OPINNÄYTETYÖ - **AMMATTIKORKEAKOULUTUTKINTO**
TEKNIIKAN JA LIIKENTEEN ALA

TESTING OF ELEVATOR DOOR SILL ASSEMBLY

KONE oy

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SAVONIA-AMMATTIKORKEAKOULU

OPINNÄYTETYÖ
Tiivistelmä

Koulutusala Tekniikan ja liikenteen ala	
Koulutusohjelma/Tutkinto-ohjelma Kone- ja tuotantotekniikan koulutusohjelma	
Työn tekijä Iiro-Elias Kaariaho	
Työn nimi Hissinoven kynnyskomponentin testaus	
Päiväys 26.3.2018	Sivumäärä 37
Ohjaaja(t) Jussi Asikainen, tutkimusinsinööri	
Toimeksiantaja/Yhteistyökumppani(t) KONE Oy Luotettavuuslaboratorio / Harri Anttila, Senior Expert, Elevator Doors	

Tiivistelmä

Luotettavuus on yksi keskeisimmistä tekijöistä kilpailussa globaaleilla markkinoilla. Luotettavuus vaikuttaa niin turvallisuuteen kuin asiakastyytyväisyyteenkin. Mekaanisessa kokoonpanossa jokainen yksittäinen komponentti on linkittynyt toiseen ja useasti kokonaisuus on juuri niin hyvä kuin sen heikoin komponentti on. Tästä syystä on tärkeää tutkia jokaista komponenttia yksittäisesti. Tämän lopputyön tarkoituksena oli suunnitella testauslaite sekä menetelmä hissin automaattioven kynnyskomponentin tutkimiseen.

Työn alussa esitellään lopputyön taustat sekä kerrotaan, millaisia tavoitteita työlle rajattiin. Teoriakappale sisältää keskeisimmät hissin automaattioveen vaikuttavat luotettavuus standardit ja niiden merkityksen. Myös luotettavuutta ja kiihdytettyä testausta tullaan tarkastelemaan.

Teorian jälkeen työssä kerrotaan hissin automaatti oven perusteet. Ne käsittävät erilaisten ovityyppien esittelyn sekä automaattioven rakenteen. Rakenteessa tullaan käsittelemään jokaisen hissin automaattioven komponentin toiminta yksityiskohtaisesti. Viimeisimpänä komponenttina esitetään kynnys- & liukuohjainkomponentin toiminta. Tämä komponentti oli myös lopputyön tutkimuskohteena. Tutkimustyö alkoi tutustumalla kynnyskomponettiin kohdistetuista vaatimuksista ja toiminnoista. Myös kynnyskomponentin luotettavuutta tutkittiin tarkastelemalla sen vikaantumista ja niiden määriä. Tutkimuksen lähteenä käytettiin asiakkaan kokoamaa tietoa komponentista.

Näiden tietojen perusteella oli tarve kehittää testauslaite sekä menetelmä komponentin tutkimista varten. Uuden laitteiston avulla kynnyskomponetin testaaminen mahdollistuu laboratorio olosuhteissa ja sen vikaantumista pystytään seuramaan sekä mittaamaan tarkasti. Testauslaite ja menetelmä ovat kehitetty niin, että niillä pystytään simuloimaan mahdollisimman paljon erilaisia tilanteita joita hissin automaattiovi kohtaa elinkaarensa aikana. Uudella testauslaitteistolla on tarkoitus testata olemassa olevia kynnyskomponentteja sekä uusia innovaatioita.

Testauksen perusteella kyetään vertailemaan ja validoimaan luotettavin vaihtoehto. Näin ollen tekijöitä, jotka vaikuttavat kynnyskomponentin luotettavuuteen pystytään ymmärtämään paremmin, minkä kautta tulevaisuudessa pystytään kehittämään entistä luotettavampia hissin automaattiovia.

Avainsanat
Vikaantuminen, luotettavuus, kynnyskomponentti, testauslaite, testausmenetelmä

SAVONIA UNIVERSITY OF APPLIED SCIENCES | THESIS Abstract

Field of Study Technology, Communication and Transport			
Degree Programme Degree Programme in Mechanical Engineering			

Author Iiro-Elias Kaariaho			

Title of Thesis Testing an elevator door sill assembly			
Date	26.3.2018	Pages	37
Supervisor(s) Jussi Asikainen, Research Engineer			
Client Organisation /Partners KONE Oy Reliability laboratory / Harri Anttila, Senior Expert, Elevator Doors			

Abstract

Reliability is a key competitive factor in global markets. Reliability affects the safety of a product as well as the customer satisfaction. In a mechanical assembly, every individual component is linked together and often the assembly is only as good as the weakest link. For this reason, it is important to study every individual component. The aim of this thesis is to design a test device and method for an automatic elevator door sill assembly.

Firstly, the background and the scope of the thesis are presented. The theory chapter contains a couple of main standards which are related the reliability of the elevator door. Also reliability and accelerated testing are studied in the chapter.

After the theory chapter the basics of elevator doors are presented. It includes a presentation about different types of doors and the mechanical structure of the elevator door. Every assembly of the door is presented briefly and their functions are explained. Last, the mechanics of the sill and guide shoe assembly are presented. This assembly is also the main research object in this thesis. The research starts by exploring the sill assembly requirements and functions. The reliability of the sill is studied also and main failure modes and the number of them are presented. KONE studies are used as a source when studying reliability.

Based on these studies there was a need to develop a test device and method for sill assembly testing. The new device provides possibility to test the sill assembly in laboratory conditions and the failure of the assembly is easy to monitor. The test device and method are designed so that the maximum number of situations which an elevator door faces during its life cycle can be simulated. Also various levels of stress are used to accelerate the test. The new testing system is mainly intended to be used for research how existing products and new innovations perform against each other under the test.

Based on the test results, it is possible to compare and validate the most reliable option. Understanding the issues which cause unreliability is the key to developing and producing better automatic elevator doors in the future.

Keywords
Failure mode, reliability, sill assembly, sill profile, test device, test method

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1 INTRODUCTION

1.1 Background & objective

The age of mega tall buildings is here. Technological breakthroughs are shaping the future of high-rise living and making the unthinkable, possible. The world`s cities are constantly growing. They attract billions of people and by 2050, more than two in every three people on the planet will live in urban areas. Estimates tell us that around 200 000 people move into cities across the globe each and every day, the same as 140 people every minute. As a result, the importance of reliability increases when functionality of the building relies on elevators and escalators. This drives elevator manufactures to satisfy the demands for better quality and reliability for elevators and escalators. (KONE 2017.)

From a reliability point of view, elevator door reliability has a huge importance for system level performance. Doors face a high level of usage and are exposed to external factors which affects their reliability. KONE has made calculations which show that approximately 30% of all unplanned works (call outs) are caused by elevator doors. By improving the reliability, it reduces the amount of call outs. This action can bring significant savings and increase customer satisfaction. KONE also has a strategy called Winning with the customer, which supports this point of view which aims to improve the relationship between the company and the customer. Understanding and ensuring the reliability and quality of a product is very important for KONE. To manage the quality, it means that every component should be studied individually. Every component has interfaces to other components so managing them wisely is important. The component interfaces are essential for enabling high performance and quality at the system level.

The aim of the thesis is to research how different factors affect the reliability of the elevator door sill and slider component. This thesis will research which issues lead to component failure. It is focused on the study of sill profile functionality, not its mechanical features. The development of the test method is based on information catered for failure mode analysis. The test method is intended to be accelerated testing, which is not a simple subject. Understanding the whole assembly is crucial, where simulated failure modes must reflect real life failures. A good qualitative test is one that quickly reveals those failure modes that will occur during the life of the product under normal use conditions. Accelerated testing uses higher load levels, which results in faster defects in the product.

The aim is to research the reasons that cause sill profile failure and use the information to create a test method, as well as a test device to examine how different sill assembly perform. The method must be standardized so that after the test, it is possible to determine how different sill components perform against each other. It means that the method must be precisely controlled. Based on the test, it is also possible to research how different stress parameters affect failure. The research gives valuable information about the sill and the slider components. This information can be used in future product- and design guideline development. Because of this development, the reliability of the components improves. It means better reliability, which leads to less call outs and finally to savings and better customer satisfaction.

1.2 Scope

The main objective of this thesis is to design a comparative test system and testing method for a sill ensembles. Sill and slider components are the main scope. The thesis will include the design of the test device and development of the test method. The test device and the test method are especially designed for sill and slider component testing. It is crucial to study how ensembles behave in real life and transfer that knowledge to test method development. Verifying the outcome of the test method will not be included in the scope of the thesis but it will be done afterwards.

1.3 KONE

KONE was founded in 1910 and today it is one of the global market leaders in the elevator and escalator business, net sales being 8.8 billion euros in 2016. KONE operates in over 60 counties and has over 50 000 employees worldwide. (KONE, 2017.)

The corporation has seven production units and eight global R&D centers and the head offices located in Helsinki. During the last few years, KONE has grown, although the situation in European markets has continued to be tough. The growth is mostly due to strong growth in Asian markets. Today KONE`s sales are divided by businesses so that new equipment business accounts for 55 % of total sales and service business accounts for 45 %. (KONE, 2017.)

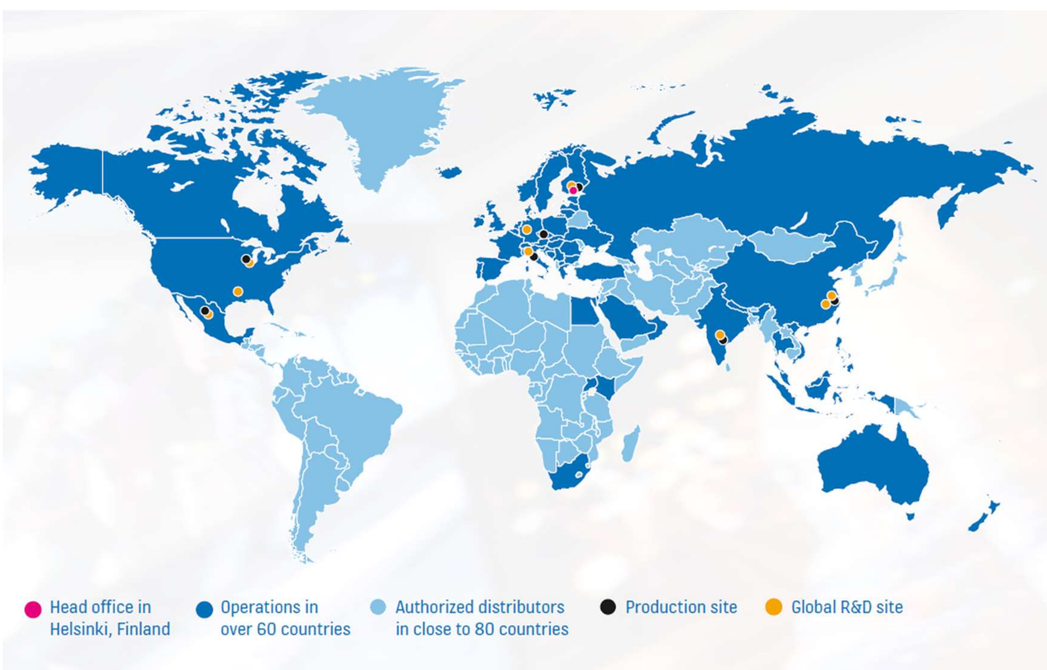

Figure 1. KONE worldwide. (KONE, 2017.)

Over 1.1 million items of equipment are in KONE service. Key customer groups include builders, building owners, facility managers and developers. Also architects, authorities and consultants play a key role in the decision-making process regarding elevators and escalators.
KONE has segmented the markets according to the purpose of the building with the main segments being residential buildings, hotels, offices, retail centers, infrastructure and medical facilities. Special sectors are also served, such as leisure and education centers, industrial properties and ships. (KONE, 2017.)

KONE`s vision is to create the best People Flow experience which means enabling people to move smoothly, safety, comfortably, and without waiting in and between buildings. To track the progress towards this vision, KONE has set five targets: to have the most loyal customers, to be a great place to work, to have faster than market growth, to have best financial development, and to be the leader in sustainability. These, as well as value, high priority areas, must-win battles and industry megatrends are shown in figure 2.

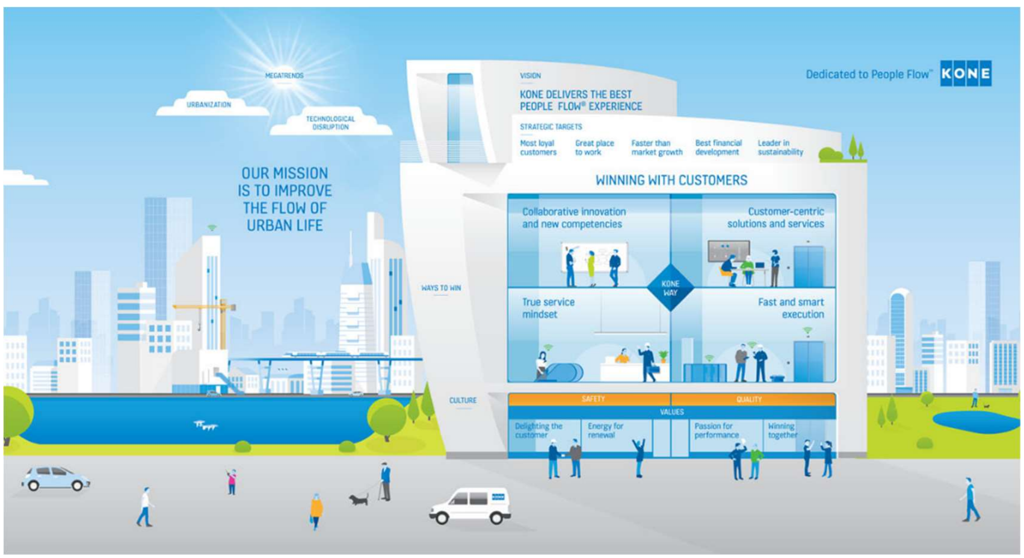

Figure 2. KONE strategy and vision. (KONE, 2017.)

KONE is a proven technology leader in the world. It has over 3,000 patents across its elevator businesses. It is by understanding urbanization; focusing on improvements for people and anticipating the needs and opportunities for people – that we can develop innovations and breakthroughs which help improve buildings and make our cities better places to live in. And as new ecosystems emerge around smarter cities and smarter buildings there is a huge potential with the integration of building design with elevators, escalators, services and other utilities, in the most sustainable ways possible. (KONE, 2017.)

KONE has also seven R&D centers across the world and two of them are from Finland. They are located at Hyvinkää and in the Tytyri mine, Lohja. These centers are mainly focusing on reliability, product management and high rise buildings.

2 THEORY

In this chapter, the basics of reliability engineering and testing are presented. Also, the standards relating to elevator safety are described briefly.

2.1 Standards

KONE follows the European lifts directive 2014/33/EU. Standards allow "free circulation" for lifts and safety components for lifts within the EU territory. Every new lift and safety component for lifts must fully comply with the provision of the directive to enjoy the free circulation. For KONE, part of this is done in the Hyvinkää reliability laboratory. As the "free circulation" objective is achieved when the lift is on the market, maintenance, modernization and dismantling of lifts is subject to national regulations.

Standards have been transposed into the national laws of 28 EU members. Therefore, a product in compliance with the directive may freely be put on the market in any Member State without restrictions.

Figure 3. 28 European Members

After the transposition, national laws of each Member State contain identical technical requirements as of the directive. A manufacture or installer must still comply with the national laws of each individual country, but those laws contain identical technical requirements**.** Each economic operator must be able to identify his supplier and his customer in relation to the safety components, up to 10 years after the transaction as shown in figure 4.

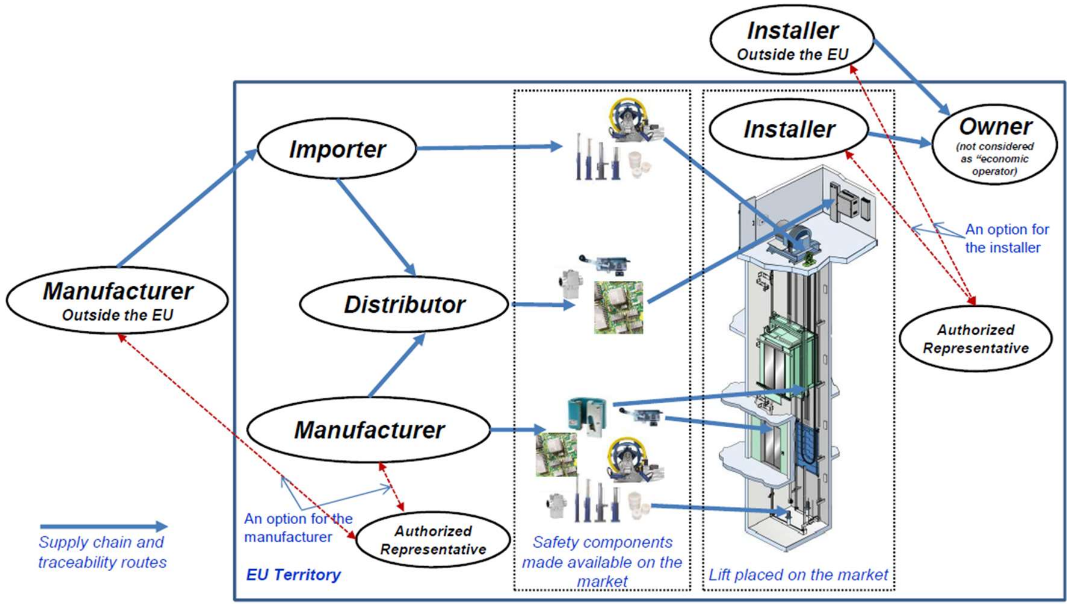

Figure 4. Supply chain and traceability routes

2.2 Standards EN 81-20

The object of this standard is to define safety rules related to passenger and goods passenger lifts with a view to safeguarding persons and objects against the risk of accidents associated with the normal use, maintenance and emergency operation of lifts. (KONE, 2017)

This standard does not repeat all the general technical rules applicable to every electrical, mechanical, or building construction including the protection of building elements against fire. It has, however, been necessary to establish certain requirements of good construction, either because they are peculiar to lift manufacture or because in the case of lift utilization the requirements may be more stringent than elsewhere. The scope of this standard is to specify the safety rules for permanently installed new passenger or goods passenger lifts, with traction, positive or hydraulic drive, serving defined landing levels, having a car designed for the transportation of persons or persons and goods, suspended by ropes, chains or jacks and moving between guide rails inclined not more than 15° to the vertical. (KONE, 2017)

For the elevator doors, the EN 81-20 is European standard for lifts for the transport of people and goods. It includes a list of regulations which elevator door must fulfill.

Mechanical strength:

- 1000N static force test panel and frame – max allowed gap 10mm (max permanent deformation 5mm)
- 1000N and 300N static simultaneous force for side opening doors linkage – integrity may not loosen
- Impact test for panels with failed guiding elements – integrity may not loosen (max gap 120mm)
- Impact test for frames wider than 150mm – integrity may not loosen

Additional safety:

- Pit Escape Device – allows to unlock lowest door from the pit – Pit Height max 2,5m
- Reset switch – after pit service drive operation reset switch must be activated from outside of shaft
- Car door lock is mandatory
- Open force limiting with glass doors
- Emergency opening device – longer key for doors higher than 2400mm
- Emergency opening device position changed to frame if doors are higher or equal than 2700mm

Curtain of Light:

- Diameter 50mm object detection whit in clear door opening area
- Detection coverage from 25mm to 1600mm (will cover EN81-70 1800mm requirement)
- Self-detection of failed receiver or transmitter -> nudging speed

2.3 Reliability

Understanding and managing reliability is very important in a global market. The reasons why reliability is so important, is that it affects many crucial things such as: reputation, customer satisfaction, warranty costs, repeat business, cost analysis, competitive advantage.

Reliability is a design engineering discipline which applies scientific knowledge to assure a product will perform its intended function for the required duration within a given environment. This means designing the product so it maintains the performance through its designed lifetime. The designed lifetime can be verified by making different analyses and tests for a particular component.
(IEEE, 2014)

Reliability is a broad term that focuses on the ability of a product to perform its intended function. Theoretically, reliability means product ability to perform as it is intended. The product must fulfill the requirements which are set to it in specified period of time without failure. For elevator components, this means that the product must fulfill the requirements which are set for it. Those Requirements can be mechanical strength and component functions (Weibull, 2017).

Quality and reliability are slightly difference even though they are closely similar. Quality is more related to manufacturing and reliability is related to component performance in real use. Even if the product seems to have reliable design, it does not mean that manufacturing can fulfill the requirements. If so, the reliability may be unsatisfactory. The reasons for low reliability may be that the design has too tight tolerances or manufacturing process are poor. The whole process from the design to the manufacturing has be to planned so the component can perform as intended. At the design phase, it is important to understand the manufacturing process. Every manufacturing method has it constraints and understanding them enables us to create and design reliable products.

Just as a chain is only as strong as its weakest link, a highly reliable product is only as good as the inherent reliability of the product and the quality of the manufacturing process. (Weibull, 2017)

2.4 FMEA

FMEA means failure mode and effect analysis. FMEA drives design improvements (design FMEA) or manufacturing or assembly process improvements (process FMEA) as the primary objective. In this thesis, FMEA potential failure modes are identified and their effects evaluated. Each failure mode, possibly leading to a high severity event or having a high-risk value, must be mitigated until an acceptable level is reached. Primarily these risky failure modes should be eliminated by design or process changes. As an alternative, the risk can be decreased by improving control or reducing the severity (not common). For all risk mitigating actions, DFMEA focuses on design improvements through identifying and preventing potential failure modes of the design in early design phases. It identifies critical design/product characteristics. Failure modes can also be externally caused. Consideration should be given to e.g. mechanical, electrical, chemical, human behavior (vandalism, known misuse, accidental), biological (animals, fungus etc.), EMC, ESD stresses and sources. (KONE, 2017.)

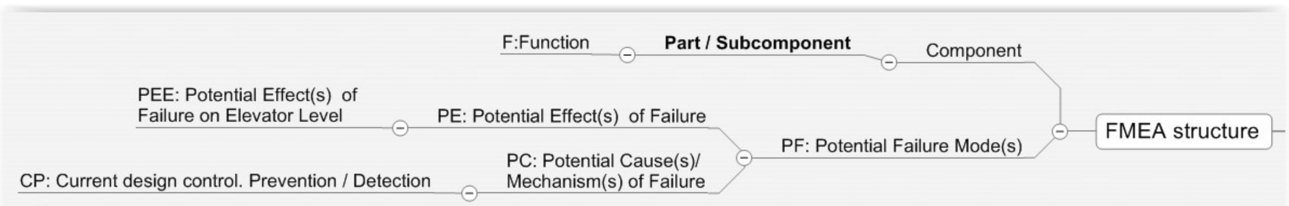

Figure 5. Basic of FMEA analysis structure

2.5 Accelerated testing

Normally life data analysis is made components or products which are under normal operating conditions. Many times, this process can be too time consuming and that's why there is a need for accelerated testing. Accelerated testing is process were component or product are placed under conditions which are extreme than conditions on normal use. The purpose is to find the failure modes in short amount of time. Ultimately, time to failure data trend can be followed and predictions can be made for the product performance.

When determining the duration of the test it is important to understand that the acceleration must occur so that it corresponds to the actual characteristics of the component or system. This can be a very difficult process because tests carried out under accelerated conditions will have to refer to the components under real conditions. When the accelerated test is able to replicate the real behavior of the component or system, it can be verified as a reliable test method and taken into use as part of the testing process. (KONE guideline, 2017.)

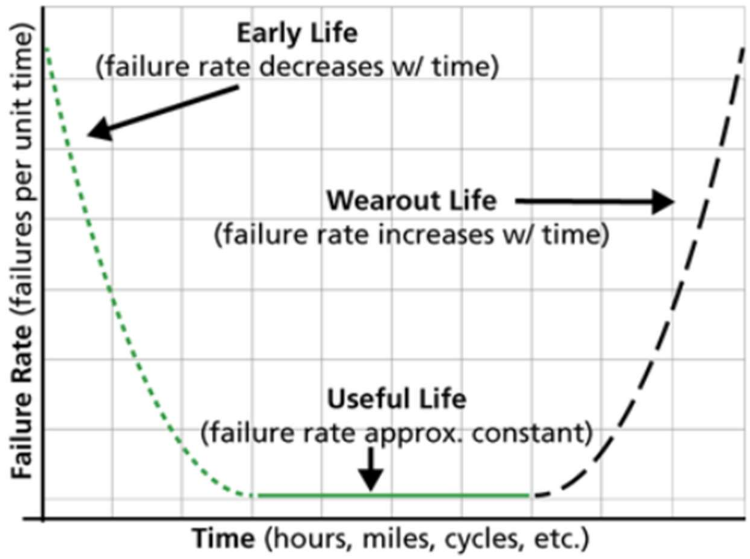

Figure 6. Failure and time ration

The most difficult part of the accelerated testing is to find right stresses and variables which are used in the test process. Finding the right parameters requires accurate background work. It means analyzing previous data about the component or system. When the right parameters are founded then the acceleration factor can be determined. It means finding the right frequency to add stress, step by step. Finding the right frequency is just as important as determining the duration of the test. In both cases the most important thing is the ability to simulate actual behavior of the component. (KONE guideline, 2017.)

The purpose of this thesis is to develop accelerated testing for different types of sill component. To compare the results, the comparative testing method is applied. Comparative testing evaluates the strengths and weaknesses of two or more products. Based on the test result a conclusion can be made to find out which products performed best and for what reasons. When the reasons of failure are founded the existing products can be developed.

3 BASIC OF ELEVATOR DOORS

Elevator doors are safety components and they are split into two parts, landing doors and car doors. Landing doors are present at every landing and fixed to the building, and their main task is to prevent access to the elevator shaft when the elevator is not present. Car doors are attached to the car front wall and their job is to prevent passengers from being able to touch the shaft wall when the elevator car is moving. Car doors have only recently become mandatory, so they are not always present in older elevators. (KONE, 2017. Design Guideline for Elevator Doors)

The car door is operated by an electric motor located on top of the car, in the operator. As the car arrives at the desired landing, a signal is sent to the motor, which then starts opening the car door via a toothed belt mechanism. As the car door opens, a coupler (lock) mechanism in the operator grabs the landing door by the railing and opens it. In this way, the landing doors are never opened unless an elevator car is present. Both car and landing doors are locked when car is out of the landing zone.

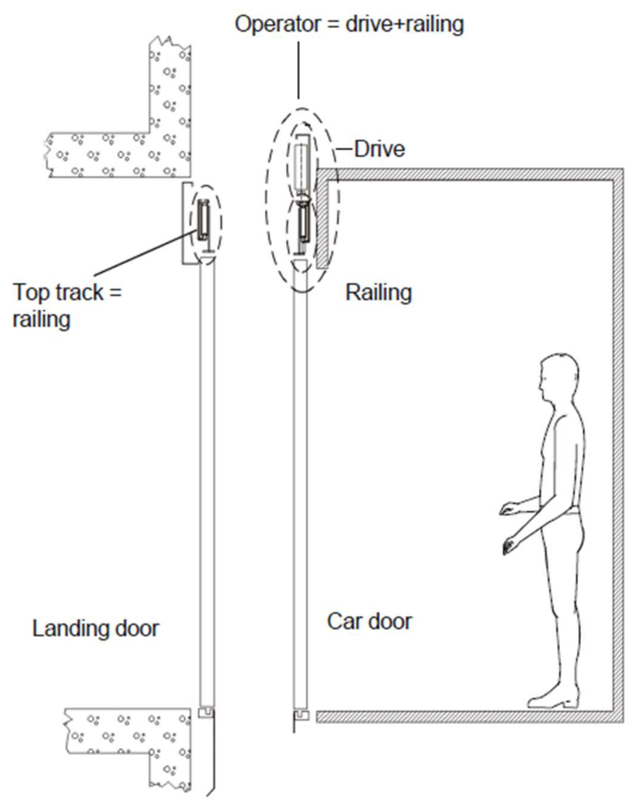

Figure 7. Elevator shaft basic structure

3.1 Door types

KONE offers three different product lines called KES (KONE Entrance System). They are designed based on the utilization of the door and they are differentiated by the duty range, shown in table 1.

Table 1. Elevator door duty ranges and their target groups

	BASE-DUTY	MID-DUTY	HIGH-DUTY
	<200.000 cycles per year. Design lifetime 10 years.	...400.000 cycles per year. Design lifetime 10 years.	...800.000 cycles per year. Design lifetime 10 years.
Examples of use	Residential	Small hotels, offices, shopping malls	All above mid-duty; big hotels, shopping malls

For different elevators layouts KONE has many different door basic structure variations. The different elevators door layouts KONE has to offer are listed in figure below. Door types 1, 2 and 3 are the most common and they cover almost over 90% of all products.

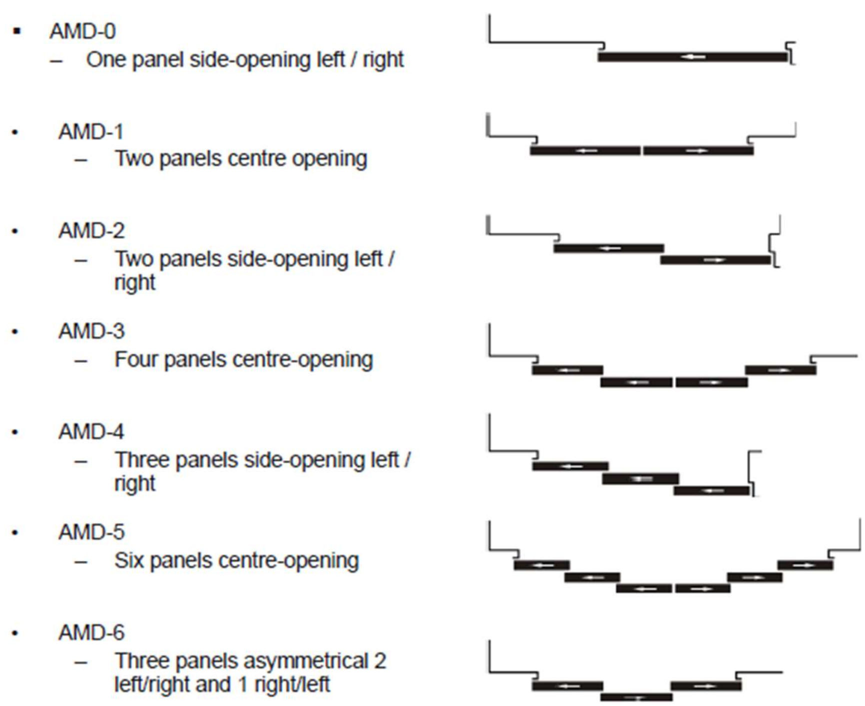

Figure 8. Different elevator door layouts

The division into duty ranges is made to avoid using over designed doors in certain situations. Over designed in this case there is the residual life left when the product is taken out of use. It ensures that a competitive product cost level can be achieved when the products and their lifetimes are designed realistically. In addition, other product development key performance indicators, such as time to market, can be achieved. (KONE 2014.)

3.2 Structure of the elevator door

The KONE elevator door structure consists of four main parts. Door panels, frame (metal panels which goes around the door opening), railing (also called top track) and sill. Door panels hang from the hanger plates which are attached to the top track. The top track includes the drive box which uses the electric motor to drive the door panels. The sill is used to guide the door panels. The panels have guiding shoes which slides in the sill groove.

Elevator doors are separated into landing and car doors. They have small mechanical differences between the components, generally the car door contains more mechanics than the landing side. Biggest difference is that the landing door does not include an operator, only the car door has it. When an elevator comes to the floor the two railings attached together and the operator moves them both.

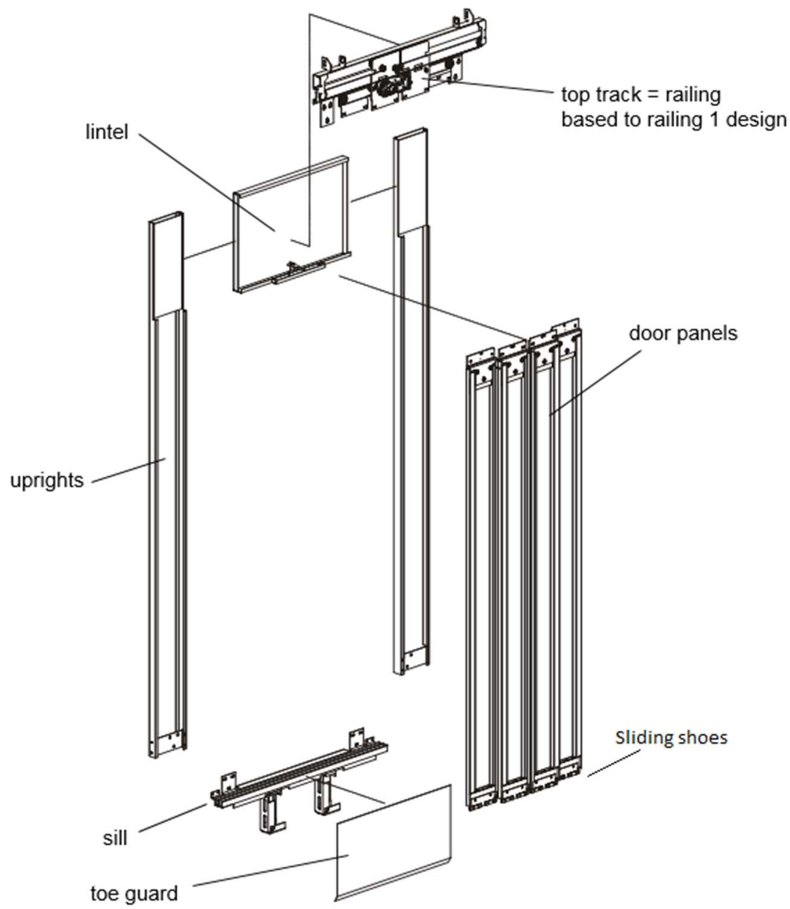

Figure 9. Elevator door main parts

There are four main type of **frames.** Frame, frameless, narrow frame and front types. The entrance is practically the only way to describe the interface between the landing door and the building. The frame of the door is visible to the user at every landing (floor). Car doors don't have frames, as they are part of the elevator car. Safety is the main function of the frame, its purpose is to cover the opening of the landing, so that the shaft is not accessible from the landings.
The frame consists of two uprights on the sides and a lintel on the top. The frame is connected to the sill at the bottom of the entrance and to the shaft on the top. The frame is also connected to the railing and it depends on the door type whether the railing supports the frame or vice versa. The different entrance types are displayed in figure 8. Different door frame types that KONE has to offer can be found in figure 10. (KONE, 2017)

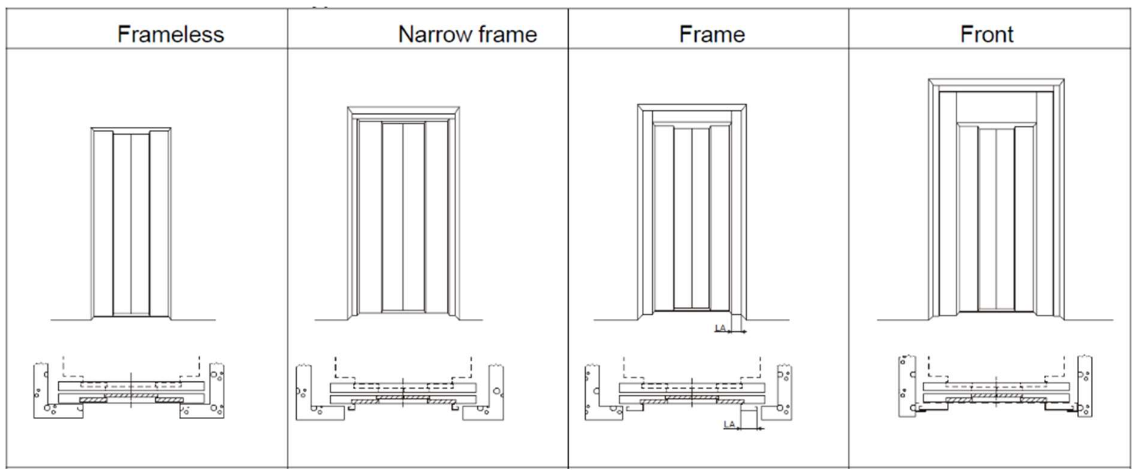

Figure 10. Door frame types

Door panels usually consist of the panel body, sliding guide and insulation. Sometimes stiffeners are used on the back of the door body plate to increase stiffness of the panels. The panel body can be either single or double skin. A single skin body means that the body plate itself is visible to the user. In a double skin body, the panel is attached to the hanger plates from the thicker body plate, which can be of cheaper and thicker material. The body plate is makes the panel rigid, while the second skin (cladding), usually of very thin material, provides the visual outlook for the lift user. Panels are also key components from a fire safety point of view. (KONE, 2017)

All KONE KES base-, mid-, high duty **operators** are installed in the same way to different KONE car front walls using operator fixing brackets as interfacing parts. Operator fixing brackets belong to the operator delivery and they are selected based on the car front wall thickness which is typically 35mm. High duty cars typically include thicker front wall like 75mm or 100mm. The car front wall transom has to include a suitable cut out for operator fixing brackets. In the case of modernization, sometimes the existing car fronts wall is removed totally (cut off) and a new front wall is delivered along with car doors and operator packages. This is to ensure that the car door operator and car front wall fits together.

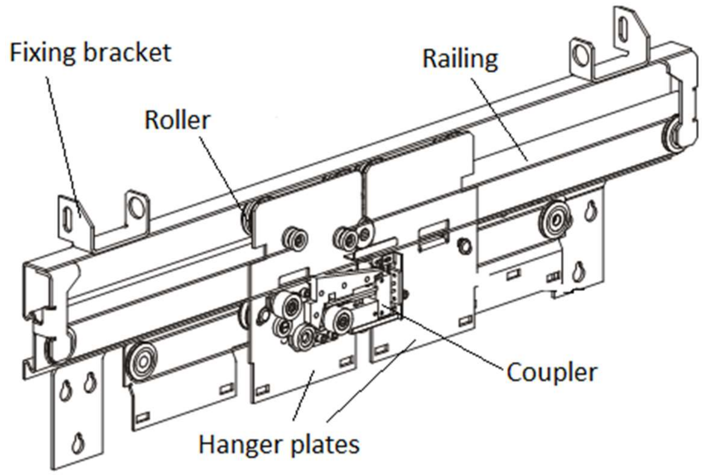

Figure 11. Elevator automatic door operator assembly

Railing (also called top track) enables movement of the door. The hanger plates (Figure 9), to which the door panels are attached, move along the railing on rollers. The railing also has a lock which prevents door opening when there is no car behind the landing door or when the elevator car is moving. A closing device, usually a spring or a weight connected to the railing via a wire and pulleys, is used to ensure that the door closes in every situation, e.g. during a power outage. Landing doors don't have any mechanisms to open by themselves, and they always need a car door behind them to open – in a sense the landing door is a slave system. The car door has a similar railing as the landing door, but it also has a so-called operator on top, which is responsible for the movement as it has a motor which runs the drive belt. The car door operator has a coupler mechanism, which grabs the landing door lock rollers with vanes to open the lock and to open the door. In this way the landing and car doors can only open simultaneously, preventing any undesired opening of the landing doors and thus increasing safety considerably. (KONE, 2017)

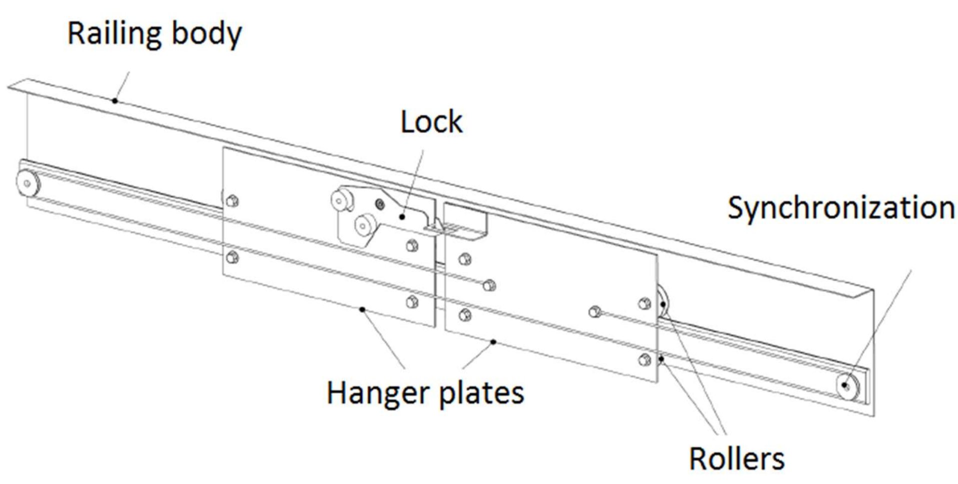

Figure 12. Elevator automatic door railing assembly

The **sill** is located at the bottom of the door and its main purpose is to guide the door panels. Sliding shoes help the panel to move smoothly to reduce surface friction between the sill and the panel. It also prevents people from falling into the shaft as it's usually located inside the shaft. The sill also acts as a fixing point for the uprights of the frame.

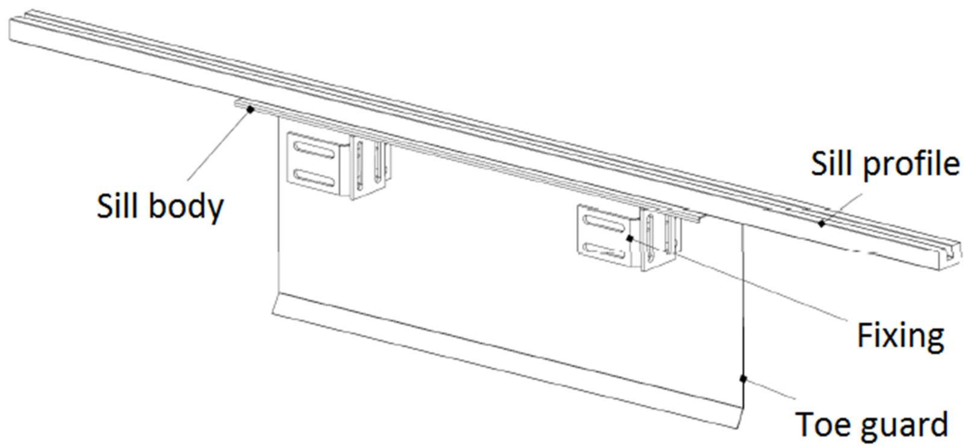

Figure 13. Elevator automatic door sill assembly

The **sliding guides** are running in a groove in the sill and only act as guides for the movement since they are not supporting the panel in the vertical direction. They only support it from horizontal forces, for example if something hits the door. Insulation material is added on the back of the panel if insulated fire rating is needed or just for noise insulation purposes. (KONE, 2017)

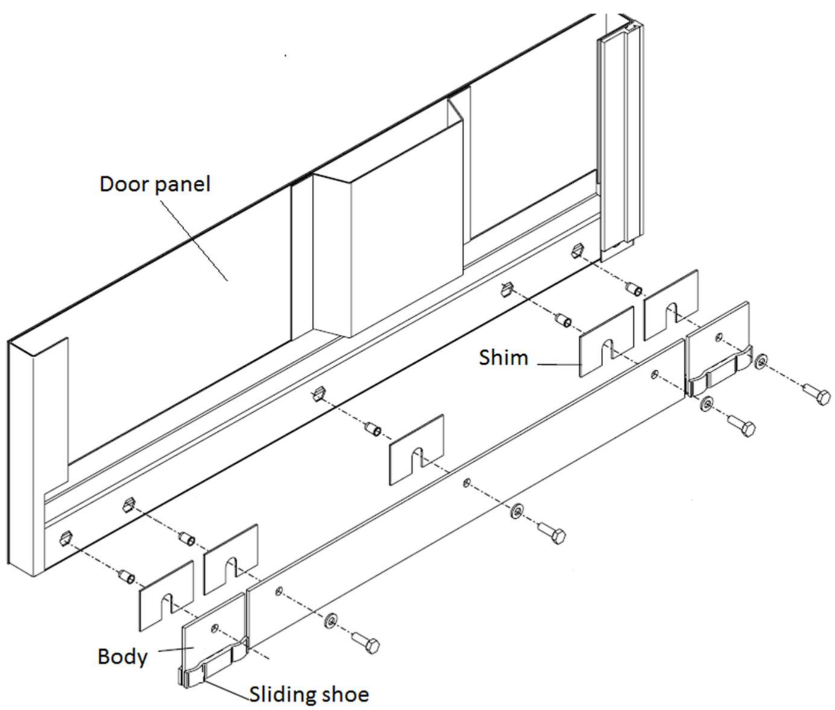

Figure 14. Elevator automatic door sliding shoe assembly

4 SILL ASSEMBLY RELIABILITY

KONE design guideline includes a list of requirements which sill components should fulfill. The design guideline is developed to give basic information about requirements which components should fulfill. Requirements can be found in table 2. The requirements are based on the elevator standard EN81-20 and knowledge about safety and ride comfort of elevators and elevator doors in general. The design guideline also includes requirements which are related to customer feedback and an understanding of components reliability. (KONE, 2017.)

Safety is the most important requirement and the sill components should function so that they perform as required. The main function is that the sill assembly must main its shape and not deform greatly. If so, the door panel loses guidance which can lead so called "mail box effect". This means that the door panel loosen from the sill and access to the elevator shaft is possible. Also, the fire resistance affects safety. The general rule for fire safety is to keep the fire on the landing side if any fire accident happens in the building. There are several different classes for fire testing in the EN81-20 standard. Every class defines that the sill assembly must not melt in case of fire. Ride comfort requires that sill assembly should work so that between the guide shoe and the sill profile there should be minimal friction. Friction between these two parts is a major problem from the reliability point of view. The sill assembly is exposed to many external impurities which end up in the sill profile and leads to the door jamming. Trash holes formed in the sill profile are designed to relieve this problem but they cannot solve the problem itself. The problem is that although the trash holes exist the sliding shoes are not designed to transfer the dirt to them.

Table 2. Sill requirements and functions (KONE, Design guideline)

Requirement	Function	Source
Safety	Durability; the frame does not deform greatly and upholds its safety functions for the duration of the products lifetime. Keeps door panel in guidance (prevents so called mail box effect) Close shaft raw opening Keep flat surface under sill- no cutting edges	EN81-20/50
Visual outlook	Uphold visual outlook for the duration of the products lifetime	Customer
Fire resistance	Must not melt in case of fire	EN81-58 (optional)
Ride comfort	Minimal friction between guide shoe and sill profile	
Self-cleaning	Trash holes	
Interface to building	From building tolerances to machined tolerances	
Guide for sliding shoes (1-3 grooves for 1-6 panels)		
Load carrying capabilities (400-10000kg)		
	Interface to frame uprights	
	Make concrete after-casting possible	

4.1 COR & FYCOR

Elevator reliability is measured by tools called FYCOR and COR. The abbreviation of the FYCOR comes from words first year call-out rate. It is the average number of call-outs in a specified equipment group during the lifetime in service after the handover. COR is the same thing except it measures all call-outs. It is any chargeable or non-chargeable unplanned work that has been opened upon a customer request or a remote monitoring system call during the reporting period, on any equipment under KONE maintenance contract. This covers:

- All type of equipment's under maintenance contract
- All equipment under maintenance or free maintenance contract
- All reasons of the callout: technical failures, vandalism, misuse, external reasons

FYCOR is an indicator of quality for the full chain from design to installation and maintenance. Eliminating FYCOR improves customer satisfaction and can bring significant savings. Every call-out damages the customer relationship especially during the first year. FYCOR is calculated so the sum (annualized) of call-outs in all equipment is divided by the number of all pieces of equipment.

4.2 Sill assembly COR

The scope of this COR is the KONE elevator MonoSpace 500, which is the most popular model of KONE elevators. This covers more than 30 percent of all KONE elevators. The time period which is used for data study is 2016 to present (22.2.2018).

As shown in the diagram the elevator doors causes the most number of call-outs, almost 30% in all. A closer look at the component level distribution shows that sill assembly is in the list with the top-track and panels. Sub component distribution shows (Not in the figure 15) that the sill assembly quantity of all sub components is about 12%.

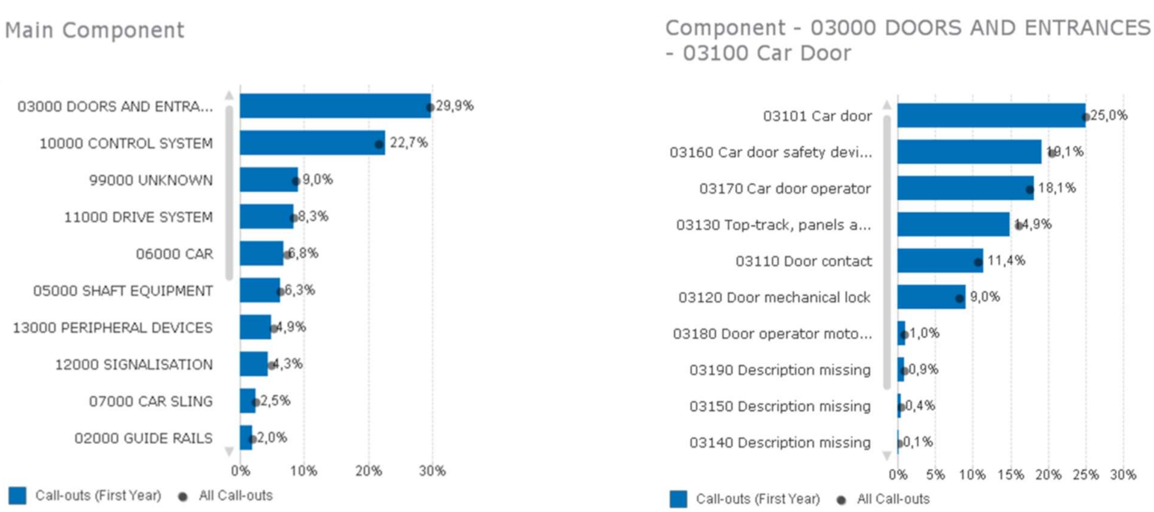

Figure 15. COR figures

4.3 Failure modes

The sill assembly faces typically three types of failure modes (PF). They are identified and listed to KOS-000036. The list includes also potential causes (PC) of the failure and how they affect component function (PE).

1. Visual errors
2. sill is bending
3. door is not closing properly

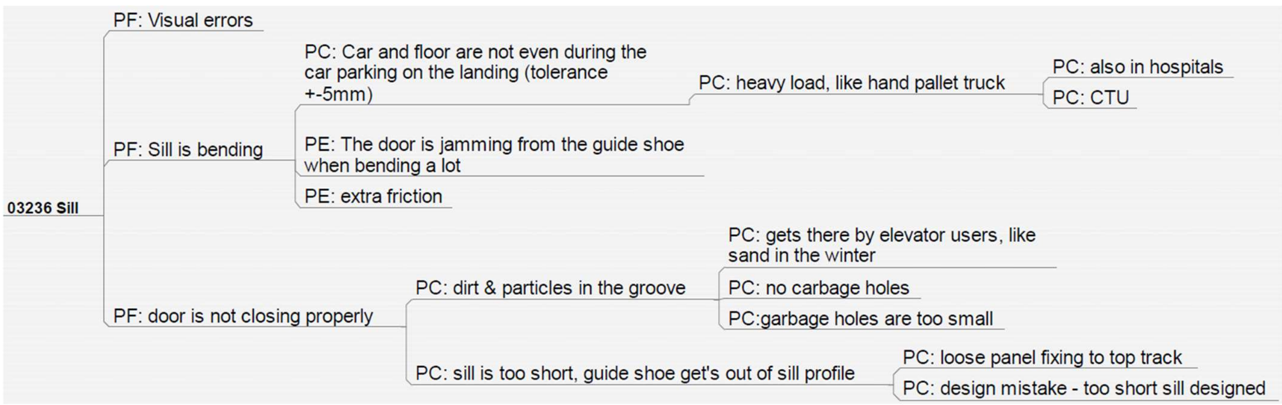

Figure 16. The sill assembly failure modes

Visual quality means typically fulfilling geometrical tolerances in terms of shape (flatness, angle etc.) as per design requirements in the final elevator installation both for parts, components and assemblies including connections between parts – no gaps, no indirect lines, no bending in critical points etc. Errors are mainly caused by mistakes in manufacturing, packing, transportation, installation and vandalism. Also, KONE Design Guideline for Elevator Doors have a requirement for visual outlook. That is to maintain visual outlook for the duration of the products lifetime. This requirement is hard to fulfill because sill assembly has a high utilization rate and faces external variables.

Figure 17. Typical visual flaw

Safety is the most important requirement and the sill assembly should function so that it perform as it required. Sill profile deformation can cause the most significant safety risks. Too much deformation can lead to the situation that the sill assembly cannot support the load, allowing the door panel to escape from the sill profile groove, so allowing access from the landing into the shaft. This event is the so called "mail box" effect, and it can happen if someone or something hits the door with a force. Fire resistance is also part of elevator door safety. There are several different levels of fire tests but they all have the same requirement that the door sill assembly must not melt in case of fire.

The bending of the sill is caused by force which shapes the sill (usually a heavy load, such as a hand pallet truck hits the sill). This is a typical situation when car and floor are not even during the car parking at the landing. It means that the elevator car-and the landing door are not at the same level. This cause situation where the elevator doors cannot not move extra friction between the sill and the guide shoe which affects ride comfort and worst case even jam the elevator door totally.

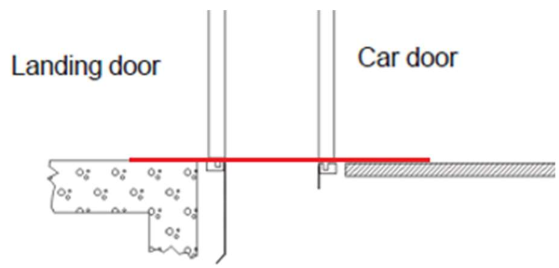

Figure 18. Landing and car door leveling

The most potential failure mode of these three are that the door does not close properly. The sill is stepped on when passengers are entering or exiting the elevator car, causing it to gather quite a lot of dust and rubbish. This can cause some issues with the door movement, as the panel sliding guides are travelling in the sill groove. This issues can affect door ride comfort and in the worst-case, it can stop the door movement totally. A situation like this means that the safety circuit is "open" so the whole elevator will not move. Trash holes are designed to guide dust and rubbish away from the sill profile, but in most cases they are too small or incorrectly placed at the design stage. In some cases, garbage holes are missing completely. The time of the year affects to the failure rate. For examples in Finland winter time there is a peak in the failure rate caused by the sand which is used in road and walkway maintenance.

Figure 19. Sill profile with carbage holes

5 SILL ASSEMBLY TESTING

This chapter presents a detailed view of how the sill assembly is designed to be tested. First the test purpose and targets are presented, and after that comes more detailed information about the testing equipment design and testing method. The test method topic covers how the sill assembly test is planned to be accelerated and how stresses/variables are measured & controlled. At the end of this chapter is also short presentation how the test is done in practice.

5.1 Test purpose

The sill tester is developed to make accelerated testing for elevator door sill assemblies. The target is to find how the flaws in design, installation and manufacturing affect the sill assembly reliability. The most essential parts of testing is to have a clear vision of the test purpose. The test has four main purposes namely:

1. Study how the sill assembly performs under stresses and different variables
    - Finding the right reasons behind the failure
2. Make comparative testing between the existing products
3. Test new design and ideas to develop the sill assembly
4. Develop the product

All the tests are planned to perform in accelerated circumstances. Different kinds of stresses and variables are used to simulate acceleration and defects caused by installation or manufacturing. The test method includes constant measuring and control of the sill assembly performance. Finding the right parameters are a key function when developing a new test method. It is crucial to develop a reliable test method because it is important to get proper results.

When the right parameters have been found the testing can start. The test purpose is to find what kind of sill assembly perform best and for what reason. Also, new ideas are to be explored with the tester. After the testing analysis can be made and based on them, the KONE design guideline can be developed. Finding the reasons which cause the failures are important in product development. This increases reliability at every level of the elevator and can also provide cost savings in the long run.

Figure 20. Basic progress of the test process

5.2 Test device structure

The tester design began by defining the requirements for it. The most important requirements for the test device were:

1. Ease to use
2. Good adjustment options
    - Any KONE operator can be installed in the frame
    - Adjustable sill assembly

The tester is designed so any KONE operator, panel and sill assembly can be installed in the frame. The tester also allows the possibility to make many different installations and setups. Good customizability means that many different real life events can be simulated with the test device and the maximum amount research information can be collected. The high utilization rate and good customizability are also a cost effect solution when only one test device is needed to research various problems.

The test device structure consists of five main parts; frame, operator, panel, controller and sill. The frame and the door panel are specially designed for the tester. The rest of the parts are pre-manufactured products.

Figure 21. Test device structure

The aluminum profile was chosen for the **frame** material in the design phase, because it allows high adaptability and it allows to make many different kinds of test setups in the tester. The frame is built from pieces aluminum profiles which are held together with anchor as in the picture 23.

Figure 22. Aluminum frame used as a main frame

The anchors are easy to loosen so, for example the bars that hold the operator and sill, can be easily moved vertically. Bars are highlighted at the picture number 22. The ability to move the bars means that every kind of KONE operator and all heights of door panel can be installed in the tester. Also, fixing the sill component to the frame is easy and the gap between the sill and the guide shoe can be adjusted to see how the friction between them affects the results.

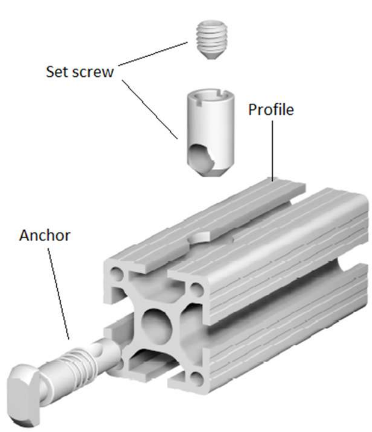

Figure 23. Anchors are used to attach the aluminum profiles together

The **operator** is installed at the top of the tester frame to the horizontal bars. They can be moved vertically which means that every KONE operator can be installed to the test device. At a later stage of the testing process it is intended to install another operator on the other side of the beams, so two tests can be executed simultaneously.

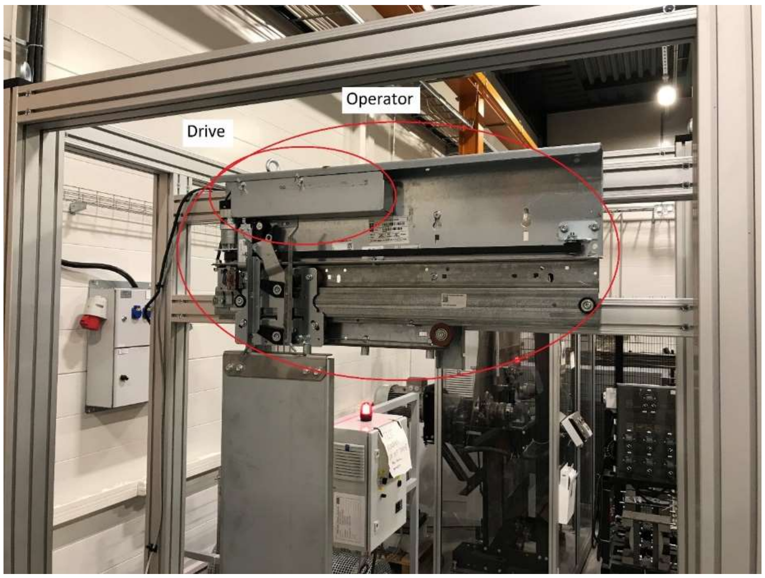

Figure 24. Operator fixing place

The operator includes a railing and a drive. The **drive** can be read by a piece of specially designed PC software called the WPT Emulation tool. It gives valuable information about the current, opening force and etc. WPT Emulation is one of the tools which are used to measure the test sample behavior under the stress. Pictures 25 and 26 is an examples output from the WPT tool. It shows how force and door speed behave as a function of time.

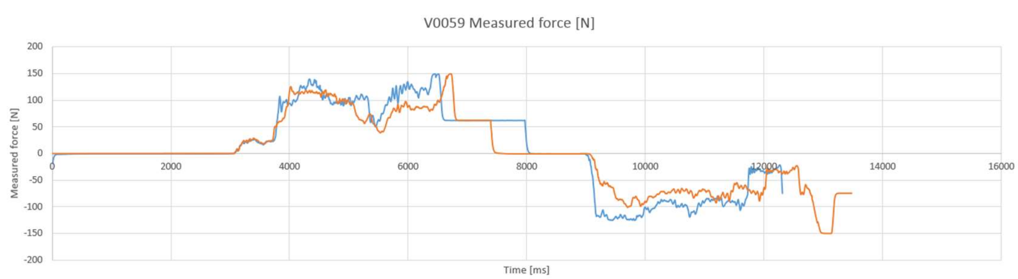

Figure 25. Example (1) for WPT emulation software

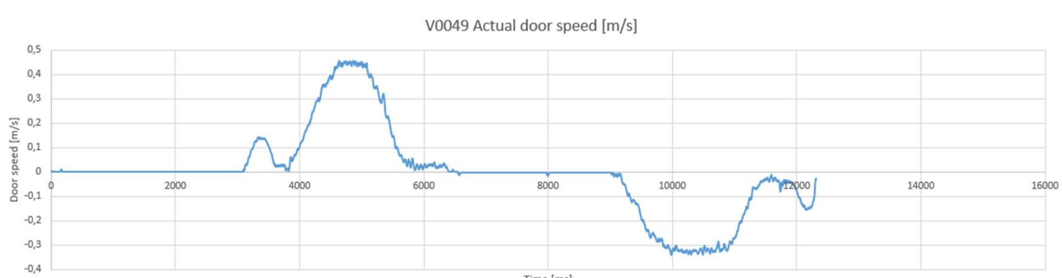

Figure 26. Example (2) for WPT emulation software

The **Panels** are built especially for the test device and they are scaled 2:3 of the actual door size. Just like the frame, the door panel is also designed to allow it to perform various amount of different test setups. The panel consists four main part: top fixing plate, panel, additional weights and bottom fixing plate.

Figure 27. Door panels specially designed for the test device

Separately detachable top and bottom plates (see figure 28) allows the possibility to change parts without having to change whole door. For example if different designs of the guide shoe component want to be tested, only the bottom part is needed to replaced. The panel weight is also adjustable. Additional weights are used to simulate heavier panels, for example glass panels. It also can be used as a acceleration parameter at the test method. Heavier panels add stress for all components of the door.

Figure 28. Separately detachable top- and bottom plates

The **Sill** profile is installed on the top of the beams by a T-slot nut. The sill can be moved vertically and horizontally by loosening the T-slot nut or the sill anchors on the frame. To avoid sill profile adjustment measuring lines are added (figure 29). It makes moving the sill component easy, fast and reliable.

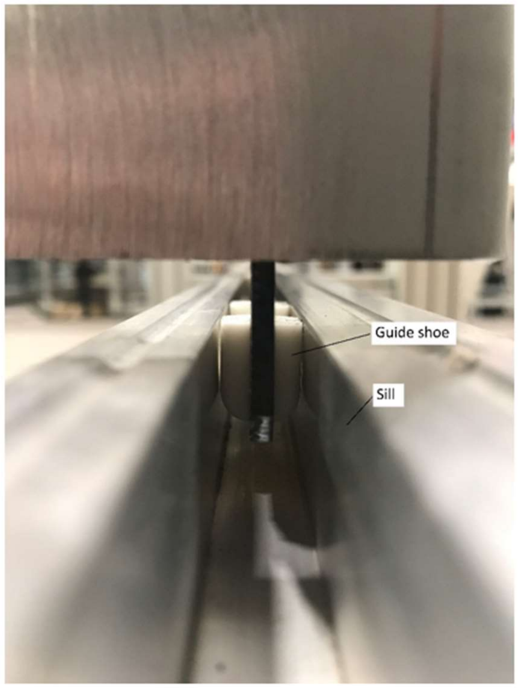

Figure 29. Sill fixing and measuring lines

5.3 Test method

Test method type is comparative testing in accelerated circumstances. The purpose of the test is to find weaknesses in the elevator door sill assembly. This means testing individual sill assembly under the accelerated circumstances and compare the results. Based on the results conclusions can be made and the product can be developed in future.

Initially, a clear vision of the test process should be made. Determining the process is fairly easy because KONE reliability laboratory has great experience in similar test processes. The second important point is to find the right stresses and variables which the sill profile faces in field conditions. Finding the right parameters is a hard task. It takes time, practice and collecting the information during the test. Only when the method is standardized does the actual testing start. It's clear that the test method will develop during the first tests. Every test will give new information about the assembly function and this information can be used in developing the test method. Determing the stress and variables are a major part of creating a reliable test method. KONE KOS-000036 are used as a source of finding the right stress and variables, it contains every know failure modes.

How to control and measure the test result are key factors when determining the component performance. The basic method is that, at first as many as possible measurements are made. After the necessary number of tests are made, the most useful measurements are validated.

The KONE research and development laboratory has its own HALT (highly accelerated testing) process. It is made for every elevator door before releasing it to the market. HALT test includes several different tests and three of them are related to the sill assembly. The test include elevator door sill durability during lifetime with mechanical loading, pressure tests and strength tests. The newly developed test method will be added as part of this group. Where the previous tests study mainly mechanical quality, the new test method focuses on sill assembly performance under real usage conditions. These have been studied very little under laboratory conditions. In the end, the goal is to develop sill assembly design so that it becomes more reliable.

5.3.1 Basic process

The testing process starts by selecting a sill assembly to be tested. After the test sample is selected, the test parameters are defined. Determining the parameters depends on what kinds of phenomena are to be researched. Parameters include all the adjustments, stresses and variables of the test, such as amount of dust which is put into the sill profile after every cycle. After defining the test sample and parameters, the test setup can be made. This means installing operator, door panel and sill assembly onto the frame.

After installation, the first measurements can be made and testing can begin. Stress levels are continuously raised during the test and the sill assembly performance is measured simultaneously. The test is due to be completed after 6000 cycles or less. It equals the average amount of cycles that an operator can execute during one work day. To study how stresses affect the function of the sill assembly, the initial measurements are compared with results from during and after the test process.

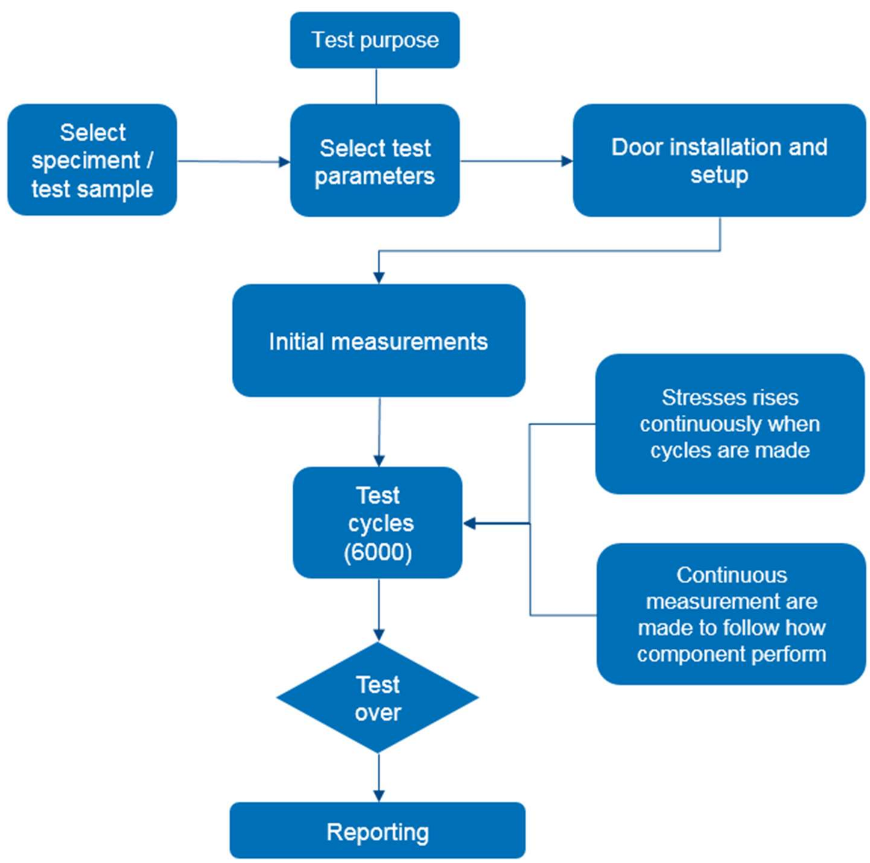

Figure 30. Basic testing process

After the test, every finding, notes and measurements are documented in detail. Measurements includes all the parameters which are gathered from the test. When the necessary amount of tests are made, they can be compared with each other.

5.3.2 Stresses and variables

Table 3. List of stresses and variables

	Stress / variable	Instrument	Description	Simulates
1	Adding friction	Standard test dust	Standard test dust added to the sill groove at regular intervals	Sand and dirt that gets into to the sill groove and jam the door
2	Installation errors	Tester frame / test setup	e.g. The profile is installed deliberately misaligned position	Defects caused by poor installation
3	Manufacturing flaws	Test sample / sill component	Insert into the tester a sill profile which has manufacturing flaws	Defect the caused by manufacturing errors
4	Weight	Additional weights	Additional weights placed on door panel	Door of all weights (e.g. glass door)
5	Garbage holes (amount, placement, size)	Sill component	Study how garbage holes affect sill profile performance	Design parameters
6	Design	Sill & guide shoe	Gain knowledge on what kind of design performs best	Design parameters

Six different stress and other variables are used to accelerate the sill assembly. They include the main causes for failure and also variables which can be changes to improve the sill performance.

By far the main cause of door failure are sand and dirt which end up in the sill groove and jam the elevator door. When an elevator door is jammed, it means that the whole elevator are does not work which can cause a major problem in huge buildings where reliability of elevators is central. To simulate this event standardized test dust is used. It is standardized sand or dust whose size varies between 1-300 micrometers. The plan is that the dust is added at regular intervals to the sill profile groove. The dust is added until the door jams, this indicates that door has reached the limit of the test.

There are two main variables relating to the sill assembly which affect its performance under dirty conditions. Design of the sill profile groove and garbage holes'. At this stage, there is no clear understanding of how changing these two variables affects the sill assembly performance. By changing these variables it is clear that the component performance will change. The test purpose is to find optimal solution for these two variables. It means testing existing products and analyzing the results. Based on those results it can be decided if new and more reliable products can be created.

Installation errors can cause also elevator door malfunctions. Typically, they are installed at out of alignment contrary to the instructions. With the new sill tester, these errors can be simulated by installing the sill profile out of alignment in the tester frame. A well designed frame allows the accurate installation of the sill assembly in any position required. Studying how errors affect the sill assembly function helps develop installation instructions in future.

When producing a high volume of products manufacturing flaws are unavoidable. Most of the flaws are related to dimension accuracy. If dimensions of the sill assembly change a lot it can cause problems when fitting guide shoes to it. Too tight a fit can cause elevator door malfunctions. A product in which a manufacturing fault has been found, can be installed in the tester in order to study how the fault affects product reliability.

Additional weight is used to add stress and simulate different weight door panels, which behave differently. For example, a glass door which is considerably heavier than a metal panel door so they load every elevator door component more. This why the additional weight can also be used as a one of the acceleration parameters. Heavier loads mean faster wear rate which will accelerates the test.

5.3.3 Control and Measurements

Table 4. List of measurements

	Measurement	**Instrument**	**Description**
1	Number of cycles / stops	Door operator / external counter	Checked after the test
2	Closing force (motor current)	Door operator / load gauge	How much force the door must use for opening? Measured by using *WPT Emulation* software.
3	Thickness of guiding shoes	Caliper	Measured manually. Monitor how guiding shoes wear out
5	Motor temperature	Temperature sensor	Measured at motor and gear
6	Noise level	Microphone	Effect on ride comfort
7	Vibration	*KONE Wibe ®* accelerometer	Effect on ride comfort

Seven measurements are made to monitor how the sill assembly performs under the test. Some measurement is made continuously and some only at the beginning and end of the test. A more accurate measurement interval can be defined later when the process is further developed. They include physical measurements, electronic control, temperature monitoring and a couple of measurements which are related to ride comfort.

The number of cycles is easy to monitor continuously. It gives a good understanding of how components perform on the test. The amount of cycles can read from the door operator by the *WPT Emulation* software. The software also tells how much force the elevator door uses when opening and closing. It is calculated from the electronic motor current and converted to newton meters. This information is vital because the door operator has an opening- and closing force limiter. The limiter is one of the safety requirements which the elevator door must have. If the limiter is exceeded, it understands that something is between the door panels (e.g. a human hand) and it opens or closes the door. The same effect happens when sand or other impurities ends up to the sill profile groove.

Physical measurement are also made to the elevator sill assembly. The thickness of the guiding shoes is measured using a caliper to study how it wears out. This information is used when new guiding shoes are being tested and compared.

Elevator ride comfort is one of the most important feature relating to customer satisfaction. Ride comfort affects user experience; it creates a perception of quality and safety for any elevator or escalator user. Elevator door ride comfort comprises of two main things, noise and vibration. Noise can be generated in many ways; dirt in the sill groove, misalignment of the door panels, poorly adjusted operator etc. A purpose of the new test device is to able measure the noise level and how it changes when stress levels increase. The increased stresses affect also door vibration. This means how smoothly do the door panels open and close. The condition of door operator components, quality of door panels installation and the condition of the sill groove have the largest effect on this part of ride comfort. The vibration can be measured by an accelerometer. KONE has developed its own accelerometer for measuring ride comfort and the idea is that the same tools are used for this testing also. This allows the possibility to compare real-life results against laboratory results.

6 SUMMARY

With the world's population constantly growing and moving to cities, the need for reliable elevators is ever growing. Reliability has a huge part to play in the increasingly competitive elevator market. It increases product functionality, safety and it has also huge effect on customer satisfaction. In the long term, cost savings are received through the reduced need for maintenance. As elevator doors have a big impact on overall elevators reliability, it is crucial to study the performance of every component to reduce the number of maintenance (call-outs).

Part of researching reliability is to create a test device and a method to study component behavior. Accelerated testing provides crucial information about component behavior and performance. It is like a short cut to finding the reasons for component failure. Understanding these issues helps to develop the component at the future and more crucial, develop the design guideline to create even more reliable product in the future.

The purpose of this thesis was to design a test device and study what kind of parameters can be used to accelerate the test and how the result can be measured. The exact test method will be created in the future and the knowledge gained in the thesis will used as a frame work for the test method.

The new tester was designed successfully, and it fulfilled the requirements which were set for it. The new test bench allows many different test setups to simulate every scenario which the sill assembly faces in field conditions. To accelerate the test, the most crucial failure modes were established and applied. Also, the test control parameters were listed and described how they can be used in a test method.

The design of the tester was completed within this thesis and guidelines for the test method were established, but verification of the testing method needs to be done once the tester has been built completely and its functions tested. One possible addition to the tester is to create fully automatic test environment, so testing can be made more easily. After the verification, the actual test process can be started. This was not done within this thesis due to time constraints.

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