# Development of a Concealed Power and Signal Transfer System for Sliding Doors

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MASTER THESIS

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# Abstract

This master's thesis report describes the product development process of a durable and concealed product for transferring power and signals to the moving door leafs of sliding doors. The thesis has been conducted in collaboration with Assa Abloy Entrance Systems, with the goal of enabling the use of accessories such as privacy e-glass, screens integrated in the glass, electric locks and sensors mounted on the door leafs for their sliding doors.

To better understand Assa Abloy's product portfolio as well as restrictions of different solutions to this problem, an extensive background research was conducted. This background research laid the groundwork for a concept generation where 28 concepts using many different technologies for power and signal transfer was generated. The concept ultimately chosen for further development consists of a spiral cable mounted on a support wire, installed completely concealed in the header profile of a sliding door.

A prototype of the concept was subject to a life cycle test, confirming the feasibility of the concept, before a detail design phase was initiated. During this phase, focus was put into developing the concept with regards to manufacturability. Tools such as CAD-modelling, 3D-printing and sheet metal manufacturing enabled a rapid iteration of prototypes.

The final design consists of a spiral cable with a durable cable jacket, a support wire that enables easy installation, an injection molded bracket securing spiral cables of different dimensions with minimal cable wear to the door leaf as well as a sheet metal bracket that enables mounting of the support wire in the header profile. This product proved to be an easy to install, low cost and durable solution for transferring power and signals to the door leafs of sliding doors.

**Keywords:** Product development; Sliding doors; Power transfer; Signal transfer; Spiral cable; Rapid prototyping

# Sammanfattning


I denna examensarbetesrapport beskrivs utvecklingen av en dold och hållbar produkt för ström och signalöverföring till skjutdörrars rörliga dörrblad. Examensarbetet har genomförts i samarbete med Assa Abloy Entrance Systems, med målet att möjliggöra användningen av tillbehör som smarta glas, skärmar integrerade i dörrglaset, elektriska lås och sensorer monterade på dörrbladen hos deras skjutdörrar.

För att bättre förstå Assa Abloys produktportfolio samt de fördelar och restriktioner som finns för olika lösningar på liknande problem, genomfördes en utförlig bakgrundsstudie. Denna studie låg som grund för konceptgenereringsfasen där 28 olika koncept för överföring av ström och signaler med hjälp av olika teknologier genererades. Konceptet som till slut valdes för vidare utveckling består av en spiralkabel monterad utanpå en stödvajer, installerad fullständigt dold i den övre kåpan som innehåller all elektronik till skjutdörrarna.

För att testa konceptets rimlighet, innan detaljutveckling av konceptet genomfördes, utsattes en prototyp av konceptet för ett livscykeltest. När detta test visade sig vara lyckat genomfördes detaljutveckling med fokus på tillverkningsbarhet av konceptet. Verktyg som CAD-modellering, 3D-printing och tunnplåtsbockning möjliggjorde en snabb och iterativ prototypframställningsprocess.

The slutgiltiga produkten består av en spiralkabel med en slittålig kabelmantel av polyuretan, en stödvajer som möjliggör enkel installation, ett beslag designat för formsprutning som möjliggör ett säkert, slittåligt och flexibelt kabelfäste till dörrbladet, samt ett bockat plåtbeslag för montering av stödvajern i skjutdörrens övre kåpa. Denna design visade sig vara ett billigt, slitstarkt och enkelt sätt att överföra ström och signaler till de rörliga dörrbladen hos skjutdörrar.



**Nyckelord:** Produktutveckling; Skjutdörrar; Strömöverföring; Signalöverföring; Spiralkabel; Prototypframtagning; Rapid prototyping.

# Acknowledgements

We have many people to thank for helping us throughout this thesis and without whom this project would not have been possible.

Firstly we would like to thank our Assa Abloy supervisor and Concept Innovation Manager, Roger Dreyer, for his support and guidance throughout the entire project. We are also grateful for him setting up a weekly meeting with Mechanical Engineers Sara Roos and Mikael Buschow who we would like to thank for their continuous feedback and investment in our project.

Furthermore, we would like to thank Test Engineer Zoltan Michis for educating us on door mechanics and for setting us up in the workshop. A lot of gratitude is also directed towards Senior Mechanical Engineer Anders Löfgren who contributed a lot to this project with his many suggestions for further development and improvement. Assa Abloy Entrance Systems allowed us to pursue our ideas freely and supported our work generously and we are particularly grateful for the opportunity to travel to the Assa Abloy office in North Carolina where we presented our work and gained a lot of inspiration. On their site, Jeffery A. Wolfe and Scott Somerville showed us incredible hospitality and support which was very appreciated.

Lastly, we would like to thank Damien Motte who provided us with great advice and quick feedback as our supervisor at the Faculty of Engineering at Lund University.

Without these people this project would not have been possible and we are very grateful for their assistance.

Lund, May 2019

Max Koskinen
Jakob Alvelid

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# List of acronyms and abbreviations

| | |
|---|---|
| AAES | Assa Abloy Entrance Systems |
| CAD | Computer Aided Design |
| ICU | Intensive Care Unit |
| PA | Polyamide |
| PE | Polyethylene |
| POM | Polyoxymethylene |
| PP | Polypropylene |
| PUR | Polyurethane |
| PVC | Polyvinyl Chloride |
| TPE | Thermoplastic Elastomers |
| UHMWPE | Ultra High Molecular Weight Polyethylene |

# 1 Introduction

*This chapter contains an introduction to the master thesis that includes information about the company, background information about the problem, goals of the master thesis as well as delimitations for the project.*

## 1.1 Company Background

Assa Abloy Entrance Systems (AAES) is a division of Assa Abloy, which focuses on automatic entrance solutions for an optimized flow of people and goods. Amongst other things they create automatic doors, industrial doors, loading dock equipment and high-performance doors. Within AAES lies Assa Abloy Pedestrian Door Solutions which main focus is sliding-, swing- and revolving doors.

During the years Assa Abloy have absorbed companies to further their growth. Their goal is to expand 50% by acquiring new companies and 50% by conventional growth of their existing businesses. Despite being founded in 1994, it was not until 2002 when Assa Abloy acquired the company 'Besam' that the company progressed from locks and key card systems into the world of automatic doors and entire entrance systems.

Today Assa Abloy exists all over the world as an multi national concern with offices in Sweden, UK, US, Mexico and over 60 other countries.

## 1.2 Problem Description

In the North American market of AAES they currently have a sliding door called the VersaMax 2.0 [1]. This door is aimed towards the healthcare segment, and especially intensive care units (ICU) in the US. Depending on the needs of the customers the door can be configured accordingly. Some examples of these configurations are a single sliding door leaf, multiple telescopic sliding door leaves, bi-parting door leaves, telescopic bi-parting door leaves, manual door opening and sensors that enables automatic door opening. The VersaMax 2.0 door have an additional option of a privacy e-glass integration system (InteGlass) which enables the use of privacy e-glass. Privacy e-glass enables privacy at the switch of a button through an electrified privacy film laminated between two pieces of clear tempered glass panes [2]. When the laminate is electrified the glass is in clear state due to the particles present in the laminate aligning which lets light through the glass. When the laminate does not receive any electricity the glass is in opaque state due to the particles being randomly oriented which blocks the light.

Power transfer to the electrified glass in the InteGlass solution is solved by a wire which is placed in a plastic e-chain in the header profile of the door that connects the top of the door leaf with the power supply in the header profile. When the door is sliding the e-chain guides the wire in a path, thus enabling the door leaf to receive power at all positions without the risk of the cable getting torn, twisted or stuck. This solution is developed especially for the VersaMax 2.0 doors due to these doors being the only doors with the option of privacy glass at this time.

AAES have a vision that in the future this privacy e-glass, as well as other accessories mounted on the door leaf that requires electricity or signals to operate, will be supplied to customers in other segments as well. Such accessories could be sensors, locks, screens integrated in the glass or other hardware mounted on the door leaves. In order to fulfill these new customer demands, there needs to be a solution applicable on more Assa Abloy doors, and not only the VersaMax 2.0 ICU door. From this, the following problem formulation was derived:

*”Is there a better way to transfer both electricity and signals to a sliding door that keeps the functionality of the current solution, while being cheaper and more universal?”*

## 1.3 Project Goals

This thesis aims to investigate the possibilities and restrictions behind different solutions of supplying the door leaves of AAES’s sliding doors with electricity and signals. The goal of the project was to realize at least one solution as a working prototype that is universal in the way that it can supply electricity and signals to different sliding doors in AAES’s product portfolio. An additional goal was to further develop this working prototype into a product that could be a part of AAES’s product portfolio. At the end of the project suggestions for improvement and further development of the solution was delivered as well.

## 1.4 Delimitations

The purpose of this project was to develop a product that can transfer power and signals to the moving door leaves of AAES sliding doors. More specifically, the project focuses on transferring power and signals from the header profile down to the top side of the actual door leaf. Therefore, power and signal transfer from the top of the door leaf to the accessories that should be supplied with power and signals located on the door leaf is outside the scope of this project.

The project is based on automatic sliding doors and not manual sliding doors. The reasoning is that the manual sliding doors have a lot of space in the header profiles as there are no electronics or motor. If the final solution was applicable on automatic doors it was assumed that it would be applicable on manual doors as well.

During the concept generation phase, concepts that were as universal as possible were developed, since this was the main goal of the project. When a final concept was later selected and pursued, this was developed towards one specific door model. This was to ensure that a tangible result was delivered to AAES since the limited time resources of this project did not allow detailed development of a concept on all existing doors in AAES's product portfolio.

# 2 Methodology

*This chapter describes the modified product development process used in this thesis. The methodology used during the different steps in the project is also described.*

## 2.1 Approach

This thesis was conducted according to a product development methodology inspired heavily by the product development process developed by Ulrich and Eppinger [3], see Figure 2.1. Due to this project being completed over a fixed time period of only 20 weeks, the original product development process was modified to better match this short time plan. The project has mostly followed the concept development process developed by Ulrich and Eppinger [3], see Figure 2.2, but with some additions to get a somewhat more complete product development process. The process used during this project is illustrated in Figure 2.3.

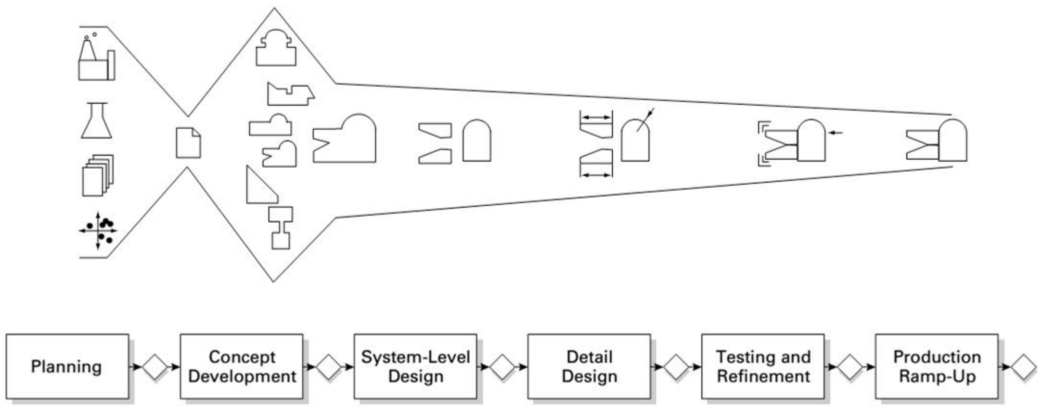



**Figure 2.1: The original product development process developed by Ulrich and Eppinger [3].**

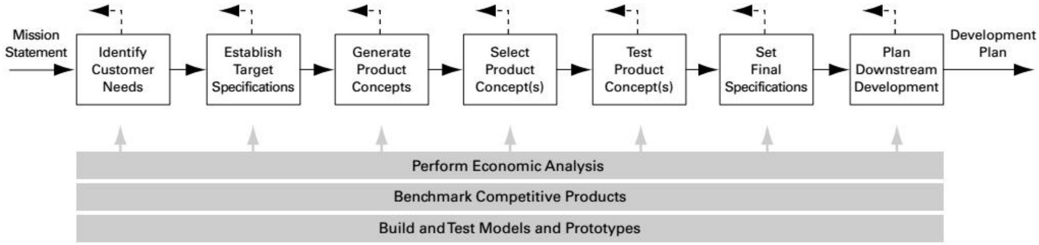



**Figure 2.2: The original concept development process developed by Ulrich and Eppinger [3].**

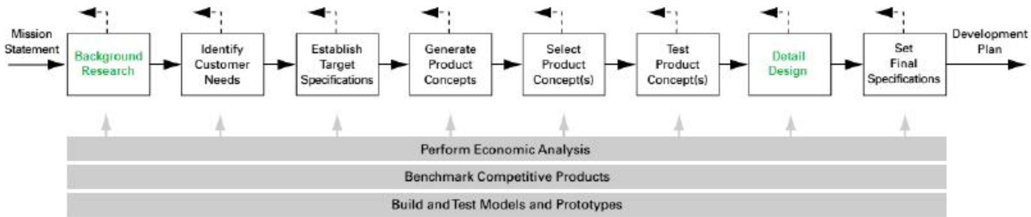



**Figure 2.3: The modified process used in this project. A background research segment and a detail design segment (in green) was added to the original concept development process, and the planning of the downstream development was removed [3].**

In consultation with the supervisors and previous master thesis students at AAES it was decided that this project would benefit from an extensive background research segment. This would partly increase the understanding of the problem, but also increase the knowledge of AAES, their sliding door systems and all components and configurations. This was deemed necessary in order to produce a solution that would be applicable on as many door models as possible. Since power and signal transfer from a stationary object to a moving object is a common problem that exists in different industries, it was also believed to be beneficial for the concept generation phase to conduct an extensive benchmarking process. This would allow the authors of this thesis to learn from similar solutions that are already on the market. To allow for the prototype to be further developed into a product that could be a part of AAES's product portfolio, a detail design segment was added to the product development process as well.

Also worth noting is that the 'Test Product Concepts' segment was modified from the way it is conducted by Ulrich and Eppinger [3]. This phase is originally dedicated to testing of concepts on customers, but due to this not being a commercially available product for individual customers, this type of testing is difficult. It was decided that this phase should instead consist of testing the actual concept and its feasibility.

After consultation with the supervisor at AAES it was also decided to have an approach in which the scope of the project was very wide in the beginning and then narrowed towards the end. What this means practically is that the research phase was widened and as many concepts as possible were generated, then a final concept was selected and developed. The process of selecting just one final solution represented the narrowing of the scope of the project since just one solution was pursued. Such heavy narrowing of the project was deemed beneficial for AAES no matter the result: if the solution was successful it was valuable to pursue it to the greatest extent that the project allowed, and if the solution was not satisfactory it would still be valuable for AAES to have the knowledge to not pursue that idea. In short, the narrowing of the project enabled AAES to draw conclusions from it, no matter the result. This reasoning is why the prototyping phase was extensive, as seen in the Gantt chart in Section A.2.

## 2.2 Time Planning

During the first week of the thesis the project was divided into activities and time was allocated for each of these activities. From this a preliminary Gantt chart was created, as seen in Figure A.1 in Section A.2. The actual allocated time for each activity is also visualized in a follow-up Gantt chart shown in Figure A.2 in Section A.2.

## 2.3 Background Research

In order to fully understand the problem associated with this master thesis and to gain knowledge of currently existing solutions for similar problems, five weeks of the project was allocated to background research. This time was spent researching existing internal solutions within AAES as well as existing external solutions in the same and other industries to gain inspiration for the concept generation phase. Some time was also spent researching patents to gather inspiration and to gain knowledge of which solutions are protected by intellectual property rights. Most of this research was done through internet search, while some of the insights were gathered through discussions with employees at AAES.

## 2.4 Customer Needs and Target Specifications

In order to generate concepts that would fulfill as many requirements as possible, target specifications were compiled early on. This was done by consulting the problem description received from AAES in the beginning of the thesis, by researching the applicable safety legislation for sliding doors in Europe, mainly SS-EN 16005:2012 [4], by consulting the supervisor at Assa Abloy, Roger Dreyer, as well as through contact with AAES's development team in the US who have developed the solution for their VersaMax 2.0 doors.

## 2.5 Concept Generation and Concept Selection

The approach for the concept development phase was to create as many concepts as possible and then eliminating these in three different steps to choose the final concept. By keeping product needs and the target specifications in mind, as well as using information and inspiration from the background research, a number of initial concepts were generated. These were then further developed or combined in various ways which generated more concepts.

In this phase, a lot of time was spent on concept elimination. In total three screenings of concepts were conducted. The initial screening was conducted by eliminating similar concepts in order to reduce the quantity of the concepts. This allowed for a much more detailed evaluation of the remaining concepts. The second and third screenings were conducted by evaluating the fulfillment of various criteria derived from the target specifications. In the end one of the concepts was chosen and refined into a more detailed concept.

## 2.6 Test of Concept

The final concept was developed into a prototype which was then subject to a life cycle test, which is described further in Chapter 6. Upon reviewing the test and concluding that the concept was feasible, detail design was initiated.

## 2.7 Detail Design

During the detail design phase the concept progressed into a more detailed product, resembling something that can be a part of AAES's product portfolio. This was achieved by developing, 3D-printing and purchasing components. These components were assembled, mounted, subject to basic tests and iterated until a final design was obtained.

When the components were specified, an economic analysis was made, detailing the cost of the product. The analysis consists of a compilation of the manufacturing prices of components in the presented solution and it is based on production of 1000, 10 000 and 100 000 units of the product.

# 3 Background Research

*This chapter presents the research conducted which acted as a foundation for the project and the concept generation phase. General theory on how different sliding door models work are discussed as well as technologies for power transfer in general. Internal solutions within Assa Abloy and solutions from competitors and other industries were researched.*

## 3.1 Introduction

The background research was conducted for two main reasons; to gain insight in the field and laying the groundwork for the concept generation phase.

Firstly, the principle for how the sliding doors function was researched. Apart from knowing how the different door configurations operate, this step was crucial to get a sense of the available space as well as to get an overview of the different models.

In order to know what the future solution needed to comply with it was also very important to have an understanding of the legislation regarding commercial sliding doors. The legislation and standards for commercially sold sliding doors in Europe as well as in North America was therefore researched.

An extensive benchmarking of similar solutions in different applications was conducted as preparation for the concept development phase. This was complemented with a patent search of solutions to similar problems. The patent search was partly done to see which solutions was protected, but also in order to gain inspiration for the concept development.

## 3.2 Sliding Door Principle

All AAES's sliding doors are based on a similar solution; an electric motor drives a belt on which the doors are attached on. By attaching one door leaf to the upper part of the belt and one to the lower, the door leaves can move in the opposite direction of each other while being attached to the same belt. This is the case for the standard bi-parting sliding doors, see Figure 3.1. The doors are mounted and connected to the belt using two door carriages each that are rolling on top of a convex plastic rail. The electronics, the drive system, the plastic rail and the door carriages are hidden in the header profile, which is an aluminum frame that is mounted above the door opening. On automatic doors, sensors are attached to the header profile, registering when users approach and opening the door accordingly.

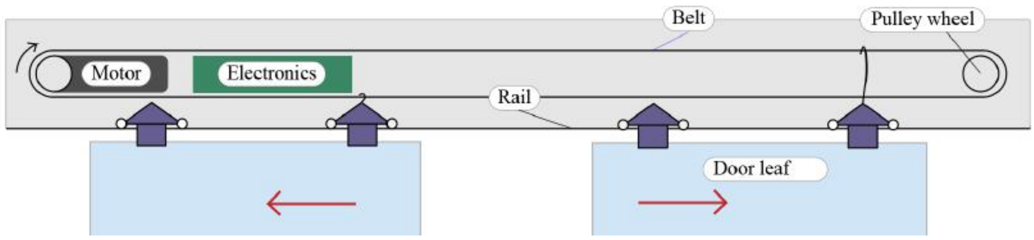



**Figure 3.1: Basic principle of a bi-parting sliding door.**

### 3.2.1 Sliding Door Configurations

In AAES's product catalogue they offer many different sliding door configurations, among them are the bi-parting sliding door described above, the single slide, the telescopic sliding door as well as the telescopic bi-parting door.

The single slide door consists of one fixed door leaf, a sidelite, and one moving door leaf which is driven by the motor and belt. An illustration detailing this is shown in Figure 3.2.

A telescopic door is a very similar configuration consisting of one sidelite and two sliding door leaves, see Figure 3.3. The outer-most door leaf is attached to the belt and is sliding the farthest distance. The other door leaf is sandwiched in the middle, between the outer door leaf and the sidelite. In order to ensure that the middle door leaf travels half the distance of the outer door leaf, a driving wire is connected to the outer door leaf and two pulleys, creating the desired effect. The bi-parting telescopic door is simply the same configuration but mirrored on the opposite side.

AAES are uncertain whether these telescopic doors are going to be configured in this way in the future. Because of this, these models were excluded from the scope of this project as it is unnecessary to begin a development project for a product that might be changed completely.

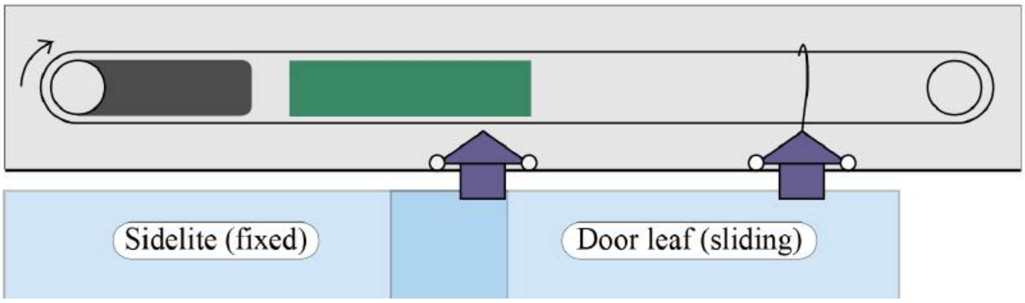



**Figure 3.2: Basic principle of a single slide door.**

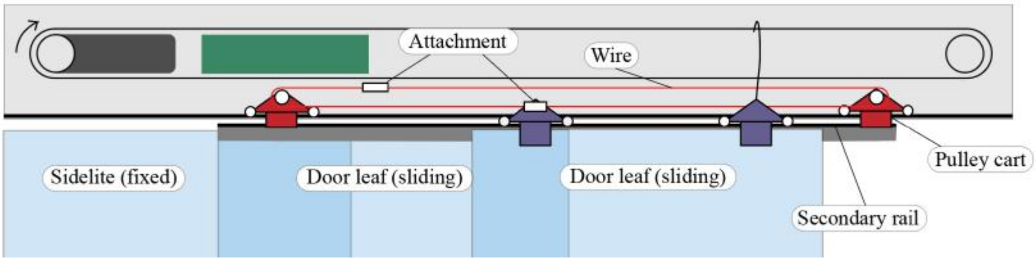



**Figure 3.3: Basic principle of a telescopic slide door.**

## 3.3 Legislation and Standards for Sliding Doors

### 3.3.1 Europe

All doors that are sold in Europe needs to follow certain legislation regarding safety for the users. The legislation SS-EN 16005:2012 [4] specifies requirements for construction and testing of machine driven inner and outer doors for pedestrian use in Sweden, which is based on the European legislation.

Relevant excerpts from SS-EN 16005:2012 [4] are presented below.

- ”Power operated sliding or folding doorsets shall withstand a durability test of not less than 1 000 000 cycles.” [4, p.24].
- ”The force required to prevent a stopped doorset from opening or closing any further - measured at the main closing edge in the direction of travel - shall not exceed 67 N at any point in the opening or closing cycle.” [4, p.18].
- ”The kinetic energy of a doorset in motion shall not exceed 1.69 J. Annex F states the speed settings for various widths and masses of doorsets required to obtain results conforming to this requirement.” [4, p.18].

- ”In the event of any interruption of mains power or failure of the drive, it shall be possible to open the doorset with a manual force not exceeding 67 N to release a latch and 90 N to open the doorset, when the force is applied to the main closing edge in the direction of travel.” [4, p.18].
- ”A static closing force up to 150 N is allowed during the last 50 mm for any type of sliding and folding doorsets” [4, p.18].
- ”Power operated sliding or folding doorsets with a clear opening width of up to 2000 mm shall open by at least 80% within 3 s after activation by the activator(s) in the escape direction or at the latest after 5 s when the power supply goes off. Opening time for larger doorset widths shall be calculated proportionally.” [4, p.24].
- ”When the mains power goes off, doorsets shall automatically open at the latest after 5 s and remain in the open position (except when in the security-locked position).” [4, p.25].

#### *3.3.1.1 France*

France have their own special legislation for pedestrian doors during emergency situations. By law it is required that pedestrian doors have a mechanical opening system in case of a complete electrical break down [5]. To comply with this, AAES utilizes a system of tension rubber bands which opens the doors during electrical failure.

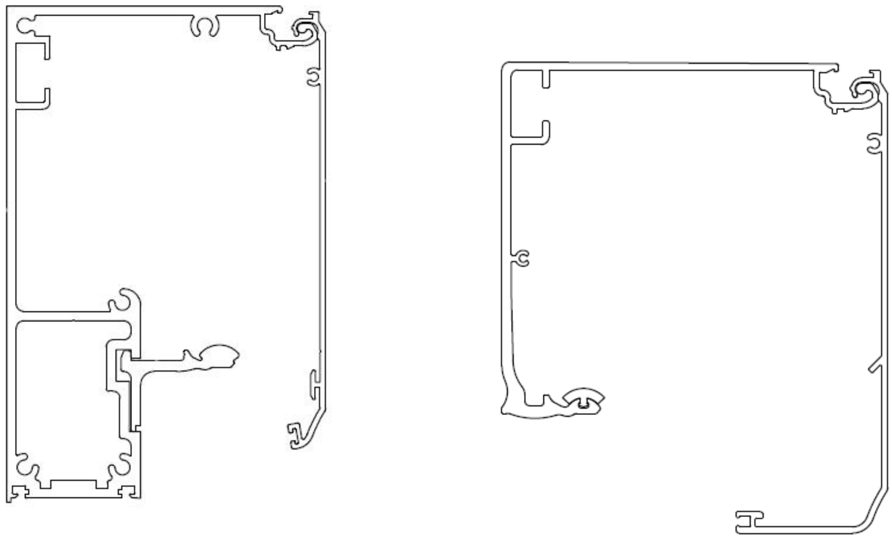
### 3.3.2 United States

The US generally has tougher requirements than Europe. According to Engineering Director of AAES US, Jeffrey A. Wolfe, risk of getting sued in the US is a much greater concern than in Europe. Products on the market need to comply with tough safety standards. An independent testing company called UL perform safety tests on products going out on the market and give their approval if the product meets their standards. Usually all commercial items sold in the US needs to be UL-listed or consist of UL-listed parts in order to be appealing for customers. This generally means that a product being sold in the US will be held to higher safety standards than one sold in Europe. It is not illegal to sell products in the US that are not UL-listed, however as stated above they are generally not as appealing for customers as a product that is UL-listed [6].

## 3.4 Power Transfer Solutions Within Assa Abloy

### 3.4.1 InteGlass

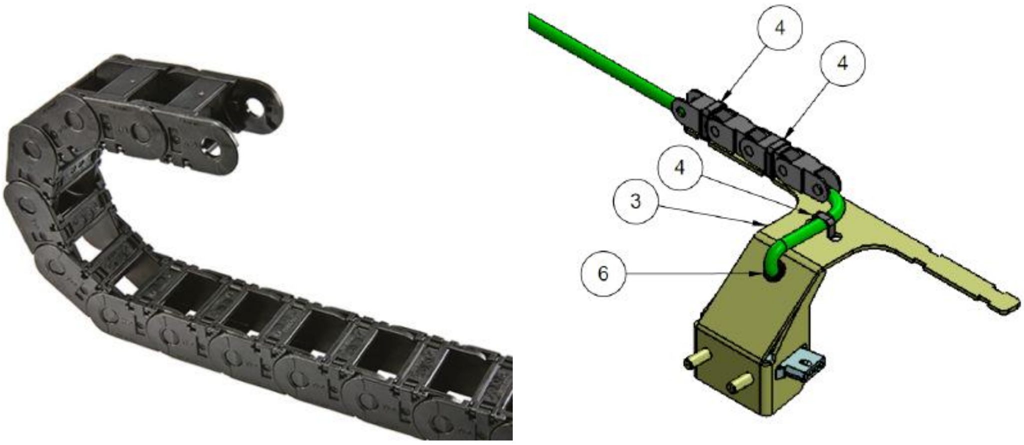
Today a solution for transferring power and signals to moving door leaves exists within AAES on their North American market. The specialized VersaMax 2.0 ICU-doors require power for customers opting for a door with a privacy e-glass function. The privacy e-glass itself is provided by a third-party supplier, but the system for transferring power and signals to the glass is provided by AAES under the name InteGlass. The specifications for the biggest privacy e-glass that has been used with the InteGlass system is rated at 70 VAC with no more than 0.5 A, i.e. a maximum of 35 W [6]. Since the InteGlass system was originally developed for the North American market and their header profiles it is not directly transferable to the European market. Below in Figure 3.4a and 3.4b are cross-sections of typical North American header profiles compared to European header profiles.



(a) (b)

**Figure 3.4: a) The cross-section of a North American SL500 header profile. b) The cross-section of an European SL500 header profile.**

By comparing the profiles in Figure 3.4a and 3.4b it is apparent that the North American header profiles has a different, usually larger, cross-section with an extra pocket in the back of the profile (left in the figures). This extra space does not contain any components or electronics and is therefore available for use. This difference is due to the American models being self-supporting, as normally the doors in the North American models are installed in the wall as opposed to the European models which are normally being installed on the wall. This space is utilized in the current solution by placing an Igus e-chain which contains the necessary wires and follows the door leaf movement. The wires are connected to power through a terminal strip in the header profile and fed through the Igus e-chain which is then mounted on a bracket at the other end. This bracket is attached to the top of a door carriage which allows the wire to be fed alongside it down to the door leaf connection. See Figure 3.5 for reference.

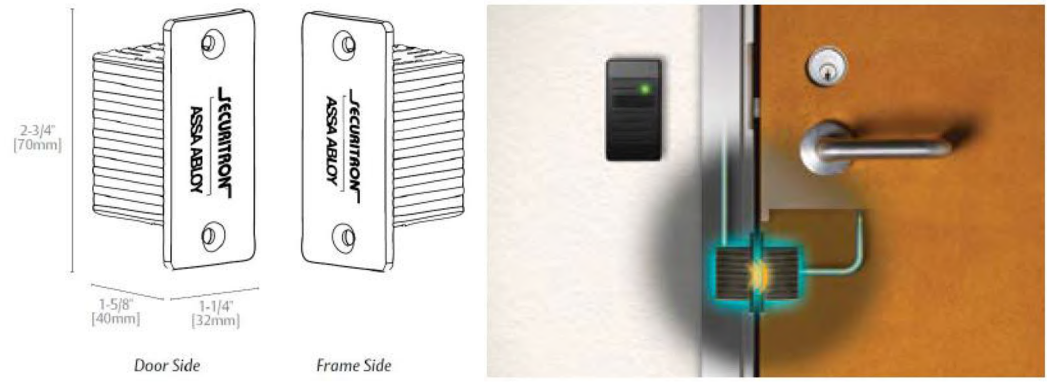



**(a)** **(b)**

**Figure 3.5: a) Igus e-chain [7]. b) The bracket attached to the door carrier in the InteGlass solution [8].**

### 3.4.2 Securitron Powerjump ICPT

The Securitron Powerjump ICPT, shown below in Figure 3.6, is an Assa Abloy product that transfer power wirelessly across the door jamb of swing doors using inductive coupling. It is aimed towards electrified door hardware such as electrified locks, latches or other hardware that require up to 6 W of power at either 12 VDC or 24 VDC. It can be installed on either the hinge or latch side of the door, or on the top of the frame as long as the gap is no greater than $3/16$ ” (4.75 mm). It is rated only for intermittent duty, hence not intended for continuous duty applications [9].




**(a)** **(b)**

**Figure 3.6: a) A drawing of the Powerjump ICPT [9]. b) Example of the Powerjump ICPT in use with an electric lock [9].**

### 3.4.3 Securitron Concealed Electrical Power Transfer (CEPT)

In Assa Abloy's product portfolio a product for electricity transfer from the door jamb to the door leaf of swing doors exists called the Securitron CEPT, see Figure 3.7 below. The product is mounted on the hinge side of the door, allowing for a more or less concealed power transfer which is rated for 1 000 000 opening cycles [10].

**Figure 3.7: The Securitron CEPT which supply swing doors with electricity [10].**

### 3.4.4 Securitron Electric Hinge

The Securitron electric hinge is an Assa Abloy product for electricity transfer from the door jamb to the door leaf of swing doors, see Figure 3.8 below. The product replaces the hinge of the door and transfers both power and signals through the hinge while being capable of transferring current up to 500 mA [11].

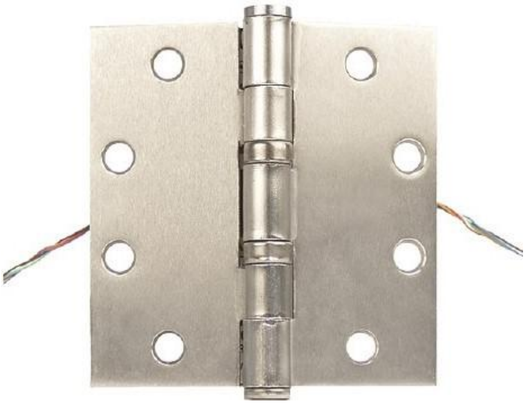


Figure 3.8: The Securitron electric hinge that supply swing doors with electricity with the highest level of concealment [11].

## 3.5 Benchmarking

### 3.5.1 Cables

Regular cabling is a trusted and well used technology. Advantages are secure connections, high power transfer and options for amount of conductors, allowing for simultaneous power and signal transfer. Disadvantages are mainly difficulties in how to manage excess cable in the withdrawn position as well as abrasion issues.

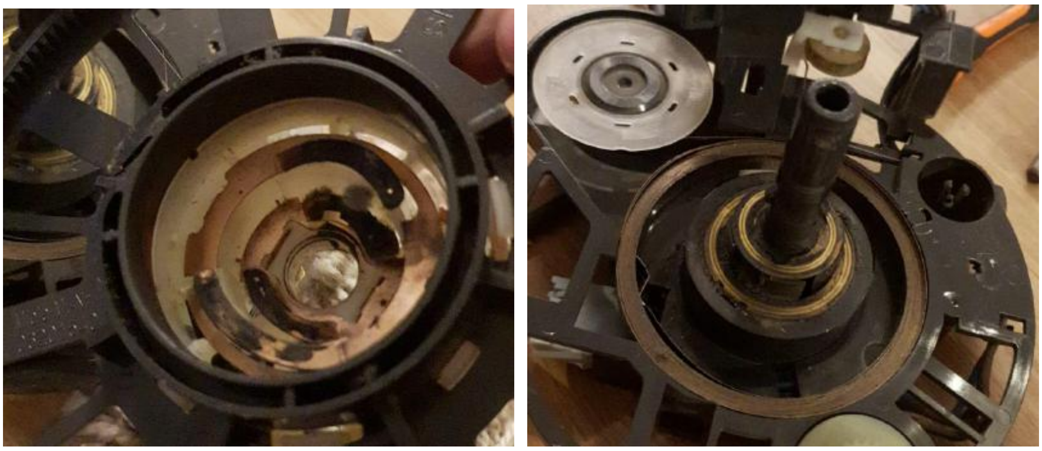
The Igus e-chain shown in Figure 3.5a is an example on how to use regular cabling with movement. Other examples are cable reels, festoon systems and pulley systems. Table 3.1 below lists pros and cons of power and signal transfer through cables.

Table 3.1: Pros and cons of transferring power and signals using cables during movement.

| Pros | Cons |
|---|---|
| Secure connection | Managing of excess cable |
| High power transfer | Abrasion on cable jacket |
| Simple | Wear of conductor |

#### *3.5.1.1 Vacuum Cleaner Cable Winder*

Vacuum cleaners and other household electronics manages excess cable by using an internal cable winder. Typically these cable winders consists of a tightened clock spring mounted on one fixed and one rotating part in the cable winder. When a locking mechanism is released, typically by pushing a button on vacuum cleaners, the spring expands, rotating an axle which spins and retracts the cable. However, there is still the issue of transferring power from the rotating cable on the axle to the fixed vacuum cleaner housing. This is usually solved by having conducive brushes sliding along circular conductive rails and thus maintaining electrical contact at all times. In Figure 3.9 below the conductive rails and circular paths of a cable winder inside a vacuum cleaner is shown.



**(a)** **(b)**

**Figure 3.9: a) Conductive brushes inside a vacuum cleaner cable winder. b) Two conductive rails corresponding to the brushes in 3.9a. An untightened clock spring is also shown.**

*3.5.1.2 Exposed Spiral Cable*

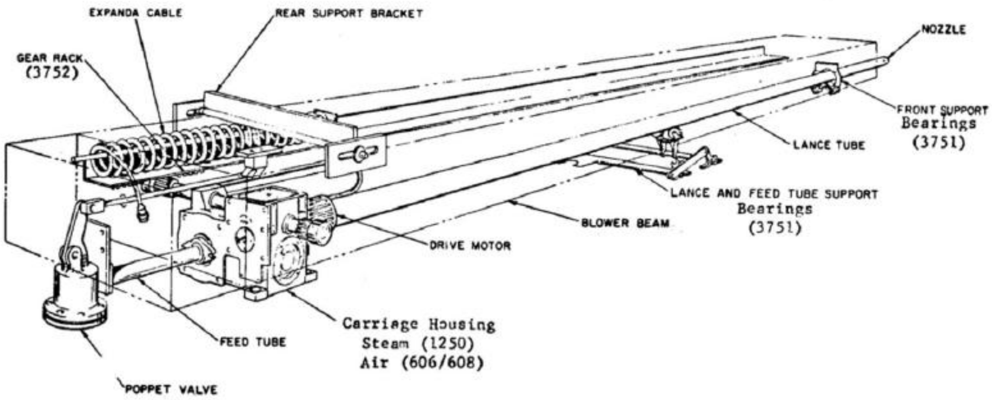
A simple aftermarket solution to transferring power and signals to sliding doors is to mount a spiral cable between the wall and the side of the door leaf. This is not a solution provided by AAES as they believe that this type of solution is an easy target for vandalism and is not aesthetically pleasing. If power is required for both door leaves in a bi-parting door configuration, two exposed spiral cables are needed. Below in Figure 3.10 such a cable on a sliding door is shown.

**Figure 3.10: An exposed spiral cable connected to the side of a sliding door leaf.**

#### *3.5.1.3 Retractable Soot Blower*

In oil, coal or multi-fuel source power plants, a retractable and rotary soot blower is used to clean ashes from the boilers where fuel is burned. The soot blower is, when the boiler is to be cleaned, inserted into the boiler with a drive motor. It then rotates and sprays high pressure steam onto the high temperature surfaces. When the cleaning is completed the soot blower retracts [12].

The relevant part about this construction is the soot blower cable that is coiled and rests on a metal rod. The cable supplies the drive motor with electricity and retracts and expands as the soot blower is inserted and retracted. To be able to withstand the harsh environment, soot blower cables are made of abrasion and moisture resistant materials such as polyurethane (PUR) or thermoplastic elastomers (TPE), is IP67 and IP68 rated and constructed to withstand 105 °C [13]. A basic sketch of a soot blower and its cable can be seen in Figure 3.11 below.




**(a)**


**(b)**

**Figure 3.11: a) Basic construction of a soot blower. [12]. b) The spiral cable mounted on top of a support rod on a soot blower [14].**

*3.5.1.4 Steering Wheel Clock Spring*

Inside a car's steering wheel, a device called clock spring allows power and signals to be sent from the various buttons and controls on the rotating steering wheel to the stationary steering column. A clock spring consists of a flat cable inside a round housing which, as the steering wheel is turned left or right, is loosened or tightened. The principle is the same as metal clock springs used in cable winders of vacuum cleaners, see Figure 3.9a, but instead of a metal spring that stores energy, a flat cable is loosened or tightened to allow for some rotation around the steering axle. An image of a clock spring is shown below in Figure 3.12.


**Figure 3.12: A clock spring from a car's steering wheel [15].**

### 3.5.2 Inductive Power Transfer

Current that flows in one wire can induce a voltage in another wire in its vicinity through its magnetic field, without a physical connection. This is called inductive coupling, or electromagnetic induction, and can be used as a means of transferring power and signals wirelessly over an air gap. By using coils of wires, the magnetic field can be amplified, thus enhancing the inductive capacity and the induced voltage. This technology allows for power transfer through non-conductive materials and between moving objects.

Even though the technology was used and patented as early as 1897 by Nikola Tesla [16], the technology is still in its infancy in commercial and industrial applications, mainly due to the limitations of the technology. The two most substantial limitations are the need for close proximity between the transmitter coil and the receiver coil as well as limitations as to how much power can be transferred [17]. Table 3.2 lists pros and cons of power and signal transfer through electromagnetic induction.

**Table 3.2: Pros and cons of transferring power and signals through electromagnetic induction.**

| **Pros** | **Cons** |
|---|---|
| Works with low and high humidity | Requires close proximity |
| Does not suffer from wear | Limited amount of power transfer |
| Flexibility in coil alignment | Difficult to send power and signals simultaneously |

*3.5.2.1 Hyundai, Non-contact Power Transmission Structure for Sliding Door*

On November 22nd 2018 the car manufacturing company Hyundai patented a solution for wirelessly powering the sliding door of a vehicle using electromagnetic induction [18]. A figure from this patent showing included components is shown below in Figure 3.13. The patented structure controls opening and closing by generating electromagnetic induction energy. This is allegedly solved using a horizontal guiding rail on the side of the vehicle containing a transmission coil. A roller assembly containing a receiver coil moves alongside the rail, generating electromagnetic induction energy.

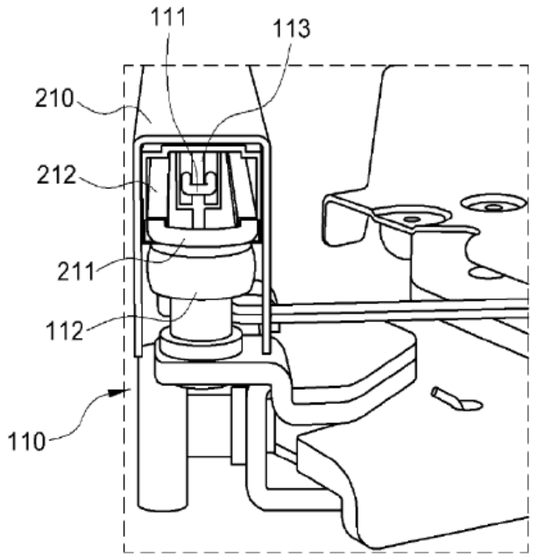



**Figure 3.13: Side view of structure. 111 shows receiver coil and 211 shows transmitter coil [18].**

*3.5.2.2 Bosch, Wireless Charging for Power Tools*

In Bosch's product portfolio they have a wireless charging system called 'GAL 1830 W-DC Wireless Charging car charger Professional' for their 18 V battery power tools that uses inductive power transfer. The battery powered tools contain a receiver coil, which when placed on top of the charger that contain a transceiver coil starts charging. According to Bosch's specification of the charger the battery charging voltage is 18 V while the charge current is 3 A [19]. This corresponds to an energy transfer rate of 54 W. The charger is shown in Figure 3.14 below.

**Figure 3.14: Bosch GAL 1830 W-DC Wireless Charging Car Charger Professional [19].**

### 3.5.3 Capacitive Power Transfer

Capacitive power transfer is based on high frequency alternating currents. By transforming a power source to a high frequency alternating current and then running it to a capacitor with high capacitance, power can be transferred wirelessly to another circuit. A capacitor is formed by two conductors separated by a dielectric and the capacitance depends on the dielectric thickness, overall area of capacitor electrodes and dielectric constant of present lubricating fluid [20]. Table 3.3 below lists pros and cons of power and signal transfer through capacitive transfer.

**Table 3.3: Pros and cons of transferring power and signals through capacitive power transfer [21] [20].**

| Pros | Cons |
|---|---|
| Works with low or high humidity | Requires close proximity |
| It has no wear on the connection | Not widely used |
| Can send power and signals simultaneously | Requires high frequency alternating current |
| Can transfer power through metal obstacles | No regulations on safety of operation |

#### *3.5.3.1 Capacitive Power Transfer Through Rotational and Sliding Bearings*

In her report 'Capacitive Power Transfer Through Rotational and Sliding Bearings', S.S. Hagen [21] researches possibilities for power transfer through linear bearings. It is proven that by using off the shelf linear bearings as capacitors, power up to 111 W can be transferred wirelessly from one circuit to another. The report further states that this allows for dual use of the bearings; partly as a load bearing sliding connection but also as a means of transferring power to the sliding object.

### 3.5.4 Conductive Rail

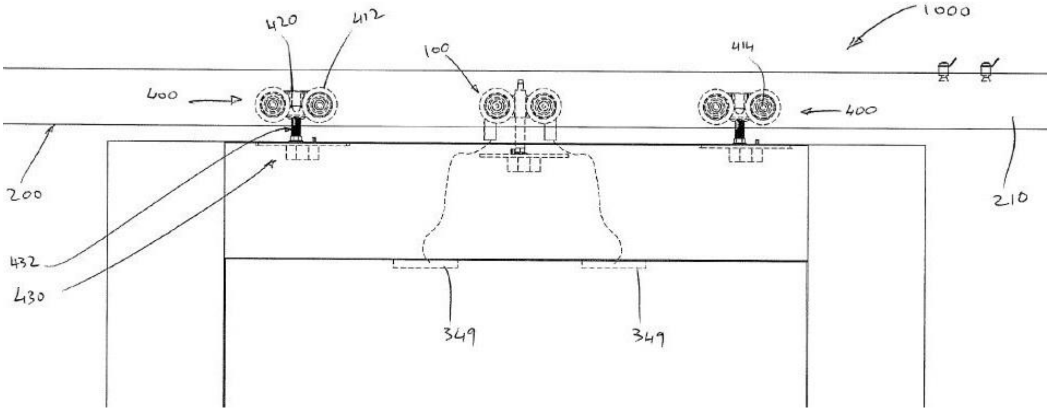
It is relatively common to transfer power to linear moving objects using a conductive brush sliding along a conductive rail, thus keeping a continuous electrical connection even during movement. Cable winders in vacuum cleaners, as shown in Figure 3.9 above, and similar applications utilizes this method for transferring power from a stationary object to a rotary object. It is also used in some industry applications such as loading bridges, hoists and warehouse equipment to name a few. Another use is as a way of grounding moving electronics through a grounding brush and conductive wire [22]. Table 3.4 below lists pros and cons of power and signal transfer through a conductive rail and brush.

**Table 3.4: Pros and cons of transferring power and signals trough a conductive rail and brush.**

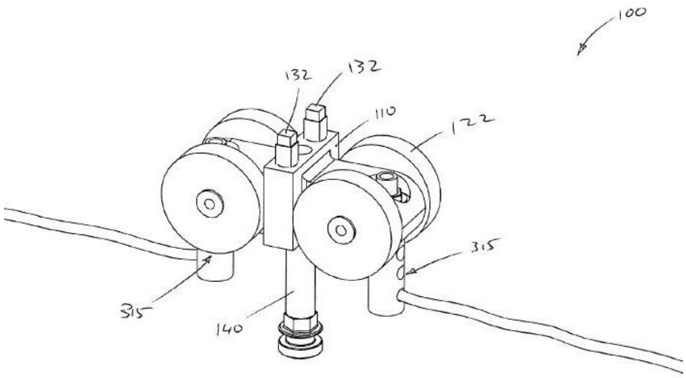
| Pros | Cons |
|---|---|
| Electrical contact in all positions | Wear on brushes |
| Can be constructed compact | Sensitive to moisture |
| | Sensitive to dust and debris |
| | Sending multiple signals will add to size |

#### *3.5.4.1 CS for doors, ElecTrack*

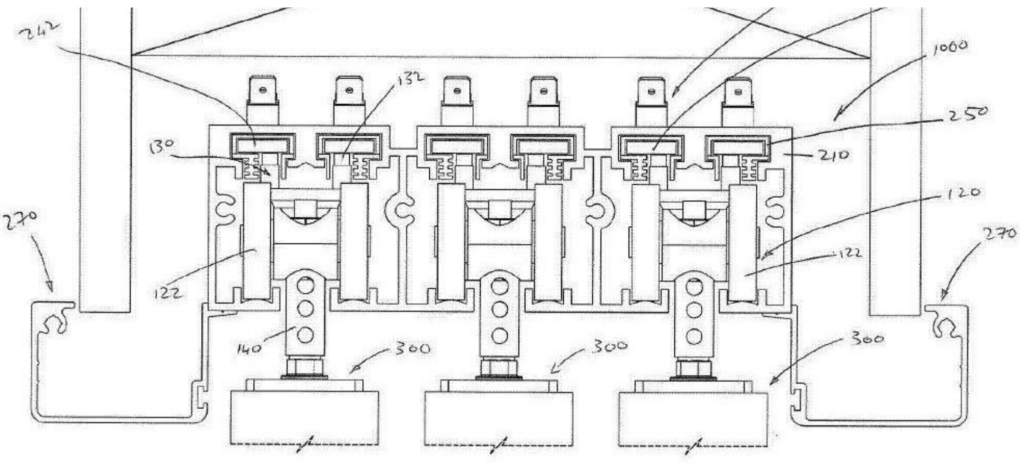
The company CS for doors have developed a power transfer system called ElecTrack for use with the door leaves of their sliding and stationary doors [23]. The system consists of, for each door, a conductive rail (242 in Figure 3.15c) with two carbon brushes (132 in Figure 3.15b) that are mounted on a carriage with wheels. The ElecTrack carriage is mounted between the two door carrying carriages and the cables from the door is routed through the ElecTrack carriage, see Figure 3.15c [24].




**(a)**




**(b)**



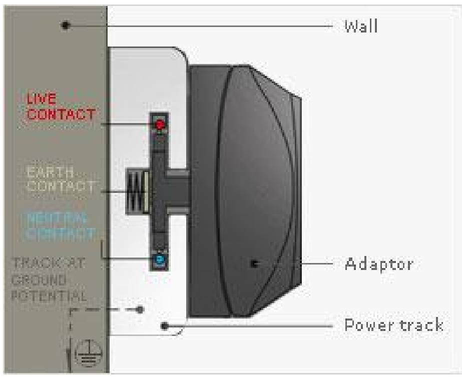

**(c)**

**Figure 3.15: a) The ElecTrack carriage between the two door carrying carriages [24]. b) The ElecTrack carriage [24]. c) The ElecTrack system [24].**

*3.5.4.2 Eubic, Sliding Sockets*

Eubic is a company manufacturing sliding electrical sockets. A cross-section of their product as well as a figure of the sockets integrated in a kitchen is shown below in Figure 3.16. The sockets are connected with conductive brushes which slide along conductive rails along one axis. Since the brushes are always in contact with the rails, power can be transferred regardless of its location along the rail [25].

As shown in Figure 3.16a the system consists of three rails and corresponding brushes: one representing the live contact, one neutral and one earth. The rails are protected making it impossible to get shocked even if one would attempt to touch the rails.




**(a)**

**(b)**

**Figure 3.16: a) Cross-section of a sliding electrical socket by Eubic [25]. b) Sliding sockets integrated in a kitchen [26].**

# 4 Customer Needs and Target Specifications

*This chapter presents the customer needs and target specifications that were compiled from information given from AAES, current legislation as well as from internal discussion.*

## 4.1 Customer Needs

A general idea for the customer needs was gained though discussions and interviews with the supervisor at AAES as well as with the development team of AAES in North America. The customer needs were defined, listed and compiled into primary and secondary needs, where the primary needs are categories to which the secondary needs belong. This helped to create a good overview of the customer needs. Lastly, the secondary needs were graded from 1-3 based on the relative importance of the needs. The full customer needs are listed below in Table 4.1.

Customer needs that have received importance 3 are needs that are crucial for the product to be viable as a product on the market, and therefore needs that should be prioritized during the development. Needs number 1-4 are for example needs that should be prioritized since these needs describe the sole purpose of the product, that it should be able to send power and signals between the door leaf and the header profile. Need number 16-19, 29-31 and 33 were also graded 3 since they are needs regarding legislation and/or safety for the users and installers of the doors.

Customer needs that have received importance 2 are needs that are not essential for the product to be a viable product in AAES's product portfolio. If however these needs are fulfilled the product will have a wider customer base, and is more likely to be a product that is superior to competitors. Examples of this are needs 5-6, 8, 15 and 26-27 since these needs allows the product to be used in environments with stricter requirements regarding for example dust, noise and special features. If need 34 and 39 are fulfilled it will most likely result in the product being retrofitted on more doors.

Customer needs that have received importance 1 are needs which are not essential for a successful product, but that are still worth mentioning. None of these needs should be the focus point during the development, but they should still be considered if they can be easily implemented. Such needs are for example need 12-14 and 37-38 that allows the product to be used in extreme environments or makes the product easier to install and manufacture. Below in Table 4.1 all customer needs and their respective importance is listed.

**Table 4.1: Customer needs. Primary needs in bold, secondary needs in roman.**

| No. | Customer Needs | Importance |
|---|---|---|
| | **Power can be sent between the door leaf and the header profile.** | |
| 1 | Power can be sent in all stationary positions. | 3 |
| 2 | Power can be sent during movement. | 3 |
| | **Signals can be sent between the door leaf and the header profile.** | |
| 3 | Signals can be sent in all stationary positions. | 3 |
| 4 | Signals can be sent during movement. | 3 |
| 5 | Multiple signals can be sent at the same time. | 2 |
| | **The system enables the door to remain clinical.** | |
| 6 | The system enables the door to be as dust free as without the system. | 2 |
| | **The system is unnoticeable for users.** | |
| 7 | The components are enclosed within the door system. | 3 |
| 8 | The system is quiet. | 2 |
| | **The system lasts for a long time.** | |
| 9 | The system can handle normal usage. | 3 |
| 10 | The system can resist small impacts. | 2 |
| 11 | The system is resistant to simple vandalism. | 1 |
| | **The system can be used in an outdoor environment.** | |
| 12 | The system can operate during rain and/or high moisture. | 1 |
| 13 | The system can operate during winds. | 1 |
| 14 | The system can operate in direct sunlight. | 1 |
| 15 | The system can operate varying temperatures. | 2 |
| | **The system allows the door to operate as normal.** | |
| 16 | The system allows the door to operate at the same speed. | 3 |
| 17 | The system allows the door to have the same opening time. | 3 |
| 18 | The system allows the door to have the same opening range. | 3 |
| 19 | The system allows the door to be opened using the same force. | 3 |
| 20 | The system allows the use of optional features on the door. | 3 |
| | **The system is applicable on all AAES sliding doors without alteration.** | |
| 21 | The system is applicable on different sizes of doors. | 3 |
| 22 | The system is applicable on bi-parting doors. | 3 |
| 23 | The system is applicable on single slide doors. | 3 |
| 24 | The system is applicable on manual doors. | 3 |
| 25 | The system is applicable on automatic doors. | 3 |
| 26 | The system is applicable on doors with break-out function. | 2 |
| 27 | The system is applicable on self-supporting doors. | 2 |
| 28 | The system is applicable on surface mounted doors. | 3 |
| | **The system is safe.** | |
| 29 | The system does not hurt users. | 3 |

**Table 4.1: Continued.**

| No. | Customer Needs | Importance |
|---|---|---|
| 30 | The system does not hurt the installer. | 3 |
| 31 | The system allows manual opening during emergencies. | 3 |
| 32 | The system prevents sparks. | 2 |
| 33 | The system fulfills European and American legal requirements. | 3 |
| | **The system is easy to install.** | |
| 34 | The system is easy to install on already operating doors. | 2 |
| 35 | The system is easy to install on new doors. | 3 |
| 36 | The system has a low weight. | 1 |
| 37 | The system has few parts. | 1 |
| | **The system is cost efficient.** | |
| 38 | The system is easy to manufacture. | 1 |
| 39 | The components are relatively cheap. | 2 |

## 4.2 Target Specifications

The customer needs on their own describes features that the product needs to fulfill to be an attractive product from the customers perspective. These needs do however not specify how these features should be accomplished, and it is difficult to measure if these needs are fulfilled. For example, it is problematic to differentiate between a product or concept that is easy to install and one that is not with no further information or measurement. Therefore, the customer needs were quantified and compiled into measurable target specifications with an importance from 1 to 3. Some needs are however not quantifiable and are instead listed as binary or subjective. These target specifications were also given designated marginal and ideal values, which corresponds to what value the quantified need has to comply with in order for the product to be acceptable or optimal in that specific criterion. The target specifications reflect in a measurable way exactly what the product has to achieve in order to be either a successful, average or an unsatisfactory product.

Customer needs that could be measured using the same unit were grouped together to form a single target specification. An example of this is customer need 37-39 which states that the product should consist of few parts, be easy to manufacture and that the components should be relatively cheap. All these needs could be interpreted into a single target specification that represents the manufacturing cost of the finished product.

The quantified numbers are based both on information received from AAES, information discussed together with the supervisor at AAES and information derived from legislation as stated in Section 3.3.1. The full target specifications are shown in Table 4.2 and a short explanation of the quantified value of each specification is shown in Table 4.3.

**Table 4.2: Target Specifications.**

| No. | Need No. | Metric | Importance | Unit | Ideal Value | Marginal Value |
|---|---|---|---|---|---|---|
| 1 | 1 | Power can be sent in all stationary positions. | 3 | W | inf | 6 |
| 2 | 2 | Power can be sent during movement. | 3 | W | inf | 0 |
| 3 | 3 | Signals can be sent in all stationary position. | 3 | Binary | N/A | Yes |
| 4 | 4 | Signals can be sent during movement. | 3 | Binary | Yes | No |
| 5 | 5 | Number of signals that can be sent simultaneously. | 2 | # | inf | 1 |
| 6 | 6, 7, 11 | Additional external surface volume. | 3 | $cm^3$ | 0 | 2200 |
| 7 | 8 | Noise during operation. | 2 | dB | 30 | 40 |
| 8 | 9 | Opening/closing cycles. | 3 | Cycles | $10^6$ | $10^5$ |
| 9 | 10, 11 | Impact resistance. | 2 | Subj. | Abusive usage | Normal usage |
| 10 | 12 | Water resistance. | 1 | IP rating | IPx7 | IPx1 |
| 11 | 13 | Wind resistance. | 1 | m/s | 30 | 3 |
| 12 | 14 | UV-radiation resistance. | 1 | years | inf | 10 |
| 13 | 15 | Operating temperature. | 2 | °C | -20 to +65 | +15 to +35 |
| 14 | 16, 17 | Opening time. | 3 | s | N/A | 80% after 3 s |
| 15 | 18 | Opening range. | 3 | % | N/A | 100 |
| 16 | 19,32 | Opening force. | 3 | N | N/A | 90 |
| 17 | 20 | Allows optional features. | 3 | Binary | N/A | Yes |
| 18 | 21,22,23,24,25,26,28 | Applicable on all AAES sliding doors. | 3 | Binary | Yes | No |
| 19 | 29,30,31,32,33 | SIS and international standards. | 3 | Binary | N/A | Yes |
| 20 | 34,35,36,37 | Installation time. | 3 | min | 10 | 60 |
| 21 | 37,38,39 | Manufacturing cost. | 2 | kr | Confidential | N/A |

**Table 4.3: Explanation of the target specification values.**

| No. | Unit | Ideal Value | Marginal Value | Explanation |
|---|---|---|---|---|
| 1 | W | inf | 6 | Power needs to be able to be sent during stationary positions since this is the main purpose of the product. The marginal value 6 W is based on the power requirements for electrical locks and similar mentioned in Section 3.4.2. Ideally the solution should be able to transfer to any accessory, regardless of power requirements. |
| 2 | W | inf | 0 | Power should be able to be sent during movement for the product to be universal, however, a few applications such as electrical locks may not need this function. |
| 3 | Binary | N/A | Yes | Signals needs to be able to be sent during stationary positions since this is the main purpose of the product. |
| 4 | Binary | Yes | No | Signals should be able to be sent during movement for the product to be universal, however, a few applications such as electrical locks may not need this function. |
| 5 | # | inf | 1 | At least one signal should be able to be sent simultaneously, but preferably more. |
| 6 | $cm^3$ | 0 | 2200 | The product should ideally be invisible, but the volume of a $10 * 11 * 20$ cm box can be tolerated. This is equal to the cross-section of an SL500 header that is extended 10 cm. |
| 7 | dB | 30 | 40 | A sliding door in use is approximated to be as loud as a human whisper, which corresponds to around 30 dB [27]. The product should not increase the noise level of a regular sliding door by a significant amount. |
| 8 | Cycles | $10^6$ | $10^5$ | The sliding doors are tested for 1 000 000 cycles and the product should ideally have the same cycle life. Can however be sold as a service product with a life cycle time of more than 100 000 cycles. |
| 9 | Subj. | Abusive usage | Normal usage | Should ideally be resistant to abusive usage, but it is a viable product even if it can only withstand normal usage. |
| 10 | IP rating | IPx7 | IPx0 | Should ideally withstand immersion up to 1m in water (IPx7) to be viable as an outside product in extreme environment. It can however be sold as an indoor product if the product is not protected against water at all (IPx0). |
| 11 | m/s | 30 | 3 | Needs to withstand small winds that can be present in indoor environments. Should ideally be able to be used during storm ($24.5 - 28.4$ m/s) [28]. |
| 12 | years | inf | 10 | Should not degrade due to UV radiation within 10 years, ideally not at all. |
| 13 | °C | $-20$ °C to $+65$ °C | $+15$ °C to $+35$ °C | Should be able to be used during normal indoor temperature. Ideally it should be able to be used in all temperatures that the sliding doors are rated for. |
| 14 | s | N/A | 80% after 3 s | Due to legislation the door needs to be at least 80% open 3 seconds after the activation, see Section 3.3.1. |
| 15 | % | N/A | 100 | The product shall not constrain the opening range of the sliding door. |
| 16 | N | N/A | 90 | Due to legislation the product shall not constrain the opening force needed to open the sliding door more than a total force of 90 N, see Section 3.3.1. |
| 17 | Binary | N/A | Yes | The product should not constrain the usage of other optional features, such as locks, on the sliding doors. |
| 18 | Binary | Yes | No | Ideally the product is applicable on all sliding doors, but it is still a viable product if it is only applicable on a few different door models. |
| 19 | Binary | N/A | Yes | The product needs to comply with international standards. |
| 20 | min | 10 | 60 | The installation of the product should take less than 60 min to be considered easy to retrofit. It is however ideal if the installation time is less than 10 min. |
| 21 | $ | Confidential | N/A | The manufacturing cost should ideally be less than the cost of the InteGlass solution used today in the VersaMax 2.0 doors, but it is not a requirement. |

# 5 Concept Generation and Concept Selection

*This chapter presents how the concepts were generated and categorized, as well as evaluated and selected. Furthermore, all generated concepts are described as well as how the selected concept was developed and refined further into a more detailed concept.*

## 5.1 Concept Generation

Concepts were generated during three different phases. Through an internal search, an external search and through concept combination matrices. During these phases, concepts were generated with the target specifications in mind, see Table 4.2, with a focus of fulfilling the target specifications with the highest importance. Concepts that did not fulfill these critical requirements were discarded since they would not be a viable solution to the problem. The goal of these phases was to diverge in the development, generating as many viable concepts as possible. In total 28 concepts were generated.

### 5.1.1 Internal Search

The internal search consisted primarily of brainstorming of ideas. This was a very open phase with lots of discussion amongst the authors as well as discussions with supervisors and employees at AAES. Examples of ideas yielded from this internal search was the pulley system concepts (Figures 5.13 and 5.14), induction and battery (Figure 5.17) and the plugs and battery (Figure 5.15 and 5.16) concepts.

### 5.1.2 External Search

During the extensive background research phase many ideas of possible solutions for how to transfer power and signals from a stationary object to a moving object were found. These ideas were then during the external search phase developed into concepts by altering the ideas to this specific application. An example of this is the cable winder concepts, see Figures 5.2-5.7, which are inspired by the cable winders that exists in products such as vacuum cleaners, but altered to fit this application.

Another example of concepts generated through external search are the capacitive power transfer concepts, see Figures 5.20-5.23. These concepts are based on the subject of S.S. Hagens report 'Capacitive Power Transfer Through Rotational and Sliding Bearings' [21], but with a sliding door application in mind.

All conductive rail concepts, see Figures 5.24-5.28, also originates from the external search with inspiration from the background research. These are altered versions of existing products shown in Section 3.5.4 such as the sliding electrical sockets made by Eubic [25].

### 5.1.3 Concept Combination Matrix

In order to generate even more concepts some of the already generated concepts from the internal and external search were divided into sub problems. Ideas for solutions to these sub problems were then generated without the original concept in mind. By combining solutions to these sub problems, new concepts were generated. Below in Table 5.1 one of these concept combination matrices is shown. For example, 'Tension wire' can be combined with 'Sliding contact' to create a new alternative version of the cable winder concept, in this case the tension wire cable winder concept shown in Figure 5.4.

**Table 5.1: Cable winder concept divided into sub problems and solutions in a concept combination matrix.**

| **Sub Problems** | Retract excess cable | Rotational to stationary power |
|---|---|---|
| **Solutions** | Tension wire | Slip ring |
| | Clock spring | Internal cabling |
| | Igus e-chain | Sliding contact |
| | Weight | |
| | Motor | |

## 5.2 Generated Concepts

Sketches of all generated concepts are shown in Figures 5.1-5.28. These concepts are not fully developed as the sketches are only intended to illustrate an idea rather than a fully defined product. The concepts were generated during the three different phases described above in Section 5.1. Below these concepts are organized with regard to what kind of technology they are based upon. Furthermore, similar concepts within the same technology have been grouped in subgroups so that similar concepts can be compared.

### 5.2.1 Cables

#### *5.2.1.1 Igus e-chain*

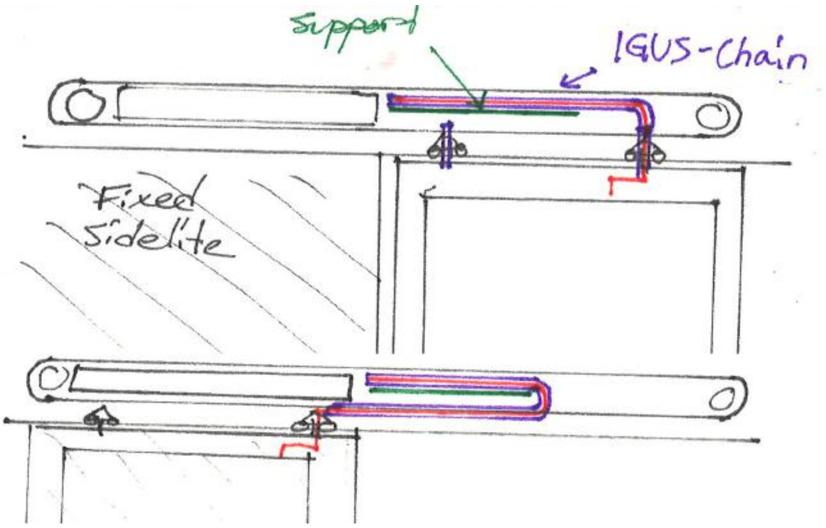



**Figure 5.1: Concept 1 - Igus e-chain. A concept similar to the InteGlass product used in the NA market, see Section 3.4.1. Since the back space in the header profile where the InteGlass solution is located in the NA headers does not exist in European header profiles, a support shelf is mounted in the header profile to support the Igus e-chain.**

#### *5.2.1.2 Cable Winding*

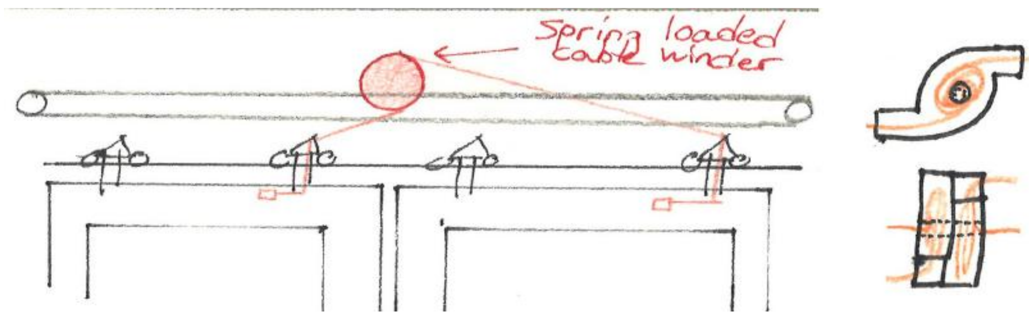



**Figure 5.2: Concept 2 - Spring-loaded cable winder. A spring-loaded cable winder that always retracts cables that are connected to the door. A slip ring or similar inside the cable winder axis converts the rotating cable to a stationary cable that can be connected to a power source somewhere in the header profile. For a bi-parting door it will have two separate compartments containing one cable for each door leaf, as seen in the lower right.**

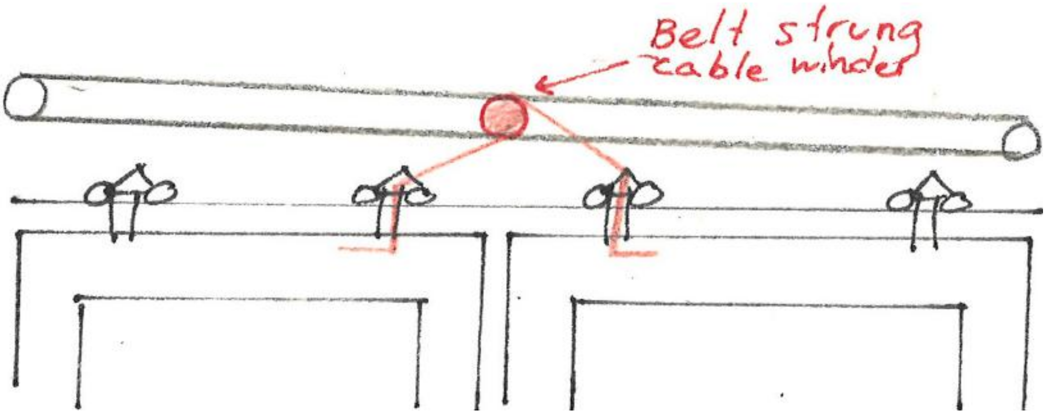



**Figure 5.3: Concept 3 - Belt strung cable winder. Similar to concept 5.2 but where the cable winder is driven by a cogwheel connected to the drive belt instead of a spring.**

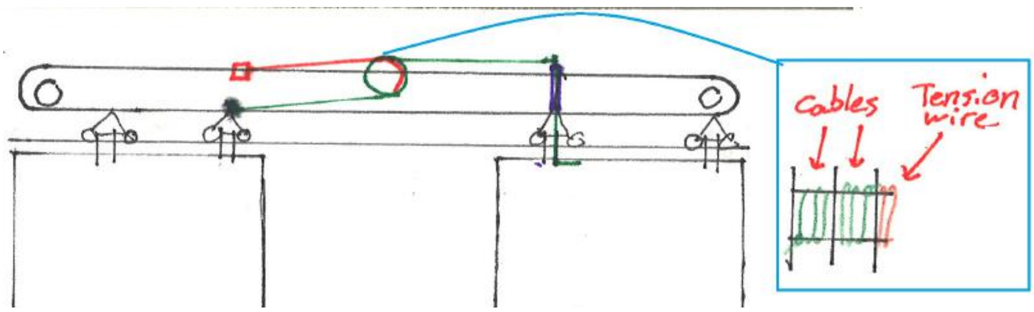



**Figure 5.4: Concept 4 - Tension wire cable winder. Similar to concept 5.2 and concept 5.3 but the cable winder is driven by a tension wire clamped to the drive belt instead of a spring or cog wheel.**

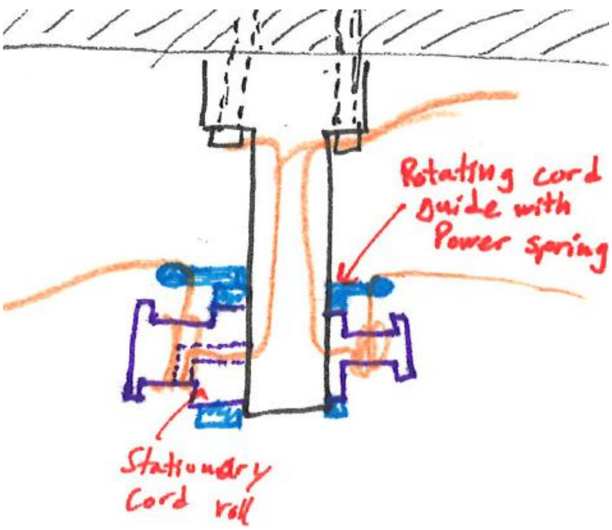



**Figure 5.5: Concept 5 - Fishing reel cable winder. A concept inspired by a fishing reel where the cable is wound on top of the axle instead of the axle itself being spun to wind the cable. This eliminates the need of a slip ring or similar. For a bi-parting door two identical mechanism are mounted opposite to each other on a bracket (as seen in the figure) that is mounted in the middle of the header profile.**

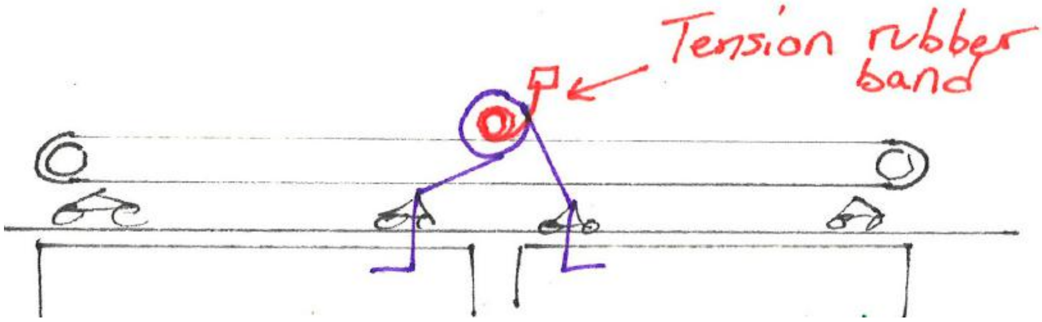



**Figure 5.6: Concept 6 - Tension rubber band cable winder. Similar to concept 5.2, 5.3 and 5.4 but where the cable winder is driven by a tension rubber band. When the door is opened the rubber band is wound up and is tightened, keeping the cables tensioned. When the door closes the tension of the rubber band will spin the axle of the cable winder, resulting in the cables being wound up on the axle.**

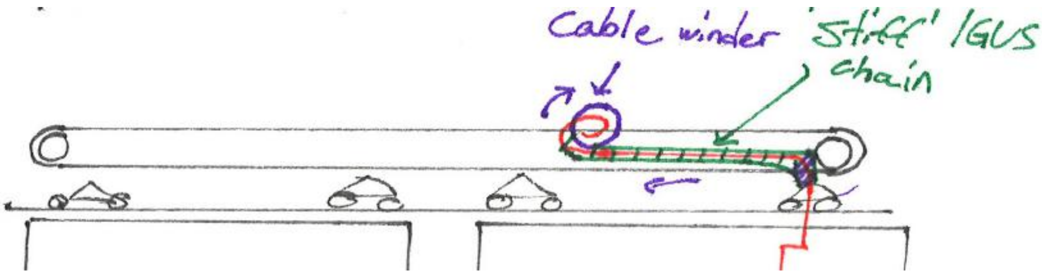



**Figure 5.7: Concept 7 - Igus e-chain cable winder. A concept somewhat similar to a cable winder, but where the cables are inside a plastic e-chain (IGUS chain or similar). The stiffness of the e-chain eliminates the need for any tension wires or springs since the e-chain will wind itself up on the axle by default.**

### *5.2.1.3 Coiled/Folded Cable*

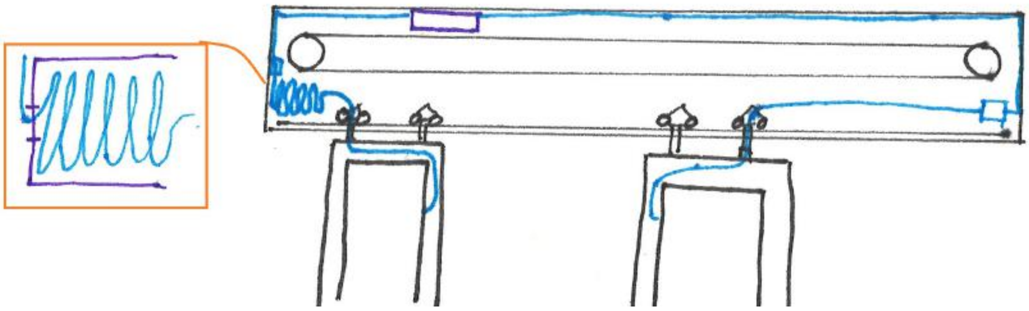


**Figure 5.8: Concept 8 - Cable and bucket. A coiled or flat folded cable is connected to each door leaf. When the doors open the excess cable is folded or coiled into a ”bucket” of some sort that is located in the ends of the header profile.**

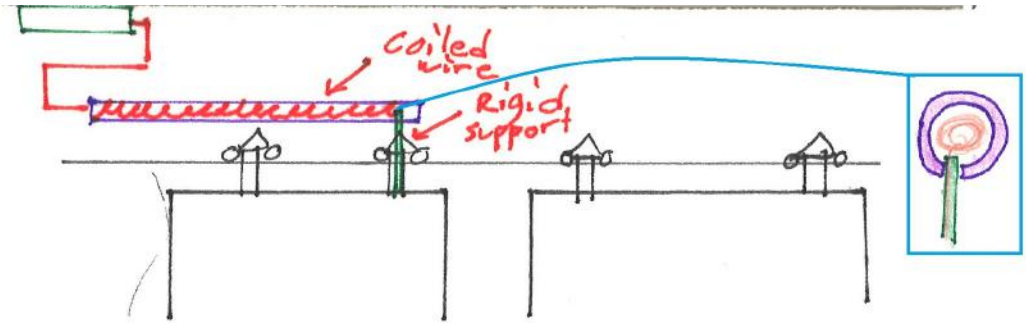



**Figure 5.9: Concept 9 - Spiral cable in pipe. Similar to concept 5.8 but with a coiled cable (wire) that is permanently located inside a pipe with a slot in the bottom that runs across the whole pipe. A rigid support, or bracket, is mounted on the door leaf and is running in the slot, guiding the coiled cable when it retracts/expands.**

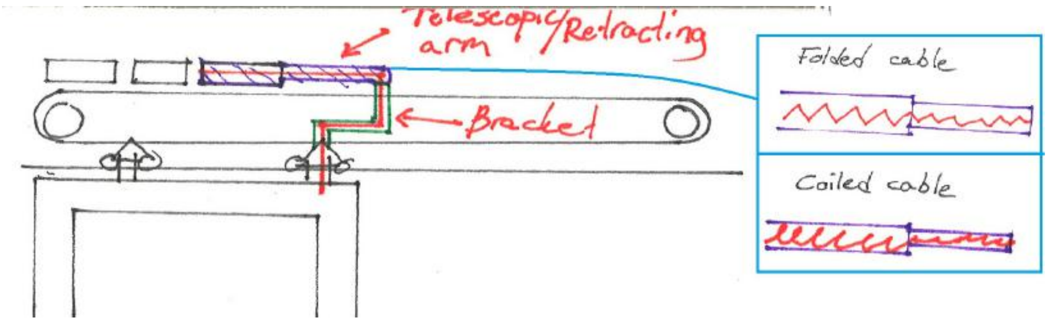



**Figure 5.10: Concept 10 - Spiral cable in telescopic pipe. Similar to concept 5.8 but where the pipe is a telescopic arm that retracts when the door is closing. This way it takes up less space in the header profile.**

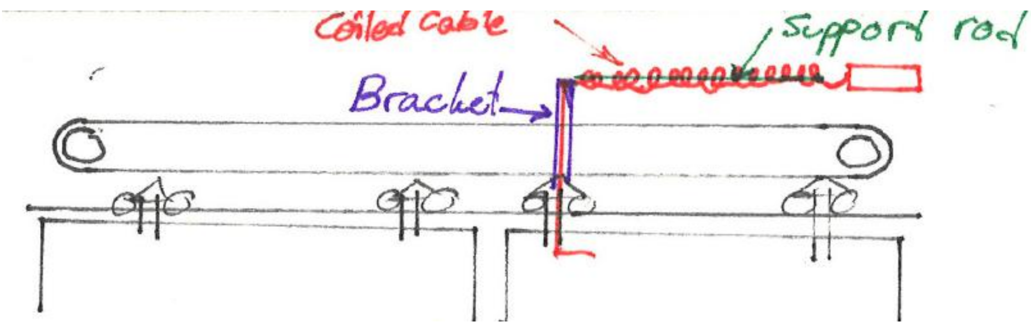



**Figure 5.11: Concept 11 - Spiral cable on support rod. A concept somewhat similar to concept 5.9 but with a coiled cable that runs on top of a support rod instead of inside a support pipe. A stiff bracket mounted on the door leaf carriage guides the coiled cable when it retracts and expands.**

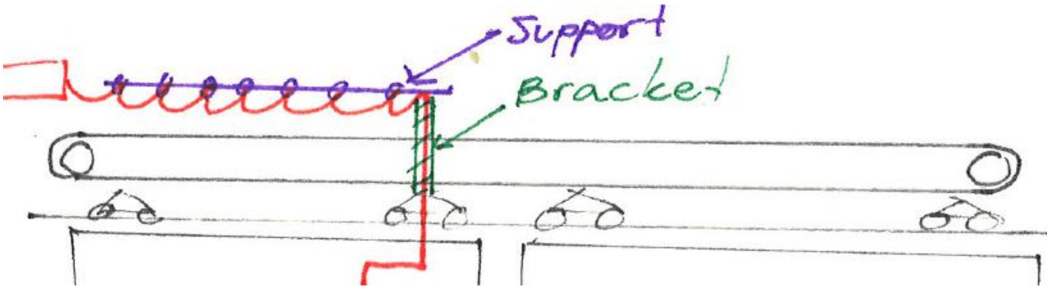



**Figure 5.12: Concept 12 - Cable festoon. A festoon system where a cable is mounted on many cable trolleys that runs on a support mounted in the header profile. As the door opens the cable gathers in loops in between the cable trolleys.**

*5.2.1.4 Pulley System*

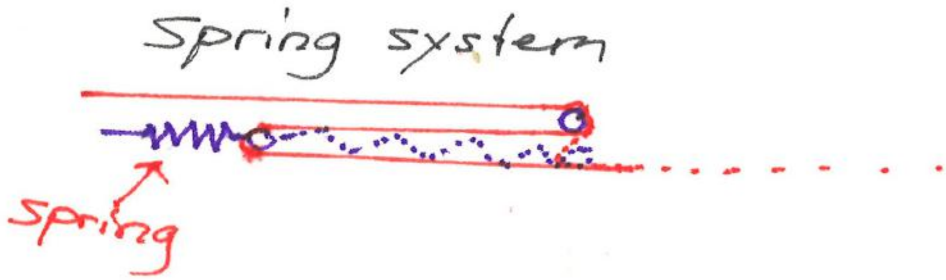



**Figure 5.13: Concept 13 - Spring pulley system. A concept where a cable runs through two or more pulleys where one pulley is supported by a spring. When the door leaf, connected to the right end of cable through a bracket, closes/opens, the spring retracts/expands which results in the cable also retracting/expanding. The cable is this way always tensioned.**

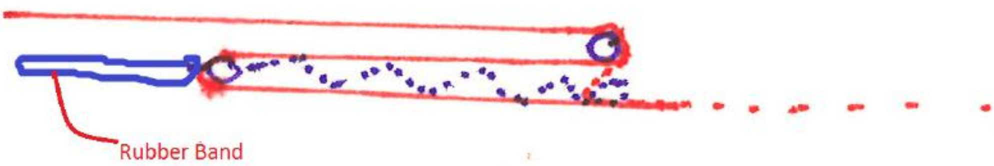



**Figure 5.14: Concept 14 - Rubber band pulley system. Identical to concept 5.13 but with a rubber band that retracts/expands instead of a spring.**

*5.2.1.5 Plugs and Battery*

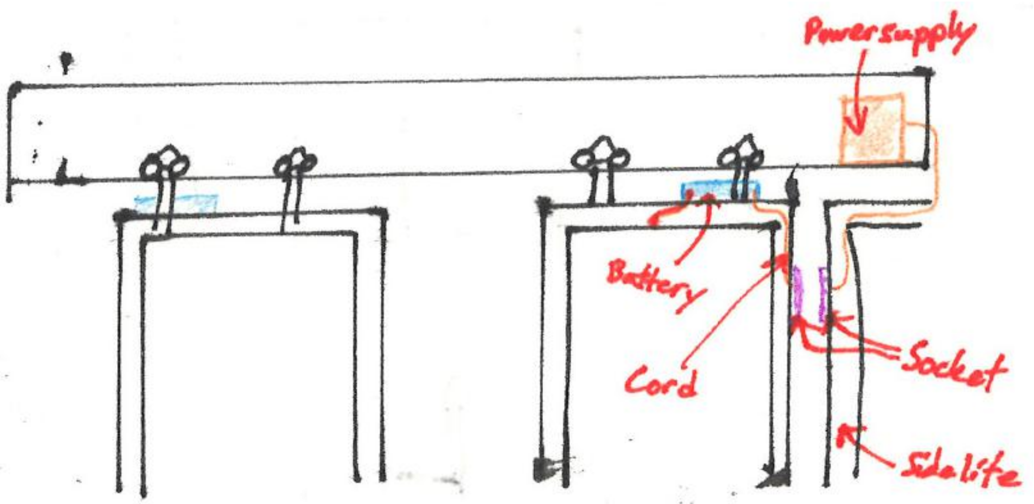



**Figure 5.15: Concept 15 - Van door plugs and battery. A concept similar to how a sliding van door is powered. The power to the door leaf is supplied by a battery mounted on top of the door leaf. This battery is constantly charged, when the door is in opened position (for a bi-parting door), through a plug and socket located on the side of the door leaf and the sidelite. Signals can be sent through the socket and plug connection when connection is made, or wireless with power provided from the battery.**

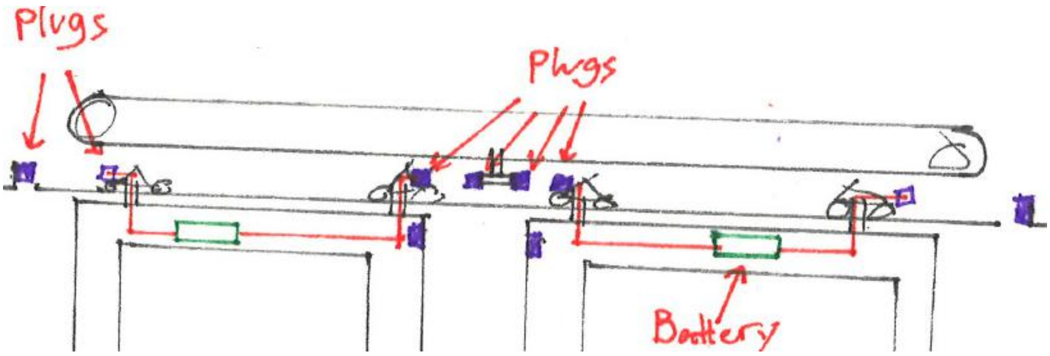



**Figure 5.16: Concept 16 - Door carriage plugs and battery. A concept similar to concept 5.15 but with the plugs located on the door leaf carriages on both ends of the door. This way the connection is invisible for the end user and the battery can be charged in both open and closed state.**

### 5.2.2 Wireless Power Transfer

*5.2.2.1 Inductive Power Transfer*

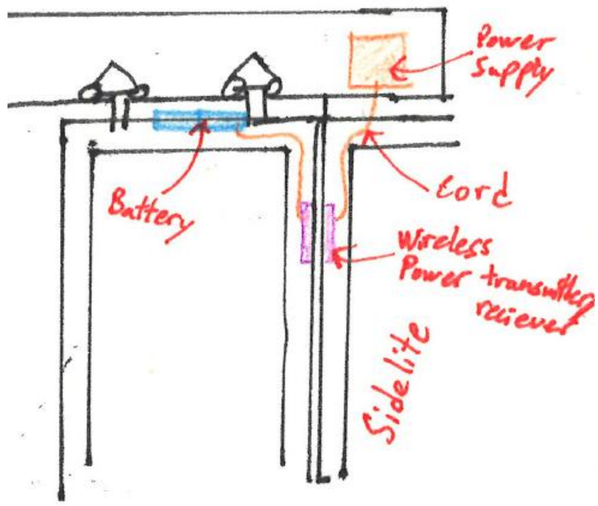



**Figure 5.17: Concept 17 - Induction and battery. A concept similar to 5.15 but where the charging of the door is completed through wireless induction instead of a conductive plug and socket. This results in the connection being somewhat more concealed and less prone to misfit and wear.**

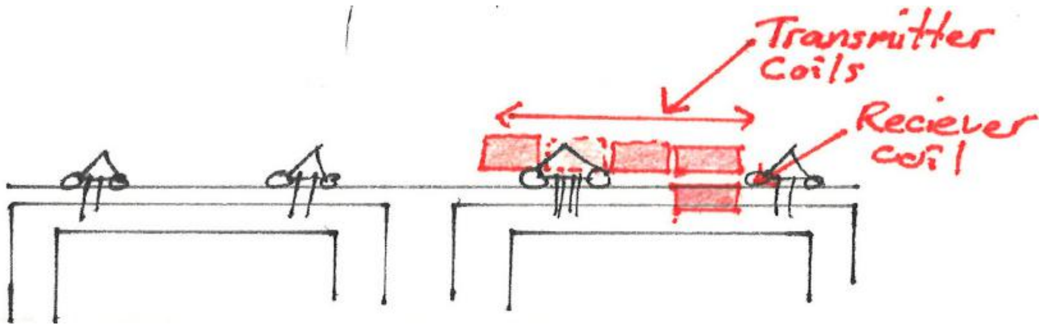



**Figure 5.18: Concept 18 - Header continuous induction. Power is transmitted wirelessly from multiple transmitter coils located in the header profile to a single receiver coil located on top of the door leaf. The power transfer is continuous when the receiver coil slides along the transmitter coil, resulting in no battery needed. Signals can be transmitted either through the induction connection or through another wireless connection.**

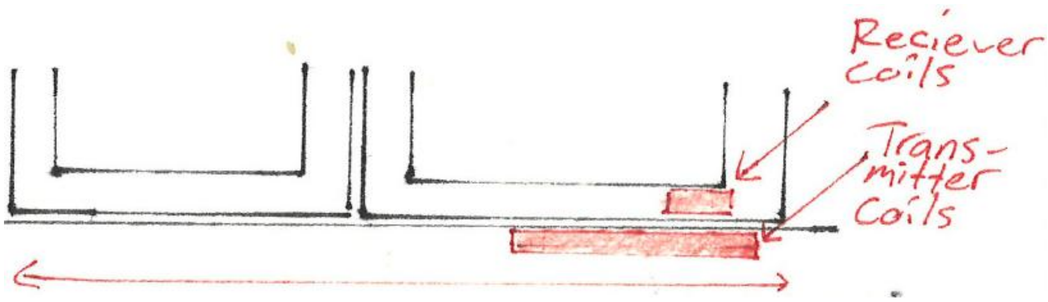



**Figure 5.19: Concept 19 - Continuous induction floor. Very similar to concept 5.18 but where the transmitter and receiver coils are located on the bottom of the door leaf and in the ground.**

### *5.2.2.2 Capacitive Power Transfer*

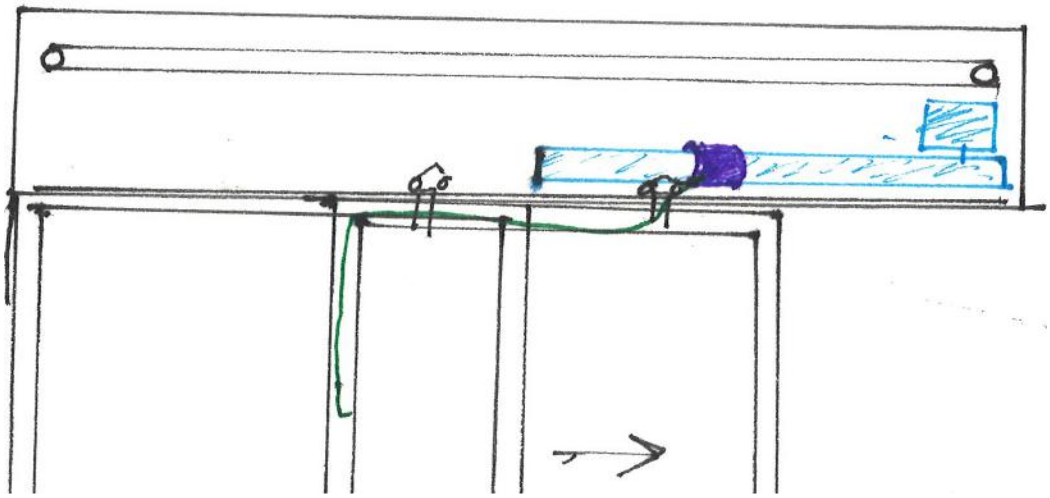


**Figure 5.20: Concept 20 - Split capacitive plain bearing. A concept where power is transmitted wirelessly through capacitive power transfer using a linear plain bearing and a shaft, where the linear bearing is mounted on the door leaf carriage and the shaft is mounted in the header profile. The shaft and bearing have two sides with isolation in between, so that a closed circuit is achieved.**

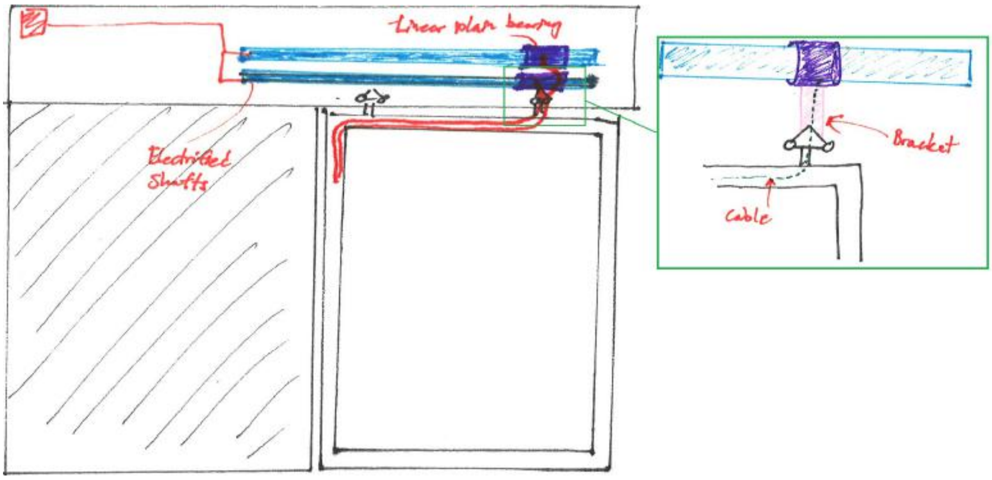



**Figure 5.21: Concept 21 - Two capacitive plain bearings. Very similar to concept 5.20 but with two linear plain bearings instead of one linear bearing. This eliminates the need for the isolation to create a closed circuit.**

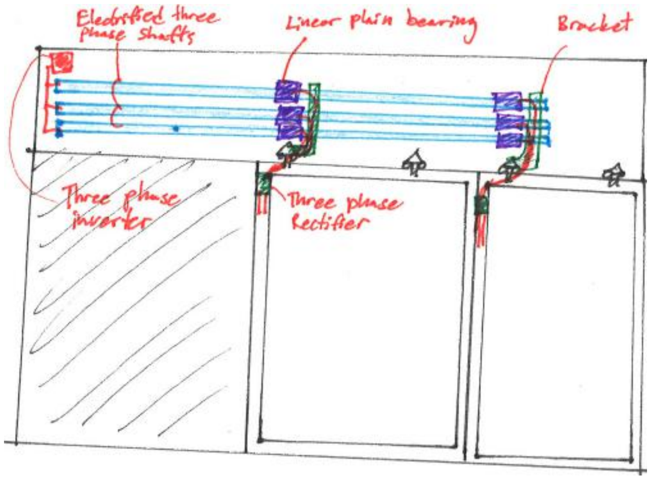



**Figure 5.22: Concept 22 - Three phase capacitive plain bearing. Similar to concept 5.21 but with three linear plain bearings. This allows for the use of three phase electricity and thus allowing more power to be sent.**

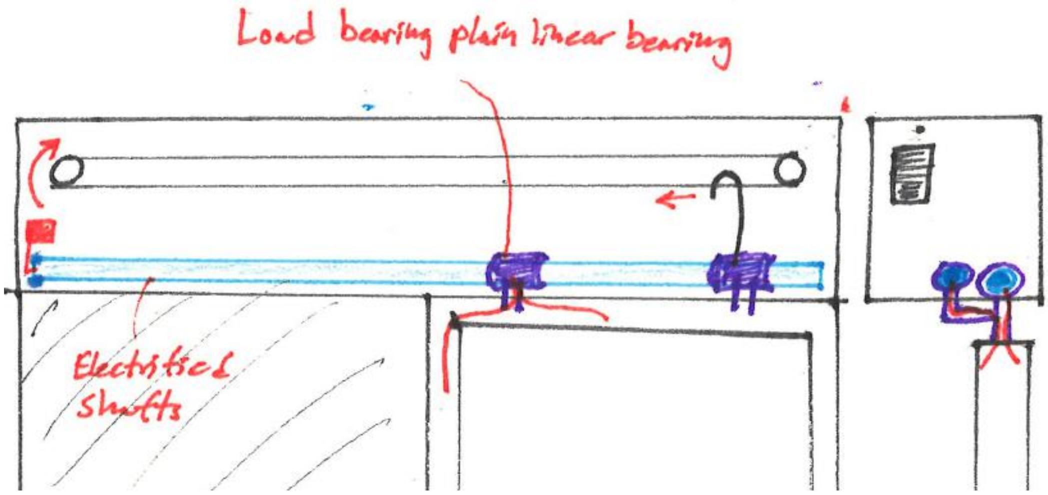



**Figure 5.23: Concept 23 - Load bearing capacitive plain bearing. A concept that eliminates the conventional door carriages, wheels and tracks from the sliding doors. These are replaced with two electrified shafts in the header profile and two load bearing plain linear bearings for each door that can both hold the door in place as well as supply the door with power through capacitive power transfer.**

### 5.2.3 Conductive Rail

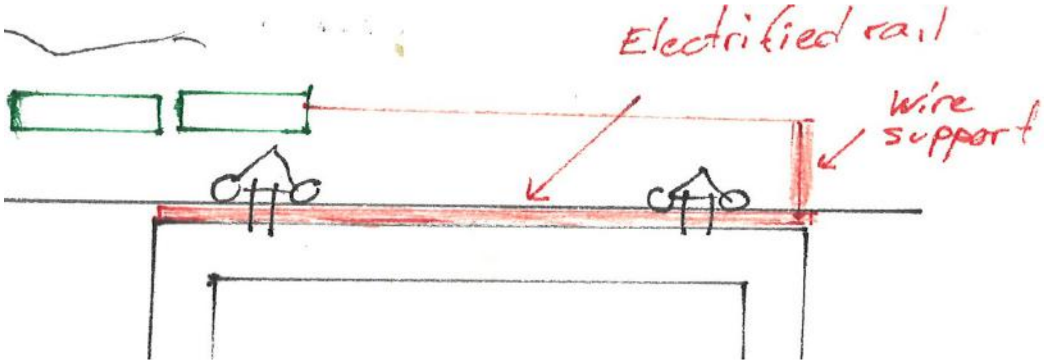



**Figure 5.24: Concept 24 - Header conductive rail. A concept that fits a conductive rail on top of the door leaf, with a conductive brush fixed in the header profile. As the door leaf slides the electric connection is maintained through the conductive brush sliding against the conductive rail.**

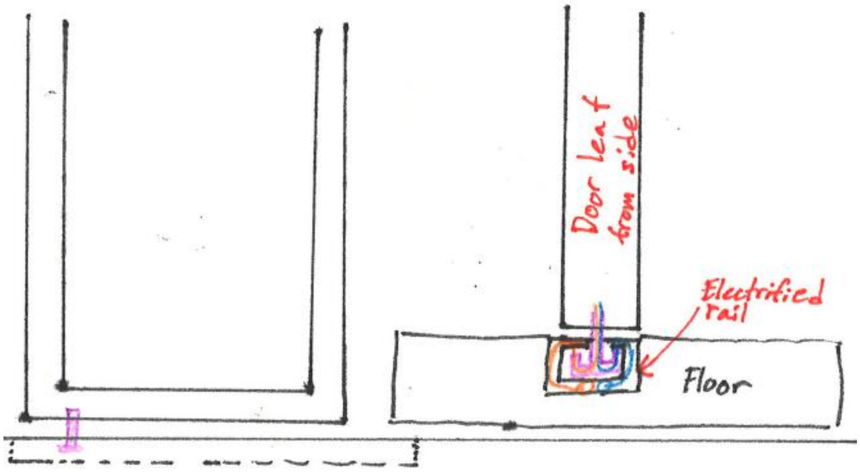



**Figure 5.25: Concept 25 - Floor conductive rail. A concept similar to concept 5.24 but where the conductive brush is mounted on the bottom of the door leaf, and the conductive rail is mounted in the floor below the door leaf.**

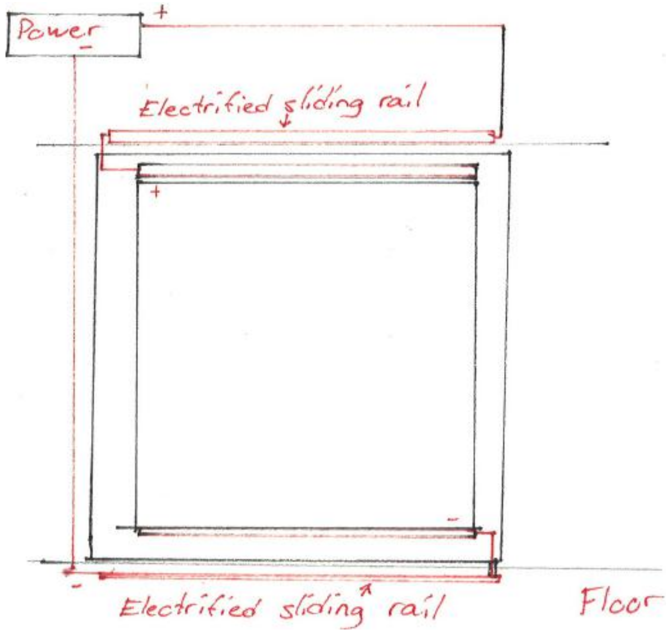



**Figure 5.26: Concept 26 - Header and floor conductive rail. A concept somewhat similar to concept 5.24 and 5.25, but where the closed circuit is maintained by passing the power and signals from the top of the door leaf down through the bottom of the door leaf and floor. This eliminates the need for multiple brushes and rails in the same spot.**

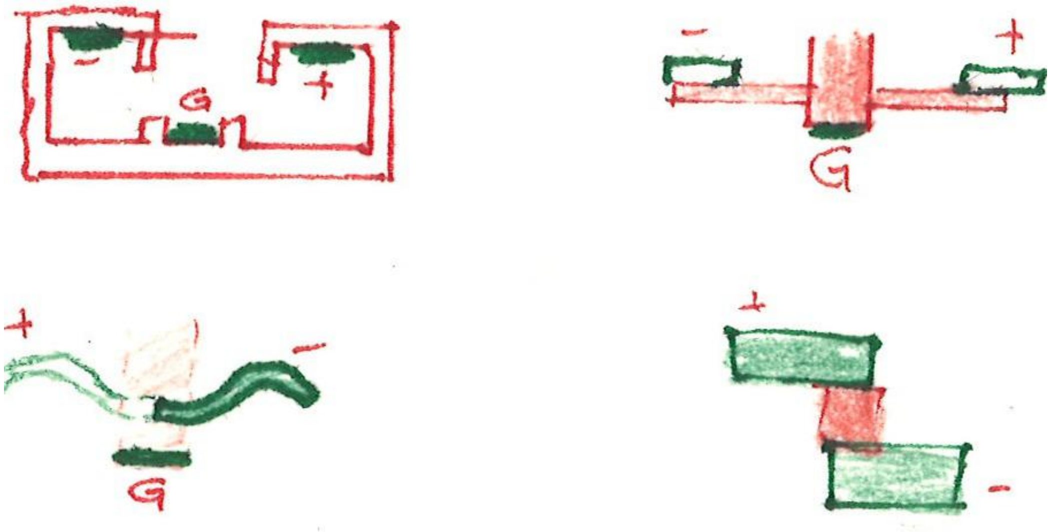


Figure 5.27: Concept 27 - Conductive rail brushes. Subconcepts for how the conductive brushes and conductive rails can be designed for concepts 5.24, 5.25 and 5.26. The design with the positive and negative conductive rail on the top and the ground in the bottom should make for a safe design since it would be hard to touch either the positive or negative rail without also touching the ground rail.

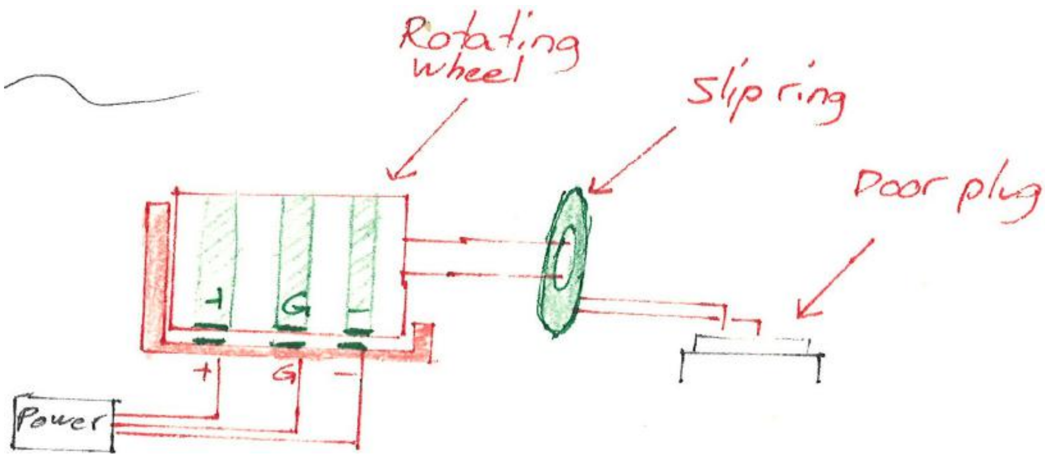



Figure 5.28: Concept 28 - Conductive rail rotating wheel. Subconcept for how the conductive brushes and conductive rails can be designed for concepts 5.24, 5.25 and 5.26. This design utilizes a rotating wheel with 3 conductive surfaces that rolls on 3 conductive rails. This eliminates the abrasion that would come from a brush that brushes against the conductive rail, but adds the need for a slip ring to translate the rotating motion to a stationary motion.

## 5.3 Concept Selection

During the concept selection phase, the goal was to converge to the best possible concept. Due to the large quantity of generated concepts, this was done in three steps to ensure that the right decisions were made.

### 5.3.1 First screening - Elimination of Similar Concepts

In order to properly evaluate the generated concepts in detail, an initial elimination of similar concepts was conducted to reduce the quantity of the concepts. This was done entirely by intuition and discussion among the authors and the supervisor at AAES, agreeing on one or maximum two concepts from each of the subcategories to proceed to the next screening.

The most promising concepts from each subcategory that were chosen to proceed to the next screening are shown below in Table 5.2. During this screening the number of concepts were reduced from 28 to 10.

**Table 5.2: The concepts from each subcategory that proceeded to the second screening. Two concepts from the subcategories Inductive power transfer and Capacitive power transfer were chosen.**

| Subcategory | Concept No. | Concept Name |
|---|---|---|
| **Igus Chain** | 1 | Igus Chain |
| **Cable Winding** | 2 | Spring-loaded Cable Winder |
| **Coiled/Folded Cable** | 11 | Spiral Cable on Support Rod |
| **Pulley System** | 13 | Spring Loaded Pulley System |
| **Plugs and Battery** | 16 | Door Carriage Plugs and Battery |
| **Inductive Power Transfer** | 17 | Induction and Battery |
| | 18 | Header Continuous Induction |
| **Capacitive Power Transfer** | 21 | Two Capacitive Plain Bearings |
| | 23 | Load Bearing Capacitive Plain Bearings |
| **Conductive Rail** | 24 | Header Conductive Rail |

### 5.3.2 Second Screening - Binary Criteria Table

The ten remaining concepts had different trade-offs which needed to be compared. In order to get an overview of the concepts and compare them and their trade-offs side by side, a table with binary criteria was established. The criteria chosen for the comparison were requirements derived from the target specifications that were then altered into binary criteria. This provided a distinct overview of the differences between the concepts, thus simplifying the elimination of inferior concepts. The binary criteria table is shown in Table 5.3. The concepts that were considered to fulfill the most criteria proceeded to the third and final screening.

The concepts represented in bold font in Table 5.3 were chosen for the final evaluation as they fulfilled the most criteria. The spring-loaded cable winder concept received the same number of check marks as the spring loaded pulley system concept and the Igus e-chain concept. The reason that the spring-loaded cable winder concept was chosen was because it was considered more important that the concepts work on both single slide models and bi-parting models than the simplicity of the concept.

**Table 5.3: Second screening of the concepts. The concepts in bold font represents the concepts chosen for the final evaluation.**

| **Criteria** | **Spring-loaded Cable Winder** | Spring Loaded Pulley System | **Spiral Cable on Support Rod** | Igus e-chain | **Door Carriage Plugs and Battery** | Header Conductive Rail | **Induction and Battery** | Load Bearing Capacitive Plain Bearings | Header Continuous Induction | Two Capacitive Plain Bearings |
|---|---|---|---|---|---|---|---|---|---|---|
| Simple | | ✓ | ✓ | ✓ | ✓ | | | | | |
| Space efficient | | | ✓ | | ✓ | | ✓ | | | |
| Works on single slide | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Works on bi-parting | ✓ | | ✓ | | ✓ | | ✓ | ✓ | | |
| Works for at least 100 000 cycles | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Provides power in all positions | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Can be retrofitted | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ |

### *5.3.2.1 Remaining Concepts*

The concepts remaining after the second screening are shown below in Figures 5.29-5.32 along with a short explanation.

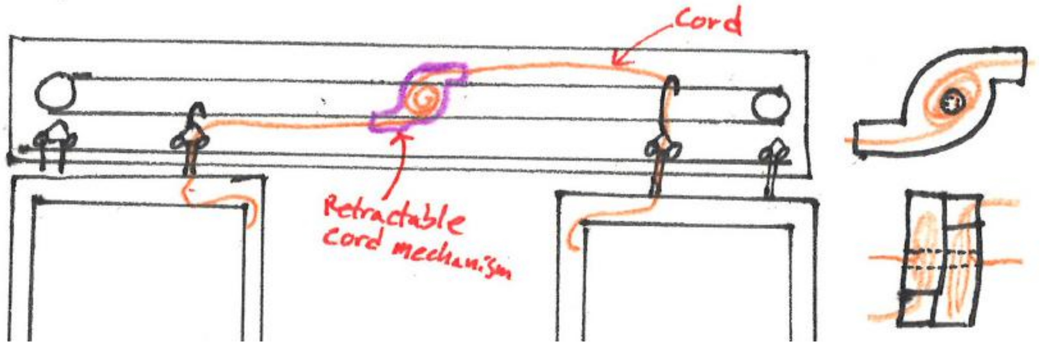



**Figure 5.29: Concept 2 - Spring Loaded Cable Winder.** A spring-loaded cable winder that always retracts cables that are connected to the door leaf. A slip ring or similar inside the cable winder axis converts the rotating cable to a stationary cable that can be connected to a power source somewhere in the header profile. For a bi-parting door it will have two separate compartments containing one cable for each door leaf.

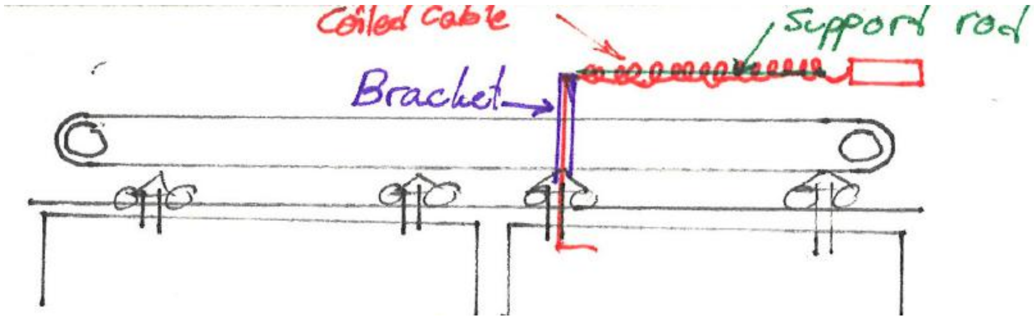



**Figure 5.30: Concept 11 - Spiral Cable on Support Rod.** A spiral cable is mounted on top of a support rod mounted in the header profile. A stiff bracket mounted on the door leaf carriage guides the spiral cable when it retracts and expands as the door slides to its open and closed position.

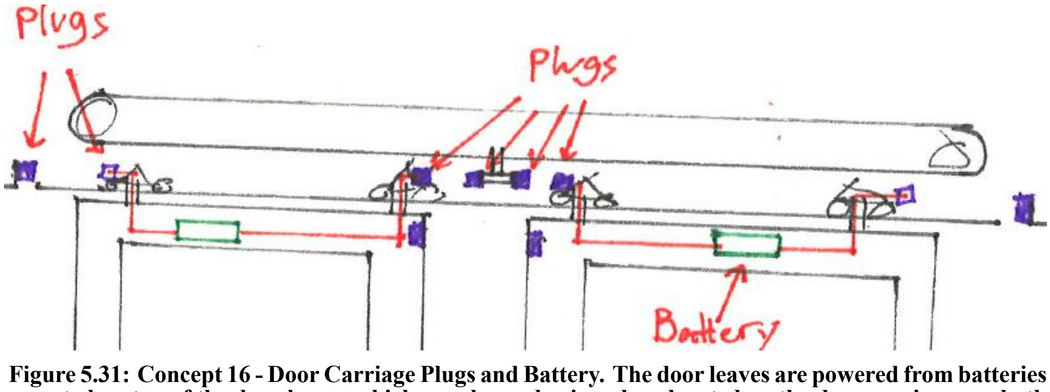



**Figure 5.31: Concept 16 - Door Carriage Plugs and Battery.** The door leaves are powered from batteries mounted on top of the door leaves which are charged using plugs located on the door carriages on both ends of the door. This way the connection is invisible for the end user and the battery can be charged in both open and closed state.

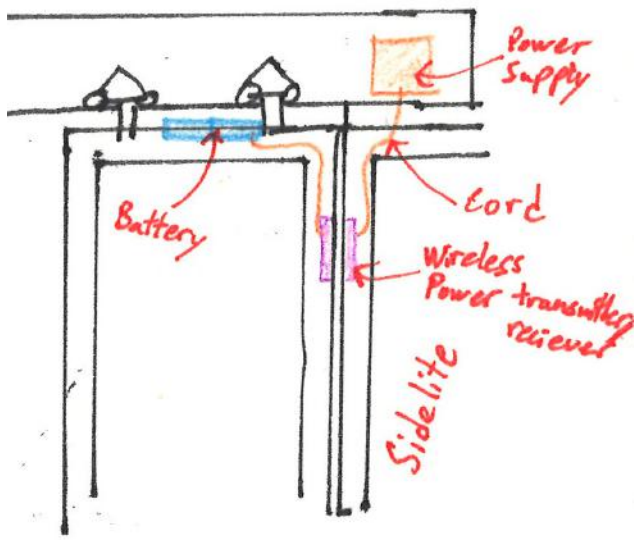



**Figure 5.32: Concept 17 - Induction and Battery. The door leaves are powered using batteries mounted on the top of the door leaf. The batteries are charged through wireless induction with transmitter coils in the sidelite and receiver coils in the side of the door leaf. This results in the connection being somewhat concealed, but has no wear and is not prone to misfit.**

### 5.3.3 Third Screening - Evaluation Matrix

The final concept was selected through an evaluation matrix shown in Table 5.4 below. The criteria used for the evaluation matrix were based on the problem formulation as well as the target specifications. They were formulated in close cooperation with AAES supervisor in order to ensure that the concept being chosen is in line with what the company hopes to achieve with the product. The AAES supervisor decided the relative prioritization of the criteria in order of importance and then a weighting factor for the individual criteria was applied. The concepts were graded from 1-5 on each criterion and the score was then calculated depending on the weight factor of said criterion. At least one concept on every criterion served as a reference and scored three points. This was done in order to have a reference basing the scoring of the other concepts on.

**Table 5.4: Evaluation matrix for concept selection.**

| | | Concepts | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Spiral Cable | | Cable Winder | | Induction | | Plugs | |
| **Evaluation criteria** | Weight | Score | Points | Score | Points | Score | Points | Score | Points |
| Unnoticeable for users | 15% | 4 | 0.60 | 2 | 0.30 | **5** | 0.75 | 3 | 0.45 |
| Enables the door to remain clinical | 15% | 3 | 0.45 | 3 | 0.45 | **4** | 0.60 | **4** | 0.60 |
| Usable in an outdoor environment | 10% | **5** | 0.50 | 4 | 0.40 | 3 | 0.30 | 2 | 0.20 |
| Resists wear | 10% | **3** | 0.30 | 2 | 0.20 | **3** | 0.30 | **3** | 0.30 |
| Allows for retrofitting | 10% | **5** | 0.50 | 4 | 0.40 | 3 | 0.30 | 3 | 0.30 |
| Easy to install | 8% | **4** | 0.32 | **4** | 0.32 | 3 | 0.24 | 3 | 0.24 |
| Serviceability | 8% | **5** | 0.40 | 4 | 0.32 | **5** | 0.40 | 4 | 0.32 |
| Safe and redundant | 8% | 3 | 0.24 | 3 | 0.24 | **4** | 0.32 | **4** | 0.32 |
| Simplicity | 6% | **5** | 0.30 | 2 | 0.12 | 3 | 0.18 | 3 | 0.18 |
| Cost efficient | 5% | **5** | 0.25 | 3 | 0.15 | 2 | 0.10 | 3 | 0.15 |
| Does not deteriorate over time | 5% | **3** | 0.15 | **3** | 0.15 | **3** | 0.15 | 2 | 0.10 |
| | Total points | **4.01** | | 3.05 | | 3.64 | | 3.16 | |
| | Rank | **1** | | 4 | | 2 | | 3 | |
| | Continue with development? | **Yes** | | No | | No | | No | |

As evident from Table 5.4 above, the spiral cable concept received the highest score and was chosen as the final concept. The reason for the high score is mainly due to it being usable in an outdoor environment, easy to retrofit, easy to service, simple and cost efficient.

The cable winder concept received lowest score. This was mainly due to it requiring a higher part count, the rotational part causing wear as well as being the concept in which the risk for added noise was highest. These downsides caused the concept to receive a low score in being unnoticeable for users, wear resistance and simplicity, giving a low overall score.

### 5.3.4 Concept Explanation - Spiral Cable on Support

The spiral cable concept consists of a spiral cable mounted in the header profile with a support in its central axis. The idea is that the door will pull the cable in a linear motion during opening and closing, thus expanding and retracting the cable during each opening cycle. The support was initially thought to be a stiff solid rod, this was however changed into a wire of some sort. The wire would claim much less space in the header profile, and the product would be much easier to transport and install. The support wire should be mounted on brackets in the header profile and will keep the cable in a horizontal position at all times, hidden in the header profile. A spiral cable bracket should be mounted on one of the door carriages, allowing the cable to be guided along the support. The spiral cable bracket should be mounted on the door carriage that is the furthest away from the spiral cable's attachment point in the header profile, thus minimizing the length that the spiral cable has to extract. A plug located at the top of the door leaf enables easy removal of the door leaf during maintenance.

See illustration below in Figure 5.33 for reference of the four main parts included in the concept: the spiral cable, the support wire, the support wire brackets and the spiral cable bracket. The best way to mount the cable would be in such a way that the cable is retracted when the door is closed and elongated when the door is opened. This is assumed to increase the longevity of the spiral cable due to most doors more often being in closed position compared to open position. This would allow the cable to be relaxed during more hours per day.

The spiral cable that is used can vary depending on the application. If the door leaf for example only needs to be supplied with electricity, it is sufficient if the spiral cable consists of only two or three conductors. If however electricity as well as many signals needs to be sent simultaneously, a spiral cable with more conductors can be used. This will certainly increase the cable and spiral diameter, however with this design this should not be an issue.

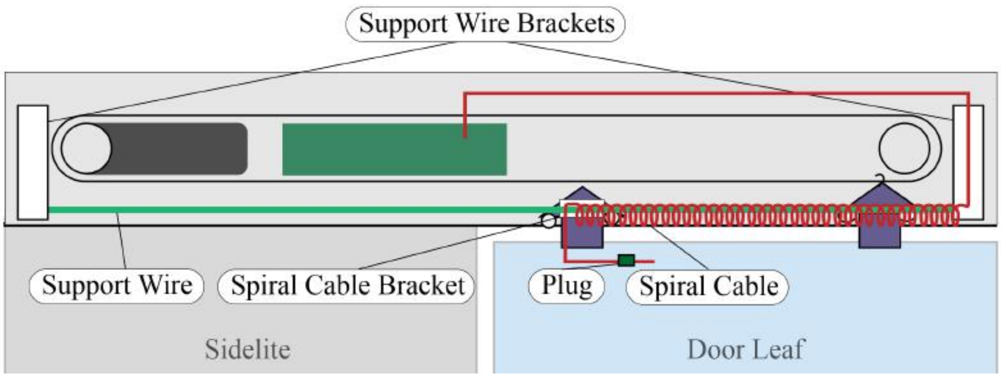



**Figure 5.33: Illustration of the included parts and positioning of the spiral cable concept.**

## 5.4 Concept Refinement

### 5.4.1 Spiral cable

#### *5.4.1.1 Requirements*

The main concerns when deciding what type of spiral cable to be used was the durability of the spiral cable jacket and the durability of the conductor. For the concept to be usable as a product in AAES product portfolio it would need to sustain many extractions and retractions. Since this product would be an optional add-on to the door and thus not affect the main door function it is not subject to the legal requirements of 1 000 000 cycles described in Section 3.3.1. As stated in Table 4.2, according to AAES supervisor Roger Dreyer it could still be a viable product for some applications if it can withstand only 100 000 cycles.

To initially confirm that this concept was somewhat feasible, cycle tests or durability tests of spiral cables was researched, but no relevant tests of any spiral cables were found. The spiral cable manufacturer LAPP Miltronic, who is a supplier of spiral cables for other uses at Assa Abloy, was contacted regarding this, but they do no such cycle or durability testing themselves. Something that however suggested that this concept was plausible was that spiral cables have been used to transfer power and signal to door leaves of sliding doors before, as described in 3.5.1.2. In these applications the spiral cables are however hanging freely, without the abrasion that will emerge from the inside of spiral cable coil rubbing against the cable support during every cycle. Another concern was how many extractions and retractions the conductors could withstand without being damaged. This ultimately led to a life cycle test being set up in AAES own test facility to test the concept, described in Chapter 6.

For the spiral cable to have as low abrasion against the cable support as possible, it is important for the spiral cable jacket to be abrasion resistant and to have low friction against the support material. The spiral cable should also at least be flexible in a temperature range from $+15$ °C to $+35$ °C representing the marginal values in Table 4.2. Finally, for the finished product to have a relatively low price the cable cannot be too expensive. Below in Table 5.5, the requirements for the spiral cable is compiled into a list.

**Table 5.5: Requirements for the spiral cable.**

| **Spiral Cable Requirements** |
|---|
| Durable and abrasion resistant. |
| Can withstand a minimum of 100 000 opening/closing cycles. |
| Low friction against the support material. |
| Flexible in the temperature range $+15$ °C - $+35$ °C. |
| Low price. |

#### *5.4.1.2 Choice of Cable*

A spiral cable has many parameters that affect the behavior and lifetime of the cable. These parameters are mainly the cable jacket material, cable insulation material, conductor type, cable diameter and spiral diameter.

Regarding the cable jackets of spiral cables there are mainly two different thermoplastics that are widely used in this application. The less expensive polyvinyl chloride (PVC) which has excellent insulation properties and protection from high and low temperatures, and the more expensive PUR which has excellent abrasion resistance and flexibility with an outstanding mechanical memory property [29] [30]. Spiral cables are commonly manufactured with other cable jacket materials such as ethylene propylene, natural rubber, neoprene, styrene-butadiene rubber, thermoplastic rubber, polyethylene (PE) and polypropylene (PP) [31], some of these materials are however expensive and they are not widely available. Considering that AAES preferably avoids any components made from PVC in their products due to the safety issue of dense smoke and corrosive hydrogen chloride gas being emitted during fire, PVC was discarded as a possible cable jacket material. It was therefore decided that a cable jacket made from PUR should be used. This was also confirmed to be a good choice by the cable manufacturer LAPP Miltronic during e-mail interaction. The most common insulation materials for spiral cables are variants of TPE.

Another important parameter for the performance of a spiral cable is how the cable conductor is constructed. The two main conductor types are solid core wires and stranded core wires. Solid core wires consist of one single core that forms a conductor. It has a higher flexing resistance and a higher electrical resistance. Because of this, spiral cables are constructed using stranded core wires instead. This means that many strands of for example copper are arranged together to form a single conductor. This allows the cable to be more flexible at the cost of a higher attenuation [32]. The total size of the conductor makes up the wiring size, that is the cross-sectional area of the conductor measured in $mm^2$ or American wire gauge.

The cable diameter is ultimately dependent on the number of conductors used in the cable as well as the thickness of the cable insulation and cable jacket. The spiral diameter is directly related to how far a spiral cable can be elongated; a longer spiral diameter allows the spiral cable to be elongated further compared to the retracted length.

The cable ultimately chosen to use for the life cycle test was considered a good trade-off between cost, abrasion resistance and convenience since this exact cable have been used for other purposes within AAES. The cable is manufactured by LAPP Miltronic, has three conductors and the properties as seen below in Table 5.6.

Table 5.6: Properties of the spiral cable used during the test [33].

| Property | Value |
|---|---|
| **Number of conductors** | 3 |
| **Conductor** | Stranded copper wire, $19x0.15$ mm => $0.34$ mm$^2$ |
| **Insulation material** | TPE-E |
| **Jacket material** | PUR |
| **Diameter (Wire)** | $4.8 \pm 0.2$ mm |
| **Diameter (Spiral)** | 18 mm |
| **Operating temperature minimum** | $-20$ °C to $+50$ °C |
| **Rated voltage minimum** | 250 VDC |
| **Maximum Amperage** | 3 A [34] |

### 5.4.2 Spiral Cable Support

#### *5.4.2.1 Requirements*

The most important requirement for the spiral cable support was that it should have low friction against the cable, and that it should be durable and abrasion resistant. The full compiled list of requirements for the spiral cable support can be seen below in Table 5.7.

Table 5.7: Requirements for the spiral cable support.

| Spiral Cable Support Requirements |
|---|
| Durable and abrasion resistant. |
| Low friction against the cable. |
| Easy to install. |
| Easy to transport. |
| Low price. |

#### *5.4.2.2 Choice of Spiral Cable Support*

Due to the many different possible shapes and materials that could be used for the spiral cable support, a research of suitable materials was conducted. It was decided that some kind of polymer was the best choice to minimize the friction and abrasion between the support and the spiral cable. To compare different polymers, a comparison table with relevant properties of the most suitable polymers was conducted, mainly by consulting the book 'Värt att veta om Plast' ['Worth knowing about plastic'] [35]. The comparison table is shown below in Table 5.8.

**Table 5.8: Compiled properties for relevant polymers [35]**

| Type | Stiffness | Operating temp. [°C] | Impact strength | Moisture absorption | Friction | Wear | Cost |
|---|---|---|---|---|---|---|---|
| **PA** | Good (high temp) | <120 | Good modified | High | - | - | Low |
| **PPA** | High | <150 | Medium | Low | - | - | High |
| **POM** | Very high | -40 to +80 | High | Low | Excellent | Excellent | Medium |
| **Polyester** | High | <130 | - | Low | - | - | Medium |
| **UHMWPE** | Moderate | <80 | Good | Negligible | Excellent | Excellent | Medium |

The friction property that is interesting in this application is the friction between the cable jacket material (PUR) and the outer spiral cable support material. The friction properties shown in Table 5.8 is however not the friction between these two materials, but rather a general friction coefficient of the material shown in the table. To retrieve the friction properties between the spiral cable jacket and possible spiral cable support materials, own tests needed to be conducted. Table 5.8 above served as a guideline for what types of polymer materials to purchase so that such a test could be conducted. The decision of what type of supports to purchase was also based on availability and price. The purchased supports can be seen in Table 5.9

When consulting Table 5.8, both polyoxymethylene (POM) and ultra high molecular weight polyethylene (UHMWPE) are great candidates for testing. However, since the cost of these materials are much higher than for example polyamide (PA) and the other tested materials, it was reasoned that these cheaper materials should be tried first. Should they fail or show very bad friction against the PUR cable, another more expensive plastic should be chosen with Table 5.8 in mind.

The friction test was conducted with a digital dynamometer measuring the force required to pull the cable at constant speed on the support. The test was conducted three times for each support and the result is an average interval of these three tests. It should be noted that since the test was conducted by hand the values should be considered more as a guideline than fact. The measured friction can be seen in Table 5.9.

By using Equation 5.1

$$\frac{F_{friction}}{F_{normal}} = \mu_k \tag{5.1}$$

where

$$F_{normal} = mg \tag{5.2a}$$

$$F_{normal} = 0.220 \cdot 9.82 = 2.16\ N \tag{5.2b}$$

the dynamic friction for the material combinations can be calculated. In Equation 5.2 the normal force of the spiral cable used during the testing is calculated by multiplying its mass, $m$, by the gravitational acceleration, $g$.

**Table 5.9: Measured friction force against a spiral cable with a cable jacket made of PUR.**

| Item | Material | Surface | Measured Friction Force, [N] | | | Avg. Friction Force [N] | $\mu_k$ |
|---|---|---|---|---|---|---|---|
| Draw Tape | PA | Smooth | 1.5-1.7 | 1.2-1.5 | 0.9-1.3 | 1.35 | 0.63 |
| Coated Steel Wire | PVC-coating | Smooth | 2.3-3.1 | 1.5-2.3 | 1.5-2.9 | 2.27[a] | 1.05 |
| Rope | HMPE | Braided | 0.9-1.0 | 0.6-0.7 | 0.9-1.0 | 0.85 | 0.39[b] |
| Rope | PP | Braided | 0.8-0.9 | 0.6-0.9 | 0.6-1.0 | 0.80 | 0.37 |
| Rope | PE | Braided (fine) | 0.7-0.8 | 1.0-1.3 | 0.7-0.8 | 0.88 | 0.41 |
| Rubber Band | PE | Braided | 0.7-0.9 | 0.8-1.0 | 0.6-0.7 | 0.78 | 0.36 |

[a] The spiral cable got stuck repeatedly, resulting in a choppy sliding motion.
[b] A very high starting friction was noted, i.e. a high $\mu_s$.

From this test together with the requirements compiled in Section 5.4.2.1 it was decided that the smooth PA wire should be used in the test described in Chapter 6 due to its low price, acceptable friction and flexible form factor. Both the PP and PE rope performed well in the friction test, but they were more difficult to manage and to tighten during installation and were therefore rejected. It was also decided to use the previously mentioned PE braided rubber band used in the French market, see Section 3.3.1.1, as a second support running in parallel to the PA wire in the testing. This was chosen due to its low friction, the ease of installation due to its elastic properties, as well as it being easy to implement as it is already used within AAES. Furthermore, they are already being used on current doors which should give some confidence in regard to their durability. The rubber bands are braided with PE strands and have an inner core of polyester.

### 5.4.3 Spiral Cable Bracket

*5.4.3.1 Requirements*

The main goal of the spiral cable bracket is to guide the spiral cable when it is being retracted and elongated, as well as to guide the cable to the top of the door leaf. The most crucial part of this design is how the spiral cable is attached to the bracket, since this could be a weak spot on the cable. The bracket should also be easy to install and should not be unnecessary expensive. Below in Table 5.10 is a compiled list of the requirements for the spiral cable bracket.

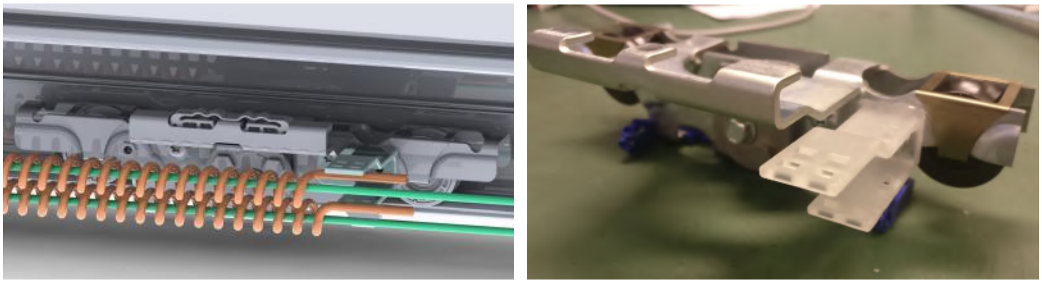
**Table 5.10: Requirements for the spiral cable bracket.**

| Spiral Cable Bracket Requirements |
|---|
| Durable. |
| Minimizes stress and critical points in the cable. |
| Easy to install. |
| Does not restrict the ability to perform maintenance on the door. |
| Guides the wire down to the top of the door leaf. |
| Low price. |

*5.4.3.2 Design of Spiral Cable Bracket for Testing*

These first iterations of the spiral cable bracket were designed with the testing, see Chapter 6, of the two cables and supports in mind. This means that one additional requirement for this bracket was that it would be able to attach two cables at the same time. The requirement that the bracket should guide the wire down to the top of the door leaf was at this point not taken into consideration. The final bracket design would be developed with only one spiral cable attachment point. Parts of the bracket design that would be able to be transferred to a final design were the actual attachment point design as well as the mounting method used for mounting the bracket on the carriage.

In Figure 5.34 the first iteration of the bracket can be seen as a rendered Computer Aided Design (CAD) model and a stereolithography 3D-printed prototype. This bracket was designed to be mounted with two screws on the right side of the bracket. One cable would be mounted on the upper flange and one on the lower flange using zip-ties. This cable mounting design was chosen since it is one the easiest and cost efficient ways to fix a cable to the bracket. Some concerns arouse regarding possible critical spots of internal wear of the cables at the mounting points, but since this mounting technique was very universal and cost-efficient it was decided that it was worth investigating.



(a) (b)

**Figure 5.34: a) The first prototype of the bracket as a rendered CAD model mounted on the door carriage. b) The first prototype of the bracket 3D-printed and mounted on the door carriage.**

Positives of this design is that it quite compact and use relatively low amount of material. It is however not symmetric, which means that it cannot be mounted on the left side of the carriage for doors that open the other way around. Another downside noted during the first mounting of the bracket to the carriage is that in order to remove the door for maintenance this bracket needed to be unscrewed as well, adding a step in the maintenance process. By re-designing the bracket so that it mounts in the already existing belt bracket screw holes, this extra step was eliminated as these screws needs to be unscrewed anyway to remove the door. A second iteration of the bracket was then designed and 3D-printed which eliminated the need for this, see Figure 5.35.

(a) (b)

**Figure 5.35: a) The second prototype of the bracket as a rendered CAD model mounted on the door carriage. b) The second prototype of the bracket 3D-printed and mounted on the door carriage.**

This bracket not only eliminated the need for extra maintenance steps, but it was also designed so that it was symmetric by mounting it in the middle of the carriage. This way it also eliminated the need for two different brackets depending on which the way the door opens. This design was deemed good enough for the testing of the two spiral cables, described further in Chapter 6.

# 6 Test of Concept

*This chapter describes the process, set up and results gathered from the life cycle test that was conducted on the spiral cables and the support wires.*

## 6.1 Objective

In order to test the feasibility of this concept, it was decided that a life cycle test of the spiral cables and the support wires should be conducted. The objective of this test was to examine the wear of a spiral cable due to mechanical forces applied from expansion and extraction. By mounting the cable to a test rig and having it run through opening/closing cycles until the internal leads failed, it was deemed possible to determine the feasibility of the concept. In order to increase efficiency two different types of support wires were tested simultaneously.

## 6.2 Measurements

### 6.2.1 Visual Inspection

During the life cycle test, daily visual inspections were conducted to verify the condition of the support wires and the spiral cables. This was done in order to find possible abrasion points, strains or other similar failures.

### 6.2.2 Conductor Resistance

Apart from visual inspection, internal wear of the conductors was measured once per working day. This was done by measuring the resistance in the conductors, as internal wear of a cable is directly related to the resistance of the conductors. If any of the copper strands that together form the conductors during the test would break, the electrical resistance would increase due to electricity having to pass through a smaller cross-sectional area. Too high electrical resistance in a conductor has a heating effect and can cause premature failure of the insulation which can lead to fire or short circuit [36].

With a DC power supply, a constant current of 1 A was passed through each of the conductors. The voltage was then monitored and recorded as the door completed a full opening cycle. Since the resistance in the conductor may vary, it was deemed best to observe the resistance of a cable during an entire cycle to ensure that the highest resistance spike was measured. Through Ohm's Law (Equation 6.1), using the highest recorded voltage during the opening cycle, the highest resistance of each conductor was calculated. The test proceeded until a complete failure of a conductor in each cable was noted, i.e. when 1 A no longer could be sent through the cable.

$$R = \frac{U}{I} \tag{6.1}$$

In Equation 6.1 above, resistance $R$ is calculated by dividing voltage $U$ with current $I$.

### 6.2.3 Slacking of Support Wires

Slacking of the support wires due to elongation was measured continuously during testing. By using the top surface of the header profile as a reference point, distance to the center of each wire was measured in the middle of header profile, see Figure 6.1. This distance was considered zero and measured difference in distance during the test was noted. The results are plotted in Table 6.8.

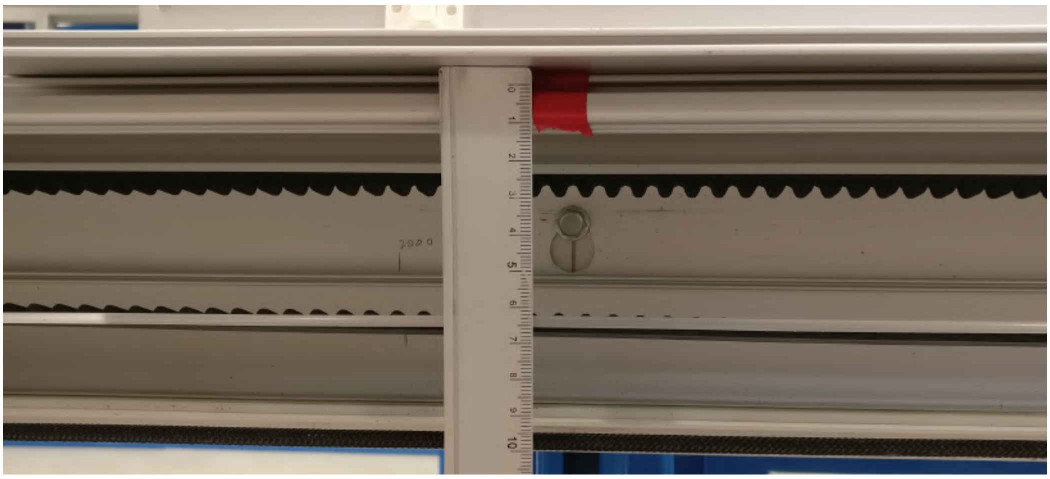


**Figure 6.1: The slacking of the two support wires was measured in the middle of the header profile.**

## 6.3 Test Setup

### 6.3.1 Mounting of Prototype

The life cycle test was conducted on a test apparatus in AAES's testing facility seen in Figure 6.2 below. As the life cycle test was conducted in order to test the wear on the spiral cables from the elongation, as well as the wear between the support wires and the spiral cables, no time was at this point spent on developing support wire brackets. These brackets would have a minimal influence on the test results, which is why the support wires was mounted crudely onto temporary support wire brackets in the header profile, see Figure 6.3 below. The spiral cable bracket developed during Section 5.4.3 was mounted as seen in Figure 6.4 below.

**Figure 6.2: An overview of the test apparatus in AAES's testing facility used for the life cycle test.**

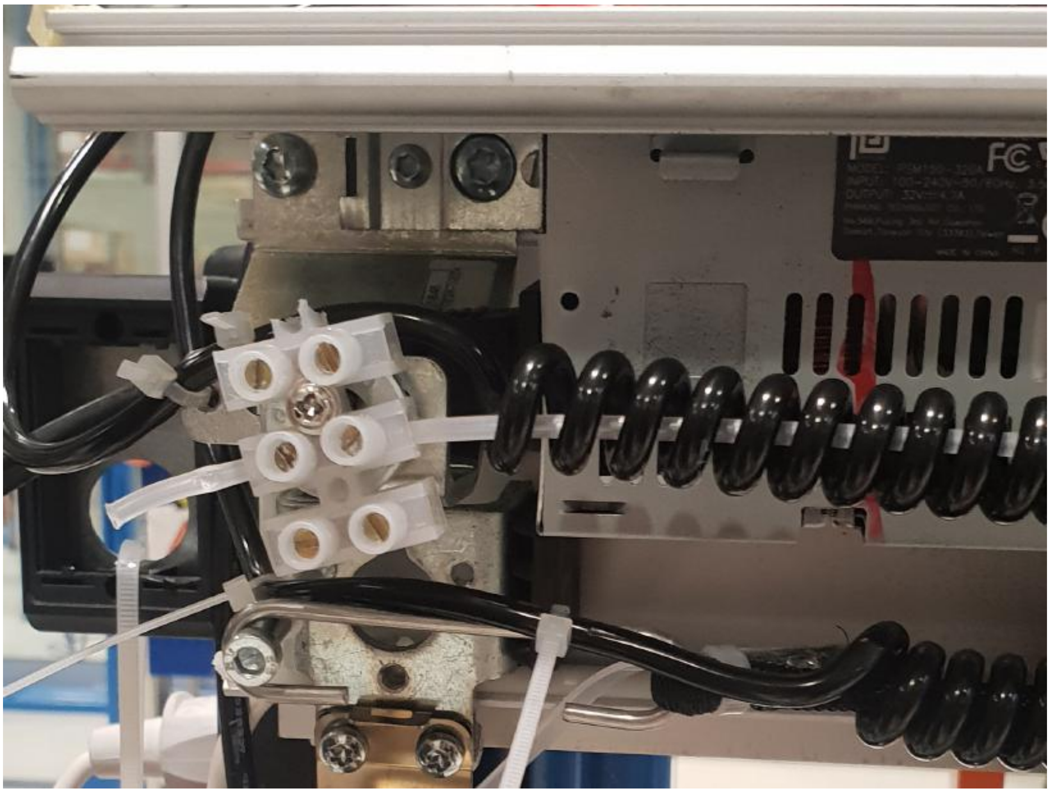


**Figure 6.3: An overview of how the two different support wires were mounted during the life cycle test.**

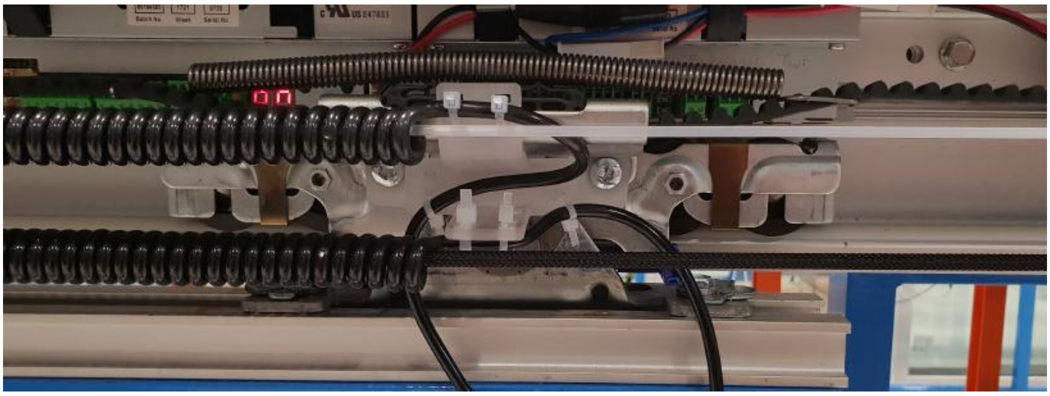


**Figure 6.4: An overview of how the spiral cable bracket used during the life cycle test was mounted.**

### 6.3.2 Test Parameters

The testing of the spiral cable was carried out according to SS-EN 16005:2012 [4], which is a standard regulating the testing of power operated sliding doorsets. Starting with the door at a closed position, two test cycles were completed as follows:

1. The door opens to an opening width of 100%.
2. The door closes to an opening width of 80%.
3. The door opens to an opening width of 100%.
4. The door closes to an opening width of 0%.

The total opening width of the door was set to 2000 mm, emulating one of the widest opening widths available on AAES doors. Note however that an opening width of 2000 mm is much wider than most normal commercial doors. Considering that the initial resting length of the spiral cables were 700 mm, this corresponds to the spiral cables being stretched to 2700 mm, approximately 3.86 times their resting lengths.

As mentioned in Section 6.2.2, the test was conducted until one conductor in each cable no longer could transfer 1 A.

## 6.4 Results

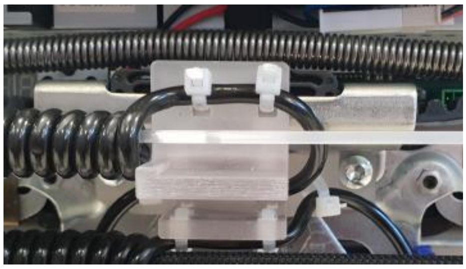
### 6.4.1 Buckling

After approximately 200 000 opening cycles the spiral cable mounted on the PA wire had developed a buckling close to the mounting point on the carriage bracket, see Figure 6.5. This buckling appeared at the end of every retraction cycle. The cause of this buckling is unknown, but a probable cause could be that the resting length of the cables was increased due to fatigue of the cables. This then resulted in the cable losing its ability to retract at the end of the retraction cycle, causing the carriage bracket to push the cable over itself. The most probable reason for this phenomenon only appearing on the PA mounted cable is that the zip-tie mounting of the cable was located further away from the support on the PA mounted wire compared to the rubber band mounted wire. The diameter of the rubber band was also thicker, which would not allow such a big buckling deformation of the cable.

At one point on the cable this buckling led to extreme abrasion, see Figure 6.6. The spiral cable had been pulled against the PA wire at the same point every retraction cycle, causing severe wear of the cable jacket and isolation, leaving the cable conductors exposed. When this abrasion was noticed it was addressed by developing a new bracket with a heel, designed for preventing the buckling. This bracket was mounted on the test rig and the test proceeded. The new bracket is shown in Figure 6.5b.

The test was originally performed in order to get an approximation of how many cycles the spiral cable can endure before failure of the conductors. In order to increase efficiency two support wires were compared as well. The test results proved to give more information than just approximate cycle life, it raised the issue of buckling, internal wear in critical points as well as how different support wires affect cable behavior.

(a)



(b)

Figure 6.5: a) The buckling of the cable that appeared when mounted on the second iteration bracket. b) The new third iteration of the bracket with a heel that prevents buckling from appearing.

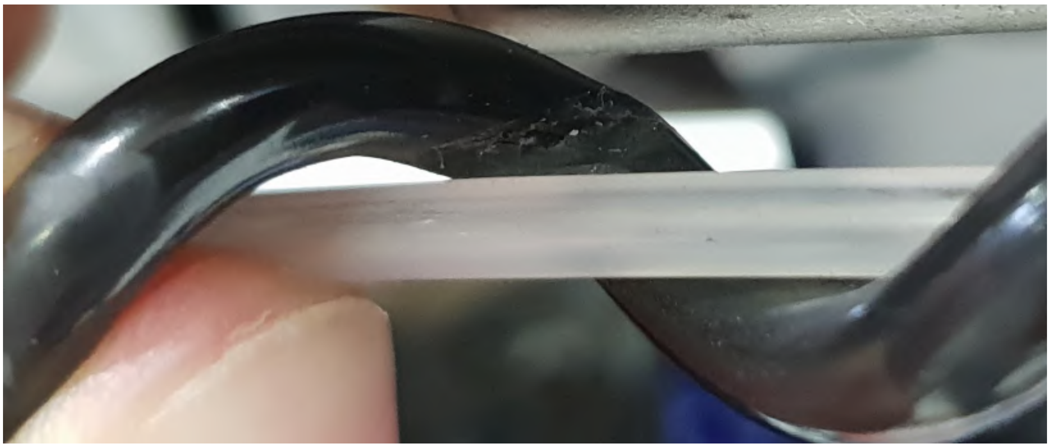


Figure 6.6: The abrasion on the inside of the spiral cable caused by the buckling. The spiral cable jacket and isolation was worn though completely in this spot.

### 6.4.2 Resistance and internal wear

In Figure 6.7, the resistance in each cable is plotted over number of completed cycles. All leads in each cable were measured and the highest resistance measured in one of the leads during one complete cycle is the plotted value in Figure 6.7. The values for the cable mounted on the PA wire is seen in blue (squares) and the one mounted on the rubber band is shown in red (circles).

A spike in resistance on the cable on the PA wire is noticeable at around 200 000 cycles, this is due to the buckling discussed in Section 6.4.1. It is evident that this buckling led to cable failure and is something that needs to be prevented in a final product. The other cable did not have any buckling and endured around 553 000 cycles before the test was terminated due to the time limited project coming to an end. At that time the test had been running for about 55 days.

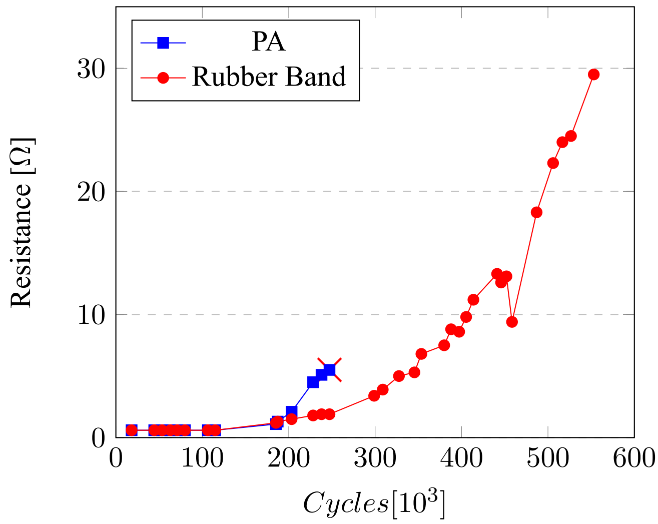



**Figure 6.7: Highest measured resistance in any of the leads in each cable.**

### 6.4.3 External Wear

The buckling caused severe abrasion which can be seen in Figure 6.6. Both the insulation and jacket material were completely worn through, exposing the wires. It is evident that this buckling leads to premature failure and is critical to prevent.

The cable not subjected to buckling did not show any wear of this magnitude. Some light external wear was noted at a specific point close to the spiral cable bracket which was not considered a major concern.

### 6.4.4 Support Wires

Both support wires were continuously compared in terms of slacking and effect on cable movement. Below in Figure 6.8 is a plot of the measured slacking in millimeters from a reference point. The PA wire expanded and the final measurement was 9 mm below the reference point. This is a significant amount compared to the rubber band which only had a difference of 2 mm between the first and last measurement. It is notable that the cause of the slacking cannot be concluded from this test. The slacking could be caused by either deterioration over time (such as moisture absorption or material fatigue) or by relaxation caused by the wire tension for example.

Apart from slacking, the supports were compared in regard to how they affect the cable and its movement. Visual inspection of wire behavior during the testing concluded that the cables did in fact behave differently. After about 100 000 cycles it was noted that the cable on the PA wire did not move as smoothly as the other one, instead some skipping was noted. This could be caused by a higher static friction, $\mu_s$, in the PA causing an oscillating effect when the cable goes from a static to a moving phase.

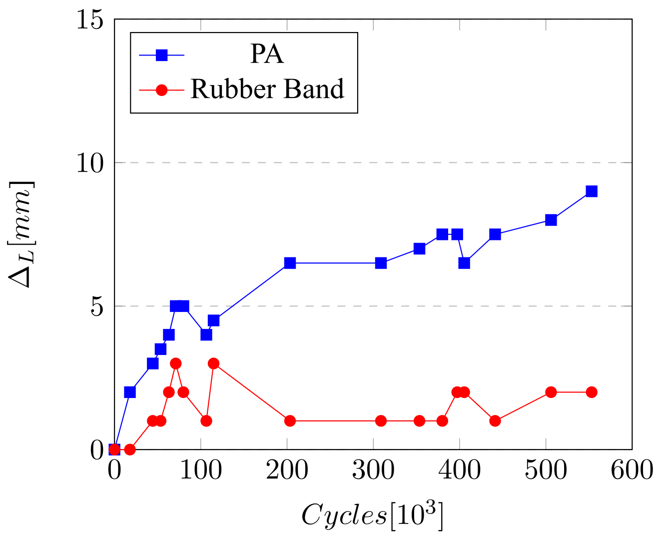



**Figure 6.8: Slacking measured in the middle of the support wires from reference point in both wires.**

# 7 Detail Design

*This chapter describes the development steps conducted in order to transform the concept into a product that could be a part of AAES's product portfolio. Manufacturability and economic analysis were a big part of this development process.*

## 7.1 Support Wire

From the results of the test, it was concluded that the PE braided rubber band was better suited as a support wire than the PA wire based on three main factors. The movement of the spiral cable was much smoother on the rubber band compared to the PA wire, which could mean less abrasion on the cable jacket. The rubber band did not suffer from any significant slacking, which the PA wire did. This was important since it could potentially minimize the abrasion on the cable over time, caused by misalignment of the support wire. Furthermore, the elastic properties of the rubber band made it easier to install and tighten compared to the PA wire. Consequently, the continued development in this project was based on the rubber band as the intended support wire.

It was decided that the support wire should be mounted on two support wire brackets in the header profile, which is described further below in Section 7.2. To easily be able to mount and demount the support wire from the support wire bracket it was secured with zip-ties around a small metal hook, see Figure 7.1. This is similar to the way that the rubber band is mounted on the sliding doors sold in France, see Section 3.3.1.1. Since this way of mounting the rubber band has already been tested for the French doors, it was deemed logical to re-use this solution.

**Figure 7.1: The metal hook mounted on the support wire.**

# 7.2 Support Wire Brackets

## 7.2.1 Design for Manufacturing

During the detailed design of the support wire bracket, the general rules listed in Table 7.1 below was taken into consideration to achieve a bracket that was designed for manufacturing.

**Table 7.1: Design guidelines for sheet metal components [37] [38], t = material thickness.**

| Description | Rule of Thumb | Avoided Consequence |
|---|---|---|
| To avoid excessive burr, deformed holes and less lifetime of the material and the punch, holes should have a minimum diameter of 1 t. | Min. hole Ø = t | Deformed hole and excessive burr. |
| To avoid deformation of holes and to ensure the strength of the part holes should have a minimum distance between them that is 2 t. | Min. distance between holes = 2 t | Tearing or deformation. |
| To avoid deformed edges and limited strength of the part holes should be located more than one material thickness from edges, preferably 1.5 t. | Min. distance from hole to edge = t, preferably 1.5 t. | Tearing or deformation. |
| To avoid distortion of holes when bending holes should be placed at least 2.5 t + the bend radius away from the bend. | Min. distance from hole to bend = 2.5 t + $R_{bend}$. | Tearing or deformation. |
| To avoid tearing when bending, a slot (bend relief) should be placed at corners of bends. The slot should have approximately 2 t in width and have and a depth of 1 t + one bend radius. | Bend reliefs should be used with dimensions: Width = 2 t, Depth = $R_{bend}$ + t | Tearing when bending. |

### 7.2.2 Bracket Development

As described above in Section 7.1 it was deemed best to mount the rubber band the way it is mounted today in the models on the French market, simply by attaching a hook on each end of the rubber band and then mount the hooks to brackets mounted on the left and right side of the header profile. This means that the support wire on a single-slide door would need two support wire brackets with holes for the hooks.

For a bi-parting door however, two sets of the entire system are needed, one for each door leaf. Because of the positioning of the lock in these models, two rubber bands are needed along with corresponding brackets on the locks. The spiral cables are mounted so that they are retracted when the door is closed and expanded when the door is opened. See Figure 7.2 for reference.

In Figure 7.3, drawing views of the designed side brackets as well as lock brackets are shown.

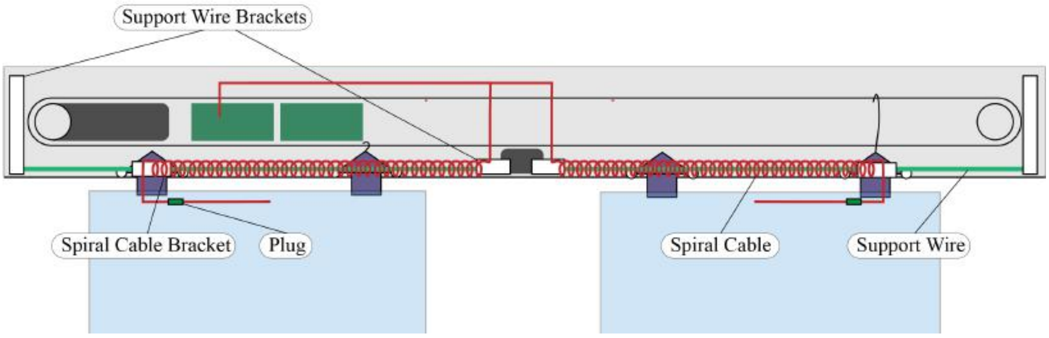
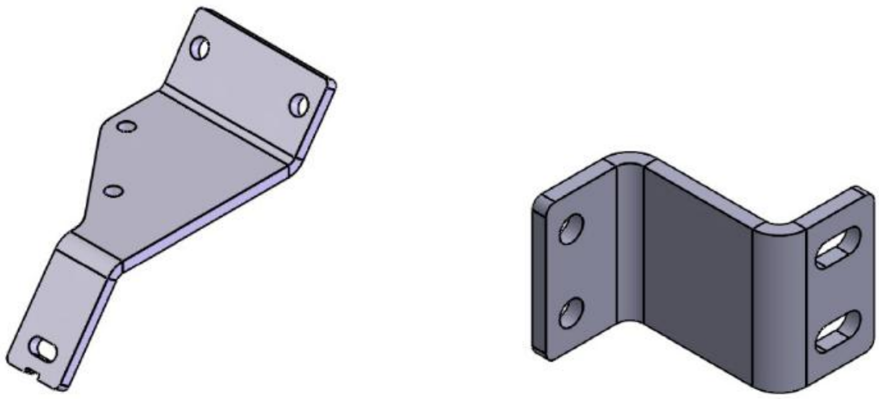



**Figure 7.2: Configuration for spiral cable solution on bi-parting doors.**



**(a)** **(b)**

**Figure 7.3: a) CAD model of the side bracket. b) CAD model of the lock bracket.**

The holes on top of the side bracket are screw joints for attaching the bracket on the mounting rail inside the header. On the bottom is an oval hole where the hook on the rubber band is attached and just below it is a cut-out for fitting a zip-tie attaching the cable. Additional holes are available for zip-tying the cable to keep it tight against the bracket.

On the right side in the door header, the belt wheel extends almost all the way to the edge limiting space at that area. To combat this, the side brackets are designed with a cut-out on its left side allowing the belt wheel and the side bracket to be mounted in the same area. The side bracket on the left-hand side does not experience this issue and thus the design on left side can be kept identical, simplifying production of the brackets.

The lock bracket was designed to fit on a standard SL500 lock as shown below in Figure 7.5. It has two holes for mounting and two oval holes for the hook attachment of the rubber band. Only the bottom oval hole is needed, but two were added to keep symmetry. This way the same design can be used on both sides, keeping down production costs.

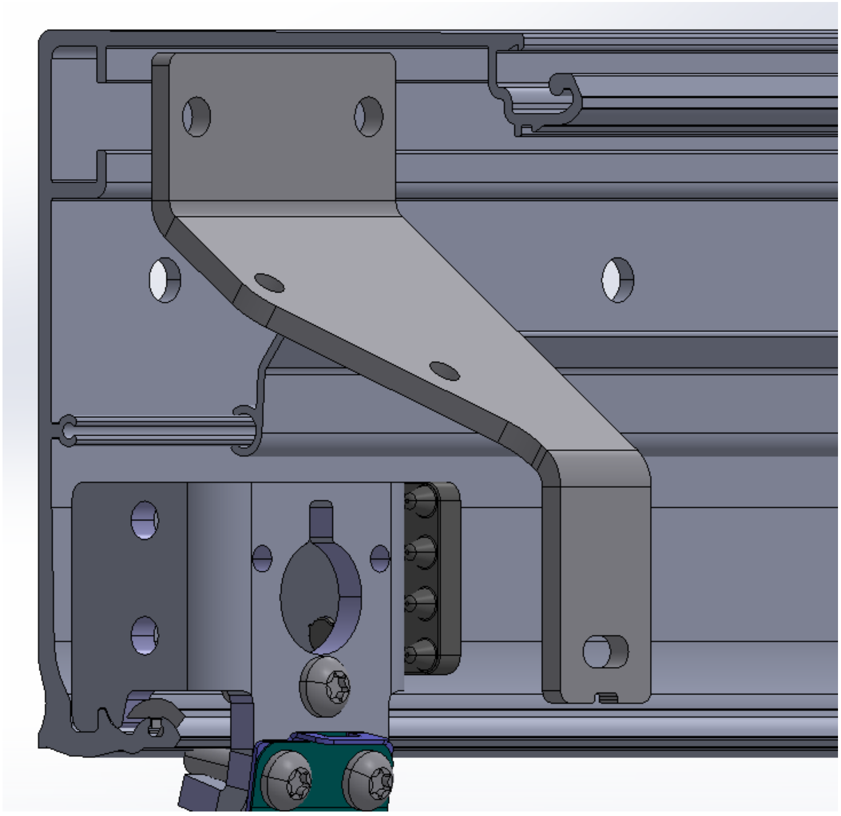
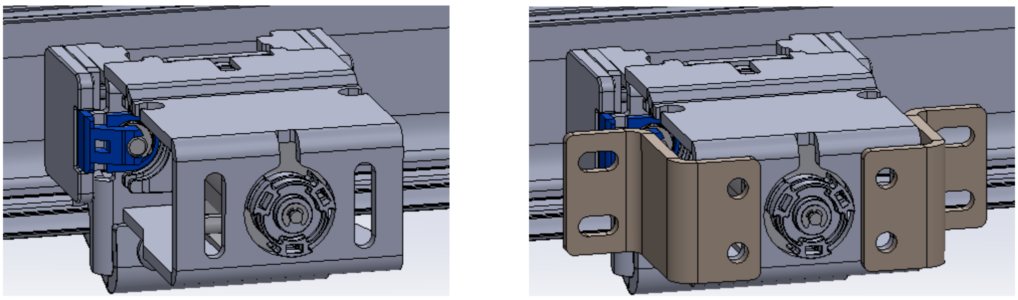


**Figure 7.4: CAD-view of the side support wire brackets mounted in a SL500.**



**(a)** **(b)**

**Figure 7.5: a) CAD model of a standard SL500 lock without the lock brackets mounted. b) CAD model of a standard SL500 lock with the new lock brackets mounted.**

## 7.3 Spiral Cable Bracket

From the spiral cable test it was concluded that the spiral cable bracket mounted on the door carriage could be developed further to increase the life time of the spiral cable. By observing the behavior of the spiral cable during the test and identifying the main issues, some additional requirements for the spiral cable bracket could be established. These requirements are listed below in Table 7.2.

**Table 7.2: Initial and additional requirements for the spiral cable bracket.**

| Spiral Cable Bracket Requirements | |
|---|---|
| **Initial Requirements** | Durable. |
| | Minimizes stress and critical points in the cable. |
| | Easy to install. |
| | Does not restrict the ability to perform maintenance on the door. |
| | Guides the wire down to the top of the door leaf. |
| | Low price. |
| **Added Requirements** | Prevent buckling. |
| | Prevent abrasion on spiral cable. |
| | Better cable attachment. |

The bracket designed in Section 6.4.1 was already designed for prevention of buckling, easy installation and with some regard to ease of manufacturing. It was however lacking in prevention of abrasion points on the spiral cable and more options of ways to attach the cable needed to be explored.

### 7.3.1 Concept Generation

With the requirements from Table 7.2 in mind, three new spiral cable bracket concepts were generated. These concepts are shown in Figure 7.6 - 7.8.

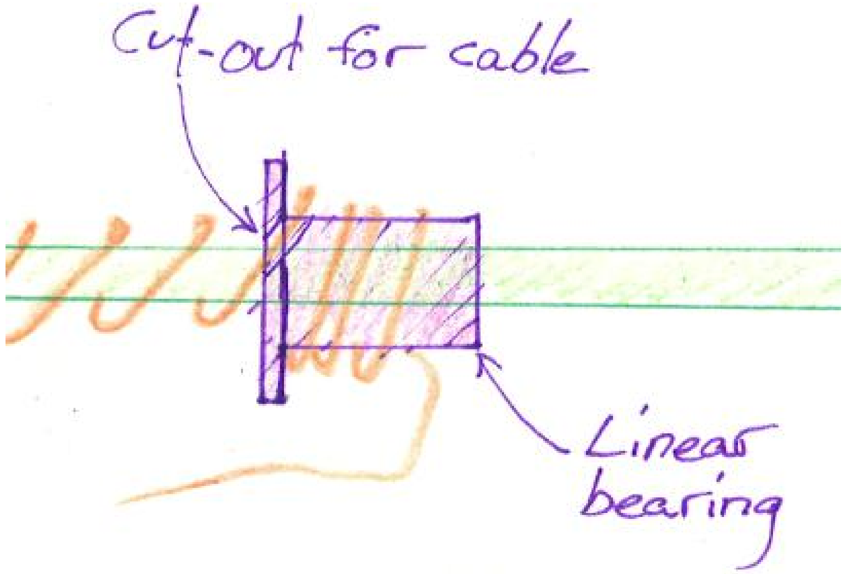



**Figure 7.6: Linear bearing concept. The spiral cable is coiled on top of the bearing which prevents the support wire to cause severe abrasion on the spiral cable. The spiral cable is held in place by snapping it in into a cut-out in the flange. The flange also prevents the cable from buckling.**

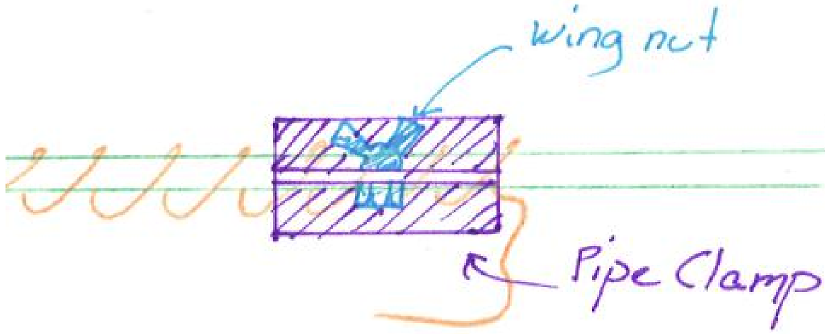



**Figure 7.7: Pipe clamp concept. A pipe clamp is put over the spiral cable where it is to be fastened. When the wing nut on the pipe clamp is tightened, the cable is secured in place.**

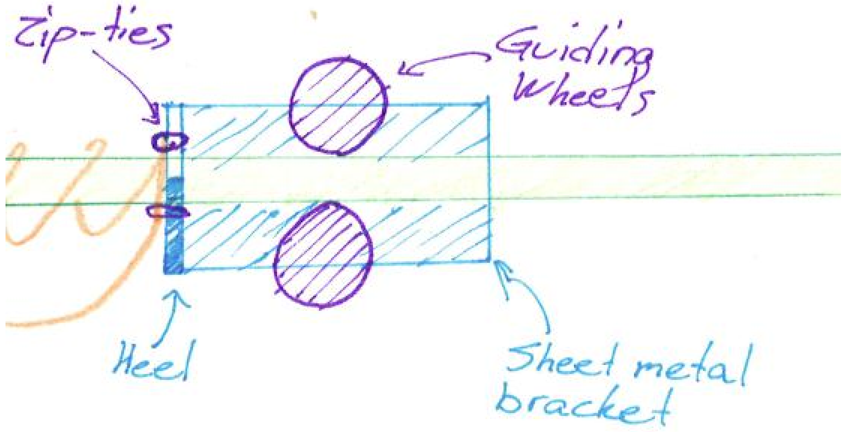



**Figure 7.8: Sheet metal concept. A bent sheet metal plate allows the spiral cable to be secured using zip-ties while also acting as a heel that prevents buckling. On the bracket two guiding wheels are mounted that guide the support wire to the cable's central axis, preventing severe abrasion.**

Due to it being difficult to evaluate these concepts in theory, it was decided that very basic prototypes should be built, and primitive tests should be conducted. By 3D-printing linear bearings and purchasing pipe clamps, the linear bearing concept and the pipe clamp concept could be prototyped and tested. The sheet metal concept was less detailed and therefore difficult to prototype, which is why this concept was further developed as seen below in Section 7.3.3.

During these basic tests, it was evident that the linear bearing concept did not work for two main reasons. The first one being difficulty in securing the cable on the bearing without it slipping. The second reason being that the concept did not work as intended due to it being impossible to coil the cable through the cut-out in the flange while keeping the spiral aligned along its own central axis, see Figure 7.9 for reference. For these reasons it was decided that this concept should not be pursued.

The pipe clamp concept also failed in these basic tests. In order to keep the spiral cable from slipping, the pipe clamp needed to be tightened very tightly, causing the cable to press against the support wire, see Figure 7.10. This could lead to severe abrasion on the spiral cable which is why this concept was also discarded.

Since neither of these concepts performed satisfactorily, none of them would be pursued. However, before they were rejected completely, they were combined into a new concept. In Figure 7.11 a sketch of this new combined concept is shown.

**Figure 7.9: Attempt to coil spiral cable on linear bearing.**

**Figure 7.10: Attempt to mount the spiral cable using a pipe clamp.**

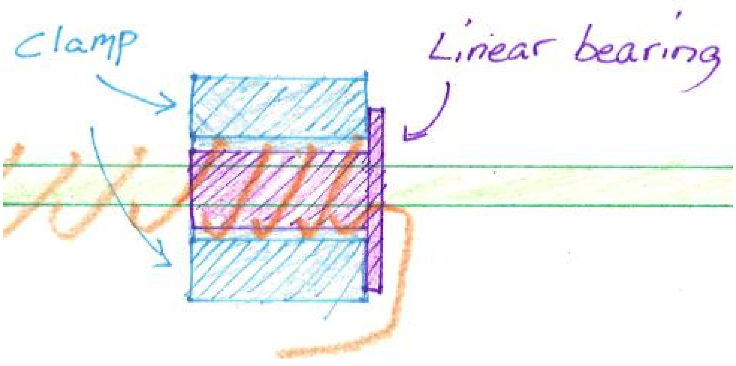
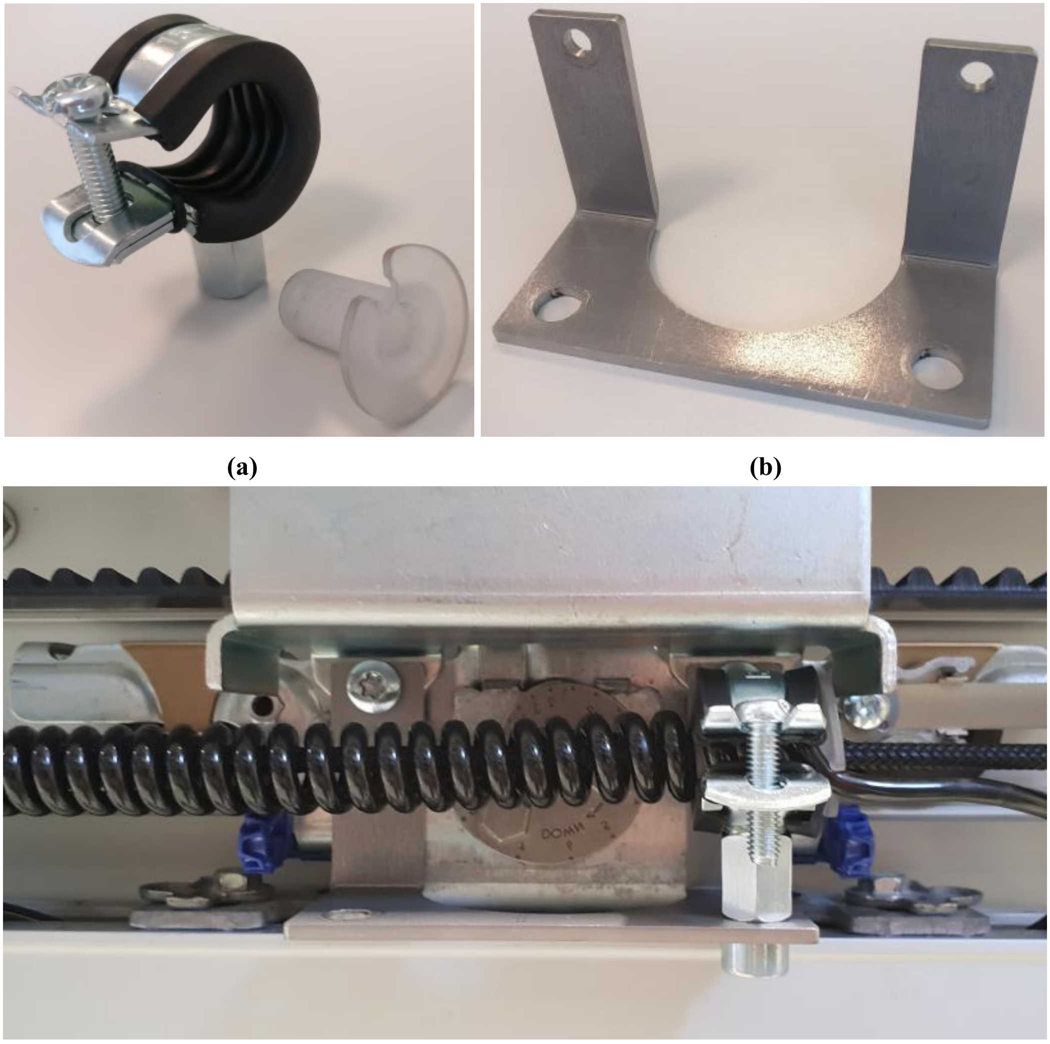



**Figure 7.11: Sketch of a combination of the linear bearing concept and the clamp concept. The flange is on the other side as the clamp itself will prevent buckling.**

This concept combines two other concepts into a more viable one. The wear resistant linear bearing slides along the support wire and is keeping the clamp from pressing the cable onto the rubber band. The clamp attaches the wire firmly while also preventing buckling due to the increased cross-sectional diameter. Since the buckling is now prevented by the clamp, the flange can be mounted on the other side which allows the spiral cable to be aligned in the central axis. Furthermore, the clamp provides an easy way of mounting the entire bracket system on the door carriage.

It was decided that a prototype should be made of the combined pipe clamp and linear bearing concept along with a prototype of the sheet metal concept.

## 7.3.2 Clamp and Linear Bearing Concept



(a) (b)

(c)

**Figure 7.12: a) The 3D-printed linear bearing and the pipe clamp used to fasten the spiral cable. b) The mounting bracket used to mount the pipe clamp to the door carriage. c) The complete prototype mounted on the door carriage.**

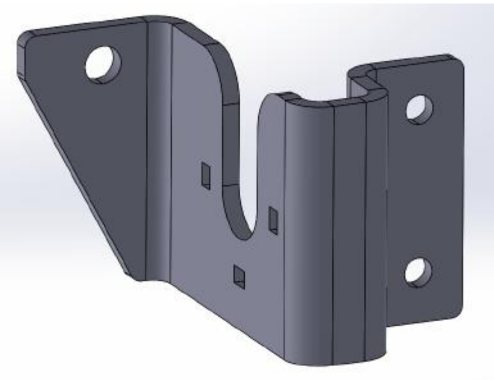
In Figure 7.12 the prototype for the clamp and linear bearing concept is shown. A bracket is attached on the door carriage and a pipe clamp is in turn attached to the bracket. A symmetrical design of the bracket allows this concept to be mounted on either side. The cable is coiled on a linear bearing and secured by tightening the pipe clamp. The bearing has a large rounded section where it is in contact with the rubber band and a cut-out in the flange of the bearing allows the uncoiled part of the cable to be guided from the clamp down to the door leaf.

Basic examination of this prototype showed that it has many advantages: it allows for a smooth transition from the moving part of the spiral cable to the attached part during extraction, correct material choice of the linear bearing allows smooth sliding, the bearing prevents critical abrasion points on the cable and the way the clamp is designed prevents any buckling.

There are however some downsides as well. The solution has a quite high part count, there is some risk that the bearing wears on the rubber band if material is not chosen properly and lastly the clamp needs to be tightened quite firmly in order to properly secure the spiral cable and prevent slipping.

### 7.3.3 Sheet Metal Concept

The crude sheet metal concept shown in Figure 7.8 was developed further through CAD-modelling. During the CAD-modeling, some design changes were made with regard to manufacturability as discussed in Table 7.1. To rapidly produce a prototype of the concept the CAD model was 3D-printed and small plastic wheels were attached. The finished CAD model can be seen in Figure 7.13a and in Figure 7.13b the 3D-printed and assembled prototype can be seen. In order to properly test the prototype, it was mounted on an SL500 door in the testing facilities at AAES. The mounted prototype is shown in Figure 7.14.



**(a)**

**(b)**

**Figure 7.13: a) CAD-view of the sheet metal concept. b) 3D-printed and assembled prototype of the sheet metal concept.**

(a)

(b)

**Figure 7.14: a) Side view of the mounted 3D-printed prototype of the sheet metal concept. b) The guiding wheels on the sheet metal prototype that guides the support wire to the middle of the spiral cable.**

The sheet metal concept was designed with slots for the use with zip-ties to mount the last spiral of the spiral cable onto the bracket. This way of mounting was expected to prevent buckling of the spiral cable. Mounted on the sheet metal bracket are two guiding wheels that guides the rubber band to the central axis of the spiral cable. This way the spiral cable is prevented from severe abrasion points that could arise due to the rubber band rubbing against the same spot on the inside of the spiral cable during every opening cycle.

Advantages of this construction is a relatively low part count, protection against buckling and abrasion points as well as some protection against improper aligning of the rubber band thanks to the guiding wheels. A disadvantage is the difficult installation procedure needed in order to zip tie the spiral cable correctly onto the bracket. The bracket is not symmetrical, which is also a drawback since this most likely would increase the cost of manufacturing the bracket.

### 7.3.4 Concept Evaluation

Through consultation with mechanical engineers and supervisor at AAES, the clamp and linear bearing concept was deemed more plausible than the sheet metal concept and it was decided that this concept should be pursued. Feedback was given for a new iteration of this bracket to lower the part count and find a design that is compatible with different spiral cable sizes, while keeping all current advantages. The spiral cable bracket was iterated further with this feedback in mind and with regard to manufacturability.

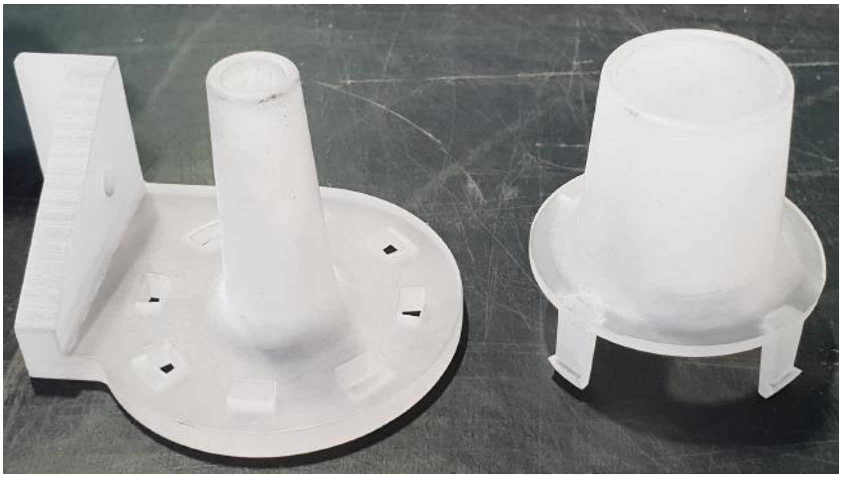
### 7.3.5 Further Development of Clamp and Linear Bearing Concept

From the consultation mentioned above in Section 7.3.4, a list of additional requirements for the clamp and linear bearing concept was compiled, as seen in Table 7.3.

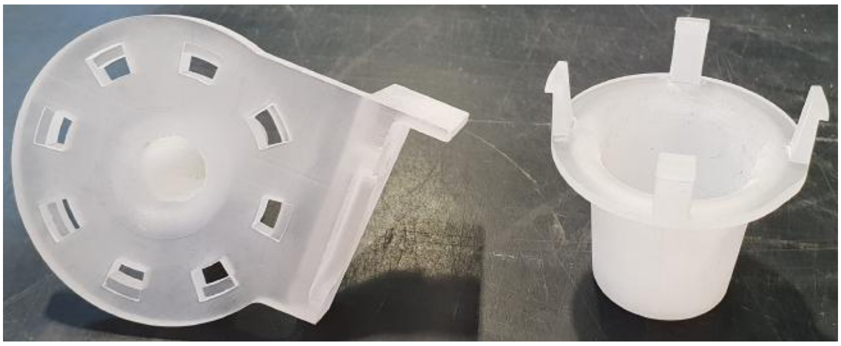
Table 7.3: **Initial and additional requirements for the spiral cable bracket.**

| Spiral Cable Bracket Requirements | |
|---|---|
| **Initial Requirements** | Durable.<br>Minimizes stress and critical points in the cable.<br>Easy to install.<br>Does not restrict the ability to perform maintenance on the door.<br>Guides the wire down to the top of the door leaf.<br>Low price.<br>Prevent buckling.<br>Prevent abrasion on spiral cable.<br>Better cable attachment. |
| **Added Requirements** | Allowing spiral cables with different spiral diameters.<br>Allowing spiral cables with different cable diameters.<br>Low part count.<br>Manufacturable. |

To enable spiral cables with different spiral diameters to be mounted using the same bracket, the product would not have to be designed for one specific spiral cable. This could be solved using a conical linear bearing as opposed to a cylindrical linear bearing. A spiral cable with a wider spiral diameter could then be mounted on the wider part of the cone, while a spiral cable with a narrower spiral diameter could be mounted on the narrower end of the cone. Pairing this design with a cover that snaps into place, securing the spiral cable into place using snap-fits that can snap at two different heights, the product would also allow spiral cables with different cable diameters to be used. This is favorable in the case of wanting to change the number of conductors in the spiral cable, which consequently changes the cable diameter. Combining the conical cylindrical bearing and the mounting bracket into one single component, the part count could be reduced. This can be made possible using injection molding. Since snap-fits are favorable to manufacture using injection molding, the cover could be manufactured using the same manufacturing technique. This would also reduce the complexity of the product as a whole. This design was realized and polished using CAD. The model was then 3D-printed into a prototype that could be tested. This new iteration of the clamp and linear bearing concept is shown in Figure 7.15.

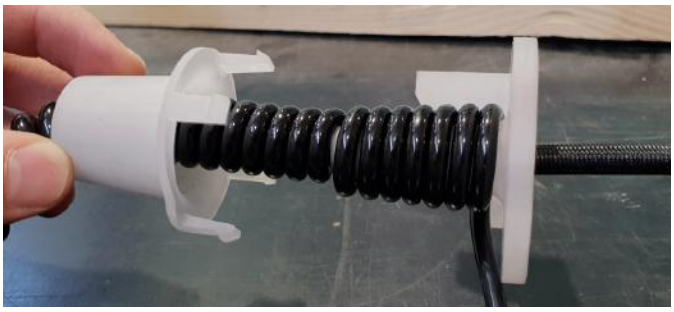


**(a)**



**(b)**

**Figure 7.15: a) The front of the two new 3D-printed prototype parts. b) The back of the two new 3D-printed prototype parts.**

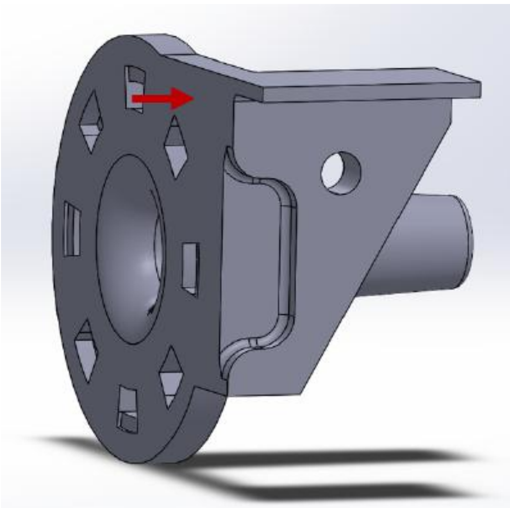
**(a)** **(b)**

**Figure 7.16: a) To mount the spiral cable on the bracket it is first coiled on top of the conical bearing. b) The cover is then snapped into place using the snap-fits, securing the spiral cable into place.**

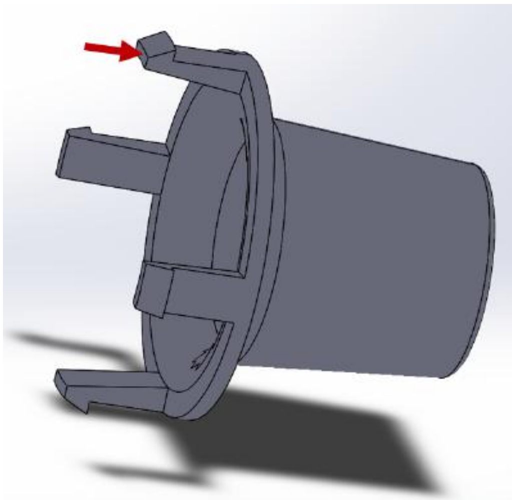
To mount the spiral cable onto the prototype it is coiled on top of the conical bearing and then secured by mounting the outer cover onto the conical bearing using the snap-fits. The outer-diameter of the cone reaches from 8 - 10 mm allowing spiral cables of corresponding inner diameters to be mounted. Furthermore, the bracket consists of a mounting hole and a top flange which keeps it horizontally aligned. A diagonal lower cut-out as well as a cut-out on the back allows the bracket to be mounted flat against the door carriage while also reducing material use. Furthermore, the design has two sets of snap grooves at different depths, depending on cable thickness. The mounting process of the spiral cable onto the bracket is shown in Figure 7.16.

This design is no longer symmetrical which is a large trade-off. This was however deemed necessary in order to produce a design that could be mounted directly on the door carrier while still being designed for manufacturing. In summary, it was reasoned that manufacturability was more important than symmetry which is why this design was chosen. The bracket is designed for injection molding. A core is required in order to create the mounting hole which is the only hole placed in a separate plane.

While in contact with ’Kanor Plast AB’, an Assa Abloy approved supplier of injection molded parts, it was clarified that cold flow lines would not be an issue due to the relatively large material thickness of the components. Furthermore, it was discussed that the most reasonable placements of the injection molding gates are as shown in Figure 7.17 [39].



**(a)**



**(b)**

**Figure 7.17: a) Recommended placement of the injection molding gate on the bracket component. b) Recommended placement of the injection molding gate on the cover component.**

### 7.3.6 Concept Evaluation

In Figure 7.18, the prototype of the clamp and linear bearing concept is shown mounted on an SL500 sliding door. During installation it was noticed that the lock brackets were somewhat unnecessary, and the question was raised that four identical brackets would serve better than two side brackets and two lock brackets. This reduces manufacturing costs but more importantly it enables the brackets to be installed regardless of lock type, making the solution even more universal.

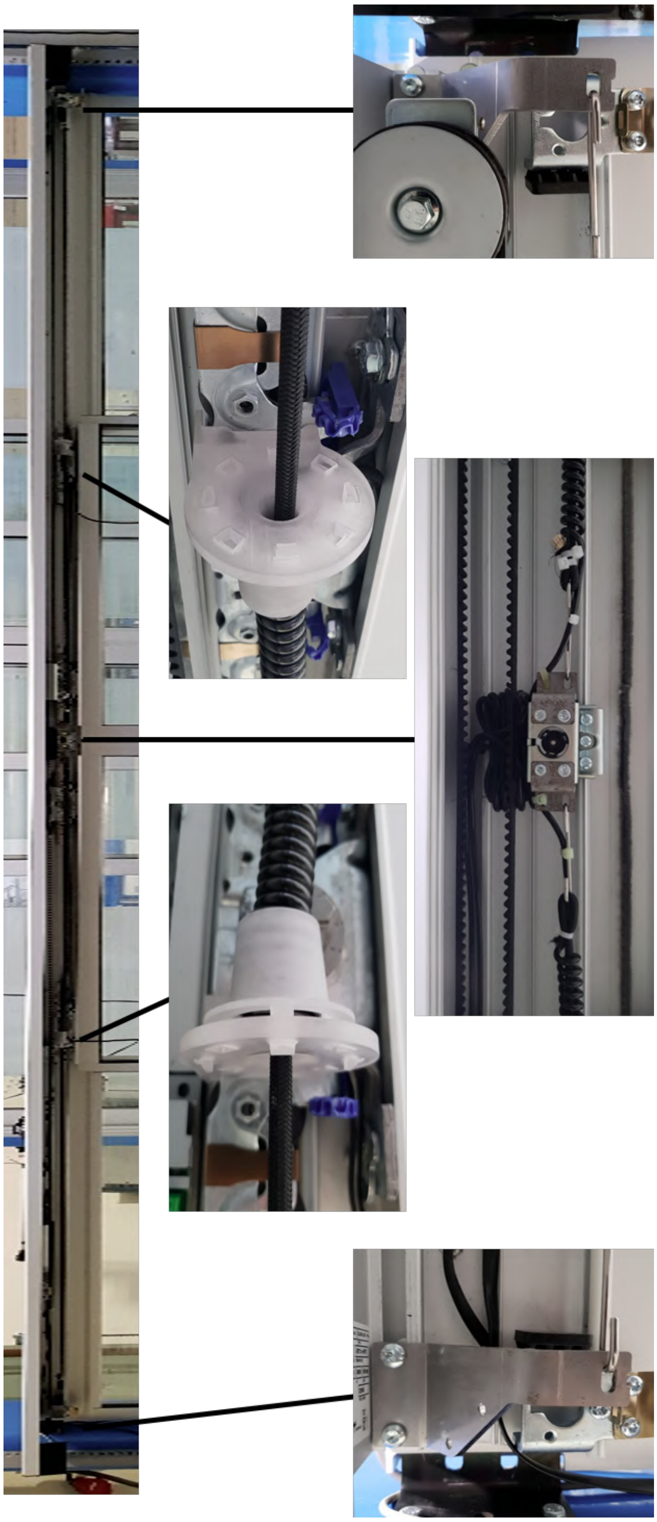
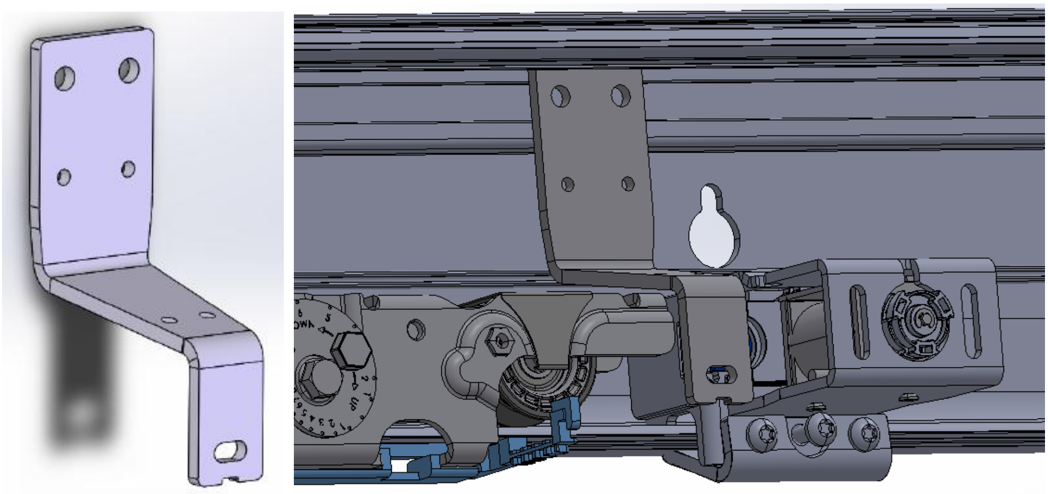


Figure 7.18: The prototype of the clamp and linear bearing concept mounted on an SL500 sliding door.

# 7.4 Final Design

The realization during the mounting of the clamp and linear bearing prototype on the SL500 led to new support wire brackets being developed. These are similar to the support wire brackets developed in Section 7.2.2, but they are symmetrical and a bit narrowed. They have a narrower angle at the bending line as to not be in the way of the belt (not shown in Figure 7.19b). The four small holes in the bracket as well as the small cut-out in the lower end of the bracket, shown in Figure 7.19b, are available for the cable to be zip-tied onto the bracket when the bracket is mounted in the middle of the header profile. This way the cable can be guided into the header profile without getting in the way of other components. Below in Figure 7.19, a CAD-model and CAD-assembly of the new support wire bracket in an SL500 sliding door is shown.

Figure 7.20 shows the intended final design of the entire product. For the final design, the support wires are mounted on the four identical support wire brackets. Apart from that, no changes have been made from the clamp and linear bearing prototype shown in Figure 7.18.



**(a)** **(b)**

**Figure 7.19: a) CAD-model of new support wire bracket. b) CAD assembly of support wire bracket at the center of the door, besides the lock.**

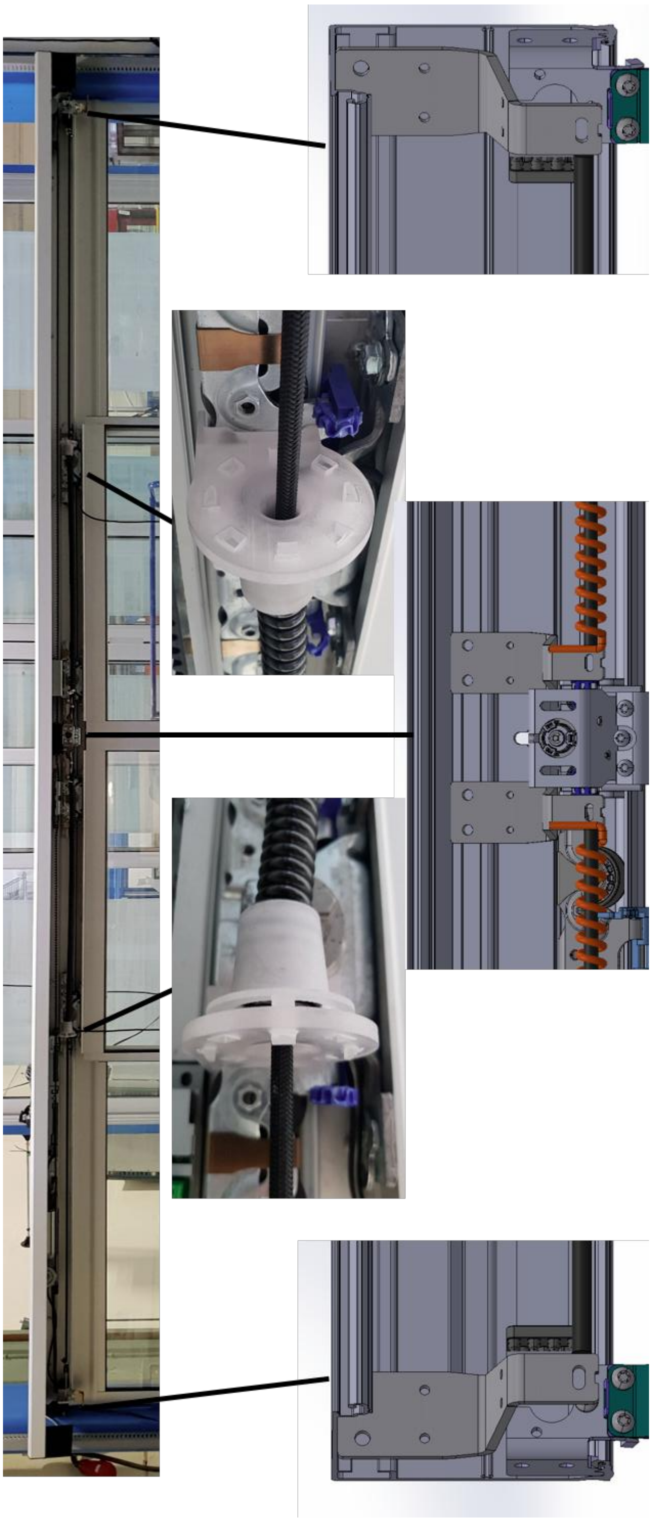


**Figure 7.20: The intended final design of the product.**

### 7.4.1 Material Choices

*7.4.1.1 Spiral Cable Bracket*

The spiral cable bracket is recommended to be injection molded using POM. POM is relatively cheap, wear resistant and dimensional stable since it does not absorb moisture [35] [39]. Specifications for the POM-material which is recommended can be seen below in Table 7.4. This material was chosen through discussions with Kanor Plast AB [40].

**Table 7.4: Specifications for TENAC©C4510 (POM Copolymer) [41].**

| | Items | Unit | Value |
|---|---|---|---|
| **General Properties** | Density | $g/cm^3$ | 1.41 |
| | Mold Shrinkage | % | 1.6-2.0 |
| **Mechanical Properties** | Tensile Strength | MPa | 66 |
| | Tensile Elongation at Break | % | 55 |
| | Tensile Modulus | MPa | 2800 |
| | Charpy Impact Strength | $kJ/m^2$ | 7 |
| **Thermal Properties** | Melt Flow Index | $g/10min$ | 9 |

*7.4.1.2 Support Wire Brackets*

The support wire brackets are recommended to be manufactured using S275JR steel. This is a common structural steel for structural purposes used in other brackets that are mounted in the header profile of sliding doors of AAES.

### 7.4.2 Placement of Product on Different Door Models

*7.4.2.1 SL500*

Below in Figure 7.21 the placement of the product on a SL500 sliding door is shown in a cross-section of the header profile.

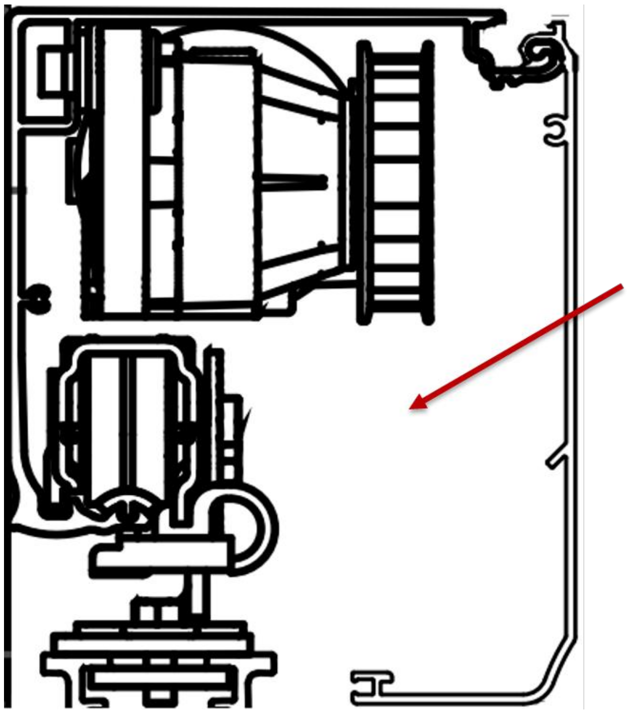


**Figure 7.21: Cross-section of SL500 header profile with indicated spiral cable placement.**

*7.4.2.2 VersaMax 2.0*

As mentioned in Section 3.4.1 the North American header profiles have a back section with extra space. The spiral cable concept can be mounted in this space without being in the way for electronics and other items in the header profile. In Figure 7.22 below available space in the cross-section of a VersaMax 2.0 header profile is shown. While being out of the scope of this project, it is worth noting that new brackets would have to be designed in order to mount the prototype in a VersaMax 2.0 door.

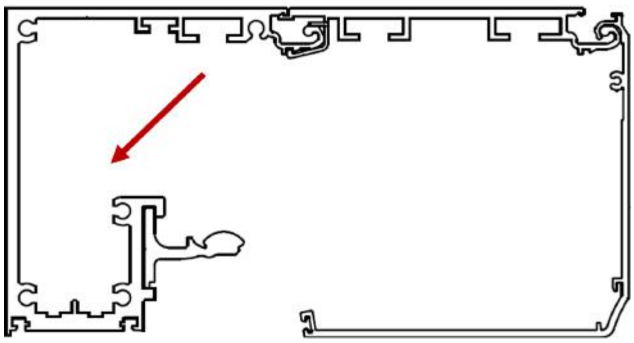


**Figure 7.22: Cross-section of VersaMax header profile with indicated spiral cable placement.**

*7.4.2.3 SL510*

Below in Figure 7.23, a cross-section of the header profile of an SL510 along with carrier and belt is shown. The arrow indicates available space for placement of the spiral cable prototype. Regarding bracketry, the same applies for the SL510 as for the VersaMax 2.0: new brackets will have to be designed in order to install the prototype.

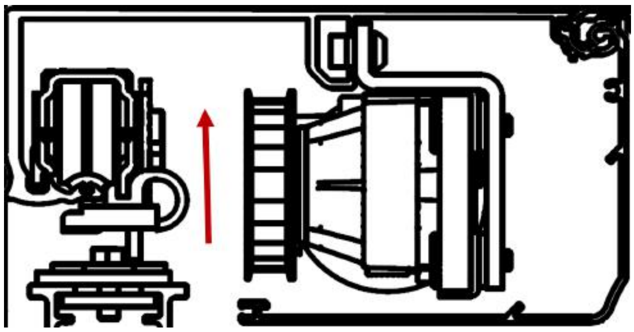


**Figure 7.23: Cross-section of SL510 header profile with indicated spiral cable placement.**

## 7.5 Economic Analysis

In order to get an approximation and overview of the cost of the product, a basic economic analysis was conducted for different production volumes. The analysis is based on installment on an SL500 bi-parting door, thus consisting of four support wire brackets, three meters of rubber band, two rubber bands and two spiral cable brackets. Hooks for the support wires are neglected.

The prices for the spiral cable bracket are received from a quote from Kanor Plast AB [40]. As for the support wire bracket, the prices have been approximated by an employee at AAES. The cost of the support wire bracket is reduced significantly if 100 000 parts are manufactured due to this enabling the parts to be manufactured using punching instead of laser cutting that is used for lower volumes. The cost of the rubber band and spiral cable are approximated by an employee at AAES.

Below in Table 7.5 the cost of manufacturing 1000, 10 000 and 100 000 pieces for a bi-parting SL500 is calculated. Depending on production volume, different tool sets for the injection molding are used. When manufacturing 1000-10 000 pieces, two different tools are used: one tool with a cavity for the bracket cap and one tool with two cavities for the left and right versions of the bracket. These two tools costs 116 000 in total to be manufactured [40]. Another tool set is used when manufacturing up to 100 000 pieces. This tool set consists of one tool with two cavities for the bracket cap and one tool with four cavities, two for each left and right version.

Worth mentioning is that this economic analysis is based on only the parts that are developed for the scope of this project. The production costs for the final solution of transferring power and signals from the header profile down to the accessories on the door leaves will have an added cost of some kind of terminal strip or similar in the header profile, as well as an added cost of cabling run through the door leaf frame to the actual accessory. Also, if more than three conductors in the spiral cable is necessary, the price will increase slightly.

**Table 7.5: Prices for manufacturing 1000, 10 000 and 100 000 pieces for a bi-parting SL500.**

| **Volume** | 1 000 | 10 000 | 100 000 |
|---:|:---:|:---:|:---:|
| **Support Wire Bracket [kr]** | 30 | 25 | 8 |
| Amount: | 4 | 4 | 4 |
| Total: | **120 kr** | **100 kr** | **32 kr** |
| **Rubber band [kr/m]** | 10 | 10 | 10 |
| Amount: | 3 | 3 | 3 |
| Total: | **30 kr** | **30 kr** | **30 kr** |
| **Spiral Cable Bracket [kr]** | 5.14 | 5.14 | 3.60 |
| Amount: | 2 | 2 | 2 |
| Toolset | 116 000 | 116 000 | 178 000 |
| Amount: | 2/1000 | 2/10 000 | 2/100 000 |
| Total: | **242.28 kr** | **33.48 kr** | **10.76 kr** |
| **Spiral Cable [kr]** | 75 | 75 | 75 |
| Amount: | 2 | 2 | 2 |
| Total: | **150 kr** | **150 kr** | **150 kr** |
| **Sum:** | 542.28 kr | 313.48 kr | 222.76 kr |

# 8 Discussion and Conclusion

*This chapter discusses test results, end specifications of the product as well as the conclusion for the thesis. Proposals to AAES for future development are also disclosed.*

## 8.1 Test Results

As evident from the plot of the resistance in the conductors of each cable, Figure 6.7, the resistance increases as the cable is subject to more elongation cycles. This seems to be true for almost all measurements made during the test, however one substantial deviation was noted for the rubber band mounted spiral cable at around 460 000 cycles. At this measurement the resistance in the cable decreased around 4 Ω from the previous measurement. This may seem abnormal, however it is worth keeping in mind that the failed copper strands in the conductor may align so that they have conductive contact during a cycle, even though they are not physically intact.

The test of the spiral cables in this thesis proceeded until a complete failure of a conductor were noticed. This gave an indication of how many opening cycles a spiral cable could handle before it could not be used anymore. It is however worth mentioning that this is not equal to that a cable should be used until a complete failure has occurred. As mentioned in Section 6.2.2, a too high resistance has a heating effect which in the worst-case scenario can result in a fire. It is therefore important to test the finalized design further, so that it is known how many cycles it can operate safely. For an additional test it would be appropriate to do a life cycle test with a spiral cable that continuously is subject to electricity running through it. This would cause a much greater heating effect compared to the test completed in this thesis, which potentially could lower the amount of cycles that the conductors can withstand. If such a test is conducted, the result from that test could be paired with an appropriate safety factor to obtain a safe estimate of how many opening cycles it is safe to let the cable operate for.

During the life cycle test the spiral cable was elongated from its resting spiral length of 700 mm to 2700 mm which is approximately 3.86 times its original resting length. This opening length is however a worst-case scenario that only the widest single slide doors have. Considering that a spiral cable is likely to suffer from more fatigue the further it is elongated, it is possible that the spiral cable life time that was recorded during this test is a worst case scenario.

## 8.2 End Specifications

**Table 8.1: End Specifications**

| No. | Metric | Importance | Unit | Ideal Value | Marginal Value | End Value |
|---|---|---|---|---|---|---|
| 1 | Power can be sent in all stationary positions | 3 | W | inf | 6 | 750 |
| 2 | Power can be sent during movement | 3 | W | inf | 0 | 750 |
| 3 | Signals can be sent in all stationary position | 3 | Binary | N/A | Yes | Yes |
| 4 | Signals can be sent during movement | 3 | Binary | Yes | No | Yes |
| 5 | Number of signals that can be sent | 2 | # | inf | 1 | >3 |
| 6 | Additional external surface volume | 3 | $cm^3$ | 0 | 2420 | 0 |
| 7 | Noise during operation | 2 | dB | 30 | 40 | 30 |
| 8 | Opening/Closing cycles | 3 | Cycles | $10^6$ | $10^5$ | 550 000[a] |
| 9 | Impact resistance | 2 | Subj. | Abusive usage | Normal usage | Normal usage |
| 10 | Water resistance | 1 | IP rating | IPx7 | IPx1 | - |
| 11 | Wind resistance | 1 | m/s | 30 | 3 | - |
| 12 | UV-radiation resistance | 1 | years | inf | 10 | - |
| 13 | Operating temperature | 2 | ° C | -20 to +65 | +15 to +35 | -20 to +50 |
| 14 | Opening time | 3 | s | N/A | 80% after 3 s | 80% after 3 s |
| 15 | Opening range | 3 | % | N/A | 100 | 100 |
| 16 | Opening force | 3 | N | N/A | 90 | 90 |
| 17 | Allows optional features | 3 | Binary | N/A | Yes | Yes |
| 18 | Applicable on all AAES sliding doors | 3 | Binary | Yes | No | No |
| 19 | SiS and international standards | 3 | Binary | N/A | Yes | Yes |
| 20 | Installation time | 3 | min | 10 | 60 | 30 |
| 21 | Manufacturing cost | 2 | kr | Confidential | N/A | Confidential |

[a] Note that this is the highest cycle count recorded during the life cycle test without electrical load. The actual cycle count in a real scenario for the cable could vary.

A successful end product should lie within the marginal and ideal values of the target specifications seen in Table 4.2. Table 8.1 shows a comparison between the specifications for the end product and the target specifications.

The end specifications values all comply with the marginal values which makes this a viable product. Some of the end specification values also complies with the ideal values, further adding to the viability of this product.

From the spiral cable properties shown in Table 5.6 it is evident that the spiral cable used during the testing can handle 750 W due to it being rated at 250 V with maximum amperage at around 3 A. This can be increased even further if another spiral cable is used.

Some of these metrics are however quite hard to verify for the final prototype without proper testing. None of the metrics 9 to 12 have been tested, but since the final product does not affect these parameters noticeably the metrics are considered to be within the acceptable margin. The PUR jacket on the cable has good UV-resistance, is resistant to chemicals and durable, this combined with the fact that the rubber band is already used on commercial doors further implies that the solution is within the accepted margins of these metrics.

The additional noise that the door generates during operation with the prototype mounted is negligible, and the prototype is therefore considered to fulfill metric 7. As for metric 18, it is verified that the final solution is applicable on the common models, i.e. SL500 (single slide and bi-parting), the slim version and also on VersaMax 2.0. Additionally, because of the placement beside the carrier, this end product is also applicable on doors sold in France as mentioned in Section 3.3.1.1. Worth noting is that there are many other sliding door models in AAES's product catalogue which are sold exclusively in markets overseas and have not been tested with this prototype.

Provided that the connection to the power source in the header profile as well as the connections in the door leaves (which are outside the scope of this project) is made properly, this solution should be accepted under European standards as represented in metric 19. For the American standards and achieving UL-listing for the assembly, some more research needs to be conducted by AAES.

When installing the prototype, see Appendix B, the installation time was measured to approximately 30 minutes for one door leaf. Connecting the cable to a power or signal source in the header profile, as well as feeding the cable through the door leaf was not included in this installation since these steps are outside the scope of this project. Nevertheless, it can be concluded that the installation time for this prototype is below 60 minutes.

## 8.3 Proposals to AAES for Future Development

The limited time frame of this project limited the amount of testing that could be done on the prototype. It is recommended that more testing and research should conducted by AAES after this project has ended in order to confirm some of the assumptions that have been made during the detail design of this product. Below are some recommendations to AAES for further actions before launching this product on the market.

### 8.3.1 Additional Life Cycle Tests

*8.3.1.1 Life Cycle Test with Continuous Electrical Load*

The life cycle test conducted in this thesis only measured the wear and fatigue of the conductor due to the mechanical forces applied to it through the expansion and retraction of the spiral cable. The electricity passed through the conductors during the test was only to confirm the condition of the conductors. By instead having a continuous electrical load similar to that of the maximum rating of the cable passing through the conductors during a test, it would be possible to obtain the actual rating of how many opening cycles that spiral cable can endure in a worst-case real-life scenario.

*8.3.1.2 Life Cycle Test with New Spiral Cable Bracket Design*

Conducting an additional life cycle test with the newly developed spiral cable bracket is crucial in order to confirm that the design of this bracket allows the spiral cable to endure more opening cycles before it breaks than in the life cycle test in Chapter 6. The design developed in Chapter 7 is developed to cope with the problems observed with the bracket design used during the life cycle test. These design choices were however not tested more than a few cycles due to the limited time available in this project and are only based on qualified assumptions made by the authors of this thesis together with engineers at AAES.

*8.3.1.3 Life Cycle Test in Cold Environment*

An additional life cycle test should be carried out in a cold environment to simulate cable behavior in an outdoor application. The retracting abilities of the cable will probably be affected by a colder temperature and it is important to see how this affects life cycle time and internal wear. The buckling shown in Figure 6.5 was potentially caused by the cable relaxing and subsequently increasing its resting length. Limiting the cable's ability to retract by testing in a cold environment could potentially increase the risk of buckling. If this is the case, it is important to see to what extent the cable buckles in a cold environment and to see how the new spiral cable bracket design handles this. It is also important so see how a colder environment affects the internal wear of the cable.

### 8.3.2 Spiral Cable

A more extensive research for the optimal spiral cable for this specific application should be conducted. Ideally, a large number of spiral cables should be tested in order to map what parameters affect the behavior of the cable. For instance, it would be beneficial to research how parameters such as spiral diameter, cable diameter, number of leads, number of strands in each lead and the total cross-sectional area of the leads affects internal wear and subsequently life cycle time of the cable.

The parameters proposed to test since they could have a positive effect on the lifetime of the spiral cable are mainly the following:

- Conductors made from copper strands with a smaller cross-section. This should, as mentioned in Section 5.4.1.2, allow for a more flexible cable.
- A bigger spiral diameter. This allows the spiral cable to be extended the same length while not extending to its maximum length specified by the manufacturer.
- A spiral cable with insulation made of PUR. PUR has better retracting ability and is more abrasion resistant than TPE-E that was used in the life cycle test.

### 8.3.3 Support Wire

From the life cycle testing conducted in this project the rubber band shows to be viable as a support wire for the spiral cable. However, further testing in a real-life application over a longer time frame and with the new spiral cable bracket design would be desirable. This would help to answer two main concerns. One of them being how the rubber band behaves over time when it is constantly elongated. If the rubber band loses its elastic properties and starts to elongate plastically, this will cause the rubber band to slack. The second concern is whether the sliding bearing that slides on top of the rubber band will cause wear on the braided surface of the rubber band. In the case of any of these concerns being legitimate, testing of other materials should be conducted. From Table 5.8, it is evident that UHMWPE and POM both has properties suitable for this application and a comparison in price and behavior of these materials is recommended.

Proposed testing of support wires are as follows:

- Test of long-term slacking of the rubber band.
- Test of how linear bearings in different abrasion resistant plastics wear on the rubber band in order to find optimal material combination.
- POM and UHMWPE support wires. These materials all have relevant qualities such as resistance to wear and dimension stability as well as potentially low friction.

### 8.3.4 Safety Indicator

The plot in Figure 6.7 indicates the internal wear of a spiral cable used in a door. It is necessary for AAES to add a safety feature that cuts power flowing through the cable when the wear is significant. This could for example be achieved by having an indication led running in parallel with the cable along with a protective load and a switching relay cutting power to the cable.

Since AAES intends to implement IoT-technology into their products, this safety circuit can be a part of that as well. Instead of having an indication led, a transmitter can send data to AAES showing that the cable needs replacing. By expanding the circuit and having it continuously measuring resistance and sending this data, AAES can even proactively replace the cable if necessary.

### 8.3.5 UL-listing

In order for the product to be viable in the North American market, components with an UL-listing should be used, especially the spiral cable since this is the most crucial part of the product. If the product or the components in the product are not UL-listed, there is a risk that customers in the US will choose products from other companies instead, see Section 3.3.2. It is therefore recommended that the spiral cable ultimately chosen for the product is UL-listed, making product viable on the markets in both Europe and North America.

## 8.4 Conclusion

The problem formulation of this master thesis was compressed into the following sentence:

*"Is there a better way to transfer both electricity and signals to a sliding door that keeps the functionality of the current solution, while being cheaper and more universal?"*

The solution developed in this thesis keeps functionality by sending power and signals while being concealed as well as durable as concluded from the life cycle test conducted in Chapter 6. From the basic economic analysis in Section 7.5 it is also apparent that this solution is low cost. Furthermore, the compact design allows for installation on different door models, provided that appropriate bracketry is developed, making the design more universal. Based on this, it can be concluded that the developed product solves the problem formulation above. The product developed is however not fully defined and polished, and if AAES wants to sell this product on the market, it is recommended that they conduct the research and tests mentioned in Section 8.3.

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# Appendix A Work distribution and time plan

## A.1 Work distribution

The authors of this thesis are both students at the department of Mechanical Engineering at the Faculty of Engineering at LTH in Lund. The authors have similar backgrounds and knowledge and both authors have therefore been involved in all activities during this thesis. The workload has been distributed equally, though occasionally the tasks have differed slightly. All tasks have however been discussed thoroughly and reviewed by both authors.

## A.2 Time plan

The time plan for this thesis was followed fairly good, however some deviations did occur. The planned time plan can be seen below in Figure A.1 and the actual outcome of the project can be seen below in Figure A.2.

The 'FEM analysis' activity was removed due to it being superfluous for the developed prototype. No parts of the construction were deemed heavily loaded, and there was therefore no need for a FEM analysis to be conducted. A 'concept testing' activity was added to the time plan instead due to the uncertainty of the feasibility of the pursued concept.

The 'legislation' activity was not pursued for the full time period since the applicable legislation was well compiled and accessible. The 'decide on project limitations' activity was somewhat extended. This was done in consensus with AAES supervisor who expressed a wish to not have the project converge too early. Both the 'concept generation' activity as well as the 'evaluate concepts with AAES employees' activity was extended greatly. This was done since the development process became even more iterative than planned. Through a weekly meeting set up with mechanical engineers at AAES we continuously got feedback regarding our concepts. The activity material choice was initiated one week early during the detail design segment of the project. Lastly, project week 11 differed somewhat from the rest of the week due to the authors of this thesis visiting AAES in the US.

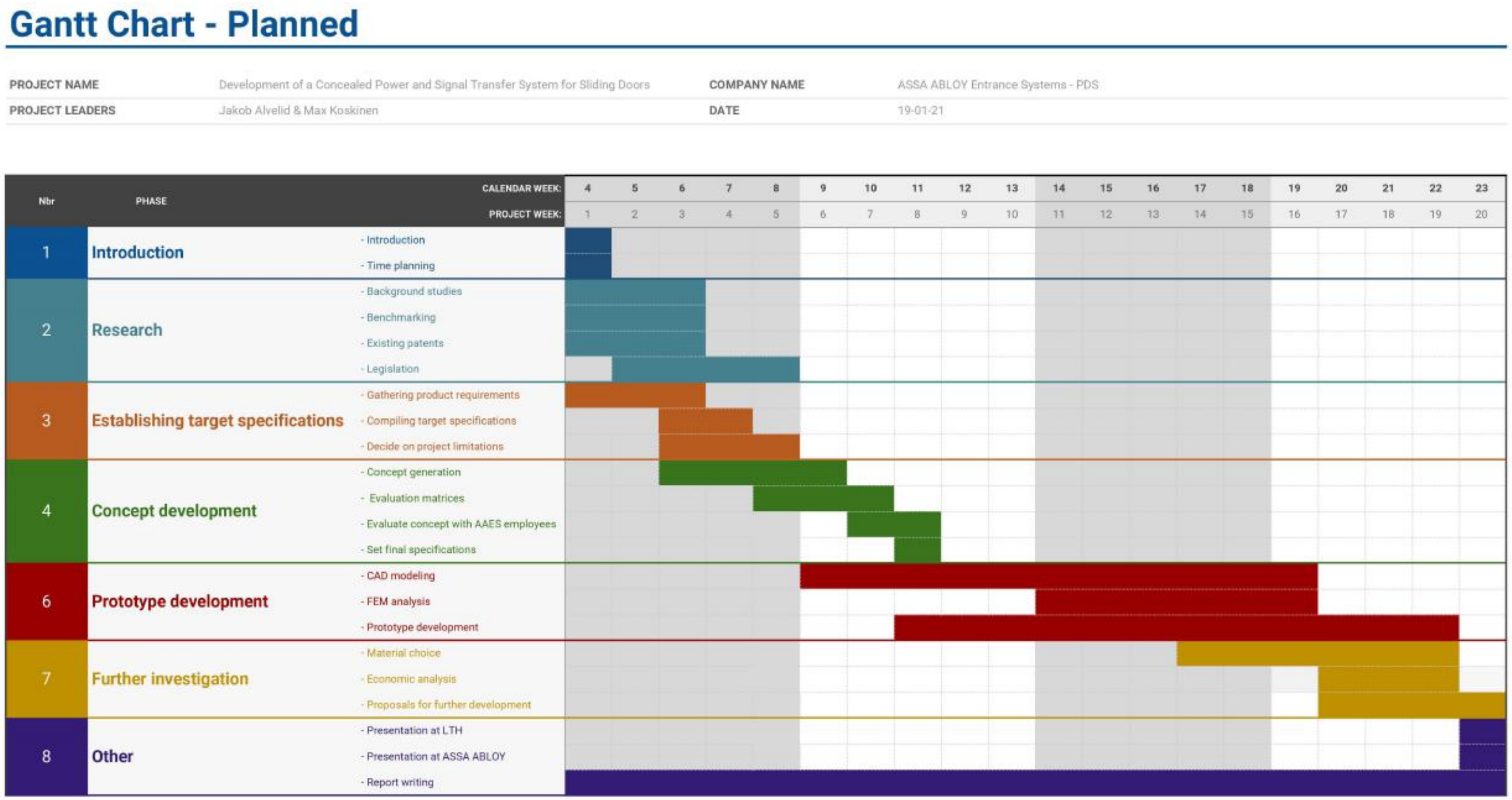



**Figure A.1: The planned project time plan presented in a Gantt chart.**

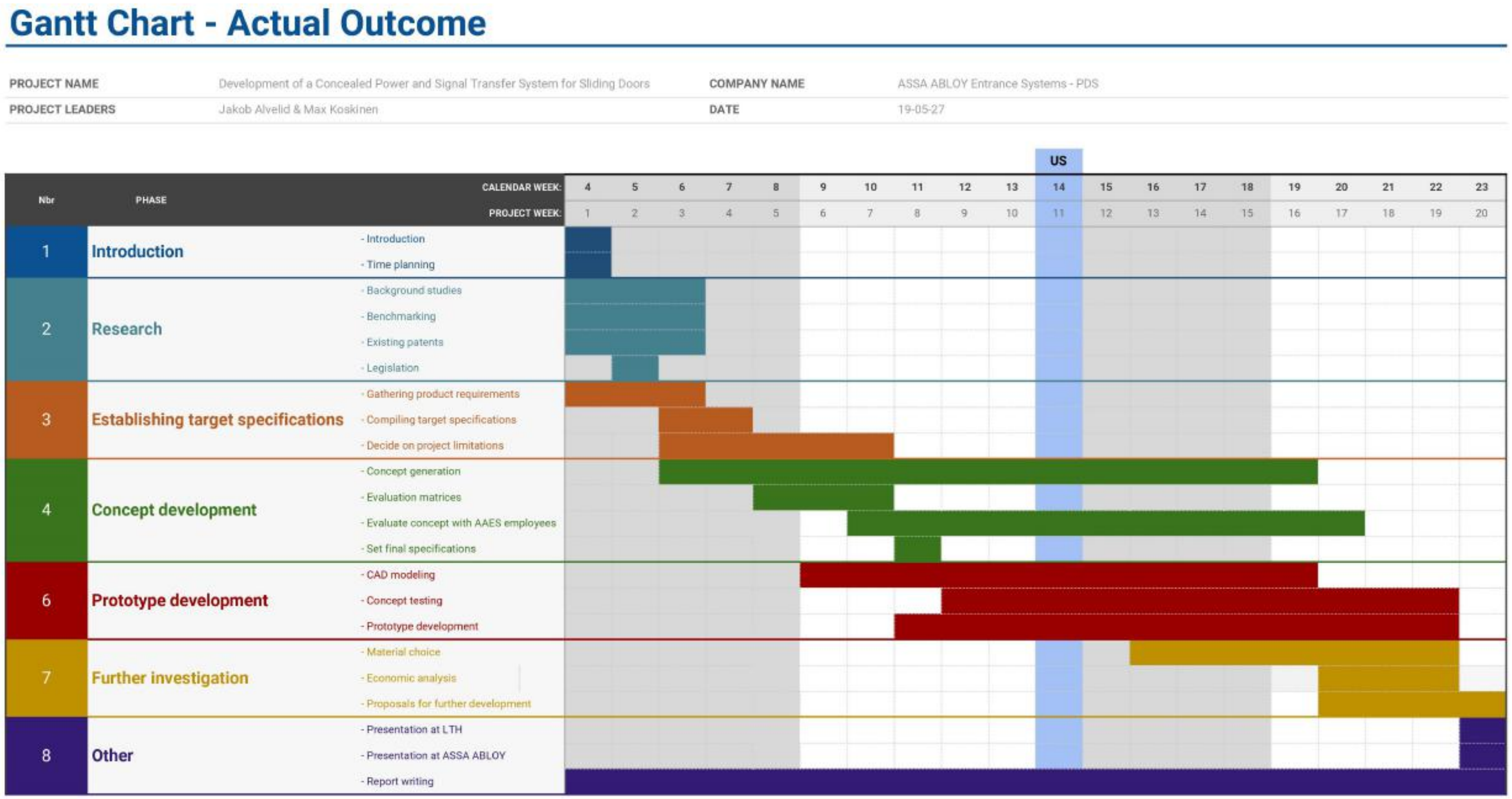
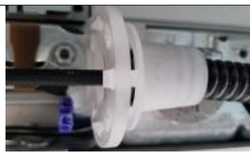



**Figure A.2: The actual outcome of the project time plan presented in a Gantt chart.**

# Appendix B Product Installation

Below in Table B.1 the different installation steps for the product are shown in order, along with a short explanation. The entire installation process from start to finish takes approximately 30 minutes for one door leaf, if performed by a mildly experienced installer.

**Table B.1: The installation procedure of the product on a single door leaf.**

| Figure | Description | Figure | Description |
|---|---|---|---|
|  | 1. Mount the first bracket in one side of the header profile. |  | 2. Mount the second bracket in the middle of the header profile. |
|  | 3. Cut roughly 0.6 times the length of the intended expanded rubber band length. |  | 4. Zip-tie a loop on one end of the rubber band. |
|  | 5. Feed rubber band through bracket hole. |  | 6. Feed rubber band through spiral cable. |
|  | 7. Attach spiral cable on bracket by expanding the coils. |  | 8. Feed cap over spiral cable, without attaching it. |
|  | 9. Zip-tie a loop on the other end of the rubber band. |  | 10. Cut excess material from zip-ties. |
|  | 11. Attach first hook. |  | 12. Attach second hook. |
|  | 13. Attach hook to side bracket. |  | 14. Attach hook to middle bracket and zip-tie the cable to the bracket. |
|  | 15. Screw the bracket on to the door carriage, aligning it straight before tightening. |  | 16. Attach cap by snapping it on bracket. If cable diameter is wide, use shallow hole set. |