Tampere University

Marko Lamminmäki

IMPLICATIONS OF EN 1009 SAFETY REQUIREMENTS FOR MINERAL PROCESSING PLANTS

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ABSTRACT

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During the last years companies have increased their investments to safety. Partly this is due to the tighter legislation, but generally attitudes have changed, and people appreciate companies that invest employee safety. Companies have also noticed that investments to safety can be seen as a better competitiveness.

Safety can be improved by different methods, such as legislations and standards. Generally, laws and directives set the minimum safety requirements, and standards give machine and industrial specified solutions to fulfil the requirements.

EN 1009 standard series affects to mineral processing plants where it is the first type-C safety standards for mineral processing plants. EN 1009 refers to other standards in many cases and guides the designer to use them. EN 1009 collects all suitable standards and uses them to set the safety requirements for the mineral processing plants. New requirements are set when other standards are not practical or there is not one.

Products of Metso fulfils the present safety requirements well, but the upcoming EN 1009 standard series include requirements that demand changes to Metso products. According to this thesis and previous studies, crusher safety devices need most of the developing work. Other modules, such as conveyors and screens, already fulfils requirements of the new standard. Partly, results can be explained that EN 1009 refers to other published standards so new standard does not add any new requirements to the existing ones. Safety standards for crushers have not been made earlier so manufacturers have depended on EN ISO 12100 and ISO 21873-2 safety standards and risk assessments to find out what safety devices are needed.

Keywords: safety, designing, crusher, risk assessment, mineral processing

TIIVISTELMÄ

Marko Lamminmäki: EN 1009:n vaatimukset mineraalinkäsittelylaitosten suunnittelulle
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Yritykset panostavat turvallisuuteen aiempaa enemmän. Osittain tämä johtuu tiukentuneesta lainsäädännöstä, mutta myös yleinen ilmapiiri on muuttunut ja ihmiset arvostavat turvallisuuteen panostavia yrityksiä enemmän. Yritykset ovat myös huomanneet, että panostamalla työntekijöiden turvallisuuteen saadaan myös omaa kilpailukykyä parannettua.

Turvallisuutta pyritään parantamaan erilaisilla menetelmillä, kuten lainsäädännöllä ja standardisoinnilla. Yleisesti lait ja direktiivit asettavat turvallisuuden minimivaatimukset, joita standardit selkeyttävät asettamalla ala- ja konekohtaisia vaatimuksia ja ratkaisuja.

EN 1009 standardisarja koskee mineraalinkäsittelylaitoksia ja on ensimmäinen mineraalinkäsittelylaitoksia koskeva C-tyypin turvallisuusstandardi. EN 1009 viittaa useasti muihin standardeihin ja ohjeistaa suunnittelijaa käyttämään niitä. Standardisarja ei tuo kovin paljoa uusia vaatimuksia mineraalinkäsittelylaitoksille vaan ennemminkin kokoaa ne standardit ja vaatimukset, joita suunnittelijan tulisi käyttää. Vaatimuksia asetetaan niille koneille ja koneen osille, joille ei ole olemassa standardia tai niiden käyttäminen ei ole järkevää.

Metson tuotteet täyttävät nykyiset turvallisuuden vaatimukset hyvin. Kuitenkin tulevassa EN 1009 standardisarjassa on myös sellaisia vaatimuksia, jotka vaativat muutoksia Metson koneisiin standardin täyttämiseksi. Aikaisempien tutkimusten ja tämän työn pohjalta voidaan sanoa, että eniten kehitystä vaativia kohteita ovat murskainten turvalaitteet. Muut osat, kuten kuljettimet ja seulat puolestaan täyttävät jo nykyisellään uuden standardin vaatimukset. Osittain tulokset selittyvät sillä, että EN 1009 standardisarja ohjeistaa suunnittelemaan tietyt osat jo olemassa olevien standardien mukaan, jolloin uusia vaatimuksia ei varsinaisesti ole tulossa. Murskaimiin puolestaan ei ole olemassa muita kohdistettuja turvallisuusstandardeja, jolloin niihin liittyvät turvalaitteet ovat aikaisemmin olleet EN ISO 12100 ja ISO 21873-2 turvallisuusstandardien sekä valmistajien riskinarviointien varassa.

Avainsanat: turvallisuus, suunnittelu, murskain, riskinarviointi, mineraalinkäsittely

PREFACE

Safety is a term that we all use in our everyday life without thinking what it actually means. It can be used in many situations and with many definitions. Machine is safe when the user cannot harm himself while using it properly. This thesis is telling more accurate how safe machines are designed and how the safety can be increased.

As a child, I once pointed out one building and said to that I am going to study there when I grow up. That was the main building of University of Tampere at that time. A lot have happened since that, but now 20 years later, I am finishing my studies in Tampere University.

In the beginning, I want to thank my supervisor Mr. Karhukivi for reading and commenting my Master Thesis multiple times during the project. It helped me a lot and pushed me to the right direction. I also want to thank my other supervisor Mr. Heikkilä and manager Mr. Martikainen who made this thesis possible.

Finally, I want to thank my family and girlfriend for supporting me during this journey. Without you, this journey would have been harder to complete. You supported me and reminded me to take free time from studying when I did not think I needed it.

In Tampere, Finland, on 28 February 2020

Marko Lamminmäki

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

ANSI	The American National Standards Institute
EU	European Union
CEN	European Committee for Standardization
HAZOP	Hazard and operability study
High risk	Combination of grave severity and significant probability of occurrence of potential injuries
HSI	Horizontal shaft impactor
ISO	International Organization for Standardization
LT	Lokotrack
MD	Machinery Directive 2006/42/EC
Metso	Metso Minerals Aggregates
OHS	Occupational health and safety
OSHA	Occupational Safety and health Administration
PHA	Process hazard analysis
US	United States

1. INTRODUCTION

Safety can refer to several different subjects, such as personal safety, environmental safety or property safety. Machines make a major contribution to safety. This thesis focuses on to improve machine safety, especially mechanical systems by analysing EN 1009 standard series and comparing it with the products of Metso Minerals Aggregates (from here on referred only as Metso).

Improving of safety does not create value to the product directly. Safety improves the working conditions which leads to a better working effectivity. Safe machine guides the worker to act safely and does not allow worker to end up in accidents or in danger where there is possibility for injury.

1.1 Background

Standards are created to make agreed ways for safe design (SFS 2019). Standardization simplifies the work of authorities and make everyday life of consumers easier. Standards increase product compatibility, and safety, protect the consumers and the environment.

Aggregates are a granular material used in construction. Aggregates are produced from natural sources extracted from quarries and pits. In some countries, aggregates are also produced from sea-dredged materials. Common natural aggregates are minerals, such as sand, gravel and crushed rock. Recycled aggregates derive from reprocessed materials previously used in construction, such as concrete or asphalt. Manufactured aggregates are sourced from industrial processed, such as blast or electric furnace slags. (UEPG 2019)

Mining is the extraction of minerals from the ground. It can be done with several different ways, such as underground or surface mining. After extraction, minerals can be processed. This can be done using machinery, such as crusher and screens. The suitable way of processing can vary depending of the mineral. (Yan, Gupta 2014, p. 63)

Crushing machinery is typically used in mines, quarries and other places where is need and easy access to crush material. Crushing reduces the particle size and eases the after treatment of the crushed material. Material is easier to transport to other locations when the particle size is smaller. Metso has a long history with the mineral processing

and as a result Metso has manufactured machines, such as Lokotrack LT1213 (LT1213) and Lokotrack LT106 (LT106) (Metso 2019a). Lokotrack LT1213 and Lokotrack LT106 are designed to crush rock, recycled materials and other materials. From now on, Lokotrack will be referred as LT.

According to Saleh and Cummings (2011, p. 765) a lot of accidents occur in mining industry when compared to other industries. Similar results are found also for aggregates production in quarrying sector (EU-OSHA 2010). However, safety levels have increased in mining and aggregates industry recently. In Sweden, mining industry has a similar safety record when compared with manufacturing or construction industries, but the accident rates are still elevated when compared to the averages (Lööw, Nygren 2019, p. 437). It is clearly proved that improving safe design is one way to reduce accidents, and that there is need to improve machine safety in mining and aggregates industry.

EN 1009 is created to cover this need. It is aimed for machines, such as crushers, screens and conveyors, used to process mechanically minerals and similar solid materials.

1.2 Research question and research methods

This thesis analyses the level of safety in crushing plants manufactured by Metso, and the new EN 1009 safety standard series. This thesis also offers suitable solutions to improve safety in mineral crushing plants.

This thesis focuses to answer the following research questions:

1. How products of Metso are fulfilling the requirements of upcoming new safety standard EN 1009?
2. What kind of possible solutions are available to fulfill the standard?
3. How useful EN 1009 is for the industry and for the machine safety?

Answer to the first question is acquired by analysing the EN 1009 standard and comparing the requirements with two case machines, LT1213 and LT106. The same analysing method can be used in other machines manufactured by Metso.

This thesis presents partial solutions to modules that do not fulfil requirements. All possible solutions are not presented, and solutions to all findings are not presented. The main objective is to find if there are machines or components already on the market that can be used to fulfil the requirements of EN 1009. The results show how practical they are for the case machines.

This thesis is carried out as a literature study to review how mineral processing plants are designed currently, and what kind of laws are affecting to the design process. Literature study is presented in Chapter 2 and their results presented in Chapter 4.

Combination of action research and case study are used to evaluate the mobile machines manufactured by Metso and suitability of EN 1009 for the mining and aggregates industry. Action research is a blend of action and inquiry that allows researchers to reflect upon the outcomes of their own beliefs, questions, assumptions, and work activities (Rowell, Polush et al. 2015). Action research is iterative, reflective, and cyclic process. Two different machines are selected for the closer examination where they are compared to EN 1009 standard series. Results presents the major requirements of EN 1009 for case machines and are they fulfilled or not.

Action research is used to evaluate the suitability of EN 1009 for the mining and aggregates industry. EN 1009 requires changes to the case machines and possibly to other products of Metso as well so opinions of implementing the changes to Metso products are listened from Metso experts. These experts provide valuable information about the requirements of EN 1009 from the manufacturer point of view. Generally, it is important for manufacturers to consider harmonized safety standards useful in order for them to implement the requirements and thus harmonize the product safety level within the industry.

This thesis composes from two parts; theory and studying of case machines. Theory part is done with literature review to collect background information about the topic. Second part is comparing the case machines with the EN 1009.

Chapter 2 presents the theoretical background of this thesis. It introduces shortly, mineral processing and hazards related to it. Study method and EN 1009 standard series are presented in Chapter 3.

Chapter 4 presents the findings from case machines. Solutions are provided to those findings that require the most developing work. Chapter 5 discusses about the results, but it also analyses the EN 1009 from the manufacturer point of view. Chapter 5 also compares the EN 1009 to the other safety standards used in mineral processing machinery to find out how well it supports other standards or removes the need of using multiple safety standards with mineral processing machines.

Manufacturers do not have to follow different standards, but they have to prove that the machines fulfil the requirements of legislations and directives in corresponding market segment. Standards can be used to prove that these requirements are covered.

EN 1009 standard must be easy to understand and take into account the specifications of the mining and aggregates industry and the machinery in order that manufacturers will start design machines according to EN 1009. In addition, manufacturers should be able to effect to the requirements of the standard.

2. THEORETICAL BACKGROUND

Safety is a term that is used in many different occasions. People use the term safety in their everyday life, and often, without thinking what safety actually mean. Personal safety, property safety and environmental safety are just examples of safety topics and its purposes of use.

Safe tools and machines have a major effect to everyday working conditions. Machines, that are considered safe, are equipped with multiple different safety devices. These devices can be, such as mechanical supports, guards or electrical interlocks, but any device, that aims to improve machine safety, can be considered, as a safety device.

2.1 Health, safety and environment

The safety culture is often used to describe community where there are social processes in companies help certain behaviors or outcomes regarding occupational health and safety (OHS) (Antonsen 2009). In other words, safety culture describes how well workers are committed to work safety. Attitudes can vary in different companies. In others, safety is not seen as important and workers might make their work in a not safe way without anyone reporting it. Accordingly, some companies are very strict where their employees are working in a safe and strict way. If someone is not working properly, others will stop the work and guide to work in a safer way. Nordlöf, Wiitavaara et. al. (2017) showed that safety culture is better in big companies than it is in small companies. Smaller companies struggle to increase OHS, and therefore they should have more help and support, such as OSH consulting services or benchmarking best practices with other companies (Nordlöf, Wiitavaara et al. 2017, p. 101).

The main objective of any company in any industry is creating profit to shareholders. This means, that management effort is primarily aimed at maximizing net benefit related to the primary products. From this perspective, the health, safety and environment (HSE) management is not aimed to create profit to final product, but it is more like a constraint. In other words, profit is maximized under the constraints of an acceptable level of HSE impact. (Duijm, Fiévez et al. 2008, p. 909)

Although, the purpose of HSE management is not to create profit to the final product, this does not mean that increasing HSE is not profitable to the companies. Battaglia et al. (2015) stated that investments in HSE generate positive economic return. Several

studies also show that investments in OHS lead to improved production and financial performance (Huang, Leamon et al. 2007, Huang, Leamon et al. 2011).

The authorities responsible of HSE have a different point of view from companies and industry. Authorities main goal is to maximize HSE and competitive companies are a constraint. Therefore, authorities impose two types of requirements on industry. The first type of requirement is normative, such as fixed standards, norms, and criteria that companies must fulfil on certain industry. Normative requirements set the minimum level of health, safety and environment, but they do not contribute to improve these conditions. The second type of requirement is performance-based, such as the obligation of continuous improvement and best practices. (Duijm, Fiévez et al. 2008, p. 910)

A good way to implement the requirements of the authorities is to use minimum normative requirements with the tools of continuous improvement of HSE and integrate these constraints with management and economic point of view. As a result, companies might be able to manufacture products which exceed the minimum safety requirements.

In addition to previous, sustainability has become a challenge for society and business from economic, social environmental and political perspectives (OSHA 2016). Companies strives for sustainability by providing workplaces, which conditions are supporting the employee health and safety (Lee 2018). Therefore HSE has become a competitive factor for sustainable companies (Duijm, Fiévez et al. 2008, Nordlöf, Wiitavaara et al. 2017). The political, social, and economic activities focus on improving HSE. HSE certificates and awards of safety performance are conventions for being in competitive market. (Toutounchian, Abbaspour et al. 2018, p. 35) Companies have to deal with HSE management to protect their employee health and safety (Lee 2018).

Level of safety affects in the productivity and performance (Barling, Loughlin et al. 2002, Neal, Griffin et al. 2000). Several of modern companies are operating globally. Supply chains and new locations may be positioned in totally new regions which has also affect to the HSE and risk assessment of the companies. (Lee 2018) New laws and requirements must be considered and integrate them to the current HSE system when companies are expanding to the new countries and market areas.

Generally, several companies have started to invest more in sustainable development which, in this case, also includes the worker safety. Larger supply chains make it harder for HSE management adding regional laws and regulations.

This chapter introduced the safety in companies, and terms related to it. Investing in safety does not need to mean, that it is not profitable. Employees work more efficiently when they feel being safe. Companies also save money when workers are healthy and

are not out of work because of accidents. This thesis focuses on personnel safety and increasing machine safety in the manufacturer point of view.

2.2 Mineral processing

Minerals exist in physical and chemical combinations with each other in nature. To separate a certain mineral from the host rock requires both physical and chemical methods. Of course, some minerals, such as gold, can be found amongst sand in beaches or in riverbeds, but most of the valuable minerals are in host rocks. To access the minerals, host rocks must be crushed and sometimes ground. (Yan, Gupta 2014, p. 63)

Crushers are often used in aggregates production in quarries and constructions sites, as well as for recycling applications and mining operations. Commonly, crushers produce aggregates, limestone, and recycled materials, such as asphalt, concrete, bricks, road-based sand, and manufactured sand.

Size reduction is typically designed to perform during one phase or multiple stages. Typically, companies use three stages or less to achieve suitable size. Crushing process can be open or closed circuit. In open circuit, material flows directly from start to end. In closed circuit, material can be screened after crushing and oversized material is lead back to the crusher. Crushers are normally fed with rock material, up to one meter in size. Larger rocks are typically broken by hammers before fed to the crusher. (Yan, Gupta 2014, p. 63)

Generally, mineral processing is a process of ores or other materials to yield concentrated products. However, enrichment is not necessary with all materials. Aggregates does not need any further processing and, for example, can be used as an ingredient in composite materials, such as concrete and asphalt.

Mineral processing typically starts by blasting rock or other minerals and is followed by a series of crushing stages (Guimaraes, Valdes et al. 2007, p. 237-238). Typically, there are between from one to three crushing stages depending on the required final product. Guimaraes et. al. (2007, p. 245) claim, that a very notable percentage of consumed energy is spent in producing non-commercial products. However, this does not apply to all minerals, such as aggregates, but for valuable minerals, such as gold.

The process of crushing and grinding ores is known as the comminution. There are three reasons for size reduction. Valuable minerals are separated from the less valuable materials. Comminution increase the surface area of the minerals which means that reactivity of the minerals also increases. Crushed material is also a lot easier to transport from one place to another. (Fuerstenau, Han 2003, p. 4)

The crushing process includes a type of size reduction, which is widely used in mineral processing and rock quarrying. Jaw, cone, gyratory, and impact crushers are used to perform the crushing process. Especially, jaw crushers are used as a primary crusher in the aggregate production. (Köken, Özarslan 2018, p. 1227)

Mechanisms used in crushing and grinding are quite different. Crushing mechanisms are based on compression and impact forces, while grinding mechanisms are based on attrition. (Köken, Özarslan 2018, p. 1227) Jaw crusher is good example, how compression forces are utilized in crushing process. Accordingly, impact crusher is good example of impact forces, and how to utilize them in crushing process.

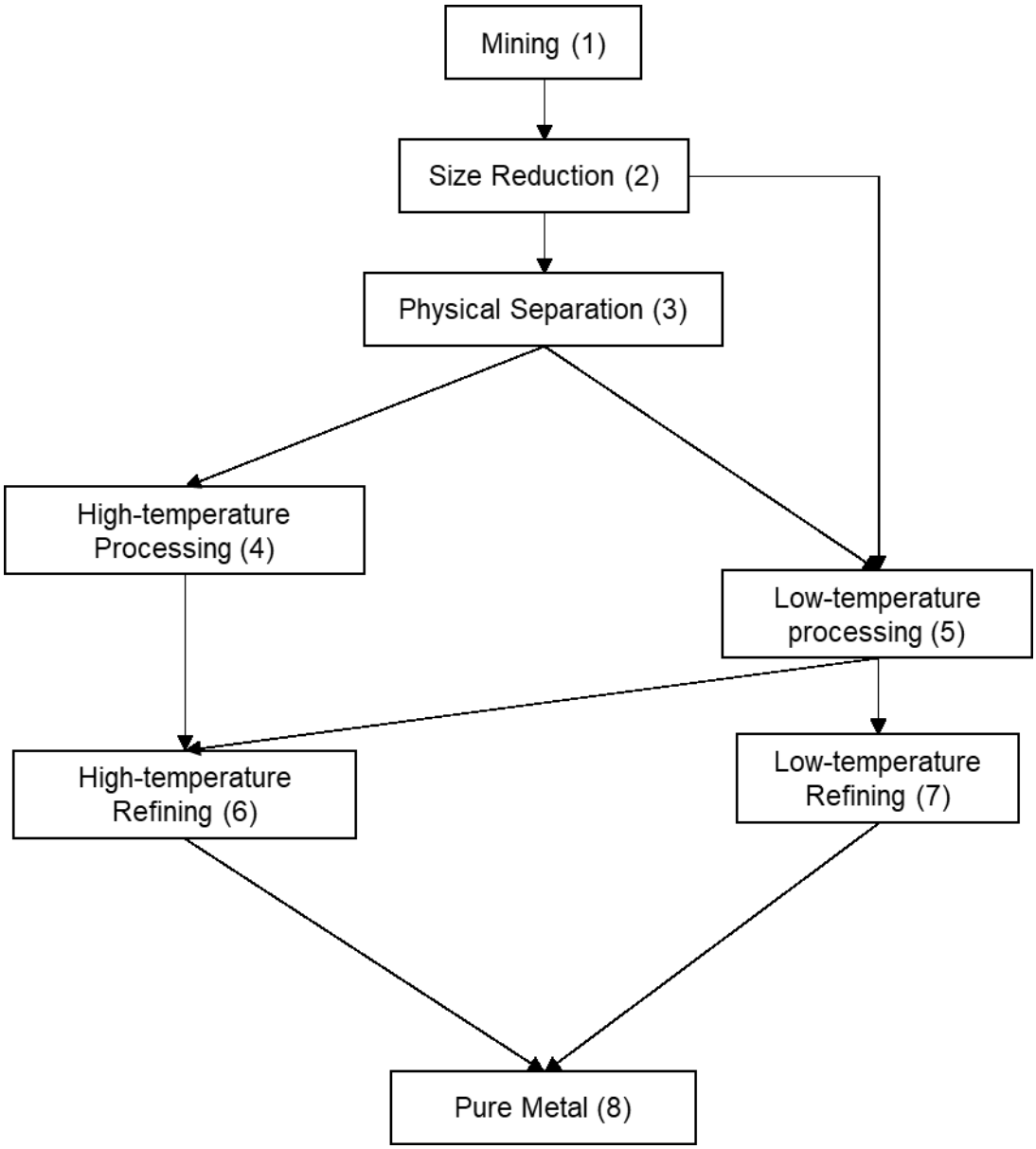


Figure 1. *Flowchart of extraction of metals adapted from (Fuerstenau, Han 2003, p. 2).*

One way to describe extraction of metals consists of eight steps, which are presented in Figure 1. This route can be used describe the whole path of mineral processing where crushing and screening are parts of the process. This thesis focuses on steps two (size reduction) and three (physical separation).

As mentioned, size reduction and physical separation can be done within a one machine. Those machines can be equipped with return conveyor so they can be used in open and closed-circuit systems. Multiple crushing and screening stages can be achieved simply by putting machines consecutively. When machines are assembled on tracks, they can be easily moved within the working area. However, when transporting machinery from

one site to another, truck and trailer are usually required. Machinery with tracks are known as mobile plants.

2.3 Mobile Plants

Previous chapter described the stages and purpose of the mineral processing. This chapter introduces the machines used to crush and separate the material, but also different terms related to mobile machines.

Mobile crushing plants are used to crush and sort different kind of rock and recycled materials, such as granite, gravel, limestone and concrete. Mobile plants produce different sized and shaped aggregate and sand, that can be transported to after processing or used directly in different applications.

For aggregate production, Metso offers fixed and mobile crushers and screens. This thesis focuses on mobile crushing plants, LTs, manufactured by Metso. More specific, this thesis focuses on the two type of crushers. LT106 is equipped with a mobile jaw crusher and LT1213 is equipped with a horizontal shaft impactor (HSI). LT106 is commonly used as a primary crusher and LT1213 is commonly used as a primary or secondary crusher.

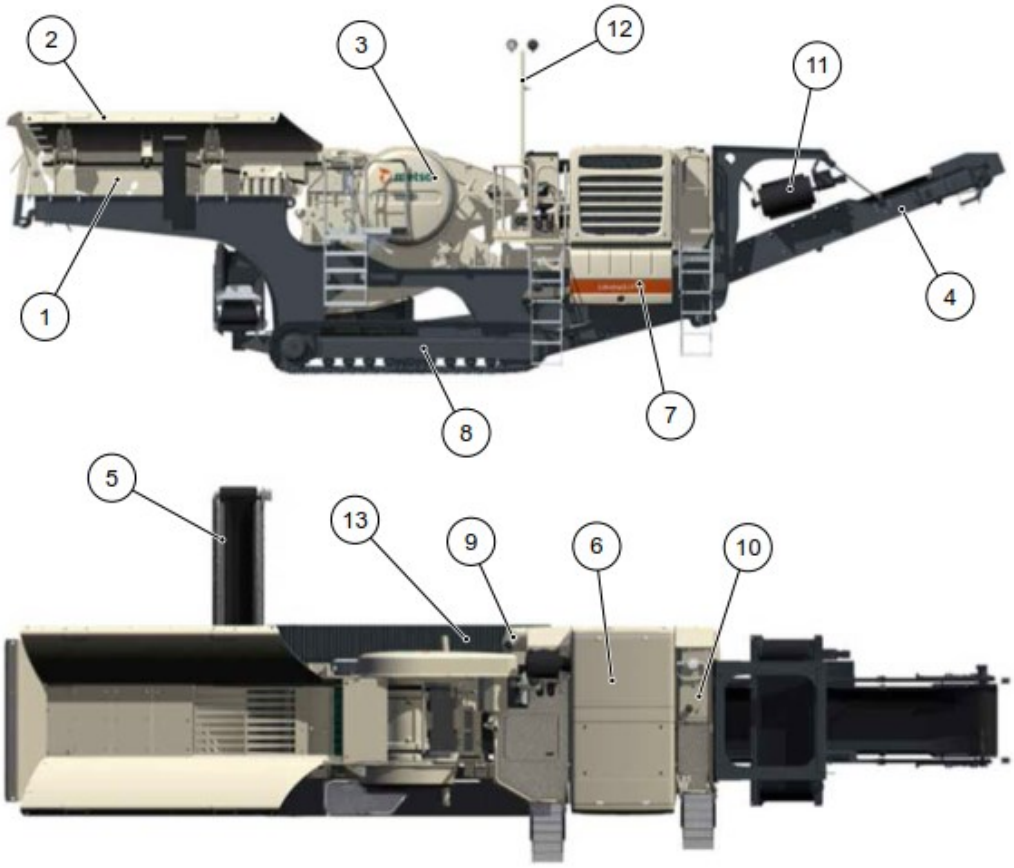


Figure 2. *Components of LT106 (Metso 2019b, p. 54).*

Figure 2 presents LT106 and its main components. To ease to understand the machine structure, main components of the machine are marked in the Figure 2 and they are explained in Table 1.

Table 1. *Components of LT106, adapted from (Metso 2019b, p. 54-55).*

Part number	Description
1	Vibrating feeder
2	Feed hopper
3	Crusher
4	Main conveyor
5	Side conveyor
6	Engine module
7	Main control center
8	Tracks
9	Fuel tank
10	Hydraulic oil tank
11	Magnetic separator
12	Light pole
13	Diesel exhaust fluid Tank

LT consists of several parts, which are presented in Figures 2 and 3 and Tables 1 and 2. Important modules for the crushing process are feeder, crusher, screen and conveyors. The material is fed on the feeder with a conveyor or bucket loader. Material is passed through the feeder and is fed to the crusher. Feeder can be equipped with vibrating chutes and screen. Vibrating chutes help to transport the material in the crusher. Screen is used to sieve the smaller particles from the material that does not need to be processed further. This increases the crushing capacity of the plant and improves the quality of the final product.

LT106 is designed to be a primary crusher in a stand-alone or multi-stage process (Metso 2019c). It is equipped with Nordberg C106 jaw crusher (3). Operating and available equipment are similar, as they are with LT1213. However, LT106 can be equipped with noise and dust encapsulation, which allows LT106 to operate in urban locations. This is not available for LT1213 currently. Jaw crushers are good option for hard rock and recycled materials.

Typically, jaw crushers are suitable for hard materials, such as granite, and impact crushers are suitable for softer materials, such as concrete. Wear parts of impact crusher wear out too fast when hard materials are crushed. Quick wearing is not a problem with jaw crushers. However, capacity of impact crusher is better than it is with jaw crusher when soft materials, such as concrete, are crushed (Guimaraes, Valdes et al. 2007, p. 239).

This thesis focuses on jaw (used with LT106) and HSIs (used with LT1213) crushers, but there are also other crushing solutions available. Jaw crusher consists of two jaw plates. The other jaw plate is fixed in a position, and the other one reciprocates. Typically,

after the crushing process, the crushed material is moved out of the crusher with the main conveyor, which is also the case with LT106. Main conveyor transports the crushed material out of the machine to the next phase of the process or removes the ready-made material out of the process. Main conveyor can work alone or with multiple accessories, such as a magnetic separator. After the crushing process there can be magnetic separator above the main conveyor to remove magnetic material out of the process. Main conveyor can also be equipped with screen that can sieve the material to achieve better final product. Screened material can be removed from the process or returned to the crusher for further processing.

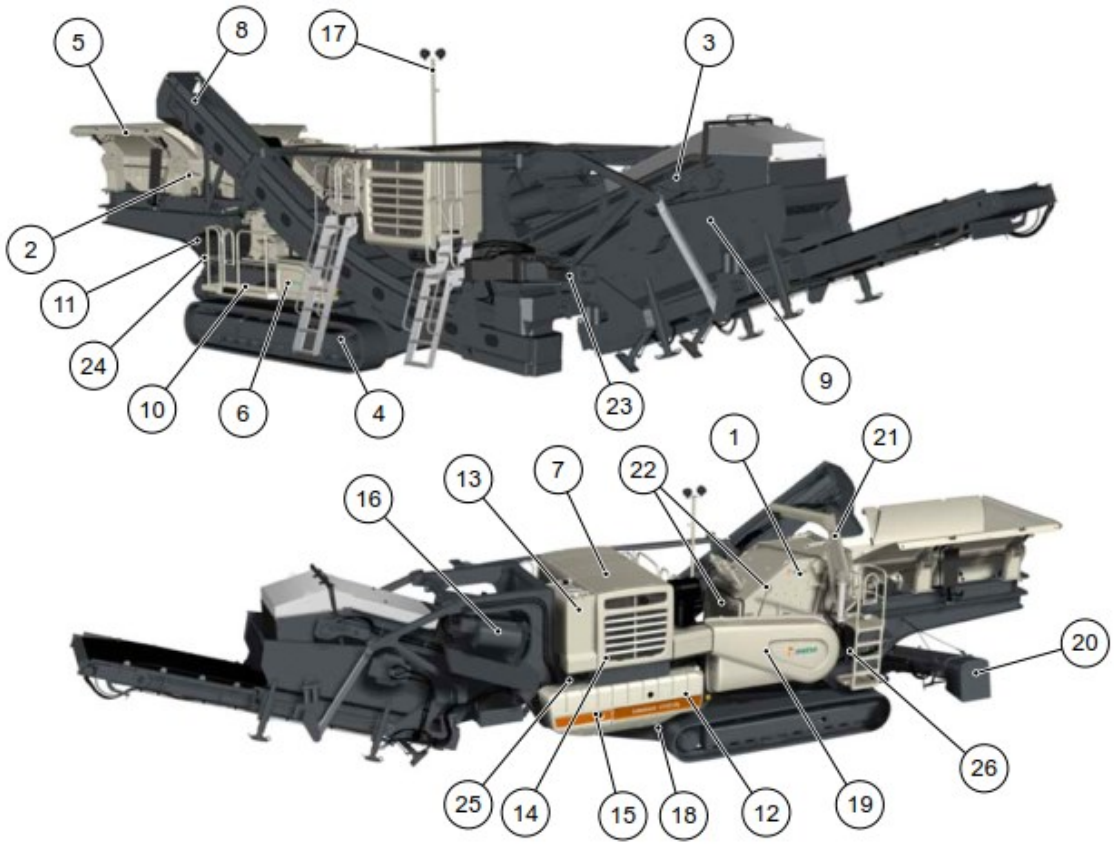


Figure 3. *Components of LT1213S (Metso 2019g, p. 58).*

Figure 3 presents LT1213S and its main components. Similar method is used with the LT1213S and LT106, so Table 2 presents the main parts of the LT1213S.

Table 2. *Components of LT1213S, adapted from (Metso 2019g, p. 58-59).*

Part number	Description
1	Crusher
2	Feeder
3	Main conveyor
4	Tracks
5	Feed hopper
6	Main control center
7	Power unit
8	Return conveyor
9	Screen unit
10	Toolbox
11	Assistance hydraulic unit
12	Fuel tank
13	Hydraulic oil tank
14	Hydraulic oil shut-off valves
15	Hydraulic control valves
16	Magnetic separator
17	Light pole
18	Refueling pump
19	Crusher V-belt cover
20	Side conveyor
21	Crusher service hoist
22	Service hoist tools
23	Return conveyor control levers
24	Interlocking connection
25	Interlocking connection
26	Diesel exhaust fluid tank

LT1213S, presented in Figure 3, can be used as a primary or secondary unit in the process and it is equipped with the impact crusher (1). LT1213S can be fine tune for aggregate, quarry or recycling applications. In similar fashion with LT106, with the LT1213S, the material is fed onto the feeder (2) by an excavator or wheel loader. The two-stage scalper removes the fines, which can be the guided to main conveyor (3) or a radial side conveyor (20). HSI crushes the feed material to the required size using kinetic energy. Horizontally positioned shaft rotates and when material is added to the crusher, shaft throws the rocks against the breaker plates and other rocks. Magnetic separator is used to separate metals from the feed material to prevent blockages in the later stages of the process (Metso 2019f). LT1213S is basically the same machine as LT1213, but it is equipped with a dual-slope screen. It separates end products and returns any oversized material back to the crusher for further processing (Metso 2019e).

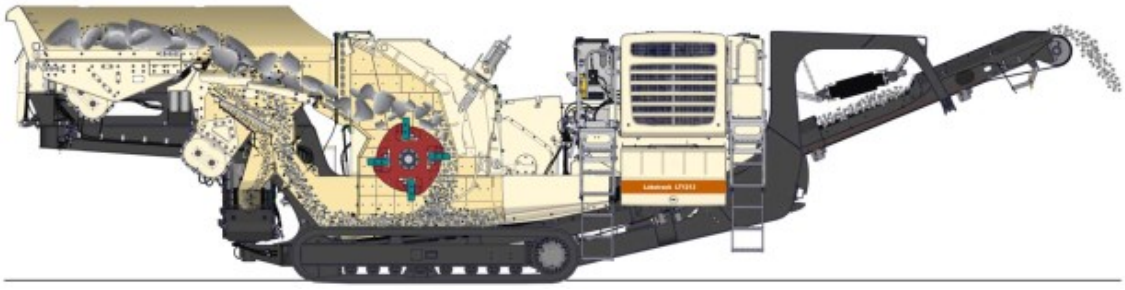


Figure 4. *Operating principle of LT1213 (Metso 2019d, p. 54).*

Figure 4 presents the material flow through the crusher. Material is fed to a vibrating feeder which conveys the material to the crusher. Small particles, that do not need crushing, can be guided bypass the crusher. Small particles can be removed from the process with side conveyor or bypass the conveyor directly to a main conveyor. These options can also be used simultaneously so that the smallest particles are removed from the process and the rest of the material are guided to main conveyor. Uncrushable magnetic material is removed from the main conveyor with magnetic separator located above the main conveyor. If machine is equipped with a screen, such as LT1213S material is screened after the separation of magnetic material. Larger particles, that must be crushed again, are guided back to the feeder with the return conveyor. Return conveyor can be turned on the side and it can also be used to remove the material from the machine for further processing. Finally, material is guided out of the machine for further processing, such as another crusher, screen or for transportation out of the work site. LT106 operates similarly compared to the LT1213 excluding the crusher where the crushing method is different.

2.4 Hazards and ways to reduce them

Accidents in process industry occur due to various reasons, such as operation issues, human errors, inadequate process design or chemicals (Taylor 2007). One way to increase the process safety is to develop current safety management systems (Athar, Mohd Shariff et al. 2019, p. 524).

According to Kletz (1993), recurrence of accidents are caused by lack of information of previous accidents, and unproper use of the information. This information can be used better by improving the process design. Khan and Abbasi (1998, p. 262) defines a hazard as a degree of harm to human beings, property, society or environment.

Workers who operate and maintain industrial machines are under several high risks. According to NIOSH (2004), high risk means a combination of grave severity and significant probability of occurrence of potential injuries. Machine related injuries were the

second highest cause of occupational fatalities in the United States (US) between 1980 and 1995 (NIOSH 2004). For this thesis, high risk means risk that have grave severity, such as death or permanent injury to personnel. Risk assessment procedure is presented in Figure 5.

In aggregates industry, these methods are sometimes very hard to execute, especially blockage of restricted areas. The same applies to the processing of demolition waste material. Mobile plants are movable machines, and for that reason danger areas are changing. Safety labels can be used to inform personnel about the hazardous location, which are commonly used with Metso equipment. These labels are only suitable for situations when working on top or close to the machine. Usually, when the machine is running, working close to the machine is prohibited by the manufacturer. However, it is known that this prohibition is sometimes not followed and thus safety labels are required.

2.4.1 Hazards related to Mobile Plants

Mechanical hazards are always present in crushing and screening plants and they might lead to a death or serious injury (Metso 2018a, p. 17-19). For example, falling or ejecting rock material is common near the processing units. All lifted and foldable structures that need mechanical support or locking devices create danger areas close to them. In addition to the severe injuries, mechanical hazards are also causing minor accidents, such as crushing of finger between moving parts.

Falling hazards occur when workers have to work in high places (Metso 2018a, p. 8). Improper guardrails or not wearing safety harnesses can cause falling. Especially, sudden movements of the machine increase the risk of falling when falling hazards are not considered properly.

Electrical hazards are always present when there are electric devices (Metso 2018a, p. 8). Typically. in LT these accidents occur when there is damage in the electrical device and maintenance is required. If system is not shut down and locked properly, for example hidden energy of UPS can cause shocks to maintenance personnel. In addition to electrical devises, mobile crushers are equipped with hydraulic equipment, which have their own risks. These risks include for example, injection of hydraulic oil, whiplashing and burns.

Hazards related to hydraulics can be categorized also in the other hazards, such as mechanical or thermal hazards (Metso 2018a, p. 12). Unforeseen pressure peaks can cause damages to hydraulic hoses and connectors. High pressurized fluid might cause serious injuries to workers near the leak point. Hazards like this can be prevented by

using protective equipment, such as hose protectors and guards as well as personal safety equipment. Hydraulic oil can also be hazardous to environment, but these hazards are not dealt in this thesis.

Thermal hazards are caused by hot surfaces or material (Metso 2018a, p. 12-13). These kind of hot surfaces or material are typically close to power source and near exhaust. Other possible hot surfaces might occur in the hydraulic systems during faulty situations.

Noise hazards are always present when processing material (Metso 2018a, p. 15). In the typical crushing area, the noise is normally over 85 dB and therefore hearing protection is required during material processing. These injuries are easy to avoid by using ear protection even in the situation where machine design is not so good. Mobile crushers can also be equipped with noise protections around the loudest modules, such as the crusher. However, this does not remove the requirement of using hearing protection (Metso 2019h).

Mineral processing always generates dust emissions (Metso 2018a, p. 8). Exposure hazards are handled by decreasing the dust emissions with encapsulation and water spraying systems in mineral processing plants. Other possible solutions are personal safety equipment and decreasing the time spend in areas where dust is present.

Crushing is suggested, as one of the major sources of dust in quarries (Bada, Olatunde et al. 2013, Petavratzi, Kingman et al. 2005). Sairanen and Rinne (2019) find out that crushing produces mainly coarse dust particles, which settle near the dust source in a research where they investigated dust emissions from crushing hard rock aggregate.

Ergonomic hazards are caused by working positions that are not natural or are causing too much load for the worker. Typically, in LTs these ergonomic hazards might occur during maintenance work. Ergonomic hazards are normally reduced by improving working areas, such as platforms and access systems, but also providing specified tools and instructions for demanding maintenance tasks.

2.4.2 Improving safety in Mobile Plants

One way to improve safety is to isolate hazard zones with safeguards. Fixed enclosing guards are fixed to machine and they are hard to remove. They are reliable, low cost and maintenance free (Caputo, Pelagagge et al. 2013). However, they also restrict personnel to access possible maintenance position within the guard.

Movable enclosing guards with interlocks provide high protection and allow access to hazardous workspace if needed. Interlocking may allow easy integration to control system. Interlocks need adjusting and maintenance. Adjustable guards allow different size work pieces and make working of operator easier. Adjustable guards do not provide complete protection and it is easy to make them ineffective. (Caputo, Pelagagge et al. 2013)

Backström and Döös (1997) stated that despite of development of automation in production, injuries from machine movements remain a problem. A study revealed that 12—17 % of all occupational injuries were caused by automatically controlled machine (Backström, Döös 1995). In other words, safety of automated machines can be increased by reducing the possibility of unwanted machine movements.

2.5 Risk assessment

One of the best methods to improve machine safety is to take risk assessments into account starting from designing process. There are several standards, such as ANSI B11.0-2015 and ISO 12100 2010, which are giving instructions for safe design of machinery (ANSI B11.0-2015 2015, EN ISO 12100 2010). In addition to these general safety standards, safety standards for specific machines are also available.

2.5.1 Risk and hazard

Chapter 2.4 introduced the hazards that are present in mobile plants. Hazards do not cause accidents, but it requires the hazard and unwanted action. Risk is used to describe how likely it is that hazard is present and unwanted action is done. For example, a hot surface does not cause burns if nobody touches it. Similarly, if somebody touches the surface, it does not cause burns when it is not hot. Here the surface is a hazard because it might be hot. Action, that somebody touches the surface, is a risk. This chapter tells what risk is and how to evaluate it.

Risks can be defined and described in several ways. According to Wilhelmsen (Wilhelmsen, Ostrom et al. 2012), risk is a probability of an unwanted event that results in negative consequences. Khan and Abbasi (1998, p. 262) defines the risk as a combination of hazard and probability of hazard occurrence. Some researches define the risk as a probability of hazard occurrence (Mannan, Lees 2012). Risk can be defined using three questions, which are:

1. What can go wrong?
2. How likely it is?
3. What are the consequences? (Kaplan, Garrick 1981, p. 13)

Concurrently with industrial development, the risk problem and the diversification of risk types have increased at the same time when the risk acceptability has decreased (Tixier, Dusserre et al. 2002, p. 291). In other words, new technologies have created new risk types while improving worker safety is crucial.

Risk assessment is normally used to reduce or remove the risk of a worker being involved in an accident. To reduce the amount of accidents, new techniques of risk assessment are being developed. (Athar, Mohd Shariff et al. 2019, p. 524) Risk assessment are typically a combination of quantitative and qualitative manners (Khan, Abbasi 1998, p. 262).

Risk assessment can be done in several ways depending on the industry as well as the case at hand. EN ISO 12100 specifies basic terminology, principles and a methodology for achieving safety in the design of machinery (EN ISO 12100 2010).

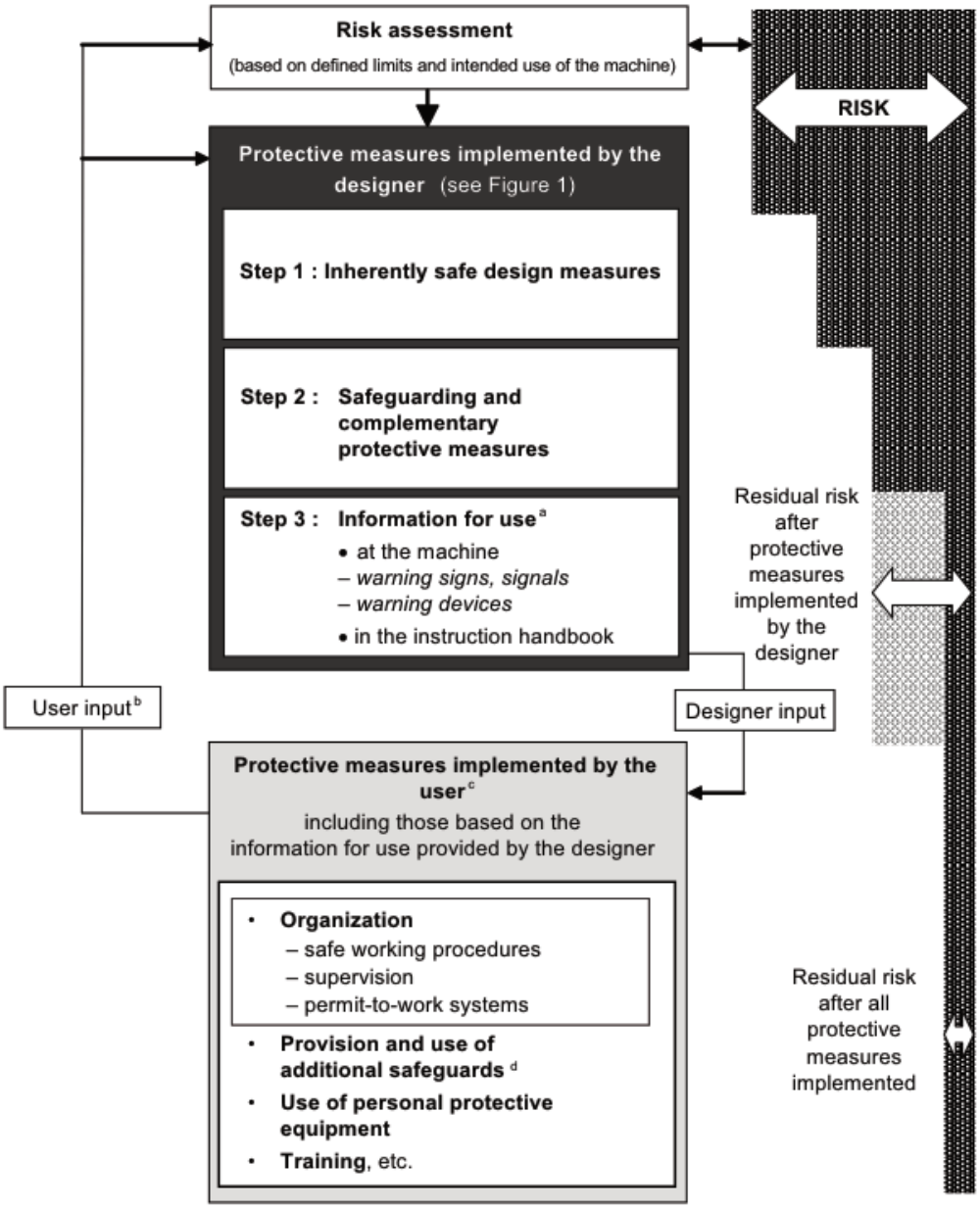
Risk assessment is a continuous process where each risk is evaluated by using a systematic step by step approach. The aim is to recognize and control each risk there are with the studied machine. (Wilhelmsen, Ostrom et al. 2012)

Several studies indicate that risk assessment can be done in many ways (Tixier, Dusserre et al. 2002). Some risk assessment methods are working well on one field of industry and not so well on other fields. Generally, risk assessment method is selected according to legislations and standards.

Hazard and operability (HAZOP) study is used to identify hazard scenarios process that may include risks to personnel or equipment (Baybutt 2015, p. 52). HAZOP focuses on investigate potential problems for the process. Although, HAZOP is most commonly used process hazard analysis (PHA), HAZOP includes many weaknesses (Baybutt 2015). Generally, HAZOP is a good tool for process industry, but it is not too practical tool for designing mechanical structures.

2.5.2 Risk assessment procedure

In Europe, Machinery Directive 2006/42/EC (MD) requires that the manufacturer of the machine has to ensure that risk assessment is carried out and documented for the machinery, which manufacturer is going to place on the EU market (2006/42/EC). Typically, risk assessment is carried out according to EN ISO 12100 standard. In similar fashion for the US, Occupational Safety and Health Administration (OSHA) requires a risk assessment from manufacturer.



[a] Providing proper information for use is part of the designer's contribution to risk reduction, but the protective measures concerned are only effective when implemented by the user.

[b] The user input is that information received by the designer from either the user community, regarding the intended use of the machine in general, or from a specific user.

[c] There is no hierarchy between the various protective measures implemented by the user. These protective measures are outside the scope of this International Standard.

[d] These are protective measures required due to a specific process or processes not envisaged in the intended use of the machine or to specific conditions for installation that cannot be controlled by the designer.

Figure 5. *Risk Assessment procedure (EN ISO 12100 2010, p. 11).*

Risk assessment comprises risk analysis and risk evaluation (EN ISO 12100 2010, p. 12). Risk analysis consists the determination of the limits of the machinery, hazard identification, and risk estimation.

Risk assessment starts by determining the limits of the machinery, and taking into account all phases of the machinery life (EN ISO 12100 2010, p. 13). Next step is to systematically identify all reasonably and foreseeable hazards as well as hazardous situations and events of the machine. Risk estimation shall be carried out by determining the elements of risk, such as severity of harm and probability of occurrence of harm, as well as consider the aspects, such as persons exposed and human factors.

Risk evaluation is done to determine if the risk reduction is required. If risk reduction is required, suitable actions must be done to reduce the risk. Risk reduction can be done by eliminating the hazards, or reducing the elements, severity of harm and probability of occurrence, that determine the associated risk. These actions are described in protective measures implemented by the designer in Figure 5.

Figure 5 presents the risk reduction process from point of view of designer according to EN ISO 12100. Protective measures implemented by the designer and how to use them correctly are important for this thesis (Steps 1—3).

When risk has found out according to risk assessment, risk should be eliminated by the design of the machine (Step 1). If the redesign of the machine cannot eliminate the risk, guards shall be used to decrease the risk to an acceptable level (Step 2). If guards and proper design are not enough, users must be informed about the risk (Step 3). Step three can be covered with methods, such as adding information in the instruction handbook, training employees and using safety labels, signals and devices. Usually, Steps two and three are used together to inform the user what is under the guard and when the guard can be removed safely.

When designer has made all appropriate actions to reduce the risk, and the risk has managed to get to the acceptable level, user can affect to the risk by his own actions. Training, safe working methods, supervising, additional safeguards, and personal protective equipment are examples how the user can affect to the risk after the machine has been manufactured. In this case, additional safeguards are guards, that user adds to machine or near to it to reduce risk that are not envisaged in the intended use of the machine by the designer, as the Figure 5 explains.

Risk assessment should be a continuous process and it should not be stopped after the product is on the market. Users can provide a valuable information related to the product safety by giving direct feedback to the manufacturer. Also, different accidents statistics can provide information about possible risks and hazards to the manufacturer either before or after the product launch.

All in all, hazard identification is a critical part of risk assessment. If hazards are not recognized, risk cannot be managed. Risk assessment, including hazard identification, can be done in through multiple techniques. Risk assessment method described in EN ISO 12100 is used with the machinery.

3. USAGE OF EN 1009 IN MINERAL PROCESSING PLANTS

Chapter 3.1 introduces the EN 1009 standard series and chapter 3.2 introduce common safety standards and legislations, such as MD that are affecting to the mining industry and machines. The final chapter introduces study and research methods.

Mahat (2017) studied prEN 1009 2017 safety requirements for routine maintenance of screening equipment. Study was focusing on part four of the prEN 1009 2017 standard series and stated that studied machines complied with the standard at that time. This thesis is not focusing on one but on several parts of the standard, and the latest version of the EN 1009 is used. The latest version of the standard is currently FprEN 1009 2020 for parts 1—5 and prEN 1009-6 2020 for part six. Other studies related to the EN 1009 standard could not be found and therefore this study is necessary but also further studies are needed to evaluate the standard.

EN 1009 is currently under preparation and as a result a prefix, *pr* or *Fpr,* has been added to the EN code of the standard (prEN 1009 or FprEN 1009). *Pr* (preliminary working draft) means that standard is a working document. In turn, *Fpr* (Final draft) means that standard is currently submitted to the Formal Vote.

3.1 EN 1009 series

EN 1009 *Machines for mechanical processing of minerals and similar solid materials — Safety* is a type-C standard family, as specified by EN ISO 12100. The standard has been prepared by CEN Technical committee 151, Working Group 9. EN 1009 applies to mechanical processing mineral and by-products in construction and industry. It comprises of six parts. In part 1, there are common requirements for the mineral processing and in parts 2—6, there are specific requirements for processing machinery.

Requirements of EN 1009 can be divided into three sections. First section gives safety and protective measures. Second section gives instructions for verification of safety requirements and protective measures, and the final section gives requirements for information for use. In other words, the first and the second sections are affecting to machine design and the third one is affecting to information that is given to operator.

Parts 1, 3 and 6 are the most relevant ones for this thesis and thus they will be focused on. As there are some important requirements from other parts, they will be briefly studied as well.

3.1.1 Part 1: General requirements

In part one (*Common requirements for partly completed machinery and processing plants*), common requirements for mineral processing machines are described (FPREN 1009-1 2020). Part one gives strict rules for mineral processing machines, which can be hard to fulfill with mobile machinery. Therefore, part six gives some freedom to mobile machinery with these requirements.

In general, part one is requiring that all machines shall be designed according to standard EN ISO 12100 for relevant hazards (FPREN 1009-1 2020). Relevant hazards are those that are dealt in EN 1009 standard.

For access openings the part one does not give specific requirements. These requirements are dealt in the following parts of this standard, because they differ a lot between machine types. Nevertheless, for all openings it is required that the person cannot be trapped inside the machine in any situation.

FprEN 1009-1 2020 describes that plant is an assembly of machines and/or partly completed machinery and/or components for the mechanical processing of minerals, arranged and controlled so that they function, as an integral whole. It also says that mobile machine is crawler or wheel, self-propelled, trailed or towed machine movable from worksite to another or within the same worksite (FPREN 1009-1 2020, p. 12). By using these definitions, it is possible to say that mobile plant is an assembly of machines assembled on tracks or wheels, that is used for the mechanical processing of minerals. These machines are designed according to PREN 1009-6 2020.

3.1.2 Part 2: Feeders

In part two (*Specific requirements for feeding machinery and continuous handling equipment*), specific requirements for the feeding machinery and continuous handling equipment are provided (FPREN 1009-2 2020). Generally, part two gives requirements for situations where feeder or continuous handling equipment is blocked, and the blockage needs to be removed. There are also requirements for the maintenance to prevent the operator from falling from the feeder.

LT106 and LT1213 are equipped with vibrating feeders. Standard requires that crushing points shall be prevented by guards or safety distances shall be provided (FPREN 1009-

2 2020, p. 8). Safety labels shall be used to identify the residual hazards. If there is a risk for burying during maintenance, means to prevent this shall be provided, such as stopping the material feed. In other words, this means that material left in the feeder must be prevented from falling. Startup of the machine must be prevented before maintaining the machine and in some occasions empty the feeder before maintenance.

3.1.3 Part 3: Crushing and milling machinery

In part three (*Specific requirements for crushing and milling machinery*), specific requirements of the different type of crushers are presented (FPREN 1009-3 2020). In this thesis, the HSI and jaw crushers are the most relevant, because of the study cases LT1213 and LT106, and thus this thesis will be focusing on.

FprEN 1009-3 requires that it shall be possible to lock the rotor of the HSI in any position (FPREN 1009-3 2020, p. 11). Standard also requires that crusher chamber cannot be opened when rotor is not stopped and locked. This includes all openings where it is possible to reach the rotor.

Part three deals only functional requirements and some informational requirements for crushers. Therefore, part one and three must be used together when designing crusher. In addition, part six should be used, if the crusher is a part of a mobile machine.

3.1.4 Part 4: Sizing and sorting

Part four (*Specific requirement for screening machinery*) gives specific requirements for the screens (FPREN 1009-4 2020). Shortly, maintenance work for screens is quite different when compared with the other machines. For example, screens require access opening for changing of the screen meshes. Therefore, part four is mainly focusing on requirements for maintenance.

Screens are closed structures to prevent the material from falling or ejecting out. Closed structure also decreases dust emissions. FprEN 1009-4 2020 includes several measures to ease maintenance work, such as minimum dimensions for hand or body accesses.

3.1.5 Part 5: Cleaning and recycling

Part five (*Specific requirements for cleaning, recycling and mud treatment machinery*) creates requirements for cleaning, recycling and mud treatment machinery (FPREN 1009-5 2020). This part of the standard is not very relevant for this thesis. Machines, that are dealt in this part, are not part of this research, but it is still important to understand

the general requirements especially those affecting to inlets and outlets of LT1213 and LT106.

For LT106 and LT1213 standard sets requirements for magnetic separators. Generally, hazards caused by ejecting material shall be prevented and strong magnetic field warning are required.

3.1.6 Part 6: Mobile equipment

Part six (*Specific requirements for mobile and semi-mobile crushing and screening equipment*) is created to be suitable for mobile machines (PREN 1009-6 2020). Generally, this part eases the requirements that part one demands. Access system for compact mobile machines shall be in accordance with EN ISO 2867. In addition, self-closing gates are required in certain parts of the machine.

PrEN 1009-6 adds three more concepts for mobile machines (PREN 1009-6 2020, p. 8). Compact mobile machine is machinery, designed where main modules, for example a feed hopper, vibrating feeder, crusher and vibrating screen do not need to be removed prior to transportation between worksites. Typically, transport is enabled by folding components, such as hopper walls, conveyors and platforms to fit the machine within legal transportation limitations. Heavy mobile machine is machinery, where main modules, such as a feed hopper, vibrating feeder, crusher or vibrating screen is required to be removed prior to transportation between worksites. Extra-heavy mobile machines are designed to remain on one worksite during its intended life, and main components, such as feed hopper, vibrating feeder, crusher, or vibrating screen, need to be removed during transportation of the machine. Generally, extra-heavy mobile machines weights more than 150 tons but it is not required (PREN 1009-6 2020, p. 8). Altogether, compact mobile machines are transported as one piece and initialization is easy. Heavy mobile machines are transported in two or more pieces, but the assembly and disassembly of the machine is made easy. Extra-heavy mobile machines are transported in two or more pieces and assembling the machine needs knowledge and time and it is not designed to be transported from worksite to another. Typically, these machines stay in the same site for decades.

PrEN 1009-6 2020 allows reliefs for the means of access of the compact mobile machines. Means of access shall be designed according to EN ISO 2867 2011. For heavy and extra-heavy mobile means of access shall be designed according to EN ISO 14122 2016 series, as stated in EN 1009-1 2020, with a few exceptions. These are dealt in chapter 3.1.7.

3.1.7 Requirements for access systems and openings

General requirements for access systems are given in part one, which demands that EN ISO 14122 2016 standard shall be used (FPREN 1009-1 2020, p. 16). Part four gives special requirements for screens and part 6 for mobile machinery (FPREN 1009-4 2020, PREN 1009-6 2020). Part 6 orders that EN ISO 2867 shall be used when designing compact mobile machines (PREN 1009-6 2020, p. 12).

Self-closing gates are one of the requirements that need to be fulfilled. EN ISO 2867 is not dealing with the self-closing gates at all and it does not refer to them (EN ISO 2867 2011). However, EN ISO 14122 requires that self-closing gates need to fulfill the same requirements than adjacent guardrails (EN ISO 14122-3 2016, p. 18). Generally EN ISO 14122 sets requirements for permanent means of access to machinery, such as requirements platforms, stairs and ladders (EN ISO 14122-1 2016, EN ISO 14122-2 2016, EN ISO 14122-3 2016, EN ISO 14122-4 2016).

3.1.8 Requirements for crushers

Requirements for crushers are given in part three. Common for all crusher types are that ejection of material shall be prevented. Typically, FprEN 1009-3 2020 suggests that guards can be used. In crusher inlet, flexible material, such as chains or rubber curtains, are suitable solutions for HSI crushers and guards for jaw crushers.

Machine shall be secured before any maintenance work. Standard suggests that different locking systems or key transfer systems shall be used (FPREN 1009-1 2020). Safe means of access around the crusher is required for handling wear parts (FPREN 1009-3 2020, p. 8). For process monitoring means shall be provided to stop the material flow in the event of blockage (FPREN 1009-3 2020, p. 8).

3.2 Related Standards and Legislations

Machine design is done almost identical around the world. Nevertheless, laws and requirements can vary a lot in different countries. In Europe, European Union (EU) makes directives, such as MD, which is the implemented to the law of each EU country. In the US, Occupational Safety and Health Administration (OSHA) control the local requirements for the machine safety.

The International Organization for Standardization (ISO) is an international federation of national standards bodies (ISO 2019). International standards are normally prepared by ISO technical committees.

American National Standards Institute (ANSI) is a private and not-for-profit organization in the US (ANSI 2019). ANSI is one of the founding members of ISO.

European Committee for Standardization (CEN) is one of the three European Standardization Organizations (CEN 2020). CEN develops voluntary standards for European countries.

Metso manufactures the machines according to ISO, ANSI, CEN (EN) and Standards Australia (AS). Standards Australia is standards organization in Australia and a member of ISO (Standards Australia 2019). Standards of Standards Australia are relevant for mobile machines, but because this thesis focuses on EN 1009 standard, Australian or US standards are not focused in this thesis.

To fulfill international laws, standards has been made to guide manufacturers to fulfill general safety requirements. Standards can be global, or they can be aimed to certain market area. ISO standards are global standards and EN ISO standards are ISO standards that CEN has accepted to be EN standards.

MD is a directive of European Union made by European parliament and council. MD requires that all machines must be totally safe (EUR-Lex 2006). A standard is a technical document used by manufacturers, consumers and regulators of a certain material, product, process or service. Standard is designed to be used as a rule, guideline or definition (CEN 2019). In US, OSHA and local mining law sets the mandatory requirements and usage of ANSI standards proves that those requirements are fulfilled.

Generally, directives are those that must be followed and standards are voluntary. However, requirements of directives can be fulfilled by following standards. All risks are considered when machine is designed according to a specific standard and its referenced standards.

EN ISO 12100 2010 is a type A standard which means that it gives the basic concepts and principles for designing a safe machine (EN ISO 12100 2010). prEN 620 gives safety requirements for fixed belt conveyors (PREN 620 2018). In many clauses, part six of EN 1009 refers to EN 620. Safety requirements include mechanical requirements, but also ways for verification. Information for use, such as documents, training and marks that must be delivered with the machine, are listed in the standard.

ISO 21873-2 2019 sets certain safety requirements for mobile crushers. ISO 21873-2 2019 applies to self-propelled, lorry mounted, or semi-trailer mounted mobile crushers, but it does not apply to fixed crushers or large mining-type movable crushers. ISO 21873-2 2019 deals with the significant hazards, hazardous situations and events relevant to

mobile crushers. Standard is not very comprehensive for the aggregates or mining industry because it does not apply to all machine types.

3.3 Study and research methods

This research was started in September 2018 by getting acquainted with the draft of the upcoming EN 1009, to the Metso machinery and to other standards and legislations like MD. Generally, two mobile plants LT1213 and LT106 are analyzed with the EN 1009 standard. In first phase, this thesis is trying to identify the hazards by using EN 1009 standard series. In second phase, the found hazards are compared to the current risk assessments and MD.

Case machines were selected so that both primary crusher types were represented, and they are manufactured in Tampere premises. However, the task was to create inspection instructions which can be used to ensure that the machine is fulfilling the requirements of EN 1009. Instructions can be used to any machine where EN 1009 applies, not just the case machines.

The approach fulfilling the safety requirements of EN 1009 standard series was developed to help engineers to design machines that fulfills the requirements of EN 1009. Requirements of EN 1009 are based on MD which sets the general safety requirements for machines in EU market.

MD requires that manufacturers have to assess the hazards of a machine and take this risk assessment into account during the machine design. EN ISO 12100 describes the risk assessment process that manufacturers can use to fulfill the requirements of MD. EN 1009 can be used as a part of the risk assessment to identify the hazards but also reducing the risk to the acceptable level by fulfilling the standard requirements. Metso has made risk assessments for LT1213 and LT106 and is updating them continuously (Metso 2018b, Metso 2018c).

Main source for the research was EN 1009 standard which is introduced in Chapter 3.1. EN 1009 standard was under preparation during the research. This means that the EN 1009 standard was changing during the project and multiple drafts has been used to collect the requirements and updating them during the project. Some changes to the standard are also possible after the publication of thesis, so differences between the thesis and published standard might occur.

All requirements of EN 1009 series are collected to the checklist. Each part of the standard is an independent checklist which can be used for different machines. Because prEN

1009-6 2020 is used for mobile machines, requirements of prEN 1009-6 2020 are combined to the checklists of the other parts of the standards. In the final stage, requirements that does not affect to LT1213 or LT106 are eliminated from the checklists. As a result, only relevant requirements for LT1213 and LT106 remain on the checklists. Figure 6 describes the way of collecting the necessary requirements of EN 1009.

EN 1009 Requirements for access systems are similar for all machine types, and therefore requirements for access systems are collected to the separate checklist. This also suits better for Metso purposes because the access systems are designed separately from the machines. Checklist for access systems does not include requirements where the access systems shall be located but it contains the information how the access systems shall be designed. Specific requirements for an access system of certain machine component are included in the checklist of the component.

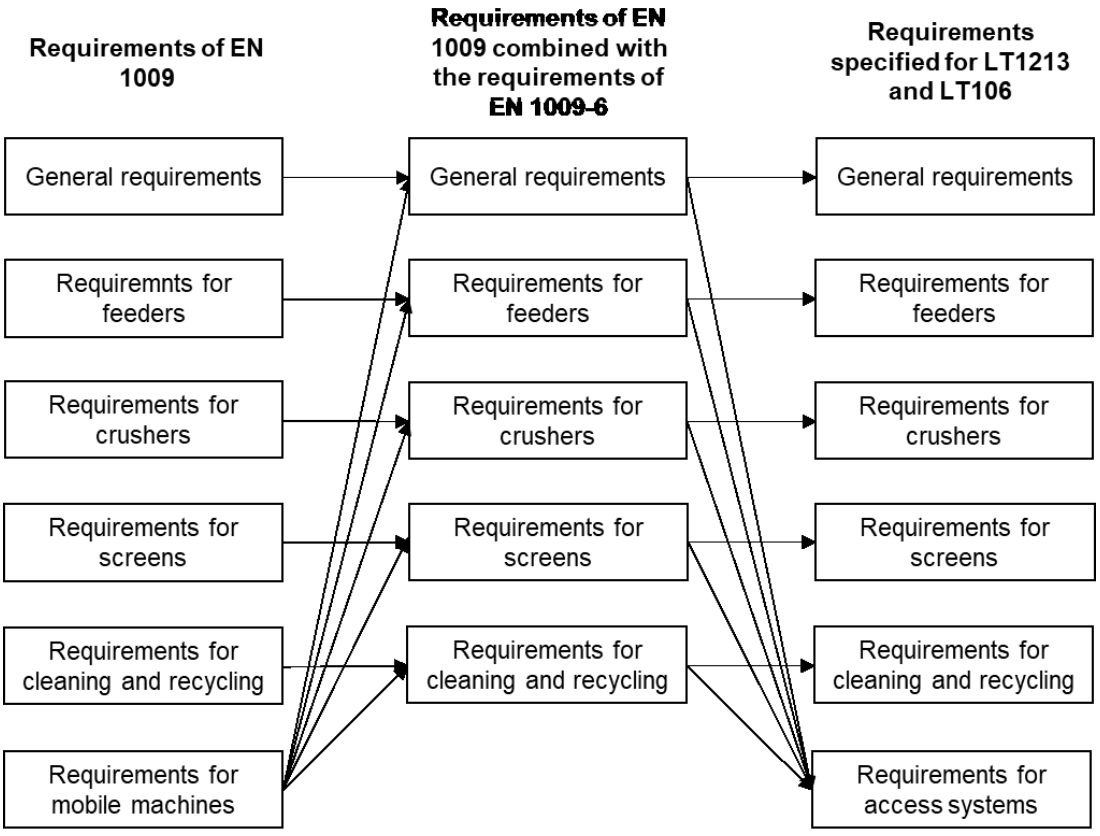


Figure 6. *Method for collecting the requirements of the standard.*

These specified checklists for LT1213 and LT106 are compared to the machines, their operation and maintenance. Relevant machine information for thesis is the machine dimensions and operation, but also the information of the typical work sites. Machine information was collected from different sources, but 3D models was the primary source for information.

All dimensions, safety devices, and components of the machines are collected from the 3D models. However, 3D models do not contain the information about the control system and its operation. Instruction manuals and other documents are used collect the information of the control systems, but also how the machine should be operated. Many of the safety requirements are demanding that movable parts have to be stopped and secured before any maintenance work can be done. After this the machine operation is well known, but there is still need to collect information about the misuse of the machine. Rest of the machine information are collected during the meetings by interviews with the experts and collecting the known hazards form the risk assessments.

Information for the operator are collected from the instruction manuals and general safety instructions which are delivered with the machine to the customer (Metso 2018a, Metso 2019b, Metso 2019d). EN 1009 requirements for information for use are also affecting to the instructions. Manufacturer has to ensure that it provides the relevant safety related information of the machine to the customers. This safety method is in use when machine safety cannot be increased by design. EN 1009 sets requirements for the machine documentation. Generally, requirements are related to the information that manufacturers shall provide to the operator, such as how to carry out maintenance tasks safely.

Meetings were held during the project when needed, but typically between one to three weeks. Main object for the meetings was to follow how the research proceeds, but also to collect information about the machine operation as mentioned earlier. Generally, information collected from the meetings are related to the use of the machine, such as foreseeable and possible misuse of the machines.

Suitability of EN 1009 for the mining and aggregates industry were studied as well. Current situation where Metso is creating a risk assessment according to the EN ISO 12100 2010 is compared to the new situation where EN 1009 can be added to be a part of the risk assessment.

4. RESULTS

This chapter presents the results of the study. Chapters 4.1—4.3 focuses on the case machines, which were presented in Chapter 2.3, and Chapter 4.4 presents the results for the access systems which are common for both machines.

Currently, Metso is fulfilling the requirements of EN 1009 standard series quite well. Safety distances are specified during the operation. Also, the maintenance has been considered by giving the instructions for different situations. However, there is always room for increasing safety, and fulfilling of standards does not mean that machines are completely free from risks.

4.1 Findings of Lokotrack LT1213 impact crusher

This chapter focuses on to the findings that were noticed when comparing case studies with the EN 1009 standard series. It was noticed that the crusher is the biggest challenge when comparing the standard requirements with the LT1213 and LT106 mobile crushers.

Requirements related to HSI crushers are dived into two categories; requirements related to the rotor and general requirements. Table 3 presents the requirements related to the rotor of the HSI crusher and comparison to current solution.

Table 3. *Requirements of the FprEN 1009-3 for the rotor of the impact crusher.*

#	Requirement	Current situation	Needed development
1	Opening of the crusher or reaching the rotor via intended means of access shall only be possible if the rotor is locked.	Locking the rotor is possible with a pin. Reaching the rotor is possible without locking.	Improve the locking mechanism so that rotor must be locked before reaching the rotor is possible.
2	Rotor shall be lockable in every position.	Rotor can be locked in only four positions.	Improve locking system so that locking is possible in every position.
3	Rotor shall stop in 3 s during maintenance.	Possible to slow, but it is not sure how long it takes to stop the rotor.	Verify that rotor can be stopped in 3 s and, if needed, make required changes.
4	During maintenance, the maximum rotor peripheral speed shall be 100 mm/s.	Not measured.	Measure the maximum speed and reduce it if needed.
5	During maintenance, possible to turn the rotor from safe areas.	Controls are located in the control station.	No need for improvements.
6	Possible to adjust the rotor without manual intervention.	Hydraulic motor is used to turn the rotor.	No need for improvements.

Table 3—7 present requirements, current situation of the machine and possibly needed improvements. Requirements are listed so that there is one requirement listed on every row. Current situation column explains shortly what kind of safety functions already exists with the studied machine. Needed development column presents what should be done to fulfill the standard requirements or are they already fulfilled. Colors indicate the state of the safety function. Red means that requirement is not fulfilled sufficiently, or it needs large changes. Yellow means that requirement is covered partly, and safety function already exists, but it is not as good as standard requires. Those requirements that could not be verified for sure are also marked with yellow color. Green color means that standard requirement is covered fully, or it is better than standard requires.

Generally, standard requires that rotor is secured in every situation and turning the rotor can be done from safe distance. The standard requires that rotor needs to be locked before reaching the rotor is possible via intended means of access. This requirement applies also in the situation when the machine has been shut down, but the rotor is still

rotating. Additionally, it shall be possible to lock the rotor in any position and not just in a few set positions with a pin, as it is currently done with the studied machinery.

Requirements related to locking are not currently fulfilled. Locking is possible in four positions with a pin, but it is not required to lock the rotor before opening the crusher or inspection door. Control system makes sure that rotor is stopped after operating, before it allows the user to change the machine to maintenance mode, which allows opening of the crushing chamber and inspection door.

Currently, rotor can be locked before or after opening the crushing chamber. Locking before opening the crushing chamber might be difficult, because the rotor has to be adjusted to the right position without possibility to see the rotor. Instructions manual guides the user to open the crusher before locking it. In the event of blockage, rotor cannot be locked before removing the blockage. Normally, this might require opening the crusher and carrying out maintenance actions close to the rotor.

Inspection door is used to measure the current crusher settings and wearing of the wear plates. If user experiences that it is difficult to lock the rotor without opening the crusher chamber, user might open the setting door without locking the rotor. Currently, Instructions manual does not require locking the rotor when actions are done through crusher setting door.

Rotor turning during the maintenance cannot be verified during this research. Currently, hydraulic motor is used to turn the rotor. In addition, the same motor is used to stop rotor. The speed or stopping time could not be verified during the study.

Standard requires that the maximum peripheral speed for rotor is 100 mm/s and it shall be possible to stop the rotor in three seconds during maintenance. Rotor position adjusting shall be possible only from outside danger area. Operator shall have visibility to danger area during adjusting. Figures 7 and 9 presents control station for crusher opening and for rotor adjusting. Control station is highlighted with red color. The crusher is closed for figure, but normally it is open during maintenance.

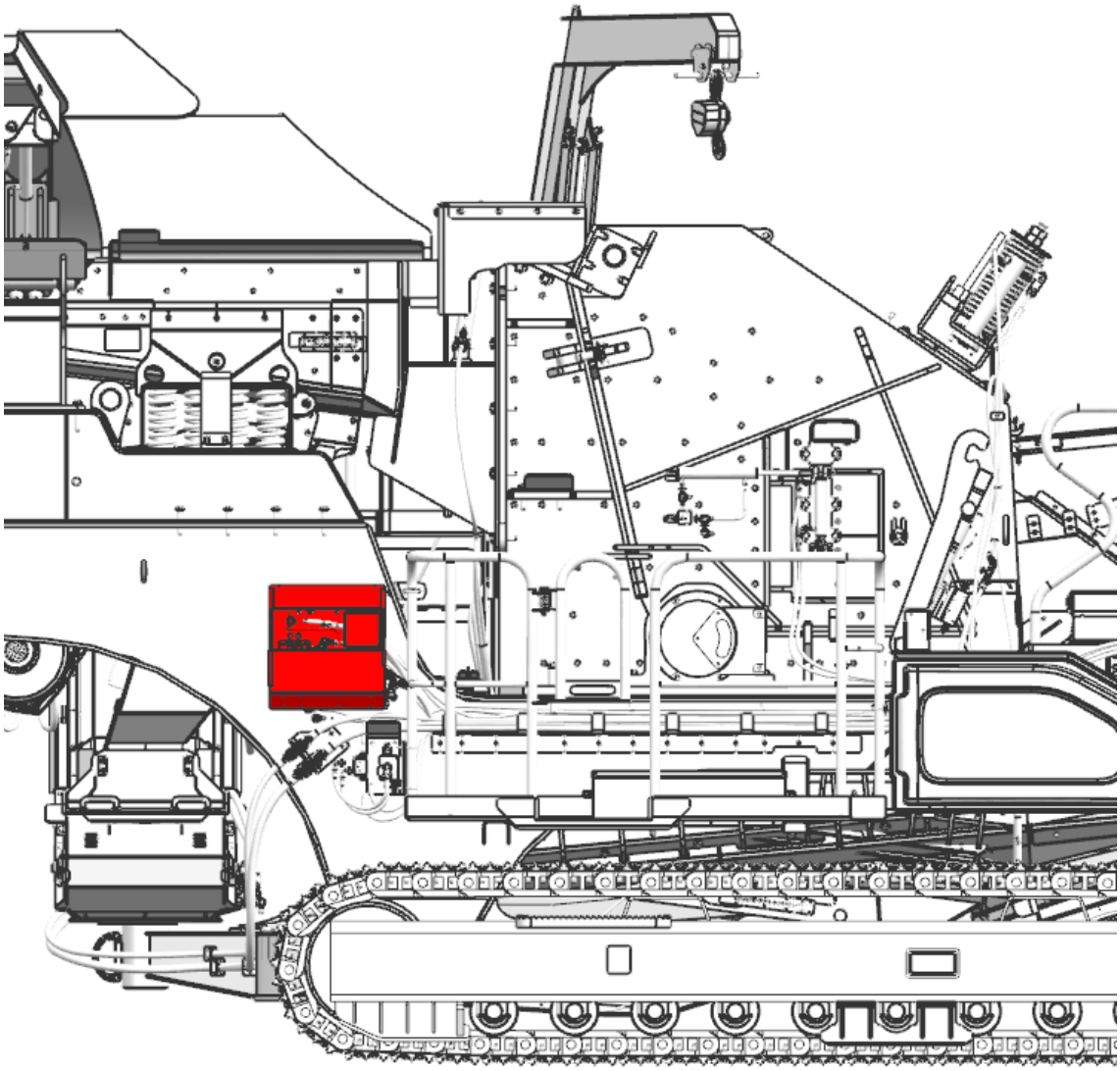


Figure 7. *Control station for crusher maintenance tasks.*

Operator has a good visibility on the right side of the crusher. However, operator has a limited visibility on left side of the machine. However, reaching to the movable parts is prevented from the left side of the machine by guards (Figure 2, position 19).

Table 3 focuses on the rotor of the HSI crusher. Table 4 present the general requirements for HSI crusher.

Table 4. *General requirements of the FprEN 1009-3 for the impact crusher.*

#	Requirement	Current situation	Needed development
1	Closed inlet and outlet to minimize the risk of ejection of material.	Inlet is protected with chains and rubber curtain. Outlet is closed structure.	No need for improvements.
2	Springs protected to prevent hands and feet from touching springs.	Springs are covered with bags.	No need for improvements.
3	Visual inspection opening for inspection inside the crusher.	Visual inspection opening with interlocking device.	No need for improvements.
4	Backside and top of housing inspection doors shall be considered as fixed guards.	Fixed guards installed and it is not possible to reach the rotor via these accesses.	No need for improvements.
5	Prevent accidental closure of the housing.	Cylinders and automatic mechanical supports are used to keep the chamber open. For other housing, gravity keeps them in still position.	No need for improvements.
6	Means of access to setting devices.	Control station on the ground level. Platform installed on the other side of the crusher.	No need for improvements.

Crusher inlet is protected with chain curtain that is presented in Figure 8. Inlet of the crusher is highlighted with red color within the Figure 8. Outlet of the crusher is closed structure without the possibility of ejection of material. EN 1009 does not require to eliminate the possibility of ejection of material, but to minimize it with proper design. In this case chain and rubber curtains are enough to minimize this risk. Instruction manual include a safety text about the possibility of the ejection of the material; LT1213S or LT1213 shall not be fed directly from the back with wheel loader because of known ejection of objects hazard.

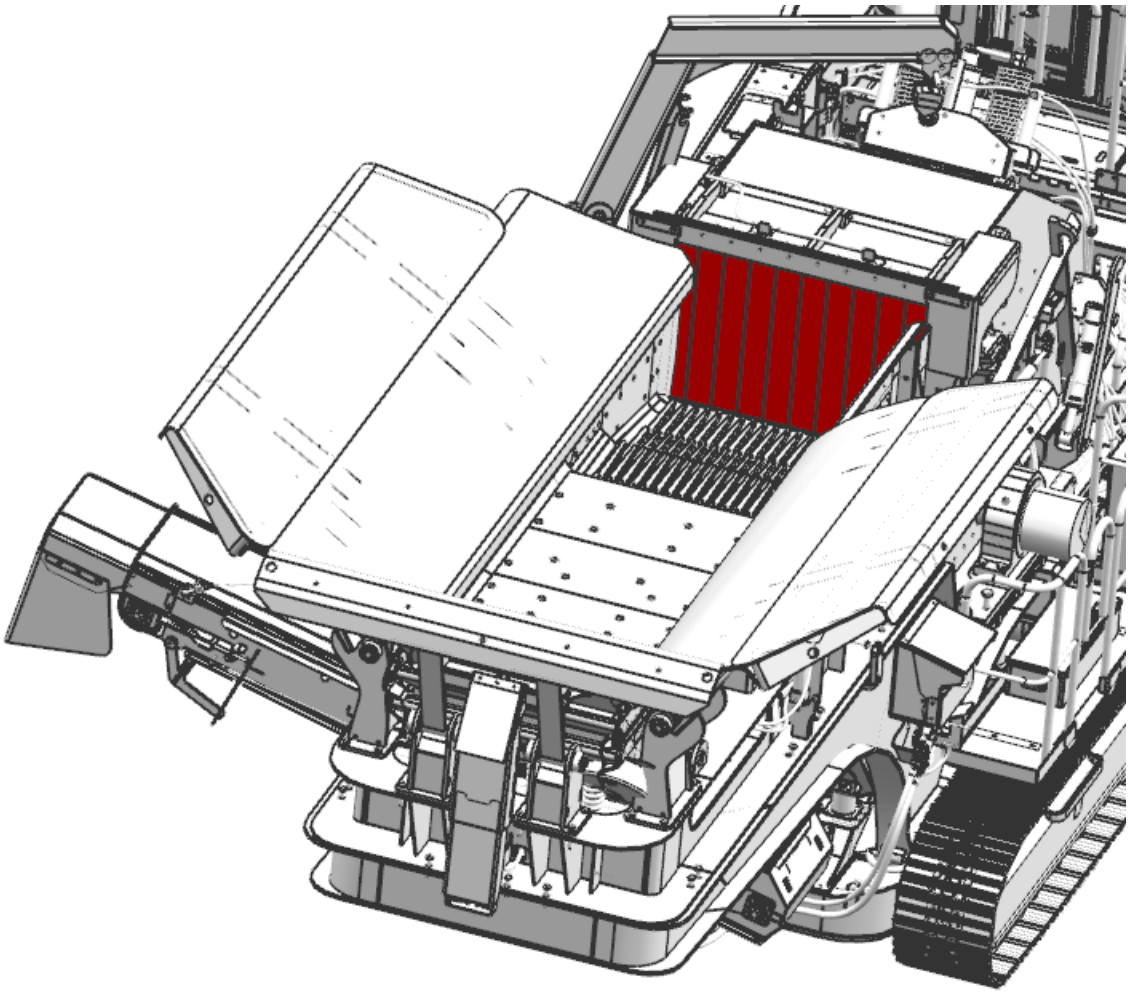


Figure 8. *Crusher inlet.*

Tramp release mechanism is protected to prevent contact with device. Springs are also located in way that touching these devices is not possible.

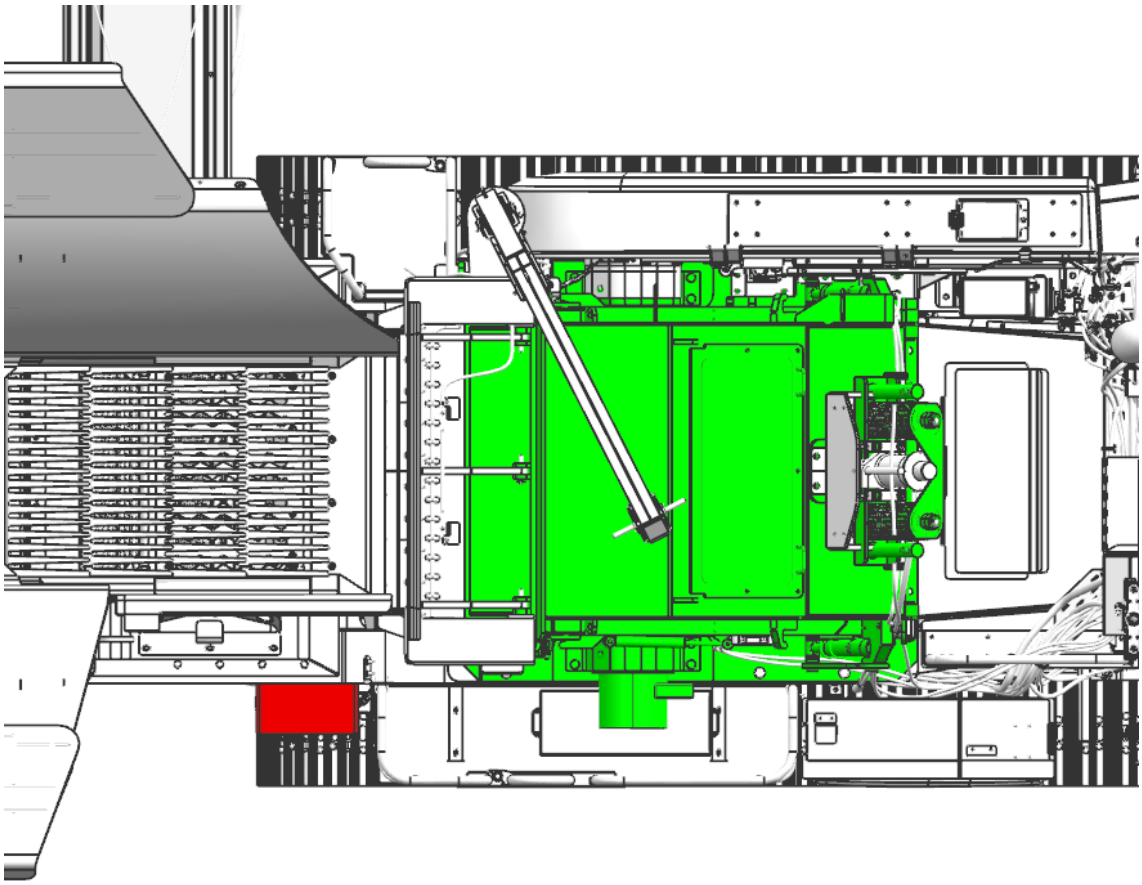


Figure 9. *Top view of LT1213S. Material flow from left to right.*

Operator has only a narrow gap where he can see to the other side of the machine. However, entering to the crusher is possible only next to the control station. On the other side, fixed guard is covering the belts and the flywheel of the crusher. Reaching to the moving parts is not possible from left side of the machine when crusher is opened. Control box is marked with red color and crusher with green color on Figure 9.

For the maintenance work inside crushing chamber of LT1213, there should be a safe access and platform to do the work. According to the findings, the present solution, where the worker is standing on the rotor, could be safer if temporary platform is provided. Also temporary hand- or guardrails could be a valid option. Alternatively, it is possible to require usage of safety harness when there is need to stand on the rotor wing. Using of this solution requires the crusher to have anchorage points.

Fixed maintenance platforms are provided to locations, which require regular maintenance. Figure 10 presents the crusher of the LT1213S and maintenance platform for crusher.

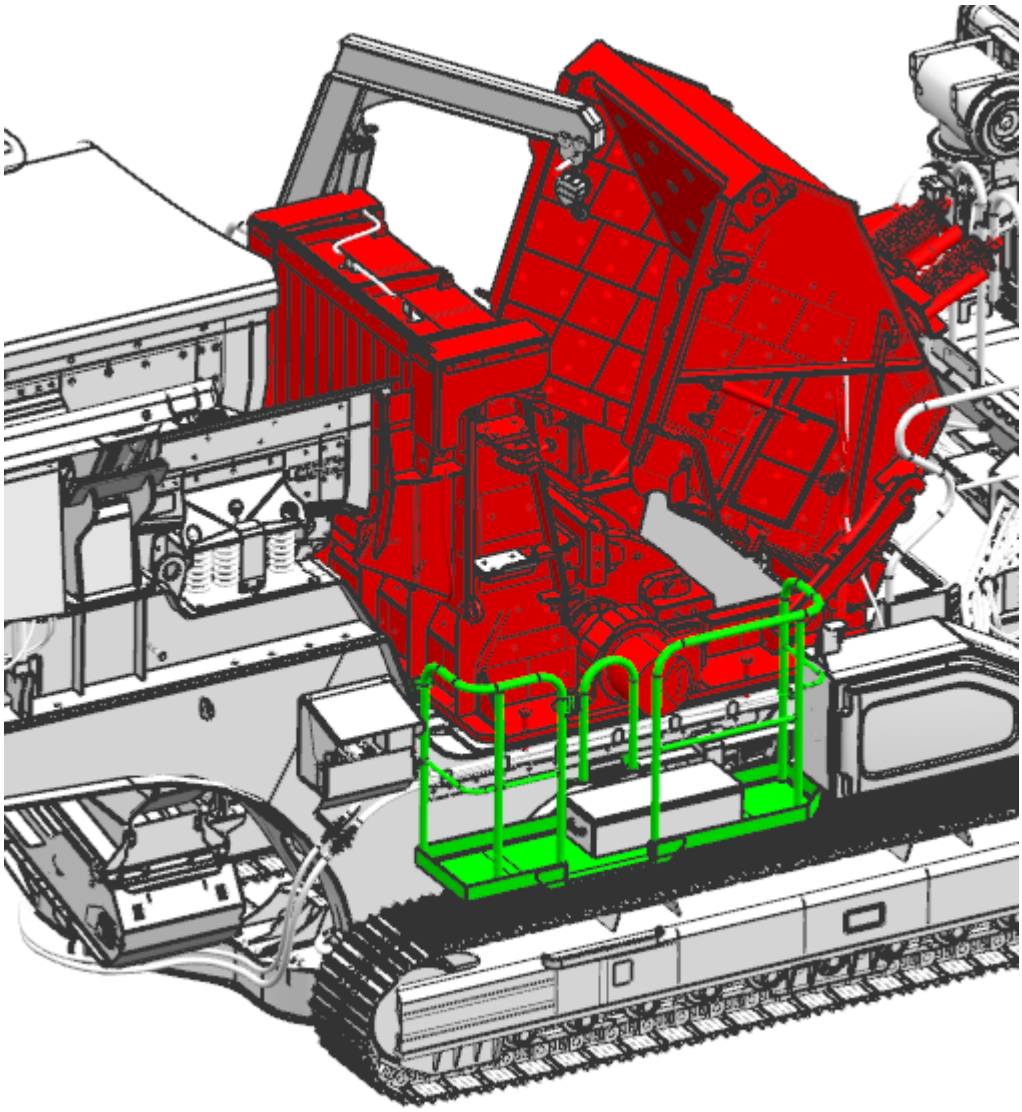


Figure 10. *LT1213S crusher in service position.*

Figure 10 presents the crusher of the LT1213S in service position. Crusher is highlighted with red color and the maintenance platform of the crusher is highlighted with green color. Return conveyor, on the front, transports uncrushable material back to the feeder or removes material out of the process. When conveyor is transporting the material back to the feeder, conveyor is directly above the maintenance platform (Figure 7). Space for maintenance work is reduced and the conveyor is partly blocking the access inside the crusher. Currently, it is possible to turn the conveyor out of the way. However, instructions are not saying that conveyor should be turned away for maintenance work.

Wear parts can weight over 25 kg, which means so according to the standard they shall not be handled manually by one person (EN 1005-2 2009, p. 18). However, in some cases employees might end up in a situation where they have to lift weights over 25 kg. Lifting tool cannot be used in all maintenance work so it needs improvement or help from

other maintenance personnel. Also, worker might be in unergonomic positions to get the work done.

4.2 Findings of Lokotrack LT106 jaw crusher

LT106, which includes jaw crusher, fulfills all requirements that EN 1009 demands. However, there is one part in the inlet of the crusher that might need some improvement. Standard requires that feed opening of the crusher shall be provided with a guard to minimize hazard caused by ejected material. Currently, there is a cover that prevents the material from ejecting directly upwards, but there is no guard to prevent the material from ejecting backwards. However, risk that material is ejected backwards, is significantly smaller than risk that material is ejected upwards because of the design of the machine. Jaw crusher operates so that rocks can be ejected upwards easily, but material ejecting backwards requires a ricochet. Figure 11 presents the cross-section view of the jaw crusher, where the crusher cavity is clearly visible.

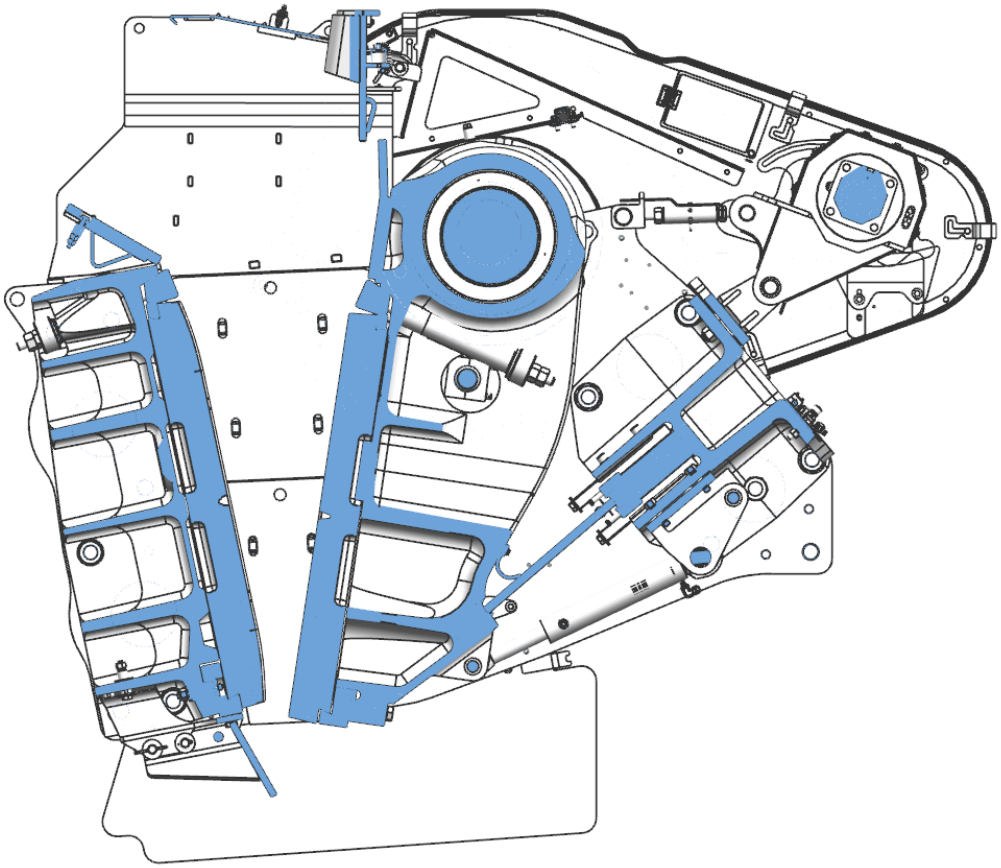


Figure 11. *Cross-section figure of the Nordberg C106 crusher.*

During the machine operation it is foreseeable that some operators will leave the cover in lifted position in order to prevent blockages caused by oversized feed. When the cover

is in up position, there is not any protection for ejected material. In the worst case, the jaw crusher might shoot rocks directly upwards from the crushing chamber and as a result, the rocks might land anywhere, even in the area that should be safe. Partially because of this foreseeable misuse, it is not allowed to stay near the machine while it is in operation. Table 5 summarizes specific requirements that are affecting to jaw crusher.

Table 5. *Specific requirements of the FprEN 1009-3 for jaw crusher.*

#	Requirement	Current situation	Needed development
1	Liners cannot accidentally fall during maintenance.	Instructions for safe maintain and liners cannot fall when instructions are followed.	No need for improvements.
2	Possible to change toggle plates, jaw dies and cheek plates safely.	Metso provides a movable platform and lifting tools for maintenance work with the crusher.	No need for improvements.
3	Operator cannot fall during maintenance inside crushing chamber.	Movable platform closes the crushin chamber.	No need for improvements.
4	Temporary working platform takes into account changes in crushing chamber geometry.	Platforms adapts to the current crusher settings.	No need for improvements.
5	Locking mechanism of temporary working platform will hold all presumable forces.	Calculated and tested platform design.	No need for improvements.

Table 5 shows that jaw crushers are fulfilling the requirements of EN 1009 well. Requirements for jaw crushers are quite general and they are not as specified as they are for HSI crushers.

Table 6. *General requirements of the FprEN 1009-3 for jaw crusher.*

#	Requirement	Current situation	Needed development
1	Safe use of ladders if needed.	Ladders are used to access to the temporary working platform inside crushing chamber.	Use of ladders requires climbing over the guardrails. Improve safety harness system.
2	Guard in the feed opening to prevent ejection of material.	Hatch on top of crushing chamber.	No need for improvements.
3	System to prevent the crusher to be overfilled.	Automatic system that monitor the level of the crusher and can adjust the feed rate.	No need for improvements.
4	Guarded tension rods. Rods are retained in the event of break up.	Rods are located inside crusher.	No need for improvements.
5	Covered spring.	Hydraulic setting control system. No springs	No need for improvements.
6	Special equipment provided if needed.	Platform and lifting tools are provided for maintenance.	No need for improvements.
7	Guard cannot fall if lifted.	Can be opened fully so that gravity keeps guard in a fixed position. If opened partly it is secured with mechanical supports.	No need for improvements.
8	Means to solve blockages.	Optional hydraulic hammer available for demanding applications. Hydraulic crusher drive motor enables reverse operation. Hydraulic setting control enables easy opening for the crusher setting.	No need for improvements.

Figure 12 presents the installation and usage of temporary working platform in crushing cavity. Temporary working platform has handrails on both sides to prevent falling of the personnel.

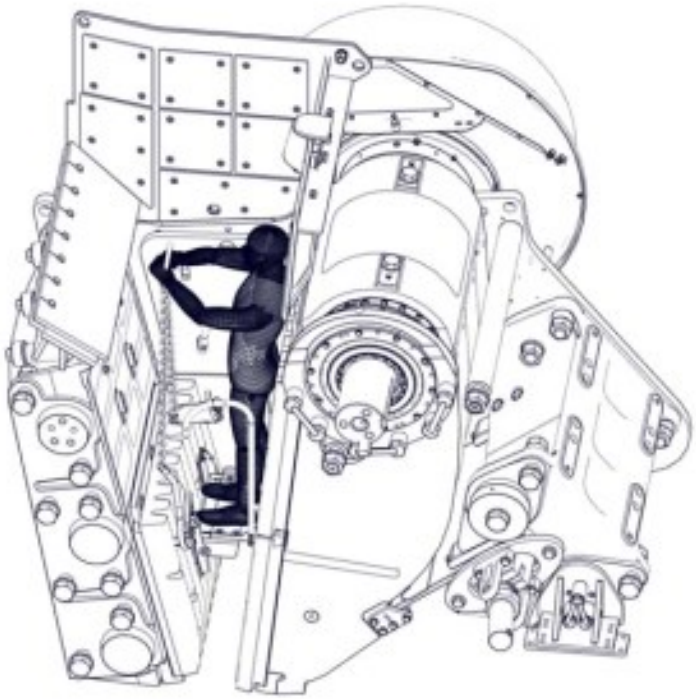


Figure 12. *Usage of temporary working platform in crushing cavity of jaw crusher (Metso 2015).*

The maintenance platform is designed to ease access and maintenance work inside crusher cavity. Platform also secures wear part mechanically to prevent unintended movement of wear part while it is installed or removed. Instructions of platform are provided with the crusher and usage of platform fulfills the requirements of EN 1009. However, if maintenance instructions are not followed or platform is not used as intended, working inside crusher cavity is not safe and might cause injury.

Figure 13 presents the crusher inlet. Cover plate is highlighted with red color and the crusher cavity is below the guard.

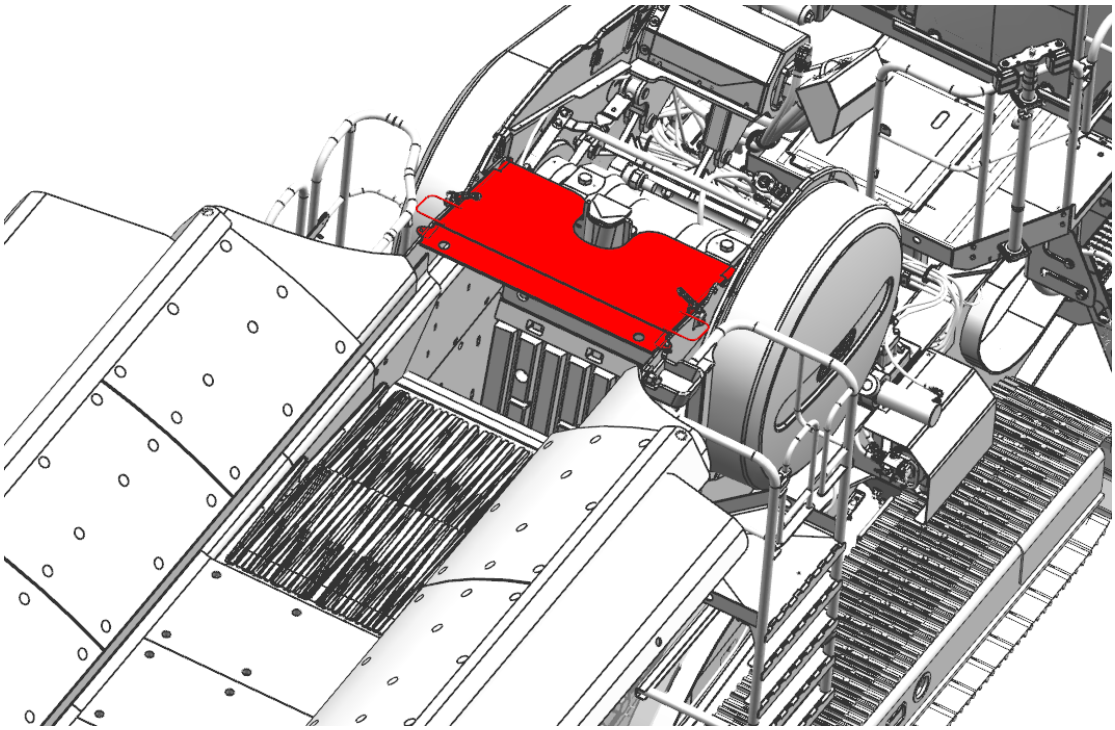


Figure 13. *LT106 crusher inlet.*

Cover is located on top of jaw crusher where cover prevents rocks from ejecting directly upwards, but it does not prevent rocks ejecting backwards. However, as mentioned earlier, movement and operation of jaw crusher mostly prevents the material ejecting backwards. In all cases, the speed of rock would be significantly lower compared to a possible crusher rock ejection with HSI type crusher.

4.3 Access systems

Platforms are used in every machine to access high maintenance locations. The service platforms are quite similar in different machines, which is why they are dealt jointly with the case machines.

Table 7. *Requirements for access systems of LT106 and LT1213.*

#	Requirement	Current situation	Needed development
General			
1	Person cannot be trapped into one component of the plant (FPREN 1009-1 2020, p. 15).	When machine instructions are followed, it is not possible to get trapped.	No need for improvements.
Platforms			
2	Platform minimum dimensions are 300 mm x 400 mm when height is less than 2 m (PREN 1009-6 2020, p. 13).	Platforms meets the dimensional requirement but, in some platforms, there are obstacles which make the working area smaller.	Remove obstacles from the platforms.
Guardrails			
3	Guardrails on the open side of the platform when height is 2 m or more from the ground (EN ISO 2867 2011, p. 10).	Guardrails provided for all platforms.	No need for improvements.
4	Distance of vertical posts is less than 180 mm (EN ISO 2867 2011, p. 10).	Distance of vertical posts is less than 180 mm.	No need for improvements.
5	Self-closing gates when there is a passage through the guardrail and the opening gives access to a fixed ladder with an angle between 75-90 degrees (PREN 1009-6 2020, p. 13).	Self-closing gates provided.	No need for improvements.
Steps			
6	First step of ladders shall be no greater than 500 mm (PREN 1009-6 2020, p. 13).	Height of first steps are under 500 mm.	No need for improvements.

Guards and hatches can be opened or removed during a maintenance work. EN 1009 (2020) requires that person cannot be trapped inside a machine. Normally, this is fulfilled

by using openings that stay open by the effect of gravity. Another possible solution is to use openings that are removed during maintenance work.

Unlike with part one, part six requires access system for compact mobile machines to be in accordance with EN ISO 2867 2011. This gives some significant reliefs for design of the access system. For example, the minimum dimensions of platforms are a lot smaller than in EN ISO 14122. Minimum length for platforms is 400 mm and width is 300 mm (EN ISO 2867 2011, p. 11) According to EN ISO 14122 the minimum width for platforms is 800 mm when regular maintenance is needed (EN ISO 14122-2 2016, p. 9).

4.4 EN 1009 suitability for the mobile plants

This chapter evaluates if the machine safety increases when all requirements of EN 1009 are fulfilled. Practicality of the safety devices required by EN 1009 is also evaluated. Chapters 4.1—4.3 shows that most of the requirements of EN 1009 are already fulfilled in LT1213 and LT106. However, parts that do not fulfill the EN 1009 completely, need further studies to evaluate the risk level after the changes have been made.

The risks of the LT106 and LT1213 typically are higher during maintenance than during operation. The rotor of the HSI crusher can cause falling and crushing hazards if the rotor is not locked properly and the worker enters the crushing chamber or reach to the rotor through crusher setting door. EN 1009 takes into this hazard by requiring that the rotor shall be locked before any accesses to the rotor can be opened. However, turning the rotor must be possible during the maintenance after the crushing chamber or crusher setting door have been opened. EN 1009 does not set requirements for locking the rotor after turning the rotor during maintenance.

Falling objects causes hazards during operation and maintenance. While feeding the crusher, rocks might fall to the ground and conveyors pile the crushed material to the piles next to the mobile plant.

During operation, HSI crusher can cause ejecting material hazard by shooting rocks out of the crusher. EN 1009 requires chain or rubber curtain to prevent this risk but this system cannot remove the hazard totally. LT1213 is equipped with chain and rubber curtains, which reduces the hazard of ejecting material, but does not eliminate it completely.

Falling hazards are present when workers work in high places. EN 1009 requires working platforms according to EN ISO 14122 for fixed, heavy mobile and extra-heavy mobile machines. For compact machines, platforms according to EN ISO 2867 and self-closing gates are required.

Typically, hazards occur during maintenance of mobile crushers. During operation, working on machine platforms or near the machine is typically restricted by the manufacturer. Operator's station is the exception to this to ensure safe use of the machine.

In some cases, falling hazards are also present if someone climbs to the machine platforms during operation. EN 1009 sets requirements for access systems by referring to the EN 2867 and EN ISO 14122. These standards are not very practical to use with mobile plants, because risk for falling is too high if only EN 2867 is used. In turn, EN ISO 14122 sets requirements that cannot be achieved with mobile plants in all possible situation.

Chapters 3.3, 4.1—4.3 shows that EN 1009 is not very practical to use with mobile plants. The requirements are good and increase safety, but the partition of the standard is not easy to use with LT1213 and LT106 mobile plants. In practice, EN 1009 is easier to understand and compare it to the machines if the partition of the standard follows the similar structure as presented in Figure 6.

LT1213 and LT106 are part of mineral processing by crushing the feed material and transferring it to the next crushing stage or removing the material out of the process. LT1213S might have four different outputs for the material and LT106 might have three outputs. LT1213 and LT106 create piles on the ground next to the machine. These piles and conveyors cause falling object and burying hazards for anyone who works too near the machine. EN 1009 does not set any requirements how to take these hazards into account while designing mobile plant. For fixed machinery, there are multiple solutions to prevent the workers to end up in the hazard zones, such as fences. Similar solutions cannot be used with mobile machinery.

Currently, Metso inform the user about the hazard zones near the machine by adding warnings in the instruction manuals and attaching warning signs to machine near the hazard zone. This way is safe enough to prevent accidents caused by material flow but EN 1009 should set a common way to prevent this hazard. Currently, manufacturers might have different methods and different safety level for hazards related to the material flow and workers have to know how each manufacturer deals with these hazards. Guards related to the material flow outside from the machine are delivered by the manufacturer for the fixed plants, but for mobile machines customer is responsible to prevent the access to the hazards zones if needed.

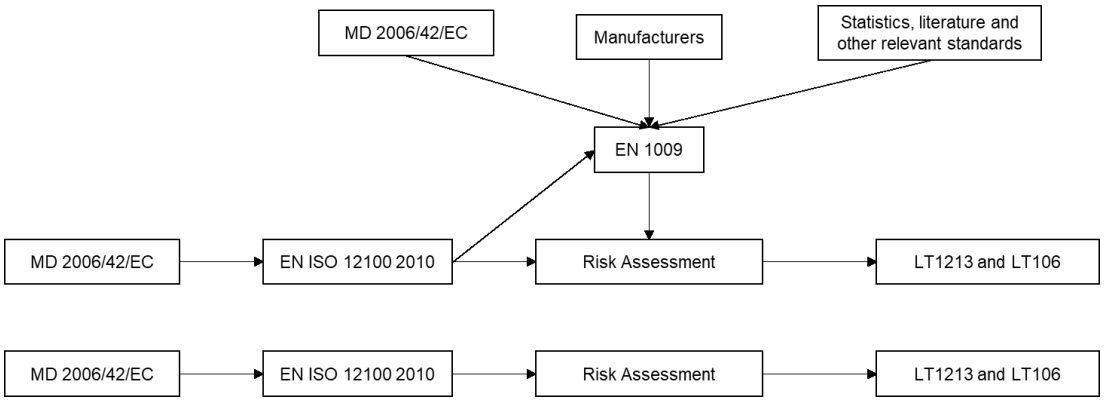


Figure 14. *New (on the top) and current (below) process for design of LT1213 and LT106 from the safety perspective.*

Figure 14 presents process of fulfilling the requirements of MD with and without using EN 1009 standard. EN 1009 is designed to help manufacturers to identify the common hazards of mineral processing plants. It also gives solutions to eliminate or reduce the hazards to the acceptable level.

The major problem is that MD does not require anything else but risk assessment so the use EN 1009 does not mean that risk assessment is not required. Generally, it is not sure how much manufacturers can rely on the EN 1009 and its solutions to reduce hazards and risks and how much manufacturers have to rely on their own risk assessments.

5. DISCUSSION

Mahat (2017), studied the prEN 1009-4 standard and stated that Metso products Lokotrack ST2.8 and Lokotrack LT330D comply with the standard requirements at the studied time. EN 1009 standard and Metso products have been updated since and thus this study is necessary. Also, further studies will be needed when the standard is published. In general, the EN 1009-4 involve minimum dimensions for different access openings and refers to other standards, such as EN ISO 14122: 2016 series. In addition, where Mahat focused on Lokotrack ST2.8 and Lokotrack LT330D machines, this study focuses on LT106 with jaw crusher and LT1213 with HSI crusher and their requirements from EN 1009 standard family.

5.1 Comparability of case study

Qualitative rigor is used to analyze credibility, transferability, dependability and confirmability of the study results (Thomas, Magilvy 2011). This thesis uses quantitative methods to analyze the LT1213 and LT106 from the EN 1009 standard point of view. Qualitative methods are used to analyze the standard and its suitability for the industry. Different dimensions, such as minimum dimension for access systems, are clearly identified and it can be stated if the machine fulfills these requirements or not. Other requirements which cannot be measured as clearly as dimensions, such as safe means of access shall be provided, can be discussed and will probably lead to different interpretation by manufacturers.

Some requirements of the EN 1009 are not unambiguous where conflicts between the parts of the standard currently occur and therefore also qualitative methods are used to analyze them. However, reviewed version of the prEN1006-6 standard is a draft so there is still time to make corrections to the standard before publication. Standards are used to unify the practices within an industry and to fulfill the safety requirements set by, for example, MD. Therefore, corrections and harmonization between the upcoming EN 1009 series should be carried out to minimize misunderstanding of the standard.

5.2 Proposed updates

Generally, requirements of EN 1009 are reasonable and they are focused on the hazardous components of the machines. However, EN 1009 covers a large variety of differ-

ent kind of machines, such as screens, crushers, conveyors and feeders. These machines can be fixed or mobile machines, and they can be used independently or combined entirety, such as Nordberg NP1213 or LT1213. Nordberg NP1213 is the crusher and LT1213 is mobile plant that includes Nordberg NP1213 crusher. Manufacturers have their own definitions for their machines and currently they might differ with other manufacturers. As a result, EN 1009 cannot define machines and their components completely and unambiguously.

Mobile machines are, for example, defined as a crawler or wheeled, self-propelled, trailed or towed machine movable from worksite to another or within a worksite. This is clearly in line with other industries where mobile machines are defined similarly. EN 1009 categorizes mobile machines to three different groups as mentioned in Chapter 2.3. Compact mobile machines are designed so that main components do not need to be removed prior transportation between the worksites. Heavy and extra-heavy mobile machines are designed so that main components need to be removed prior transportation. EN 1009 does not define these main components or explain what they are, it just mentions a few examples of main components. For this thesis main components are those that are mentioned in the standard. As a result, power source or conveyors are not considered as main components for this thesis. However, LT1213 and LT106 are still compact mobile machines because they can and are designed to be transported as one piece. In addition, other interpretations can be used without having a conflict with the EN 1009.

LT1213 and LT106 are typically transported by truck with chassis, but also other machines are transported similarly. This means that local laws for road transportation sets the requirements for maximum mass and dimensions for the transport. In Finland, law 4.12.1992/1257 sets requirements for road transport (4.12.1992/1257 1992). However, requirements might differ in different countries. As a result, it is not clear, if the machine is compact or heavy mobile machine in a situation where manufacturer has designed the machine to be transported as one piece but also without main components if local laws require smaller transportation.

As a result, EN 1009 still needs some developing work related to the terms and requirements. Standard could be improved so that terms and requirements are corrected to be unambiguous. Mobile machines could be defined according to their mass or dimensions instead of transportation method because the dimensions are already set by the local laws.

For the machines, LT1213 needs updated rotor locking system (Table 3, rows 1—4) while LT106 does not need changes to fulfill the EN 1009 (Table 5). EN 1009 requires that rotor shall be lockable in all positions including the event of blockage, and before the intended means of accesses can be used. Mechanical, hydraulic, and electromagnetic solutions can be used to fulfill the requirements. However, these devices are typically designed for breaking the shaft which might make them expensive for LT1213.

Views to the rotor and crusher openings are clearly visible when operator is rotating the rotor of the LT1213 (Figure 7 and 9). Control devices are located so that it is not possible to reach any movable part from the control station. However, currently it is hard to see to the other side of machine, and thus it is hard to know if another person is working near hazard area or not. There is not access to the crushing chamber, but the operator cannot see for example a person who is working close to crusher with the flywheel and the belts.

Ejection of material shall be prevented in all crusher types. HSI crushers use rubber or chain curtains, and jaw crushers use plate above the crushing chamber. In HSI crushers material is flying in all directions including directly backwards so curtains are a very good solutions, but also other methods can be used. LT1213 is equipped with both rubber and chain curtains so it is surprising that the new standard requires only one curtain (Figure 8). With LT106 material is not flying, but the crusher creates tensions to the material which might result shooting the material directly upwards. Shooting the material backwards is nearly impossible so guard is needed only above the crushing chamber (Figure 11). EN 1009 standard does not specify the guard for the jaw crusher as it does for the HSI crusher.

For LT106 Metso provides a temporary working platform for maintenance work inside crushing chamber (Figure 12). Jaw crusher does not have flat surfaces inside the crusher where the worker can stand so removable working platform is the only available solution to provide safe means for maintenance work inside crushing chamber. Temporary working platform is not provided for the LT1213 because worker can use rotor wing for working inside crusher. Figure 10 presents the LT1213 in a service position and the rotor wing where the worker can stand. However, Metso provides temporary working platforms for certain HSI crushers currently so it should be considered to provide similar platform for LT1213 also.

Naturally, it is possible to find different solutions for the conflicting parts of the LT's with the EN 1009 standard series requirements. EN 1009 does not prevent usage of different solutions, so technically mechanic, hydraulic, electric or pneumatic solutions can be

used. Solutions presented in this thesis are suitable for at least LT1213 and LT106 but also other similar product types can use them.

Generally, the results show that safety requirements are quite well considered in Metso products. Machines are safe to use when they are used according to the instructions given by Metso. However, it is known that the safety instructions are sometimes ignored when different kind of customers or individual operators are working with the machinery. The safety could be improved by updating systems to make it harder to abuse the machines.

Inspection doors of the crusher are well designed, and it is not possible to get trapped inside the machine. Currently, it is not possible to open the crusher setting door of LT1213 when the crusher is operating, and it is fulfilling the requirements of EN 1009. However, the present solution is complicate and vulnerable for faulty situations. For example, dust can prevent the position sensor from working. When safety devices are not working properly or they are making the maintenance more difficult, operators might remove these safety devices from the machines. Despite the good safety level in the manufacturing company, it does not mean that the end-user has same safety level. It might be dramatically lower if safety is not so important to the companies using the products.

5.3 Suitability of EN 1009 for mineral processing plants

EN 1009 is the first safety standard aimed precisely for the mineral processing plants. It contains six parts, which makes it large standard family. It also enables the possible discussion about dividing the standard into two different standards, such as one for mobile and one for fixed processing plants.

Following of EN 1009 requirements makes it easier for the manufacturers to fulfill the safety requirements of the MD. The standard is also sectioned well. There are general requirements for all types and parts of the mineral processing machinery as well as also specific requirements for partly completed machines, such as crushers, screens and conveyors. This is in line with the mines, where there are different machines to sort, crush and transport the material.

However, machines that can be designed with EN 1009 are used in multiple different places, such as mines and construction sites. This makes it very hard to compile standard that covers all regulations from different fields. Work sites can have both fixed and mobile machines, which are taken into account with EN 1009 series. Typically, standards that are referred in EN 1009 are designed to be used with fixed machines inside factories. In addition, there are standards for certain types of mobile machines, such as machines

that can move during operation. Referring to standards that are designed for factory environment can have undesired effects, as these standards do not consider, for example, the weather conditions. Factories are well designed places where all situations are easier to forecast than with changing conditions in the mines and quarries. Standards for mobile machines are typically designed for a smaller machinery, such as crawlers.

Generally, it is easy to say that some standards referred in EN 1009 are too strict and some too loose for mineral processing plants. In factories the space and conditions for the machinery are well known and walls and floorings ease the installation of the access system, which is not possible with the mineral processing plants. In typical mobile machines, mobility is part of the machine operation, such as excavator. Mineral processing plants are not like machinery in factories, but they are not typical mobile machinery either.

5.4 Purpose and practical contribution of this thesis

Results of this thesis are mainly used by designers in product development. The purpose was to analyze machines manufactured by Metso and the upcoming EN 1009 standard. Study was focusing on two case machines, but the results can be used as general view with other similar machines as well.

Access systems are designed similarly in all machines so for access system study succeeded well. Also, conveyors, feeders and screens are similar in all machines and results are convergent with all machines types. However, different crusher types have totally different requirements and those used with HSI crusher cannot be used with the jaw crusher. This also applies with other crusher types such as, gyratory and cone crushers. Hazard types, such as ejecting material are similar, but they appear totally differently between crusher types. As a result, different protection is needed in order to increase safety. Results of this study can be utilized to all HSI and jaw crushers. For other crushers, the specific requirements for certain crusher types of EN 1009 have to be used.

6. CONCLUSION

This thesis evaluated the EN 1009 standard family, and how the standard implicates with the Metso products. EN 1009 consist of six parts, which set general and specific requirements for the different mineral processing machines. EN 1009 standard parts 1—5 will be published in 2020 so it is currently not publicly available. Standard has not been studied widely so further studies are needed when the standard is published.

The aim of this thesis was to study Metso products, more specific machines LT1213 and LT106, and how well these machines are fulfilling the requirements of the new EN 1009 standard. Both machines are installed on the tracks allowing them to move within a work site and being easily transported from one work site to another. LT1213 is equipped with HSI crusher and LT106 is equipped with jaw crusher. Therefore, parts one, three and six were studied the most while other parts were analyzed briefly. Table 8 summarizes the components that Metso should pay attention in future development (marked with red color in Chapter 4).

Table 8. *Requirements of EN 1009 which are not fulfilled currently.*

#	Requirement	Current situation	Proposed solution
HSI crusher			
1	Opening of the crusher or reaching the rotor via intended means of access shall only be possible if the rotor is locked.	Locking the rotor is possible with a pin. Reaching the rotor is possible without locking.	Consider electric sensors to get information when the rotor is locked.
2	Rotor shall be lockable in every position.	Rotor can be locked in only four positions.	Consider mechanical or hydraulic solutions for HSI crusher.

Results show that Metso is fulfilling the requirements well, especially service platforms are already designed according to EN 1009. Metso is already using self-closing gates in their products and also in locations where EN 1009 does not require them.

LT106 is currently fulfilling the standard well, while LT1213 requires some safety functions for the HSI crusher. For maintenance, HSI crusher can be opened fully or inspection doors can be used. These tasks require reaching the rotor or standing on the rotor wing, and EN 1009 is giving requirements for securing the rotor so that unwanted movement cannot occur.

LT1213 sets certain requirements for the rotor locking system. The conditions around the machine are rough. Machine itself vibrates much during operation, but during maintenance, when the locking system is in use, vibration does not occur. Also locking system has to be protected from falling material and dust. Available space for the locking system is limited which sets requirements for the size of the locking system. When the EN 1009-6 is published, mobile HSI crushers, such as LT1213 must have rotor locking system and Metso should continue developing rotor locking system but also keep developing the safety in all machines and evaluate the other machine types as well.

Currently, locking systems on the market are using a pin which will not meet the requirements of FprEN 1009-3. Suitable solutions are typically designed also to act as a brake, not just hold the position, which might make them expensive for this purpose. Preventing the accidental closure of the locking system during operations has to be taken into account during the design process.

EN 1009 standard is intended to be used so that part one is used in conjunction with the required other parts. For the designer the result is not the best possible when the part one sets the common requirements and then other parts are setting new requirements that might have conflicts with the requirements of the part one.

Platforms are currently designed well in LT1213 and LT106. Metso is already combining the EN 2867 and EN ISO 14122 standards similarly as the EN 1009 does. However, EN 1009 should create more own requirements and define the concepts, such as access and opening, better for platforms instead of using these standards mentioned earlier.

Mineral processing industry clearly needs the EN 1009 safety standard to give further safety requirements when compared with general requirements for MD to safety of the mineral processing plants. EN 1009 does not remove the need of the risk assessments of the manufacturers at this state. Further studies are also needed to evaluate the standard from multiple points of view to remove the remain conflicts within the standard.

This thesis was studies upcoming safety standard EN 1009 and how it will affect to the products of Metso. Two case machines, LT1213 and LT106, were used in this thesis but the study can be easily widened to other machines as well. EN 1009 is needed in the industry of mineral processing. With six parts, it is a large standard family that could be divided into two different standards for fixed and for mobile machines as it is in other industries at the moment.

Finally, results of this thesis can be used for product development. Nevertheless, this thesis does not provide finalized solutions for the machines, but it is clearly pointing out

the components that need changes in order to fulfill the upcoming safety standard EN 1009.

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