecological profile of product and benefits of ecodesign. (2009/125/EC, 2012, pp. 13, 19).

Process for CE marking, and the EC declaration of conformity follows similar principles as directives introduced before this one. The process has implementing measures that shall be taken before CE marking is affixed and EC declaration of conformity is drafted. (2009/125/EC, 2012, pp. 16-17.) However, most of the criteria set in directive's article 15 that would make the electric breaker hammer follow directive's implementing measures does not apply to the machine. And the only part that might be applicable refers to Community strategic priorities set out in decision No 1600/2002/EC, which hasn't been valid since 21st of July 2012. (2009/125/EC, 2012, p. 20; Decision No 1600/2002/EC, 2002). Criteria mentioned in the article 15 can be seen in Appendix 12.

3.1.6.1. Commission Regulation (EU), 2019/1781

According to European Commission's website about electric motors and variable speed drives, rules on ecodesign for electric motors are mandatory if manufacturers and suppliers are intending to sell products in the EU. These rules are set in the commission's regulation 2019/1781, which has been consolidated 1st of July 2021. (European Commission, n.d.)

The regulation list types of electric motors that are within its scope, and energy efficiency requirements for motors. It also mentions what types of motors fall outside of the scope of energy efficiency measurement and what data isn't required from them. The electric breaker hammer doesn't fit into scope since it's not intended to be used on continuous duty operation. And when it's run with variable speed, AC voltage can be adjusted, which is also excluded from the scope. (Commission Regulation (EU) 2019/1781, 2021, p. 2.)

Following excluding point will also make electric breaker hammer fallout from the energy efficiency requirements scope.

> "(2) The requirements in section 1, and points (1), (2), (5) to (11), and (13) of section 2 of Annex I shall not apply to the following motors:
>
> (a) motors completely integrated into a product (for example into a gear, pump, fan or compressor) and whose energy performance cannot be tested independently from the product, even with the provision of a temporary end-shield and drive-end bearing; the motor must share common components (apart from connectors such as bolts) with the driven unit (for example, a shaft or housing) and shall not be designed in such a way that the motor can be separated in its entirety from the driven unit and operate independently. The process of separation shall have the consequence of rendering the motor inoperative;" (Commission Regulation (EU) 2019/1781, 2021, pp. 2-3.)

The part 1 of annex I of the regulation that is referenced above contains energy efficiency requirements for motors and variable speed drives. The section 2 is available in Appendix 12 of this research.

3.1.7. RoHS Directive 2011/65/EU

Restriction of Hazardous Substances (RoHS) directive set limits for amounts of hazardous substances in electrical and electronic equipment (EEE). It also focuses to environmentally friendly recovery and disposal of EEE. The current directive is from 2011, and latest version of it is from 1st of November 2021. (2011/65/EU, 2021, p. 4.) Restricted substances in current version of the directive are plasticizers, flame retardants and heavy metals. (2011/65/EU, 2021). List of these substances and allowed amounts is in Appendix 14.

The directive applies to ten different categories of electrical and electronic equipment that are listed in the directive's Annex I. And then mentions 11th category that is all the other EEE that is not covered by other categories that were listed. (2011/65/EU, 2021, p. 20.) This means that the directive applies to all EEE that is not mentioned in list of equipment that is excluded from the scope.

According to the list of excluded equipment, electric breaker hammer may be excluded from the scope, since on the list of excluded equipment is following category:

"non-road mobile machinery made available exclusively for professional use;" (2011/65/EU, 2021, p. 4).

According to the directive non-road mobile machinery is defined as:

> "non-road mobile machinery made available exclusively for professional use' means machinery, with an on-board power source or with a traction drive powered by an external power source, the operation of which requires either mobility or continuous or semi-continuous movement between a succession of fixed working locations while working, and which is made available exclusively for professional use." (2011/65/EU, 2021, p. 7.)

The electric breaker hammer fits into definition of non-road mobile machinery. If it is also meant for professional use only, it doesn't need to follow RoHS Directive.

If it's made available for non-professional use, it falls within the scope of the directive. Then the manufacturer needs draw up technical documentation and have internal production control to ensure that the machine complies with set limits for substances listed in the directive. This list can be seen in Appendix 14 of this research. In the case where directive needs to be followed, the hammer also needs to be supplied with instruction how to recycle the hammer and if some parts could be reused as spare parts. (2011/65/EU, 2021, pp. 4, 8, 12.) And finally, the declaration of conformity is drawn up according to Appendix 15 and CE marking can be affixed to the product. (2011/65/EU, 2021, p. 15.)

3.1.8. UN regulation R100 Rev.2 for wheeled electric vehicles

This regulation a non-legislative act and is not requirement for electric breaker hammer for acquiring CE marking. The reason it's part of this research is that some electric carrier vehicles, which can use the electric scaling hammer, follow this regulation. To ensure these carrier vehicles will comply with the regulation with the hammer attached, the hammer should follow this regulation.

Important aspects in the regulation are protection against electrical shock, and especially isolation resistance between live parts and chassis. The regulation lists required isolation resistances for AC high voltage buses and DC high voltage buses. It is also important to notice that high voltage in this regulation means alternating current between 30 and 1000 volts and direct current between 60 and 1500 volts. (UNECE R100, 2021, p. 3.) These voltages are within the limits of low voltage directive. Another noteworthy aspect is that regulation

Isolation resistance for electric power train depends on the structure. If the electric power train has separate alternating current and direct current buses, isolation resistance for DC high voltage buses is 100 Ω/volt and for 500 Ω/volt for AC high voltage buses. The resistance is measured between the bus and the chassis of the machine. It can be demonstrated either by measurements, calculations, or by combination of both methods.

Regulation gives instructions how to perform measurement but doesn't specify how the calculation should be done. (UNECE R100, 2021, p. 10.)

If the power train is combination of DC- and AC-buses that are galvanically connected, the minimum resistance between the buses and chassis is 500 Ω/volt, unless AC-high voltage buses have extra measures in protection. This can be either two or more layers of solid insulators, barriers or enclosures that individually would offer IPXXD or IPXXB protection degree. Or mechanical protection that has durability to stay functional over the vehicles service life. Mechanical protection can be motor housing, case for electrical components, or case for connectors. If extra measures were taken, the combined AC- and DC-buses can have isolating resistance of 100 Ω/volt, instead of 500 Ω/volt. (UNECE R100, 2021, p. 10.)

In case of fuel cell vehicles, the regulation mentions that if the isolation resistance can change over time and there is risk of it going below the required value. The machine should have system that monitors isolation resistance and warns the operator if the resistance is lower than required value. Alternative method is same as the first method for AC- and DC-bus combination systems, by using two or more layers of solid insulators, barriers or enclosures that individually would offer IPXXD or IPXXB protection degree. (UNECE R100, 2021, pp. 8, 10.)

It is noteworthy that this regulation talks about isolation resistance most of the time, but in sections that are about measurement methods, this changes to insulation resistance.

The regulation also specifies that colour of cables that are not within enclosures shall be orange colour. This requirement appears to only apply to cables themselves, and not to any extra protective sleeves that would offer double protection that was mentioned earlier. (UNECE R100, 2021.)

3.2. Standards in EEA

When it comes to electrical standards, notable organization is International Electrotechnical Commission (IEC). It has committees within itself, such as International Special Committee on Radio Interference (CISPR) and liaison partners such as International Organization for Standardization (ISO), which is a worldwide independent organization that has members from 167 countries. It drafts and publishes standards that are globally recognized. (ISO, n.d.) In the EU they cooperate with European Committee for Electrotechnical Standardization (CENELEC), European Telecommunications Standards Institute (ETSI), and European Committee for Standardization (CEN). (IEC, 2022.)

EN standards are harmonized European standards that have been developed by a recognized European Standards Organization: CENELEC, ETSI or CEN. There are also standards called EN ISO, in which case they are standards that have been published by The International Organization for Standardization ISO and then implemented as harmonized European standard. These are referenced by Official Journal of the European Union and following these standards can be used to demonstrate compliance with EU legislation. (European Commission, n.d.)

This section presents contents of the level A and level B standards that affect the electric breaker hammer. Proposal how to apply these standards in practice is presented in chapter 4.1. Some level C standards are mentioned as they give more detailed information about potential carrier vehicles and may be applicable if the hammer is integrated to the carrier vehicle.

In the Figure 8 below can be seen a chart that includes directives, regulations and standards that were considered to be relevant when doing this research. Ones that were deemed to be applicable are outlined green. Potentially applicable, e.g. after minor design changes, are outlined yellow. And standards that were deemed to be not applicable are outlined red. Dashed outline means request by a third party.

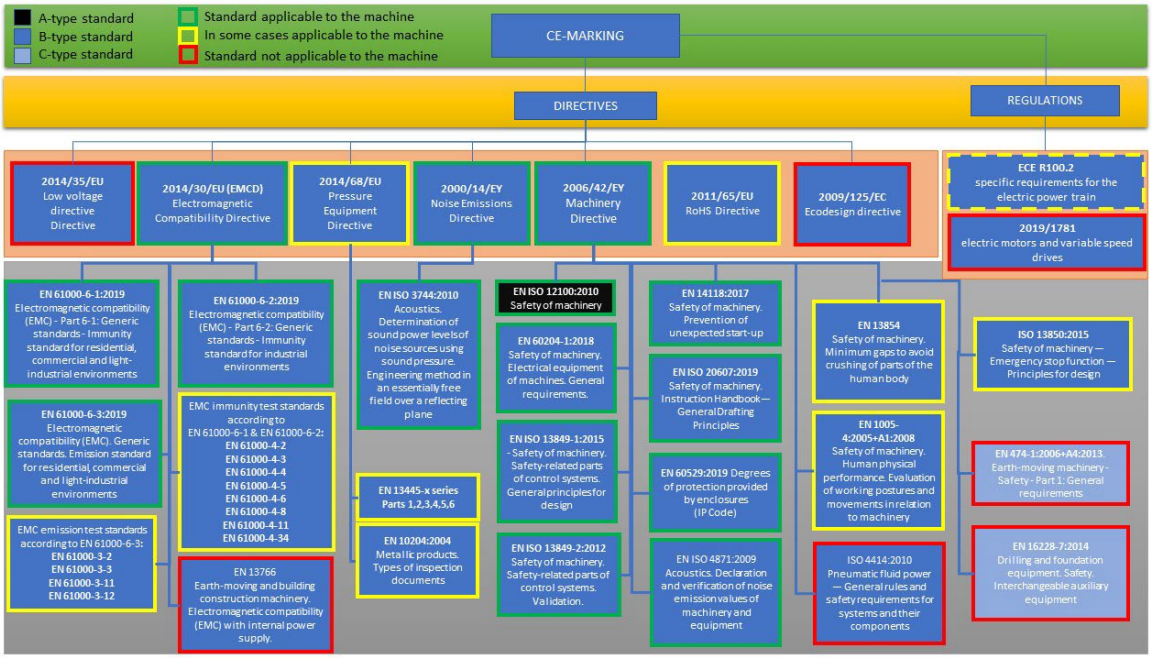

Figure 8 Directives, regulations, and standards that are applicable to the machine.

Some standards that could be applicable and shown in the Figure 8 were excluded due concerns being taken care of by other safety standards and inherently safe design already in the prototype stage. For example: "*EN 13854: minimum gaps to avoid crushing of parts of the human body*" is not necessary since there are no humans near the machines moving parts during operation. During maintenance the machine is de-energized, and safety aspects can be covered by *EN ISO 12100:2010 Clause 6.2*.

3.2.1. EN ISO 12100 Safety of machinery. General principles for design. Risk assessment and risk reduction.

Safety of machinery standard intends to give an overall framework and guidance for designers for machine development process. When adequately applied it helps to reduce risks of machinery during its life cycle, when the machine is used as intended. This standard is type-A standard, which means it can be applied to all machinery. Type-B1 standards would be focused on safety aspects and give more in depth look into safety, while type-B2 standards are focused to safeguards. (EN ISO 12100, 2010, p. 10.)

The standard begins by listing actions that should be taken to do the risk assessment and steps for the risk reduction process. It assumes that if hazard is present, it will eventually lead to harm. To avoid this, necessary measures to avoid harm should be taken. The clause 5 of this standard goes though risk assessment process in detail and mentions *ISO 14121* standard that can help in the risk assessment process when using qualitative methods. The process of risk reduction is introduced in Figure 9 below.

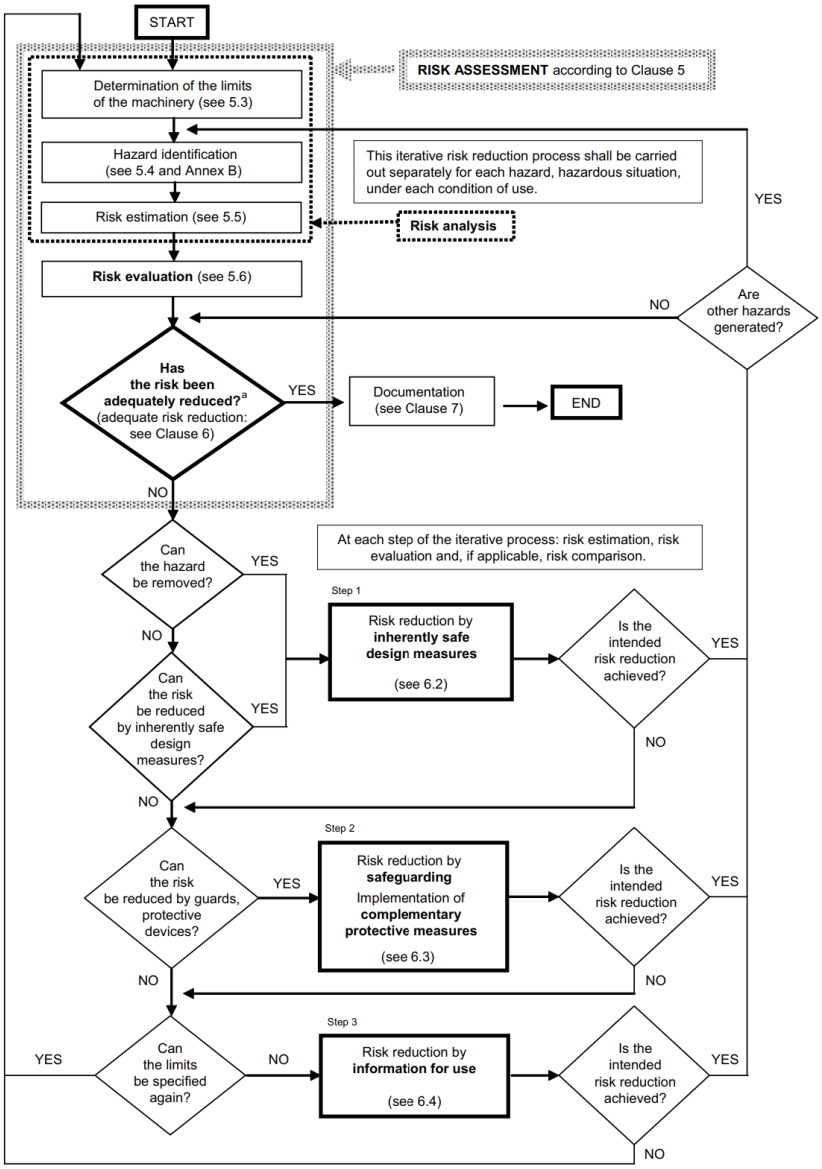

Figure 9 Risk reduction process with three-step iterative method. (EN ISO 12100, 2010, p. 10)

In the Figure 9 above is the risk reduction flow chart as it's given in the standard. The first step is defining the limits of the machine, the process starts with the same step is in the machine directive. The process then moves to hazard identification and risk estimation as also mentioned in the machine directive. Risk estimation and risk evaluation are then done individually to each hazard. The risk reduction process goes through multiple steps and including inherently safe design measures, safeguards, and information about safety. If the risk is reduced enough after these steps, process is considered complete and documentation about risks and risk reduction measures is drafted. (EN ISO 12100, 2010, p. 10.)

The standard also has another flowchart that visualizes the risk reduction after every risk reduction step. That flowchart also mentions protective measurements in forms of actions taken by organization, use of additional safeguards, personal protective equipment, and training. The standard doesn't really provide information about these elements but mentions the product instruction handbook and information of use that should be supplied to the customer. (EN ISO 12100, 2010, p. 11.)

Detailed contents of steps 1 to 3 in Figure 9 can be found in clause 6 of the standard, which focuses to risk reduction methods. When choosing protective measurements, Annex B of the standard can be helpful for designer, since it provides examples about different hazards and directs to a subclause that provides information about eliminating or reducing risk of the hazardous event. (EN ISO 12100, 2010, pp. 22, 53-62.)

Finally, the clause 7 explains the contents of risk reduction assessment and risk reduction documentation. This documentation is also mentioned in the machine directive's Annex VII

which is about the technical file of the machinery. Clause 7 of this standard is more detailed on that matter than the machine directive. (EN ISO 12100, 2010, p. 51.)

3.2.2. SFS-EN 60204-1 Safety of Machinery. Electrical equipment of machines.

The part one of EN 60204 is type-B about general requirements set for electrical equipment of machines. It goes through requirements set for electrical components and installation in machines. It also mentions some cases in which hazardous situations can be caused due failures that lead to malfunction of the machine. (Finnish Standards Association SFS, 2018, p. 155.)

The standard promotes:

> "— safety of persons and property;
> — consistency of control response;
> — ease of operation and maintenance."
> (Finnish Standards Association SFS, 2018, p. 142.)

When going through the machines structure and applying this standard to the machine, following Figure 10 is helpful since it directs to the clause of standard that applies to specific machine part. It also gives insight to the contents of this standard and relations between different sub-systems in the case of a typical machine.

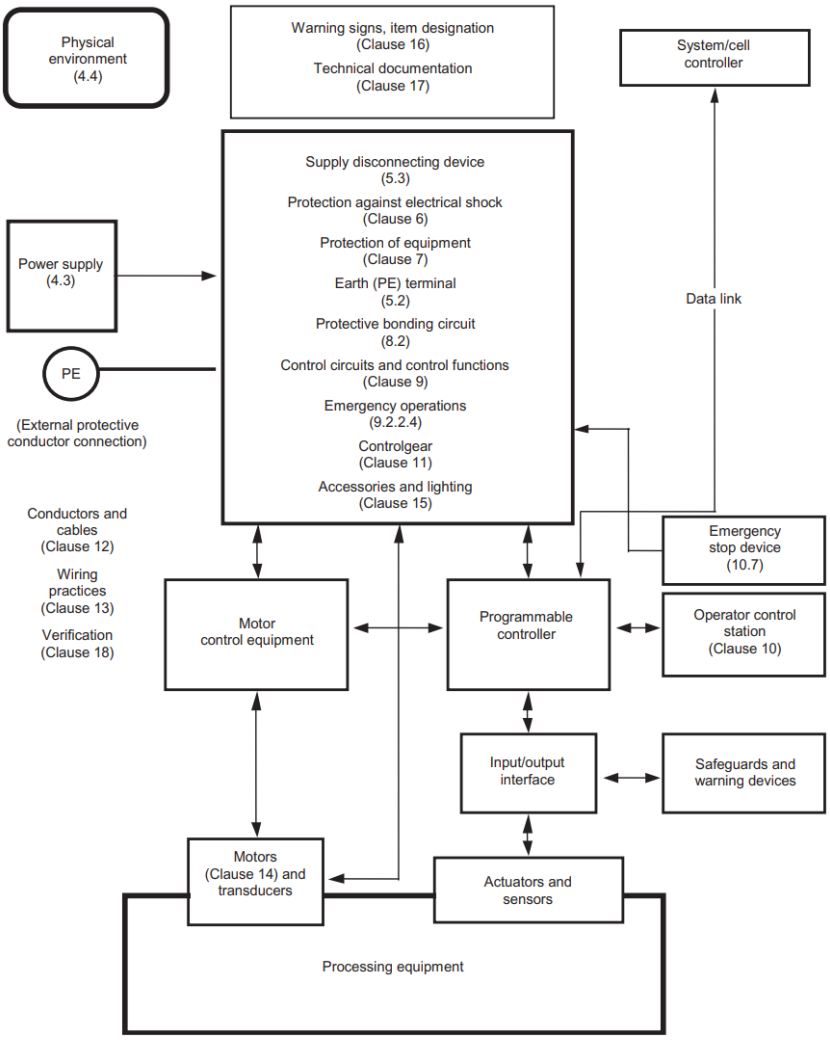

Figure 10 Block diagram of a typical machine and SFS-EN 60204-1 standard's clauses. (Finnish Standards Association SFS, 2018, p. 143).

As from the Figure 10 can be seen, the standard offers some guidance for almost all aspects of the machine. If some area that may cause health risk is not covered by this standard, it must be covered by other standard. Other standards can also provide more detailed instructions for these topics, if instructions in this standard are not sufficient.

The standard gives three general rules that apply to selection of electrical components and devices for the machine:

1. Those need to be suitable for intended use and applied by following supplier’s instructions.

2. If relevant IEC standard exists, the component or device needs to comply with that.
3. Components need to be used according to supplier's instructions.

(Finnish Standards Association SFS, 2018, p. 156.)

Generic information and guidelines for operating conditions and environment are given in the standard. In cases of EMC and vibration, special conditions may apply and limits in the standard can be exceeded. If limits are exceeded, supplier and user may have to exchange information about that. Environmental aspects that are discussed in the standard are:

- Electromagnetic compatibility
- Ambient air temperature
- Humidity
- Altitude
- Contaminants
- Ionizing and non-ionizing radiation
- Vibration, shock, and bump

(Finnish Standards Association SFS, 2018, pp. 157-158.)

3.2.3. EN ISO 13849-x Safety of Machinery. Safety related parts of control systems.

The standard is type B standard and the first part of this standard EN ISO 13849-1:2015 focuses to general principles of design and integration of safety related parts of control systems (SRP/SC). Additionally, in case of programmable electronic systems the standard provides requirements SRP/SC. Safety objectives of the standard rule that principles of *EN ISO 12100* are fully considered. Meaning that risk reduction processes in that chapter can be used when carrying out risk assessment. Contents of this chapter are relevant if in the risk reduction measures are based on control equipment. Figure 11 below shows how contents of this standard can be implemented into the process risk reduction process of EN ISO 12100

that was shown in Figure 9. It also shows sections of Performance Level (PL) evaluation process, these are better described later in this chapter.

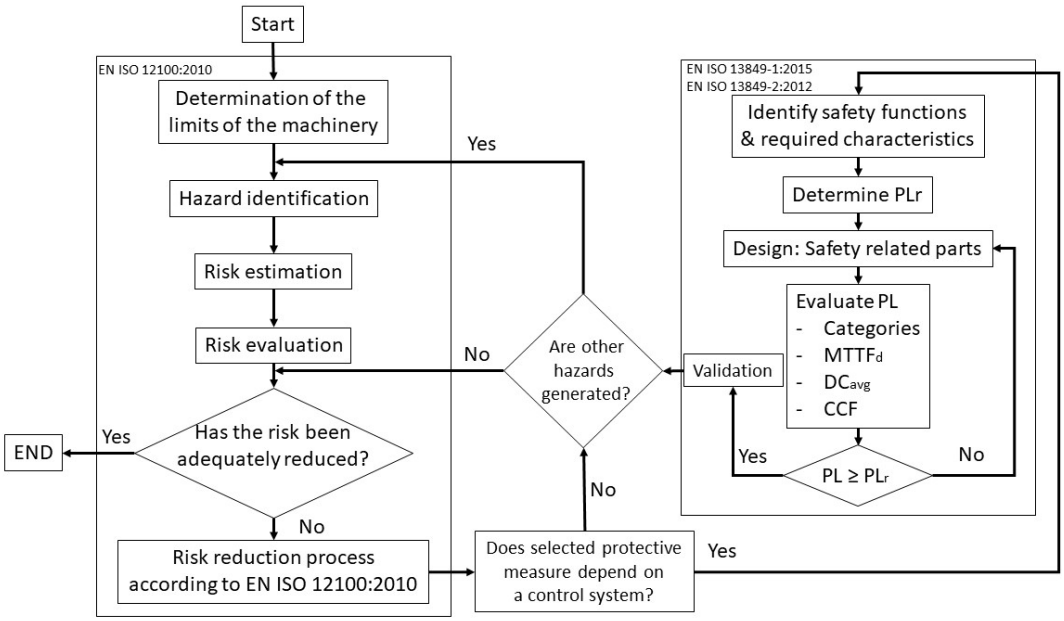

Figure 11 Relation between EN ISO 13849-1:2015 and EN ISO 12100:2010 illustrated.

When evaluating SRP/SC, the performance level (PL) of used components must be taken into consideration. PL are described as letters from a to e, and they describe what is the average probability of dangerous failure per hour (PFH_D), lowest PL is a and highest is e The table that contains performance levels and corresponding PFH_D ranges is in the end of the report in Appendix 1. The performance level should be equal or greater than the determined required performance level (PL_r). Determination of required performance level, shown below, follows similar principles as the risk assessment method in EN ISO 12100. (EN ISO 13849-1, 2015, p. 17.)

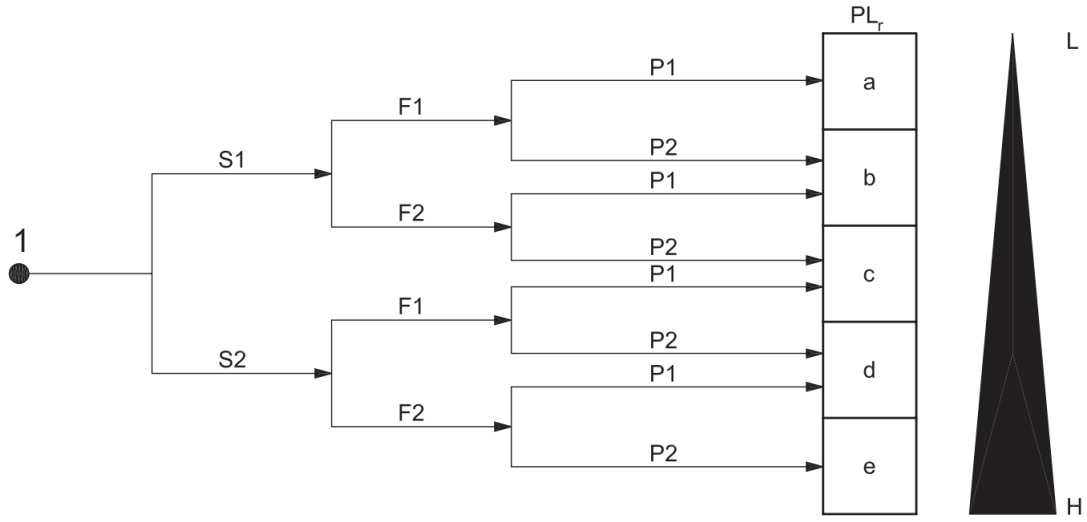

Figure 12 Determination of required PL_r (EN ISO 13849-1, 2015, p. 51).

Process is Figure 12 starts by determining whether the severity of risk is slight, normally reversible injury (S1). Or serious, normally irreversible injury or death (S2). Then the frequency and exposure to hazard is evaluated. The standard doesn't define clear limits for exposure, but it mentions that regular exposure hazard leads to higher frequency class (F2). Lower frequency class could be used if exposure frequency and exposure time is low, for example doesn't exceed 1/20 of overall operating time and happens less often that once every 15 minutes. The last step of the process is defining the possibility to avoid the hazard and limit the harm. Category (P1) can be selected if avoidance is possible under specific conditions. Such conditions could be slow movement of machine and possibility to escape and avoid the hazard. Or being able to identify the hazard before getting exposed and avoid it by not getting into the hazardous situation in the first place. Category (P2) should be selected if avoidance is scarcely possible. After selection of P1 or P2 the required performance level is known. PL_r a requires low amount of contribution to risk reduction, while PL_r e requires high amount of contribution to risk reduction. (EN ISO 13849-1, 2015, pp. 49-51.)

The main evaluating performance level of a safety related control system's is done with four quantifiable parameters.

1. MTTFd (Mean Time To Dangerous Failure)

2. DC_{avg} (Average Diagnostics Coverage)
3. CCF (Common Cause Failure)
4. Structure, later called category

(EN ISO 13849-1, 2015, p. 21.)

Additional evaluation parameters that are non-quantifiable:

- Safety functions behaviour under fault condition or fault conditions.
- Software, if it is used with safety related components.
    - EN ISO 13849-1 Clause 4.6 covers this in detail.
- Behaviour during systematic failures, such as over- or undervoltage, voltage variations or voltage breakdown.
- Performance of safety functions under different environmental conditions.

(EN ISO 13849-1, 2015, p. 21.)

Mean Time To Dangerous Failure (MTTFd) has three different levels: low, medium and high. It describes estimated time it takes for a failure to happen in a channel or in a component, estimated times for categories are listed in

Table 1 below. Component specific data about MTTFd is often provided by the manufacturer of the safety related component. If the manufacturer doesn't provide the data, estimates can be found from the annex C and of the standard. Or if neither of these can be done, MTTFd shall be 10 years. (EN ISO 13849-1, 2015, pp. 22-23.)

Table 1 MTTFd ranges. (EN ISO 13849-1, 2015, p. 23).

MTTFd	
Low	3 years ≤ MTTFd < 10 years
Medium	10 years ≤ MTTFd < 30 years
High	30 years ≤ MTTFd < 100 years

Diagnostics Coverage (DC) describes reliability of a safety control component and Average Diagnostics Coverage (DC_{avg}) describes reliability of whole safety control system. DC_{avg} focuses to frequency and accuracy of systems self-diagnostics, and it also takes software into consideration. Diagnostics coverage is split into four different levels that can be seen below in Table 2. (EN ISO 13849-1, 2015, p. 23.)

Table 2 Diagnostics Coverage (DC) ranges. (EN ISO 13849-1, 2015, p. 23).

DC	
None	DC < 60 %
Low	60 % ≤ DC < 90 %
Medium	90 % ≤ DC < 99 %
High	99 % ≤ DC

Common cause failure (CCF) can be described as multiple different failures caused by one event, and they are not consequences of each other. Annex F of the standard has informative table for evaluating and scoring of CCF, maximum score in the evaluation is 100 and result needs to be over 65 to be applicable. It's worth noting this parameter only applies to SRP/CS structure categories 2, 3 and 4. Categories are introduced in following paragraphs. (EN ISO 13849-1, 2015, pp. 9, 37, 67-68.)

Categories for SRP/CS structures are B, 1, 2, 3, and 4. The lowest category is B. It meets requirements and basic safety principles for machinery. It offers no diagnostics coverage, $MTTF_D$ of channel is low to medium, and typically there is no need to take CCF into

consideration. Despite low requirements, SRP/CS needs to comply with required EMC standards. The highest possible PL for category B is PL = b. (EN ISO 13849-1, 2015, p. 38)

Table 3 Keys for following figures from Figure 13 to Figure 15.

Key	Meaning		Key	Meaning
i_m	Interconnecting mean		O	Output device, e.g. contactor
I	Input device, e.g. sensor		TE	Test equipment
L	Logic		OTE	Output of TE
m	Monitoring		c	Cross monitoring

Figure 13 Designated architecture for categories B and 1. (EN ISO 13849-1, 2015, pp. 38, 40).

Category 1 follows same principles as category B, but it needs to be constructed using well-tried components and designed using well-tried safety principles. In this case well-tried means previously widely used with successful results in similar applications. Or if components are newly developed, those need to be verified using principles which demonstrate suitability for SRP. Additionally, components $MTTF_D$ needs to be high. For category 1 maximum PL = c. (EN ISO 13849-1, 2015, p. 39.)

Category 2 follows same principles as categories B and 1, and additionally it must be designed in a way its functions are checked by test equipment at suitable intervals e.g. before start up and before each new cycle when hazardous situation could occur. Check will either give an output that allows operation or generates an output that leads to a safe state which will be maintained until fault is cleared, or lead to warning if steady state is not practical. The maximum PL for category 2 depends on $MTTF_D$ and DC_{avg}, maximum being PL = d. (EN ISO 13849-1, 2015, p. 40.)

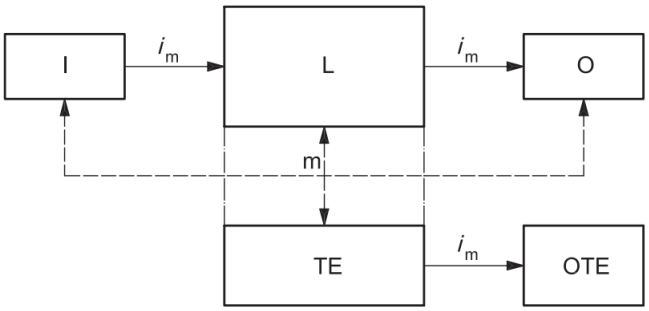

Figure 14 Designated architecture for category 2. (EN ISO 13849-1, 2015, p. 41).

Category 3 follows same principles as categories B and 1, but additionally it needs to make sure a single fault in any SRP doesn't lead to a loss of safety function. And the fault is detected before or during the requirement for safety function. DC_{avg} needs to be at least low and $MTTF_D$ of each channel should be low to high. According to the standard, category 3 consists of two channels that have cross monitoring between them. This type of architecture can perform even after single fault is detected. It will detect some, but not all faults. Additionally, it has potential of losing safety function due accumulation of undetected faults. (EN ISO 13849-1, 2015, p. 41.)

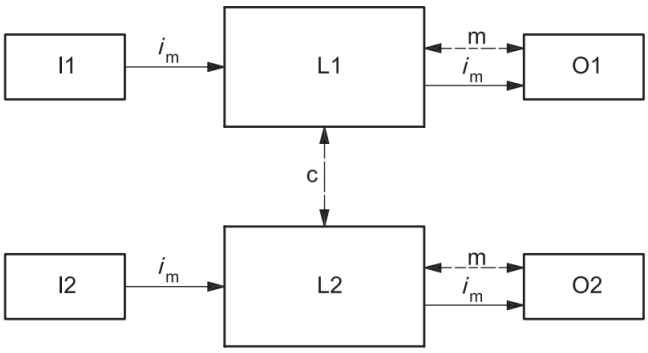

Figure 15 Designated architecture for category 3. (EN ISO 13849-1, 2015, p. 42).

Category 4 follows same principles as categories B and 1, but additionally it needs to make sure a single fault in any SRP doesn't lead to a loss of safety function. The fault is detected during or before the next use of safety functions. For example, at start up, at the end of operating cycle, or immediately when fault occurs. In category 4 undetected fault can't lead to loss of safety function. Key difference between category 3 and 4 is higher DC_{avg} in category 4. Also required $MTTF_D$ is high. (EN ISO 13849-1, 2015, p. 43.)

After selecting designated architecture for safety relate control system and components, channel specific MTTFd and DC_{avg} values for channels are calculated. Equations for MTTFd and DC_{avg} values for channels are covered in Appendix 2 and Appendix 3. Results of these equations are then compared to value ranges in Table 1 and Table 2. When MTTFd and DC_{avg} levels are obtained, those and category of SRP/CS are inserted to Table 4 below.

Table 4 PL achieved by SRP/CS. (EN ISO 13849-1, 2015, p. 25).

Category	**B**	**1**	**2**	**2**	**3**	**3**	**4**
DC_{avg}	**none**	**none**	**low**	**medium**	**low**	**medium**	**high**
$MTTF_D$ of each channel							
Low	a	Not cove-red	a	b	b	c	Not cove-red
Medium	b	Not cove-red	b	c	c	d	Not cove-red
High	Not cove-red	c	c	d	d	d	e

The table 4 provides PL of the SRP/CS. After this PL is compared to PL_r and actions are taken according to the second part of the standard EN ISO 13849-2, which covers the validation phase.

EN ISO 13849-2:2012 has detailed instructions about validation plan, analysis of the system and required documentation for different system categories. It goes into more details than the first part of the series and offers validation tools with different safety principles and potential faults that may be applicable to the machine.

3.2.4. EN ISO 14118 Prevention of unexpected start-up

This standard is type B standard, and it is relevant to all machine manufacturers, and health and safety organizations that set rules to machinery. The scope of the standard is keeping the machine stopped while there are people present in danger zone. This is not only limited to moving parts of the machine but includes also other hazards that may be caused by

unexpected start-up of the machine. These other hazards can be caused by power supply, stored energy, or external influences. (EN ISO 14118, 2017.)

Instruction manual that is provided with the machine should list measures for preventing unexpected start up. It should mention what is the source of energy and what means are taken to prevent unexpected start-up. Also, it should list tasks that may require persons presence is danger zone, and different levels of protection that are implemented. (EN ISO 14118, 2017.)

Isolation and energy dissipation should be done by using isolation devices that reliably disconnect or separate energy source. In case of electrical isolation, requirements can be met by using device that is compliant with *EN 60204-1:2016*, subclause 5.3. (EN ISO 14118, 2017.)

3.2.5. EN 13445-x Unfired pressure vessels

EN 13445 Unfired pressure vessels is multi part standard. In this chapter is brief description of contents of parts that may apply to the electric breaker hammer. These are not explained in detail since application of those depend on many variables.

The first part of the standard is EN 13445-1. It briefly describes contents of each part of the standard and has list of topics covered and which part of standard focuses to it. The scope of the standard series is unfired pressure vessels with design pressure above 0,5 bar. Some pressure vessels are excluded from the scope, such as ones that are pre-stressed, or made from lamellar cast iron or any material that is not mentioned in parts 2, 6 or 8 of this standards series. (EN 13445-1, 2021, p. 6.)

Additionally, it also has hazard consideration flowchart that is like risk reduction flowcharts in *EN ISO 12100*. (EN 13445-1, 2021, p. 13). And finally, relationship between this standard

and *Pressure Equipment Directive 2014/68/EU* is explained. According to section 4 of EN 13445-1 the equipment that falls into the scope of PED shall also follow parts 1 to 6, 8 and 10 of EN 13445 standard series when applicable, to ensure compliance with the directive. While no other Union legislation is mentioned, the standard says that other Union legislation may be applicable to products falling to scope of this standard series. (EN 13445-1, 2021, pp. 9, 57.)

The second part of this standard series is EN 13445-2 - Materials. It provides information about material selection for plates, tubes, bars, etc. Tables provided by the standard are useful for designer when the design reference temperature is -20 °C or colder, and there is risk of brittle fracture. (EN 13445-2, 2021, pp. 20-26.) When this part of the standard is used, pressure bearing steel parts shall have certification for steel according to *EN 10204*, inspection certificate 3.1 or 3.2. (EN 13445-2, 2021, p. 11.)

The third part of standard series is EN 13445-3 - Design. It provides basic design criteria and methods. Also, different corrosion, erosion, protection, and load cases are covered. The standard provides necessary information for calculating normal load cases, but when it comes to testing load cases for final assessment, the standard refers to the fifth part of this standard series. (EN 13445-3, 2021, pp. 12-19.)

The fourth part EN 13445-4 – Fabrication covers all fabrication aspects that are linked to permanent joints of pressure vessels. It gives detailed instructions for different types of welds between parts, alignments, tolerances, weld details and welding procedure specification. Also, testing of welds, forming of pressure parts, post weld heat treatments and documentation of fabrication is covered in this standard. (EN 13445-4, 2021.)

The fifth part EN 13445-5 Inspection and testing focuses to what documentation is needed for pressure vessels that comply with the standard. And what tests are required in different cases. Documentation listed in the standard is partially the same as in pressure equipment directive. (EN 13445-5, 2021, pp. 10-14, 51.)

Part six of the series is EN 13445-6 Requirements for the design and fabrication of pressure vessels and pressure parts constructed from spheroidal graphite cast iron. It has materials listed for different temperature ranges. (EN 13445-6, 2021, p. 13.) It also provides information about founding, required materials testing, and benefits of ductile materials in pressure vessels. (EN 13445-6, 2021, pp. 21-26, 30-31.)

Design methods in EN 13445-6 are mainly based on EN 13445-3, and technical documentation shall be done according to EN 13445-5. (EN 13445-6, 2021, p. 14.)

3.2.6. EN 60529 Degrees of protection provided by enclosures

Standard EN 60529 Degrees of protection provided by enclosures is also know as IP Code. The standard is drafted by IEC, and it provides rating system for different levels of protection. It also lists required tests for different protection levels. The standard is applicable for enclosures for devices that have design voltage up to 72.5 kV. The standard doesn't include factors that may be listed in device specific standards, such as mechanical impacts, corrosion, freezing, and moisture through condensation. External parts that are not the permanent part of the enclosure are not part of this standard either. (EN 60529, 2019, p. 10.)

IP Code is formed from letters "IP" that stand for International Protection. After those letters are two characters, typically numbers. The first character is a number, anything from 0 to 6 or letter X. It describes how well the enclosure protects against foreign objects and dust. Higher number means better protection and covers all the situations described by lower numbers. While the letter X means that conditions are not specified. The second character is anything from 0 to 9 or letter X. It describes how well the enclosure prevents water entering the enclosure, under specific conditions, and causing harmful effects. If the application is versatile, and the product needs to comply with multiple different water ingress situations,

it's possible to give multiple IP codes for a product, as higher number doesn't automatically cover all the situations covered by lower numbers. (EN 60529, 2019, pp. 13-14.)

The first two characters are mandatory in the IP code, if a requirement for protection is not specified, it will be omitted and replaced with X. After these two mandatory characters, there is possibility to add one additional letter and one supplementary letter. These describe extra conditions that may apply to an enclosure. (EN 60529, 2019, p. 13.)

To be able to have IP-code on product, the product needs to be tested according to relevant the test methods listed in the standard. If the test is required in other standard, test conditions in that standard shall apply during the test. If conditions are not specified, manufacturer shall give instructions for the test. (EN 60529, 2019, p. 22.)

3.2.7. EN ISO 13766-x Earth-moving and building construction machinery. Electromagnetic compatibility (EMC) with internal power supply.

The part 1 of EN ISO 13766 is *type-C* standard and it describes general EMC requirements under typical electromagnetically conditions. Within its scope are drilling and foundation equipment. Equipment that is used for compacting, conveying, and preparing concrete and mortar. And processing reinforcements. Also, equipment and machinery that is used for road construction or maintenance is covered. (EN ISO 13766-1, 2018, p. 7.)

The machine could fall under the scope, but the standard excludes machinery that is used while being connected to grid. According to EN 13766-1, grid connected machinery should follow *IEC 61000* series. EN 13766 may be relevant if the machine is operated with battery operated carrier vehicle and the machine isn't connected to grid. (EN ISO 13766-1, 2018, p. 7.) The part 2 of this standard gives additional EMC requirements that may be applicable with battery operated vehicle.

3.2.8. EN ISO 4414:2010 Pneumatic fluid power

The standard sets general rules and safety requirements for pneumatic fluid power systems and their components. Originally the design of the hammer included an air compressor and possibility to change pressure in pressure tank of the hammer. This feature was dropped in design and therefore this standard is not relevant to the final version of the hammer. If the adjustable pneumatic system was returned to the hammer later, this standard would give basic requirements for the design, info for verification process and testing. Finally, the standard lists required information that should be given in documentation for different kinds of components that are part of the machine.

3.2.9. EN ISO 20607 Safety of machinery. Instruction handbook. General drafting principles

EN ISO 20607 is a type B standard, that gives guidelines for drafting instruction handbook for machinery. While the machine directive gives general principles and contents what instructions must contain, this standard goes deeper into details of instructions, adds extra contents, and provides content examples. These extras contain things such as how to formulate guidance to instructions, what kind of wording should be used, and details for warnings. Additionally, it gives detailed instructions what kind of font and colours should be used to ensure its easy readability. (EN ISO 20607, 2019.)

The standard is not necessary when drafting an instruction handbook but is a good resource for a person who hasn't drafted one before, or if there is some aspect of drafting one that requires additional support.

3.2.10. EN ISO 3744 Acoustics. Determination of sound power levels

Standard EN ISO 3744 "Acoustics. Determination of sound power levels and sound energy levels of noise sources using sound pressure. Engineering methods for an essentially free

field over a reflecting plane." The standard describes how to determine the sound power levels of machinery. This standard is used, since it is an updated version of standard that is mentioned in *Noise emission directive 2000/14/EC*, when measuring noise emissions of a hydraulic hammer, that is very similar to the electric breaker hammer.

The standard says that it's applicable to all types of machinery and assemblies. Also, all types of noises, ranging from steady to fluctuating to bursts, are covered. The test environment specified in the standard is either a laboratory room or a flat outdoor area with at least one sound reflecting plane. Environmental conditions that may affect test results should be minimized. This kind of issues can be strong electric and magnetic fields, background noise or wind. The standard lists criteria for background noise and frequency band used. (EN ISO 3744, 2010, p. 6.)

In the standard is also detailed descriptions for measurements, sound pressure level calculations and information that needs to be recorded in different test setups. Finally, instructions for reporting are given. (EN ISO 3744, 2010.)

3.2.11. EN ISO 9001 Quality management systems

According to the machine directive, some quality assessment processes require that a quality system approved by a notified body should be in use. The directive doesn't mention which quality system process should be used and it is not required by all the assessment processes. (2006/42/EC, 2006.) EN ISO 9001 is well known quality management system (QMS) that could meet this requirement.

Practices of this standard are likely to be beneficial for a company, even if quality management system is not required by the machine directive. The main idea of the standard can be simplified to the Plan-Do-Check-Act cycle, which can be seen below in Figure 16.

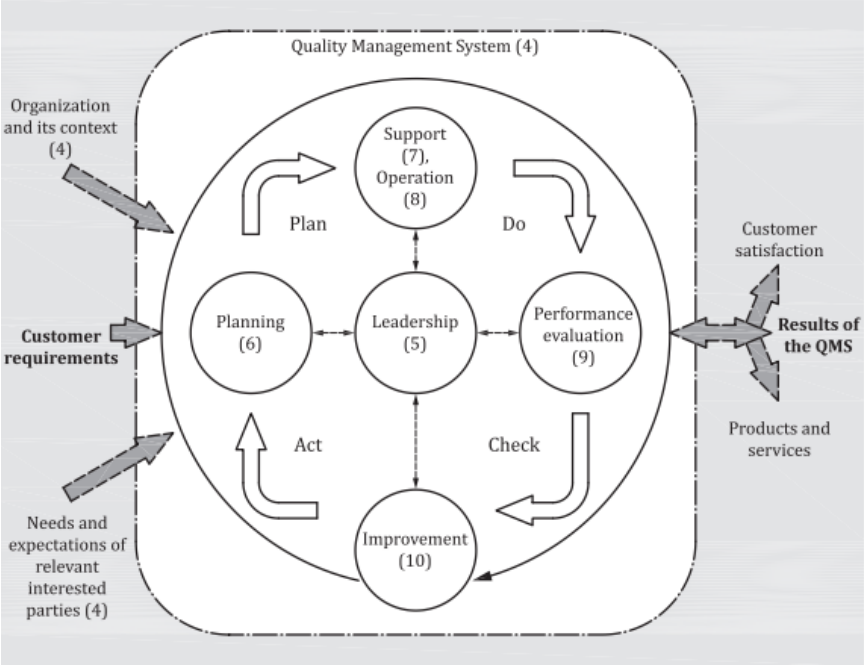

Figure 16 PDCA-cycle. (EN ISO 9001, 2015)

Figure 16 shows main topics of the standard how clauses 4 to 10 are related to each other and where they fit in the cycle. Under those clauses are more detailed explanations what is included in them and what are necessary steps.

3.2.12. EMC standards

There is no type-C standard that would be applicable to the machine, so the compliance must demonstrate through type-B standards on parts that it is necessary. For the EEA there are over one hundred standards about EMC, and therefore it is not possible to go through all potentially relevant standards in detail in this research. Additionally, access to these standards was very limited while doing the research. Because of these limitations, this chapter focuses to most common and most likely required standards.

In the Figure 17 below can be seen commonly used EMC standards in consumer electronics and their relations and interactions to different parts of the machine. Standards mentioned in the Figure 17 are developed by IEC. (Academy of EMC, 2022.)

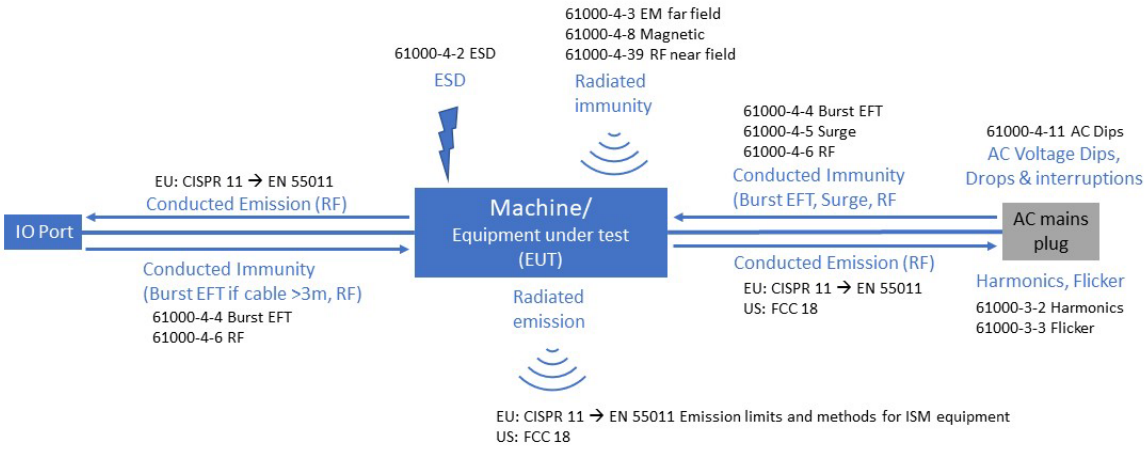

Figure 17 Commonly used EMC standards. (Academy of EMC, 2022).

The Figure 17 is not directly applicable to the machine, but it gives an idea about which part different standards could be applicable to.

According to Finnish Standards Associations book SFS Käsikirja 660, which focuses to the most used EMC-standards, EMC-standards can be divided to three groups. First is generic EMC-standards that can be used when products don't have product- or product family specific standards. Second is product and product family standards, which would be primarily used if these are available. And the third standards group is basic EMC-publications that describe EMC-testing methods and give requirements for resting equipment and test environment. (Suomen Standardisoimisliitto SFS ry, 2013, pp. 4-5.)

Out of the standards in Figure 17, only EN 55011 falls into product family standards, but it shouldn't be relevant in case of the machine since it applies to machines that generate and locally use radiofrequency energy. Other standards in the Figure 17 are basic EMC-publications. On top the standards that were mentioned in the figure, there are generic EMC-standards that may be applied if necessary. This kind of scenario is when there is no product family standard that would cover the product. Relevant generic EMC-standards in case of the machine are parts 1, 2 and 3 from EN 61000-6-x standard series. Parts 1 and 3 give requirements and limits for immunity and emissions in residential, commercial, light

industrial environments. Parts 2 gives requirements for immunity in industrial environment. (Academy of EMC, 2022.)

Relevant immunity tests standards and required performance criteria for residential and industrial environments according to generic EMC-standards *EN 61000-6-1* and *EN 61000-6-2*, can be seen in Table 5.

Performance criteria that is mentioned in the standards can be divided to three different categories. Criterion A means that Equipment under testing (EUT) has no degradation of performance during the test. Criterion B means that EUT continues operating as intended after the test, and performance level doesn't drop below manufacturer specifications. And finally, criterion C means that during the test there can be temporary loss of function, but EUT can recover with use of controls. If EUT becomes unsafe or dangerous, it has failed the test entirely. (IEC 61000-6-2, 2016, p. 9.)

Table 5 Required EMC tests and performance criteria according to EN 61000-6-1 and EN 61000-6-2.

	Required standards and performance criteria according to EN 61000-6-1 and EN 61000-6-2.	
Ports	Basic standard	Performance criterion
Enclosure port (physical boundary around equipment)	61000-4-8	A
	61000-4-3	A
	61000-4-2	B
Signal/control port	61000-4-6	A
	61000-4-5	B
	61000-4-4	B
Input & output DC power ports	61000-4-6	A
	61000-4-5	B
	61000-4-4	B

Input & output AC power ports	61000-4-6	A
	61000-4-11/34	B/C
	61000-4-11/34	C
	61000-4-5	B
	61000-4-4	B

Table 5 shows same performance criterion for all ports in both environments. While this is true, test specifications differ between these two environments, and industrial environment occasionally requires higher immunity. Therefore, these two standards cannot be used interchangeably. Tables in these standards provide more information about test specifications and remarks when tests are needed. (IEC 61000-6-1, 2019, pp. 12-16; IEC 61000-6-2, 2016, pp. 12-16.)

EN 61000-6-3 sets limits for EMC emissions in residential, commercial, and light industrial areas. And *EN 61000-6-4* for industrial environment. While industrial environment is not in the scope of EN 61000-6-3, it still covers requirements in EN 61000-6-4, as requirements of EN 61000-6-3 are stricter. (IEC 61000-6-3, 2020, p. 7) It will reference to following emission standards and applies to frequency ranges listed below in Table 6.

Table 6 Emission test standards and frequency ranges. (Academy of EMC, 2022)

Emission type / Port	Required standards for emissions according to 61000-6-3	Frequency range
Conducted (mains port)	61000-3-2	0 – 2 kHz
	61000-3-3	0 – 2 kHz
	61000-3-11	0 – 2 kHz
	61000-4-12	0 – 2 kHz
Conducted (mains, telecom port)	CISPR 32	150 kHz – 30 MHz
Radiated	CISPR 32	30 MHz – 6 GHz

On top of these standards there may be other EMC standards that are component specific and should be taken into consideration when selecting components for the assembly. Example about that kind of standard would be *EN 61131-2:2017* about "Industrial-process measurement and control – Programmable controllers – Part 2: Equipment requirements and tests."

3.3. The United States of America

In the United States of America there isn't one legislative body that would set all requirements for machinery that is sold to companies. In the U.S. multiple different agencies and organizations provide instructions for machine safety. Those range from ones that are part of United States Department of Labor, such as the Occupational Safety and Health Administration (OSHA), and the Mine Safety and Health Administration (MSHA). (U.S. Department of Labor, n.d.). Like these is National Institute for Occupational Safety and Health (NIOSH), which is part of the U.S. Centers for Disease Control and Prevention, which is part of the U.S. Department of Health and Human Services. (National Institute for Occupational Safety and Health, 2018.)

During the research an inquiry was sent to OSHA, asking what machinery falls under OSHA regulations, and how the compliance is demonstrated? Also, since OSHA's website and OSHA Regulations Standard 1910 seemed to be directed more toward employers than manufacturers, a question about who OSHA's regulations apply to was added. And if there are other regulators that set rules for machine manufacturer.

OSHA's responses were:

> "OSHA regulations associated with the NRTL program require that electrical equipment that is installed or used in the workplace must receive NRTL certification to the appropriate US safety standard and be marked in accordance with the NRTL program." (OSHA, 2022.)

NRTL means Nationally Recognized Testing Laboratory. This section of email also contained link to OSHA website about Type of Products requiring NRTL Approval. The email continued:

> "OSHA's authority is limited to employers; therefore, with regard to the NRTL program OSHA does not require manufacturers or suppliers, as applicable, to have the products they manufacture or supply certified by an NRTL. That said, it would be in the interest of manufacturers or suppliers, as applicable, to have products requiring approval under OSHA standards to be NRTL-certified, as many, if not all, of their customers are most likely employers that must follow applicable OSHA standards requiring approval of products and equipment.
>
> Please note that in addition to the NRTL Approval requirements the product may also need to comply with the requirements of other regulators including but not limited to other OSHA requirements, Food and Drug Administration (FDA), Federal Communications Commission (FCC), the Consumer Product Safety Commission (CPSC) and each state. Each of these regulators may have unique requirements for the product." (OSHA, 2022.)

The second part clearly rules that OSHA's regulations only apply to employers, not the machine's manufacturer. And depending on the machine, other regulators may have requirements for the machine. From the other regulators that were mentioned, relevant one in the scope of this thesis is Federal Communications Commission (FCC) as they have regulations about EMC. Consumer Product Safety Commission's regulations are outside of the scope of this research since the machine is sold to businesses only.

According to OSHA website, test standards that are developed by standards developing organizations, and developed standards are often approved as American National Standards by American National Standards Institute ANSI. (OSHA, n.d.)

Other private product safety agencies and organizations that operate in the U.S., and have standards that have relevancy to electric breaker hammer, are:

- National Fire Protection Association (NFPA)
    - Published NFPA 70 and 79 codes about electrical safety.

- Underwriters Laboratories (UL)
    - UL is accredited by ANSI, and Standards Council of Canada (SCC).
    - Provides testing and certifying of machines.
    - Some UL standards and certificates recognized in Canada.
- CSA Group
    - Accredited by SCC, OSHA and ANSI.
    - Provides testing and certifying services of machines.
    - Some CSA standards and certificates recognized in the U.S.

(NFPA, n.d.; Underwriters Laboratories, n.d.; CSA Group, n.d.)

Underwriters Laboratories (UL) page about Machine safety standards says following,

> "The ANSI B11 series of American National Standards and Technical Reports specify requirements for both the manufacturers (suppliers) and users of the machines". (Underwriters Laboratories, n.d.)

Also, the same site mentions ANSI / NFPA 70 and 79 as additional machine safety standards. Additionally, OSHA 29 CFR 1910 General industry regulations is mentioned as applicable machine safety standard. (Underwriters Laboratories, n.d.)

3.3.1. Occupational Safety and Health Administration (OSHA)

Occupational Health and Safety Administration (OSHA) is part of United States department of labor. According to OSHA and OHS Act, the employer is responsible for the safe work environment and ensuring that used machines are safe. This can be done by complying with standards, rules, and regulations under OSH act. These regulations can be found from Code of Federal Regulations (CFR), under title 29 Labor.

OSHA's list of types of products requiring NRTL Approval, that was mentioned in previous chapter 3.3 e-mail from OSHA, starts with category "Electrical conductors or equipment". (OSHA, n.d.) And then continues to list of specific references under 1910.303 and 1910.307, which are OSHA standards for General requirements and requirements for hazardous classified locations. It's also noted that even if material or equipment is mentioned in specific references, it may be only applicable under specific circumstances or conditions. (OSHA, n.d.) The only specific reference that applies to the machine under the scope of this research is:

> "1910.303 - General Requirements
>
> 303(a) - The conductors and equipment required or permitted by this subpart shall be acceptable only if **approved**, as defined in Sec. 1910.399.
>
> 303(g)(2)(i) - Except as required or permitted elsewhere in this subpart, live parts of electric equipment operating at 50 volts or more shall be guarded against accidental contact by **approved** cabinets or other forms of **approved** enclosures, or by any of the following means:" (OSHA, n.d.)

Section 1910.399 defines Approved as:

> "*Approved.* Acceptable to the authority enforcing this subpart. The authority enforcing this subpart is the Assistant Secretary of Labor for Occupational Safety and Health. The definition of "acceptable" indicates what is acceptable to the Assistant Secretary of Labor, and therefore approved within the meaning of this subpart." (CFR Title 29, 2022.)

Acceptable, according to same section 1910.399 is defined as:

> "Acceptable. An installation or equipment is acceptable to the Assistant Secretary of Labor, and approved within the meaning of this Subpart S:
>
> (1) If it is accepted, or certified, or listed, or labeled, or otherwise determined to be safe by a nationally recognized testing laboratory recognized pursuant to § 1910.7; or
>
> (2) With respect to an installation or equipment of a kind that no nationally recognized testing laboratory accepts, certifies, lists, labels, or determines to be safe, if it is inspected or tested by another Federal agency, or by a State, municipal, or other local authority responsible for enforcing occupational safety provisions of the National Electrical Code, and found in compliance with the provisions of the National Electrical Code as applied in this subpart; or

> (3) With respect to custom-made equipment or related installations that are designed, fabricated for, and intended for use by a particular customer, if it is determined to be safe for its intended use by its manufacturer on the basis of test data which the employer keeps and makes available for inspection to the Assistant Secretary and his authorized representatives." (CFR Title 29, 2022.)

Based on the definition, wording "approved" in the context of OSHA standards Subpart S – Electrical, covers situations where equipment has been determined to be safe by recognized testing laboratory. Or inspected by another federal agency, or Authority Holding Jurisdiction. Or equipment is custom made and manufacturer can provide sufficient test data to prove safety. Potentially relevant regulations can be found from standard's Subpart S 1910.302 through 1910.308, as these are about design safety. Additional useful info can be found from Subpart S Appendix A that contains list of non-mandatory standards that can aid when trying to reach compliance with subpart S. (CFR Title 29, 2022.)

3.3.1.1. State plans

In the U.S. states can also set their own legislation for Occupational Health and Safety, known as state plan. Below in Figure 18 can be seen a map of the U.S. which shows different levels of state plans and what states use them.

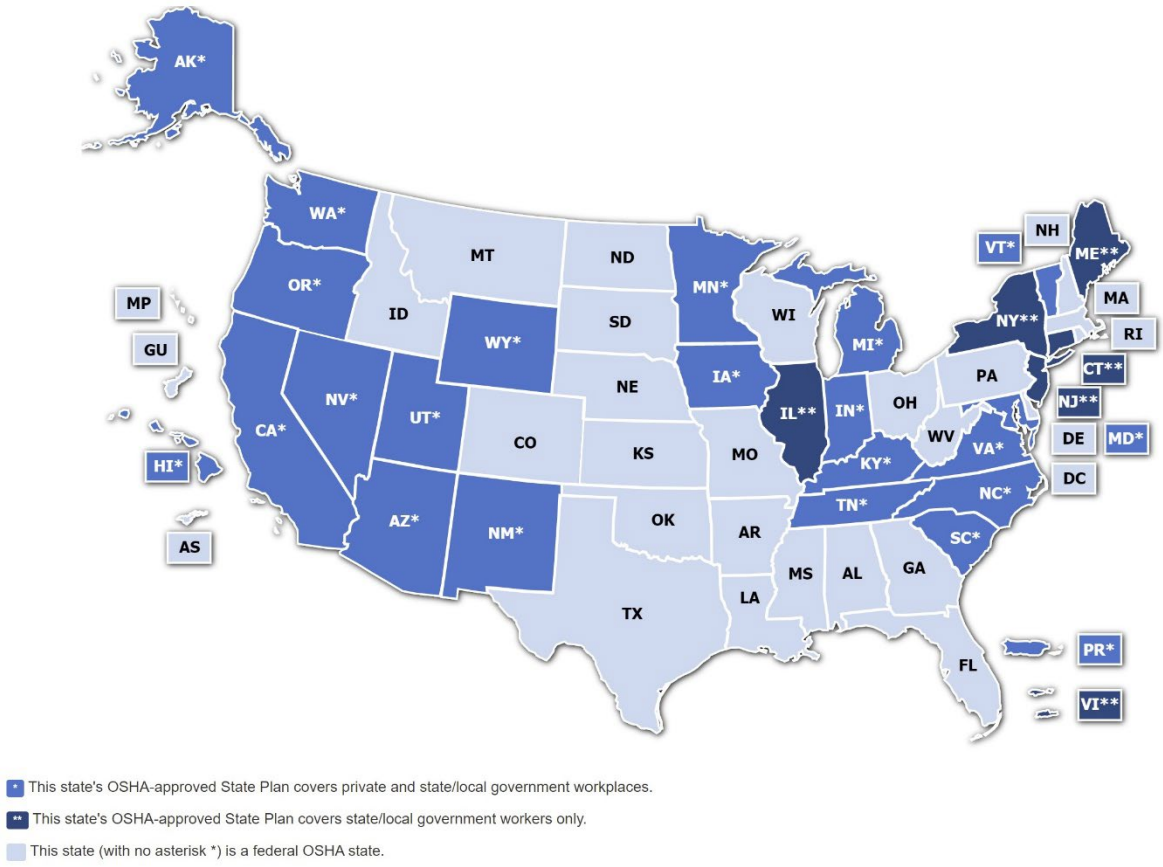

Figure 18 State plans. (OSHA, n.d.).

Overall, 22 states have a state plan that covers all workers and 6 states that have state plan that only covers state and local government workers. While rest of the states follow federal OSHA regulations. Since most of the states follow federal OSHA requirements, this research shall focus to that. (OSHA, n.d.)

3.3.2. Mine Safety and Health Administration (MSHA)

Mine safety and Health administration (MSHA) operates under United States Department of Labor. It focuses on workplace safety in mining. Main work is put to preventing death, illness, and injuries. It is very similar to OSHA and there is a document that defines when MSHA regulations should be followed instead of OSHA regulations. The document is called: “Interagency Agreement between The Mine Safety and Health Administration U.S. Department of Labor and The Occupational Safety and Health Administration U.S.

Department of Labor". In short, MSHA regulations take over when operating in a mine where minerals are extracted in non-liquid form. Also, roads leading to the mine, and milling processes of mined materials fall under MSHA jurisdiction. Machinery used in such areas is under MSHA jurisdiction. (MSHA, 1979.)

MSHA has equipment approval and certification requirements for certain mining products that are used underground coal and gassy underground metal mines. (MSHA, n.d.) The machine that is under the scope of this research doesn't fall under these requirements since it's not intended to be used in coal mines or gassy mines.

While researching the approval and certification requirements mentioned above, some sites compared acceptance, certification, and approval to each other. Following was said about acceptance:

> "Acceptance is written notification by MSHA that a product has met the applicable requirements and will be listed by MSHA as acceptable. For example, if a hose meets the applicable requirements for the regulation regarding electric motor-driven mine equipment and accessories, it will be listed by MSHA as acceptable flame-resistant auxiliary equipment. An accepted product is not a certified or approved product." (Jeremiah, 2012.)

Information that was stated above about acceptance was not found from MSHA site. Or from regulations by MSHA which can be found from Code of Federal Regulations (CFR), under Title 30 Mineral Resources. Despite of that not being found, design of machine should follow parts of Title 30 that are applicable, to ensure machines safety in mining environment. Also, it's worth noting that according to CFR Title 30 chapter 6.2(a), using non MSHA product safety standards can be accepted if they provide at least same level of protection as equivalent MSHA standard would require. (CFR Title 30, 2022.)

3.3.3. Federal Communication Commission FCC

Federal Communication Commission is an independent U.S. government agency that implements and enforces U.S. communications law and regulations. FCC regulations can be found from CFR Title 47, Telecommunications. (FCC, n.d.)

CFR Title 47, Chapter 1 has EMC limits for devices that are unintentional radiators. Section 15.107 is about conducted limits and 15.109 about radiated emission limits. Title 47 doesn't specify any limits for immunity or susceptibility. Also, details of test methods are not specified out under this title. Section 15.31 about measurement standards refers to ANSI C63.4-2014 mentions it shall be used for unintentional radiators. (CFR Title 47, 2022.)

3.3.4. ANSI

The American National Standards Institute ANSI is a non-profit organization that responsible about coordinating U.S. conformity assessment system and voluntary standards. It represents the U.S. to the ISO, and also cooperates with IEC through U.S National Committee. ANSI's purpose is promoting the U.S. standards internationally and progress adoption of international standards in the U.S. when possible. (ANSI, n.d.)

ANSI B11 standards series about machine safety follow the same type A-B-C structure as ISO standards and EN standards have, meaning that the type A is most generic, type-B is safety feature specific, and type-C is product type specific. These are explained in ANSI adopted type-A standard *ANSI/ISO 12100:2012* – Safety of Machinery – General Principles for Design – Risk Assessment and Risk Reduction. This is the same standard as *EN ISO 12100:2012*. (Kelechava, 2017.)

Below are some ANSI standards that are relevant to the machine. During the research there was no direct access to the contents of the standards, so they are introduced through journal

article that reviewed contents of some standards in the ANSI B11 series and blog posts on ANSI website.

3.3.4.1. ANSI B11.0 Safety of Machinery

ANSI B11.0-2015 – Machines – Safety of Machinery is type A standard which focuses on general safety of machines that fall under ANSI B11 series. By following this standard, compliance with *ANSI/ISO 12100:2012* is ensured, since B11.0 covers same requirements and goes into more details, by covering supplier and end users. (Kelechava, 2017.)

Underwriters Laboratories (UL) page about Machine safety standards says following,

> "The ANSI B11 series of American National Standards and Technical Reports specify requirements for both the manufacturers (suppliers) and users of the machines". (Underwriters Laboratories, n.d.)

The standard has risk reduction system that is similar to ISO 12100. On top of this, the standard recommends using scoring system for risks. It references scoring systems in *MIL-STD-882D*, *RIA 15.06* and ISO standards. According to that, risk matrix like one in Figure 19 could be used.

	Severity			
Probability	*Catastrophic*	*Critical*	*Marginal*	*Negligible*
Frequent	High	High	Serious	Medium
Probable	High	High	Serious	Medium
Occasional	High	Serious	Medium	Low
Remote	Serious	Medium	Medium	Low
Improbable	Medium	Medium	Medium	Low

Figure 19 Risk chart. (Harris & Current, 2012).

The risk chart shown in Figure 19 is like one in MIL-STD-882D, and the standard offers better explanation to what steps need to be taken with each risk level. Alternatively, chart about performance level requirement from *EN ISO 13849-1* shown in Figure 12 could be utilized. Chart in RIA 15.06 is like EN ISO 13849-1, with exception of RIA 15.06 having safeguard selection chart based on risk. (Harris & Current, 2012.)

3.3.4.2. ANSI B11.19 Performance criteria for Safeguarding

The sets requirements for safeguard design, operation, and construction. It has sections about hazard control, general safeguarding, awareness devices and requirements for safe work procedures. Also, maintenance and training are covered. Some sections of this standard are harmonized with ISO standards. Throughout the standard references to ISO standards are made to give additional information. Following information in these references is not mandatory. (Harris & Current, 2012.)

3.3.4.3. ANSI Z535.1, Z535.3, Z535.4, Z535.5

Awareness signs, barriers and signals need to comply with requirements set in these standards. These standards are referenced in *ANSI B11.19*. (Harris & Current, 2012.) Most likely relevant standards to the machine in scope of the research are ones about signs and audible warnings, since the machine doesn't exactly utilize barriers unless enclosures are counted as barriers.

3.3.4.1. ANSI/ASSP Z244.1 Control of hazardous energy: Lockout/Tagout & Alternative methods.

The standard is drafted by ANSI-accredited standards developing organization American Society of Safety Professionals (ASSP) and has been approved by ANSI. The standard aims to avoid risks caused by hazardous release of stored energy or unexpected start-up of the machine. Preferred method for controlling hazardous energy is eliminating hazardous source

of energy when possible. Other methods are controlling the energy or utilizing control methods. This can be done with energy isolating devices that can be locked. (Kelechava, 2020.)

The standard also mentions the possibility to use tag-out method to avoid hazardous release of energy and the procedure for this method. And specifies that lock-out is preferred method. (Kelechava, 2020.)

3.3.4.1. Other ANSI standards

Following ANSI standards were defined to be most likely relevant to the machine, due safety reasons:

- ANSI B11.TR5 Sound Level Measurement Guidelines: A Guide for Measuring, Evaluating and Documenting Sound Levels Emitted by Machinery
    - The National Institute for Occupational Health and Safety (NIOSH) has set 85 dBA sound intensity as maximum recommended occupational exposure limit. (NIOSH, 2018.)
    - 85 dBA limit is also limit is under OSHA Hearing conservation program. (OSHA, n.d.)
- ANSI B11.26-2018 Machines - Functional Safety For Equipment: General Principles For The Design Of Safety Control Systems Using ISO 13849-1
    - ANSI adaptation and guide how to design Safety Control Systems using ISO 13849-1.

3.3.5. NFPA 70 National Electrical Code (NEC)

The National Electrical Code is developed by National Fire Protection Association, and it has been approver as American National Standard by ANSI. The code is advisory and

focuses to electrical installations. The focus is on fixed installations, but some mobile installations are covered in chapter 6 of the code. (National Fire Protection Association, 2020.)

The code has enclosure type number system that is like IP code, and a table for enclosure selection. Noteworthy thing is that according to NEC IP ratings are not substitute for enclosure type ratings, if enclosure type ratings are required. (National Fire Protection Association, 2021, p. 53.)

Another interesting part in the case of the machine is article 430 of the code that lists requirements for motors, motor markings, terminals, minimum wire bending spaces, maximum fuse delays, and protection against liquids. Name plate markings include the power of motor and different duty cycles it is rated for. The code also has good presentation which parts of a motor are covered by different parts of the article, this can be seen below in Figure 20. (National Fire Protection Association, 2021, p. 308.)

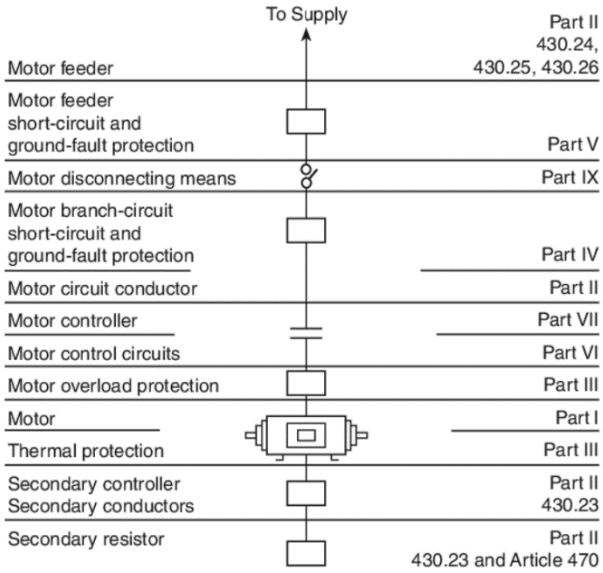

Figure 20 NFPA 70, contents of article 430 and relations to parts of motor control circuit. (National Fire Protection Association, 2020).

Additionally, article 670 of the code focuses to requirements of industrial machinery and refers to UL standard *508*. (National Fire Protection Association, 2020).

3.3.6. NFPA 79 Electrical safety standard for industrial machines

Since 2002 this standard has gone through harmonization efforts to match existing IEC standard *IEC 60204-1* Safety of machinery. Electrical components of machines, which is also available as harmonized EN standard. This means NFPA 79 is like the EN 60204-1, but it's not the same. On many parts NFPA 79 offers more specific details about requirements, for example about cable sizing and requirements for components. (National Fire Protection Association, 2021.)

Underwriters Laboratories (UL) page about Machine safety standards lists *NFPA 70* and *NFPA 79* as additional machine safety standards. (Underwriters Laboratories, n.d.)

3.3.7. UL standards

OSHA and MSHA don't specify whether UL standards directly apply to the machine under the scope of this research. But the OSHA website about Nationally recognized and ANSI approved-test standard list has many UL standards that apply to many electrical components of the machine. (OSHA, n.d.)

Depending on the machine's final structure, such testing standards and components could be for example:

- UL 50E Enclosures for Electrical Equipment, Environmental Considerations
    - Standard drafted in cooperation between ANCE, CSA Group and UL. (UL 50E, 2020, p. 2.)

  - Includes locations specified in NFPA 70, Canadian Electrical code part 1, and CSA C 22.1. Also, includes Mexico's electrical installations, but those are not in the scope of this research. (UL 50E, 2020, p. 7.)
  - Similar to EN 60529, but more detailed, e.g., chapters about corrosion protection and requirements for gaskets. (UL 50E, 2020, pp. 12-13, 16.)
- UL 198M Mine-Duty Fuses
  - Covers class K and R rated fuses that are defined in UL 248-series, and purpose of the standard is to protect trailing cables in D-C circuits in mines.
  - Maximum current rating of fuses is 600A with voltages of 300 or 600 V dc. (UL 198M, 2018, p. 4.)
- UL 508 Industrial Control Panels
  - Requirements for industrial control devices that are part of starting, stopping, protecting, or controlling electric motors. Also covers systems that store and process information that is linked to motor output control functions.
  - Equipment is used in locations accordance to NFPA 70.
  - Covers devices up to 1500 V in ambient temperatures of 0 – 40 °C. (UL 508, 2018.)

To ensure machine safety, components used in the machine that fall under OSHA testing standards should have UL marking. Or equivalent CSA marking when those components are for the machine's low voltage distribution or control equipment since UL and CSA components in those categories can be used interchangeably because of Memorandum of Understanding between UL and CSA. List of standards in these categories can be found from CSA groups website. (CSA Group, 2003.)

3.3.8. Other standards

Other safety standards may be applicable to the machine depending on the state legislation and authority holding jurisdiction in the area where the machine is being used.

3.4. Canada

In this section of research safety regulations in Canada are covered in similar way as in previous chapter about United States of America. Federal and Ontario OHS regulations are briefly covered by pointing some important aspects for machine design and manufacturers responsibility. This highlights how federal and province regulations can differ. Then some relevant standards are introduced in more detail.

In Canada for safety of federal employees, the main regulation to follow is Occupational Health and Safety Regulations, which is enabled by Canada Labor code. (Canada Occupational Health and Safety Regulations, 2022.) This is relevant, for people working in uranium mining and processing, as those fall under the federal labor code, and the machine may be used in conventional underground or open-pit mining. This legislation sets minimum requirements for safety. Outside of federal regulation, each province has their own provincial legislation that can be more strict than federal regulation. Approximately 94% of all employees fall under province specific legislation. In total there are ten provinces and three territories. If a company operates in multiple provinces or territories, they always need to follow jurisdiction that applies to the area where operations are located. (CCOHS, 2022.)

Below in the Figure 21 is a chart how Canadian regulatory system works in case of electrical safety. In it can be seen how provinces and territories hold the jurisdiction in the case of safety requirements. The federal government, that is put aside in the figure, affects through Standards Council of Canada that coordinates standards development. (CSA Group, 2001.) On top of these regulations, cities and municipalities can create by-laws that will be in municipal codes and apply locally. (City of Toronto, n.d.)

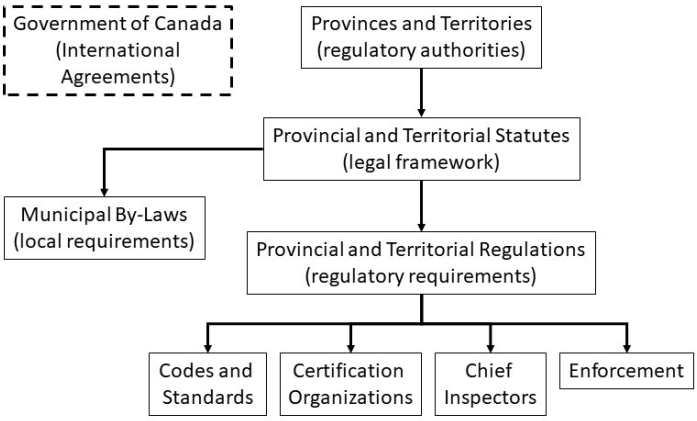

Figure 21 Canadian safety regulatory system. (CSA Group, 2001).

Provincial and territorial regulations may refer to codes and standards that need to be followed. Those regulations may also set rules about certifications, inspections, and enforcement that is required locally. (CSA Group, 2001.)

In Canada codes and standards developed by different standardization organizations such as CSA group, are voluntary application standards. Standards become mandatory if authority decides to adopt those in regulations. Only the standards that are adopted by regulations are mandatory and must be used in the design. Other similar standards can be used, but compliance with regulations can't be proven through them. (Tsisserev, 2013.)

On top of OSHA, Canada also has other government organizations that set rules for machinery that is being used in Canada. One of these is Innovation, Science and Economic Development Canada (ISED) that sets requirements for interference-causing equipment, which appears to be Canadian version of EMC compliance. (Government of Canada, 2019.)

3.4.1. Occupational Health and Safety Act, Federal

The federal OHSA focuses mainly to the responsibility of employer. It mentions things such as hazardous product, and hazardous products act are mentioned with supplier, but those only cover substances that would be hazardous and don't comment machine design.

Manufacturer of a machine is mainly mentioned when Federal OHSA talks about following manufacturer's instructions to ensure proper and safe use of machinery and equipment. (Canada Occupational Health and Safety Regulations, 2022.)

According to rules set in the Part V, about Boilers and pressure vessels, the machine doesn't have to follow rules set in the Part V, as section 5.2 excludes pressure vessels that have capacity of 40 litre or less. The pressurized compartment of the machine is less than 40 litres. (Canada Occupational Health and Safety Regulations, 2022.)

Federal OHSA mentions generic requirements and recommendations for machine guards, lockout - tagout practices, switches, and control devices. Part VIII about electrical safety refers to Canadian Electrical Code, which is also known as CE Code. More specifically it refers to *CSA Standards C22.1-1990, Canadian Electrical Code, Part 1* and *C22.3 No.1-M1979, Overhead Systems and Underground systems.* About these standards, following is said in the federal OSHA:

> "8.3 (1) The design, construction and installation of all electrical equipment, if feasible, shall meet the standards set out in the Canadian Electrical Code, Part I.
>
> (2) The operation and maintenance of all electrical equipment shall meet the standards set out in the Canadian Electrical Code." (Canada Occupational Health and Safety Regulations, 2022.)

According to the quoted section, the federal regulation allows some exceptions to the practices set in part 1 of CEC.

It's also worth noting that Part VIII Electrical Safety, Part XIV Materials Handling, and Part XVII Safe Occupancy of the Work Place don't apply to the underground workings of mines. (Canada Occupational Health and Safety Regulations, 2022.) These are covered under province specific regulations.

3.4.2. The Certification and Engineering Bureau of Innovation

ICED is federal organization in Canada that works in all areas of economy and in all parts of the country. Part of ISED is The Certification and Engineering Bureau of Innovation, Science and Economic Development Canada, which provides information about compliance of devices that fall under their scope. (Government of Canada, 2022.) On the Government of Canada website, their ISED page about compliance says following:

> "In Canada all Radio apparatus, interference-causing equipment and Terminal equipment are subject to Canadian regulations, therefore, Canadian consumers should verify that equipment meet Innovation, Science and Economic Development Canada's technical regulations (see below), prior to making any purchases.
>
> Technical regulations can apply to the following types of equipment:
>
> …
>
> Interference-causing equipment - Any device, machinery or equipment, other than radio apparatus, that can cause interference to Radiocommunication (includes digital equipment that uses a microprocessor or microcontroller, and Industrial, Scientific and Medical equipment such as switching power supplies used in halogen lamps)." (Government of Canada, 2019.)

According to this section responsibility about interference-causing equipment is on customers, while the manufacturer obviously should ensure the equipment meets the criteria if they want someone to buy the equipment. The machine falls under category II equipment that needs to meet requirements in applicable regulatory standards, but it doesn't need certificate. (Government of Canada, 2019.) In the case of the machine under the scope of research, this means *Interference-Causing Equipment Standards (ICES)* and at minimum fulfilling requirements of *ICES-Ger - General Requirements for Compliance of Interference-Causing Equipment*. (Innovation, Science and Economic Development Canada, 2018).

According to ICES-Ger the supplier of the machine needs to fill the Suppliers Declaration of Conformity (SDoC) after assessing that the machine meets criteria. (Innovation, Science and Economic Development Canada, 2018.)

3.4.3. Occupational Health and Safety Act, Ontario

Ontario Occupational Health and Safety Act, Part III, Duties of employers and other persons, under section 31 adds duties for supplier of machine under specific circumstances:

> "Duties of suppliers
>
> 31 (1) Every person who supplies any machine, device, tool or equipment under any rental, leasing or similar arrangement for use in or about a workplace shall ensure,
>
> (a) that the machine, device, tool or equipment is in good condition;
>
> (b) that the machine, device, tool or equipment complies with this Act and the regulations; and
>
> (c) if it is the person's responsibility under the rental, leasing or similar arrangement to do so, that the machine, device, tool or equipment is maintained in good condition." (R.S.O. 1990, c. O.1, 2021.)

In short, if machine is rented or leased, it is manufacturers responsibility to ensure the machines compliance with regulations when it is in use. Also, the manufacturer must ensure good condition and maintenance of the machine. After this in the same section, the responsibility of engineers is explained:

> "Architects and engineers
>
> (2) An architect as defined in the Architects Act, and a professional engineer as defined in the Professional Engineers Act, contravenes this Act if, as a result of his or her advice that is given or his or her certification required under this Act that is made negligently or incompetently, a worker is endangered." (R.S.O. 1990, c. O.1, 2021.)

This part of the section 31 puts responsibility on engineers if negligence or incompetence causes danger to workers. The professional engineers act defines professional engineer as a person who holds a license or temporary license but applies only to people who practice engineering in province. (R.S.O. 1990, c. P.28, 2021.)

3.4.4. R.R.O. 1990, Reg. 854: Mines and Mining plants

This regulation is under Ontario's Occupational Health and Safety act that was introduced in the previous chapter. The regulation focuses to safe operating practices and maintaining machinery in mines. According to the part I of the regulation the owner of the mine and the employer are mainly responsible about following safety practices in the regulation. (R.R.O. Reg. 854, 1990).

The regulation doesn't specify responsibilities of manufacturer. It often mentions that manufacturer's recommendations should be followed to ensure the safety. (R.R.O. Reg. 854, 1990.)

3.4.1. CSA standards

Canadian standards association (CSA) is non-profit organization that consists of two organizations. One focuses to standards development. The other to testing, inspection, and certification. CSA is accredited by the SCC, and ANSI. It also cooperates with ISO and IEC. (CSA Group, n.d.)

Searching CSA standards referenced in provinces OHS regulation can be done through CSA Group's OHS Standards View Access site. The site is free but requires registration. (CSA Group, n.d.) Following standards that are relevant to the machine were listed under Ontario.

3.4.1.1. C22.1 Canadian Electrical Code, Part 1

The way Federal OHSA part VIII, referred Canadian electrical code makes this standard required by law when using equipment that is not used in mines. In the scope of this standard, CSA M421 is recommended for mines and quarries. (CSA C22.1:21, 2021).

The standard covers wide variety of safety aspects of electrical installations. It goes through basic requirements such as marking requirements of the machinery, enclosure types, and installation practices. And in many sections, it even goes into very details, such as what kind of soldering flux should be used with specific types of cables. (CSA C22.1:21, 2021.)

The section 28, about Motors and generators contains lots of useful information that is in the scope of this research. For wiring, it provides conductor insulation temperature ratings and ampacity. Wiring methods also cover portable motors and cord types that are permitted with portable motors. Additionally, requirements for control systems, overcurrent and overheating protection and disconnecting means are covered. (CSA C22.1:21, 2021.) Overall, the standard is like *EN 60204-1*, but much more comprehensive.

3.4.1.2. M421 Use of Electricity in Mines

Specifies requirements for electric installations and machines. It covers fixed installations and mobile machinery. Chapters 4.6, 4.7 and 4.8 are about requirements for moveable equipment and mobile electrical equipment. (CSA M421-16, 2016.)

Chapter 6.11 about protection and control mentions that protective control devices must allow regular protective ground and ground-fault monitoring. Chapter 6.12 about grounding says that the metallic covering of cables can be used as ground, but it can't be the only ground. Also, electric motors and their components must be grounded with copper conductors to power-supply ground system. The standard also lists more requirements for conductivity of ground and minimum size. (CSA M421-16, 2016.)

3.4.1.1. Z432 Safeguarding of machinery

Parts of this standard are based on international standards: *ISO 12100* parts 1 and 2, *ISO 14121*, *Ansi B11 TR3* and *BSI PD 5304*. Reason behind that is Technical Committee's intent to harmonize standards when possible. (CSA Z432-04, 2006.) ISO standards that were

mentioned are now replaced by updated ISO 12100 which came out in 2010. (EN ISO 12100, 2010.)

Below in Figure 22 is the overview of contents of the standard and the workflow how the standard should be used. Clauses 1 to 3 contain generic information about the standard and connection to other standards and definitions, in similar way as ISO standards begin. Starting from clause 4 in the actual flow of safety assessment process.

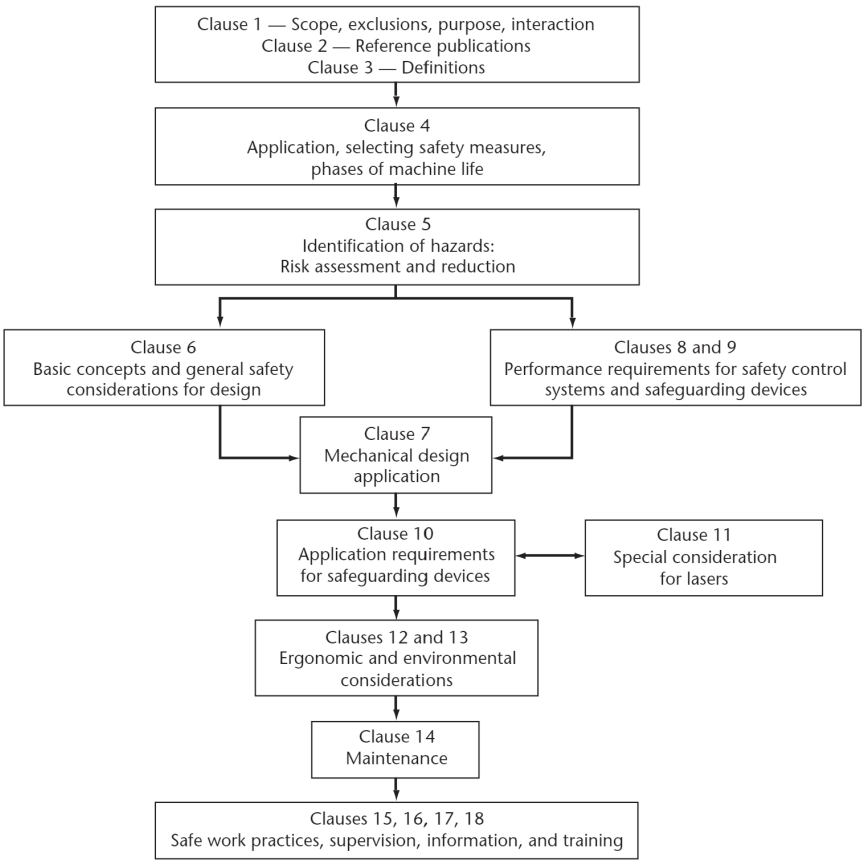

Figure 22 Flow of responsibilities. (CSA Z432-04, 2006.)

The safety assessment process follows similar framework as *EN ISO 12100* and *EN ISO 13849-1*. At first describing that this standard applies new machinery and rebuild- and redeployed machinery. Then goes through different safety measures that are better explained in the chapter 5 of the standard. Then gets divided to Clause 6: Basic concepts and general

safety considerations that are like ones described in EN ISO 12100, EN ISO 13849, and EN ISO 60204. And Clauses 8 and 9; performance requirements for safety control systems and safeguarding devices that are like ones mentioned in ISO 13849-1. After those, the workflow returns to clause 7 and goes to clause 10 from there. Clauses 12 and 13 are similar to ISO EN 614-1:2006 and EN 1005-4:2005+A1:2008. Clauses 15 through 18 are linked to instructions that are provided with the machinery.

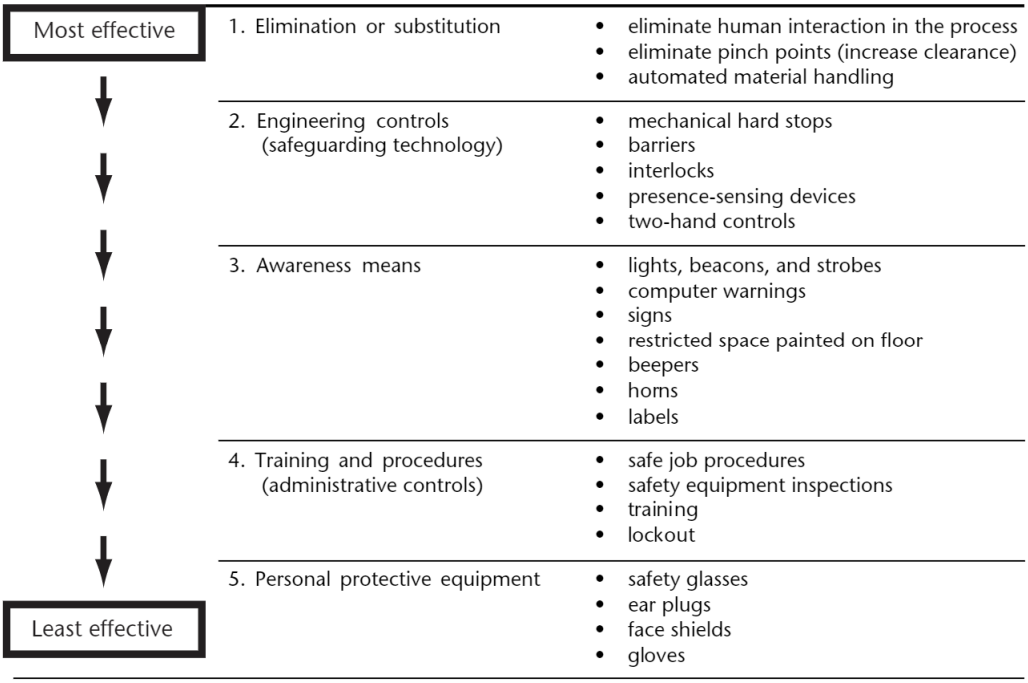

Figure 23 Hierarchy of safeguarding controls. (Z432-04 p.12).

The actual risk assessment and reduction process model in Figure 23 follows same principles as risk reduction process in ISO 12100.

3.4.1.2. CSA Z460-20 Control of Hazardous Energy – Lockout and Other Methods

The standard starts by listing references and noticeable references are ANSI/ASSE Z244.1, that was introduced in the U.S. standards and multiple ISO standards, including *ISO 12100*

and *ISO 13849-1*. (CSA Z460-13, 2013, pp. 13-14.) ISO 14118 is not referenced, despite that covering unexpected start-up of machine.

The standard goes over principles of energy isolation devices, hazard identification, tasks, and equipment. The main difference between *ANSI/ASSE Z244.1* and CSA Z460, is that CSA standard doesn't allow tag-out practices. Apart from this, they follow same principles.

3.4.2. Other standards

When selecting components for low voltage systems or control systems, components can either have CSA or UL marking, as mentioned in the paragraph 3.3.7 of this research.

To what extent standards outside of CSA standards for assessing machines safety, and outside of specific CSA/UL standards for components, can be used is not completely clear. Some machine safety consulting sites list ANSI B11 standard series applicable as well as various ISO standards, e.g., ISO 12100 and ISO 14118. (CE Consulting Inc, n.d.) ISO standards are mentioned on Government of Canada website about Canadian and international standards. (Government of Canada, 2018). Additionally, the CSA Group's website refers various IEC and EN standards and mentions those provide a firm foundation in context of functional safety and proving safety of the machine. (CSA Group, n.d.)

4. Case Study: Electric breaker hammer

This chapter focuses to applying information gained in chapter 3 to the pilot product. Process for declaration of conformity and CE-marking is introduced in chapter 4.1. with examples about structure of machine, potential solutions, and documentation. Product safety requirements for Canada and the United States of America are introduced in chapters 4.2. and 4.3. These chapters are more concise and focus to highlighting differences between these market areas and European Economic Area (EEA).

In EEA the machine directive gives main guidelines to machine safety and other directives complement this directive by giving more specific requirements for machinery. Fulfilling requirements in the directive, a machine will acquire CE marking that is a requirement for machinery that is being sold in the EU. When it comes to more specific process of ensuring machine safety, standards give guidelines how to ensure safety. Type-A standard EN ISO 12100 Safety of machinery gives basic principles that should be followed when more specific directions are not available. As there are multiple type-B standards that apply to the electric breaker hammer EN ISO 12100 is not constantly the main standard that provides information how to ensure safety.

While CE marking is mandatory requirement in the EEA, the U.S. and Canadian market don’t have similar systems. In those rules most often apply to customers that need to ensure safety of employees by ensuring machine meets safety requirements. Naturally it is machine manufacturers best interest to offer safe machine that meets criteria to the customer.

4.1. Obtaining CE-marking

In case of electric breaker hammer and CE-marking, the machine needs to fulfil requirements listed in the machine directive. It needs to be inherently safe for the user of the machine and surroundings. Also, there needs to be required documentation available, and machine needs

to have instructions for the end user. Finally assessing conformity should be done as shown in Figure 3, and then the declaration of conformity can be prepared, and CE marking can be affixed. Other directives that apply to the machine are the EMC directive and the Outdoor noise directive.

Since no type-C EN standards exist for the machine, it shall follow type-B standards to ensure machine safety and demonstrate compliance with directives that apply to the machine.

4.1.1. Functions, operating environment, and design values

In practice process should start by determining functions of machine and the operating environment. What it can do, what limits it has, and what are the design values. Functions in this case could look like what is listed in Table 7 below.

Table 7 Functions of the machine.

Functions:	**Limitations:**
Breaking rocks	Can't break bedrock.
Scaling rocks	
Breaking concrete	Issues caused by rebars in concrete.

Table 7 has divided hammers functions into three different cases. The first intended function would be breaking rocks, with exception of breaking bedrock. Bedrock was deemed to be not ideal for the hammer and therefore it was ruled out. Scaling of rocks in mines after exploding was deemed to be ideal use case and that shouldn’t have any limitations for the hammer in scope of this research. Breaking concrete is the third function, and it has potential issues with rebars in concrete.

After functions listing of potential operating environments and limits should be listed. These may have same or separate limitations, depending on the machine. In case of electric breaker hammer operating environments are listed in Table 8 below.

Table 8 Operating environment.

Operating environment:	**Limitations:**
Mines; Surface and underground	Not ATEX. Use only in non-explosive mines. Industrial environment. Sound level should be as low as practically possible. Industrial environment EMC.
Construction sites	Potentially urban environment. Sound level should be as low as practically possible. Urban environment EMC.

Operating environments are divided in two main categories: mines and construction sites. At mines it's important to notice that the machine is not ATEX approved. And at both environments, noise emission levels should be known so the risk of loss of hearing is reduced. In urban environment this is even more important than in mines, since in urban environment there may be bystanders without hearing protection.

Subassemblies of the machine are same as introduced in the Figure 1 and Figure 2:

- Hammer.
- Auxiliary unit.
- Cables connecting auxiliary unit to the hammer.
- User interface; controls and connections.

After listing functions, operating environments, and subassemblies table of design values is drafted. Some design values are requirements set by operating environment, and some are defined by components that are being used to ensure the machines functionality and safe operation. Examples about design values can be seen below in Table 9. Some of the design values are not accurate yet, since the machine is still under development.

Table 9 Design values.

Design values:	
Electricity input	400 V, 50 Hz 3-phase AC
Electricity internal	- DC-link (between INU and AFE rectifier) 600-750V. - Motor phase voltage up to 204V (AC). Phase current up to 255A. - During operating: current and voltage adjustable.
Isolation resistance	Depends on bus voltage, rules of R100.02 followed. ≤30 V AC or ≤60 V DC is low voltage, no set limit. >30 V AC and ≤1000 V AC or >60 V DC and ≤1500 V DC is high voltage, limits apply.
Pressure chamber volume	0.1 to 3 litres, depending on final design.
Pressure	20 to 300 bars, depending on final design.
Gas under pressure	Nitrogen
PED class	PED not applicable, machine follows pressure directive.
Operating temp. Ambient	-20C to +40C
Operating temp. Machine: Hammer	+0C to +90C
Operating temp. Machine: Aux. unit	-20C to +40C
Operating altitude	-3000m to +4500m
Operating conditions	Relative humidity: Up to 90%. Corrosive: Occasionally water Ph level: 2
IP rating; hammer	IP66/IP68/IP69 (SFS-EN 60529)
IP rating; Aux unit	IP66 (SFS-EN 60529)
IP rating; Aux. to hammer cable	IP66/IP68/IP69 (SFS-EN 60529)

In Table 9 values such as ambient operating temperature, operating altitude range from sea level and operating conditions are defined by intended operating environment. Electricity input depends on intended market area and standard electricity there. In EEA 400 volts, 50 Hz, three phase AC is the standard electricity that should be applied to electricity input. Electricity internally depend on what functions the machine has and what components are required to achieve these functions.

4.1.2. Machine design, components and enclosures

Components that are selected for the machine shall have CE marking and EU Declaration of conformity when it is applicable for components. In case of electrical components this typically means either compliance with the EMC directive, low voltage directive or the machine directive. Components selected also need to be able to operate in intended environment and conditions.

IP ratings of the machine are based on EN 60529. IP ratings are relevant since those ensure that electrical components are protected from contact against solid foreign objects, which in this case could be the person installing the hammer to a carrier vehicle. Since the machine can be used in mines, electrical components must be protected from dust. Meaning that the IP rating of enclosures of electrical components are IP6X. Designing enclosures and connectors based on this rating means those are protected from solid objects. Under normal operating conditions there is no risk of being able to touch live electrical components.

On the hammer part the rating should be IP66/IP68/IP69 because the hammer operates in versatile environment. The environment is dusty, and the hammer has water nozzles integrated to suppress the amount of dust in the air. Therefore, there is risk of water jet bouncing from wall back to hammer. Designation IP66 means that hammer is dust proof and protected against powerful water jets from all directions. IP68 means that hammer can be continuously submerged in water. Additionally, according to information provided by a potential customer company, IP69K rating is also required as the hammer is occasionally

pressure washed to keep it clean. IP69K means that hammer is dust proof and won't have harmful water ingestion, even when high pressure and high temperature water jets are used. It is noteworthy that standard ISO 20653 calls this IP rating IP69K, while IEC 60529 and EN 60529 call it IP69. This research follows harmonized standard EN 60529, and markings are according to its instructions.

IP-rating for the connector that connects cables from hammer to the cables from auxiliary box are located near the hammer at the side of the boom of the carrier vehicle. Because this location is near the hammer, the connection is operating under same conditions as the hammer. Because of this the IP rating for this piece is IP66/IP68/IP69. Additionally, the connector should have caps that protect the connectors contacts from dirt and water when the hammer is disconnected.

The auxiliary unit is located away from the boom and hammer. At this location it won't require as high IP rating as the hammer as it won't be sprayed with hot high-pressure water. For the auxiliary unit IP66 is enough as it prevents dust from entering and offers protection against high pressure water sprays. Other extra measures that fall outside of the IP rating should still be taken into consideration when designing the auxiliary unit. As the carrier vehicle moves from level to level in the mine, the pressure changes. If the carrier vehicle moves from low pressure to higher pressure, the auxiliary unit will suck air from the surrounding to balance this pressure difference. This may become a problem if the air has high humidity, and the environment is corrosive. To protect electrical components inside the auxiliary unit, a breather vent with vapor barrier should be used. To maintain IP rating, this vent and barrier should be in a place where it can't be sprayed directly with high pressure water.

Below in the Figure 24 is the concept picture of auxiliary unit's enclosure. Dimensions for the unit are approximately 500 mm x 400 mm x 400 mm. On the right side is the wet side of the enclosure. This side will house radiators that will be installed at openings that are numbered as 1. in the figure. If radiators need protection and there is risk of hot surfaces causing burns, they can be protected by louvres that get installed outside of the opening.

Fans installed behind radiators shall be IP66 protected, as well as any other components that are installed on the wet side. Bottom of the wet side will have drain holes, numbered as 3. On the left side in the picture is the dry side that is IP66 rated. It is connected to the wet side by opening in the internal wall, that is numbered as 2. This opening will have vapor barrier and metallic mesh installed on it. Components installed on the dry side don't need any specific IP rating.

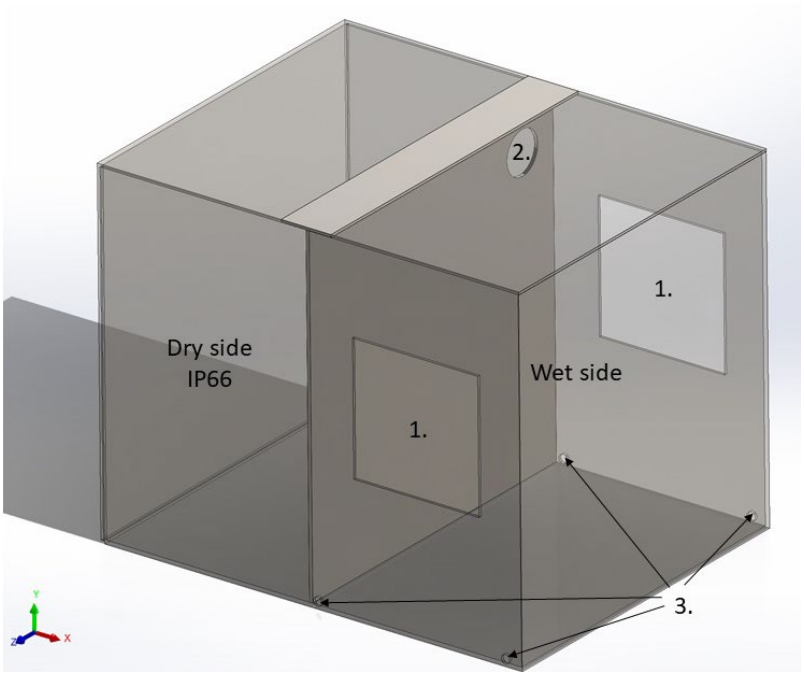

Figure 24 Auxiliary unit, concept picture

The hammer, interconnecting cables, and the auxiliary unit shall be installed in a way that it forms comprehensive faraday cage with galvanic connections. To make this possible, the cable shall be EMC power cable with shielding. Over the cable shall be installed tube or spiral cable protector, to protect the cable from potential contact with the boom and rocks. If additional EMC protection is needed, this protector may have EMC shielding and gasket integrated into it, or these can be installed underneath the protector.

The auxiliary unit shall also come with mounting hardware and have handles to aid with lifting and installation. If the auxiliary unit is too heavy to lift by the operator, it shall have

handles that make ergonomic lifting by two people possible or have mounting points for lifting devices.

4.1.3. Pressure bearing machine casing

Parts under pressure are integrated part of the machine and shall be designed following good engineering practice and according to the machine directive. Instructions from standard series EN 13445-x may be applied.

- Materials for pressure vessels EN 13445-2.
- Pressure vessel design EN 13445-3.
- Testing and inspection according to PED. And documentation EN 13445-5.
- Pressure parts constructed from spheroidal graphite cast iron EN 13445-6

If a standard from EN 13445-x is applied and used to prove inherently safe design, it should be documented according to instructions given in the standard series. Documentation should be included in instruction handbook.

4.1.4. Risk reduction

When the basic design of the machine is mostly clear, potential use cases with risk involved should be listed. This would include normal day to day operation, as well as more occasional situations such as changing the tool to the hammer, mounting, and dismounting the hammer from the carrier vehicle. Also, basic maintenance of the machine should be considered, and foreseeable misuse of the machine. In short, every foreseeable event that may possess risk should be evaluated separately.

Some examples about parts and events that may cause hazardous situation:

- Connector at boom.
  - Hazard event: Connector opened without switching off the auxiliary unit first.

  - Hazard: Electric shock due exposed contactors.
  - Solution: Using connector with minimum of IP2X or IPXXB rating when the connector is open. This rating prevents access to potentially live parts with a finger.
    - Connector shall also have Protective Extra-Low Voltage (PELV) circuit, monitored by control module that gives hammering command during operation. When connector is opened low voltage circuit opens, and connectivity is lost. Control module programmed to prevent hammering when there is no connectivity in the circuit.
    - Alternatively, PELV should be connected to isolation relays that cut off the feed to the connecting cable once the connector is open.
  - Additional safety measures: Clear instructions for actions that should be taken before opening the connector.
  - Standards for more info:
    - EN 60204: Clauses 6.2, 6.3, 7.7
    - EN ISO 13849
    - EN 60529

- Door at auxiliary unit.
  - Hazard event: Auxiliary unit's door is opened without disconnecting the unit from electricity input.
  - Hazard: Electric shock due live parts in the unit's enclosure.
  - Solution: Auxiliary unit treated as enclosed electrical operating area. The door opening handle acts also as an isolation switch, turning the handle to open position switches electricity feed off. Also, the door is marked with clear warning signs.
  - Standards for more info:

        - SFS-EN 60204-1: Clauses 5.3

- Isolation resistance in daily operation.
    - Hazard event: Isolation resistance drops below 500 Ω/volt in hammer, or interconnecting cable between the hammer and auxiliary unit.
    - Hazard: Risk of electric shock.
    - Solution: Hammer built according to UN regulation R100.02 for wheeled electric vehicles. In case of the hammer this means mechanical protection that has durability to stay functional over the machine's service life. In case of cables this means using cables that are double insulated.
    - Alternative solution: At every start-up of the machine, system does isolation resistance check. During this check machine measures isolation resistance between ground connection and phases.
    - Standards for more info:
        - SFS-EN 60204-1: Clause 8

- Loss of insulation resistance due cable break.
    - Hazard event: Cable breaks due contact to rocks
    - Hazard: Risk of electric shock.
    - Solution: Use of insulation-monitoring relay and fuse. Electricity is cut off automatically if the insulation resistance is suddenly lost.
    - Standard for more info:
        - SFS-EN 60204-1: Clause 7

- Unintentional hammering

- Hazard event: Hammering command given unintentionally after start-up of the machine.
- Hazard: Unintentional hammering while people are near the hammer.
- Solution: After start-up of the machine hammering not possible before the operator communicates with the user interface: Before hammering after start-up, operator must clear a warning message that informs that system is live.
- Hammering done with hold-to-run controls.
- Standards for more info:
  - SFS-EN 60204-1: Clause 9.2.3
  - EN ISO 14118

Hazards and safety measures above are some examples about potential hazards. These and all the other hazards should be evaluated. And if the elimination of hazard requires actions from the machine operator, it should be mentioned in the instruction handbook. In all situations that were listed, it is assumed that components are from reliable manufacturers and the designer of the machine has general knowledge of machine design. Also, ISO 12100 can be applied to practically all scenarios, but other standards give more detailed descriptions.

4.1.5. Integration to carrier vehicle's safety features.

As there are multiple different types of potential carrier vehicles, it is difficult to define uniform instructions how the machine should be integrated to the carrier vehicles safety features. Since the electric breaker hammer shouldn't be operated when the carrier vehicle is switched off, at minimum it would be advisable to monitor state of carrier vehicle and automatically switch off the hammer's auxiliary unit power supply if the carrier vehicle is switched off. This switch off of carrier vehicle can be either due normal shut down, or due malfunction.

4.1.6. Measurements

This chapter goes through required testing for the machinery. And test methods if there is something special to mention about them.

4.1.6.1. Enclosure IP testing

Enclosures shall be tested according to EN 60529. Tests for different sub-assemblies:

- Hammer: IP66/IP68/IP69
- Auxiliary unit: IP66
- Connection at the cable: IP66/IP68/IP69

Testing shall be done at test laboratory.

4.1.6.2. EMC compliance

EMC compliance and measurements shall be done according EMCD 2014/30/EU. The process of this starts with a flowchart that can be seen in Figure 7. According to it the first step is defining whether harmonized standards are applied.

Since there are no type-C standards that would be applicable to the machine, the compatibility shall be proven through type-B standards. EN 61000-6-x series, parts 1 to 4 provide limits for EMC immunity and emissions. The machine doesn't have any intentional radiofrequencies. EN 61000-6-1 and EN 61000-6-2 list following test standards for testing EMC immunity of the machine that operates in residential, commercial, light industrial or industrial areas.

EMC immunity tests that shall be done if the compliance assessment is done according to relevant harmonized standards EN 61000-6-1 and EN 61000-6-2. These refer to following standards:

- EN 61000-4-2 Electrostatic discharge immunity test.
- EN 61000-4-3 Radiated, Radio-Frequency, Electromagnetic Field Immunity Test.
- EN 61000-4-4 Electrical fast transient/burst immunity test.
- EN 61000-4-5 Surge immunity test.
- EN 61000-4-6 Immunity to conducted disturbances, induced by radio-frequency fields.
- EN 61000-4-8 Power frequency magnetic field immunity test.
- EN 61000-4-11 Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current up to 16 A per phase.
- EN 61000-4-34 Voltage dips, short interruptions and voltage variations immunity tests for equipment with mains current more than 16 A per phase.

EMC emission testing should be done according to EN 61000-6-3 if the testing is intended to be done according to harmonized standards. This standard refers to test standards:

- EN 61000-3-2 Limits for harmonic current emissions (equipment input current ≤16 A per phase).
- EN 61000-3-3 Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection.
- EN 61000-3-11 Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems - Equipment with rated current ≤ 75 A and subject to conditional connection .
    - Not necessary if EN 61000-3-3 applies.
- EN 61000-3-12 Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase.

Some tests listed may not be applicable if the machine doesn't have circuits or components operating with applicable phase currents. Most likely due to the size of the machine these tests need to be done as site tests. Details about testing should be discussed with authorized testing laboratory. If testing is not done according to harmonized standards, manufacturer needs to describe solutions adopted to meet requirements.

4.1.6.3. Noise emissions

Noise emission measurements should be done and documented according to Directive 2000/14/EC and ISO EN 3744:2010. For electric breaker hammer testing can be done by altering test method that is meant for hydraulic breaker hammer and can be seen in Appendix 9-Appendix 11. Below are testing instructions for electric breaker hammer that are based on instructions for hydraulic breaker hammers.

When doing noise testing for the electric hammer, test must be conducted in a way that 90 % or more of maximum electric power is reached.

I_s The mean value of current during the hammer's operation including at least 10 blows.

V The mean value of voltage during testing

T The temperature of hammer must have been stabilized to normal operating temperature before starting measurements.

P_a The prefill gas pressure of accumulator must be measured before testing, in static situation, at ambient temperature of +15 - +25 °C. The prefill gas pressure and ambient temperature shall be recorded.

Parameters to be evaluated:

P_{elec} Electric power of the hammer $P_{elec} = I_s * V$

Period of observation shall be at least 15 seconds, and measurements are repeated at least three times. The result is calculated as the arithmetic mean of the two highest values that do not differ by more than 1dB.

4.1.6.4. Energy efficiency and impact energy

The energy efficiency of the electric motor of the hammer cannot be tested according to the EU directives and regulations, and it is excluded from those. The impact energy of the hammer can be calculated and tested with methods that are used by hydraulic breaker hammer manufacturers. Theoretical impact energy can be calculated from the kinetic energy of linear movement of the part that hits the tool. Or it can be tested from the tool of the hammer. These tests are not required for CE marking.

4.1.7. Documentation

Documentation can be divided to documentation that needs to be available to the customer with the machine, and documentation that needs to be available if authorities demand it. Technical documentation must be kept available at least 10 years after the machine is manufactured.

Documentation available to customer:

- Instruction handbook.
    - Required contents in Appendix 4.
    - Additional instructions in standard EN ISO 20607.

Documentation available for authorities:

- Technical file.
    - Required contents in Appendix 6.
    - Technical file shall also contain documentation linked to declarations of conformity.
- EC declarations of conformity.

- Declaration of conformity of:
  - Machine directive. (List of contents in Appendix 5)
  - EMC Directive. (List of contents in Appendix 7)
  - Outdoor noise directive. (List of contents in Appendix 8)

Technical documentation of different revisions of the product must be stored according to instructions given int the blue book: (blue book 4.3.)

> "In the case where a product has been subject to re-designs and re-assessments of the conformity, the technical documentation must reflect all versions of the product; describing the changes made, how the various versions of the product can be identified and information on the various conformity assessment. This is to avoid situations where during the whole life of a product, a market surveillance authority is faced with previous versions of the product for which the version of the technical documentation it is presented with, is not applicable."

According to this, all revisions of the machine that have been put to market must have documentation available for the required time. Which according to directives is 10 years.

4.2. US market

The safety system in the U.S. differs drastically from the one in the EEA. In the EEA responsibility is on the manufacturer of the machine, and CE marking is the assurance that machine complies with requirements set in EU directives. And to prove this manufacturer uses harmonized standards to ensure compliance.

In the U.S. there are multiple regulators that set rules for machinery. In many cases those regulations apply to the employer that has purchased the machinery e.g., OSHA regulations. And even occupational health and safety regulation may differ if the state where machine is being used is using has its own state plan that is more strict than federal OSHA regulation.

Sometimes regulations directly apply to the manufacturer and the importer of the machine e.g., FCC regulations, which in the case of the machine regulate EMC levels. And sometimes regulations may or may not apply directly to the manufacturer of the machine, like in the case of MSHA regulation. In the case of machine that is under the scope of research MSHA appears to affect the employer in similar way as OSHA regulations. If the machine would be used in explosive environment or coal mines, MSHA regulations, testing and certificates would be on responsibility of the manufacturer.

Tests that are applicable to components machine and sections of the machine can be narrowed down by utilizing OSHAs list of appropriate ANSI approved test standards. While test standards were on the list, it didn't contain ANSI B11 series that entirely focuses to machine safety, and NFPA codes about electrical safety, and electrical safety standard for industrial machines weren't on the list.

According to UL website ANSI B11 series should be used as it specifies requirements for manufacturers and users of the machine. During this research that information wasn't found from federal regulations. But using it is encouraged as it covers machine safety and follows same principles as many EN standards that are used for conformity assessment in the EEA.

When it comes to selecting electrical components for the assembly, UL certified components should be used primarily to ensure compliance with OSHA regulations. Alternatively, CSA certified components can be used if those fall under the Memorandum of Understanding between UL and CSA can be used.

4.3. Canadian market

Canadian market works similarly as the U.S. market, regarding on requirements that directly apply to the company that is the manufacturer of the machine. Federal level Occupational Health and Safety Act lays the basic rules for federal workers. Provinces and territories set their own rules that cover all non-federal workers. Typically, these rules apply to the

employer whose employees use the machine. As in the case of the U.S. market, in Canada it is machine manufacturers best interest to ensure the machine meets safety requirements that are set for employees. In Canadian market the main difficulty is varying legislations between provinces.

Organizations that create standards are partially same across north American market and components that meet CSA/UL standards can be sometimes used interchangeably.

Difference in comparison to the U.S. market and EEA market is that according to ISED, the machine doesn’t need certificate about EMC compliance. It just needs to meet set requirements and have conformity assessment according to The Supplier’s Declaration of Conformity (SDoC).

5. Analysis

Ensuring product safety of the machine follows same principles in EEA, the US and Canada. The machine needs to meet safety criteria set in legislations and demonstrating this typically happens through standards that are developed by standardization organizations.

In EEA EU-directives that set rules for machinery, apply to the manufacturer of the machine and in some cases the distributor of the machine. Harmonized EN standards are used to demonstrate compliancy with EU directives. Standards are voluntary application and in theory compliance can be demonstrated without them. The easiest and often the best way to demonstrate compliance is following standards or parts of them that are applicable to the machine and doing the documentation according to requirements set by directives and standards that are being followed. Harmonized standards can be recognized by EN abbreviation before the number. Directives rarely mention what standards must be used and finding the right standards that apply to the machine and regulation is on the manufacturer's responsibility. Also, declaration of conformity is on manufacturer's responsibility once necessary steps for ensuring machines safety have been taken. These rules are the same across the EEA.

In the US rules for machinery are set by various authorities holding jurisdiction. Main one is Federal level organization OSHA that sets work safety rules and applies to employers that purchase machinery and whose employees use machinery. While the responsibility is on employees, it's still in the best interest of machine manufacturer to ensure product safety and comply with requirements set for employers. In some cases, local authority holding jurisdiction that ensures applicability with OSHA can approve a machine that hasn't been certified by nationally recognized testing laboratory. This makes this system appear similar as one in EEA, where harmonized standards are the easiest way to demonstrate compliance with directives, but sometimes also other methods can be used if necessary. There may also be variance in regulations since 22 states have OSHA-approved state plan for Occupational Health and Safety that covers all workers in the state.

Standards and codes in the U.S. are often partially harmonized with ISO standards. Noteworthy is that they seem to go into more details in requirements, while ISO standards appear to rely on the expertise of the engineer who has designed the machine. Reason to this might be that in the U.S. responsibility of safety is on the employer side and they need to be able to understand what requirements for machinery are.

The system in Canada is similar as in the US, but federal level Occupational Health and Safety Act only applies to fraction of employers and employees. Provinces and territories have jurisdiction in most cases, and they set safety requirements. Also, municipal by-laws may set requirements that differ from requirements set by provinces. This make it difficult to judge which standards are needed for assessing compliance.

Some standards across all market areas are almost the same and therefore it can be difficult to judge sections of those can be used interchangeably. In these cases, the stricter standard for each area where is difference should be used.

One key difference between EEA and the U.S and Canada that should be taken into consideration when choosing electrical components, is different standards for components. The U.S. and Canada uses components that are UL and CSA approved, while EEA typically has IEC approved components.

6. Conclusion

In the EEA machine manufacturer must follow EU directives and regulations to affix CE marking to the machine. Following these is on responsibility of the machine manufacturer and harmonized EN standards should be used to ensure machine safety and compliance with directives. While this requires lots of work from a small company, it ensures compliance across EEA.

In the U.S. the employee whose workers use the machine is primarily responsible about machine safety. These rules can vary depending on the state where the machine is being used. Because of this, manufacturer of the machine should meet basic criteria set by federal OSHA and do market research about potential customers locations. Then look into legislation of these areas and consult potential customers about legislation that they need to follow, and what certificates machinery typically needs. In the US, there are very few rules that are set directly to the machine manufacturer. The only one that this research came across, is the need to comply with EMC requirements by FCC. To prove compatibility with this, the machine needs a certificate.

In Canada system works in similar way as in the U.S. but federal legislation affects only fraction of potential customers. In Canada the legislation is set by provinces and territories, so the machine should meet regional requirements that employees need to follow. Again, doing market research about potential customers could be done. Alternative is going through legislation of all 10 provinces and 3 territories and making a machine that meets criteria of all of those.

If machine type specific standard is not available it is important to keep in mind that while many voluntary standards are applicable, only ones that are referred in legislation are mandatory. And from voluntary standards, only the standards that are required to demonstrate compliance and safety are really needed. Following all type-B standards that may be applicable doesn’t necessarily offer substantial increase in machine safety.

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Appendix 1 Performance levels and average probability of dangerous failure per hour according to (EN ISO 13849-1, 2015, p. 17)

PL	Average probability of dangerous failure per hour (PFH_D) 1/h
a	$\geq 10^{-5}$ to $< 10^{-4}$
b	$\geq 3 \times 10^{-6}$ to $< 10^{-5}$
c	$\geq 10^{-6}$ to $< 3 \times 10^{-6}$
d	$\geq 10^{-7}$ to $< 10^{-6}$
e	$\geq 10^{-8}$ to $< 10^{-7}$

Appendix 2 MTTFd calculations.

$$MTTFd = \frac{1}{\sum_{i=1}^{n} \frac{1}{MTTFdi}} \quad \text{(Equation 1)}$$

Equation 1 is the basic equation for MTTFd of a channel.

MTTFd for safety related components is either provided by component manufacturer. If it's not provided, it can be calculated based on annex C of EN ISO 13849, by using MTTFd or B10d values for same type of component. B10d means the number of operations that makes 10 % of samples suffer a dangerous failure.

$$MTTFd = \frac{B10d}{0.1 \times Nop} \quad \text{(Equation 2)}$$

N_{op} is defined by:

- tcycle: An average operating cycle time. (Unit: seconds per cycle)
- hop: Number of operating hours per day. (Unit: hours per day)
- dop: Number of operating days per year. (Unit: days per year)

$$Nop = \frac{dop \times hop \times 3600}{tcycle} \quad \text{(Equation 3)}$$

Appendix 3 DCavg calculations

Average diagnostics coverage for channel can be calculated by using DC values of components in the channel.

$$DCavg = \frac{\sum_{i=1}^{n} \frac{DCi}{MTTFdi}}{\sum_{i=1}^{n} \frac{1}{MTTFdi}} \quad \text{(Equation 4)}$$

Appendix 4 Contents of instructions according to Machine directive (Directive 2006/42/EC)

Each instruction manual must contain, where applicable, at least the following information:

(a) the business name and full address of the manufacturer and of his authorised representative;

(b) the designation of the machinery as marked on the machinery itself, except for the serial number (see section 1.7.3);

(c) the EC declaration of conformity, or a document setting out the contents of the EC declaration of conformity, showing the particulars of the machinery, not necessarily including the serial number and the signature;

(d) a general description of the machinery;

(e) the drawings, diagrams, descriptions and explanations necessary for the use, maintenance and repair of the machinery and for checking its correct functioning;

(f) a description of the workstation(s) likely to be occupied by operators;

(g) a description of the intended use of the machinery;

(h) warnings concerning ways in which the machinery must not be used that experience has shown might occur;

(i) assembly, installation and connection instructions, including drawings, diagrams and the means of attachment and the designation of the chassis or installation on which the machinery is to be mounted;

(j) instructions relating to installation and assembly for reducing noise or vibration;

(k) instructions for the putting into service and use of the machinery and, if necessary, instructions for the training of operators;

(l) information about the residual risks that remain despite the inherent safe design measures, safeguarding and complementary protective measures adopted;

(m) instructions on the protective measures to be taken by the user, including, where appropriate, the personal protective equipment to be provided;

(n) the essential characteristics of tools which may be fitted to the machinery;

(o) the conditions in which the machinery meets the requirement of stability during use, transportation, assembly, dismantling when out of service, testing or foreseeable breakdowns;

(p) instructions with a view to ensuring that transport, handling and storage operations can be made safely, giving the mass of the machinery and of its various parts where these are regularly to be transported separately;

(q) the operating method to be followed in the event of accident or breakdown; if a blockage is likely to occur, the operating method to be followed so as to enable the equipment to be safely unblocked;

(r) the description of the adjustment and maintenance operations that should be carried out by the user and the preventive maintenance measures that should be observed;

(s) instructions designed to enable adjustment and maintenance to be carried out safely, including the protective measures that should be taken during these operations;

(t) the specifications of the spare parts to be used, when these affect the health and safety of operators;

(u) the following information on airborne noise emissions:

— the A-weighted emission sound pressure level at workstations, where this exceeds 70 dB(A); where this level does not exceed 70 dB(A), this fact must be indicated,

— the peak C-weighted instantaneous sound pressure value at workstations, where this exceeds 63 Pa (130 dB in relation to 20 μPa),

— the A-weighted sound power level emitted by the machinery, where the A-weighted emission sound pressure level at workstations exceeds 80 dB(A).

These values must be either those actually measured for the machinery in question or those established on the basis of measurements taken for technically comparable machinery which is representative of the machinery to be produced.

In the case of very large machinery, instead of the A-weighted sound power level, the A-weighted emission sound pressure levels at specified positions around the machinery may be indicated.

Where the harmonised standards are not applied, sound levels must be measured using the most appropriate method for the machinery. Whenever sound emission values are indicated the uncertainties surrounding these values must be specified. The operating conditions of the machinery during measurement and the measuring methods used must be described.

Where the workstation(s) are undefined or cannot be defined, A-weighted sound pressure levels must be measured at a distance of 1 metre from the surface of the machinery and at a height of 1,6 metres from the floor or access platform. The position and value of the maximum sound pressure must be indicated.

Where specific Community Directives lay down other requirements for the measurement of sound pressure levels or sound power levels, those Directives must be applied and the corresponding provisions of this section shall not apply;

(v) where machinery is likely to emit non-ionising radiation which may cause harm to persons, in particular persons with active or non-active implantable medical devices, information concerning the radiation emitted for the operator and exposed persons.

Appendix 5 Contents of EC Declaration of conformity according to Machine directive (Directive 2006/42/EC).

EC DECLARATION OF CONFORMITY OF THE MACHINERY

This declaration and translations thereof must be drawn up under the same conditions as the instructions (see Annex I, section 1.7.4.1(a) and (b)), and must be typewritten or else handwritten in capital letters.

This declaration relates exclusively to the machinery in the state in which it was placed on the market, and excludes components which are added and/or operations carried out subsequently by the final user.

The EC declaration of conformity must contain the following particulars:

1. business name and full address of the manufacturer and, where appropriate, his authorised representative;

2. name and address of the person authorised to compile the technical file, who must be established in the Community;

3. description and identification of the machinery, including generic denomination, function, model, type, serial number and commercial name;

4. a sentence expressly declaring that the machinery fulfils all the relevant provisions of this Directive and where appropriate, a similar sentence declaring the conformity with other Directives and/or relevant provisions with

which the machinery complies. These references must be those of the texts published in the Official Journal of the European Union;

5. where appropriate, the name, address and identification number of the notified body which carried out the EC type-examination referred to in Annex IX and the number of the EC type-examination certificate;

6. where appropriate, the name, address and identification number of the notified body which approved the full quality assurance system referred to in Annex X;

7. where appropriate, a reference to the harmonised standards used, as referred to in Article 7(2);

8. where appropriate, the reference to other technical standards and specifications used;

9. the place and date of the declaration;

10. the identity and signature of the person empowered to draw up the declaration on behalf of the manufacturer or his authorised representative.

Appendix 6 Technical file according to Machine directive. (Directive 2006/42/EC)

1. The technical file shall comprise the following:

(a) a construction file including:

— a general description of the machinery,

— the overall drawing of the machinery and drawings of the control circuits, as well as the pertinent descriptions and explanations necessary for understanding the operation of the machinery,

— full detailed drawings, accompanied by any calculation notes, test results, certificates, etc., required to check the conformity of the machinery with the essential health and safety requirements,

— the documentation on risk assessment demonstrating the procedure followed, including:

(i) a list of the essential health and safety requirements which apply to the machinery,

(ii) the description of the protective measures implemented to eliminate identified hazards or to reduce risks and, when appropriate, the indication of the residual risks associated with the machinery,

— the standards and other technical specifications used, indicating the essential health and safety requirements covered by these standards,

— any technical report giving the results of the tests carried out either by the manufacturer or by a body chosen by the manufacturer or his authorised representative,

— a copy of the instructions for the machinery,

— where appropriate, the declaration of incorporation for included partly completed machinery and the relevant assembly instructions for such machinery,

— where appropriate, copies of the EC declaration of conformity of machinery or other products incorporated into the machinery,

— a copy of the EC declaration of conformity;

(b) for series manufacture, the internal measures that will be implemented to ensure that the machinery remains in conformity with the provisions of this Directive.

Appendix 7 Contents of EU Declaration of conformity according to EMC Directive (Directive 2014/30/EU, Annex IV)

EU declaration of conformity (No Xxxx)

1. Apparatus model/Product (product, type, batch or serial number):

2. Name and address of the manufacturer or his authorised representative:

3. This declaration of conformity is issued under the sole responsibility of the manufacturer.

4. Object of the declaration (identification of apparatus allowing traceability; it may include a colour image of sufficient clarity where necessary for the identification of the apparatus):

5. The object of the declaration described above is in conformity with the relevant Union harmonisation legislation:

6. References to the relevant harmonised standards used, including the date of the standard, or references to the other technical specifications, including the date of the specification, in relation to which conformity is declared:

7. Where applicable, the notified body … (name, number) performed … (description of intervention) and issued the certificate:

8. Additional information:

Signed for and on behalf of:

(place and date of issue):

(name, function) (signature):

Appendix 8 Contents of EU Declaration of conformity according to Outdoor noise Directive (Directive 2000/14/EU, Annex II)

EC DECLARATION OF CONFORMITY

The EC declaration of conformity must contain the following particulars:

— name and address of the manufacturer or his authorised representative established in the Community

— name and address of the person who keeps the technical documentation

— description of the equipment

— conformity assessment procedure followed, and, where appropriate, name and address of the notified body involved

— measured sound power level on an equipment representative for this type

— guaranteed sound power level for this equipment

— a reference to this Directive

— the declaration that the equipment conforms to the requirements of this Directive

— where appropriate, the declaration(s) of conformity and references of the other Community Directives applied

— the place and date of the declaration

— particulars of the signatory authorised to sign the legally binding declaration for the manufacturer or his authorised representative established in the Community.

Appendix 9 Test setup for electric breaker hammer according to Outdoor noise directive (Directive 2000/14/EU, 28. Hydraulic hammers)

Basic noise emission standard

EN ISO 3744:1995

Measurement surface/number of microphone positions/measuring distance

Hemisphere/six microphone positions according to Part A, item 5/r = 10 m

Operating conditions during tests

Mounting of the equipment

For the test the hammer is attached to a carrier and a special test block structure shall be used. Figure 28.1 gives the characteristics of this structure and Figure 28.2 shows the position of the carrier

Carrier

The carrier for the test hammer shall meet the requirements of the test hammer's technical specifications especially in weight range, hydraulic output power, supply oil flow and return line back pressure

Mounting

Mechanical mounting as well as connections (hoses, pipes ...) must correspond to specifications given in the hammer's technical data. All significant noise caused by pipes and various mechanical components needed for installation, ought to be eliminated. All component connections have to be well tightened

Hammer stability and static hold force

The hammer shall be firmly held down by the carrier in order to give the same stability as that existing under normal operating conditions. The hammer must be operated in an upright position

Tool

A blunt tool shall be used in the measurements. The length of the tool must meet the requirements given in Figure 28.1 (test block)

Test under load

Hydraulic input power and oil flow

Operating conditions of the hydraulic hammer shall be appropriately adjusted, measured and reported along with the corresponding technical specification values. The hammer under test must be used in such way that 90 % or more of the maximum hydraulic input power and oil flow of the hammer can be reached

Care shall be taken that the total uncertainty of the measurement chains of ps and Q is kept within ± 5 %. This assures the hydraulic input power determination within ± 10 % accuracy. Assuming linear correlation between hydraulic input power and emitted sound power this would mean variation of less than ± 0,4 dB in the determination of the sound power level

Adjustable components having effect on the hammer power

Pre-settings of all accumulators, pressure central valves and other possible adjustable components must meet the values given in technical data. If more than one fixed impact rate is optional, measurements have to be made using all settings. Minimum and maximum values are presented

Quantities to be measured

p_s	The mean value of the hydraulic supply fine pressure during the hammer's operation including at least 10 blows
Q	The mean value of the breaker inlet oil flow measured simultaneously with p_s
T	The oil temperature must lie between + 40/ + 60 °C during measurements. The temperature of the hydraulic breaker body must have been stabilised to normal operating temperature before starting the measurements
P_a	The prefill gas pressures of all accumulators must be measured in static situation (breaker not operating) at stable ambient temperature of + 15/ + 25 °C. The measured ambient temperature shall be recorded with the measured accumulator prefill gas pressure

Parameters to be evaluated from the measured operating parameters:

P_{IN} Hydraulic input power of the breaker $P_{IN} = p_s \cdot Q$

Hydraulic supply line pressure measurement, p s

— p_s must be measured as close to the breaker IN-port as possible

— p_s shall be measured with a pressure gauge (minimum diameter: 100 mm; accuracy class ± 1,0 % FSO)

Breaker inlet oil flow, Q

— Q must be measured from the supply pressure line as close to the breaker IN-port as possible

— Q must be measured with an electric flowmeter (accuracy class ± 2,5 % of the flow reading)

Measuring point of the oil temperature, T

— T must be measured from the oil tank of the carrier or from the hydraulic line connected to hammer.

Measuring point shall be specified in the report

— accuracy of the temperature reading must lie within ± 2 °C of the actual value

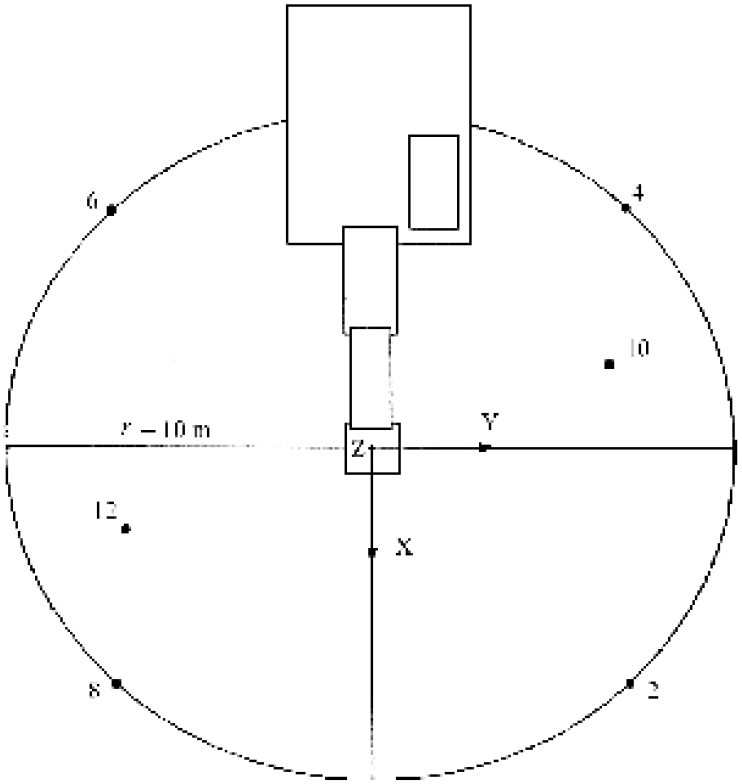
Period of observation/determination of resulting sound power level

The period of observation shall be at least 15 seconds

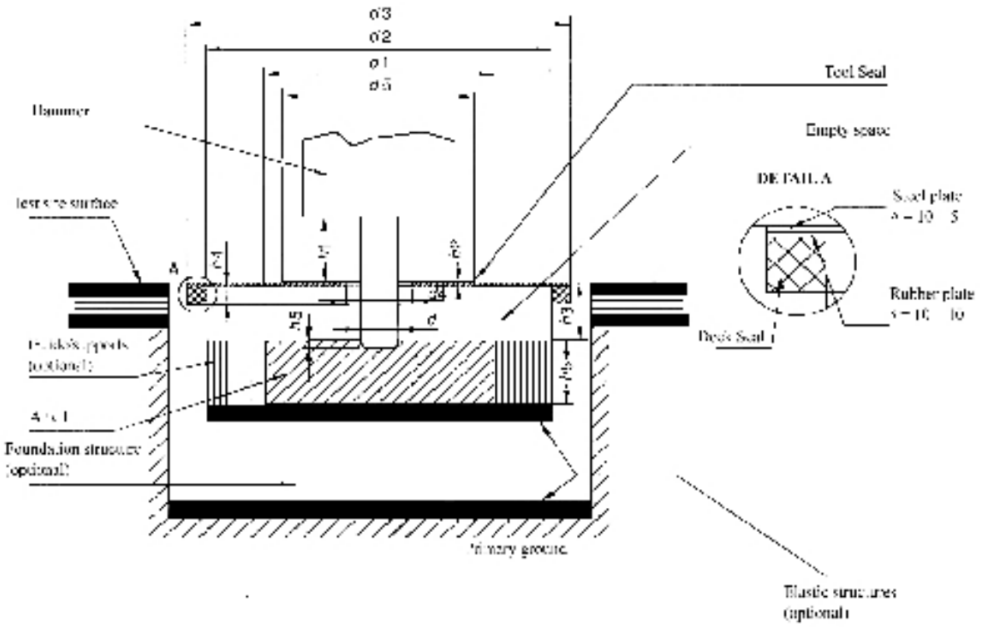
The measurements are repeated three times, or more if necessary. The final result is calculated as the arithmetic mean of the two highest values that do not differ by more than 1dB.

Appendix 10 Test setup for electric breaker hammer according to Outdoor noise directive (Directive 2000/14/EU, Figure 28.1)

Figure 28.1



Appendix 11 Test setup for electric breaker hammer according to Outdoor noise directive (Directive 2000/14/EU, Figure 28.2)



Definitions

d	Tool diameter (mm)
d_1	Anvil diameter, 1 200 ± 100 mm
d_2	Inner diameter of the anvil support structure, ≤ 1 800 mm
d_3	Diameter of the test block deck, ≤ 2 200 mm
d_4	Diameter of the tool opening in the deck, ≤ 350 mm
d_5	Diameter of the tool seal, ≤ 1 000 mm
h_1	Visible tool length between the lowest part of the housing and tool seal upper surface (mm), $h_1 = d \pm d/2$
h_2	Tool seal thickness above the deck, ≤ 20 mm (if the tool seal is located below the deck, its thickness is not limited; it may be made of foam rubber)
h_3	Distance between deck upper surface and anvil upper surface, 250 ± 50 mm
h_4	Isolating foam rubber deck seal thickness, ≤ 30 mm
h_5	Anvil thickness, 350 ± 50 mm
h_6	Tool penetration, ≤ 50 mm

If the quadratic shape of the test block structure is used, the maximum length dimension equals 0,89 x corresponding diameter

The empty space between the deck and the anvil can be filled with elastic foam rubber or other absorption material, density < 220 kg/m3

Appendix 12 Ecodesign directive (2009/125/EC, Article 15)

Implementing measures

1. Where a product meets the criteria listed under paragraph 2 of this Article, it shall be covered by an implementing measure or by a self regulation measure in accordance with paragraph 3(b) of this Article. Such implementing measures, designed to amend non-essential elements of this Directive by supplementing it, shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 19(3).

2. The criteria referred to in paragraph 1 are as follows:

(a) the product shall represent a significant volume of sales and trade, indicatively more than 200 000 units a year within the Community according to the most recently available figures;

(b) the product shall, considering the quantities placed on the market and/or put into service, have a significant environmental impact within the Community, as specified in the Community strategic priorities as set out in Decision No 1600/2002/EC; and

(c) the product shall present significant potential for improvement in terms of its environmental impact without entailing excessive costs, taking into account in particular:

(i) the absence of other relevant Community legislation or failure of market forces to address the issue properly; and

(ii) a wide disparity in the environmental performance of products available on the market with equivalent functionality

Appendix 13 Ecodesign requirements for motors and variable speed drives (Regulation 2019/1781, Annex I, section 2)

Strikethrough applied to parts that are not be applied in case of the electric breaker hammer.

2. PRODUCT INFORMATION REQUIREMENTS FOR MOTORS

The product information requirements set out in points (1) to (13) below shall be visibly displayed on:

(a) the technical data sheet or user manual supplied with the motor;

(b) the technical documentation for the purposes of conformity assessment pursuant to Article 5;

(c) free access websites of the manufacturer of the motor, its authorised representative or the importer, and;

(d) the technical data sheet supplied with products in which the motor is incorporated.

As regards to the technical documentation, the information shall be provided in the order as set out in points (1) to (13).

The exact wording used in the list does not need to be repeated. The information may be displayed using clearly understandable graphs figures or symbols rather than text.

From 1 July 2021:

~~(1) rated efficiency (ηN) at the full, 75 % and 50 % rated load and voltage (UN), determined based on the 50 Hz operation and 25 °C ambient reference temperature, rounded to one decimal place;~~

~~(2) efficiency level: 'IE2' 'IE3' or 'IE4', as determined in the first section of this Annex;~~

(3) manufacturer's name or trade mark, commercial registration number and address;

(4) product's model identifier;

~~(5) number of poles of the motor;~~

~~(6) the rated power output(s) PN or range of rated power output (kW);~~

~~(7) the rated input frequency(s) of the motor (Hz);~~

~~(8) the rated voltage(s) or range of rated voltage (V);~~

~~(9) the rated speed(s) or range of rated speed (rpm);~~

~~(10) whether single-phase or three-phase;~~

~~(11) information on the range of operating conditions for which the motor is designed:~~

~~(a) altitudes above sea-level;~~

~~(b) minimum and maximum ambient air temperatures including for motors with air cooling;~~

~~(c) water coolant temperature at the inlet to the product, where applicable;~~

~~(d) maximum operating temperature;~~

~~(e) potentially explosive atmospheres;~~

(12) if the motor is considered exempt from efficiency requirement in accordance with Article 2(2) of this Regulation, the specific reason why it is considered exempt.

From 1 July 2022:

~~(13) The power losses expressed in percentage (%) of the rated output power at the following different operating points for speed versus torque: (25;25) (25;100) (50;25) (50;50) (50;100) (90;50) (90;100) determined based on 25 °C ambient reference temperature, rounded to one decimal place; if the motor is not suited for operation at any of the operating points for speed versus torque above, then 'N.A.' or 'Not Applicable' should be indicated for such points.~~

~~The information referred to in points (1) and (2) as well as the year of manufacture shall be durably marked on or near the rating plate of the motor. Where the size of the rating plate makes it impossible to mark all the information referred to in point (1) only the rated efficiency at full rated load and voltage shall be marked.~~

~~The information listed in points (1) to (13) does not need to be published on free access websites for tailor-made motors with a special mechanical and electrical design manufactured on the basis of a specific client request if this information is included in the commercial offers provided to the clients.~~

~~Manufacturers shall provide information in the technical data sheet or user manual supplied with the motor on any specific precautions that must be taken when motors are assembled, installed, maintained or used with variable speed drives.~~

~~For motors exempt from the efficiency requirements in accordance with point 2(m) of Article 2 of this Regulation, the motor or its packaging and the documentation must clearly indicate 'Motor to be used exclusively as spare part for' and the product(s) for which it is intended.~~

~~For 50/60 Hz and 60 Hz motors, the information set out in points (1) and (2) above may be provided for the 60 Hz operation in addition to the values at 50 Hz, with clear indication of the applicable frequencies.~~

~~Losses are determined in accordance with Annex II.~~

Appendix 14 Restricted substances according to RoHS Directive (Directive 2011/65/EU, Annex II)

ANNEX II

Restricted substances referred to in Article 4(1) and maximum concentration values tolerated by weight in homogeneous materials

Lead (0,1 %)

Mercury (0,1 %)

Cadmium (0,01 %)

Hexavalent chromium (0,1 %)

Polybrominated biphenyls (PBB) (0,1 %)

Polybrominated diphenyl ethers (PBDE) (0,1 %)

Bis(2-ethylhexyl) phthalate (DEHP) (0,1 %)

Butyl benzyl phthalate (BBP) (0,1 %)

Dibutyl phthalate (DBP) (0,1 %)

Diisobutyl phthalate (DIBP) (0,1 %)

The restriction of DEHP, BBP, DBP and DIBP shall apply to medical devices, including *in vitro* medical devices, and monitoring and control instruments, including industrial monitoring and control instruments, from 22 July 2021.

The restriction of DEHP, BBP, DBP and DIBP shall not apply to cables or spare parts for the repair, the reuse, the updating of functionalities or upgrading of capacity of EEE placed on the market before 22 July 2019, and of medical devices, including *in vitro* medical devices, and monitoring and control instruments, including industrial monitoring and control instruments, placed on the market before 22 July 2021.

The restriction of DEHP, BBP and DBP shall not apply to toys which are already subject to the restriction of DEHP, BBP and DBP through entry 51 of Annex XVII to Regulation (EC) No 1907/2006.

Appendix 15 RoHS Directive Declaration of conformity (Directive 2011/65/EU, Annex VI)

ANNEX VI

EU DECLARATION OF CONFORMITY

1. No … (unique identification of the EEE):
2. Name and address of the manufacturer or his authorised representative:
3. This declaration of conformity is issued under the sole responsibility of the manufacturer (or installer):
4. Object of the declaration (identification of EEE allowing traceability. It may include a photograph, where appropriate):
5. The object of the declaration described above is in conformity with Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (*):
6. Where applicable, references to the relevant harmonised standards used or references to the technical specifications in relation to which conformity is declared:
7. Additional information:

Signed for and on behalf of: .....

(place and date of issue):

(name, function) (signature):