Rotating current collector for dynamic charging of electrical vehicles

Alexander Bjursåker and Linnea Romare

DIVISION OF PRODUCT DEVELOPMENT | DEPARTMENT OF DESIGN SCIENCES
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MASTER THESIS

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Alexander Bjursåker and Linnea Romare

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Supervisor: Glenn Johansson
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Abstract

Cutting carbon emission from road transports worldwide is a key component in limiting global warming, and electrification is one of the most likely automotive technologies to achieve this goal. Therefore, Elonroad is developing an electric road system that will allow its users to charge while driving. This allows greater range and a reduction in battery sizes.

This master thesis is therefore aiming to develop a new and improved current collector pick-up which is smaller, has great precision and the ability to follow the rail without fault.

A user study has been conducted through interviews with experts, needs have been defined and several idea generating phases have been passed. Multiple concept selection phases and prototype evaluations, both digital and physical, have been done in order to develop the best possible solution for the pick-up. The prototype testing has been a large and important phase of the master thesis in order to validate the concept. A full-scale prototype was also the final goal for the project.

The master thesis resulted in an entirely new and simple design of the pick-up, which allows two degrees of freedom for the pick-up to follow the electrical road even when a vehicle sways sideways while driving. The concept has a rotational solution which simplifies the movement. The pick-up arms are all controlled individually which creates modularity as another arm easily can be added to the concept depending on the vehicle.

Keywords: Electrification, electrical roads, dynamic charging, Elonroad, pick-up

Sammanfattning

Att minska koldioxidutsläppen från vägtransporter över hela världen är en nyckelkomponent för att begränsa den globala uppvärmningen, och elektrifiering är en av de mest troliga bilteknikerna för att uppnå detta mål. Därför utvecklar Elonroad ett elektriskt vägsystem som gör att användarna kan ladda under körning. Detta möjliggör större räckvidd och en minskning av batteristorlekar.

Detta examensarbete syftar därför till att utveckla en ny och förbättrad strömavtagare som är mindre, har stor precision och förmåga att följa rälsen utan fel.

En användarstudie har genomförts genom intervjuer med experter, behov har definierats och flera idégenererande faser har passerats. Flera konceptvalsfaser och prototyputvärderingar, både digitala och fysiska, har gjorts för att ta fram bästa möjliga lösning för avtagararmen. Prototyptestningen har varit en stor och viktig fas i examensarbetet för att validera konceptet. En fullskalig prototyp var det slutliga målet för projektet.

Examensarbetet resulterade i en helt ny och enkel design av avtagararmen, som tillåter två frihetsgrader för avtagararmen att följa den elektriska vägen även när ett fordon svajar i sidled under körning. Konceptet har en rotationslösning som förenklar rörelsen. Avtagararmen styrs alla individuellt vilket skapar modularitet då ytterligare en arm lätt kan läggas till konceptet beroende på fordon.

Nyckelord: Elektrifiering, elektriska vägar, dynamisk laddning, Elonroad, avtagare

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Alexander Bjursåker
Lund, June 2022

Linnea Romare
Lund, June 2022

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1 Introduction

This chapter describes the background of the project and the goals, including the criteria, of the master thesis.

1.1 Background

Cutting carbon emission from road transports worldwide is a key component in limiting global warming, and electrification is one of the most likely automotive technologies to achieve this goal. With existing battery-driven electric vehicles (EVs), raw materials for batteries could be a bottleneck for the worldwide automotive electrification [1]. Looking at heavy-duty vehicles, batteries have so far not been compact enough to make an appreciable impact on the market [2]. Electric road systems (ERS) is an emerging technology where these problems are addressed by charging EVs while driving, which means battery sizes can be reduced. With Elonroad's conductive ERS technology, the vehicle is charged while driving by making physical contact with an electric rail submerged into the asphalt. For this to work, the vehicle is fitted with a current collector underneath, a pick-up, which has the capability to move in two dimensions automatically, so the driver does not have to focus on how to drive to keep charging. Elonroad has built one prototype of such a current collector which proves the concept, but this design has several drawbacks, and it is very likely that it can be greatly improved in terms of weight, simplicity, assembly, and number of parts. Hence this master thesis project. This existing concept will be presented later in the report, as seen Figure 5. The vision for Elonroad's ERS technology is that the submerged rails should be implemented in segments of 1.5 kilometres along highways, bus lines and other heavily trafficked roads. The biggest advantage of being able to charge while driving is that it increases the range of EVs and therefore it will be possible to reduce the size of the batteries of these vehicles with up to 40-70 percent which would lower the climate impact from EVs significantly.

1.1.1 **Company Background**

Elonroad was founded in 2014 and has since then had the goal to cut transportation related CO_2 emissions by enabling dynamic charging while driving. The vision is to enable sustainable transportation for a greener future where range limitations and charging times belongs to the history.

1.1.2 **Primary customers**

Elonroad's main area of business as of today is the electrical rail and not the pick-up. The primary customers are therefore not the end users, nor the customers of the rail. The pick-up will be used to collect data on the rail and to show the customers a complete concept. Therefore, the primary customer for the pick-up, which is the product to be redesigned during this master thesis, is Elonroad itself. The goal is that car manufacturers in the future integrate a pick-up that is compatible with Elonroad's rail. However, it is very likely that the pick-up will be a prioritised product in the future when the time is available.

In the future, however, the pick-up will most likely be used by the costumers during the early phases of the technology. Which results in the current primary users also being for example municipalities, logistics companies, mining companies and harbours.

1.2 Aim

The aim of the master thesis project is to help Elonroad investigate and develop a new and improved version of the current collector for dynamic charging of EVs. The collector shall be able to be lowered and raised in order to make contact when above the rail and withdraw when outside the rail's range. It should also be able to move sideways in order to parry movements of the vehicle as it drifts slightly from side to side while along the lane. The expected result of the project is a manufactured prototype which is derived from an investigating process exploring widely to evaluate as many concepts as possible.

1.2.1 **Given criteria**

The new version of the ERS is recessed into the road, which creates new demands on the pick-up. The new demands in combination with evaluation of the old versions of the pick-up have generated some criteria for the new prototype. These requirements are listed below.

- Move smoothly horizontally to follow the rail
- Move vertically
- Capability to transfer 600 Volt and 125 Amperes

A few sub criteria have also been given. These are not requirements; however the company would highly appreciate and benefit from these being met. Those are listed below.

- Fewer components to reduce production time
- Reduce the friction caused by the cables
- Thinner concept

1.3 Delimitations

There will be a few delimitations during this master thesis, due to the time limitation. One of the delimitations will be to only build one of the three arms of the pick-up. The reason for this is to save both time and money, and it is doable since the concept is repeatable for the other two thirds of the concept. It does not affect the concept generation. Another limitation is that the prototype will only be tested in a test rig, and not on a vehicle that is driving on the rail. This is because it requires a more developed and integrated prototype than this master thesis aims to accomplish. The physical prototype will not include all the sensors that the future product would require. Some material choices will also be specifically for the prototype in order to save time during manufacturing. Another delimitation is that only one source for each process have mainly been used, instead of comparing the theory thoroughly.

2 Project overview

The methodology chapter describes the planning of the master thesis and the chosen theory that is to be used throughout the project.

2.1 Planning

The master thesis project started with a remote presentation of the subject where the scope, expected results and delimitations were presented. Together with the supervisor a preliminary project plan was created containing the five main phases. These five phases includes: planning, concept development/concept generation, system-level design and detailed design, testing and refinement and lastly report writing. The plan was then further developed in detail with all the necessary steps required. A resulting Gantt chart can be seen in Appendix B.1 followed by updated Gantt chart in Appendix B.2 with the actual time spent. [3, pp. 401-402].

2.2 Approach

The master thesis project was conducted with a methodical and theoretical approach, as described in chapter 3 and chapter 4. Since the technology for the ERS is in development and on the edge of futuristic, gathering in-house knowledge was key to understanding the problem. The internal data collection was done through semi-structured interviews, which is a preferable method when the answers are not pre-known [4, pp.269-271]. The collected knowledge was then translated into customer needs to be the base for the product development process and especially for the concept selection. Throughout the process internal experts have helped evaluate the concepts in order to allow refinement and an iterative process. Both computer-based models and physical prototypes have been required to enable a final concept that can be further developed by Elonroad if desired in the future. The physical prototypes acts as a proof of concept and has thereby allowed testing of several functions [4, pp.296-299].

2.3 Resources

To manage the project, several different resources have been utilized. The university have provided the master thesis students with computer-aided design (CAD) and simulation tools such as SolidWorks, Creo Parametric and Arduino. For the more creative parts of the project Procreate has been used to digitalise the ideation and concept generation. To structure the work and collaboration, the Google Drive suite has been used with its many tools whilst Microsoft Word were the teams choice of text editor to produce this report.

3 Product development theory

This chapter describes the product development process used as the framework for this thesis project. The six different phases are described briefly and the necessary adjustments of the theory are discussed.

3.1 Product development process

Ulrich and Eppinger's product development process [3] will be the main theory followed for this project. The reason for choosing Ulrich and Eppinger is because it uses structured methods which can help when evaluating and deciding which concepts to choose. Another reason is that this theory have been used it in previous courses during the teams master studies within Industrial Design and is therefore proven to the team to be a suitable theory for this type of project. Their process includes six phases, which are shown in Figure 1. Certain phases of the process are more interesting for this project, for example the concept development phase [3, pp.12-16].

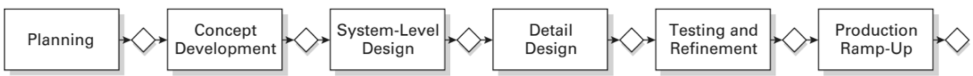

Figure 1. Ulrich and Eppinger's product development process[3, p.14].

According to Ulrich and Eppinger [3, pp.12-13] a well-defined project process is of great importance in order to assure the quality of the project. It generates checkpoints that are facile to validate against and therefore ensures that the project is going through all the predefined phases. The well-defined process also "*acts as a master plan that defines the roles of the players on the development team*" [3, p.12]. This will help to allocate the phases between the team members and to collaborate on the phases that requires collaboration.

Ulrich and Eppinger is a stage-gate process, which according to G. Cooper is of great importance for success. Both creativity and discipline are key in order to have a successful product launch [5, p.45]. G. Cooper believes that market orientation is important to avoid product failure [5, p.48]. This is a risk for this thesis, since there are no other products on the market to study. Due to the technology and concept being new.

The planning phase, called phase zero [3, p.13], is where the actual development process is declared and the project mission statement is specified. It is during this phase that the project is approved and the opportunities are defined. The project planning phase occurs before the project is formally approved. It acts as a decision basis to whether the project is to be proceeded or not. The planning can however be changed along the project, depending on the changes in technology and business goals [3, p.55]. As the project runs, there will likely be more information revealed and therefore affect the planning. According to Ulrich and Eppinger [3, pp. 55-56] there is a five step process to develop a product plan. These steps include: identify opportunities, evaluate and prioritize projects, allocate resources and plan timing, complete pre-project planning and reflect on the results and the process.

The concept development phase, called phase one, is where the customer needs are identified and a few concepts are generated. These are then evaluated and tested. Concept descriptions are made in order to evaluate the ideas against a few criteria. The concept development phase is an iterative process, where one activity will interact with others [3, p.119]. The seven main processes within concept development are shown in Figure 2.

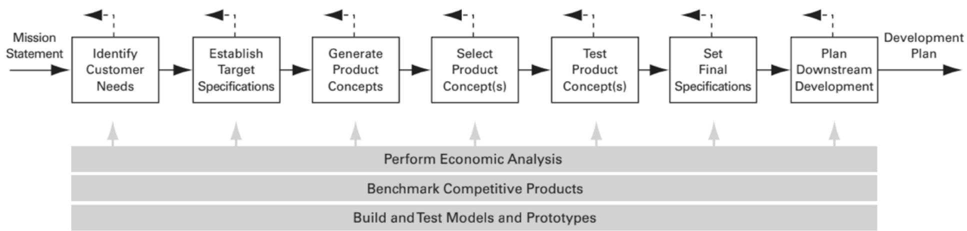

Figure 2. The different activities of the concept development phase [3, p.16].

Phase two, the system-level design, is where a more detailed design is generated and sub-designs can be made. The production plan, final assembly and product architecture is declared [3, p.15].

The detailed design phase, phase three, is where the specifications are set out. Such as the tolerances, materials and exact geometries. Topics such as production cost and robust performance are discussed during this phase [3, p.15].

A proof of concept is made during the fourth phase, testing and refinement. A few simple prototypes are generated in order to test and evaluate the concepts. This phase is essential since it evaluates the concepts' function [3, p.15].

The aim of the production ramp-up phase is to predict how a larger scale production would be like later on. This will eliminate possible problems in the future. This phase slowly goes into a full-scale production. The early produced products are usually delivered to a selected client, where data can be further collected [3, p.16].

3.2 Concept development

This chapter describes the concept development's seven steps, as seen in Figure 2.

3.2.1 **Identifying customer needs**

According to Ulrich and Eppinger [3, p.16], the first step is to identify customer needs. Here data is collected and carefully interpreted to understandable statements and ranked in terms of importance. This also aligns with G. Cooper [6, p.2], that understanding the customer needs is of great importance in terms of having a successful project. Therefor this stage is important to not stress.

According to Interaction Design: beyond human-computer interaction [4, pp.268-278] there are four types of different interviews, depending on how much control the interviewer has on the dialogue. Semi-structured interview is a combination of open-ended and structured, where the interviewer has prepared a few questions in order to guide the interview.

A small pilot study, making sure that the questions are understood and that they give the right results is to be done before beginning the larger part of the data collection. The pilot study should not be carried out with a person who is included in the main study since this person would then have too much knowledge about the questions and the purpose [4, p.265]. Triangulation of data, when data is collected from different sources, increases the reliability of the data collected.

There are also other types of data collection methods, such as questionnaires and observations [4, pp.278-300]. Questionnaires are mainly used to reach out to a greater quantity of people and demography. The amount of data collected using this method is therefore often quite large. Observations are helpful when understanding the users' point of view. Understanding how they interpret with the object, how they understand it and interact with a, for example, product.

3.2.2 **Establish target specifications**

The target specifications are then established, based on the customer needs. The target specifications are a translated version of the needs, expressed in technical terms. The specifications can be refined later in the process depending on the chosen concept.

3.2.3 **Generate product concepts**

Once completed, the concept generation process can begin, where several different concepts should be generated within the frame of the needs and target specifications. The aim is to generate around $10 - 20$ concepts which are then to be analysed during the concept selection phase.

The concept generation step is where the team can be creative and explore several different ideas in order to have a great base to lean on for later decisions. This step can be organised into five different steps. Having a well-structured approach reduces the risk of having high cost problems later on in the product development process [3, p.119].The five-step theory includes clarifying the problem, search externally, search internally, explore systematically and reflection on the solutions and the process, as shown in Figure 3.

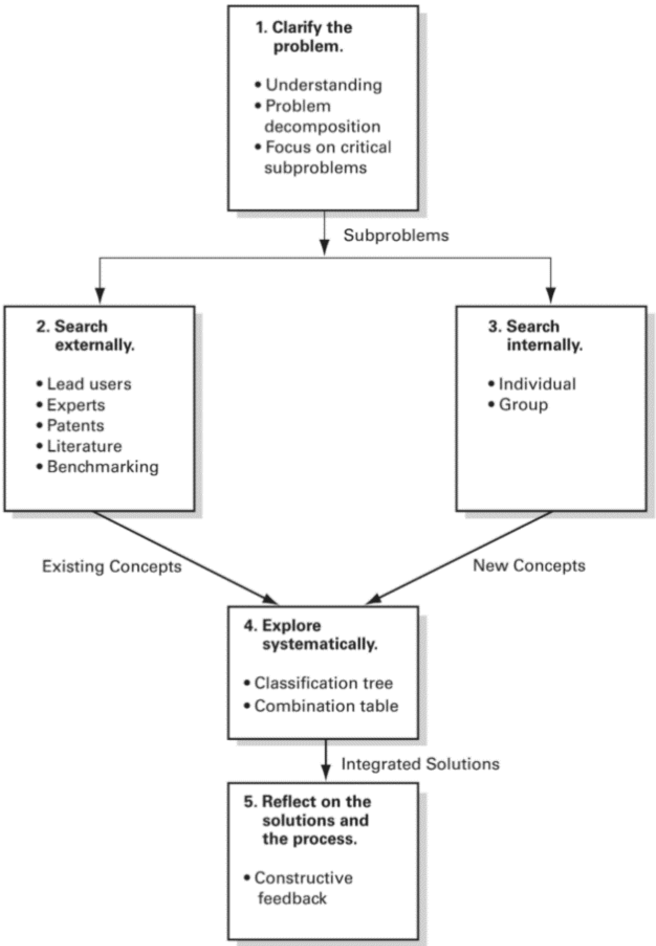

Figure 3. The concept development's five steps [3, p. 120].

The first step, to clarify the problem is a wise first step in order to develop a great understanding of the project and to divide the tasks into subproblems, in order to be able to tackle the challenges [3, p. 120-121]. There are several methods on problem decomposition, such as generating a function diagram [3, pp. 121-122].

The external search's, the second step, aim is to find out if there are any existing solutions to the problem, or subproblems. There are several methods on how to gather this information. It could for example be done through interviewing lead users or by literature research. Benchmarking is also included in this step, and it is when existing products' functions are studied [3, pp.124-127].

An internal search is also to be done and according to Ulrich and Eppinger it is when internal knowledge is used to create solutions [3, pp.127-128]. This phase is where the team is allowed to be the most creative during the entire product development. This phase is more commonly known as brainstorming.

After the internal search, the next step is to systematically explore. The team will likely have collected several ideas from the internal and external search. These need to be gone through systematically. There are several ways of going through all the concepts. Ulrich and Eppinger recommend two different methods, concept classification tree and concept combination table [3, pp. 131-139]. This goes hand in hand with having a product champion, which according to G. Cooper is a key factor to success [6, p.4].

The last step is to reflect on the process. The reflection should however be done throughtout the whole process to generate the best reflections. There are several questions to ask, such as for example "*are there alternative ways to decompose the problem?"*[3, pp. 139-140].

3.2.4 **Select product concepts**

Many phases of the product development process are creative and includes divergent thinking. However, it is important to constantly evaluate the concepts in order to make sure no more time than necessary is put into a concept that will not work. It is an iterative process, which goes through several stages and finally results in a final concept [3, p.147]. The stages used in this project are described below.

3.2.4.1 Product champion

The product champion method is when an expert within the product development team makes a decision based on their wider knowledge [3, p.147]. In this thesis the product champion will be the company supervisor as well as other employees with insight in the project.

3.2.4.2 Intuition

To commence the selection, the large number of concepts were presented visually and discussed, combined and evaluated. Several concepts were then selected to continue with, based on the group's intuition. The group mostly consisted of the two team members conducting the master thesis and sometimes also of two employees at the company, who are lead of research and development and a mechanical engineer. This is a good method to quickly evaluate a wide range of ideas and begin to narrow down the concepts in order to be able to work more in detail with fewer concepts [3, p.147].

3.2.4.3 Concept scoring

The concept scoring matrix method is when the team, the two master thesis students, rates the different concepts against the needs, which are pre-specified [3, p.147]. This method is suitable if the team is evaluating a smaller number of concepts, which is the case for this project at this stage since several selections have already been done. These criteria could include production cost, ease to use and other important criteria. According to Ulrich and Eppinger, a suitable amount of concepts is no more than twelve. After rating the concepts the results should be discussed and verified [3, p. 156-159].

3.2.5 **Test product concepts**

The concepts are then to be tested to make sure the customer needs and target specifications are met. Once the concepts are tested, the earlier specified target specifications can be refined. These are then to be set and cannot be changed further.

3.2.6 **Set final specifications**

During this phase the specifications are refined and trade-offs between for example cost and performance are made. The team must commit to dimensions and other values at this point [3]. This stage will not be included in our master thesis since the project will end in a prototype.

3.2.7 **Plan downstream development**

This phase, where the production is planned [3], is excluded for this master since the project will end in a prototype.

3.3 Adjustments

There are several adjustments to the theory that will be done in order to better suit this master thesis. Firstly, the process will be more iterative than Ulrich and Eppinger's theory. The reason for the process being more iterative is because of the task being quite complex, and being only two people in the team, it will have to divided into subtasks and do several evaluations and generations along the way. Another reason for this is because the guidelines and preconditions for the master thesis are not crystal clear, in terms of which data to use, because of Elonroad being a start-up where not all specifications have been discovered yet.

Another adjustment that will be done for this master thesis is during the data collection stage. The team cannot interview the end user since the aim is not to sell the pick-up to the end user. It is rather to show that the whole concept, with the rail, is working properly. Therefore, in the long-term, the teams design will not be used by the end user. It will be used by Elonroad to collect data from the rail during their testing phase and to show the possible customers the concept. Therefore, when collecting data for this project, the interviews had to be done within the company, where both the experts and the end users were to be found. According to Ulrich and Eppinger, external research should be done to gain knowledge about the existing products and solutions on the market. However, in this case, where there is no existing solution today the external search will have to be limited. Some external search can of course be done, for example looking at similar technology such as trains.

The chosen theory suggests a detailed design, where tolerances and other detailed design choices are specified. For this master thesis, where the aim is to deliver a well-functioning prototype that can be properly tested, the detailed design phase will be minimised. It will of course have to be taken into account, in order to deliver a good base for the company to continue develop the concept. For the same reason, that the master thesis project will end in a functional prototype, the production ramp-up phase that is included in Ulrich and Eppinger's theory will not be considered for this master thesis. The company's aim is not to develop the pick-up in-house in the future, and a production ramp-up is therefore not of value.

The last adjustment to the earlier described theory is that the prototype is of extra great importance for this master thesis, since it is the end goal. The product will end as a prototype that can be tested to evaluate the entire concept, including the rail. Therefore, a large amount of the total master thesis will be devoted to the testing and refinement phase.

4 Identifying costumer needs and establishing target specifications

This chapter describes how the data collection, interpretation and translation into customer needs have been conducted, resulting in organized and ranked needs. It will also discuss the adjustments done relative to the chosen theory.

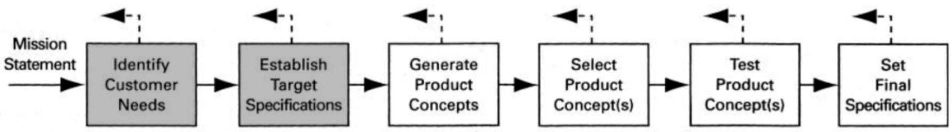

Figure 4. The identifying customer needs and establishing target specifications phases.

4.1 Data collection

To commence the project, knowledge about how the product is supposed to work and which criteria are the most important have to be established. The employees at Elonroad will be very valuable for gathering this knowledge. This is of importance in order to be able to evaluate the concepts towards what the company desires and how well it satisfies the requirements.

4.1.1 **Interviews**

The purpose of the data collection for this project is to get a wider understanding of how the product is supposed to function. Since Elonroad is a start-up, where time has not yet been spent on writing product specifications the structure of the interview is of great importance, since the team do not know which answers are to be looked for. Therefore, the interview form chosen is semi-structured.

A pilot study was carried out with the company supervisor. However, in this project, the supervisor at Elonroad is a key person for the main study. Therefore, having a pilot study with an external person cannot be conducted.

Since different people within the company have different areas of expertise and therefore different priorities for the redesign, triangulation of data will be used [4, p.264]. However, for this project, it is more important to collect data from the right people, who have the right knowledge, rather than reaching out to a large amount of people. Since the end customer in the future should not have to interact with the product the right knowledge for this thesis can be collected from the people who are working with the project.

The semi-structured interview questions asked are listed below [4, pp.269-271]. Five people within the company where interviewed, who have all been involved with the pick-up at times. The reason that these five people are suitable to interview is that they are aware of the current challenges that the technology is facing. They also know which specifications the technology requires. The requirements are not yet listed due to the start-up phase. Since the project is to develop a new concept, there are not any distinct specifications listed of the product. Instead, the overall expectations have to be collected. Two examples of who were interviewed are the chief of technology and the head of research and development. A full list of who participated in the interviews is shown in Appendix C.1. Since it was a semi-structed interview, the length of the answers differed. During the interviews one's task was to conduct the interview and one's to take notes. These are to be found in Appendix C.2.

- Which are the most important changes and improvements that could be made to the existing solution?
- What is working the best with today's solution? Any advantages?
- If you were to redesign the pick-up, how would it be constructed?
- Is there any feedback missing, that would improve the solution?
- Which materials would you mainly manufacture the pick-up in?
- What do you think is the greatest challenge with redesigning the pick-up?
- Which is the most unlikely idea for redesigning the pick-up?

4.1.2 Previous version

The company has an earlier version of the pick-up, which has been studied to gain understanding about the company's target. Part of the master thesis' aim is to develop a new pick-up which is improved in several aspects compared to today's version. However, since the goal is not to redesign the current one but to develop a new concept without the issues of today's, the concept of today have not been studied in detail. In order to avoid getting too influenced and to be able to generate new concepts later on without being too inspired by the previous one. The previous version can be seen in Figure 5.

Figure 5. Pictures on the previous version of the pick-up.

4.2 Understanding the needs

How the collected data is processed and organised in terms of importance is described in the chapters below.

4.2.1 **Interpretation of customer statements into customer needs**

All the statements from the semi-structured interviews were translated into needs in order to identify the criteria for the product. Several statements, from different interviewees were similar and therefore not repeated when interpreted into needs. An example of how this was done is shown in Table 1.

Table 1 Example of statements being translated into needs.

Need statement	***Need***
The braid is not allowed to create electrical arcs	The braid shall avoid generating electrical arcs
The braid needs to be able to have good contact with the rail	The concept should enable good conductive capabilities between rail and pick-up
The pick-up needs to be able to move the full width	The concept should allow a horizontal movement of at least 450 mm

4.2.2 **Organising the needs into hierarchy**

Once the statements have been translated into needs, the importance of each need were specified based on several criteria. These were electrical safety requirements, number of statements a need was based on, the teams own intuition as well as expert assessment from the head of research and development. Discussions were held within the team, to elaborate how relevant the collected data was and to analyse the data. The sorted needs can be seen in Table 2. The importance rating goes from one to three asterixis and the exclamation mark denotes that it is a latent need.

Table 2 Needs sorted by importance.

Needs	***Importance***
The concept should have a robust design	***
The concept has sufficient clearance to avoid creep	***
The concept has flexible design to reduce the need of preciseness in vertical positioning	***
The concept enables good conductive capabilities between rail and pick-up	***
The concept must be isolated to avoid electrifying the car body	***
The concept allows a horizontal movement of at least $450\ mm$	***
The concept is the simplest possible	***
The braid shall avoid generating electrical arcs	***
The concept handles up to $600\ volts$	***
The concept handles up to $125\ amperes$	***
The concept has as low resistance as possible	***
The concept applies $27N$ on the rail	***
The concept withstands vibrations caused during normal circumstances	***
The concept does not generate any unintended antennas	**
The concept is simple to manufacture	**
The concept can passively parry objects $< 1\ cm$ on the rail	**
The concept is adaptable with the vehicle's ground clearance	**
The concept has a minimal weight	**
The concept's height is minimised	**
The concept is dampened to handle variable loads	**

The concept needs to withstand harsh environments	**
The antenna is not placed within close presence of metal	**
The concept is compliant with the existing rail solution	**
The concept has a minimal number of movable parts	**
The concept enables horizontal and vertical positional feedback	**
The concept allows the braid to be easily replaced	(!)**
The concept adjusts the force applied depending on the velocity	*
The concept minimises the cost	*
The concept excludes unnecessary parts	*
The concept measures the force applied on the rail	*
The concept can be locked in an upright position without powering the motors	*

4.3 Adjustments to the needs and metrics

As seen in Table 2, some of the needs contains specified values. Since Elonroad is in a start-up phase, there are a lot of metrics that should be defined for the pick-up, but the company has not had time to prioritise this. Therefore ideally, more studies should be conducted about the requirements of the pick-up with their respective ideal and marginal values. Hence, these numbers are provided as target specifications for this thesis project by the company supervisor and therefore further investigation was deemed to be outside the scope of the project.

5 Generate product concepts

In this chapter all the stages of the actual concept generation are described with its necessary adjustments to the theory. The main and sub- targets are also declared, to clarify how the team tackled the design problem.

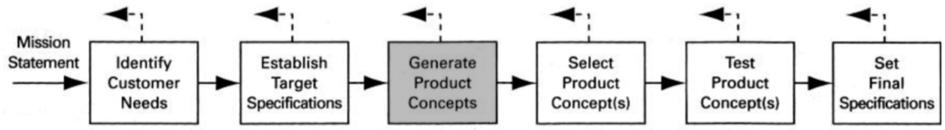

Figure 6. The generate product concepts phase.

5.1 The iterative process

Both the concept generation and the concept selection have been iterative. In order for the concept generation to be successful, selection amongst the concepts have been done iteratively to be able to evaluate throughout the process. This process has been divided into two chapters, where chapter 5 describes the concept generation stages and chapter 6 the concept selection steps. Hence, this chapter will reference to decisions made in chapter 6 and vice versa. The number of iterations is an adjustment to the theory. This has been done to improve the final outcome y having several feedback session with valuable input.

5.2 Target

The main target is to make the pick-up compatible with the new submerged rail. This requires another degree of freedom, the horizontal movement, and therefore a more complex design.

There are several sub targets for this project. However, the two main sub-targets are to improve the horizontal movement of the pick-up and to make the concept thinner. Another issue with the current horizontal movement is that there are large amounts of friction between moving cables and isolating plastic sheets, which decreases the reliability of the movement.

The aim is to design a concept that includes three arms on the pick-up, however only one will be built when prototyping. The reason for this is because the concept is considered to be repetitive and that it therefore is no extra gained value in building all three. This is also why some of the concept illustrations in this chapter will include either one or three arms. The real pick-ups can either be manufactured with three or six arms depending on the vehicle. Therefore, the concepts should be viewed as presentations of a concepts where the number of arms are to be decided at a later stage.

5.3 Benchmarking

To commence to understand the technology that could possibly be used, benchmarking research was done which also acted as a source of inspiration. There are not many competitors on the market today and therefore the benchmark focused more on other similar solutions, such as trains and metros. The benchmarking did not give the team too much useful knowledge about the product of this master thesis. However, it allowed the team to collect knowledge about how the technology of current collection works for, for example, a train. Not having a proper benchmarking stage is a necessary adjustment to the theory since, as described above, it is not possible. To summarize the benchmarking did not allow the group to collect knowledge about other current collectors since the technique is rather new and competitors do not reveal their technology. However, similar technologies such as trains gave inspiration and understanding to the group.

5.4 Broad concepts

To generate a broad range of ideas, the concept was divided into three different categories: horizontal movement, vertical movement and cable management. Brainstorming was then made. Material, production and cost aspects were at this point not taken into consideration. This in order to allow a wide brainstorming regarding the function. These concepts were then combined into a fewer number of complete concepts. Dividing the whole concept into sub solutions simplified the quick idea generation and allowed for a more creative approach, since the solutions became less complex. A selection of these concepts is described below, the rest are to be seen in Appendix D.1.

5.4.1 **Horizontal movement**

Presented below is a selection of concepts for horizontal movement from the concept generation phase. The selected concepts are the ones that the team have discussed further and evaluated in more detail.

5.4.1.1 Parallelogram

The concept seen in Figure 7 uses the principle that a parallelogram has two pairs of parallel beams. This way when the top rod moves in the horizontal plane, the sliding contact collector will stay perpendicular to the rail. The three arms are connected with a frame that allows an unspecified mechanism to lower and raise the collectors all together.

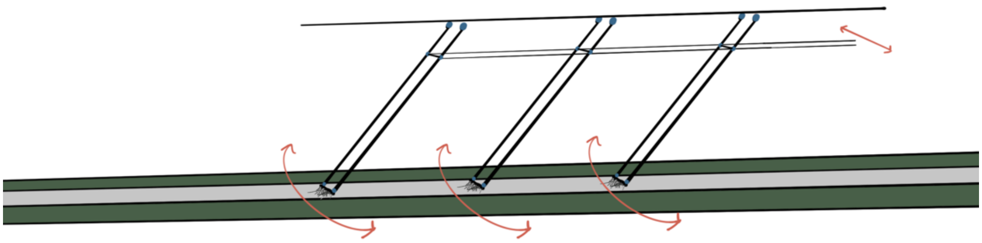

Figure 7. Sliding contact collector always perpendicular to the rail.

5.4.1.2 Scissors lift

A concept that is inspired by a scissors lift. The idea is that a rotational force can be transferred easily into a linear motion by a thin horizontal scissor as seen in Figure 8. This concept requires the arms to move horizontally the entire width criteria, on a supporting beam.

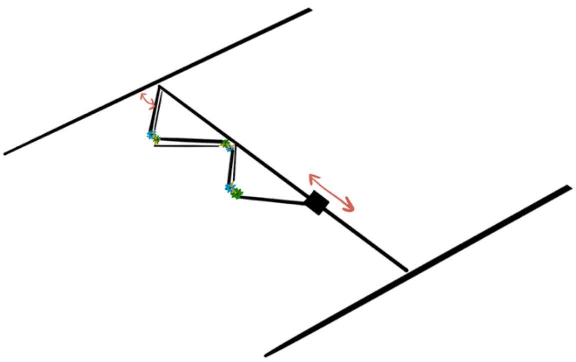

Figure 8. Scissors lift concept.

5.4.1.3 Concept of rotation

This concept has a rotational movement. The fixed point, marked in Figure 9 as a black circle, will be mounted on a frame that can be attached to the car and the rotational movement will be generated by either a servo or linear servo.

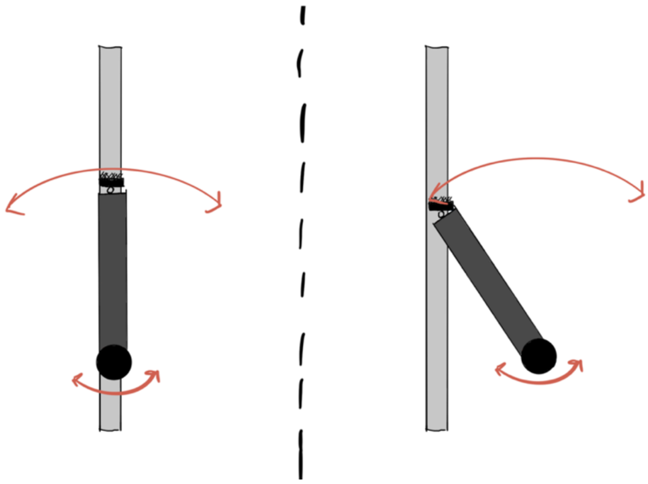

Figure 9. Concept of rotation.

5.4.1.4 Gearwheel rotation

The idea with this concept is that one gear will steer the rotation for the arms attached to the three larger gears, which can be seen in Figure 10. The idea is to use gearing to be able to size down on the servos making the entire concept thinner.

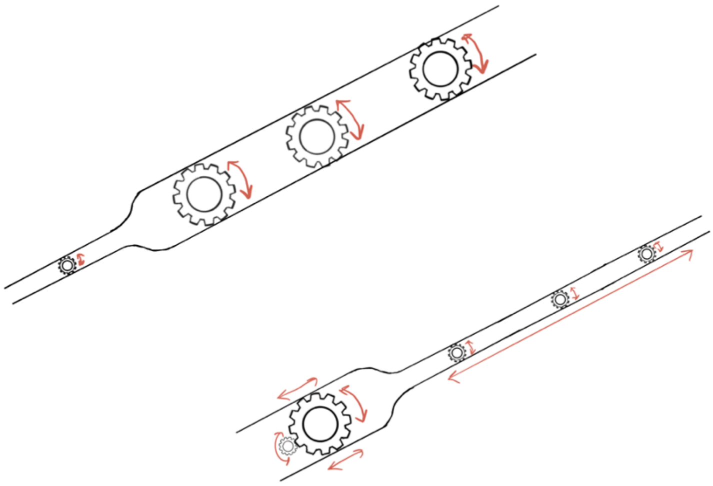

Figure 10. Gearwheels for rotation.

5.4.1.5 Tape measure

The tape measuring concept, shown in Figure 11, is based on the idea of a carriage sliding on a beam. By using a thin metal strip, like the one in a tape measure, the carriage can be moved back and forth. The carriage is mounted on wheels that can slide freely on the beam.

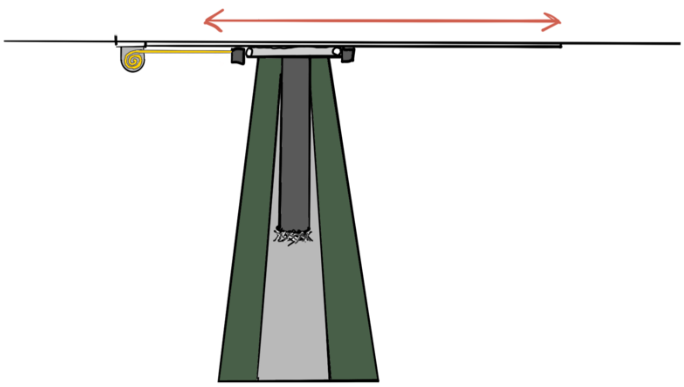

Figure 11. Carriage driven by a tape measure.

5.4.1.6 Rotational movement using gearwheel

This concept, shown in Figure 12, builds on a linear movement working on the edge of the large gear, which rotates the small gear where the arm will be attached. A small linear movement will be translated into a rotational movement for the sliding contact collector.

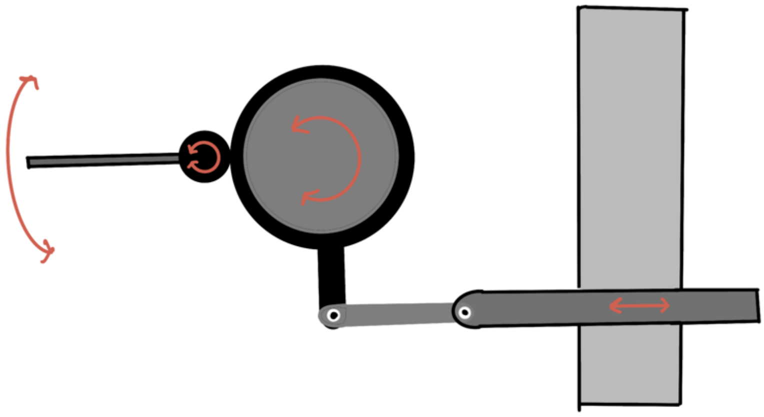

Figure 12. Rotational movement using gearwheel.

5.4.2 **Vertical movement**

Presented below is a selection of concepts for vertical movement from the broad concept generation. The focus when generating ideas for vertical movement has been on reducing the number of moving parts, the number of parts in total and reducing the thickness.

5.4.2.1 Compliant mechanism

The idea of the compliant mechanism, shown in Figure 13, is that the entire part can be produced in one piece. Compliant mechanisms are flexible and can create a motion through its flexible integrated pieces [7]. When this concept is not folded down it is very thin. The hinge is built into the material and therefore reduces the total number of parts.

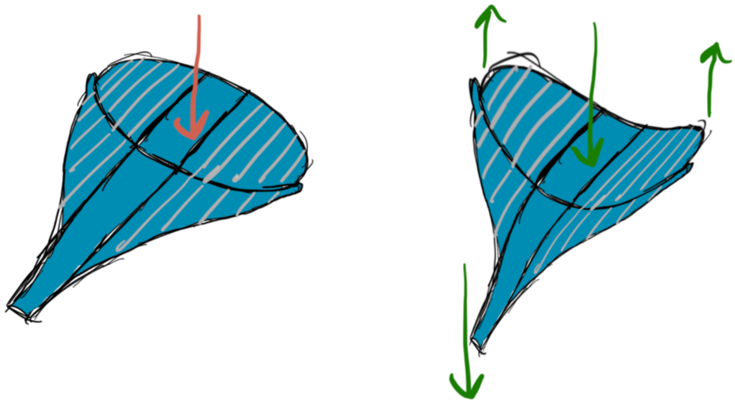

Figure 13. Compliant mechanism, lowering and raising the collector arm.

5.4.2.2 Linear force fold down

The linear force fold down consists of four linked arms, which creates a stable folding down mechanism, using only a small linear motion. This concept is shown in Figure 14. This concept has a robust construction and only requires a small linear horizontal movement to create the vertical fold down.

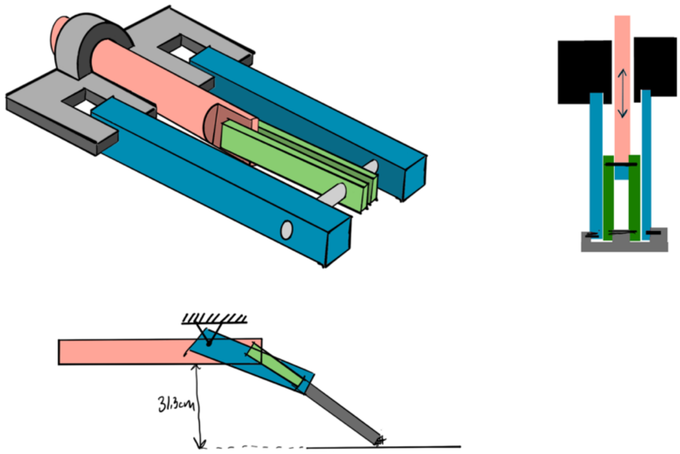

Figure 14. Linear force fold down.

5.4.2.3 Folding beam

The concept, shown in Figure 15, uses a small linear or rotational movement between the three top beams to separate them vertically. This small motion creates a larger displacement of the end which is what is desired. The whole concept becomes very thin when raised and is considered to be relatively robust in its design.

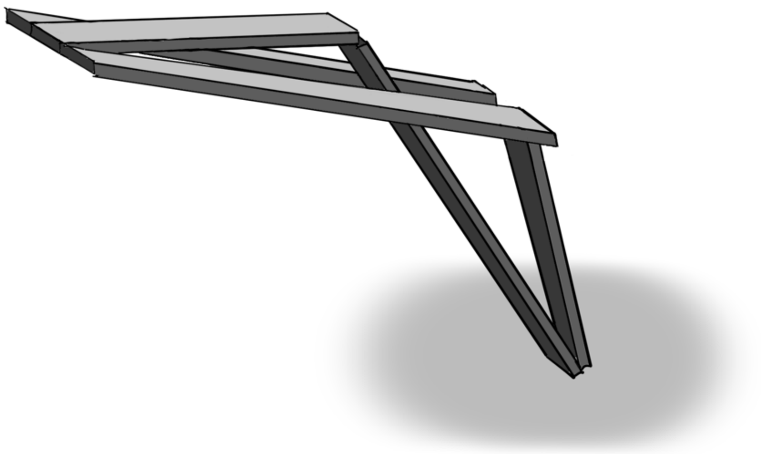

Figure 15. Folding beam concept.

5.4.3 **Cable management**

How the cabling is solved is of great interest and it is important that the cable management is taken into consideration from the very beginning of the design phase. If not, it can create large design problems and create unintended antennas. Therefore, the cable management was one of the three categories when doing the broad concepts of the concept generation.

5.4.3.1 Middle position

If the cables are to be placed in the middle of the frame, instead of to one side, it could result in that the cables not needing to move as much in comparison to today's solution. With this reduction in movement, the amount of friction from the cables could be reduced to when operating the pick-up. The cable's small bend radius could be less aggressive with this solution. This is illustrated in Figure 16.

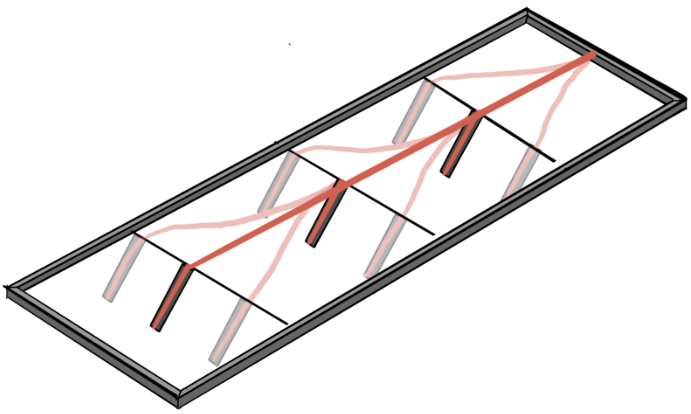

Figure 16. Cables placed in the middle of the frame.

5.4.3.2 Rotation axis

If the concept is a rotational solution the cables can run through or close to the rotation axis, which results in the cable only having to twist slightly and not being bent. This would probably result in less friction and increase the reliability of the pick-up. This is illustrated in Figure 17.

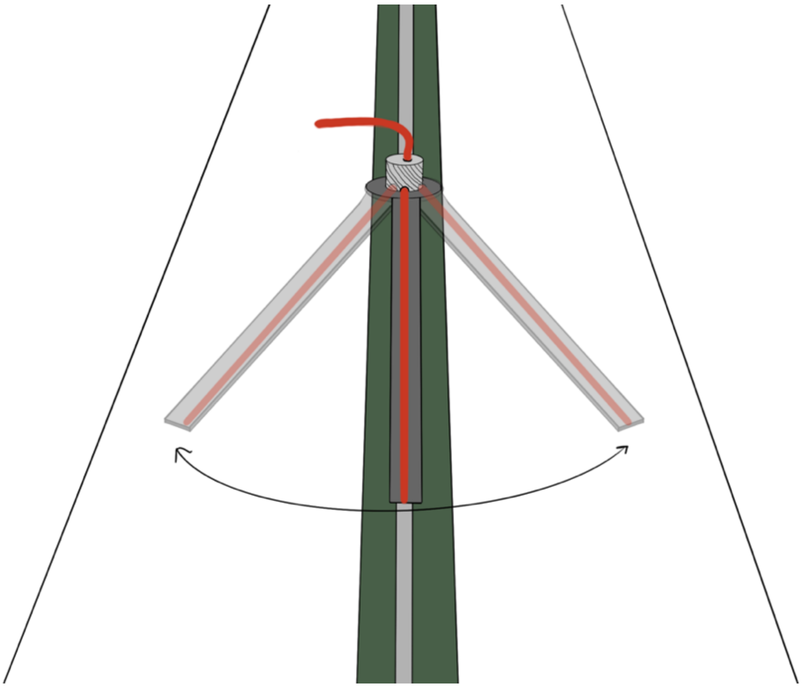

Figure 17. Cables going through the rotation axis.

5.5 Final concepts for concept scoring

The concepts that were selected from the combination table seen in Figure 39 with new combinations were studied in more detail. The concepts needed to be combined properly and evaluated once combined. The combining generated unexpected dilemmas that had to be solved before they could be evaluated. The reason for still having six concepts is to not be to narrow and locked in on a concept too early, without having discussed and refined all the chosen concepts.

5.5.1 **Concept A**

As shown in Figure 18, concept A consists of the compliant mechanism in combination with a rotational solution. The rotational solution is based on a linear servo moving a short linear distance, using gearing to create a large rotational movement for the arm. Here, the compliant mechanism is connected directly to the small gear as close to the arm as possible to allow the cable to easily run through the rotational axis. Since the small gear does not interfere with the outer parts of the wings of the compliment mechanism there are plenty of room for different solution for the vertical folding. However, the exact method for folding down the compliant mechanism is not decided or evaluated in this step.

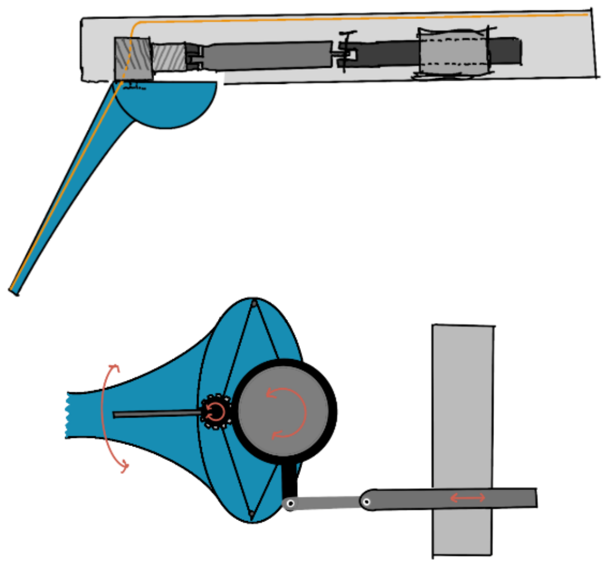

Figure 18. Compliant mechanism with rotation from linear motion.

5.5.2 **Concept B**

The rotational movement is created through rotating one gear, by using a servo motor. The gears are all connected to each other by the arms with internal racks, which creates the rotation for all the pick-up arms. For the vertical movement there is a compliant mechanism, which is connected directly to the gear. The gear is hollow as seen in Figure 19, which allows the cable to easily run through the centre of rotation. This concept does not have the same flexibility in terms of space for the vertical solution as concept A described above. However, the two beams could act as great support for the folding down mechanism although the exact method for this is not yet decided or evaluated.

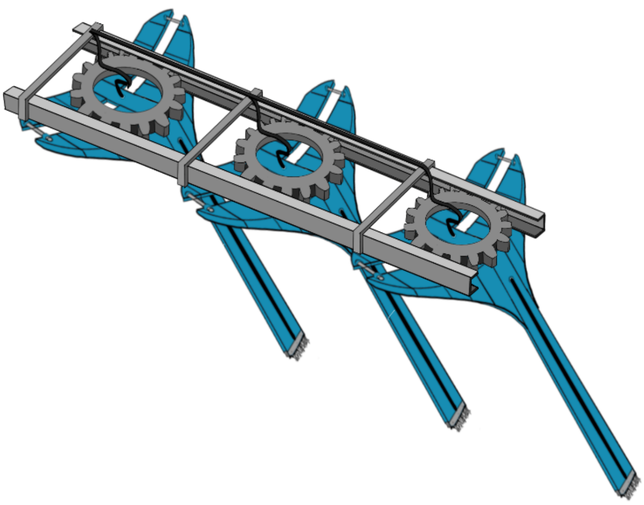

Figure 19. Compliant with rotating gears and racks.

5.5.3 **Concept C**

The rotational movement is the same as described in chapter 5.5.2. However, this is combined with the vertical concept described in chapter 5.4.2.3 where a small movement between the top three beams will result in a larger movement of the arm. This combination allows easy cable management through rotational axis as well as plenty of room in the centre for a servo to control the vertical movement. The concept is shown in Figure 20.

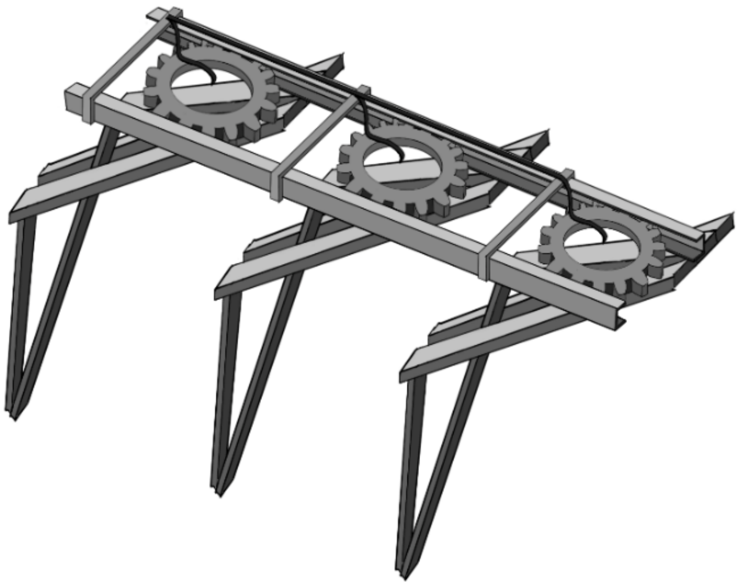

Figure 20. Rotating gear with folding beam.

5.5.4 **Concept D**

This concept showed in Figure 21, uses the horizontal movement described in chapter 5.4.1.5 to move the arm. The idea is that a very thin strip, similar to a tape measure, can push and pull a carriage where the vertical solution is attached to. The vertical folding mechanism is based on the one described in chapter 0 and is controlled with a linear servo pushing on the rod through the carriage in the horizontal plane. One advantage compared to today's solution is that it consists of fewer moving parts such as gears with belts. The metal strip is supported on both sides along the path in between the rail for the carriage making it strong even when pushing.

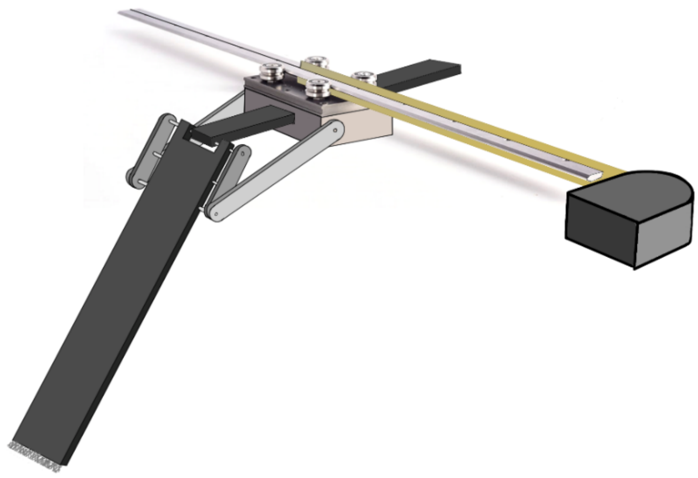

Figure 21. Tape measure and linear force fold down.

5.5.5 **Concept E**

The horizontal movement for this concept is the same as described in Concept D with the thin supported strip pushing and pulling on a carriage. The vertical movement is the same as described in Concept C where a servo pushes the beam down or through some other means of applied force between the three top beams. The cable management for this concept are based on the same premise as in Concept C where the power cable needs to follow the carriage, which is not optimal. The concept is shown in Figure 22.

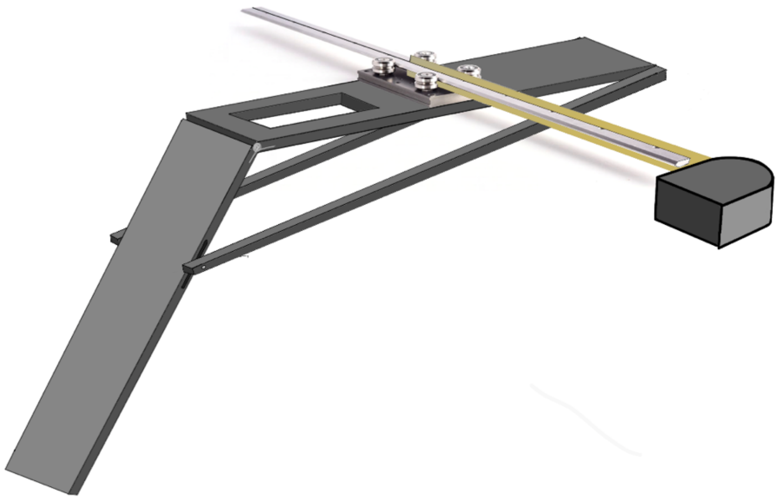

Figure 22. Tape measure with folding beam.

5.5.6 **Concept F**

This concept has not been combined nor changed since described in chapter 5.4.1.1. To summarize, the concept uses the principle that a parallelogram has two pairs of parallel beams. This way when the top rod moves in the horizontal plane, the sliding contact collector will stay perpendicular to the rail. The horizontal movement is achieved by pushing on the frame from the side whilst the vertical movement is done by dragging the inner frame forward or backward, as shown in Figure 23. The cable management for this concept is quite similar to the rotating concepts, since the fasteners at the top are fixed and not moved horizontally.

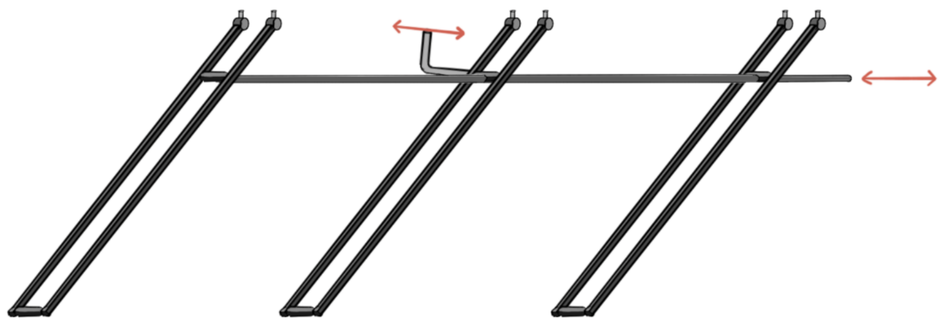

Figure 23. Parallelogram concept for vertical and horizontal movement.

5.6 Concept development after concept scoring

The concept scoring, shown in Table 3, resulted in the project going forward with two concepts. The plan was to continue with three concepts, as described in chapter 6.2 Concept scoring. However, the result concluded in only two concepts being further developed. This decision is also further discussed in chapter 6.2. The concepts that were selected were Concept A and Concept E, which are described below in chapter 5.6.1 and 5.6.2. Both the concepts were further developed in more detail than before, in order to make sure that the mechanisms work. This included a semi detailed CAD-model and 3D-printed prototypes. This allowed the team to test the functions, the proportions and the feasibility of the concepts.

5.6.1 **Further concept generation, concept A**

When further generating Concept A the main goal was to define how the vertical folding of the compliant mechanism was supposed to function. Here the team developed four different solutions for the vertical folding that were tested with quick prototypes. These are described in the chapters 5.6.1.1 - 5.6.1.4. The physical prototypes allowed tests on for example the forces required, dimensions and other important functions.

5.6.1.1 Wire folding

This vertical folding mechanism consists of a wire connected to a pulley wheel on a servo. Depending on which direction the wheel is rotated, the wire pulls on the compliant mechanism either underneath or above which lowers or raises the arm of the compliant part. The wire mechanism was inspired by bio-robotic fingers using wires to control the motion. The solution can be seen in Figure 24.

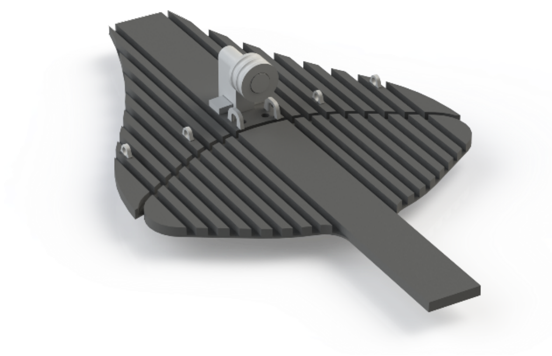

Figure 24. Prototype model for the wire concept.

5.6.1.2 Rack folding

The rack folding mechanism consists of a rack and pinion, controlled by a servo motor. The idea is that the servo motor is fastened on the back end of the compliant mechanism, rotating with it. On the horizontal rod seen in Figure 25, there are two slots in which the end of the compliant mechanism can slide along when the rack is riven up or down. This allows the compliant mechanism to also bend inwards as it must do to function properly.

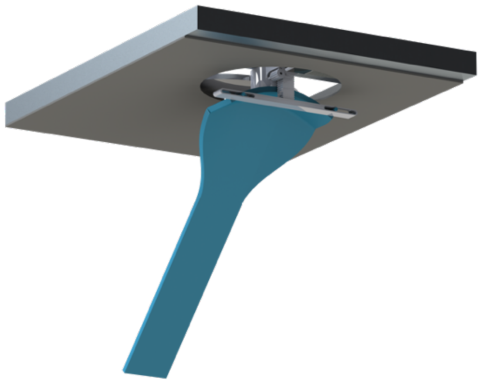

Figure 25. Prototype model for the rack folding.

5.6.1.3 Leverage folding

The leverage mechanism consists of two arms that are attached to the outer edge of the compliant mechanism and to two separate shafts slightly of centre. The arms are also connected to a common axis in the middle, which is moved upwards or downwards, depending on if the mechanism should be folded up or down. The concept can be seen in Figure 26.

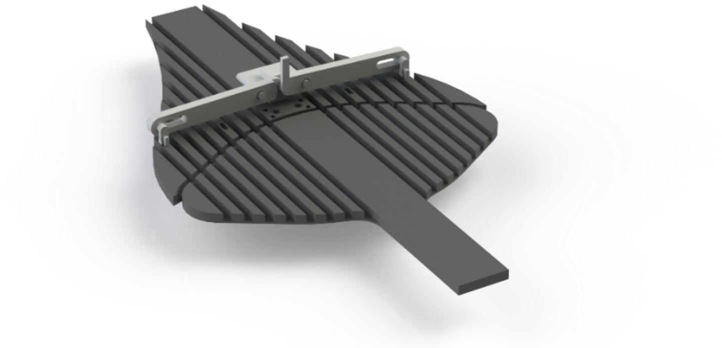

Figure 26. Prototype model for the leverage concept.

5.6.1.4 Rotating rods folding

The rotating rods concept is a solution where two L-shaped rods are rotated so that the ends push down the outer edge of the compliant mechanism. It could be attached at the ends so that it also drags the edges up back to the original position when rotating the opposite direction. The concept can be seen in Figure 27.

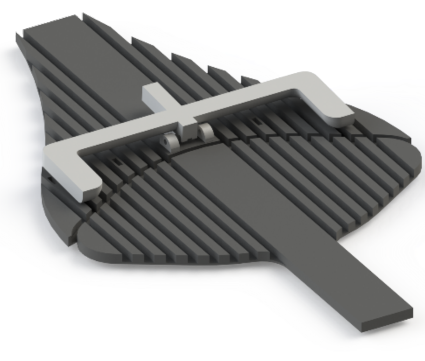

Figure 27. Prototype model for the rotating rods concept.

5.6.1.5 Results

The testing of the different vertical compliant mechanisms seen in chapter 5.6.1.1-5.6.1.4 resulted in a decision to not continue with any of the concepts. As explained later in the chapter named Second reflection, the testing and evaluation still gave the team great knowledge. However, due to the time limitations and the goal to produce a testable prototype, the compliant concepts were put aside.

5.6.2 **Further concept generation, concept E**

For this concept the main goal was to develop a carriage that could move freely without the metal strip supports being in the way and to try optimizing the shape of the rail. Therefore, a quick prototype was made to prove the concept. Another thing that was evaluated and tested at this stage was whether all the beams included in the concept were necessary. The early-stage CAD-model can be seen in Figure 28.

Figure 28. Concept E, folding beam and metal strip.

5.6.2.1 Results

When testing the folding rail, the only thing really tested physically were a simple prototype for the measuring tape, as seen in Figure 31. The mechanism for the vertical folding were tested in the CAD-model at this stage. Both tests were successful but more tests, especially on the vertical solution, must be done if the concept were chosen. The team could also confirm that the supports did not interfere with the carriage and a design change to reduce the number of beams were made after a decision were made that they were redundant.

5.7 Final concept generation

After evaluating the earlier described concepts, as discussed later in section 6.5 Second reflection, a final concept is to be generated. This concept is a combination of earlier concepts. Vertical movement is solved through the folding beam and the horizontal movement through rotation. The reason for this late change in combinations of concept was mainly a consequence of a tight timeline. From the prototypes created for the compliant vertical concept, it was deemed feasible, but a lot more time would need to be dedicated to developing only that single sub-concept. Therefore, a more straight forward approach, the vertical solution from Concept E, is chosen to be combined with the concept based on rotational horizontal movement from Concept A. The company also supported this decision since both the vertical and horizontal concept were substantially different from their original concept. Therefore, it would still add great value to the understanding of the pick-up.

5.8 Prototypes

In order to quickly test certain ideas, low-fi prototypes were created which allowed rapid evaluation. Some of the prototypes were done using CAD and then 3D-printed, as shown in Figure 29. These had to be printed in order to test the compliant mechanism and could not be tested in CAD. This resulted in quite a few tests where different radii, lengths, widths, shapes and thicknesses were tested and evaluated.

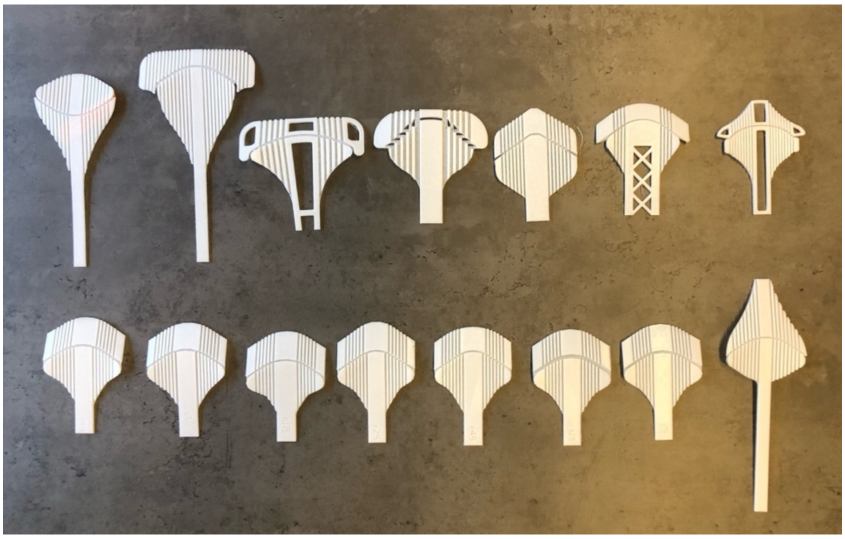

Figure 29. 3D-printed prototypes to test function.

A quick prototype for a cable management concept was also created and tested. This concept is described in section 5.4.3.1 - Middle position. The idea was to have all the cables in a central lane, in order to reduce the side movement for the cables when the pick-up moves. The prototype and test are shown in Figure 30.

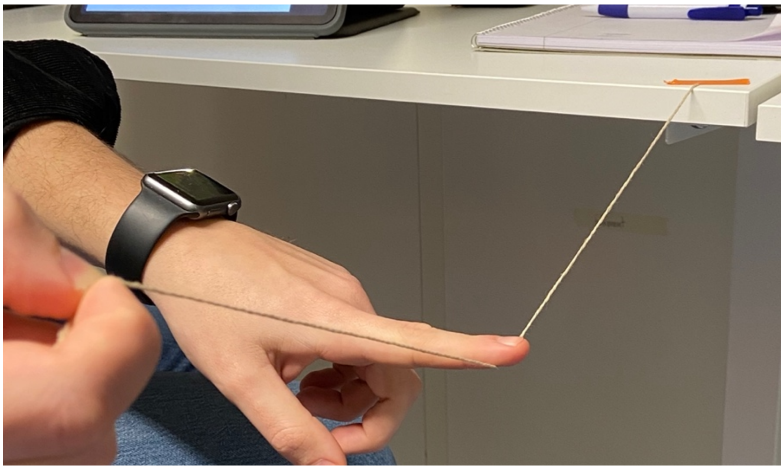

Figure 30. Cable management test.

The tape measure concept was tested with a quick prototype. The prototype consisted of two wooden sticks, a 3D-printed part and a weight to simulate the weight from the pick-up arm, as shown in Figure 31.

Figure 31. Prototyping measuring tape concept.

A prototype of the rotational concept, described in chapter 5.4.1.6, using a linear movement and gears to create a rotation was printed. This was done to make sure that the concept worked as intended. This prototype can be seen in Figure 32.

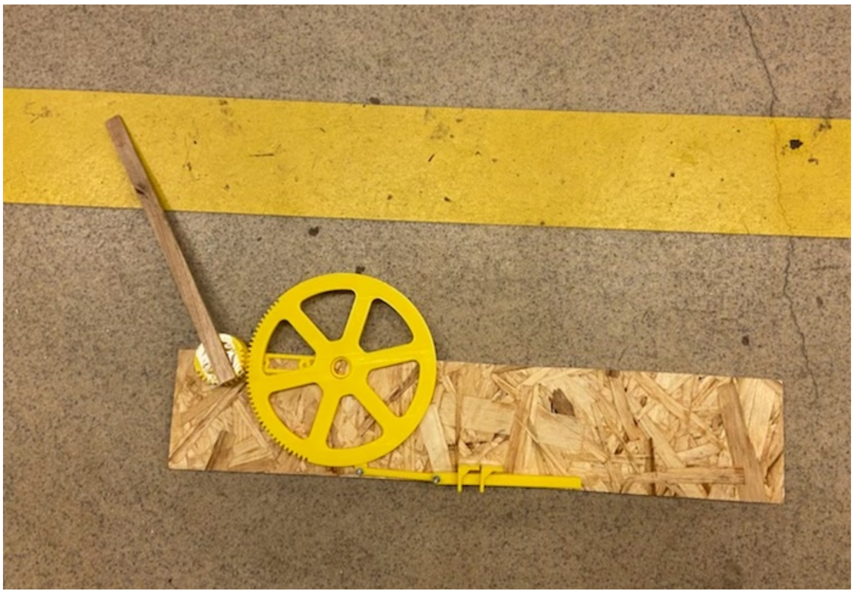

Figure 32. Test of rotational movement using gears.

A prototype for the folding beam was also printed. A printed version, compared to a CAD prototype allowed the team to see small design parameters that need to be changed, and proof the concept. This prototype is shown in Figure 33 and Figure 34.

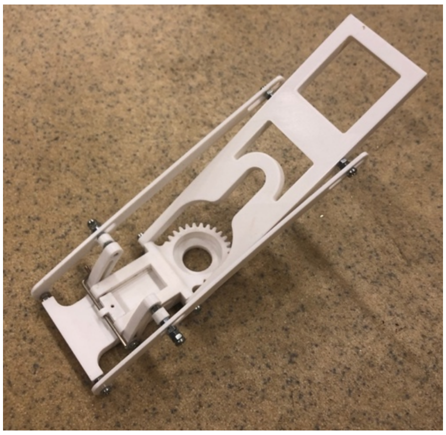

Figure 33. Prototype of the folding beam.

Figure 34. Prototype of the final concept with rotation and folding beam.

A simple control was made using a finite element method (FEM) analysis in order to test whether the frame of the concept is strong enough and to validate if it is over dimensioned. The FEM analysis were made in SolidWorks and the results from this are shown in Figure 35 and Figure 36. The maximum stress was $7.47\ MPa$ and the total deformation was only $0.038\ mm$. The chosen material for the entire frame for the a analysis is an aluminium 1060 alloy with a tensile strength of $68.94\ MPa$ as defined by the SolidWorks material library. With these results, the team can see that the hollow profiles with a thickness of $3\ mm$ and dimensions of $15x20\ mm$ is probably a bit over dimensioned and can be decreased in the prototype. The forces applied were gravity and $150\ N$ on each of the crossbeams for the arms and $40N$ on each support crossbeam. These forces were roughly approximated and way too large in comparison to the actual weight of the arms.

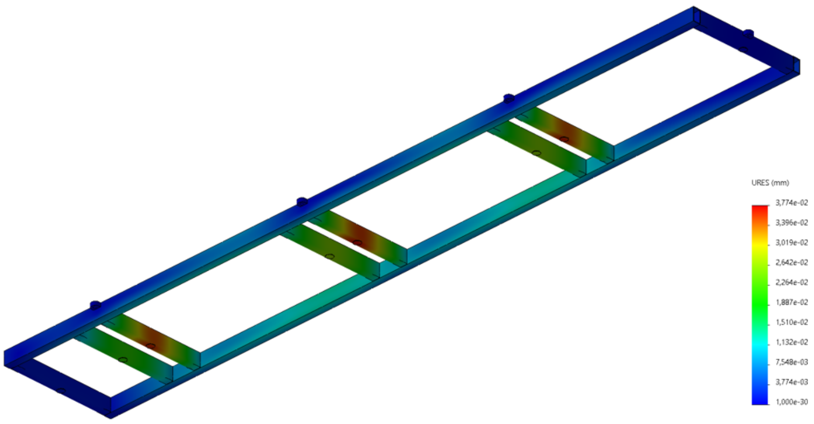

Figure 35. Deformation results of FEM analysis.

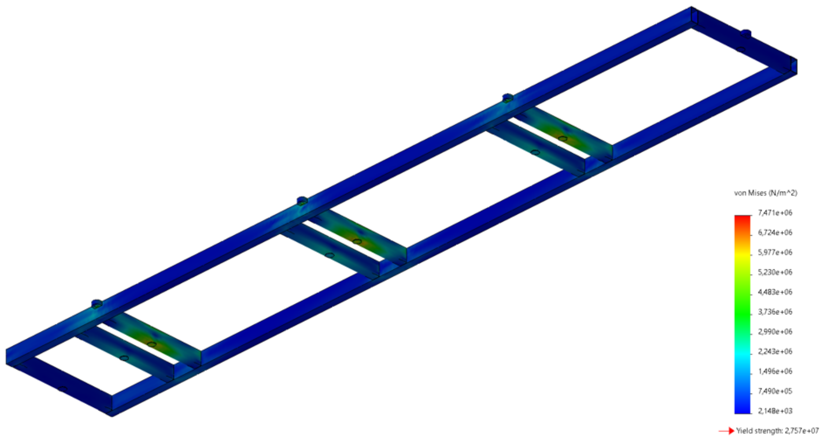

Figure 36. Von Mises-stress results of FEM analysis.

5.8.1 **Results of prototyping**

Prototyping is a good way to evaluate the concepts and allows a good proof of concept at an early stage.

The prototypes of the compliant mechanism resulted in disbanding the concept and not going forward with it since it was too unsure if it would work properly, and the time limitation did not allow further exploration. The concept relies a lot on the material properties, which needs a lot of expertise consultation and testing. There are also a lot of design parameters affecting its function which would need fine tuning. Some of these are wall thickness, radii of the bend, width of the ribs, number of ribs and the length of the back piece as well as several more. Some of these parameters would also be material dependent and would need even more tweaking after the prototype phase. Therefore, the team decided to leave the concept. However, a lot of concept testing have been done, and can be further developed in the future.

The prototyping of the cable management seen in Figure 30 also resulted in not going forward with the concept, since the excess cable length when the pick-up would be in the centre position, was hanging down much greater than expected. The result did not meet the requirements of reducing the concept's height and it was also deemed to be dangerous to have a loosely hanging high voltage cable. Therefore, the team decided to further develop the rotational concepts instead, to reduce the moving distance of the cable.

The prototyping of the rotational concept, described in chapter 5.4.1.6, was combined with the prototype of the folding beam, described in chapter 5.4.2.3, as showed in Figure 34. This allowed the team to test the final concept combined. The prototype is 70% of the actual size and therefore also gave a good indication on how the final prototype would be like. This resulted in the folding up and down mechanism having to be redesigned slightly. The mechanism must start at a slight angle to reduce the required force to start folding up the pick-up. As it is designed today, the slot is perpendicular to the linear servo when in the down position. Because of this, when beginning to fold up the arm it would require quite a large force, which would be reduced if the angle was to be reduced. An unintended feature found from the prototype was that the concept is self-locking in its upright position due to the angle of which the slider ends up at when fully folded up. This is an advantage, if the construction would malfunction, to not fall and get connected to the rail unintentionally. The slider piece that is affecting these angles shown in Figure 37.

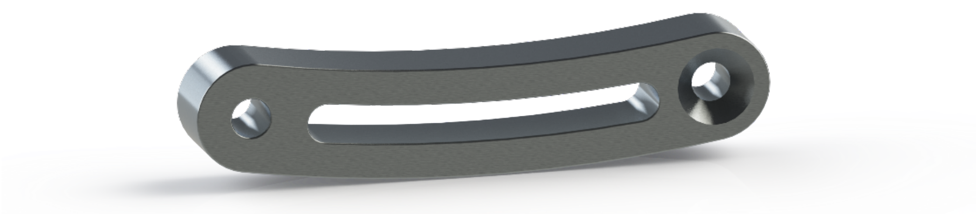

Figure 37. The slider piece which was redesigned for a better angle.

6 Select product concepts

In this chapter, the process of selecting the most promising concept is described as well as general reflections about the choices.

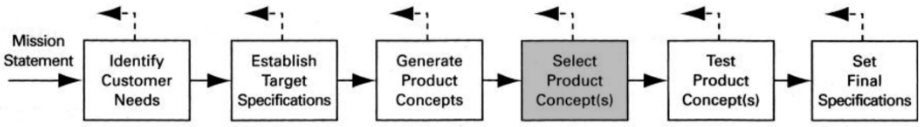

Figure 38. The select product concepts phase.

6.1 Concept combination

During this phase, the concepts were discussed to generate new combined concepts, which were then re-evaluated into new ideas and even further developed. This phase allowed a more detailed concept generations with low-fi CAD models. After developing a few concepts further, in order to gain more details, the concepts were to be discussed with two product champions, i.e. employees at Elonroad. The team organised this internal evaluation by organising the horizontal and vertical concepts into a matrix, which were then combined. These were internally evaluated using the group’s intuition. The intuition is somewhat based on the collected data for the needs and the knowledge that the group has collected by working on the project. This resulted in six concepts going through to the next stage, the concept scoring. The concept combination table is shown in Figure 39.

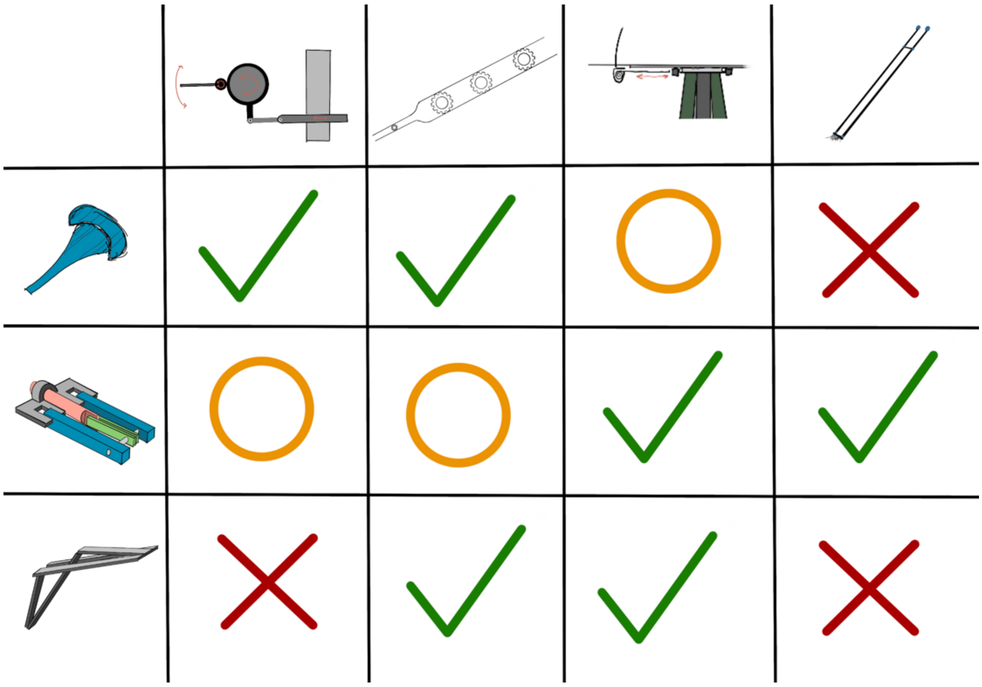

Figure 39. Matrix of concepts. The concepts with the green ticks were the concepts that were combined and evaluated to be continued with. The orange circles are concepts that could be further developed, however are to be excluded for this master thesis. The red crosses are concepts that the group decided would likely not work.

The combinations from the matrix in Figure 39 will be evaluated in the concept scoring, shown later in Table 3, to allow the group to evaluate the six concepts against the customer needs. This resulted in a continuation with three concepts for the horizontal movement and four concepts for the vertical movement, which are to be combined and further evaluated. All six concepts are presented in detail in chapter 5.5.

6.2 Concept scoring

The most important criteria according to the group is the horizontal movability and therefore has the highest weight, as seen in Table 3. Some of the criteria, such as "Sufficient clearance to avoid creep" and "No electrical arcs created", has a quite low score. This is due to the scope of the master thesis project focusing on the mechanical design and not so much on the electrical parts. There is some need to take a few electrical aspects into consideration due to how they can affect the design, but it is not as important as other factors. The weighting of the criteria was made based on the knowledge the team have gained during the project so far and on the needs that have been collected. They were also discussed with the company to be in line with their expectations. This concept scoring resulted in three concepts passing, which will then be further developed and discussed.

Table 3. Concept scoring matrix.

Concept													
		A		B		C		D		E		F	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Robust design	0,19	4	0,76	3	0,57	2	0,38	2	0,38	3	0,57	2	0,38
Sufficient clearance to avoid creep	0,04	5	0,2	4	0,16	4	0,16	3	0,12	3	0,12	3	0,12
Flexible design to allow differences in height	0,15	5	0,75	5	0,75	4	0,6	4	0,6	4	0,6	3	0,45
Minimum $450mm$ horizontal movement	0,3	4	1,2	4	1,2	4	1,2	3	0,9	4	0,9	2	0,6
No electrical arcs created	0,03	3	0,09	3	0,09	3	0,09	5	0,15	5	0,15	4	0,12
Apply $27N$ on the rail	0,07	3	0,21	3	0,21	4	0,28	4	0,28	4	0,28	3	0,21
The concept should be the simplest possible	0,16	4	0,64	3	0,48	3	0,48	4	0,64	3	0,48	3	0,48
Withstand vibrations from normal circumstances	0,06	5	0,3	5	0,3	4	0,24	3	0,18	4	0,24	3	0,18
Total Score Rank			4,15		3,76		3,43		3,25		3,64		2,54
Continue?			Yes		Yes		No		No		Yes		No

6.3 Evaluation with experts

When the concept scoring matrix was done the three selected concepts were presented to Elonroad. The concepts were then to be discussed and evaluated together with us. The reason for involving them at this stage was to make sure that the concepts were aligned with what the company wanted and what would generate new insights for them. Their opinion was also very valuable because of their prior knowledge and experience when discussing how reasonable the concepts were. After discussing the three concepts, it was decided to only continue with two of the concepts: Concept A and Concept E. This decision was based on Concept B being too similar to Concept A .Concept A and Concept B both use the compliant mechanism and rotation, the feedback given was that the concepts are relatively similar and therefore they did not prioritise developing both further in detail. Concept A was decided to continue with since the feedback was that it was a very interesting mechanism that could result in a very thin concept. Another interesting thing with the concept is the rotational solution which excludes problems with friction that has earlier been a problem. The feedback about concept E was that it is interesting since it will reduce the risk of gear slipping, which is a disadvantage of today's solution.

6.4 First reflection

Constant evaluation is of great importance during concept selection and concept generation. It allows the selection and generation to be iterative and minimises the risk of working too far with a concept that is not worth the time. Due to reflections being of such an importance, this was made throughout the process.

This reflection resulted in a continuation with only Concept A, the rotational concept with the compliant mechanism. This was because further prototyping and experimenting needed to be done and time did not allow doing experiments on both solutions. The mechanism for folding it up and down was not explored enough and needed to be focused on. Therefore, focus was on generating new ideas for the folding up and down mechanism for the compliant concept.

At this stage, concept generation was decided to be done together with employees at Elonroad. This was because new influences and ideas were very welcomed. The concepts were then prototyped to acquire a proof of concept, which was the basis for the next concept selection.

6.5 Second reflection

After reflecting on the process, where the compliant in combination with a rotational movement have been in focus, the team together with experts within the company decided to put the compliant mechanism aside, since it was too unsure how it would work and because of the time limitations. The compliant mechanism had three main uncertainties when it was decided to put the idea aside: the material, the shape and the folding mechanism.

The material properties are of great importance for the compliant mechanism since it needs to be produced in a durable material that does not break from experiencing a great amount of cycles. Therefore, the concept would require a large study of different materials to use and an extensive test phase. It is not only the mechanical properties that is of importance, the chemical properties are also significant since the part will be exposed to different solutions in the environment underneath a vehicle when driven around. Salty water, gasoline, diesel, oil and washer fluid are just examples of potentially damaging fluids. Another aspect is the temperature differences during winter and summer which affects the properties of the material as well.

The other uncertainty for this concept was the shape. A large number of different shapes were printed and tested, as shown in Figure 29. These were quite difficult to evaluate since the material properties were not correct and when deforming the printed part, delamination's were frequent. This resulted in material failure rather than allowing the geometry to be evaluated with sufficient results.

Lastly, the mechanism for folding the compliant part were investigated with several concepts. Without the proper material and geometry, together with layer delamination, it was very difficult to test the folding mechanism and maintain certainty in the results.

Hence, the compliant mechanism was put aside after more than a week of testing the concept. This decision was made together with the company. They prioritised having a finished prototype at the end of the master thesis, and therefore thought it was the right path to go to try a more mechanically safe solution. The company considered the horizontal movement to be the most important task, and therefore thought that the rotational movement should be prioritised at this stage.

This being said, the rotational concept worked well and were therefore decided to be kept which concluded in a new combination with the vertical solution from Concept E. This because it seemed to be a safer solution, that were more straight forward mechanically instead of a concept highly dependent on material properties and unknown geometries.

7 Test product concepts

This chapter describes the testing of the product concept, including refinements, a finished concept for prototyping as well as the process of building the first iteration of the prototype.

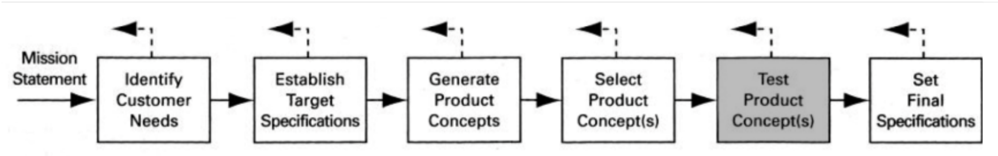

Figure 40. The test product concepts phase.

7.1 Concept refinement

In this chapter the different refinements are described and argued for. The refinements have been discussed within the team and with internal and external experts.

7.1.1 **Straight gears**

One refinement that was done, was to not have helical gears and have a spur gear instead. This was decided together with Rikard Hjelm, lecturer at Lund University. The meeting notes with Hjelm can be seen in Appendix E.2. The advantage of having a helical gear is a more gradual engagement of the teeth which results in a smoother and quieter product. However, with the angular velocities that will be used in this product, both prototype and actual product, there will not be any loud noises from vibrations that have to be taken into consideration. Having the spur gears simplifies the manufacturing of the product, which is one of the needs stated. The change can be seen in Figure 41.

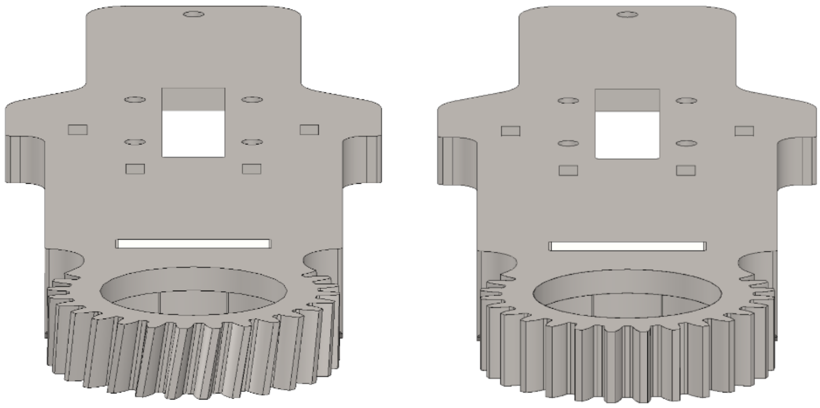

Figure 41. Redesigned gears from helical to spur gears.

7.1.2 **Angle rail**

The dimensions and fastening points of the folding rail is changed to generate a smaller angle for the starting position the folding up movement. This due to a smaller force being required if the slot is at a slight angle at the beginning, compared to being right angled. This was proven through testing the prototype and then redesigned. The change of the starting angle can be seen in Figure 42.

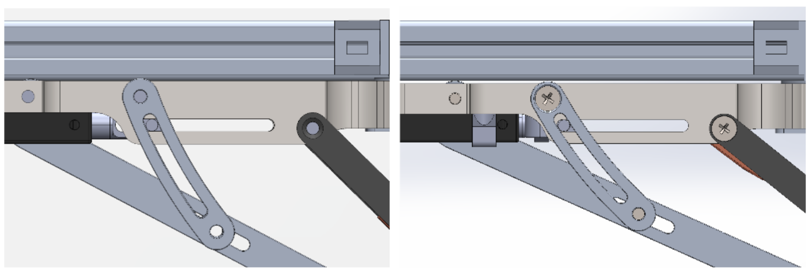

Figure 42. Updated angle of the folding rail.

7.1.3 **Rack**

Once the prototype was printed and tested, discussions whether the larger gear was required began, shown in Figure 34. The reason for the original design having two gears was to make sure, through gearing, that there was enough force to control the pick-up arm. However, after discussing the design by looking at the prototype and trying it out, the larger gear was changed into a rack. This has several advantages. Firstly, the linear servo can be placed along the beam going across the frame, which simplifies the construction and makes it more stable. The second advantage is that there are fewer movable parts when replacing the gear with the rack. The gearing solution included two linked arms that were attached to the linear servo, and the team agree on the fact that fewer movable parts are better. The gear with the linked arms can be seen in Figure 32. Another advantage is that the whole solution is smaller with the rack, since the gear requires a larger space. One of the needs that was that the concept should be simple to manufacture and another one was to reduce the weight. The rack replacing the gear fulfils both of these needs. The rack can be seen in Figure 43 below. Another need is that the design should be as simple as possible. The rack is a simpler design due to the reduced number of parts.

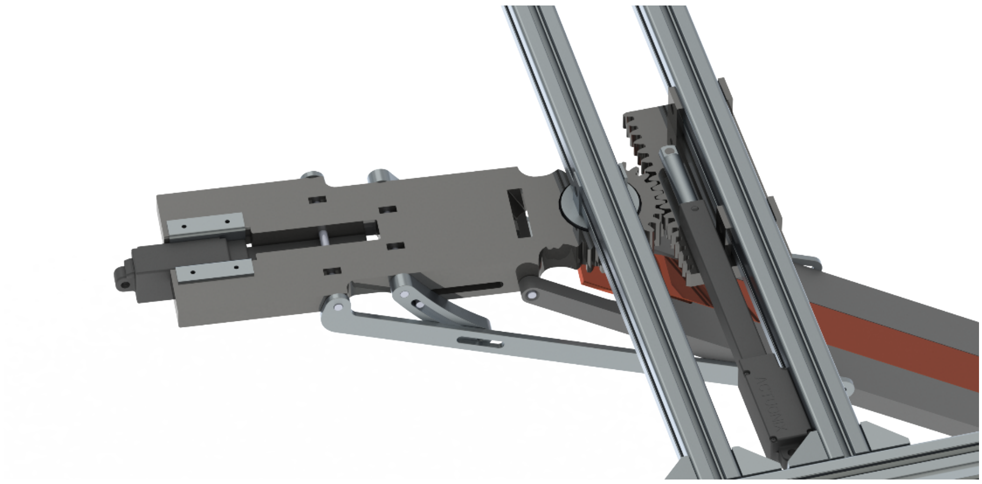

Figure 43. Rack.

7.1.4 **Ball bearing**

The design first included an axial needle ring bearing. However, after discussing the bearing choice with R. Hjelm, a decision were made to change to a groove ball bearing instead since the axial needle ring bearing cannot handle the radial forces. It might not be necessary for this product since the weight and forces are not great. However, it is unnecessary to not design for it. Other circumstances, such as for example vibrations, were also discussed. However, the groove ball bearing will not be the weak link in the construction and therefore other external influences do not have to be taken into consideration.

7.1.5 **Angle and size of cable slot**

The slot for the copper braid has been refined, to have a more tilted angle. This was done to improve the cable management, especially since it turned out to be quite difficult to bend the braid as desired with the original angle of the slot. It became easier to bend the copper braid if the angle was adjusted. The size of the slot has also been increased in order for the cable to move more freely and to be able to have a shrink tubing around the cable to isolate it. The slot is shown in Figure 44.

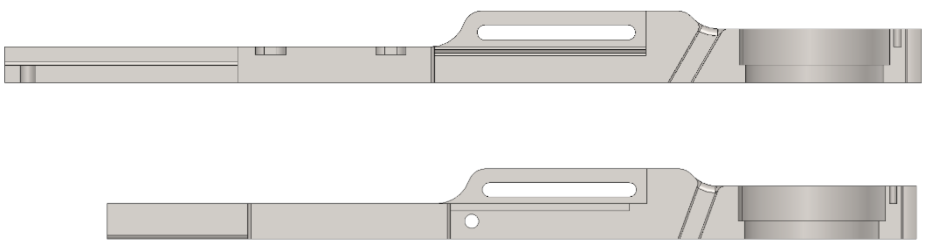

Figure 44. Change of angle for the cable slot. New angle is shown in top image.

7.1.6 **Integrated fit for nuts through axis**

The original design included three axes going through the entire part. This has been changed to integrated fits for nuts, so that the axes can be replaced with screws. The new design with the slots is showed in Figure 45. The advantages of this are that the screws are easier to fasten in the correct position and that there is space for the linear servo. The axes would have been in the way for the linear servo.

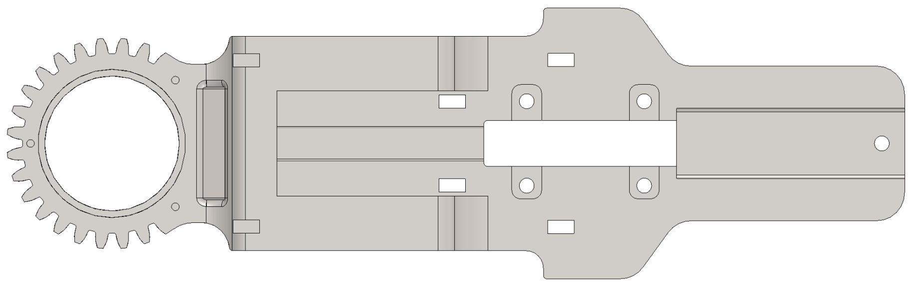

Figure 45. Integrated slots for nuts.

7.2 Finished concept for prototype

This chapter describes the finished concept that is to be built in full scale. Including: material choices, the groove ball bearing, the gears, the vertical movement, the horizontal movement and the cable management.

7.2.1 **Material choice**

After consultation with Katarina Elner-Haglung, lecturer at Lund University, the team decided to clearly separate the material choice for the prototype and for the future product. For this master thesis the focus will be on the prototype and therefore the material for the final product will only be a recommendation. The whole interview can be seen in Appendix E.1.

7.2.1.1 Material prototype

The prototype, which is to be tested in a controlled scenario without the harsh environment that the final product will be exposed to, can according to K. Elner-Haglund be made using a selective laser sintering (SLS) 3D-printer that uses polyamide powder, i.e. nylon. The result when using polyamide powder when SLS printing is a very homogeneous detail and that it will last long when testing in the right climate. The tolerances are also relatively good and are more than good enough for the thesis project and its prototype.

The reason for not using a simpler 3D-printer, such as a fused deposition modelling (FDM) printer with polylactic acid is that the material is too brittle for this type of project and the risk of malfunctioning due to the material is too large.

The nylon prototype will not have as fine surface finish as a final product using injection moulding. However, this can be solved by polishing the surfaces that require a higher finish, for example where the friction needs to be reduced for a sliding contact.

7.2.1.2 Material final product

After guidance from Magnus Ullman, who work at Erteco Rubber & Plastics AB, a material proposal has been made. There are several aspects that need to be taken into consideration when choosing the material. It is a very uncertain scenario, with aspects such as stones on the lane hitting the current collector arm or large drag forces from the wind, just to mention a few.

Due to the circumstances the material will have to be tested in the real environment to make sure that it can withstand the loads in the actual environment. Therefore, two materials have been proposed, that can both be tested.

The first material to test is Grivory GV-6H EF Black 9915, which is a "*60% glass-fibre reinforced engineering thermoplastic material based on a combination of semi-crystalline Polyamide with partially aromatic copolamide*" [8, p.1]. This material is a somewhat standard material, which is an advantage from a cost perspective. The most important properties that were looked at when deciding the material were: tensile modulus, stress at break, Charpy impact strength and thermal expansion [8].

If failure with Grivory GV-6H EF another plastic, Grivory GVN-5H black 9915 [9], with better material properties can be tested.

Ullman recommended the gear and the rack to be manufactured in different materials, since two parts of the same material would wear out more easily. Another solution is that a lubrication additive is used in one of the two parts if the same material is chosen.

Another alternative is Girlamid LVX-65H SST black 9288, which could be used for all parts since it can withstand high tensions [10]. Either the gear or the rack would have to have a lubricant additive to minimise the wear here as well. The advantage of choosing this plastic is that it can be used in all the parts and therefore reduce the costs.

7.2.2 **Groove ball bearing**

The bearing chosen, is a SKF 61806. This is a groove ball bearing which can handle both radial and axial forces and has the dimensions of $30x42x7\ mm$ [11, p.272].

7.2.3 **Gear**

The gear in the final concept is a pinion gear combined with a rack. To make sure these are designed correctly, some criteria are to be met. According to Hjelm, issues with vibrations and high pitch sounds from high-speed interference is not something needed to be taken into consideration since the speed of the product is quite slow, only rotating about 80° in 6,8 seconds. There will not be any extreme forces on the gear and rack either, which also lowers the requirements on these parts. Therefore, especially for this master thesis project, the gear and rack are not fully calculated on and only designed to fulfil the power transmission good enough for the prototype to be built. However, some thoughts have been put into the design. Both the gear and rack have the same module of $m = 2$ and the same tooth profile which can be seen in Figure 46.

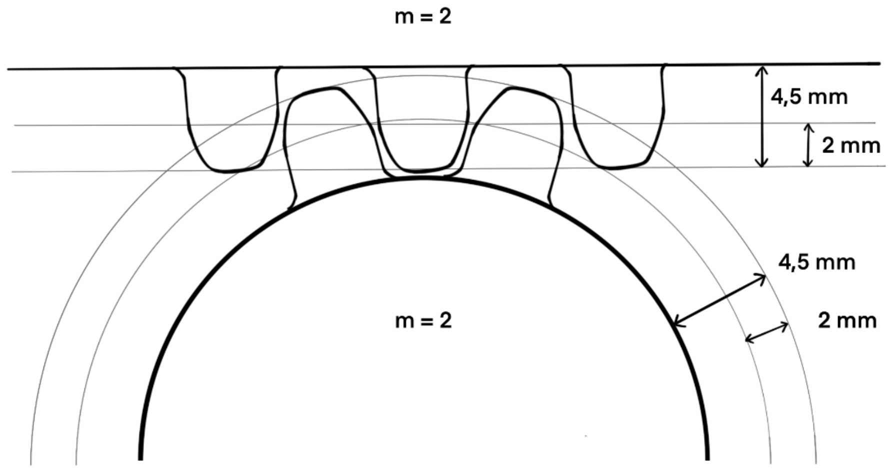

Figure 46. Basic parameters of gear and rack.

7.2.4 **Vertical movement**

The vertical movement is done by a linear servo dragging and pushing an axis back and forth. The axis is attached to the angled rails. The axis will then slide in the angled rails' slot and move the construction vertically. For easier visualization, the axis has been made red and the axis servo connector transparent as can be seen in Figure 47.

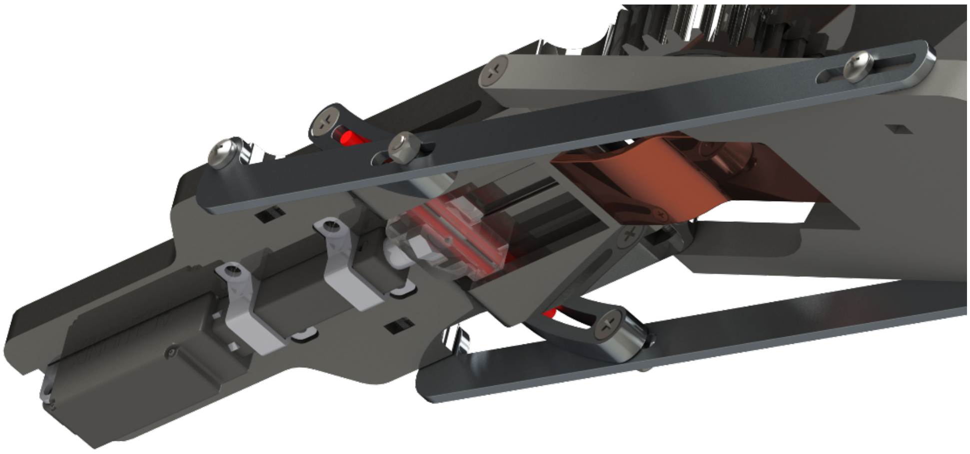

Figure 47. Axis through angled rail.

The angled rail is designed so that the construction is self-locking in the upright position. This is an advantage if the construction fails since the risk of unwillingly folding down is reduced which is safer both to prevent damage to the collector arm and to avoid unwanted connections to the powered rail.

7.2.5 **Horizontal movement**

The horizontal movement for the final concept is based on a rotational movement that is created by a linear servo moving a rack left and right. The rack drives a gear that is integrated to the main part that holds up the arm. The rack, gear and linear servo can be seen in Figure 48 below. The rack is mounted using 3D-printed T-slots that can slide in the V-slot profiles. This is a solution for the prototype. The frame would likely not be constructed with V-slot profiles in the future and instead be welded and the rack therefore mounted on wheels to reduce the friction.

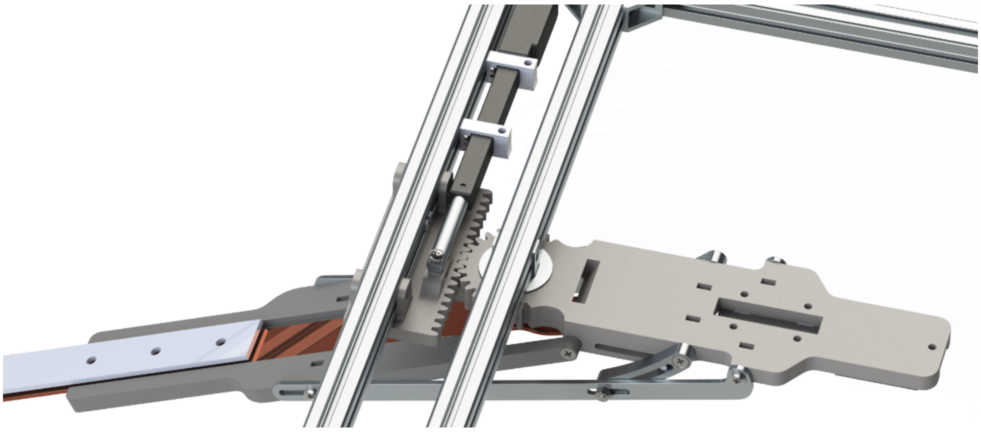

Figure 48. Servo, rack and gear.

7.2.6 **Cables**

The copper braid runs along the construction's arm. It then goes beneath the rotation axis and up through a slot. The slot is designed to be at an angle so that the braid does not have to bend more than necessary, in order to reduce the force needed to twist the braid in the rotational movement. The braid is then bent 180° to be attached to the cable that is attached to the beam that goes across the frame. The cable management is of great importance to not create unintended antennas and to not create more friction than necessary. The advantage of having the cables close to the rotation axis is that there is hardly any excess cable that need to follow the movement. How the cables are organised can be seen in Figure 49.

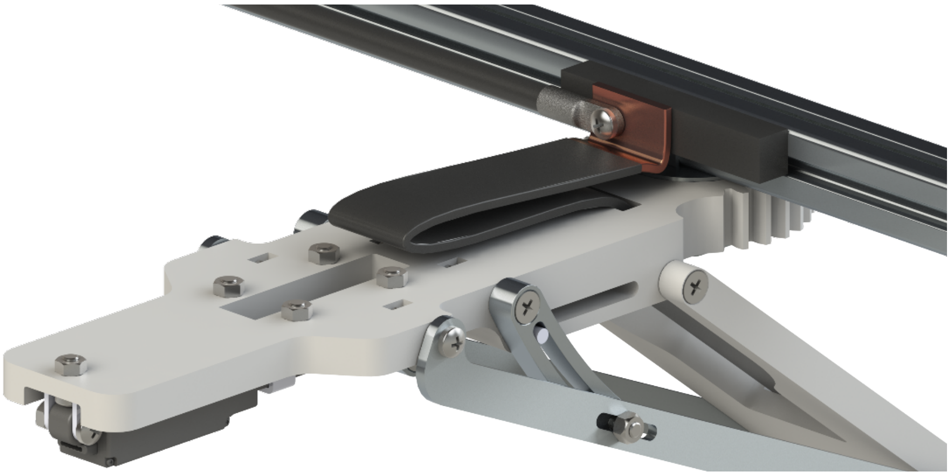

Figure 49. The cables.

7.2.7 **Beams**

The beams for the final prototype will be the same for both the frame and the beams going across. The reason for this is to simplify the prototype manufacturing. In the future product the beams going across could likely be at least $5\ mm$ thinner. The chosen beams are v-slot aluminium profiles that are $20x20\ mm$. V-slot profiles simplifies the prototype construction since it is rather simple to attach them to each other and attach different parts to the profile. Due to the slots, there is no need to weld anything when manufacturing the prototype. This also makes the prototype more flexible and allows for easily changing the design and test different components. The aluminium v-slot profile can be seen in Figure 50.

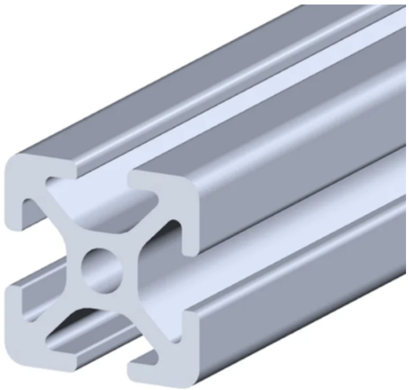

Figure 50. V-slot aluminium profile [12].

7.2.8 **Linear servo**

The linear servo chosen for the final concept is a L16-P Miniature Linear Actuator with Positional Feedback from Actuonix [13]. The unique characteristic for this servo is that its form factor is very small, which allows the construction to be thinner than today's solution. The thickness today is about $70\ mm$ and that is mainly due to the servo's size. Therefore, these servos can contribute to reducing the total thickness. The total thickness for the prototype will be $42\ mm$, and likely $37\ mm$ in the future when the beams are to be thinner.

The two servos have the same characteristics apart from the stroke length. One has a $50\ mm$ stroke length and one $100\ mm$. The gear ratio for both the servos are 150:1 and the maximal operating voltage is 12V.

The servo controlling the horizontal movement is attached to the frame, the beam running across and the rack. As seen in Figure 51, the servo has integrated attachment possibilities. The loop at the very back of the servo is used to attach it to the frame, using a metal bracket that came with the product. In order to make sure that the servo is stable, there are two attachment points along the side of the servo.

These attachment points have been 3D-printed to make sure they fit perfectly. The loop at the very front of the servo is attached to the rack by simply using a nut and a screw.

The servo controlling the vertical movement needs to move with the rotation. Therefore, the servo is attached to the moveable part. It is attached using brackets that came with the servo. Instead of the loop at the very front of the servo, a screw and nut are attached and mounted to the axis controlling the vertical movement.

Figure 51. Linear actuator [13].

7.2.9 **Servo control circuit**

To control the servos in the concept, some micro controller will be used together with motor drivers for power. The described components are what is to be used for the master thesis project with prebuilt components and controllers. What the company will use in the future is outside the scope of this project but will probably be developed internally at Elonroad to specifically fulfil the needs of the pick-up.

To note is that the specified electronics and implemented code will not be seen as a part of the concept, but only as a means to test and evaluate how the prototype performs. Therefore, the development process of the code seen in in Appendix H.1 and the electric schematic described in Figure 52 will not be described in detail.

7.2.9.1 Arduino

To control the servos in the concept, at least for the prototype, an Arduino Uno will be used. This is a small, cheap, and simple micro controller perfect for prototype building. Another reason for choosing this micro controller is that both members have previous experience in prototyping with this exact model, which speeds up the process. The Arduino micro controller can both read and write different signals and has the capability to produce pulse-width modulation (PWM) signals. The PWM signal is an 8-bit signal which equals to a $0 - 255$ range.

7.2.9.2 Linear actuator control board

To power the servos, an external linear actuator control board accompanying the servos from Actuonix will be used. The servos can be plugged in directly on the boards which are powered with $12\ V$ and receives a control signal from the Arduino micro controller. In Figure 52 below, a schematic overview of the setup can be seen. One benefit of the linear actuator control boards is the simplicity of setting them up, both electrically and in the code. The linear actuator control boards receive an 8-bit

PWM signal from the Arduino micro controller which is internally on the control boards translated into a relative position for the servo. The stroke length of the servos, $50\ mm$ or $100\ mm$, is linearly scaled to the $0 - 255$ values of the PWM signal. This means that if the $100\ mm$ servo receives a PWM signal of 128, half of the maximum value, it will move to its middle position of $50\ mm$. Since the servos have positional feedback, nothing else than outputting the desired PWM value is required to be programmed to set a position to a servo, the linear actuator control boards handle the rest.

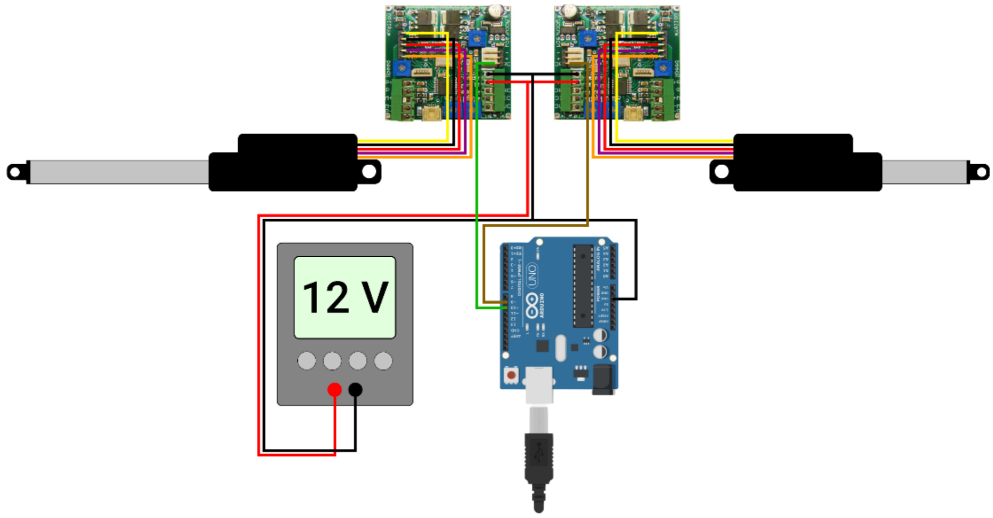

Figure 52. Circuit schematic for servo control. All credits for Arduino graphics go to its creator [14].

7.2.10 **Sliding contact collector**

The sliding contact collector consists of a copper braid which is attached to a limited rotatable mount. The rotatable current collector is designed to be able parry for the angle offset introduced when the arm moves horizontally through rotation. The idea is that the sliding contact collector will with the help of friction from the rail stay parallel with it. The sliding contact collector can be seen in Figure 53.

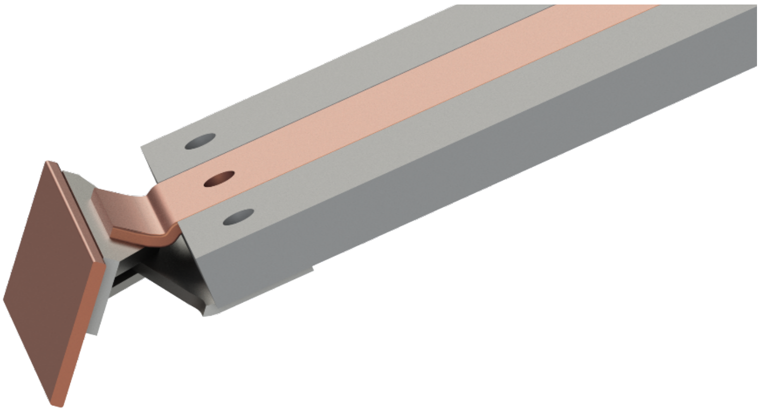

Figure 53. Rotating sliding contact collector.

7.3 Full scale prototype

This chapter describes the manufacturing stage of the first full-scale prototype. This includes possible improvements and decisions regarding the coding.

7.3.1 **First prototype**

A preliminary prototype was first constructed. The idea of this rather simple prototype was to make it full scale in order to see if there were any obvious changes that needed to be done. The design changes can easily be identified even though the prototype is not in the correct material. This prototype can be seen in Figure 54 and Figure 55 below.

Figure 54. First prototype from below.

Figure 55. Overview of first prototype.

7.3.1.1 Needed improvements

When testing the preliminary prototype several areas of improvements were identified. The most obvious improvement that needed to be done was the axis servo connector part for vertically folding up and down. The square shaped part tended to twist which locked the mechanism making it tough to move. It was also too weak and ended up breaking twice in the loops that the servo was connected to. This is shown in Figure 56.

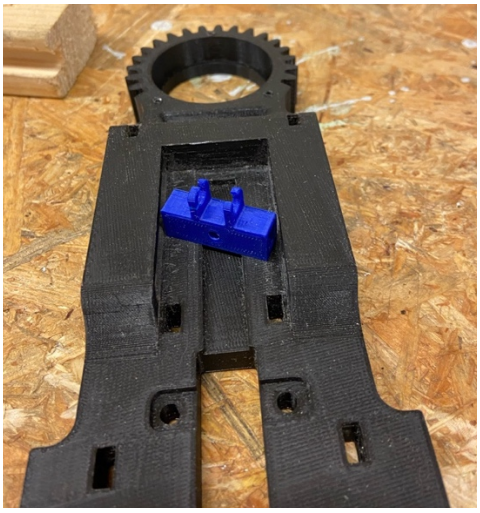

Figure 56. Twisted and broken part that locks the movement.

Another important improvement that needs to be corrected are the tolerances. The tolerances around the groove ball bearing were too large which resulted in the entire construction not being stiff enough. This led to it tilting and therefore hindering the design from becoming as slim as possible. The tolerances for the screw holes on the locking ring could also be improved, since the mounting was difficult due to the holes being too small.

The t-slots used in the v-slot beam do have a spring-ball on its back to increase the friction to make sure that they do not move. For this prototype these were used for the sliding attachment of the rack, which was not optimal due to the friction.

The last desired improvement is greater precision in the ability to position the arm at a certain spot. As of this prototype, the number of control steps within the defined range are only 45 for the desired $450\ mm$ range. This gives the prototype one step per $10\ mm$ which is deemed too large for a single step. Therefore, another method to control the servos is desired.

7.3.1.2 Code controlling the prototype

In the first prototype where the linear actuator control boards were used, the code is rather simple which can be seen in the code in Appendix H.1. Due to the design and implementation of the actuator control board discussed in chapter 7.2.9.2, all the code needs to do is emit a PWM signal that is tuned between the set limits. Small automations for flipping between each end position was also implemented.

8 Set final specifications

This chapter describes the finalized concept after evaluating and improving the first full scale prototype. The refinements, overall dimensions and a final iteration of the prototype will be presented.

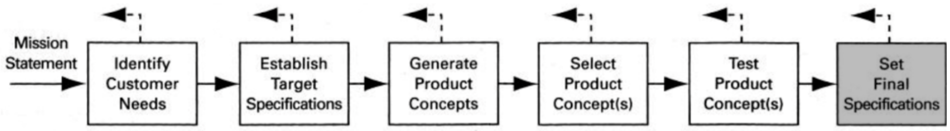

Figure 57. The set final specifications phase.

8.1 Concept description

The concept has been refined and the final version of the concept can be seen below in Figure 58 through to Figure 60. This includes all the refinements described below in chapter 8.3.

Figure 58. Final concept overview.

Figure 59. Final concept overview from behind.

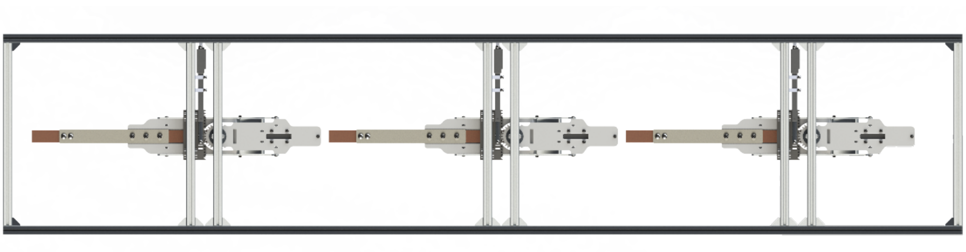

Figure 60. Final concept overview from above.

8.2 Overall dimensions

Blueprints are not prioritised for this master thesis and time has therefore not been spent on details. The overall dimensions for the design can be seen in Figure 61 through to Figure 63 and is summarised in Table 4.

Table 4. Summarized overall dimensions.

State	Length	Width	Height
Folded Up	$2100\ mm$	$440\ mm$	$46\ mm$
Folded Down	$2100\ mm$	$440\ mm$	$315\ mm$

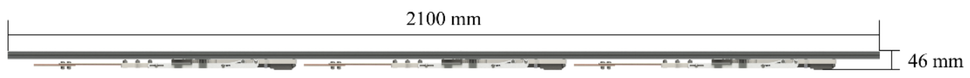

Figure 61. Dimensions for length and high for concept when folded up.

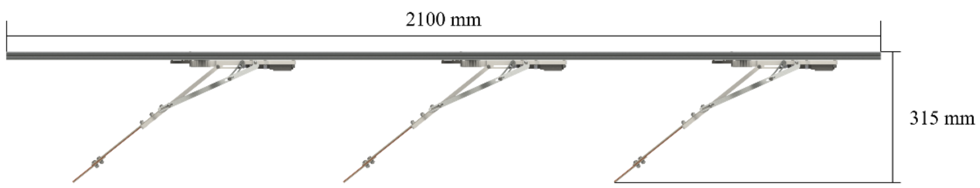

Figure 62. Dimensions for length and high for concept when folded down.

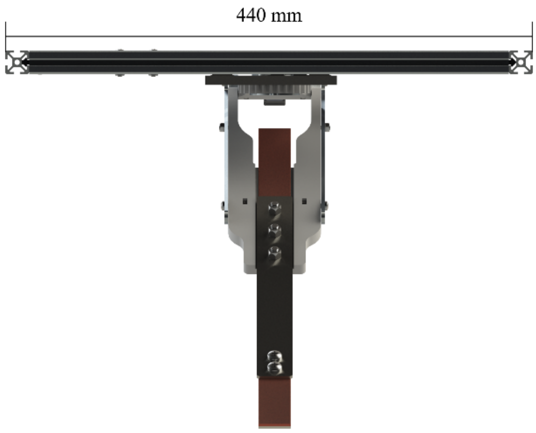

Figure 63. Width for the concept.

8.3 Refinements

The specific refinements done after evaluating the first full scale prototype are described below in detail.

8.3.1 **Re-designed axis servo connector**

The part controlling the vertical movement tended to twist before and thereby lock the vertical movement, as shown in Figure 56. To prevent this, the part has been redesigned with an extruded piece that fits perfectly into a slot on the surface where it slides against, to be compared to the T-slot nuts sliding in the V-slot beams. This prevents the twisting and allows the part to always move straight and deliver the desired vertical movement. This design change is shown in Figure 64.

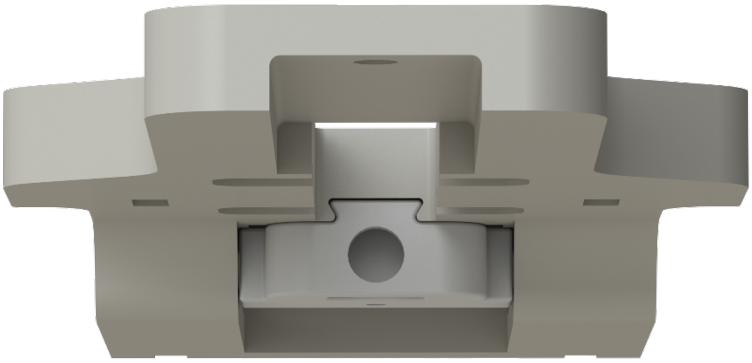

Figure 64. Axis servo connector in the slot.

8.3.2 **Tolerances**

The updated tolerances can be seen in a cross-section image in Figure 65. There are three changes made that are believed to improve the rigidity of the concept and thereby decrease the tilting of the arm. The arrow labelled *a* in Figure 65 shows where the locking ring at the bottom have been made longer to be able to squeeze the groove ball bearing more tightly into place. The second arrow labelled *b* shows a gap that has been created to enable the central axis that is holding the bearing being pushed upward when screwed into place, which allows a stronger mounting. Lastly, the third arrow labelled *c* points at the perimeter of the central axis which has been given a bigger radius. This creates a stronger press fit between the bearing and axis, making it securely mounted on the axis.

One thing that shall be noted is that the manufacturing method used will affect what these tolerances should be. For additive manufacturing, which is used for the prototype, the exact tolerances specified cannot be entirely ensured.

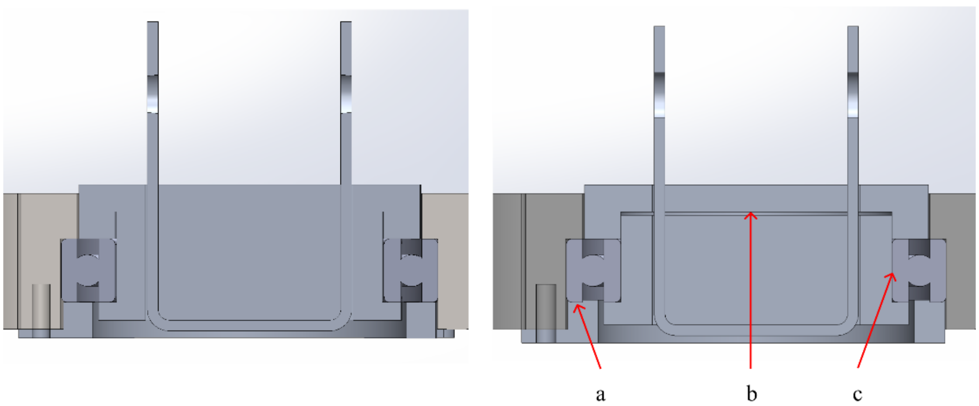

Figure 65. Cross-section comparison between old (left) and updated (right) tolerances.

8.3.3 **Screw mounting for axis servo connector**

The design of the axis servo connector piece where it connects to the servo for the vertical movement has been changed since it broke in the last design. Instead of having two arches where the servo was mounted in between, a screw is mounted at the front edge of the servo and then attached using a nut to the new and improved axis servo connector part. This creates a more secure fastening with more material being pulled on, reducing the stress created in the connector and the risk of the part braking. The new design can be seen in Figure 66. The screw and nut used came with the servo and is therefore an easy adjustment.

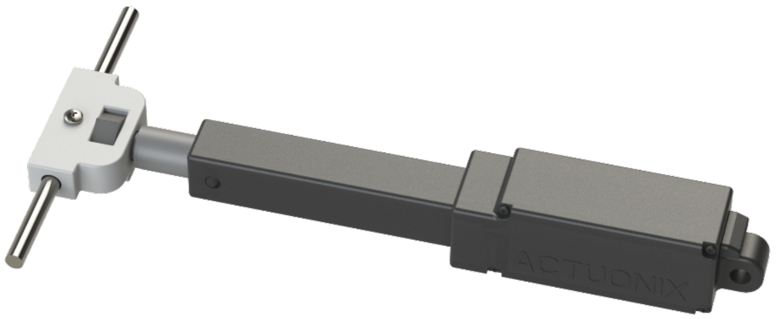

Figure 66. Axis servo connector part with nut and bolt.

8.3.4 **Arm's shape and length**

In order to simplify the production of the prototype the arm's design has been changed. The arm is manufactured in a SLS-printer where the maximum size was $220\,mm$. Therefore, the original arm did not fit. Instead of choosing another manufacturing method specifically for the arm, the team decided to reduce the amount of material printed and instead make the arm into two parts by using a steel piece at the end for the extra length. The steel piece in combination with the new sliding contact collector increases the flexibility of the design. The braid is much more flexible and the steel piece is stronger than the nylon arm would have been, which is a great advantage. This makes the design more robust in terms of not breaking if there is an object on the ground and it also makes it more flexible in terms of adjustability to the height of a vehicle. The new arm can be seen in Figure 67.

Figure 67. Shorter arm with steel plate.

8.3.5 **Sliding contact collector**

The first physical prototype did not have a sliding contact collector. However, the digital prototype did have the one described in chapter 7.2.10, but that design has now been updated. The reason for it being changed is due to it being oversized and unnecessary complex. Also, this design is inspired by a new version Elonroad is currently looking at. The new sliding contract collector simply consists of a $120\,mm$ long steel braid, a long copper braid that runs all the way along the arm and a metal sheet for support. The steel braid is more durable and is used to reduce the wear of the copper braid, which has better conductive characteristics. The two braids are $60\,mm$ longer than the metal sheet. This is due to the construction needing some flexibility, which the braid can provide by their own. Since the sliding contact collector does not need to consist of more than two braids in order to be able to fulfil the requirements, the risk of short circuits is lower since the two braids are rather slim. Before when the sliding contact collector was wider it had the risk to short circuit if it was not to be rotated as well, this is not a risk with the new one. The new sliding contact collector can be seen in Figure 68.

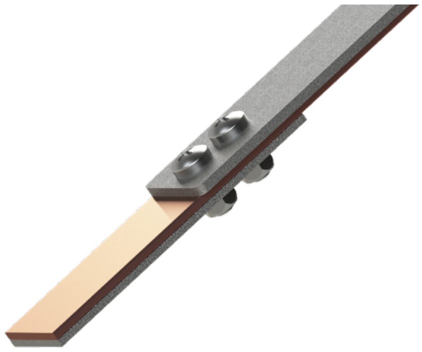

Figure 68. Redesigned sliding contact collector.

8.3.6 **T-slots for rack**

The rack was previously mounted on the beam using t-slots. These t-slots are designed with a spring-loaded ball to be kept in place and self aligned. The t-slots had therefore higher friction than believed and were not optimal for the rack which is going to slide. Instead, new t-slots were designed and 3D-printed without the ball and slightly smaller. These slide perfectly in the v-slots on the beam with a lot lower friction. The 3D-printed t-slots can be seen in Figure 69.

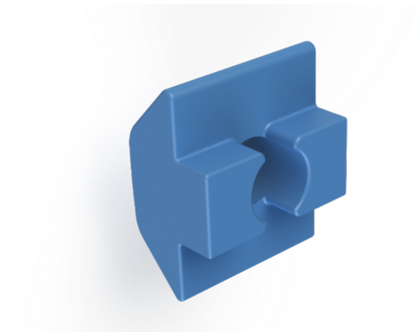

Figure 69. T-slot slider for rack.

8.3.7 **Dual H-bridge motor driver**

To improve the accuracy and number of control steps available, a decision was made to remove the linear actuator control boards. Instead, a dual h-bridge motor controller together with a PID controller has been used. With this h-bridge, the speed and direction of the linear servos can be controlled more precisely. This new configuration increased the number of steps from 45 to 470 steps for the horizontal range of $450\ mm$. This gives the prototype one step per $0.96\ mm$ which is more than enough for a prototype. More on how this was achieved is described in chapters 8.4.1 and 8.4.2.

8.4 Code controlling the final prototype

Since the accuracy and number of control steps was deemed too low, the code and setup were updated. This is still only for the prototype, but a more accurate result was desired in order to be able to test the prototype more reliably. An updated schematic image can be seen in Figure 70 below.

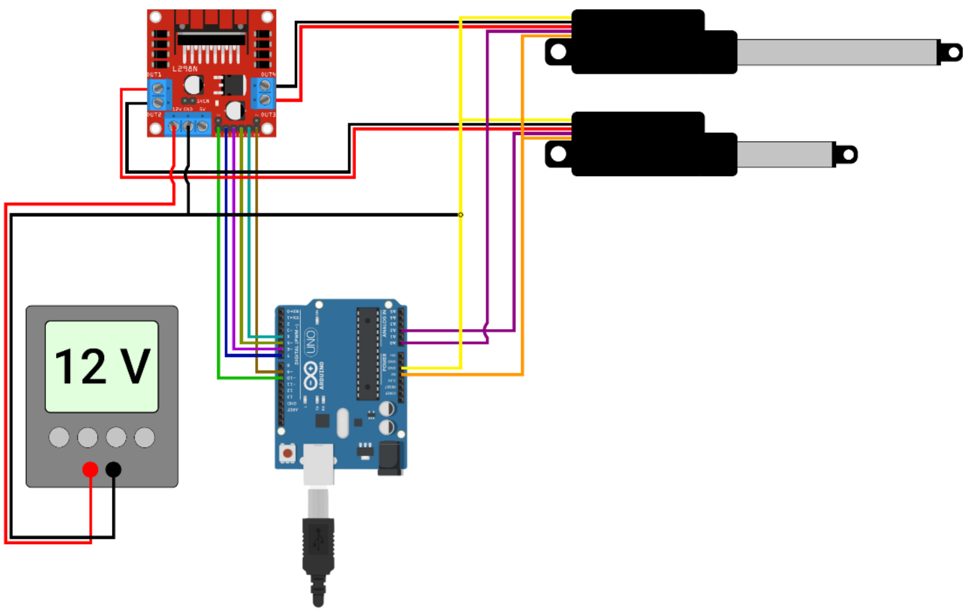

Figure 70. Circuit schematic of the new configuration. All credits for Arduino graphics go to its creator [14].

8.4.1 **Servo control**

The control of the servos is still based on the Arduino micro controller but with the new dual h-bridge motor driver instead of the linear actuator control boards. This setup gives more control with the drawback of being more complex than using the linear actuator control boards. Instead of two outputs from the Arduino, six outputs and two inputs must be used to control both the servos. For each servo, there must be one input signal to the Arduino to read their position via the internal potentiometer. This reference voltage signal gets translated into a range of $0 - 1023$ which is linearly relative to the servos' current position. Then, each servo needs three output signals, one for the PWM signal controlling the speed and two digital outputs controlling which direction to move. All is handled by the micro controller. The code used can be seen in Appendix H.2.

8.4.2 **PID- regulator**

To make sure that the current collector arm moves to the correct position, a PID regulator is implemented in the code. This takes the input signal from the potentiometer and calculates the correct output signal, both for the speed and in which direction to move. The vertical servo is not implemented with the PID regulator since the prototype only uses two states, folded up or down. This is instead controlled with only two end limits which when reached, the servo is shuts off.

8.4.3 **Long duty test**

To be able to get more data on the performance of the final prototype, a long duty test was implemented in the code. This consisted of two functions randomising what position the collector arm should travel to, as well as if it should be folded up or down. This was to simulate real scenario use. Combined with the random positions, functioned were set up to measure and count if the arm moved within less than $0{,}5\ mm$ from the desired target. This was all saved in two arrays which were streamed to an excel spread sheet.

8.5 Final prototype

After the design changes have been identified and implemented, a last and final prototype is to be manufactured. The refinements that have been done to this final design are described above. This prototype can be seen in Figure 71 and Figure 72.

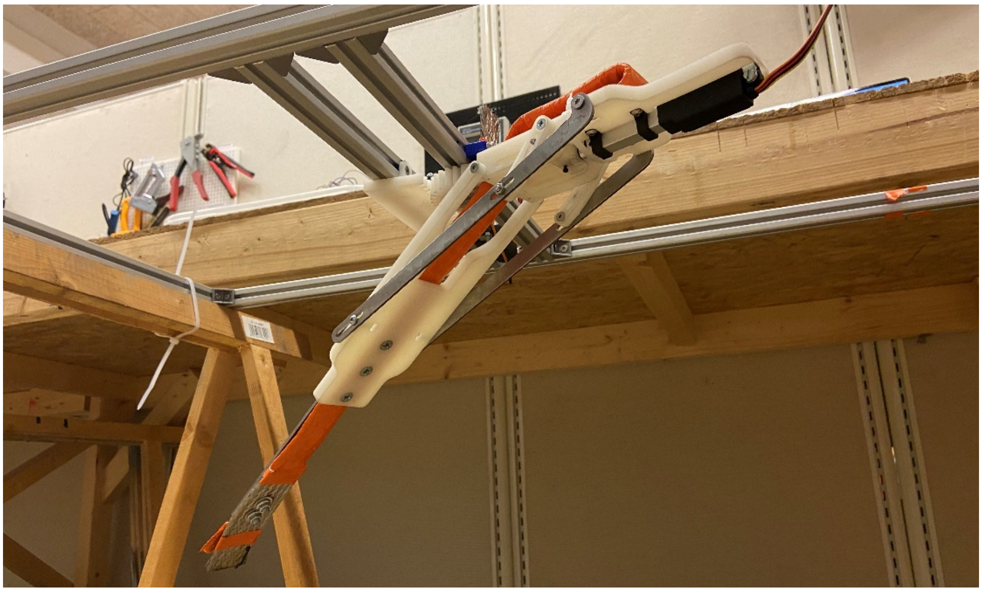

Figure 71. Final prototype from below.

Figure 72. Final prototype from the front.

9 Final testing for product evaluation

This chapter describes the process and results of the tests conducted on the prototypes. Both mechanical and electrical reliability tests are included in this chapter.

9.1 Mechanical specification tests

To measure the performance of the concept, different tests of the mechanical properties of the prototype will be conducted. These tests are for example testing aspects such as the movement's speed, the accuracy and fulfilment of criteria.

9.1.1 **The different tests**

Eleven different tests are to be done on each iteration of the design. The tests are a good measurement on whether the design improves. The different tests are described below.

9.1.1.1 Achieves 450 mm horizontally

One of the criteria given is that the pick-up need to be able to move $450\,mm$ horizontally. Therefore, one test was to make sure the design fulfils the criteria. The test was simply done by measuring the outer positions.

9.1.1.2 Speed reaching outer edges horizontally

Another factor that defines the design's performance is the speed from one outer position to the other. This test is to be conducted six times and an average of the results will be calculated. A reason for doing several tests and calculating the average is due to the human reaction time, which could affect the results slightly.

9.1.1.3 Speed 200 mm inner range horizontally

The pick-up will most of the time not move its entire horizontal range. Therefore, a test of the speed at the inner $200\,mm$ will be conducted. This represents a more common use of the product. The test will be carried out six times and an average will be calculated for the same reason stated above.

9.1.1.4 Precision horizontally

An important factor for the construction is that the pick-up is trustworthy in its precision. The need stated about robust design, in Table 2, also includes the precision. This is of great importance since it decides how well the pick-up will be able to interact with the rail. This test was measured at a range of $\pm 110\ mm$ from the middle, since it is a range where the pick-up will interact frequently. The test was conducted through changing the PWM-signal sent from the Arduino. First, a reference point was set up on both targets at $\pm 110\ mm$ from the centre. Then three iterations on each side were conducted and noted. The deviation between the reference point and the three iteration points on each side is measured and an average calculated in order to simplify the comparison.

9.1.1.5 Achieves 320 mm vertically

Another need that was stated at the very beginning of this master thesis project was that the design needs to fulfil the $320\ mm$ height requirement. The design needs to be able to move $320\ mm$ vertically. This test will simply be measured when the pick-up is fully lowered.

9.1.1.6 Speed folding up vertically

The time it takes for the construction to fully move upwards vertically is another test to measure the performance. This test will be done three times and an average will be calculated.

9.1.1.7 Speed folding down vertically

For the same reasons as the previous test, the time it takes for the construction to move fully downwards vertically will be measured three times and an average will be calculated.

9.1.1.8 Distance lower edge frame to the upper edge arm

The concept's height should be minimised. Therefore, the distance to the arm from the frame is to be measured when raised. If the distance is large, it will affect the concepts height which is not desired. The distance will be measured from where the lower edge of the frame to the upper edge of the arm.

9.1.1.9 Number of parts

Since the design is to be as simple as possible the number of parts is an important factor. The reason for the design to be as simple as possible is to reduce assembly time and manufacturing costs. Also, it is a great advantage if the design is easy to iterate on without being very time consuming. All the electronics apart from the linear controllers and the Arduino micro controller are excluded from the number of parts.

9.1.1.10 Assembling time

The company has previously spent quite some time on assembling the previous pick-up. Therefore, they stated that it would be preferred if the assembling time could be reduced. The time it takes for the whole design to be assembled will be measured, including the frame. The electronics are not included.

9.1.1.11 Force on rail

A need for the design is that can be able to apply $27N$ on the rail. This will be measured by using a scale.

9.1.2 **Results performance**

The results from the tests are summarised in Table 5. The complete tables can be seen in Appendix F.

Table 5. Results from testing prototypes.

Number	Type of test	First prototype	Final prototype
1	Achieves $450mm$ horizontally	Yes	Yes
2	Speed outer edges horizontally (s)	7.66	6.88
3	Speed $200mm$ inner range horizontally (s)	4.42	3.29
4	Precision horizontally (mm)	2.21	1.04
5	Achieves $320mm$ vertically	Yes	Yes
6	Speed folding up vertically (s)	5.16	5.52
7	Speed folding down vertically (s)	Fail	4.9
8	Distance lower edge frame to the upper edge arm (mm)	67.90	47.00
9	Number of parts	149.00	150.00
10	Assembling time (min)	31.33	37.55
11	Force downwards (N)	Fail	5.06

When doing the assembling time test for the second iteration, the test was split into two. One based on the same premise as the first iteration and another where the sliding contact collector, the metal bracket and the braid was included. When included the total assembling time was 47.55 minutes. The reason for this complete time not being the comparison time is that the sliding contact collector was not finished when the first design iteration was tested.

For the same reason the total number of parts has been deducted by 21 in order to not include the parts regarding the braids, bracket, sliding contact collector, nor the parts for the bracket attaching the braid to the beam. This results in the total number being 171 parts.

9.2 Long duty test

The final concept's performance when being used for a longer period is important to make sure it will last when being used in the future. Therefore, a test that simulates the use on a highway will be done. The vertical movement will be done roughly once every 25 cycles, which simulates a future use when having rail segments that are $1.5\ km$ long. An estimation was also made that most often the pick-up will move in the inner range horizontally. Therefore, two thirds of the target set points will be at the inner $200\ mm$. The estimated normal use is based on an estimation on how much a driver will move sideways while driving and the vertical movement is calculated using a highway's average speed and that the segments are $1.5km$. Every time the movement fulfils the desired position the loop will count a success. At the end of the test there should hopefully not be any difference between the counted successes and the number of targets that should have been achieved. This will help in evaluating how reliable the construction is. For these tests some conditions must be met. For example, the arm should never move horizontally in the folded-up position.

9.2.1 **Results**

The results from the long duty test can be seen in Figure 73 and Figure 74 below. The test ran for five hours and for the targets in the range $225\ mm$ to $-144\ mm$, there are only 21 fails. For the last three targets in the range there are a great amount of fails, 270 fails to be exact. Further tests on why the fails are frequent from $-169\ mm$ to $-225\ mm$, the last three points, will have to be done. In total the test ran for five hours, had a total amount of set point targets of 6332 points and achieved 6041 points. Which results in 95.4% accuracy.

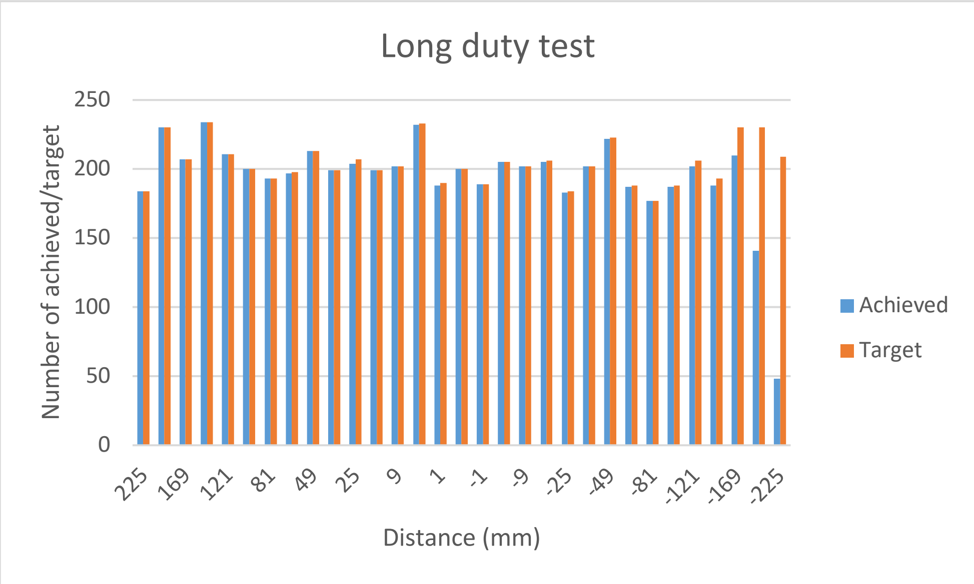

Figure 73. Results from long duty test. Target is compared to achieved.

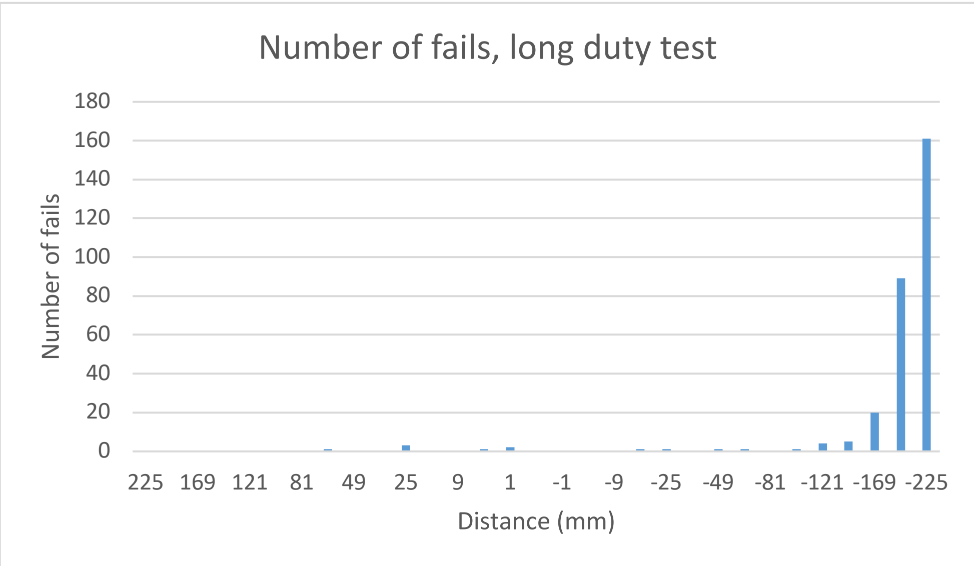

Figure 74. Number of fails for long duty.

9.3 Braid heat test

A heat test has been carried out in order to see whether the concept can conduct the required current. The testing equipment conducted 143 $Ampere$ through the braids while the heat was measured. 143 $Ampere$ is more than the stated need requires of the design, which is 125 $Amperes$. The reason for using 143 $Ampere$ is due to the testing equipment's capacity.

The temperature is also to be measured on both braids individually, isolated from each other. This will be done by using electrical tape and a heat camera. This will allow the team to gain knowledge about the two different braids and their thermal characteristics.

9.3.1 **Results**

The results from the test with both braids can be seen in Figure 75. The warmest part was the stainless-steel braid which reached $75.0°C$. The other parts of the construction, for example the SLS printed nylon did not become warmer than the room temperature. All the results can be seen in Appendix G.

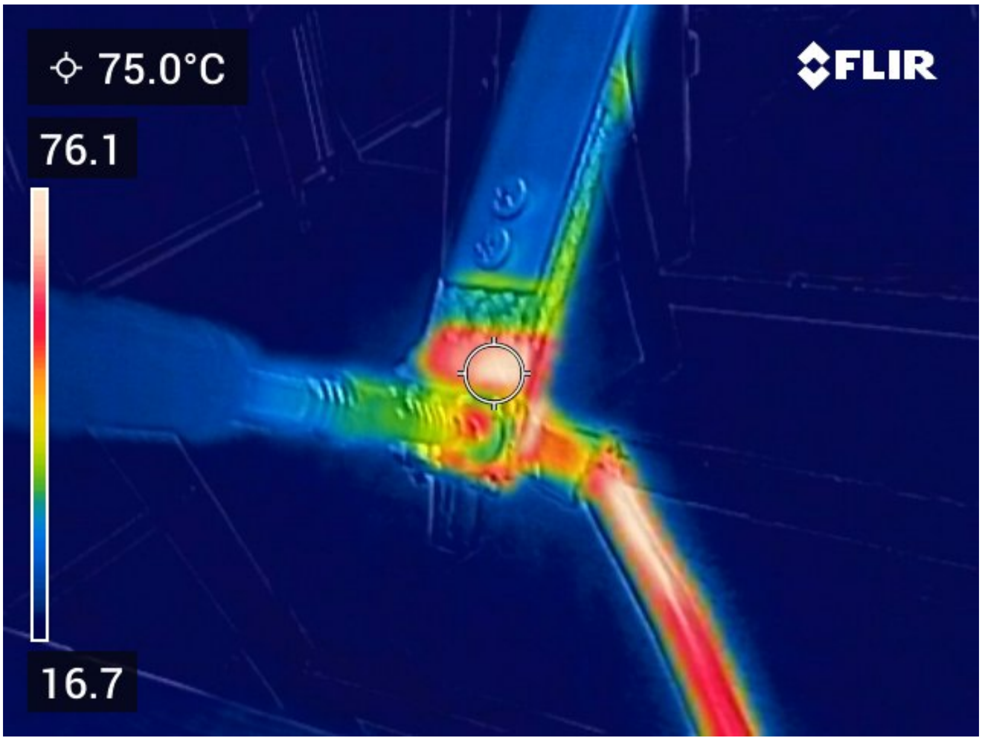

Figure 75. 75°C when conducting 143A, steel and copper braid.

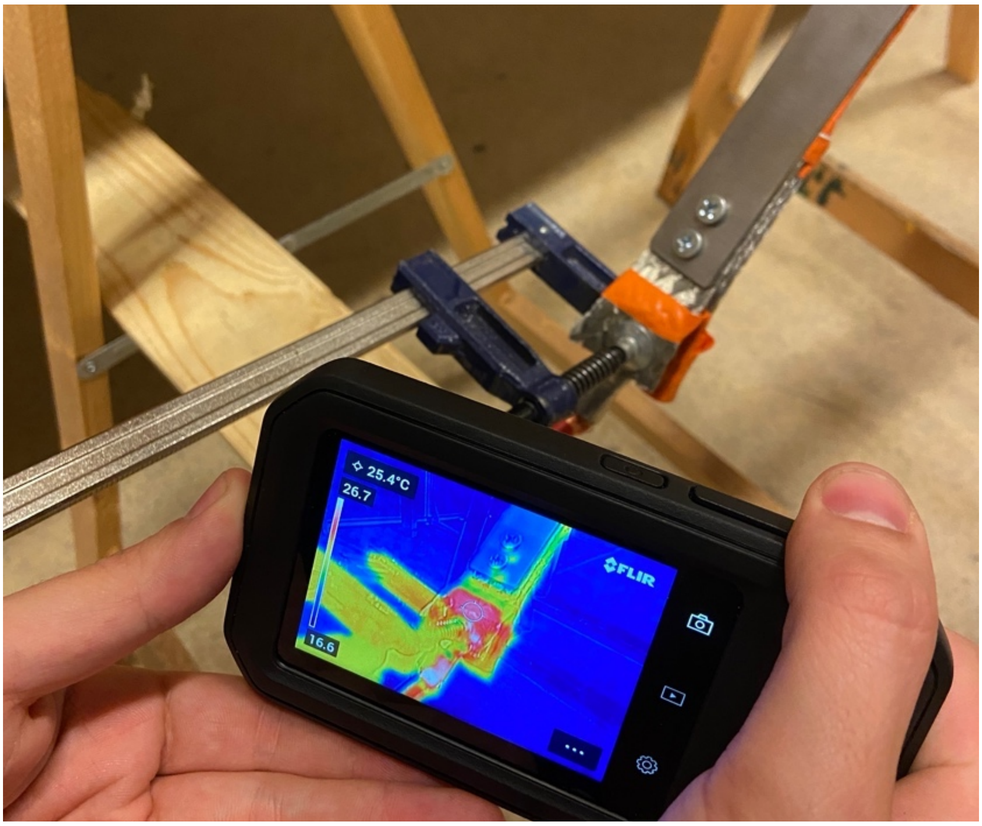

Figure 76. Measuring the heat when conducting 143 Ampere, only copper braid.

The test that was made was to measure the temperature individually on both braids. The results of the tests can also be seen in Appendix G. When only drawing the current through the steel braid, it reached the highest temperature of $155°C$. The same test for the copper braid had a maximum temperature of $28.7°C$ and can be seen in Figure 76. The test of the steel braid was aborted when it reached $+150°C$ after about 20 seconds. The copper braid did not get warmer even though the test ran for several minutes.

9.4 Contact point current test

One of the main needs that was presented at the very beginning of the master thesis project was that the pick-up needs to be able to conduct up to $125\ Ampere$. Therefore, a test that simulates the real situation will be done. A stainless-steel top rail will be placed underneath the pick-up and the current flowing through the braid will be measured. This will evaluate how well the design can conduct $125\ Ampere$. The heat will be measured simultaneously to make sure that the construction is not over-heated. An over-heated construction would mean that the contact between the top rail and the sliding contact collector is not good enough. In a real case there would also be a constant flow of air, cooling down the braid. The testing setup can be seen in Figure 77.

Figure 77. Setup for current conductive test.

9.4.1 **Results**

The current conductive test resulted in the concept being able to conduct $80\ Ampere$. The maximum temperature measured during this test was $301°C$. The heat measurement can be seen in Figure 78. The heat was concentrated to the very end of the stainless-steel braid where the braid had individual strands of wire sticking out. No other parts became over-heated.

Figure 78. Heat measured during the current conductive test.

9.5 Creep distance test

A creep distance test will be done to make sure that no unintended parts have any voltage. To test this, Elonroad uses a machine that sends out a desired voltage and measures if it flows between the negative and positive nodes of the machine. The positive node is connected to the braid and the negative node is connected to the frame of the prototype. The setup for the test can be seen in Figure 79.

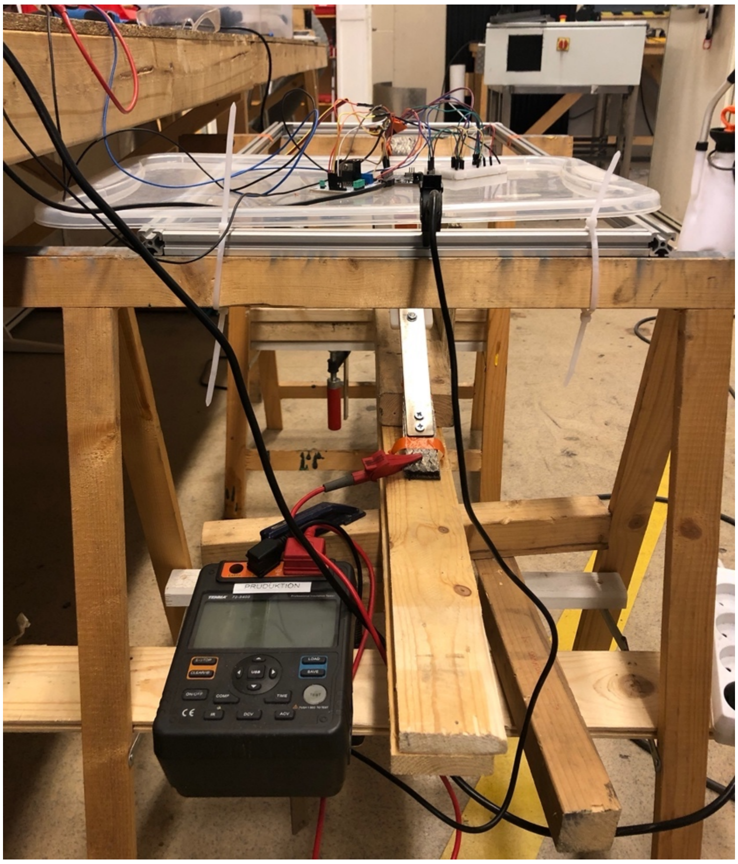

Figure 79. Setup for creep distance test.

9.5.1 **Results**

No unintended voltage from arcs or creep was detected. The resistance measured in the frame was at the 10 $G\Omega$ scale, which means that there is neither any current nor voltage in the frame. The results from the screen can be seen in Figure 80.

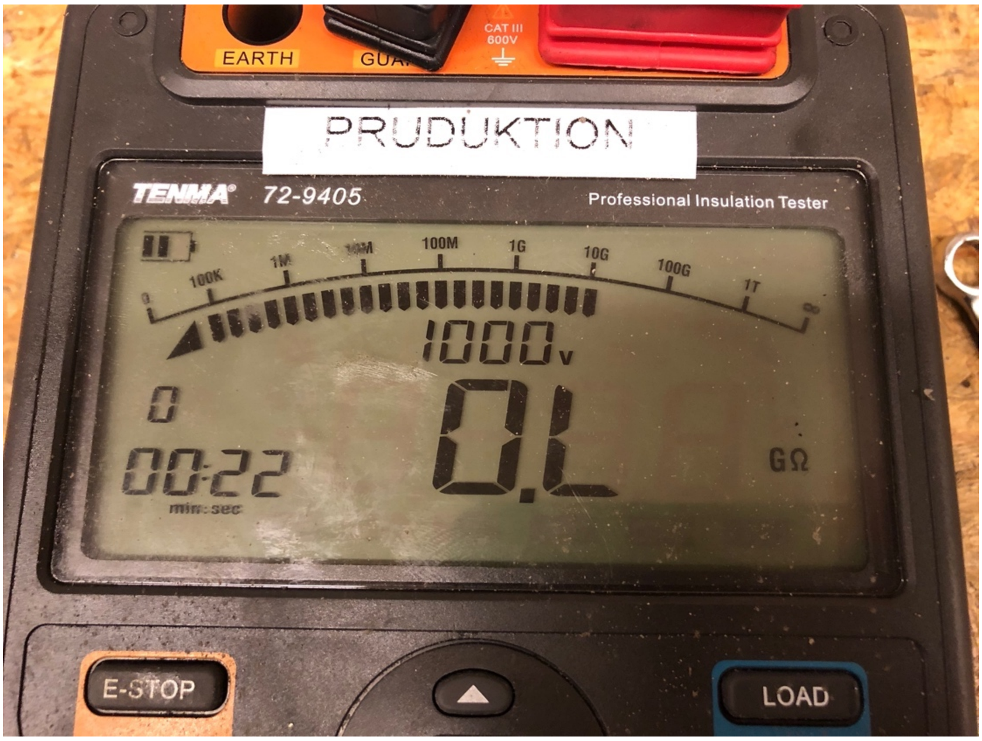

Figure 80. Result from creep distance test.

9.6 Evaluation against needs

All the needs have been evaluated to see whether they have been fulfilled with this master thesis or not. The needs that have not been evaluated are deemed to be outside of this thesis scope and have not been taken into consideration at a later stage of the master thesis. For example, the need stating that the concept must be isolated to avoid electrifying the car body, is outside of the master thesis since it only requires an isolating layer and does not affect the concept design. Some of the needs are marked with “Dis” which indicates that they need to be further discussed, tested or evaluated.

9.6.1 **Results of evaluation**

The result of the evaluation can be seen in Table 6. Most of the needs have been fulfilled as shown. Some need to be further discussed. Such as for example, the flexibility of the pick-up to reduce the preciseness in vertical positioning has never been tested and therefore only a qualified guess can draw a conclusion.

Table 6. Whether the needs are fulfilled.

Needs	***Fulfilled?***
The concept should have a robust design	Yes
The concept has sufficient clearance to avoid creep	Yes
The concept has flexible design to reduce the need of preciseness in vertical positioning	Dis
The concept enables good conductive capabilities between rail and pick-up	No
The concept must be isolated to avoid electrifying the car body	---
The concept allows a horizontal movement of at least $450\ mm$	Yes
The concept is the simplest possible	Yes
The braid shall avoid generating electrical arcs	Yes
The concept handles up to $600\ volts$	Yes
The concept handles up to $125\ amperes$	Yes
The concept has as low resistance as possible	Yes
The concept applies $27N$ on the rail	No
The concept withstands vibrations caused during normal circumstances	Dis
The concept does not generate any unintended antennas	Dis
The concept is simple to manufacture	Yes
The concept can passively parry objects $< 1\ cm$ on the rail	Dis
The concept is adaptable with the vehicle's ground clearance	Yes
The concept has a minimal weight	Yes
The concept's height is minimised	Yes
The concept is dampened to handle variable loads	Yes
The concept needs to withstand harsh environments	Yes
The antenna is not placed within close presence of metal	---
The concept is compliant with the existing rail solution	Yes

The concept has a minimal number of movable parts	Yes
The concept enables horizontal and vertical positional feedback	Yes
The concept allows the braid to be easily replaced	Yes
The concept adjusts the force applied depending on the velocity	No
The concept minimises the cost	---
The concept excludes unnecessary parts	Yes
The concept measures the force applied on the rail	No
The concept can be locked in an upright position without powering the motors	Yes

10 Possible improvements

In this chapter the possible improvements are listed. These were discovered while testing the prototype.

10.1 Stronger servo for vertical movement

A stronger servo would increase the force that the sliding contact collector can apply on the rail. Today it can only apply about $5\ N$ which is quite a bit less than required. However, the team believe that a stronger servo could easily solve this problem. When testing the prototype at this early stage, a decision was made to go for a rather cheap servo. The team believe it is a good next step to invest in a stronger servo to improve the results.

10.2 Faster servo

From the results of the mechanical specification test, another possible improvement has been noticed. This is to have a faster servo for the horizontal movement, which would improve the general performance of the pick-up capabilities of following the road.

10.3 Straight arm

As the prototype is now, the arm does not quite end in a straight horizontal position when folded up. The height from the lower edge of the frame to the upper edge of the arm is $47\ mm$. It should only be $26\ mm$.

This could be improved by adding a spring, passively helping the arm the last millimetres. Another possible improvement for this could be to redesign the angled rails and evaluate if it improves the result. Lastly, this could also be improved by even tighter tolerances in around the bearing supporting the arm.

10.4 Weight arm

When the arm is folded up it tends to not go all the way, as test number eight shows. A reason for this could be the arm's weight. The arm itself is made from nylon which is not heavy. However, the steel piece attached to the arm is a 3 mm thick which has a noticeable weight. This steel piece could either be replaced with a thinner spring steel piece or a narrower steel piece, alternatively be manufactured in aluminium instead. The steel piece is there to create stability and support for the braid. A lighter arm could possibly also improve the speed of the folding up and down.

10.5 Flexibility in arm

The flexibility in the arm is a possible improvement. An increase in flexibility would make the design more robust in terms of not being affected by for example gravel and other possible larger objects on the road.

An increase in flexibility would likely also increase the conducting ability by increasing the contact surface against the rail. However, tests on the effect of a more flexible design would have to be carried out before drawing a conclusion on whether it would help.

10.6 Counter sunken holes

The copper braid on top of the vertical servo does, as the design is today, sometimes slides against the screws and nuts that attach the vertical servo. These could be counter sunken to avoid being an obstruction for the copper braid. The plastic part where the counter sunken holes would be is rather thick and therefore should allow this change without affecting the mechanical strength drastically. The counter sunken holes for the nuts would allow the braid to move more freely and follow the rotation easier.

10.7 Rack and gear

When designing the gear and the rack in the future, more theoretical details should be taken into consideration. That high level of detail is not required for the prototype phase. However, it is of great importance to make sure it will not malfunction due to simplifications.

10.8 Reduce friction vertical movement

The axis in the angled rail could in the future need a bearing in order to reduce the friction since high friction could decrease the preciseness of the movement. A bearing would also decrease the wear and could therefore increase the product's lifespan.

10.9 Tolerances

The tolerances for the locking parts for the gear can be further improved. They are still a bit too loose which makes the arm tilt more than necessary. This is also a question of which tolerances the manufacturing method can manage.

11 Discussion

This chapter discusses whether the purpose of the master thesis has been fulfilled and which aspects that could be improved.

11.1 Theory

The theory being used during this master thesis is Ulrich and Eppinger's theory [3] for product development. The reason for this theory being used is because it uses a structured approach which can help when evaluating and deciding which concepts to choose. Another reason for this theory being selected is due to us having used their theory previously and therefore both are confident in using it. The advantages are that it allowed us to be faster in the process since we were familiar with the theory, which was of great importance since the time has been of shortage the entire master thesis. However, there could be several other product development theories that could have helped us being more innovative and that could be more suitable for this type of project. However, we have not researched in detail any other theories due to time limitations. Still, we believe that the Ulrich and Eppinger's theory have been valuable for us and with the adaptions we made it allowed us to tackle the task with confidence. It is a fine balance between using a theory that goes quickly due to experience and exploring for the right one without letting it consume too much of the valuable time available.

11.2 Concept evaluated against the needs

In general, the concept meets eight of the thirteen most important needs. But as described in chapter 9.6, some of the most important needs are not fully tested since they were either outside our scope for the master thesis or in need of testing in real circumstances. More testing and measurements would give a better evaluated concept that would have been easier to evaluate against the old version.

The time limitation of this master thesis does not allow this refinement and generation to be very extensive and there exist lots of potential for the concept if improved and redesigned correctly.

The needs that are not fulfilled have been given possible solutions in chapter 10, named Possible improvements. These will however need to be tested in order to se what magnitude of improvement they bring. For the need that has not been fulfilled saying that the concept adjusts the force applied depending on the velocity, no given solution has been presented. However, this could probably rather easily be solved in the controlling code if there is an input for how fast the vehicle is driving.

11.3 Concept Generation

This master thesis project has relied heavily on a broad concept generation phase followed by an iterative concept selection phase. This phase could have needed more time to find an optimal solution. However, we believe that for the relative short amount of time of two weeks of generation followed by five weeks of refinement and selection, a lot of concepts have been discussed and evaluated leading to the one presented as our final concept.

Benchmarking is usually an important part of the data collection phase, however, in this master thesis it was not given any great amount of time. Since the technology is new and emerging, there are not a lot of similar products that can give valuable insights. It is debatable whether the result could be improved if the group was to spend more time on the benchmarking extending the search to other products on other markets and researching in detail how they work.

A possible improvement of the final concept could be reached if more prototypes were to be built. This would allow us to be creative with solutions for the defaults noted, for example that the concept does not become as slim as designed. Another design aspect that could be elaborated with is the ability to withstand for example gravel on the road, i.e. have more integrated flexibility in the design. This could possibly also improve the contact surface between the braid and the rail.

In the future the pick-up might have to follow a standard to be compatible with the ERS. As the market looks today, this is not the case yet. Once the technology hopefully has emerged, it is likely that the car manufacturers will have to design the pick-up integrated in their EV models and that they therefore must adapt their design to the existing ERS in their country. Since Elonroad has prioritised the rail at this stage, we have been given a lot of freedom in the development of the pick-up. Which can likely have affected the result of our master thesis since it has not been a prioritised product before, and a lot of choices were to be decided freely by us.

11.4 Prototype

A lot of prototypes have been built during this master thesis, all in different levels of scale and fidelity which can be seen in chapter 5.8, 7.3 and 8.5. The prototypes have in a lot of cases been worth the amount of work put into them. However, sometimes the strive after a good prototype may have been too large in comparison to the value they have contributed with. This is something that is difficult to know during the process, but in hindsight a good lesson to keep when working in similar projects.

Building these prototypes have in some stages been a real challenge, especially in the evaluation of them. This is particularly the case regarding the compliant mechanism concept. For such a concept, some of the most crucial aspects of this concept are the scale, material, proportions, and manufacturing method. All these aspects differ in the prototype that we could produce compared to the proposed final product. If that was the case, how much could be said witch certainty about the performance of the prototype and what conclusions can be draw on how the real product would perform. Since the time was scarce, building several full-scale prototypes in appropriate materials was deemed just not possible and this is one of the main reasons why we decided to disband the compliant concept which had already gotten a lot of commitment and time.

Neither of us have a lot of experience of programming or are well versed in the field of mechatronics. Therefore, a lot of trial and error have been put into the control of the prototype, which have been very developing for us personally. A lot of discussion internally have been necessary to make sure that our decisions and reasons are reasonable and sound. There are still a lot of questions that can be asked about the execution though. For example, should the input signal from the servos be filtered more to avoid outliers? But how does this affect the speed and accuracy of the system and what is most important of these aspects? Should the PID regulator be used, or would it be better and simpler to only use a PI regulator? The PID regulator took some time to finetune to have the desired result of being both accurate and fast enough. The decision was made to only implement the PID regulator for the horizontal movement to be able to precisely position it on the full range of $450\ mm$. We are satisfied with what we have achieved and believe that this is somewhat outside our scope of expertise, and therefore not to crucial for the master thesis. Hence, more time than necessary was not put into these aspects of the project. Also, since the concept would be further developed before a new iteration is built and different components would be used, these questions would most certainly be revisited and answered in the context of a revised concept developed by someone with expertise in the subject.

Testing the prototype with code from the road might increase the reliability of the prototype. As it is now, the long duty test simulates the road scenario with assumptions made by the team of how the product will be used. We have assumed that the inner part of the range is more frequent than the outer range and assumed how often it will fold up and down. Therese assumptions could of course differ from the real case scenario. However, the prototypes performance is still well represented by the assumed use.

11.5 Test results

The results from the mechanical specifications tests showed in almost all cases that the refined version was an improvement, which is positive yet expected. The only test where the first iteration was better is in test number six, the speed of folding up vertically. One reason for this is that with the refined design of the axis servo connector and greater precision in manufacturing of this prototype, different range limits could be set up. In the first prototype iteration, the vertical servos limits were $47 - 110$, which is 63 out of 255 set point steps or around $\sim 24{,}7$ percent of the total range. Compare this to the refined prototype where the limits were $80 - 730$, which is 650 out of 1024 set point steps or around $\sim 64{,}5$ percent of the total range. With this increase in travel range, it is not difficult to see why the result is worse than the first iteration. However, this almost tripling in range should be seen as a great source of error in the testing of the vertical movement when comparing the first and final iteration. An increase in range can be expected with the better precision in manufacturing from being able to tune the ranges finer, but such a large increase questions the amount of time set into tuning the limits in the first iteration. In general, the results from the mechanical specifications were quite expected. However, we did not expect the total height to be greater than in the CAD-model. This was caused by the sliding contact collector being too heavy sand the servo not having the force to pull it all the way up. When the prototype is to be tested when mounted underneath a vehicle the wind force will likely affect the movement of the construction. For example the vertical movement folding upward will likely be helped by the wind which is an advantage since the construction does not quite fulfil the desired total thickness today due to the arm tilting slightly. The mounting time was a bit faster than expected, which is a great advantage seen to developing costs. However, the number of parts was greater. This is however mostly due to the frame consisting of six v-slot beams and numerous t-slots.

The long duty test that was carried out for five hours gave a 95.4% accuracy in its achievements. We are content about the results. However, since 93.1% of the fails occurs on one of the outer ranges, $-169\ mm$ to $-225\ mm$, which is only 9.7% of the range, it is questionable whether the results are even better. There is likely something causing the large amount of gathered fails. The product is symmetric, except for the horizontal servo position, and there is therefore no obvious reason why the results differ greatly on one side. A reason could be that the braid is not mounted symmetrically by us and thereby creates a larger resistance on one side. Another possible reason could be that the servo is stronger or more precise in one direction. However, during the tests we could set the position past the -225 target which shows that the servo should be strong enough to reach the target. Therefore, the problem could also lie in our implementation of the code with the test program and PID regulator. Another way to detect if the target is reached and a finer tuned PID regulator could help remove these errors. Regardless, looking at the other part of the range where there only were 21 fails in total, the accuracy here was $99{,}63\ \%$ which is an excellent result for the prototype.

The heat test resulted in the sliding contact collector reaching $78.5°C$ when measuring on the stainless-steel braid. This is not a surprising result and therefore also an accepted result. When driving, the air will naturally cool down the braid and therefore likely never reach these warm temperatures. The parts around the braid, for example the nylon arm did not become warmer due to the current in the braid, which is a great result. During the test we could conclude that if the sliding contact collector does not have great contact with the top rail it will become a lot warmer. Therefore, it is of great importance that the contact between the rail and braid is constantly good enough to avoid the parts around the braid to get hot and possibly start glowing.

The current conductive test did not go as expected. The measured current was only $80\ Ampere$ which is $45\ Ampere$ too low. The reason for this is that the sliding contact collector and the top rail does not have enough contact. There could be two solutions to this. Either replacing the current servo with a stronger one, the servo that is used today only achieved a downward force of $5\ N$. Another way to increase the conductivity between the two is by creating more flexibility in the sliding contact collector. This could enable a larger surface area that is in contact with the top rail. One way to achieve this is by using spring steel in the arm.

The creep distance test was a success for the concept and should not differ with three arms. However, more tests on this should be done to make sure that no changes in the result occurs when expanding on the concept.

The tests were created and conducted in quite a short time, which could affect the accuracy of their respective methods. Especially the mechanical specifications tests are suspect to errors since they in some cases relied on the human performance. All measurements in test $2-8$, except number five, relies on us measuring either the time or distance between set points. The tests measuring some sort of speed or time relied on us starting and stopping the stopwatch, which depends on our reaction time. In these testes where the magnitude of time is seconds, our reactions could affect the results by several percent. To improve on this the time measurements could, and probably should, be automated with internal measurements in the code to get more reliable and comparable results. In the future, more extensive tests should be conducted. These should be performed in different environments, settings and be more defined to fully acquire enough data to be able to draw accurate conclusions.

11.6 General results

We are truly content with the concept and the final prototype. There are a few things that could be further investigated and thereby possibly improved. The cable management have been investigated partly during this master theses. However, it has not been prioritised throughout the thesis. Instead, focus has been on the mechanical movability. We believe that if more time was to be spent on the cables it could improve the results for long term usage of the concept. The copper braid generates more resistance in the horizontal movement than expected and time could be spent on solving this.

Quite early during the concept generation the team decided to have one servo per arm. This has not been further investigated whether it is an advantage or disadvantage. If the pick-up is to be used for stationary charging as well in the future, it could be an advantage to be able to control the arms individually to manage vehicles not parking straight. If not, it might just be an additional cost and hassle to implement them individually if there is no real benefit to this flexibility.

The main takeaway from the thesis' is that this truly is a complex problem with multiple intertwined aspects all needing attention during the development. The task has been broken down in order to be manageable, but in the process, it is easy that some aspects does not get the attention needed or in our case been deemed outside of the scope. However, this master thesis' goal was to develop a new mechanical concept which have been achieved with satisfaction.

12 Conclusion

This chapter presents the conclusions of the project and the overall fulfilment of the project.

The concept is a reliable product with great flexibility, being easily varied depending on what vehicle it is mounted upon. It achieves most of the needs declared but there are still improvements that can be done or that need further testing. Some of the needs cannot be evaluated against the old version since there is no data on such tests. Therefore, more tests on the old version would have to be done in order to increase the reliability of the conclusion.

We are content with what has been achieved and to answer the question if the concept is an improvement of the old version, no definitive answer can be given. There are too many unknown factors and no tests performed in its real environment which are needed in order to make an accurate statement. However, there are several aspects such as reliability and size factors where the concept has an obvious advantage. The concept developed in the master thesis is thinner than the old version and gives a slimmer impression. The group's impression is that the reliability is improved. However, there is no comparable data on the old version proving the improvement. The rotational solution does not fulfil the requirement regarding the conductivity, due to the contact between the rail and sliding contact collector not being good enough. This is an improvement that needs to be addressed in a future version.

To summarise, the concept can be seen as an entirely new approach to the problem with several improvements compared to the old version. Which leads to the conclusion that the master thesis' aim is fulfilled. However, more data on the improvements will have to be gathered in order to make a qualified conclusion.

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Appendix A - Work distribution and time plan

According to the course syllabus for master theses, if the project has been performed by a group, the contribution of each student must be clearly discernible. The student(s) need to demonstrate the ability to plan such a project and possibly reflect on the planning, execution, and follow-up. This can be presented in the body of the document or in an appendix.

A.1 Work distribution

The work has been distributed between both of us, depending on expertise and time. In general, the work has been done together. Especially the physical work, when building and testing the prototype.

Appendix B - Gantt chart

This Appendix shows the initial planning and the actual outcome.

B.1 Initial planning

In order to plan the master thesis project, a Gantt chart was created [3, pp.401-402]. A Gantt chart is used to plan the activities within the large project, where the activities are displayed against time. This gives a good overview of the different stages and allows the group to see whether the schedule is followed. The Gantt chart is made during the planning phase and then evaluated at the end of each week. It can also be modified if the timeline is no longer possible. The projects planned Gantt chart is shown in Figure 81. There will of course be unexpected events during a project of this length, twenty weeks, and will therefore have to be taken into consideration along the project. Another Gantt chart, who shows the actual outcome is shown in Figure 82.

B.2 Initial planning

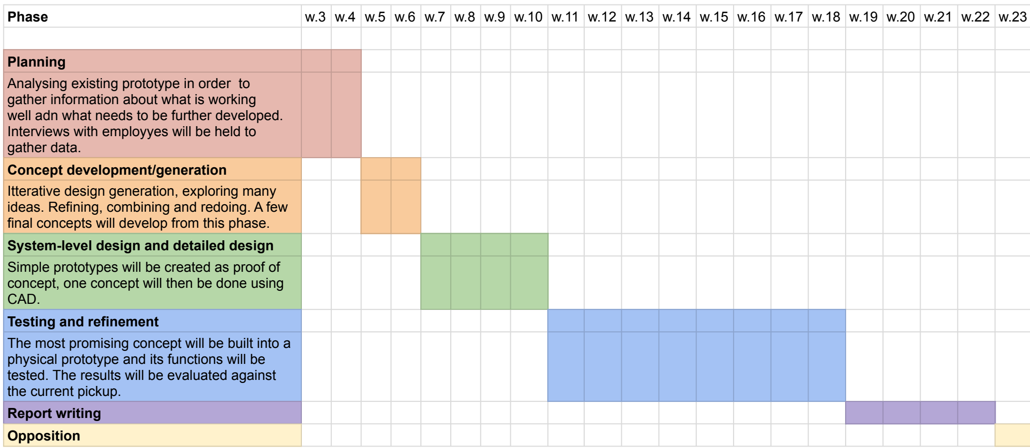


Figure 81. A Gantt chart showing the initial planning of the project.

B.3 Actual outcome

The actual outcome differed slightly from the planned timeline. This is due to unplanned activities such as more tests or failed ideas taking longer than expected. The report took a lot longer time and work than expected, which was luckily discovered early during the master thesis. Therefore, the report phase has been running over nearly the whole project. We can conclude that the preliminary Gantt was followed quite well and that the scheme helped us to go forward with the project.

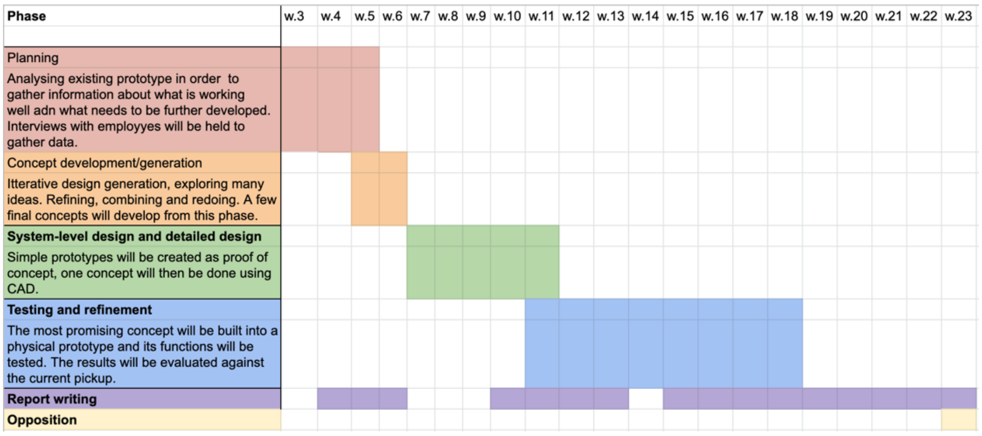


Figure 82. Actual outcome Gantt.

Appendix C - Interviews

This Appendix lists the participants in the interviews and shows the raw notes taken during the interviews.

C.1 Participants interview

The people who participated in the interviews are listed below, all employed at Elonroad.

- Johan Teleman- R&D Lead
- Dan Zethraeus- Founder & Innovation Lead
- Andreas Sörensen- CTO
- Albin Andersson- Mechanical Engineer
- Petter- Consultant

C.2 Interviews

The notes that were taken during the interviews are shown in Figure 83 - Figure 95. Since the interviews were conducted in Swedish, the notes are in Swedish as well.

Johan, lead R&D:

Vilka är de viktigaste förändringsområdena/förbättringsområdena med dagens lösning?
Svar:
- Göra den enklare att producera, det är tidsboven och kostandsboven
- Mer tillförlitlig mekanisk
  - Inga uppenbara slitagepunkter
    - Kablar som drar mot kanter eller smutsiga områden. Dessa ger hög friktion och därmed slitage.
  - Får för mycket motstånd i ändlägena. Idag är kabeln väldigt styv och tjock. Det medför att det blir högt motstånd i extremlägena där kabeln böjs/kläms som mest.
    - Böjning av kabel
    - Trångt någonstans
    - Grus eller smuts i tex remmarna skapar onödigt motstånd.
    - Fastnar i startuploopen, kör tills den hittar sin homesensor. Startar alltså aldrig.
      - Förtydligande: För att hitta sin position i x-led, kör den fram och tillbaka tills någon sensor har läst av. Problemet är att den inte når dessa lägen då det är för högt motstånd. Detta leder till att den aldrig startar.
  - Hoppar eventuellt en kugg, eller försöker accelerera snabbare än motorn klarar. Kanske hoppar i steppermotorn. Kan också vara att det är trögt någonstans. Orkar kanske inte accelerera. Kodat själva. Om den är trögare än vad den var när de trimmade den så klarar den inte det, dvs om det är ökad friktion.

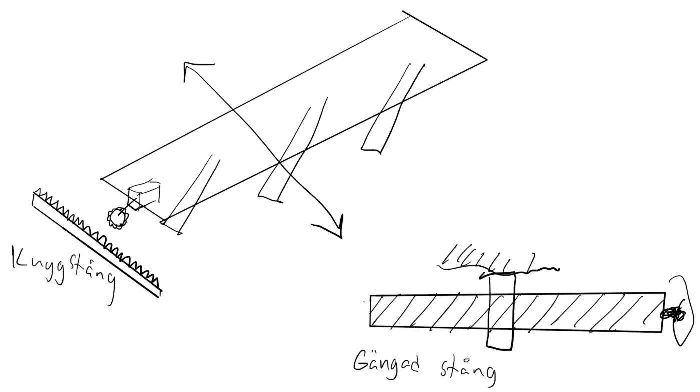
Vad är det som fungerar bäst med dagens lösning? Några fördelar?
Svar
- Har bara två motorer för att styra de två frihetsgraderna
  - Förenkling
  - Funkar ändå, har dratt effekt genom den
  - Har inte fullkomligt isolationstestat den med saltvatten
  - Är självbärande
    - Egentligen inget krav. Mer trevligt att hantera

Om du hade fått i uppdrag att designa den nya pick-upen, hur hade den fungerat?
Svar
- Försöker se det från first principles. Vill ha den så enkel så möjligt
  - Den absolut simplaste lösningen vore att ha en kopparkabel med en fläta längst ut och två trådar/remmar som släpper ner den och låter den släpas. Två remmar som styr både i sidled och y-led. Marionettdocka liknande
    - Ingen aning om trycket nedåt. Med en tillräckligt tung kabel, kanske egentyngden skapar ett tillräckligt stort tryck. Vet inte riktigt. Det beror

Figure 83. Notes from interviews.

på vilket material som används i slutändan. Olika material är olika strömförande och kräver olika tryck.

- Solid eller flexibel avtagararm, kombinera strömledning och struktur. Hellre få komponenter och material. Helst ska armen i sig vara strömledande för att slippa extra material och komponenter. Förenkla monteringen
- Minimera vikten man flyttar på för att minimera motorns kraft. Minimera kostnader . Framförallt det ledande materialet som avgör för det är det som har en märkbar tyngd.
- Minimera höjden, bok-fold out. Han har gjort en kartongprototyp. Stor vining vid personbil som är 14cm (?) hög. Kanske mer för den breda versionen, alltså den gamla versionen.
- Två tillstånd, snap lägen. Lite som en schampooflaska med två naturliga lägen. Bockad stål och två fjädrar borde lösa det. Kan eventuellt minska höjden.
- Nu används en stepmotor med en rem, Tror ev inte remmen kommer hålla i längden. En som jobbade mycket med grävmaskiner(?) sa att remmarna aldrig skulle hålla i längden, utan att tex en kedja behövs för att den ska hålla.
    - Vända motorn på den rörliga delen och fixa kuggar, förtydligat i bilden nedan
    - 3D skrivare, fix gängad stav, förtydligat i bilden nedan



- Vinner på enkelhet. Tog två månader med montering. Stor vining på att ha bra CAD så att alla placeringar av kablar, delar och skruvar är planerade.
- Fjäder placerad lite längre ner för att dra i rätt läge.
    - Finns några skisser på detta.

Saknas det någon feedback i systemet som hade förbättrat lösningen?
Svar

- Induktiv sensor som känner när man kör av. Kommer inte garanterat göra det bättre. Måste nästan vara i kombo med kameran.
- Annars, fäller ner och sveper över marken för att hitta. Inte lika bra känsla. Tvek, metall är rätt vanligt i marken. Typ spårvagnsräls.

Figure 84. Notes from interviews.

- Någon alternativ ljussensor för kameran, men är nog inte relevant för vårt projekt.

Vilka material hade du framför allt valt att konstruera pick-upen i?

Svar

- Fråga om hur stor batch
- Mest värdefullt att tänka en batch med 100-1000 → frästa. 3D skriva mindre saker. Väldigt attraktivt att vika eller pressa plåt.
- Prototypa, huvudsakliga syftet. Kolla så den funkar och att isolationen fungerar ok
- Behöver vara isolerad så inte bilen blir strömförande
    - Men kan vara bra att ha med storskaligheten i beaktning
    - Tänk inte på mängden under idégenereringen utan ta det i beaktning senare inpå.

Vad tror du blir den största utmaningen med att designea avtagaren?

Svar

- Få högspänningen från den rörliga till den fasta biten. Kablar kräver massa plats och behöver vara tillräckligt mjuka. Blir mycket böjradie.
    - Pratade med ZF sa att de hade böjradie på 20cm. Tvingat dagenslösning att ha en svängradie på 8 cm. Kommer vara svårt att hitta en bra lösning på att få ner svängradien mer.
- Vill ha kablar för att det är obruten kontakt och därmed en säkrare konstruktion. Har redan en avtagare mot skenan.
    - Men man skulle kanske kunna konstruera att den rörliga delen har en fläta mot den fasta, eller ett kopparblock eller kolblock. Kan glida mot och överföra ström. Lite som en pensel. Detta är alltså för att slippa klämma kabeln från armen.
- Hela axeln är rörlig, undvika en kabel.
- Det är inte jättebra att leda strömmen ut i sidan för det skapar en antenn vilket kan ha stora störningar. EMC. Desto större loopar man har desto större random spikar med radiovågor skickar man ut.
    - Kanske ha som ett lamelltak med isolation, plus, isolation, minus och isolation
    - Fråga andreas ang plus och minus bredvid varandra för att minska strålning

Allmänt:

- Tänk inte för mycket på begränsningarna i tillverkning nu. Sikta på framtiden för att få en bra CAD-modell att ta beslut ifrån
- Kika lite på 3D skrivare hur de fungerar.
- Bra om man skulle bygga en bit i plast, fräsa in spår för att dra sladdar. Detaljer som är viktiga.
- 10cm för att vara säkert mot saltvatten. Blocket längst ut måste vara 10. Från en strömförande detalj till nästa metall behöver det vara 10cm.
- Kontaktytan mellan flätan och skenan behöver vara Xmm3
- Det vore bra om pickupen är lite anpassningsbar så att den kan hantera om fordonet lutar aningen. Beroende på last

Fråga albin eller dan:

- Inte superenkelt att veta hur armen ska fjädras och hur den ska styras upp och ner. Rem som går på ett hjul och linjärmotor. Värt att kolla på oupp och nedfällning, slitage på axel.
- Fråga albin eller Dan ang friktionstal mellan fläta och mark

Figure 85. Notes from interviews.

Lägg till:
- Vad är din mest osannolika idé för att lösa det här
- Vad tror du inte skulle funka

Albin, mekanikingenjör:

Vilka är de viktigaste förändringsområdena/förbättringsområdena med dagens lösning?
Svar
- Sidorörelsen med remdriften är opålitlig och linjärlagrerna är jättedåliga.
- Lagrerna är inte bra, öppna kullager som går på en skena.
- Remdriften är svårinställd. Svår att få rätt balans av styvhet och lätthet för att manövrera den. Lite sned installation ger mycket friktion. Hamnar ur sitt läge och behöver behöver då kalibreras om.
    - Utförandet snarare än principen som är felkällan.
    - Principen att röra sig på en släde på ändarna är ganska bra.
    - Remdrifter är han inte helt säker på hur bra den är kanske med hjälp av ett bättre lager.
- Stor friktionen överallt.
    - Kablar
    - Upp och ner
    - Motorn måste jobba mycket hårdare
    - Desto mindre friktion, desto mindre motor, desto mindre höjd.
        - Sidoförflyttningsmotorn är det som är kritiskt till storlek idag.
- Den gamla lösningen kanske går att få att funka. Det är mycket spel i mekanismen då det är så många olika variabler vilket leder till en oprecis och svårkalibrerad.
    - Bättre med direkt överföring av kraft istället via flera steg som rem.
    - Kan jobbas på att ha uppfällningsmekansimen närmare, mer direktkopplad istället för bromskabeln.
- Kablarna överlag är opraktiska och funktionellt dragna.
    - Friktionen blir stor och motståndet tungt för motorn.

Vad är det som fungerar bäst med dagens lösning? Några fördelar?
Svar
- Tunnare än han förväntade sig.
- Har krävt mycket intrimning pga egentillverkad och byggd efter hand. CAD-ritning var ej helt färdig.
- På armarna är “hävstången” väldigt smooth och smidig, Alex har bild. Får ner höjden. Nära 90 gradig kraft där man trycker vilket ger en kort men effektiv hävarm.

Om du hade fått i uppdrag att designa den nya pick-upen, hur hade den fungerat?
Svar
- Satt motorn för vertikal manövrering individuellt med en per arm. Då sitter de på släden som flyttar sig. Med mindre individuella motorer kan man slippa t.ex. bromskabeln som är relativt grov och icke-böjlig i jämförelse med enbart tunna kablar för styrsignaler.

Figure 86. Notes from interviews.

- Linjärmotorer som jobbar mer med magnetfält istället för t.ex. gängad stång. Det blir som ett lager och motor i ett paket.
- Googla: https://linmot.com/products/linear-motors/
    - Svindyra
    - Snabba men inte så starka
- Vill ha så att den kan stå lite snett.
    - Kan då parkera lite snett för att minska kraven på precision från föraren. Inte lika viktigt på körande väg.
        - Styrda tillsammans, inte individuellt
        - Fristående blir nog bara mer komplext och dyrare. Om man inte kan underdim, mindre starka motorer

Saknas det någon feedback i systemet som hade förbättrat lösningen?

Svar

- Nope
- Allt som inte funkar beror snarare på montering eller konstruktion
- Möjligen positionering på var vagnen är i x-led
    - Vet inte om det spelar någon roll
    - Om kameran inte sitter på den rörande delen behövs den feedbacken
- En lägessensor på vardera sida i maxläget så den inte slår i kanterna och förstör mekanismen. Finns inte idag och om den tappar sitt läge så kan den slå i ändläget.

Vilka material hade du framför allt valt att konstruera pick-upen i?

Svar

- Produktion av 100-1000 stycken:
    - Inget rostfritt stål för det är dyrt
    - Extruderade aluminiumprofiler
    - Formpressad plast → mycket styrka per vikt
    - Inget behöver vara särskilt starkt.
        - Sprider ut lasten rätt bra med egendesignade bitar.
        - Den kommer ha så pass mycket höjd på avtagan av andra designproblem så styrkan bör finnas oavsett vad man än använder för material så länge det inte är skräp.
    - Önskvärt att minska höjden→ ett av de stora designkriterierna.
        - Speciellt för personbilar då det inte finns så mycket höjd under.
- Produktion av några få prototyper:
    - Aluminium, färdigextrauderade. Bort från rostfritt stål. Dyrt och tungt samt svårarbetat.
    - Ingen formsprutning om inte kvantiteten ökar någorlunda.
        - Säg 50:
            - Armarna kanske skulle kunna vara formsprutade ty 6 st (6*50 = 300 delar)
    - Ta bort så mycket fräsoperationer som möjligt. Blir dyrt och är tidskrävande. 1-10 fortfarande värt det.

Vad tror du blir den största utmaningen med att designea avtagaren?

Svar

- Sidorörelsen
    - Ett sätt som gör att det är lätt och exakt att flytta den fram och tillbaka.
    - Tunnt nog. Tar plats i höjdled.

Figure 87. Notes from interviews.

  - Att precisionen är nog: en tiondel i positionering.
  - Någon slags tillverkningsjig kan va bra, svårt när man bygger själv att få precisa mått. Investera lite pengar i en monteringsjig kan också vara värt.
  - Rätt lång rörelse, måste vara väldigt exakt tillverkad/toleranser för annars blir det väldigt mycket slitage om t.ex. linjära rörelserna drar snett.
- Upp och nedfällning som inte tar upp för mycket plats men som inte har några drawbacks.
  - Får välja vad som är viktigast

Mest osannolika idé:
- Att allt ska röra sig med bara fästpunkter i bilen.
  - Kan då slimma allt väldigt mycket, ingen ram?
  - Om man har en lagrad stång som är axel för armarna och axel för fram och tillbaka. Någon liten vagga som kan köra upp och ner tre eller sex stänger som är strukturen
  - Vill verkligen få bort så mycket onödigt som möjligt

Vad hade inte fungerat:
- Svårt med dagens kraftöverföring med remmar, stång, skruv, kedjor. Svårt att få till bra sätt som är robust.
  - Man behöver ha minimala toleranser
  - Det är en smutsig miljö —> slitage.
  - Slitage, kanske kan vara kedjor isåfall.

Friktion:
Trycket på skenan beror på:
- 20-40 N per släpsko
  - Upp mot 100N i stillastående
  - Om vi kan öka så hjälper det vissa funktioner som laddning men ökar friktionen
- Om man har nått sätt att mäta trycket mot marken hade detta varit bra.
  - Trådtöjningsgivare är en lösning.
- Mäter positionen på fjädern så borde man kunna mäta trycker
- Modulera trycket jämfört med hastigheten, pga värme
- Någon slags feedback

Stöttålighet:
- Måste vara lite flexibel, svårt att ha något som fäller sig och positionerar sig på en exakt punkt.
  - Ska kunna fälla upp sig om den kör på något.
  - Kommer vara vibrationer, bra om det är tåligt.
  - Flätan måste kunna lägga sig platt.
  - Kontaktytan bör vara flexibel för att den ska kunna vara lite formbar mot skenan.
- Koppar: tio gånger så högt tryck. Slits väldigt mycket då.
  - Kontaktytan är det som slits mest.
- Snabbfäste för släpskon så att den är lätt utbytbar.
  - Typ med en skruv
  - Kommer vara service

Figure 88. Notes from interviews.

        - Lätt för sig vore bra

Krav:
- Mer robusthet
- Så tunn som möjligt

Önskvärt:
- Rör sig med mjukhet

Hur snabbt rör den sig idag:
- Dan var inte nöjd, använde en trapetsskruv. Inte snabb nog. Utväxling kanske kan användas.
- Snabb nog nu.
    - Direktkopplad, går att räkna ut maxhastigheten.
    - Den har 20 tänder på sina hjul till remmarna.

CAD-fil

Andreas, CTO:

Vilka är de viktigaste förändringsområdena/förbättringsområdena med dagens lösning?

Svar
- Vill inte ha en med så stora komponenter
- Dyrare men smidigare
    - Linjärmotor, permanent, stav med plus minus, spole i motorn, kullager
    - Snabb
    - Har ett minne till nästa gång
- Nackdel idag
    - Friktion
    - Stor konstruktion
    - Trög
    - Dagens kuggar över om den är för snabb
        - Den är programmerad för ett visst motstånd men om motståndet senare är större än tänkt pga ökad friktion kuggar den över och tappar bort sig.
            - En felkälla är om monteringen inte är tillräckligt exakt utan att vissa delar hamnar lite snett.
    - Vet inte positionen, tappar bort sig. Måste nollas
        - Nollpunkten sitter i ytterkanten, induktiv givare
            - Pga måste kunna dra slutsats, är den till höger eller vänster
    - Petters linjärmotor,
        - Hastighets reglerad, massa andra regleringar. Kan hitta nollan
        - Ha encoder inuti, störningarna så smarta. Magnetfältet konstigt, stannar
    - Linjärmotor
    - Hinder: trögt, lätt

Figure 89. Notes from interviews.

- Accelerometer → x, y, z mäter tyngacc, känns av lutningen. Känna av vibrationer så att man vet om något är skumt, felaktikt.
    - Har man lutningen, så har man friktionen —> styra (position, hastighet och moment), Den ena är momentstyrd, 2kg tryck mot marken, räknar om. Ska man trycka mer eller midnre. Den andra styr positionen
  - Infällt läge:
    - Magnet eller nått som gör att den är fastlås så att man slipper ha motorn igång.
    - En fjäder som sitter så att de alltid trycks ifrån varandra. SÅ att om strömmen skulle gå fälls den upp
  - Samma problematik som på pickupen idag, få bort strömmen:
    - En fläta som ligger i armen och kopplas ner till avtagarskon
    - viks av och går upp på sidan med en kabel motsvarande den idag.
    - Kanske kan dra strömmen i kablarna om man har borst, svetsar lätt?
    - Kanske starkare med två motorer, går bättre?
  - Motorerna är 4cm, kanske blir en tjockare lösning
    - Mer höjden som är problematisk, inte bredden
  - Framtiden, kanske skåra i bilen, batteriet eller liknande
- Några cm i marginal, -+-, inget exakt krav
- 1115 (CC mått) mellan isolations mitt till nästa isolations mitt. Isolation är ca 150
- Om man inte har 100% kontakt med flätan, kan verkligen bygga svetsloppor. Blir bara värre och värre. Borde testa ut
  - Konkurenter har block → tex Ahlstrom
  - Flexar lite i sidled
- Olika dimensioner beroende på personbil och lastbil. Behöver inte bli dubbelt så låmg utan kan sätta de lite tätare. Begränsningen är hur tätt de kan sättas utan att slå i varamdra
- Om man ska dubbla effekten, behöver man nå två plus och två minus (?)
- Kan idag ta 150kW
- Bussen idag 5cm
- Personbil 2-3cm

Vad är det som fungerar bäst med dagens lösning? Några fördelar?
svar
Om du hade fått i uppdrag att designa den nya pick-upen, hur hade den fungerat?
svar
Saknas det någon feedback i systemet som hade förbättrat lösningen?
Svar
- Från dagens nya:
  - Feedback var man är någonstans
  - Kameran löser det hyfsat, men om den kuggar över kaos
  - Positionsfeedback
- Linjärmotorn har en pulsgivare så man kan beräkna hur långt den har rört sig. Men om det skulle vara en default vet man inte
- DC kan mäta strömmen, om den drar för mycket stängs den av
- Temp är viktigaste, inte överladdar. Så inte bara en mm nuddar. Plastarmarna börjar smälta

Vilka material hade du framför allt valt att konstruera pick-upen i?
Svar

Figure 90. Notes from interviews.

100-1000

- Metall måste rören vara, motorn aluminium
- Armarna plast eller glasfiber. Måste vara isolerande
- Plåten är inte jättebra, så lite som möjligt som är spänningssatt. Får krypavstånd så litet som möjligt. 10-20cm som man behöver ha. Har inte det idag.
- Svårt att isolera i framtiden. Vill komma ifrån
- Batteriet är isolerat i glasfiber

Vad tror du blir den största utmaningen med att designea avtagaren?

Svar

- Få den att röra sig smidigt
- Tillräckligt isolerad. KRYPAVSTÅND
- Utveckla avtagarskorna (kolblandning, eller koppar, svetsar inte men nackdelen är att de lägger ut en beläggning som kan bli ledande över isolationsdelen, slits ganska fort, byts ca var tredje dga på bussar)
    - SLita på klossen och inte vägen

Fråga andreas ang plus och minus bredvid varandra för att minska strålning

Svar

- Inga loopantenner
    - Minimera hålet ovanpå
    - Bunta ihop

- Blanda aldrig kraftledningar med dataledningar. Olika sidor
- Skärma datorledarna
- Spikar ger DIT spikar → väldiga radiostörningar och påverkar kablarna
- CADa alltid in kablarna, rör sig

Mest osannolika:

- Kanske den han visade, pga att den är dyr
- Material som böjer sig elektrisk nr msn värmer dem
- Gör en robotarm
- Festo
- Luftblåsa

Vad hade inte fungerat:

- Allt funkar
- Långa loppet:
    - Kontaktmaterialet kommer slitas för mkt
    - Något som ser till att den inte kan svetsa metall mot metall

Friktionstal mellan släpsko och vägen: inte mätt
Hållfasthet: inte där , sten eller metallföremål. Armen får gå sönder men inte lossna!!
Tryckkraft: beror på material men 1-1.5 kg. Upp till tre kilo. Lastbil kan man tillåta mer. Vill inte slösa friktion för personbil. Kan varieras utifrån omgivningen. Är det blött och halt behöver man kanske trycka hårdare.

Feedback: Reglerar på temperaturen för det är det som säger hur bra ledningsförmnåga du har. Tillåter 30 grader→ viss kraft. Tryckkänning genom temp, till exempel

Figure 91. Notes from interviews.

Dan, grundare:

Vilka är de viktigaste förändringsområdena/förbättringsområdena med dagens lösning?
svar

Vad är det som fungerar bäst med dagens lösning? Några fördelar?
Svar
- För lite data för att säga nått

Om du hade fått i uppdrag att designa den nya pick-upen, hur hade den fungerat?
Svar
- Mer slimmad och mindre material
- Vill utveckla för personbilar och då:
    - 2 cm höjd eller till och med enbart 15 mm höjd
    - Eventuellt minsta borsten lite för att ha vingelmån på borst
- Den idag är utvecklad för en lastbil
- Ska kolla hur acc rör sig över skenan. Filmar med en gopro
    - Vill samarbeta med den autonoma styrningen på personbilar. Då kanske bilen bara vinglar 10cm iställer för de 450mm som den är byggd för idag.
    - Om man utvecklar ett koncept för en personbil är det betydligt mer komplext än för en lastbil, så det går alltid att skala upp.
- Lastbil:
    - Släpskon behöver utvecklas. Har inte riktigt haft tid med det.
    - För trög sidoteknik
        - Kablarna som tar emot
        - Har byggt en mer lättböjlig. Andra mtotorer som flyttar den i sidled, kollar istället på en utsträckt rotor. Inga remmar och tjafs

Saknas det någon feedback i systemet som hade förbättrat lösningen?
Svar
- Temperatursensorn är bra
- Accelerometer skulle vara bra att implementera för att hjälpa till med hur man styr ratten
- En metod kan vara en induktiv sensor för att känna av skenan.
- Vet ej vilken än så länge

Vilka material hade du framför allt valt att konstruera pick-upen i?
Svar
- Vet ej
    - Vill överlämna till kunniga

Vad tror du blir den största utmaningen med att designea avtagaren?
Svar
- Släpsko material
    - Se gnoistor och sprak
    - Grus
    - Filmat mycket i slowmotion på gamla vägen

Figure 92. Notes from interviews.

        - Går att lösa bra men släpskon får då kort livslängd.
        - Bäst resultat med mjuk borstliknande sko, slits dock snabbare
    - Kameran behöver testas under många fler förhållanden för att testa pålitlighet.

Mest osannolika lösning:

- Ingen sidostyrning alls.
- Utveckla egen självkörning.
    - Om bilen rör sig efter skenan behövs ingen komplicerad konstruktion.

Petter, konsult:

Vilka är de viktigaste förändringsområdena/förbättringsområdena med dagens lösning?

svar

- Upphissningen har en bromskabel, skapar mycket friction, blir trög
    - Drar inte upp släpskorna, försöker fixa detta genom linjärmotorer
- Problem med glidlagerna fram och bak på vagnen
    - Extrema förhållanden för lagerna med smuts, blöta, sand ,salt
    - Ganska stor belastning. Kommer fallera.
- Skapade metallkullager istället, tanken var att smutsen skulle ramla av.
    - I efterhand, bättre med plastbussningar
    - Kombinerat nya linjärmotorer med plastbussningar
    - Vanligt med plastbussningar inom gruvindustri och jordbruk
- Lite för tjock

Vad är det som fungerar bäst med dagens lösning? Några fördelar?

Svar

- Har ganska kompakt lösning
    - Fjädrad i ena riktningen men statisk i andra - önskvärt

Om du hade fått i uppdrag att designa den nya pick-upen, hur hade den fungerat?

Svar

- Läs under osannolika idé samt förbättring

Saknas det någon feedback i systemet som hade förbättrat lösningen?

Svar

- Prototyp
    - Accelerometer på armarna
        - Hittepå med dagens siffror, vet inte krafter idag egentligen
    - Många krafter, vet ej långsiktiga dynamiska effekter

- Storskaligt/ Produktion
    - Temperatur
    - När de är helt uppfällda
    - Eventuellt änd-sensorer

Figure 93. Notes from interviews.

Vilka material hade du framför allt valt att konstruera pick-upen i?
Svar
- Storskalig produktion
    - Ramen i plast på valda ställen
        - Där det behövs fästpunkter kanske metall
        - Hela vikten av vagnen ligger vid lagrerna
        - Om något slår i pga hinder på vägen så är metall bra

Vad tror du blir den största utmaningen med att designea avtagaren?
Svar
- Miljöförhållandena
    - Under en bil är inget roligt förhållande
- Upphissningsanordningen
    - Kompakt konstruktion med tillräckligt kraftig hävarm

Vad är din mest osannolika idé för att lösa det här:
Svar
- Nya versionen dras kablarna i sidled istället
    - Stela armar på sidan det enda som håller uppe vagnen
    - Platta steppermotorer
- Storskaligt
    - Extrudera hela vagnen i mitten
    - Fräsa ur och optimera
    - Grova beräkningar —> får bort flera kilo
- Bocka hela vagnpaketet
    - Försänkningar för styvhet
- Stora utmaningen i linjärstyrningen i sidled
    - När det är löst så kan andra designparametrar börja finslipas
- Formspruta i plast

Vad tror du inte skulle funka:
Svar
- För alla linjärstyrnings-system
    - Metall mot metall kommer aldrig funka på lagrena
    - Plastmaterial är the way to go
    - Färre rörliga delar

Tillägg:
- Lagret
- Linjärmotorstyrning
- Remdrift (rörlig del) bli av med i nya konstruktionen
- Nya stängerna kanske för klena? Återstår att se
- Upphissningen är svår
    - Motorerna för det
- Kabeldragning
    - Kablar vill inte röra på sig

Figure 94. Notes from interviews.

- Flätor där de rör sig
- Vill inte ha saker som släpar mot varandra
- Topplasten har en förmåga att bukta och trycka ner mot kablar
    - Teflonpuckar för att underlätta friktion
- Skapa inga antenner
- Kolla dragspelsbussar och dess kablar
- Kolla mellan tågvagnar för att kolla kablars böjningsradier med kraftiga kablar
    - Upp till 250 ampere
    - Kablarna idag ca 1,5cm^2 kanske på den svaga + gummihölje
- Kan dra flera små istället

- Något storskaligt bra är vajerlösning (som den breda)
- Kolla på skivbromshävarm
    - Kort hävarm med mycket kraft

- Krux med linjärmotorerna, de som är valda idag är inte vattentäta
    - Tål skvätt men inte vattentäta
- Täta hela boxen vore bra
    - Svårt dock

Figure 95. Notes from interviews.

Appendix D – Concepts

All the concepts generated during the master thesis are presented in this Appendix.

D.1 Broad concept generation

At an early stage of the concept generation numerous concepts were created. These are not discussed in detail in this report. However, they are all shown in this Appendix in Figure 96 through Figure 111.

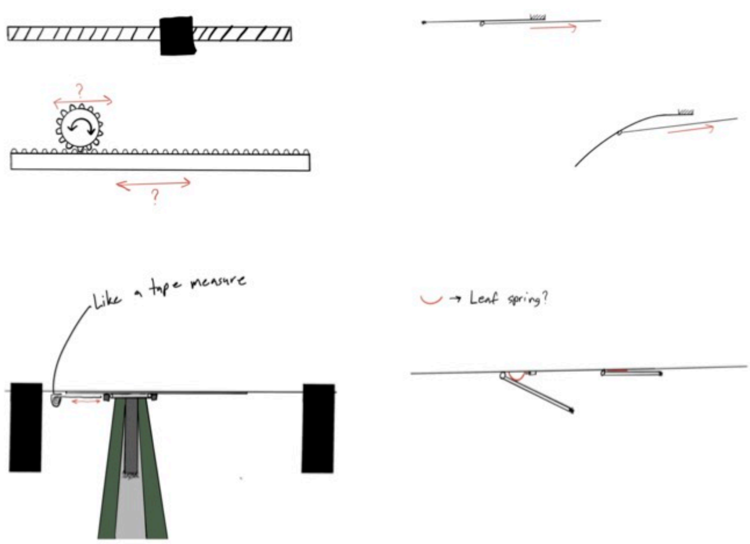


Figure 96. Broad concept generation.

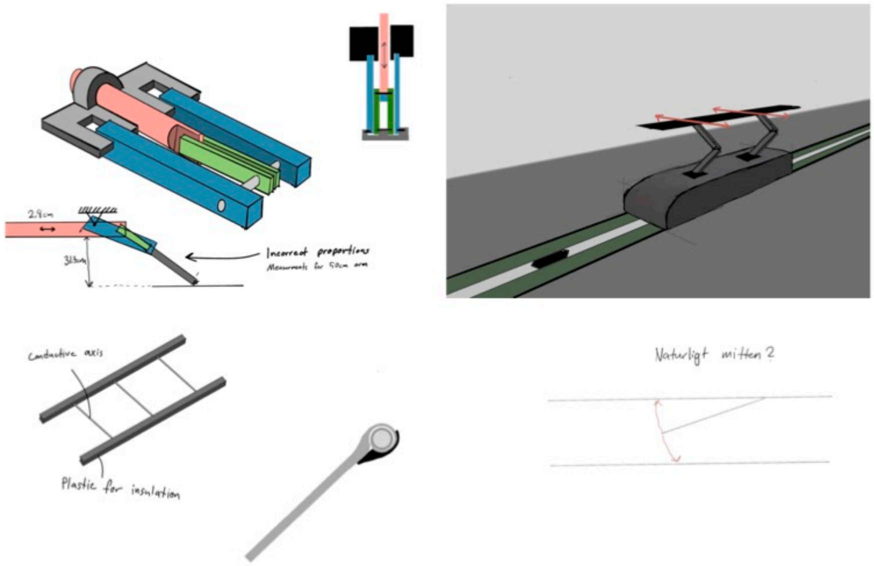


Figure 97. Broad concept generation.

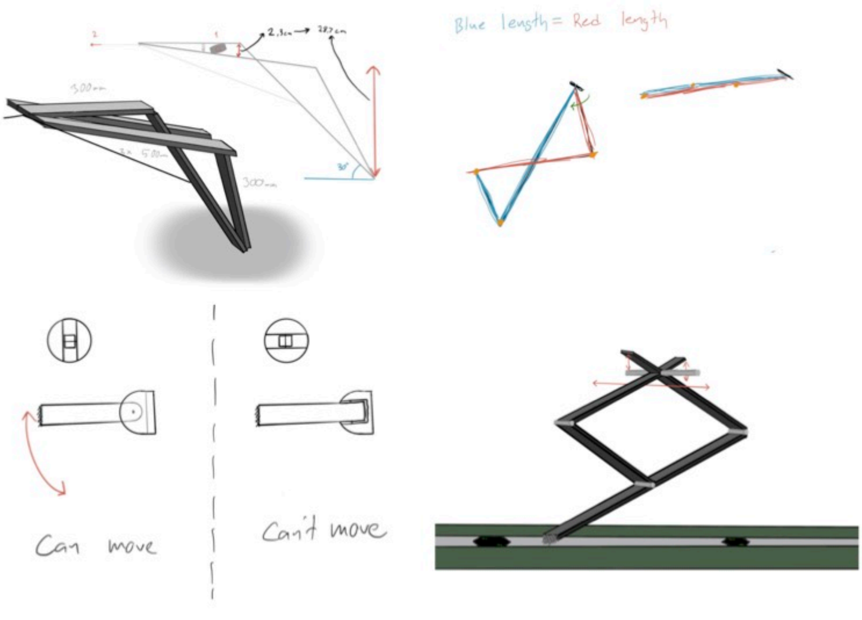


Figure 98. Broad concept generation.

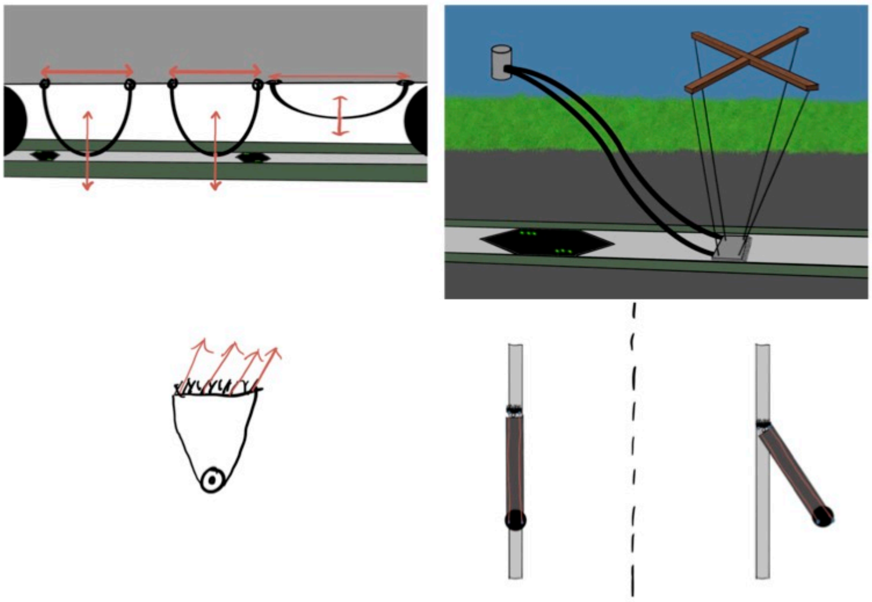


Figure 99. Broad concept generation.

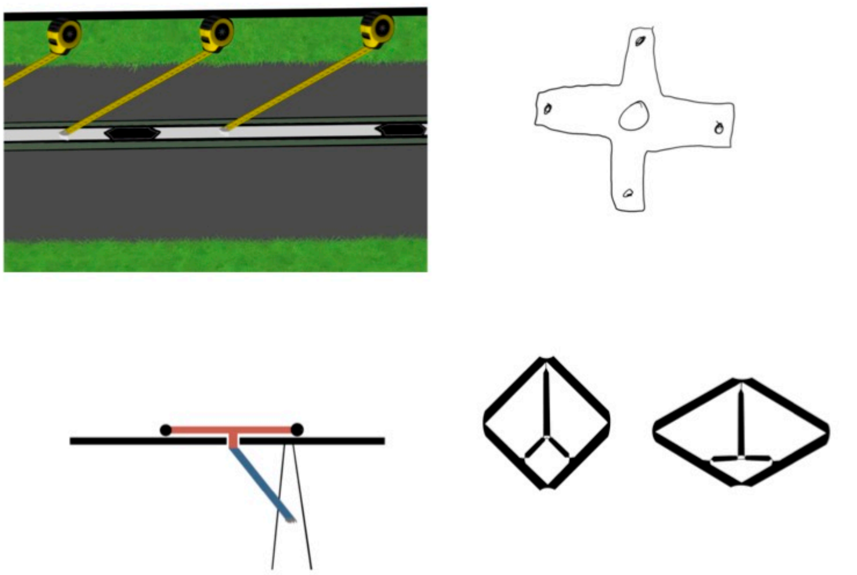


Figure 100. Broad concept generation.

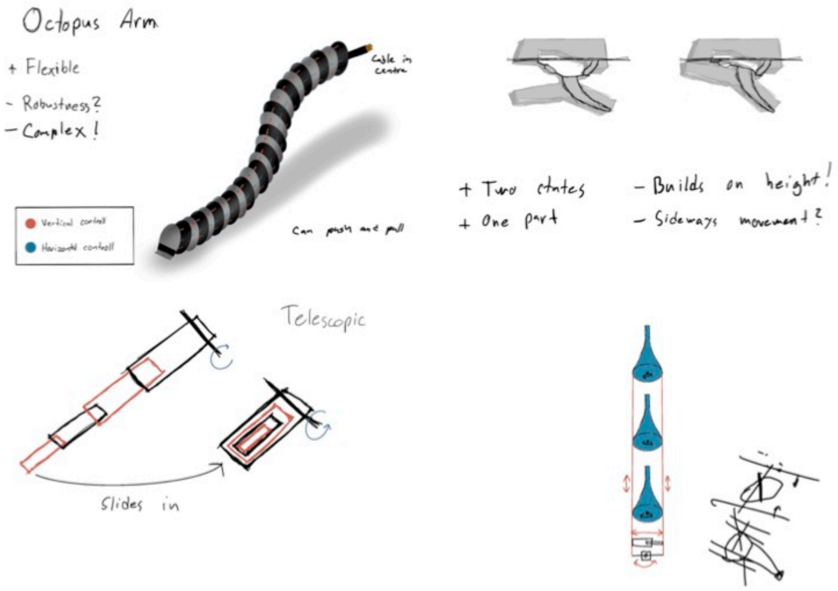


Figure 101. Broad concept generation.

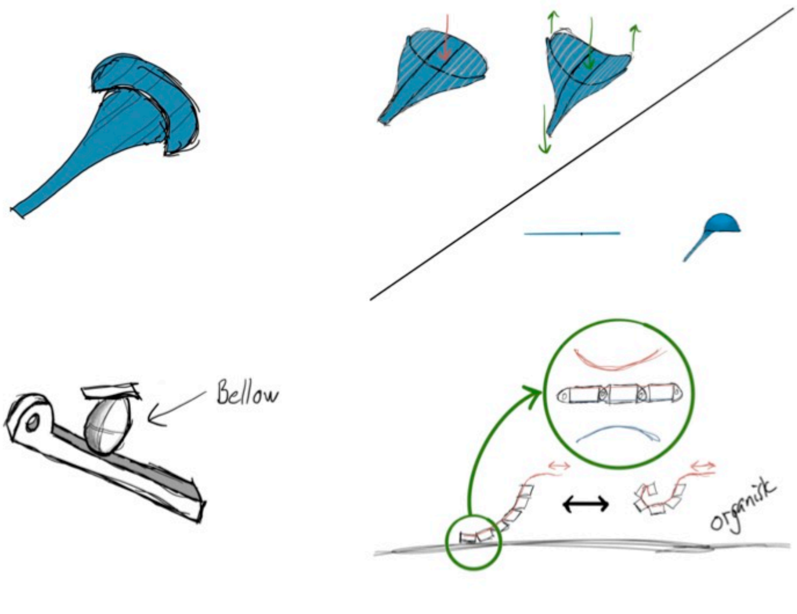


Figure 102. Broad concept generation.

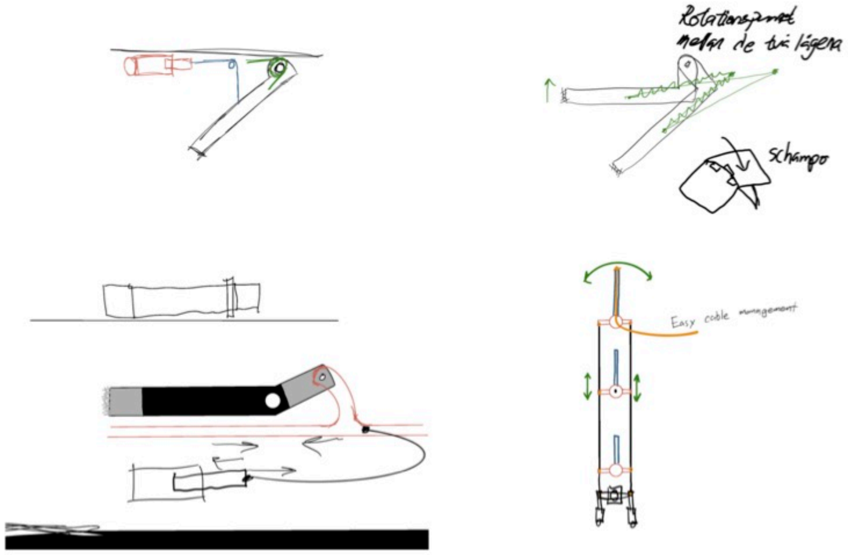


Figure 103. Broad concept generation.

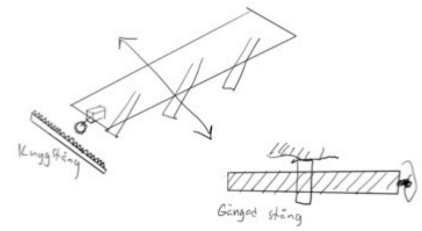


Figure 104. Broad concept generation.

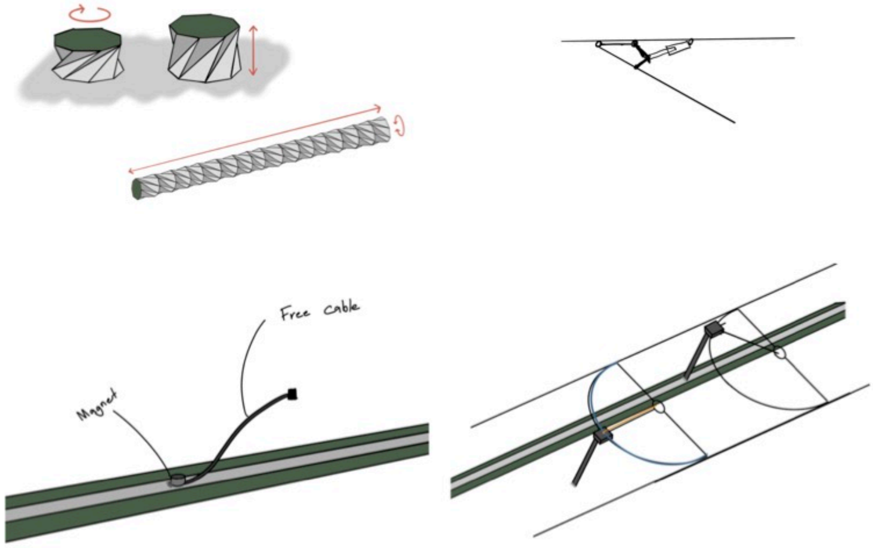


Figure 105. Broad concept generation.

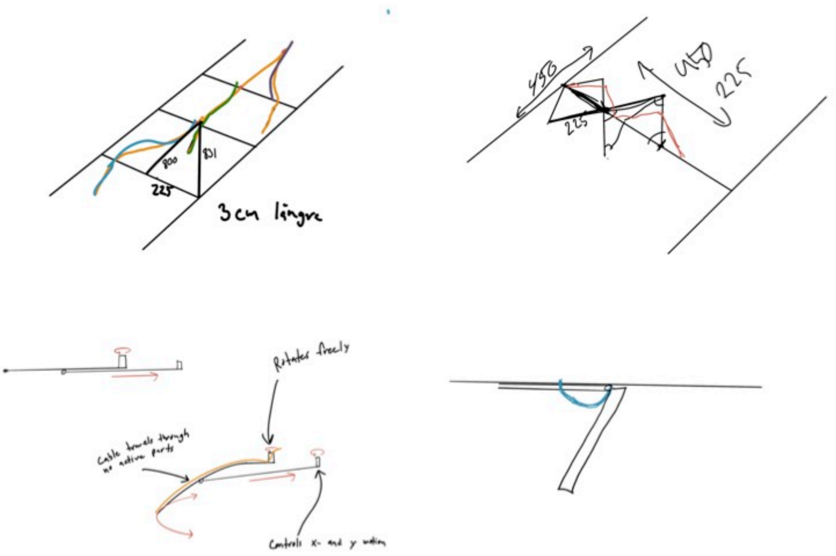


Figure 106. Broad concept generation.

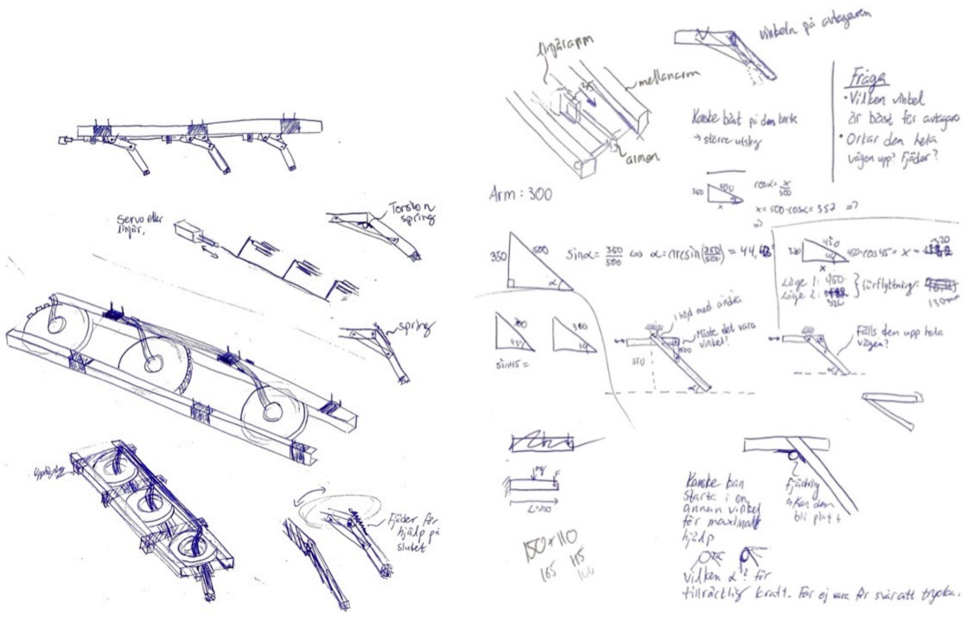


Figure 107. Broad concept generation.

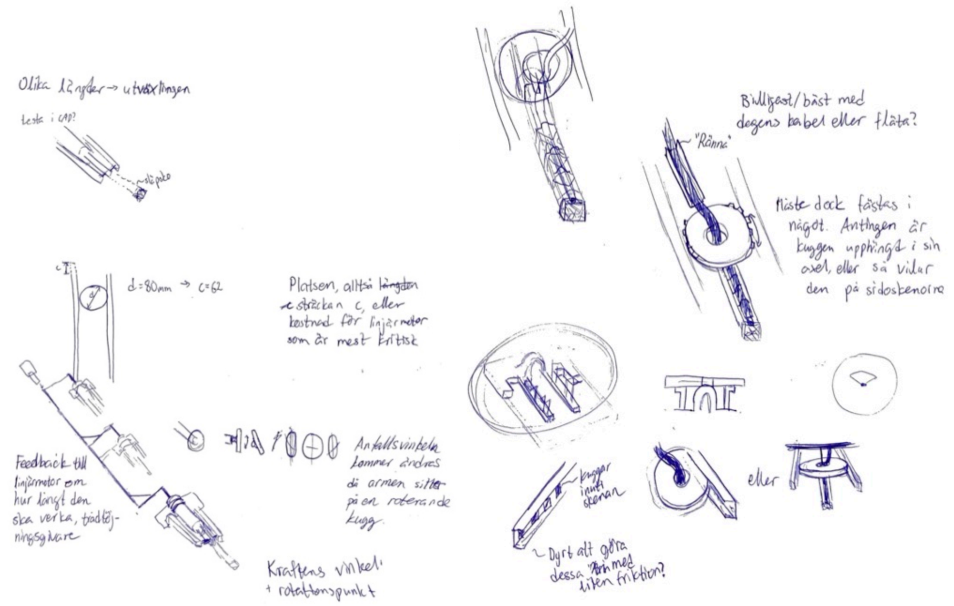


Figure 108. Broad concept generation.

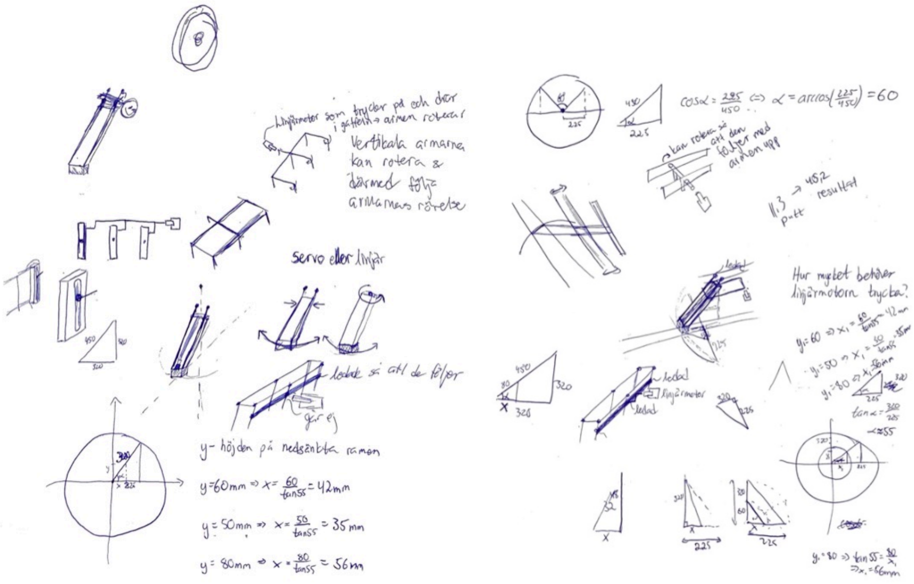


Figure 109. Broad concept generation.

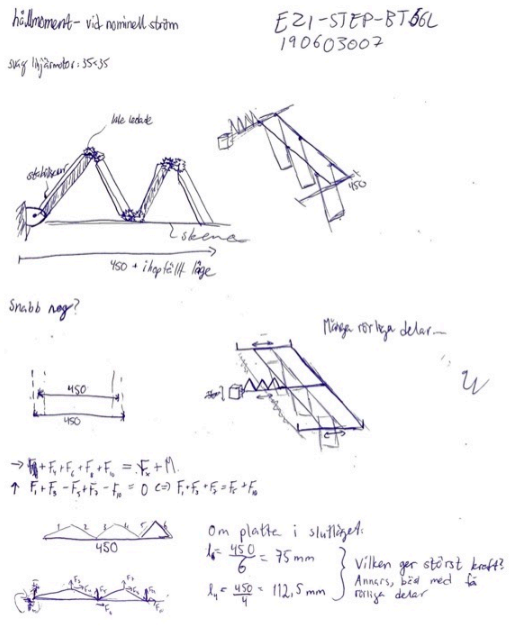


Figure 110. Broad concept generation.

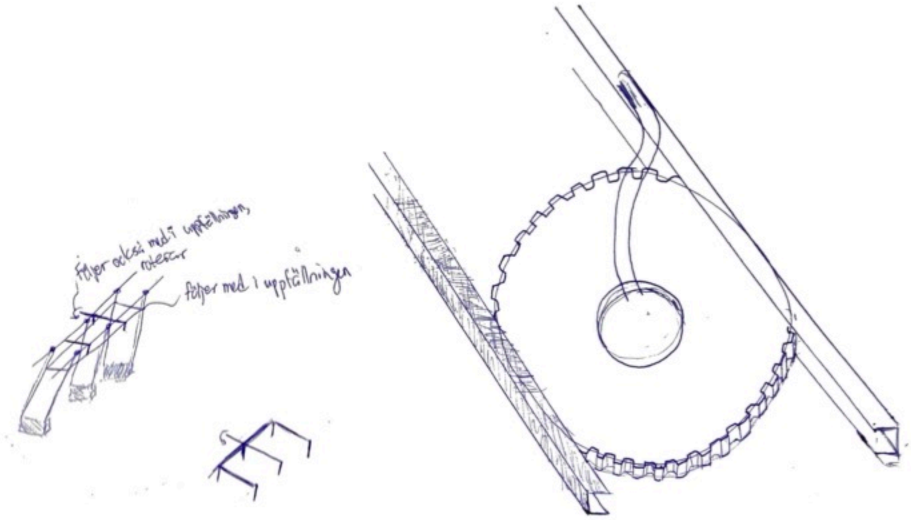


Figure 111. Broad concept generation.

Appendix E – External Interviews

The external interviews that were conducted with several experts are shown in this chapter.

E.1 Katarina Elner-Haglund

An external interview with Katarina Elner-Haglund who has a Master of Science in Chemical Engineering, with specialization polymers, was conducted in order to gain knowledge about which plastic to use. The material choice for the prototype and for the final product differ. For this master thesis there will only be recommendations for the future product since the project will end in a prototype. The notes taken during the interview can be seen in Figure 112.

Vilken plast behövs för prototypen?
- Avtagararm + monteringskugghjul
    - 27N
    - Isolerande
    - Små krafter

Konstruktionen behöver egentligen bara klara av tester i verkstaden, och inte på bil.
- Utomhus
    - Med dess temperaturer
- Under bil
- Salt
- Regn
- Bensin
- Olja
- Spolarvätska
- Smuts
- Grus
- Damm
- Vind
- Kommer få lite värme från flätan

Nylon som används i pulver-printern i skolan är utmärkt för dessa förhållandena.

Bussningar:
- Vilken typ av plast?
- Printa?
    - Tycke och smak
    - Vi sätter förutsättningarna.
    - Skriva om det: i vårt case är det så här. Skiljer sig på det här sättet. En potentiell felkälla, skriv det

Hur är plasten i pulverprintern?
- Nylon, polyamidpulver. Passar alldeles utmärlt för det här. I skarpt läge längre fram, med elsituationen, kan kse man kan behöva glasfibertillsats för att göra dne nötningstålig ohc robustare. Plasten är insultor. Glasfiber kan dock påverka → spännande omrpde att titta vidare på.
- Homogen och bra prodult
- JKan testas funktionellt väldigt låmgt.
    - Pulvret är ingen vabnlig polyamid. Man vet inte riktigt. Man har modifierat kulorna. Kan inte använd apulver igen om det har vlivit värmeskadat
    -

PLA vid 3D printning? Hållbart nog?
- Sprött

- Inte noggrant
- Inte så bra

Formspruta sen → högglansyta. Utmaningen nu är relaterad till prototypkvaliten. Nu kan man ta ett sandpapper för att efterlikna framtida kvalitet. Printar en halv millimeter för mycket och efter bearbetar med fräsning.

Fördelar med plast:
Lätt
Komplexa former
Hälften så dyr

Framtiden: som ska hålla temperaturintervallen
- Måste definiera en omgivningstemperatur
    - -30 till 40 grader (i skuggan)
    - Ta höjd för kopparens temperaturbeteende
    - Antingen en högpresterande plast, dyrare
        - Eller en konstruktionsbaserad lösning

Polyeten under tågen för snöskydd
Kolla vad som används under bilar , titta på olika typer av fordon. Lastvagnar (högre krav), tåg och bilar

Tips: reservera oss så fort det finns skillnader mot framtidens lösning. Motivera vad produkten ska klara, livslängd, nötning issue, etc

Figure 112. Interview with K. Elner-Haglund.

E.2 Rikard Hjelm

An external meeting with Rikard Hjelm, who is a lecturer of Machine Elements at Lund University, was held. The notes taken during the meeting are shown in Figure 113.

Mått:
Liten kugg: 42mm (stora innerdiametern), 26mm (liten)
Stor kugg: Samma
Kan inte gå större än 42 och inte mindre än 26. Men kan röra oss däremellan

Höjd:
Stora: 8mm → kan gå upp till 10mm
Lilla: 15mm → upp till 20mm

Vikt totalt: 750g, armen i plast och kuggarna i aluminium + alla stänger. Motorn är inräknad.
TIllkomma för kabel, släpsko och ev dragmekanism

Förslag:
Cylindriska rullager
Kan man lösa det genom att ha två?

Krux:
Minimera höjd
Inte för dyrt

Spårkullager
S.272'
'Rotspänning
Hertz formel → aluminium
Kolla så att axelavstånet är ok map interferens och ingreppstal
Yttre faktorer påverkar mer

Sammanfattning:
- Det är såpass små krafter att det är väldigt förlåtande
- Vi kan designa perfekt men omgivningens vibrationer kommer ändå vara dominanta
- Spårkullager s.272 SKF.
    - Finns andra leverantörer, verkar vara standrardmått idag
- Spårkullager är lämpliga
    - Kan låta den bara glida i radialriktning men onödigt egentligen
- Smmanfattningsvis behöver vi inte räkna särskilt mycket på det då det rör sig om så små krafter och hastigheter
- Ingen idé att ha snedställda kuggar då ljud inte kommer vara problematiskt för oss. Han trodde inte att den ökade friktionsytan var nödvändig.

https://www.skf.com/binaries/pub19/Images/0901d1968096b7e7-Rolling-bearings---17000_1-SV_tcm_19-121486.pdf

Figure 113. Notes from meeting with Rikard Hjelm.

E.3 Magnus Ullman

Notes from an external meeting with Magnus Ullman, who works as Erteco Rubber & Plastics AB. The notes taken are shown in Figure 114.

- Plastval i olika delar
    - Miljö:
        - Under fordon, han känner nog till
            - Snö, salt
            - Stort spann temp (vinter/sommar)
            - Blåst
            - Grus, damm, smuts
        - 27N
        - Strömförande kopparfläta
            - Värmeutveckling: kan vara 50-60°C
        - Flexibel plast för stötdämpning?

    - Delar
        - Arm
        - Mittenkuggdel
        - Banan
        - Kuggstång
        - Sidoarmar
        - Låsmekanismen för lagret

Material
Bör ha intervallet: -35 —> +80 grader (vanliga automotive kraven)
Bör vara ett slagkraftigt material, pga stenar och andra hinder på skenan.

Kuggstång och kugghjul måste vara olika material, de kan “äta upp” varandra annars. Det man kan göra är att man blandar i något i den ena delen, ett “smörjmedel” för att de inte ska äta upp varandra.
Brukar vara POM, aldrig med GF

POM 60-70 MPa

Olika polyamider
en smörjd en icke-smörjd (för att undvika uppätning)

Lila kuggen - ICKE POM
- Måste ha fiberförstärkt, samma material som armen.

Kuggstång i annat material
- Något riktigt
- Aramidfibrer (kevlar)

Polyamid 12, hög GF
kanske metall
Girlamid LVX-65H SST (skulle kunna användas till alla)

- använd en med smörjmedel och en utan till kuggar
- Med riktigt höga spänningar får man addera något special-compound
- Tror den tål hinder rätt så bra.
- Konstruktionen behöver hantera hinder, inte deformationer i materialet

Plattorna i vägen (Grilon BG-50)

-

Rädd att vi komer få slag, kan vara flaskhalsen för konstruktionen

Grivory GVN-5H black 9915 är ett bra alternqtiv för amrnen då den har väldigt konstanta egenskaper. Bra kemikalier resistans. Rör sig inte så mycket, speciellt inte utmed fibrerna. Tål höga konstanta spänningar. Bra med fläta, men påverkas inte med annat.

Ett annat alternativ, Grivory GV-6H EF black 9915. Testa denna först, mer standard. Billigare och mer standard. De har den i dragprobellrar och i block i segelbåtar. Har hållit i tio år. Data sheet, finns mer spec.

Figure 114. Notes from external meeting with Magnus Ullman.

Appendix F - Prototype tests

The results from the eleven mechanical specifications tests are shown in this Appendix, in Figure 115 through Figure 125.

F.1 Achieves 450 mm

Test 1			
	Specification	**Iteration 1**	**Iteration 2**
Achieves 450mm horisontally	Ieration 1: PVM-signal 60-105 Iteration 2: PVM 150(-50)-620(-50)	Yes	Yes

Figure 115. Test results for test 1.

F.2 Speed outer edges

Test 2			
	Specification	**Iteration 1 (s)**	**Iteration 2 (s)**
Speed outer edges horisotnally	average 6 measures	7.655	6.883

Figure 116. Test results for test 2.

F.3 Speed 200 mm

Test 3			
	Specification	**Iteration 1 (s)**	**Iteration 2 (s)**
Speed 200mm inner range horisontally	average 6 measures	4.422	3.287

Figure 117. Test results for test 3.

F.4 Precision horizontally

Test 4					
	Specification	Iteration 1 (mm)		Iteration 2 (mm)	
		In	Out	In	Out
Precision horisontally	Average distance from original measure. original +3	1.983	3.867	1.667	0.413
	Total average		2.925		1.04

Figure 118. Test results for test 4.

F.5 Achieves 320 mm

Test 9			
	Specification	Iteration 1	Iteration 2
Number of parts		149	150

Figure 119. Test results for test 5.

F.6 Speed folding up

Test 6			
	Specification	Iteration 1 (s)	Iteration 2 (s)
Speed folding up vertically	Average 3 measures	5.163	5.517

Figure 120. Test results for test 6.

F.7 Speed folding down

Test 7			
	Specification	Iteration 1 (s)	Iteration 2 (s)
Speed folding down vertically	Average 3 measures	Fail	4.903

Figure 121. Test results for test 7.

F.8 Distance lower edge

Test 8			
	Specification	Iteration 1 (mm)	Iteration 2 (mm)
Distance lower edge frame to the upper edge arm		67.9	47

Figure 122. Test results for test 8.

F.9 Number of parts

Test 9			
	Specification	Iteration 1	Iteration 2
Number of parts		149	150

Figure 123. Test results for test 9.

F.10 Assembling time

Test 10			
	Specification	Iteration 1 (min)	Iteration 2 (min)
Assembling time		31.33	37.55

Figure 124. Test results for test 10.

F.11 Force on rail

Test 11			
	Specification	Iteration 1 (N)	Iteration 2 (N)
Force downwards		Fail	5.06

Figure 125. Test results for test 11.

Appendix G Heat test details

In this Appendix more pictures of the results from the heat tests are presented.

G.1 Both braids

The stainless-steel braid is the warmest part of the sliding contact collector, which is shown in Figure 126. 78.5°C when conducting 143A, stainless steel.

Figure 126. 78.5°C when conducting 143A, stainless steel.

The nylon, which is the majority of the arm did not become warmer than 17.6°C, as shown in Figure 127. 17.6°C is roughly the room temperature where the test was conducted.

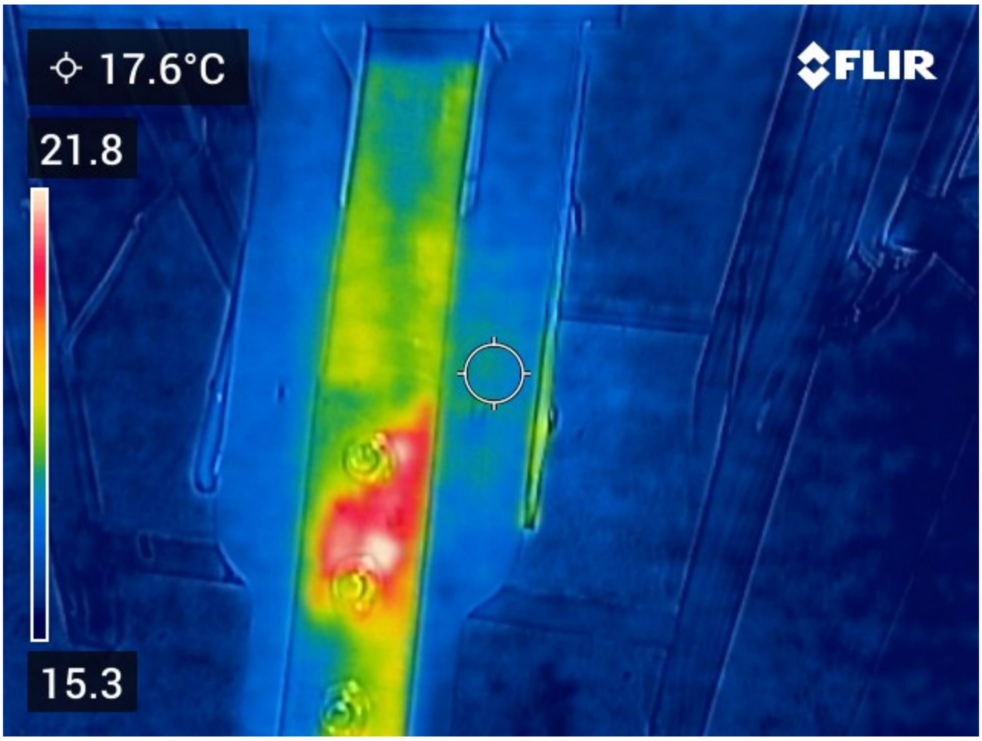


Figure 127. Nylon's temperature.

G.2 Separate

Tests were also made when separating the two braids. Figure 128 shows the temperature of the copper braid and Figure 129 the temperature of the stainless-steel braid. This clearly shown that the steel becomes a lot warmer than the copper.

Figure 128. 28.7°C when conducting 143A, copper braid.

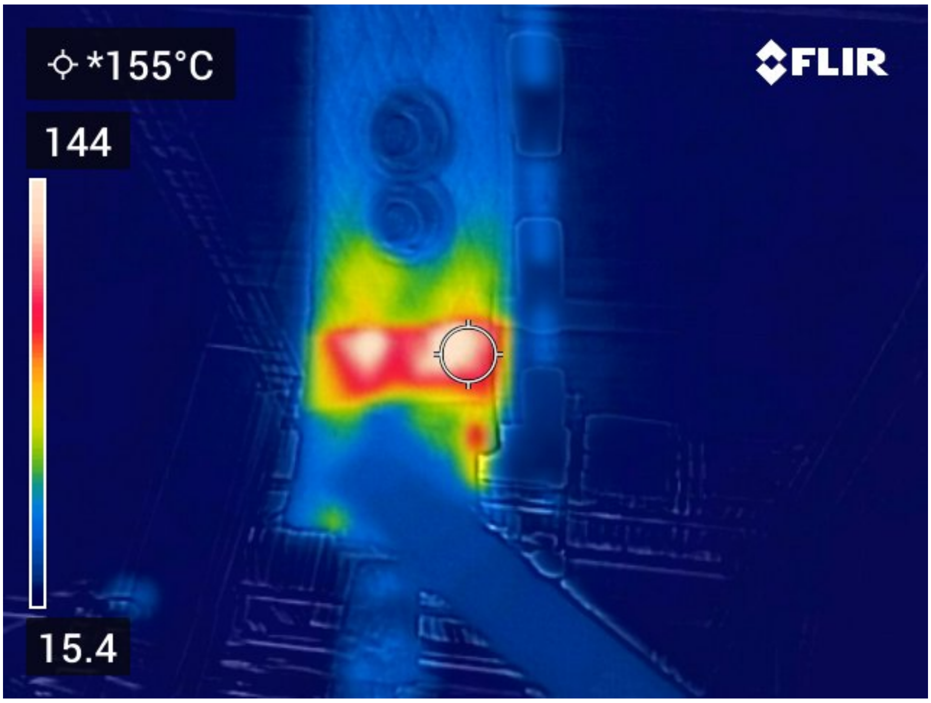


Figure 129. 155°C when conducting 143A, stainless steel braid.

Appendix H – Code

This chapter contains the code controlling both prototypes.

H.1 Code controlling the first iteration

```
#include <Servo.h>

Servo myservoh;
Servo myservov;

int pos = 0;                 // variable to store the servo position

void setup() {
  myservoh.attach(5);
  myservov.attach(6);        // attaches the servo on pin 9 to the servo object
}

void loop() {
  myservov.write(50);        //gränser vertikal 47 till 110

  myservoh.write(81);        //Gränser horisontal 60 till 105 (81 är 22.5/23pa
linjalen)
  delay(9000);
  myservoh.write(100);       // tell servo to go to position in variable 'pos'
  delay(9000);
}
```

H.2 Code controlling the second iteration

```
// Analog Pins
int HorizontalPot = A0;
int VerticalPot = A2;

//Digital Pins
int MotorForward = 4;
int MotorBackward = 5;
int MotorDown = 6;
int MotorUp = 7;
int MotorPWMH = 9;
int MotorPWMV = 10;
int VerticalButton = 2;
```

```
//Values to change
int VerticalState = 0; //ett är upp
float RealPositionH = 0;  //-225mm < RealPositionH < 225 mm

//Values to be constant
int TargetDown = 80; //min 80 (vill vara 280mm) (40 är 320mm)
int TargetUp = 730; //max 730
int TargetH = 600;    // 170 < TargetH < 640 (300-509)
int CurrentPosH = 0;
int PosHUp = 380 ;
float HorizontalR = 352;

//Filter
int EMA_S = 0;
float EMA_a = 0.20; //(0.1)
int LastPosH;
int PosDif;

//Timer
unsigned long previousMillis = 0;
unsigned long currentMillis = 0;
long interval = 10000;
unsigned long previousMillisV = 0;
unsigned long currentMillisV = 0;
long intervalV = 6000;
unsigned long CMprint = 0;
unsigned long PMprint = 0;

//Variables for PID
const float Kp = 52 / 2;  // The value for Proportional gain (52 är värdet)
const float Ki = 85;    // The value for Integral gain
(20/20/20)(*5/5/85)(50/50/8)
const float Kd = 170; // The value for Differential gain (170)

int iMax = 5;     // Used to prevent integral wind-up
int iMin = -5;    // Used to prevent integral wind-up
int Err_Value;      // Holds the calculated Error value
int P_Term;     // Holds the calculated Proportional value
int I_Term;     // Holds the calculated Integral value
int D_Term;     // Holds the calculated Differential value
int PWM_New;      // Holds the new PWM value
int i_Temp;
int d_Temp;
int PWM_Temp;
int DirSignalH;

//Test
int IndexH = 0;
int VerticalChange = 0;
int RecordH[31];
int RefH[31];
int tempRandom = 0;
float RealPositionTemp = 150;
int count = 0;
int countfail = 0;
int TargetDif = 0;
int PosSwitch = 0;

void setup() {
  for (int i = 0; i < 31; i++) {
    RecordH[i] = 0;
    RefH[i] = 0;
```

```
  }
  Serial.begin(9600);
  pinMode(VerticalPot, INPUT);
  pinMode(MotorDown, OUTPUT);
  pinMode(MotorUp, OUTPUT);
  pinMode(HorizontalPot, INPUT);
  pinMode(MotorPWMH, OUTPUT);
  pinMode(MotorForward, OUTPUT);
  pinMode(MotorBackward, OUTPUT);
  LastPosH = analogRead(A0);
  RecordH[0] = -1;
}

void loop() {
  currentMillis = millis();
  currentMillisV = currentMillis;
  ReadHPos();
  Position();

  TargetDif = abs(TargetH - EMA_S);

  if ((TargetDif) <= 4 && VerticalState == 0) {
    RecordH[IndexH] = RecordH[IndexH] + 1;
    RandomHorizontal();
    previousMillis = currentMillis;
    //Serial.println("1");
    delay(11);
    count = count + 1;
  }

  if (currentMillis - previousMillis >= interval && VerticalState == 0) {
    RandomHorizontal();
    previousMillis = currentMillis;
    countfail = countfail + 1;
  }

  if (currentMillisV - previousMillisV >= intervalV) {
    RandomVertical();
    previousMillisV = currentMillisV;
    delay(11);
  }

  if (VerticalState == 0) {
    PWMChange(ReadHPos(), Position());
  }

  delay(10);
}


int RandomVertical() {
  VerticalChange = random(0, 26);

  if (VerticalChange == 25) {
    VerticalState = 1;
    intervalV = 20000;
    RecordH[IndexH] = RecordH[IndexH] + 1;

    for (int i = 0; i < 31; i++)
    {
      Serial.print(RecordH[i]);
      delay(11);
```

```
      Serial.print(",");
      delay(11);
      Serial.println(RefH[i]);
      delay(11);
    }
    RecordH[IndexH] = RecordH[IndexH] - 1;

  }
  else if (VerticalChange != 25) {
    VerticalState = 0;
    intervalV = 6000;
  }
  VerticalSwitch();
}


int RandomHorizontal() {
  tempRandom = random(-15, 16);
  RealPositionH = tempRandom * abs(tempRandom);
  IndexH = map(tempRandom, -15, 15, 0, 30);
  RefH[IndexH] = RefH[IndexH] + 1;
}


int Position() {
  RealPositionTemp = HorizontalR * asin(RealPositionH / HorizontalR);
  TargetH = map(RealPositionTemp, -244, 244, 640, 170);
  return TargetH;
}


int ReadHPos() {
  CurrentPosH = analogRead(HorizontalPot);

  PosDif = abs(CurrentPosH - LastPosH);
  if ( PosDif > (5) && PosSwitch != 2) {
    CurrentPosH = LastPosH;
    PosSwitch += 1;
  }

  if (PosSwitch == 2) {
    CurrentPosH = analogRead(HorizontalPot);
    PosSwitch = 0;
  }

  EMA_S = (EMA_a * CurrentPosH) + ((1 - EMA_a) * EMA_S);
  LastPosH = CurrentPosH;
  return EMA_S;
}

void VerticalSwitch() {
  if (VerticalState == 1) {
    while (analogRead(VerticalPot) < TargetUp) {
      digitalWrite(MotorDown, LOW);
      digitalWrite(MotorUp, HIGH);
      PWMChange(ReadHPos(), PosHUp);

    }
    digitalWrite(MotorForward, LOW);
    digitalWrite(MotorBackward, LOW);
    delay(20);
  }
```

```
  else if (VerticalState == 0) {
    while (analogRead(VerticalPot) > TargetDown) {
      digitalWrite(MotorUp, LOW);
      digitalWrite(MotorDown, HIGH);
      PWMChange(ReadHPos(), Position());
    }
    delay(20);
  }

  digitalWrite(MotorUp, LOW);
  digitalWrite(MotorDown, LOW);
}


int PWMChange(int CurrentPos, int TargetH) {
  // More efficient to read this once and store as used 3 times

  Err_Value = (TargetH - CurrentPos);

  // This calculates Proportional value
  P_Term = Kp * Err_Value;

  // Prepare Integral value
  i_Temp = i_Temp + Err_Value;

  // Prevents integral wind-up, limits i_Temp from getting too positive or
negative
  if (i_Temp > iMax) {
    i_Temp = iMax;
  }
  else if (i_Temp < iMin) {
    i_Temp = iMin;
  }

  // Calculates the Integral value
  I_Term = Ki * i_Temp;

  // Calculates Differential value,
  D_Term = Kd * (Err_Value - d_Temp);
  d_Temp = Err_Value;


  PWM_New = /*PWM_Temp +*/ (P_Term + I_Term + D_Term);

  // PWM overflow prevention
  if (PWM_New > 1023) {
    PWM_New = 1023;
  }

  else if (PWM_New < 0) {
    PWM_New = 0;
  }

  // Assigns the current PWM duty cycle value to PWM_Temp
  // PWM_Temp = PWM_New / 1.2;

  DirSignalH = map(PWM_New, 0, 1023, -255, 255);


  if (EMA_S > 645) {
    DirSignalH = -50;
```

```
    i_Temp = 0;
  }

  else if (EMA_S < 165) {
    DirSignalH = 50;
    i_Temp = 0;
  }


  if (DirSignalH > 0) {
    digitalWrite(MotorBackward, HIGH);
    digitalWrite(MotorForward, LOW);
  }

  else if (DirSignalH < 0) {
    digitalWrite(MotorForward, HIGH);
    digitalWrite(MotorBackward, LOW);
  }

  analogWrite(MotorPWMH, abs(DirSignalH));

  return 1;
}
```