New Motor for Weather Shelter

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DIVISION OF PRODUCT DEVELOPMENT | DEPARTMENT OF DESIGN SCIENCES
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MASTER THESIS

ASSA ABLOY

New Motor for Weather Shelter

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Abstract

The goal of this thesis has been to develop and evaluate a proposal as how to integrate a new motor system for the top horizontal roller of an ASSA ABLOY weather shelter. This required changes to the current system, both in hardware and software. The main challenge was that the old motor could be back driven by the system, and the replacement motor could not. Thus, a solution where the new motor continuously controlled the position of the roller had to be developed.

Throughout this work, the well-known product development methodology defined by Ulrich and Eppinger has been followed, with adaptations inspired by the Double Diamond methodology to suit this project. This led to a partly self-documenting product development process which supported the report writing process in parallel to the practical work.

Prototypes of the three most promising concepts were constructed and evaluated at a workshop to select a winner. The winning concept was made in a larger prototype for further detail design and concept testing. This resulted in a promising proposal on how to integrate the new motor system with the weather shelter.

The conclusion of this thesis is that, even though additional validation remains, a promising and worked through solution on how to integrate the new motor package with the existing weather shelter has been proposed.

Keywords: Weather Shelter, Docking, ASSA ABLOY, Product Development, Prototyping

Sammanfattning

Målet med arbetet har varit att utveckla och utvärdera ett förslag på hur ett nytt motorpaket till den övre horisontella duken i ett ASSA ABLOY väderskydd kan integreras. Detta krävde förändringar av det nuvarande systemet, både av hårdvaran och mjukvaran. Den största utmaningen var att den gamla motorn kunde drivas baklänges av systemet, vilket den nya motorn inte kunde. Därför behövde en lösning där den nya motorn kontinuerligt reglerade positionen på duken utvecklas.

Genom hela arbetet har en produktutvecklingsmetodik definierad av Ulrich & Eppinger följts, med vissa anpassningar inspirerade av Double Diamond-metodologin för att passa projektet. Det resulterade i en delvis självdokumenterande produktutvecklingsprocess vilket stöttade rapportskrivandet parallellt med det praktiska arbetet.

Prototyper av de tre mest lovande koncepten byggdes och utvärderades sedan på en workshop för att välja en vinnare. Det gjordes en större prototyp av det vinnande konceptet för fortsatt detaljdesign och test. Detta resulterade i ett lovande förslag på hur det nya motorsystemet kan integreras med väderskyddet.

Slutsatsen är att även om viss validering av prototypen kvarstår, har ett genomarbetat och lovande förslag för hur man ska integrera det nya motorsystemet med det befintliga väderskyddet föreslagits.

Nyckelord: Väderskydd, lastkaj, ASSA ABLOY, produktutveckling, prototyp

Acknowledgments

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Lund, May 2022

Elin Elfström and Mattias Neumann

Table of Contents

1 Introduction

This section introduces the reader to the authors, the company, and the problem disserted by the thesis. The goals and delimitations are described as well.

1.1 Student Background

The authors of this master thesis, Elin Elfström and Mattias Neumann, both have a background in mechanical engineering and mechatronics at the Faculty of Engineering at Lund University. As graduate master students, this thesis has expanded the knowledge of product development on an industrial level and provided preparatory experiences for the life outside of the academic world.

1.2 Company Background

ASSA ABLOY Entrance Systems IDDS AB (from here on known as ASSA ABLOY) is a division at ASSA ABLOY specifically focusing on entrance systems for both people and goods. With experience from merged companies such as Crawford, Besam and Megadoor, ASSA ABLOY strives to supply innovative, dependable, and automatic doors and entrance solutions to the industry. (Systems, Vår historia, 2022)

1.3 Problem Description

ASSA ABLOY aims for high flows of material and robust weather shelters for the separation of different climate zones in loading docks. The separation of different climate zones can be done by, for example, using inflatable bellows to seal against the sides of a truck docking to a loading bay, and a horizontal “top roller” that can be adjusted in height by a motor to seal against the roof of a truck. The right tension is needed to achieve the standards and requirements set by the company regarding robustness and weather protection. Without this stiffness, the top roller will be bent by the wind and the sides will not be insulating properly.

This system is called an SIR-system, Shelter Inflatable Roller, and the model relevant for this thesis is the DS6070R which can be seen in Figure 1.1. The existing motor package for this top roller is going to be replaced and the shelter therefore needs to be updated to continue to meet the requirements and specifications set by the company.

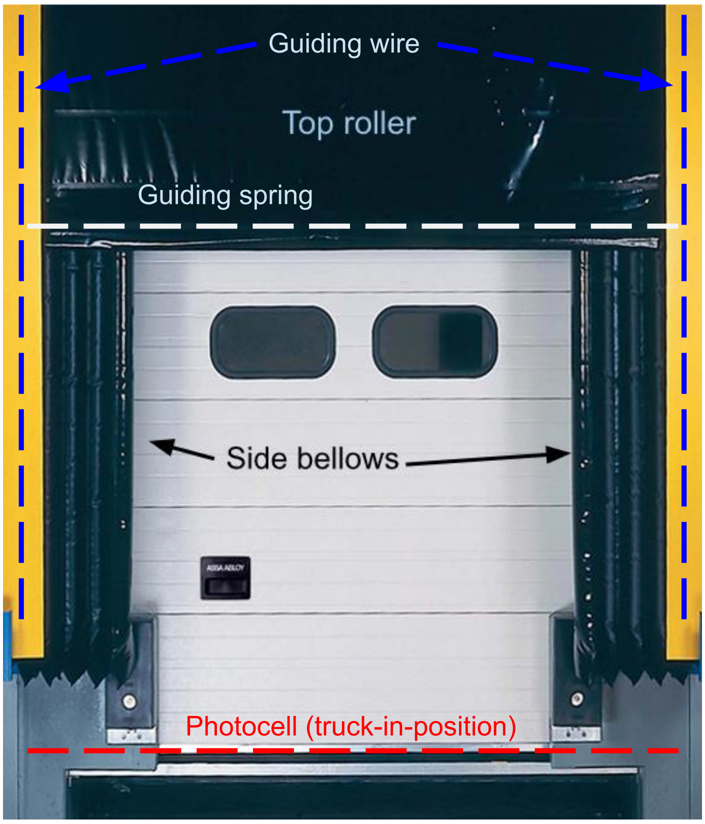


Figure 1.1.The DS6070R weather shelter, modified and reprinted with permission (Systems, Uppløsbara vädertätningar, 2022).

The system to be replaced is a “free-floating” system where the top roller is in contact with the top of a truck, and a counterweight hanging from the other side of the shaft tensions it. The photocell detects if there is a truck in position. To increase the wind resistance of the top roller there are guiding wires behind the yellow warning strips in Figure 1.1, one on each side. Through the bottom of the roller runs a spring that hooks on to these wires, providing rigidity. The idea is that the top roller can move freely up and down, which require that the motor can be turned from the output shaft, instead of the motor turning the shaft. With the current transmission it is possible. However, the new system uses a worm drive gearbox between the motor and the roller, which inherently cannot be back driven. For this reason, a system that controls the height of the top roller by controlling the motor directly is required. For the motor to know the position of the roller, sensors are assumed to be used to provide feedback. It is therefore necessary to do a study to produce the best solution according to the goals that have been set up. Since the entire motor system is replaced, certain hardware will need to be redesigned as well.

1.4 Goal

The goal of the master thesis is to develop and evaluate a proposal on how new components can be integrated into the existing platform for weather shelters. The result of the study is expected to be a prototype of the proposal and to give answers to the following issues:

- How can the new motor package be integrated with the existing platform for weather shelters to meet the high requirements of robustness?
- What type of sensors are best suited based on the requirements and how can the sensors be integrated with the platform?

1.5 Delimitations

To clearly limit the scope of this thesis some demarcations are made, and they are as follows.

- The weather shelter’s user functionality is final and will not be changed;
- The new motor system is assumed to be sufficient in all relevant ways (it was supplied by ASSA ABLOY) and is not subject to change, except for additional software implementations;
- Only economic analysis that will be performed is an estimation on if the new system will be cheaper or more expensive than the current system;
- No investigation of the manufacturing process will be done.

2 Methodology

This section is ordered as follows. Firstly, different product development methodologies are introduced and the most suitable is chosen. This methodology is then presented in its original form, followed by an adaptation for this thesis project. Lastly, the outline of the report is presented.

2.1 Product Development Processes

The waterfall process is a sequential development process that goes through all stages of product development, not moving on to the next phase until the previous phase is entirely completed. The project activities are broken down into linear sequential phases, which makes it a non-iterative process. With a waterfall project, it is harder to change course than it is with an agile methodology. (Waterfall Methodology, 2022)

Another methodology for product development is the agile process, which is based on the Agile Manifesto, established in 2001. According to Cline (2015), agile is considered a holistic process of product development, which works well for delivering high quality products. The requirements are written as small “chunks” of scope and are then developed one at a time. Once one small chunk of scope is developed, it is presented to the customer, which allows the customer to continuously give feedback throughout the development process. This is done iteratively until the requirements are met. (Cline, 2015)

The British Design Council introduced a visualization of their product development process called the “Double Diamond” process in 2003. This was an adaptation of earlier researched methodologies, based on diverging and converging elements with iterative properties. More on this in section 2.3. (Ball, 2022)

Another framework for product development is Ulrich and Eppinger’s model for product development, which can be seen in Figure 2.1. The phases of the product development process are described there, from product planning to production ramp-up. (Ulrich & Eppinger, 2008)

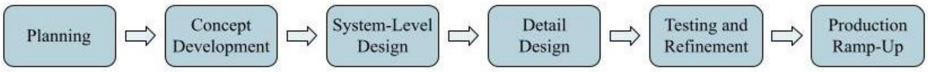


Figure 2.1. Ulrich and Eppinger's process for product development. Modified from "Product Design and Development" by Ulrich & Eppinger (2008, p. 9).

This process is well defined with checklists and explanations for how the phases should be conducted. The authors state however, that "Although the methods are structured, they are not intended to be applied blindly…teams should adapt and modify the approaches to meet their own needs." (Ulrich & Eppinger, 2008, p. 7).

The waterfall-like structure, with some iterative steps, of this process suits the purpose of this thesis of updating an already well-defined product. In comparison with the more iterative Double Diamond process, it is easier to see progress as one flow through the steps, as well as the Ulrich & Eppinger (2008) product development process is almost self-documenting, with the clearly defined phases. Furthermore, the authors former experience with Ulrich & Eppinger's methodology helped motivate the decision of using their methodology for this thesis. However, some inspiration from the Double Diamond methodology is used for the initial stages of the project, and the relevant stages are presented partly in section 2.3.

2.2 Product Development Process According to Ulrich and Eppinger (2008)

Ulrich and Eppingers' (2008) process for product development will be described in detail below, since it is chosen as the main methodology for this thesis.

2.2.1 **Product Planning**

The first phase is the product planning phase, which identifies the portfolio of projects to be developed by the organization as well as the timing of the introduction of the projects to the market.

2.2.2 **Concept Development**

Figure 2.2 shows the following front-end product development activities which are recommended in *Product Design and Development* (Ulrich & Eppinger, 2008) the concept development phase: identifying customer needs, establishing target specifications, generating product concepts, selecting product concepts, testing product concepts, setting the final specifications, and planning downstream development.

Figure 2.2. Flowchart of a concept development process. Modified from "Product Design and Development" by Ulrich & Eppinger (2008, p. 98).

2.2.2.1 Identifying Customer Needs

The identification of customer needs is presented as a five-step-method:

1. Gather raw data from customers.
2. Interpret the raw data in terms of customer needs.
3. Organize the needs into a hierarchy of primary, secondary and (if necessary) tertiary needs.
4. Establish the relative importance of the needs.
5. Reflect on the results and the process.

Gathering raw data from customers can be done by, for example, interviews, focus groups, surveys or by observing the product in use. The raw data from the customers then need to be interpreted as customer needs and are to be expressed as written statements. Furthermore, the needs should be organized into a hierarchy and the relative importance of the needs established.

2.2.2.2 Establishing Target Specifications

While customer needs are great for explaining the issues of interest, they can be difficult to design the product after. Therefore, the customer needs are translated into target specifications, which in turn are the precise description of what the product should do. For example, a customer need "the stroller can be stored easily" could be interpreted as the target specification "the stroller can be collapsed in less than 10 seconds". A customer need could be interpreted as several target specifications. A target specification states *what* the product should do, not *how* it should be approached, is measurable, and consists of a metric and a value. In the earlier example, “time to collapse” is the metric and “less than 10 seconds” is the value.

The target specifications are established immediately after the customer needs are set, and they represent the hopes and ambitions of the developing team. However, they are often established before all the technical limitations are known. Therefore, the target specifications are often revisited and modified later in the product development process, until the final specifications are set. To set the target specifications there are four general steps:

1. Prepare the list of metrics
2. Collect competitive benchmarking information
3. Set ideal and marginally acceptable target values
4. Reflect on the results and the process

2.2.2.3 Generating Product Concepts

The target specifications and customer needs are the input to the concept generation phase, and a set of concepts are the output. Ulrich and Eppinger (2008) states that good concept generation induces confidence that the full space of alternatives has been explored, meaning that many concepts could be generated. They also state that by following the five-step method shown below, costly mistakes could be avoided.

1. Clarify the problem
2. Search externally
3. Search internally
4. Explore systematically
5. Reflect on the solutions and the process

2.2.2.4 Selecting Product Concepts

There are different methods for choosing which concepts to continue developing, Ulrich and Eppinger (2008) present a two-stage method, concept screening and concept scoring. The purpose of the concept screening is to quickly reduce the number of concepts and improve the quality of the ones remaining. This is useful when dealing with large numbers of concepts and can be done in many ways. Ulrich and Eppinger (2008) suggest using the multi voting technique to quickly reduce the number of concepts. If the number of concepts is smaller a screening matrix with a known reference is recommended. For each criterion, every concept is given -, 0, or + in comparison with the reference. The sum of the scores is the base for the screening process.

In the concept scoring stage, stage two of the concept selection process, Ulrich & Eppinger (2008) lists the following methods:

- External decision
- Product champion
- Intuition
- Multi-voting
- Pros and cons
- Prototype and test
- Decision matrices

The method that is chosen by the team depends on the situation. The screening and scoring of concepts facilitate the refinement and improvement of concepts. This phase will lead to one or more concepts for further development.

2.2.2.5 Testing Product Concepts

The purpose of concept testing is that the results are based on data gathered from potential customers whereas concept selection is based on the development team's perception or interpretation of the customer needs. A structured approach and well documented testing can be helpful when trying to evaluate the concepts and give important feedback on which to continue with. Ulrich and Eppinger (2008) suggest a seven-step method:

1. Define the purpose of the test
2. Choose a survey population
3. Choose a survey format
4. Communicate the concept
5. Measure customer response
6. Interpret the results
7. Reflect on the results and the process

2.2.2.6 Setting Final Specifications

Once the concept selection and testing phase is complete, the final specifications are set. Ulrich and Eppinger (2008) suggest a five-step process to do this as well:

1. Develop a technical model of the product
2. Develop a cost model of the product
3. Refine the specifications, making trade-offs where necessary
4. Flow down the specifications as appropriate
5. Reflect on the results and the process

2.2.2.7 Planning Downstream Development

The final stage of concept development phase which entails precising a detailed development schedule to minimize development time, and specifying which resources are needed to complete the project.

2.2.3 System-level Design

The product architecture and subsystems are defined here, and the expected output is functional specifications of the subsystems, process description for the assembly process, and a geometric layout of the product.

2.2.4 Detail Design

Exact designs, tolerances, tooling, process plans, and control documents are produced. The product is essentially finalized, and the last adaptations and tradeoffs are done.

2.2.5 Testing and Refinement

Alpha and beta prototypes are created with the intent of validating the product and manufacturing process. According to Ulrich and Eppinger (2008), alpha prototypes are built with the same geometry and material as the final product, but necessarily not manufactured the same way, since the point of an alpha prototype is not to check the process but that the product works as intended. Beta prototypes are usually used to investigate any performance and reliability issues.

2.2.6 Production Ramp-up

The work force is trained and any last issues with the production system is worked out. The first series of products produced in this phase are sometimes made available to certain select customers. Eventually the product is launched and made available to everyone.

2.3 The Double Diamond Methodology, first steps

The Double Diamond process consists of four steps: Discover, Define, Develop and Deliver. During these phases, the iterative workflow is pronounced, making it useful for design processes where prototypes are involved early on. (Drew, 2019)

2.3.1 **Discover**

In the Discover-phase, a lot of focus is put on creativity and an open-mindedness. To understand the product or problem at hand, many different methods are given such as creating a workspace to manage all the information and observing the product/problem in use. Set a goal and brainstorm as many ideas as possible, without being too perfectionist about them. This phase is about broadening the perspective and create inspiration, building understanding of the project. (Council, Design Methods Step 1: Discover, 2015)

2.3.2 **Define**

In this stage, all the knowledge and experienced gathered in the Discover phase is handled and sorted to narrow down the perspective and define the main challenge of the project. A few tips are given to do this, focus groups being one. Comparing notes and using assessment criteria are two more. (Council, Design Methods Step 2: Define, 2015)

2.4 The Adapted Model

Since the DS6070R weather shelter is product already on the market and one delimitation of this thesis is to not make any user functionality changes to it, all the steps of the general product development process are not used. The adapted model can be seen in Figure 2.3. The main differences are that the system-level design is removed, as well as the production ramp up, since these phases are not within the scope of this thesis. Furthermore, the Double Diamond design process was partially used for the research phase. The two phases Discover and Define was used to get an insight into the problem and to know which areas to focus upon initially. The phases of the adapted model are described next.

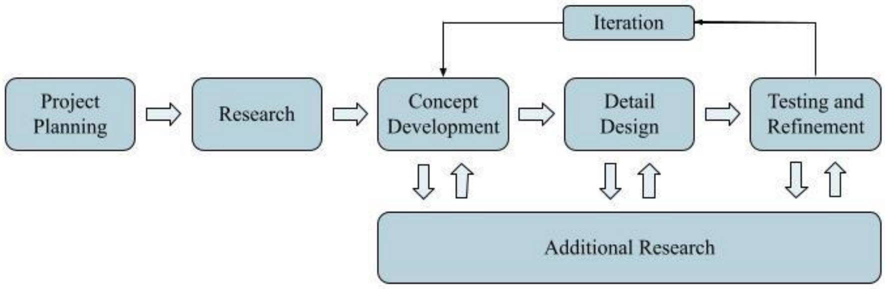


Figure 2.3. Adapted model for product development.

2.4.1 **Project Planning**

The product planning is not included in the scope of this thesis; hence the planning phase is replaced by the thesis project planning phase. This is because the product has already been launched and on the market for many years, and the purpose is to upgrade the parts without changing the esthetic design or the perceived function. The adapted product development model, important deadlines, and a time plan is produced in the project planning phase instead. The time plan and work distribution are presented in Appendix C.

2.4.2 **Research**

From the Double Diamond design methodology, the Discover and Define phases are the inspiration for this research phase. Initially, research is made regarding the product itself but also generally about areas of interest for the project. This is done since the product already exists and a thorough understanding of it is needed, as well as a baseline of knowledge in the different areas that the project will encounter. The output from this phase is presented in section 3.

The research is done by studying literature, acquiring knowledge from ASSA ABLOY by talking to different employees, and meeting with professors from LTH. This part of the project could also be considered as the first three stages of the concept generation phase (see section 2.2.2.3), but since this research is general and not regarding the concept development exclusively, it is presented separately.

2.4.3 **Concept Development**

The concept development phase followed in this thesis is similar to Ulrich and Eppinger (2008)'s model, with only a few differences presented below.

2.4.3.1 Identify Customer Needs & Establishing Target Specification

For this thesis, the customer needs are replaced by the needs established by the company since the product is already launched and is expected to maintain the same user functionality. Therefore, the process of collecting customer needs is replaced by collecting needs specified by the company. These needs are in theory close to the final specification of the current version of the product since the functionality is not to be changed. The needs are collected by talking to engineers at ASSA ABLOY.

Furthermore, to establish the values of some of the target specifications, some measurements are performed since the new system should not differ from the current in functionality. For the same reason, step 2 in "Establishing Target Specifications" (Collect competitive benchmarking information) means recording the performance of the current system instead of comparing with competitors. These values are used as the metric values in the target specifications.

2.4.3.2 Generate Product Concepts

Since the problem and current product is defined in the research phase prior to generating concepts, the first activity of the concept generation stage, clarifying the problem, is left out.

The external search consists of talking to experienced employees of ASSA, and of investigating competitors' products as well as other applications where similar solutions may be implemented.

The internal search is performed next. To increase creativity and be confident that the entire design space is explored when generating concepts, a brainstorming session is held. The generated concepts are then discussed and sorted based on their main working principle. During this activity, pruning of concepts will also be performed. If less promising concepts are identified, these are discussed and potentially disregarded.

Regarding the control system, the methodology for concept generation and selection is done as suggested by co-supervisor Gunnar Lindstedt (personal communication, 25 January 2022). It is conducted in an iterative manner, starting with the simplest possible concept. The concept is evaluated, and if deemed not sufficient, a more advanced concept is developed. This is done iteratively until a concept meeting the requirements is found.

2.4.3.3 Select Product Concepts and Test Product Concepts

Concept selection and concept testing are performed together as one step, starting with a workshop with ASSA ABLOY employees. This is done since the group of people who take part in the concept selection and concept testing are the same. The employees are chosen in a way that a wide range of relevant expertise is achieved. To start the workshop, the generated concepts are presented, followed by a discussion to receive feedback from the employees. The multi voting method is used to identify the winning concepts, since this is an effective method to quickly reduce the number of concepts to choose between. This means that each member of the team gets to vote for three concepts, ranked one through three. The concepts are then scored based on the votes, three for a first-place vote, two for second, and one for third.

The three winning concepts are then prototyped, and the physical models tested. These models are not necessarily built exactly like the finished product since the purpose of this phase is to compare the functional principles between the concepts. Once the models are built and evaluated, another workshop with the same participants as the first one is held, allowing for input and feedback from the employees and experts of ASSA ABLOY. The outcome of this phase is a single concept chosen for further development.

2.4.3.4 Set Final Specifications and Plan Downstream Development

The process suggested by Ulrich and Eppinger (2008) is followed, and the target specifications are translated into final specifications and any further development relevant to this thesis is planned.

2.4.4 **Detail Design, Testing and Refinement, Production Ramp-up**

In the detail design phase, the used components in the winning concept is designed in detail and an estimation on if the new system is cheaper or more expensive than the current system is made. In the testing and refinement phase, the prototype of the winning concept is further tested and iterated to improve overall performance. The manufacturing process as well as the production ramp-up are not included in the scope of this thesis, therefore these phases have been omitted.

2.4.5 **Additional Research**

The additional research in Figure 2.3 is meant to visualize the need for continuous research regarding anything that is not already known. For example, if a certain sensor is used, research regarding how it works is needed. Furthermore, if a test or validation fail, research is made to investigate why. This continuous gathering of information and knowledge happens all the time and about many different things, and the results are therefore not presented in its own section.

2.5 Disposition

The outline of this thesis is as follows.

1. Introduction
2. Methodology
3. Research
4. Concept development
5. Detail design
6. Testing and refinement
7. Results
8. Discussion
9. Appendix

3 Research

The research section includes the background regarding the current product, old and new motor package, control theory, and applicable standards.

3.1 Current Operation of the Weather Shelter

The current operation of the weather shelter (see Figure 1.1) is described below.

1. A truck reverses into the shelter.
2. A “START” signal is given from the control unit.
3. The bellows inflate and the top roller motor break is released.
4. With the roller motor shorted, gravity pulls the weighted roller down until it rests on top of the truck, with the counterweight creating tension.
5. If the software does not detect a truck with the “truck-in-place” photocell, the motor rewinds and sends a signal to the control unit when retracted.
6. When the loading/unloading is completed the “START” signal is removed and the motor is activated to wind up the top roller. The bellows are deflated.
7. The motor brake is applied and the truck drives away.

The layout of the current system is shown in Figure 3.1.

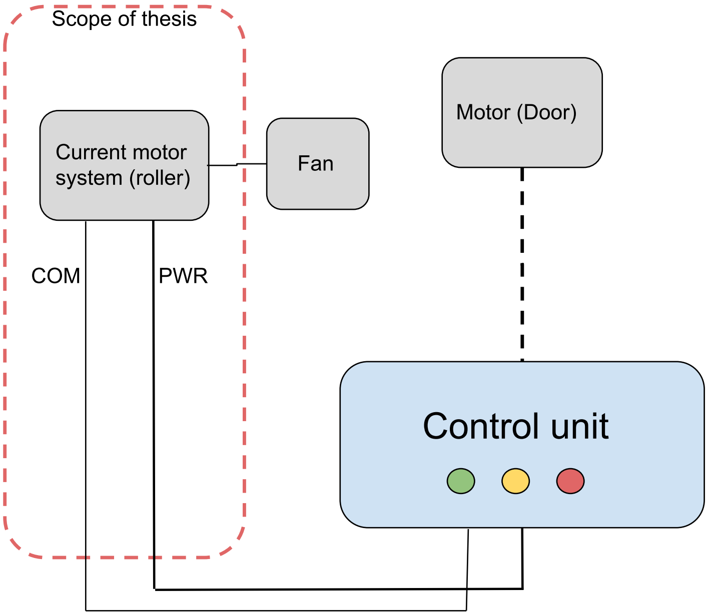


Figure 3.1. Current system layout.

3.2 Current Mechanical Setup

The motor package which is going to be replaced consists of a brushed DC motor with a chain drive mounted to the output shaft and can be seen in Figure 3.3. The balance shaft that holds the roller accepts the other end of the chain transmission. A counterweight is also attached to the balance shaft, but so that the moment exerted on the shaft will counteract the moment caused by the top roller, which can be seen in Figure 3.4. This balancing act is the mechanical control of the tension in the fabric of the roller and is what needs to be replaced in the new system.

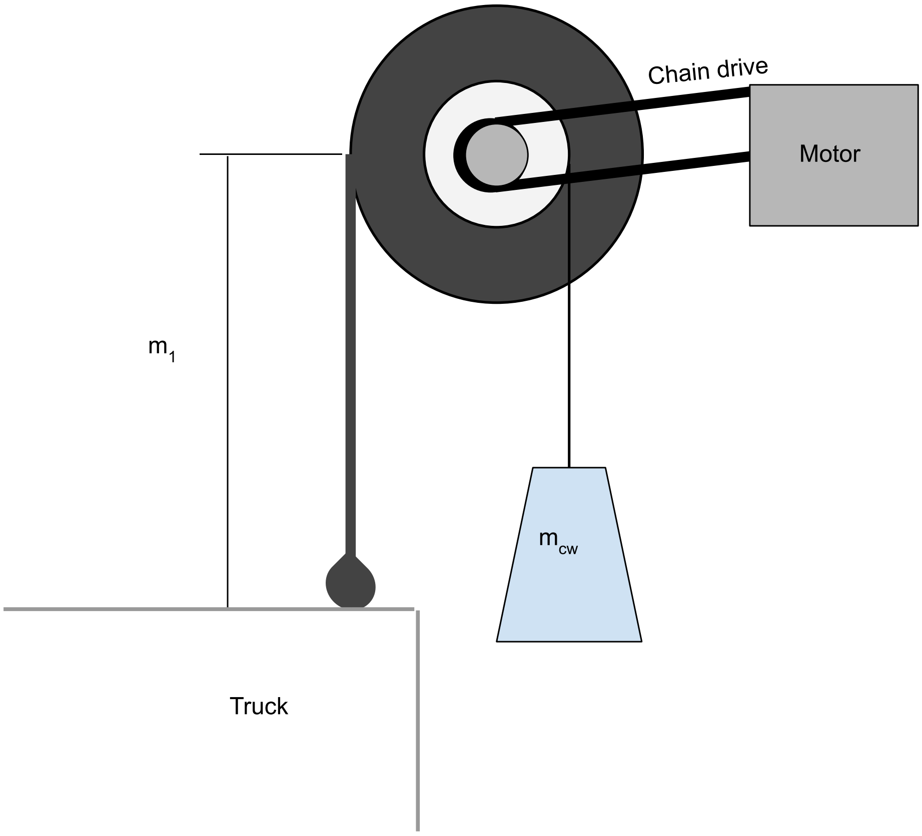


Figure 3.2. Mechanics of the current system.

Figure 3.2 shows how the current system works. The mass of the roller (m_1) is greater than the mass of the counterweight (m_{cw}). The counterweight's purpose is to stretch the roller so that it does not bulge due to wind. If the truck moves up or down, the roller follows it, meaning that the motor cannot be fixed. With the current transmission is it possible for the balance shaft of the roller to turn the motor through the chain drive, meaning that the roller can move freely.

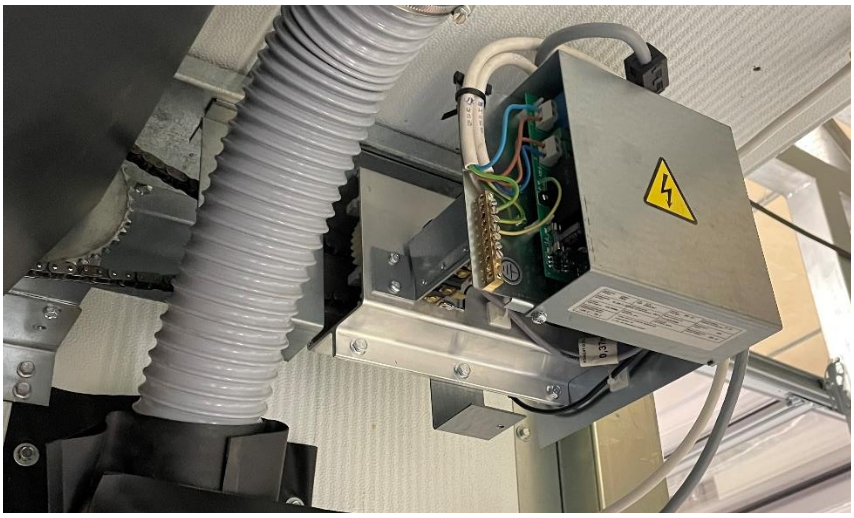


Figure 3.3. Old motor system mounted on weather shelter.

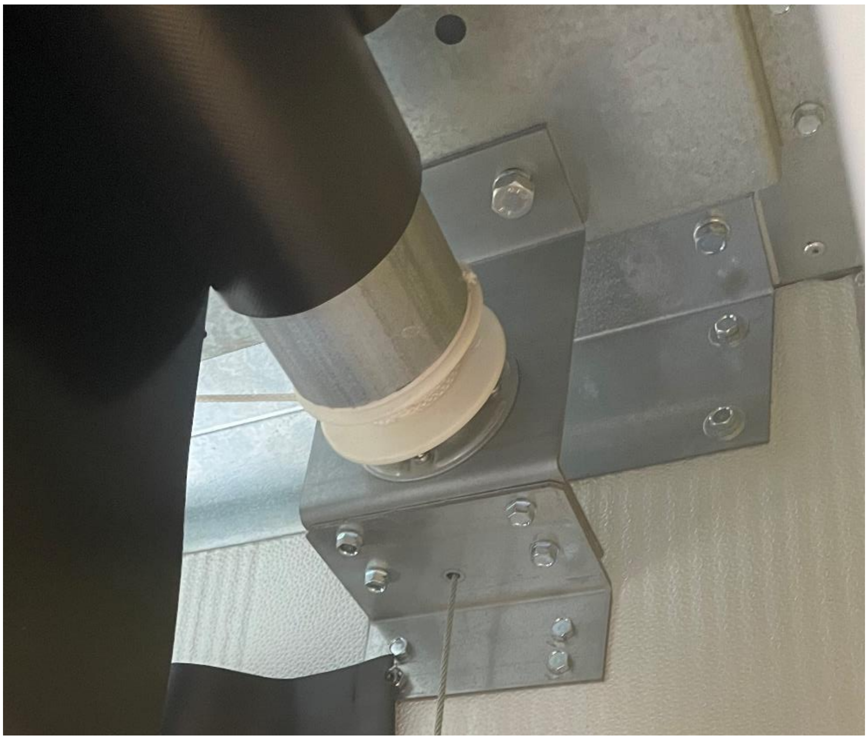


Figure 3.4. Line to counterweight connected to the balance shaft.

3.3 New Motor Setup

The CDM9 motor system (from here on called "the motor" or "CDM9") can be seen in Figure 3.5. This setup consists of a three-phase asynchronous motor, control electronics, power electronics, and a worm drive gearbox incorporated in the same aluminum housing. Since this motor incorporates a worm gear drive, it is not possible to turn the motor from the output shaft, meaning that the roller cannot move freely. This means that the position of the top roller needs to be controlled directly by the motor, instead of by gravity as in the current setup.

Figure 3.5. The CDM9 motor system.

Since the position of the top roller must always be controlled by the motor, a new system needs to be designed. A layout of such system can be seen in Figure 3.6.

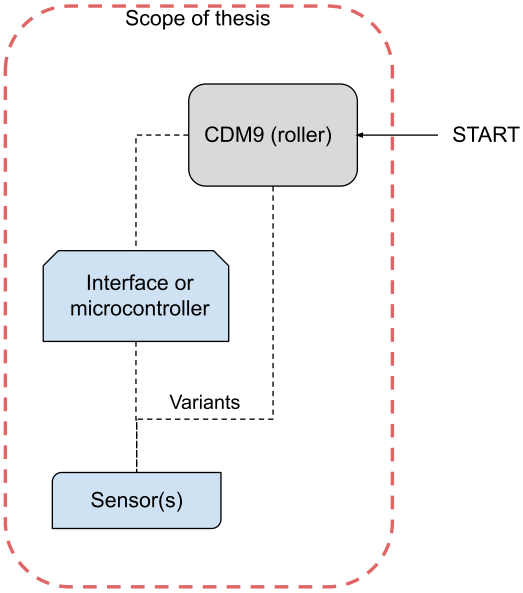


Figure 3.6. Layout of the new system.

3.4 Communication with the New Motor

The CDM9 has ten connections, where two are reserved for RS485 serial communication. The other ones are: 24V, GND, PE, UP, DOWN, STOP, SE (safety edge), and PHC (photocell). However, not all of these will be needed for this implementation. The SE and PHC ports are available since no safety edge or photocell is used here. (S. Paulsson, personal communication, 28 January 2022)

Since all the inputs on the CDM9 are opto-coupled for full electronic isolation, the communication with the motor is digital. However, the main feed that is going to be used for the sensors is a 50Hz 24V AC-system. The opto-couplers are doubled, meaning that they could be depicted as two opto-couplers mounted in parallel to each other but in alternating orientation (see Appendix B). For a description of what an opto-coupler is, see Appendix A.2.1. This means that if a port gets a 24VAC signal, the control electronics after the opto-coupler will see a double half square wave, a constant high. However, opto-couplers are inherently inverting as well, so the signal will be interpreted as a digital zero. (S. Paulsson, personal communication, 28 January 2022)

By modifying the 24VAC signal in certain ways, which is detectable by the logic in the motor, it is possible to use the same port for multiple signals. Using discrete components such as rectifying diodes and Zener-diodes, it is possible to produce a non-modified wave, a half wave, and pulse trains with varying duty cycles. For more information regarding these, see Appendix A.1. With the use of software, these signals can be detected and identified from each other. In the CDM9, both polling and measuring the pulse width by time is used to determine what signal is being received. (S. Paulsson, personal communication, 28 January 2022)

In Figure 3.7 and Figure 3.8, two example signals are presented. These signals were simulated as examples only, using a free software called LTspice. For more information on the simulation, more signals, and the schematics, see Appendix B. Figure 3.7 shows the output (red) compared to the input (blue) when a rectifying diode is added before the optocouplers, to the input. Figure 3.8 displays the same circuit but with a Zener-diode added to the input. Note that one of the outputs are inverted and one is not, this is because an inverter was added to the circuit between the two measurements.

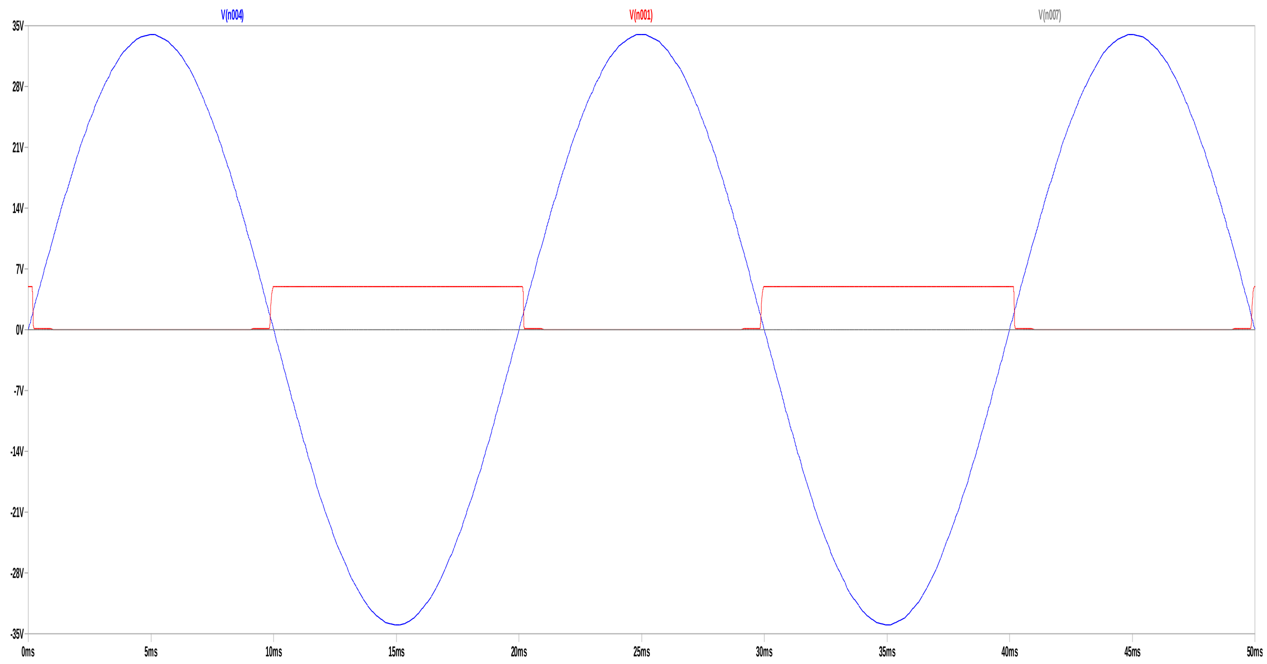


Figure 3.7. Half wave rectification of a 24VAC signal with opto-coupler and diode (inverted).

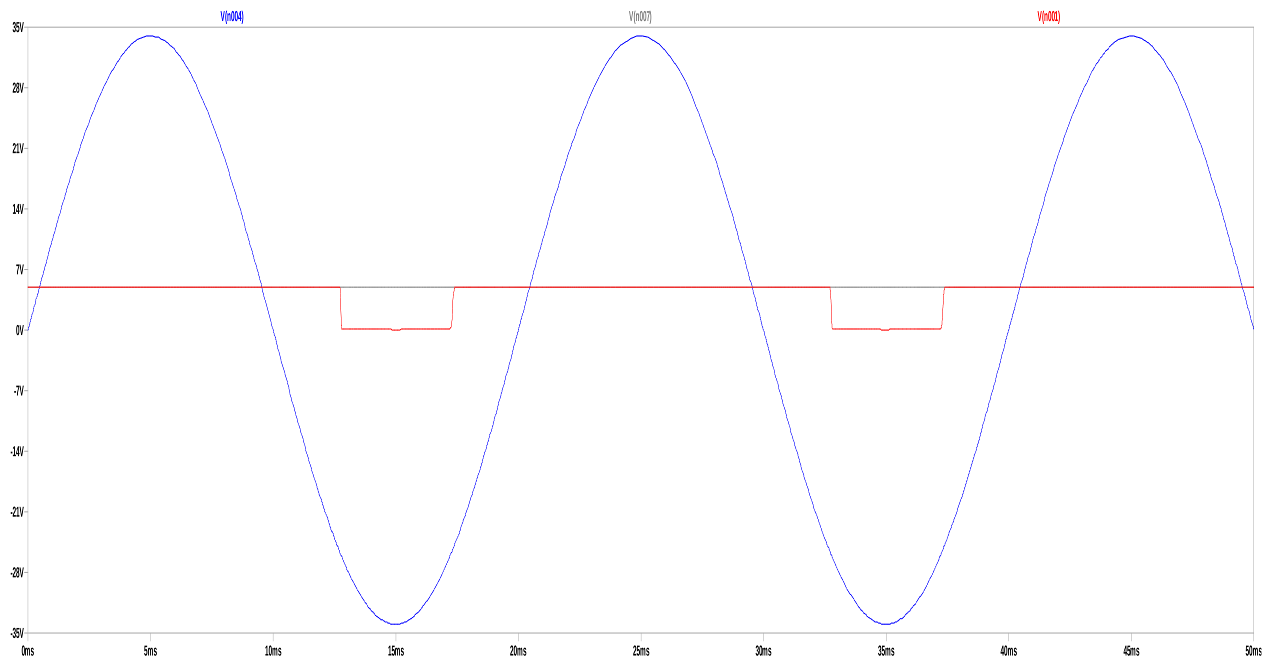


Figure 3.8. Half wave rectification of 24VAC signal with opto-coupler and Zener diode (non-inverted).

Using these methods, a higher resolution than binary can be achieved on each port, while keeping the two systems electrically insulated from each other using the opto-couplers. However, due to variations in the properties of the discrete components, the resolution is limited. For example, two Zener diodes of the same make and model might have a slightly different breakdown voltage, resulting in two different pulse widths. (S. Paulsson, personal communication, 28 January 2022)

3.5 Control Theory

Throughout this thesis, some basic concepts of control theory such as on-/off-control and hysteresis will be mentioned, for further information regarding these concepts see Appendix A.4.

4 Concept Development

This section presents the execution and results of the phases of the concept development process.

4.1 Identifying Needs and Establishing Target Specifications

Discussions were held with Sr. Mechanical Engineer & Supervisor Anders Löfgren at ASSA ABLOY to identify the needs defined by the company. The information gathered from the discussions were interpreted as needs and then compiled into a list, see Table 4.1. To minimize the risk of misunderstanding and to ensure that the needs were correctly perceived, this list was then sent to Anders Löfgren for confirmation. Some interpreted needs require some further explanation and will be discussed after the table.

Table 4.1. Interpretations of statements into needs.

Need number	*Question/ Prompt*	*Statement*	*Interpreted need*
1	Functionality	The system should detect if there is no truck	The system detects if there is no truck present
2	Functionality	The top roller should be at least as wind resistant as before	The system is as wind resistant as the old system
3	Functionality	The top roller should always follow the truck without any gap	The system continuously seals against the truck
4	Functionality	The new motor should be mounted directly to the balancing shaft	The system has few parts
5	Functionality	The functionality of the new system should be the same as for the old system	The new system is operated the same way as the old system
6	Functionality	"	The new system is as fast as the old system
7	Functionality	"	The new system separates the indoor climate from the outdoor climate better than the current
8	Functionality	The motor should detect automatically that it is an SIR-unit	The system detects if it is an SIR-unit automatically
9	Serviceability	The motor should be detached from the system easy	The motor is easily replaced
10	Compatibility	The new roller should use a 35mm shaft instead of the current 25mm	The system is easily assembled
11	Compatibility	The new motor should be retrofitted to the old system	The system is retrofittable
12	Compatibility	The SIR-detection should not interfere with current functionality of other products	The motor system can be used in other products without manual modifications
13	Problems – current system	The counterweight is one of the largest problems today, remove it	The system is tangle-free
14	Safety	The truck should be able to drive away with the top roller down without anything breaking	The top roller operates normally after a truck drives away while the roller is down
15	Safety	The new system should fulfill all current and applicable safety regulations	The system fulfills all current and applicable safety regulations
16	Cost	The new system should be cheaper than the old system.	The new system is cheaper than the old system

A weakness with the current design of the system is that there are areas not covered by the roller, meaning that the outdoor climate is not completely separated from the indoor climate, see Figure 4.1. Need number 7 refers to this weakness. Need number 9 refers to a problem with the serviceability today. The service technicians have trouble with replacing the motor since the location of the motor is difficult to access with a ladder. It would therefore be preferred to design the new system so that the motor is easily accessed and replaced. Furthermore, need number 13 means that the system does not have to be free from lines, but the system should be designed in a way that, if there are lines, they should not be tangling as the lines for the counterweight does today.

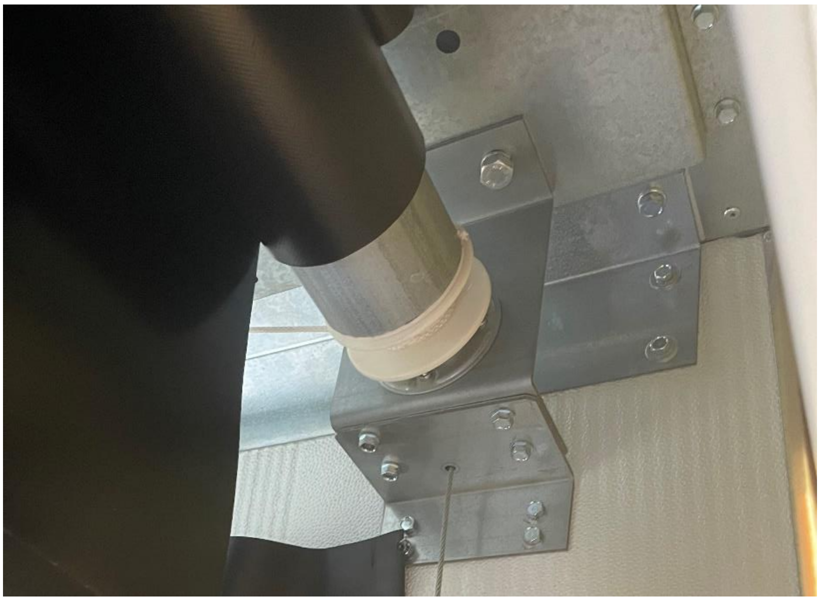


Figure 4.1. Area not sealed by the roller.

The needs were then organized into groups with similarities in the needs they expressed, and a primary need was set for each group. The secondary needs were then ranked with relative importance, on a scale between one and two where one is the most important. The result of this can be seen in Table 4.2 where primary needs are in bold and secondary are not.

Table 4.2. Hierarchal presentation of primary and secondary needs.

Need number	*Relative importance*	*Interpreted need*
		The new system functions the same way as the current system
1	1	The system detects when there is no truck present
3	1	The system continuously seals against the truck
5	1	The new system is operated the same way as the old system
6	1	The new system is as fast as the old system
7	1	The new system separates the indoor climate from the outdoor climate better than the current
		The system is designed for outdoor use
2	1	The system is as wind resistant as the old system
13	1	The system is tangle-free
		The motor system has high compatibility
8	1	The motor detects if it is an SIR-unit automatically
11	2	The system is retrofittable
12	1	The motor system can be used in other products without manual modifications
		The system is easily serviced
4	2	The system has few parts
9	2	The motor is easily replaced
10	2	The system is easily assembled
		The system is safe
14	1	The top roller operates normally after a truck drives away while the roller is down
15	1	The system fulfills all current and applicable safety regulations
		The new system is economically viable
16	1	The new system is cheaper than the old system

The next step was to translate the needs specified by the company into target specifications. Each need was written as a metric with corresponding importance, which can be seen in Table 4.3. The unit of metric 13 and 14 is 1-5, meaning that 1 is best and 5 is worse.

Table 4.3. The metrics and their importance.

Metric number	*Need numbers*	*Metric*	*Importance*	*Unit*
		The new system functions the same way as the current system		
1	1	The system detects if there is no truck in the shelter and retracts	1	Binary
2	3	The top roller follows the truck throughout the (un)loading procedure	1	Binary
3	3	The top roller is stretched by a force of	1	N
4	5	The new system is operated the same way as the old system	1	Binary
5	6	The top roller is unwound in less than	1	Seconds
6	7	The open area between roller and shelter is less than for the current system	1	cm^2
		The system is designed for outdoor use		
7	2	The top roller withstands the wind pressure specified by SS-EN 13561:2015	1	Wind class
8	13	The system is tangle-free	1	Binary
		The system has high compatibility		
9	8	The motor detects if it is an SIR-unit automatically	1	Binary
10	11	The system is retrofittable	2	Binary
11	12	The motor system can be used in other products without manual modifications	1	Binary
		The system is easily serviced		
12	4	The system has few parts	2	Pieces
13	9	The motor is easily replaced	2	1-5
14	10	The system is easily assembled	2	1-5
		The system is safe		
15	14	The top roller operates normally after a truck drives away while the roller is down	1	Binary
16	15	The system fulfills all current and applicable safety regulations	1	Binary
		The new system is economically viable		
17	16	The new system is cheaper than the old	1	Binary

To set the values for the metrics that were not binary, benchmarking information of the current system was collected by measuring and calculating its performance. Some further explanation of how the values of some of the metrics were decided is needed and are explained below.

The calculations made to set metric number 3 can be seen in Appendix C.

The time to unwound the top roller needed to be found to set the target value for metric number 5, so this was measured on the current system using a stopwatch. Lastly, the open area between the roller and shelter, metric number 6, needed to be approximated. This was done by measuring the largest gaps with a folding rule and summing up the area.

Metric number 7 (the top roller withstands the wind pressure specified by SS-EN 13561:2015) was decided in discussion with the company supervisor and is referring to standard SS-EN 13561:2015 presented below.

Furthermore, metric number 12 (the system has few parts) was difficult to estimate and were used to relatively compare the concepts later in the product development work.

4.1.1 External Blinds and Awnings – Performance Requirements Including Safety, SS-EN 13561:2015

The standard used by ASSA ABLOY regarding the roller is EN 13561, which specifies the performance requirements for blinds and awnings intended to be fitted externally to buildings and other construction work. It applies to all external blinds and awnings no matter what their design and materials used are, but do not apply to non-retractable products. (Swedish Institute for Standards, 2015)

Table 4.4 shows the wind resistance of the different classes in this standard. The wind resistance is defined as the blinds ability to withstand specified loads simulated as wind in positive or negative pressure. The nominal pressure, p_N, represents the wind pressure that the blind should be able to withstand without any deformation or deterioration harmful to its correct position. The safety pressure, p_s, is specified as the nominal pressure multiplied with a safety factor of 1.2 and represents the wind pressure at which no danger for the users should be observed. (Swedish Institute for Standards, 2015)

Table 4.4. Classes of wind resistance. (Swedish Institute for Standards, 2015)

Classes	*0*	*1*	*2*	*3*	*4*	*5*	*6*
Nominal wind pressure p_N (N/m²)	< 40	40	70	110	170	270	400
Safety wind pressure p_s (N/m²)	< 40	48	84	132	204	324	480

The target specifications with metrics and values can be seen in Table 4.5.

Table 4.5. Target specifications.

Metric number	*Need numbers*	*Metric*	*Target value*	*Unit*
		The new system functions the same way as the current system		
1	1	The system detects if there is no truck in the shelter and retracts	Yes	Binary
2	3	The top roller follows the truck throughout the (un)loading procedure	Yes	Binary
3	3	The top roller is stretched by a force of	81	N
4	5	The new system is operated the same way as the old system	Yes	Binary
5	6	The top roller is unwound in	< 23s	Seconds
6	7	The open area between roller and shelter is less than for the current system	<1200	cm^2
		The system is designed for outdoor use		
7	2	The top roller withstands the wind pressure specified by SS-EN 13561:2015	2	Wind class
8	13	The system is tangle-free	Yes	Binary
		The system has high compatibility		
9	8	The motor detects if it is an SIR-unit automatically	Yes	Binary
10	11	The system is retrofittable	1	1-5
11	12	The motor system can be used in other products without manual modifications	Yes	Binary
		The system is easily serviced		
12	4	The system has few parts	-	Pieces
13	9	The motor is easily replaced	1-3	1-5
14	10	The system is easily assembled	1-3	1-5
		The system is safe		
15	14	The top roller operates normally after a truck drives away while the roller is down	Yes	Binary
16	15	The system fulfills all current and applicable safety regulations	Yes	Binary
		The new system is economically viable		
17	16	The new system is cheaper than the old	Yes	Binary

4.2 Concept Generation

To start the concept generation phase, the authors individually brainstormed concepts using pen and paper. The mindset was to write and draw everything that came up with no limitations, except having the needs in mind. After the individual brainstorming session, the concepts were presented to each other and categorized into working principles in a mind map to get an overview of the concepts, which is shown in Figure 4.2. To get further inspiration and to be able to come up with more concepts, competitors' weather shelters were looked at. Discovering those weather shelters facilitated the creative thinking and resulted in more concepts, which also were added to the mind map.

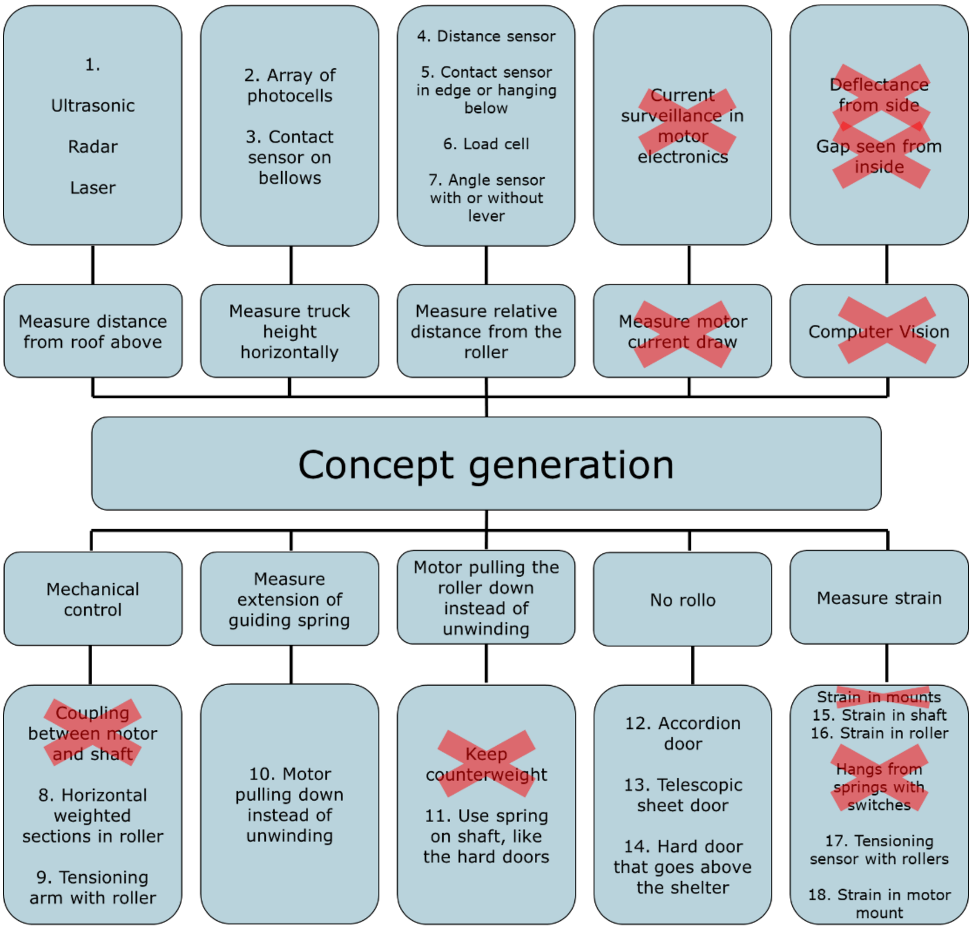


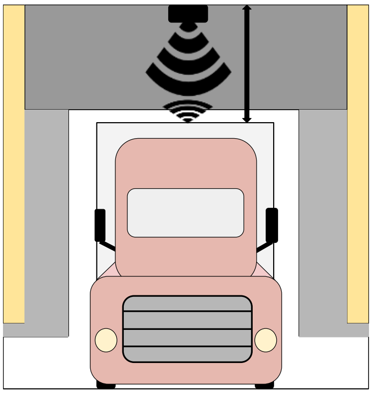
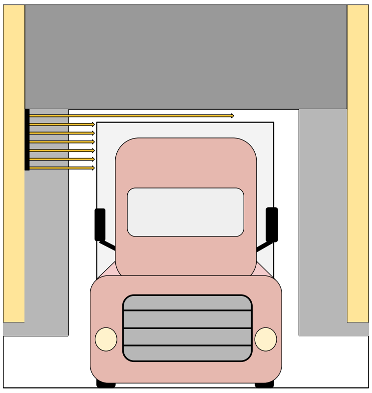
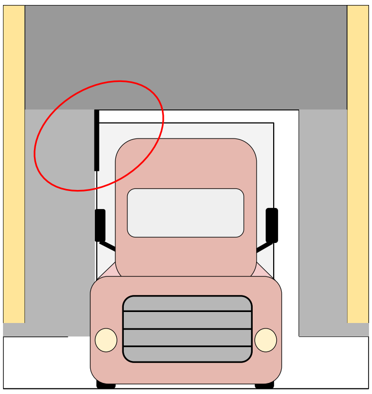
Figure 4.2. Generated concepts sorted by functional principle.

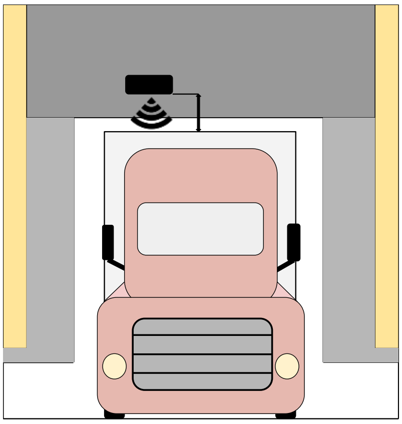
Throughout the concept generation phase, concepts that were deemed unreasonable were brought to attention and thoroughly discussed with the mindset of rather keeping them than removing them. If they were still considered unreasonable after the discussion, they were pruned from the set. Pruned concepts are presented below and are marked with a red X in Figure 4.2.

- Measure motor current draw through built in electronics
  - Since the motor cannot be used at stall to hold the system stationary, it would have to be polled to measure the necessary current to get it moving again. This would cause oscillations in the system and unnecessary wear since the motor would start when it is not needed to.
- Keep current counterweight
  - Too many problems today with tangling lines.
- Computer vision
  - A computer vision system for detecting deflection of roller was deemed too expensive with the need for a camera, a computer and software.
- Coupling between motor and shaft
  - Keeping current counterweight was ruled out, therefore this concept is pruned with it.
- Measure strain
  - Hang from springs with switches was pruned since the motor mount would affect the measuring of the spring extension, and the entire system would be significantly less robust/stiff.
  - Measure strain in the mounts of the roller was pruned due to the interference from the motor mount.
  - Generally, ASSA ABLOY has experienced problems with load cells in outdoor conditions and are therefore not keen on using them (M. Bejhed, personal communication, 15 February 2022).

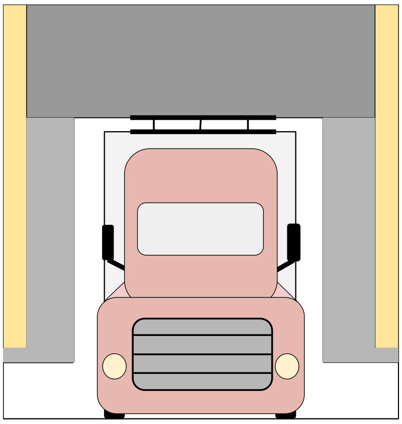
The concepts that were left are presented in Table 4.6.

Table 4.6. The concepts left after pruning

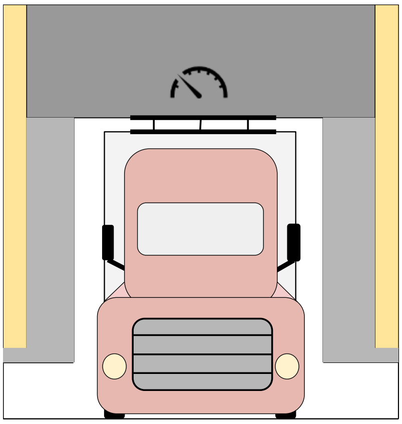
Concept	*Sketch*	*Description*
1		Controlling the position of the roller using a sensor that detects the distance from above to the roof of the truck. Can be done with for example ultra-sonic, laser or radar.
2		Vertical array of photocell sensors that detect the height of the truck.
3		Vertical contact sensor that detects the height of the truck.

4 

Sensor that detects relative distance from the edge of the roller to the roof of the truck.

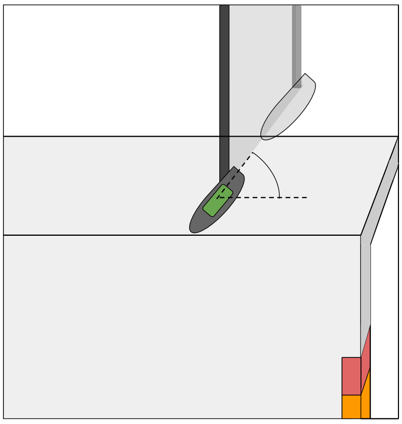
5 

Contact sensor that detects the edge of the roller's contact with the roof of the truck.

6 

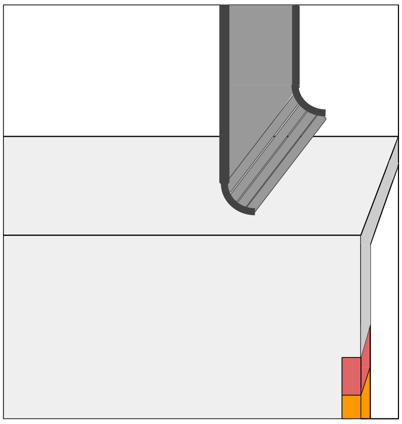
Force sensor that detects the amount of force applied by the roller to the roof of the truck.

7



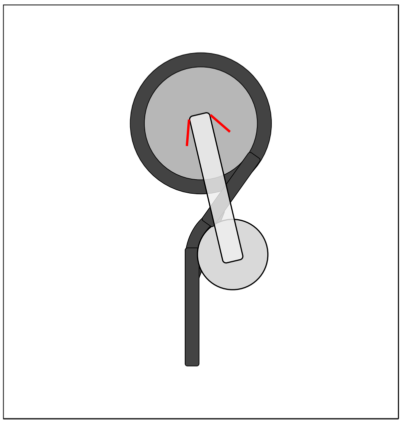
Tilt sensor, with or without lever, measuring the relative angle between the edge of the roller and its normal position (not resting on the truck).

8



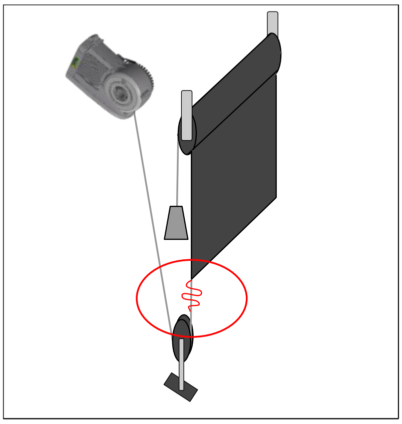
Horizontal weighted sections in roller that spreads the weight over a larger height, acting as a “buffer” for movement of the truck.

9



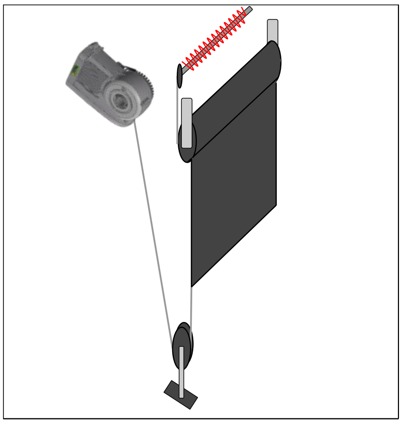
Lever with horizontal roller and limit switches. The horizontal roller stretches the roller using gravity. The limit switches are used for control of the position of the roller.

10



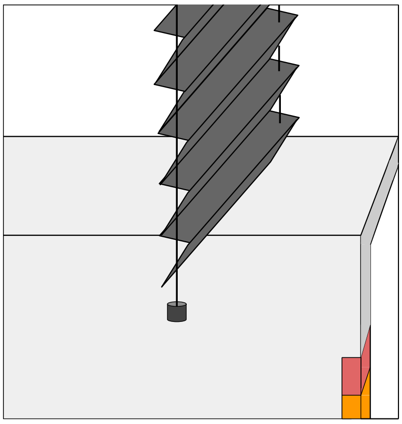
Motor pulling down the roller instead of unwinding. Controlling the position of the roller by measuring the extension of the guiding springs.

11



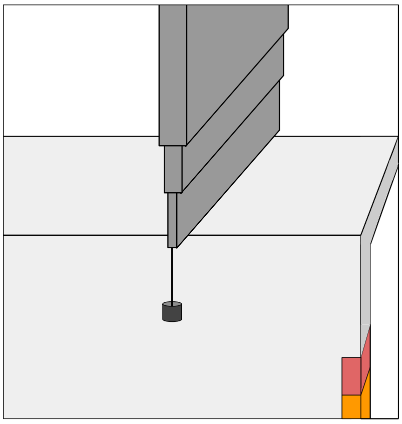
Motor pulling the roller down instead of unwinding. Spring on a shaft that stretches the roller.

12



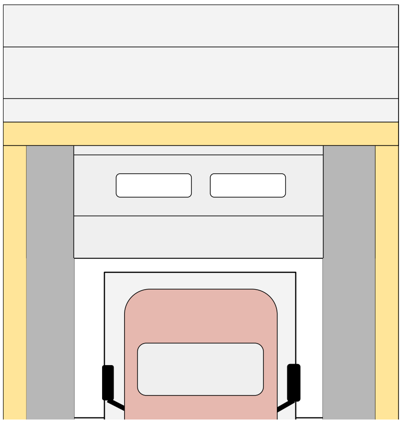
Accordion door instead of roller. No position control is needed since this is done by gravity.

13



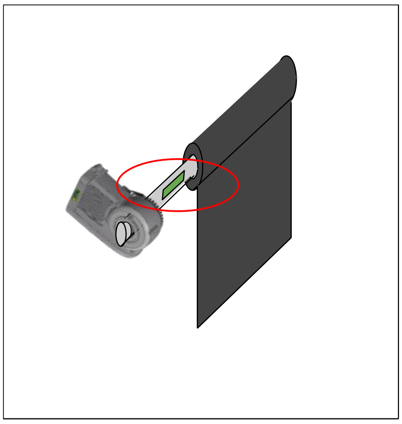
Telescopic door instead of roller. No position control is needed since this is done by gravity.

14

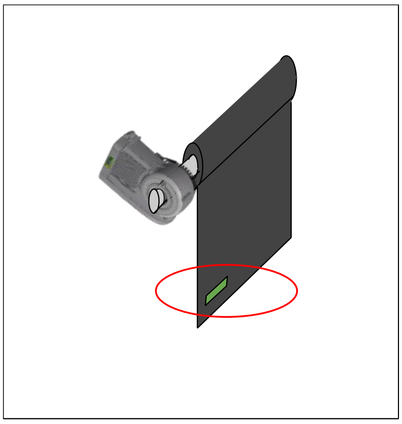
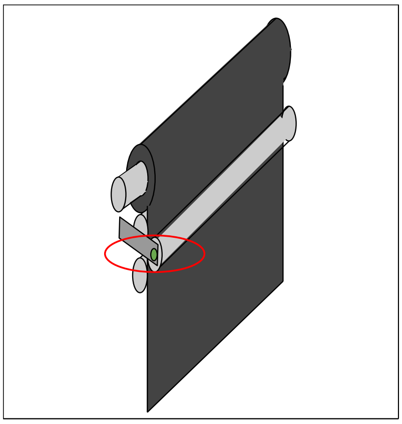


Hard door instead of roller that goes above the shelter.

15



Using a sensor to measure the torsional strain in the shaft and controlling the position of the roller according to this.

16		Using a sensor to measure the strain in the fabric of the roller.
17		Measuring the tension in the roller with sheet tension sensors.
18		Measuring the force in the motor mount.

4.3 Concept Selection and Concept Testing

To select and test the concepts, a workshop with engineers at ASSA ABLOY was held as a physical meeting and was scheduled for two hours. The agenda was as follows:

- Introduction of the problem to be solved by the concepts
- Presentation of concepts
- Discussion to receive feedback by the engineers
- Multi voting

Each member of the workshop voted for three concepts in prioritized order. Therefore, the votes were weighted when calculating the total amount of points for each concept, using the largest weight for each member's top vote and the least weight for the least prioritized vote. The result of the multi voting, which can be seen in Appendix E, was that concepts 7, 1 and 9 got the most points. However, another discussion was held after the voting regarding concept 12, the accordion door. An intuition decision was made to replace concept 9 with this. Therefore, concepts 7, 1 and 12 were chosen for further development.

4.3.1 **Prototyping & Test Rig**

To further refine and test the winning three concepts, a test rig was constructed. This model was made to resemble an actual weather shelter with the motor (CDM9) and large enough to make any critical parts of the concepts in a 1:1 scale. Thus, testing the principles without having to design full scale prototypes, saving time and money.

The test rig was constructed out of sheet metal and firstly drawn in SolidWorks CAD software, which can be seen in Figure 4.3. The model was made from 3mm galvanized steel sheets bent to shape. Since structural integrity optimization was not of any concern for the model, it was designed in a way that it can be intuitively judged to sustain the relevant forces at hand. From this model, drawings of all the sheet metal parts were produced and the parts ordered from a local business.

Figure 4.3. Test rig CAD.

Once the parts were produced and delivered, the test rig was assembled and tested without the concepts to validate the functionality. The real motor was used for this, along with the real control electronics. A picture of the assembled test rig can be seen in Figure 4.4.

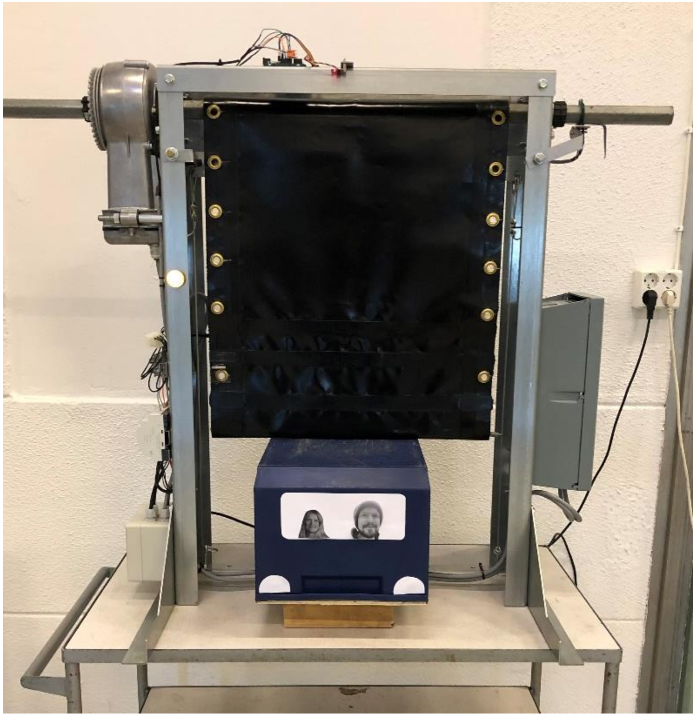


Figure 4.4. The assembled test rig with a mockup truck.

A Programmable Logic Controller (PLC) was used to simulate software changes in the CDM9 or an external microcontroller. The PLC used was an XD26 from Crouzet, along with their provided software for programming with functional blocks. This was chosen for convenience since it was already available in-house. With this hooked up to the control unit, the motor could be controlled from the PLC which could be programmed differently for each concept depending on sensor setup, limit switches, thresholds, and timers etc.

4.3.1.1 Concept 1: Distance measurement from above

Concept one is based on position control of the roller with regards to the roof of the truck through a distance measuring device, such as a laser or ultrasonic sensor. General discussions regarding which type of sensor would be best were held but decision was postponed until after concept selection. Therefore, the prototype was built using a laser Time of Flight (TOF) sensor available, together with an Arduino microcontroller to interpret the data. To track the position of the roller, the intention was to use the CDM9's built in encoders. However, due to not being able to modify the software of the CDM9 at this stage an encoder was constructed and mounted to the output shaft of the motor. It consisted of a 3D-printed indexing wheel and a photo-electric sensor. Furthermore, since this was placed after the transmission (outside of the motor housing) the resolution of this encoder was going to be lower than the built in. The encoder can be seen in Figure 4.5. The position of the roller was then mapped to the corresponding distance value read by the TOF sensor, and some hysteresis was added for stability. The setup can be seen in Figure 4.6.

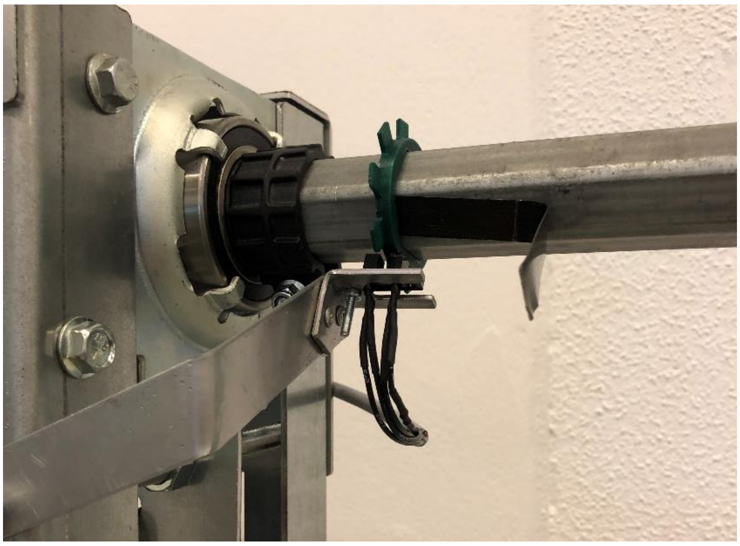


Figure 4.5. The encoder used for position control.

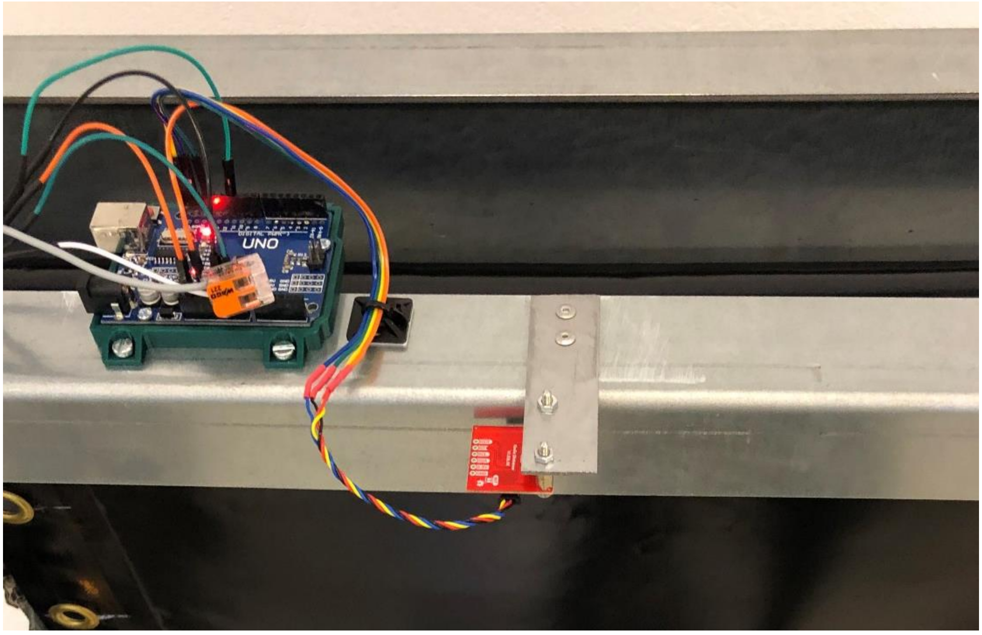


Figure 4.6. The TOF sensor and Arduino setup.

The Arduino was used to link the 3.3V sensor to the 24V PLC with parts already at hand to limit the time spent on waiting for deliveries. This was done by mapping the digital distance value of the sensor to a 0-5V PWM output of the Arduino, sent through a low pass RC-filter, to a 0-10V analog (ADC) input on the PLC. This setup only utilized half of the bandwidth of the 0-10V analog input, therefore losing some resolution, but when tested it was acceptable for the prototype.

4.3.1.2 Concept 7: Angle measurement

The angle measurement concept was based on a sketch of something similar to a duck, therefore called "the duck", and the working principle is a gravity-controlled pendulum and limit switches as can be seen in Figure 4.7.

Figure 4.7. "The duck" pendulum concept.

When the roller is not in contact with the truck, the duck will hang close to vertical, therefore activating the lower sensor, that sends a signal to the PLC that the roller is too high up and needs to be lowered. Once the duck comes in contact with the truck, it starts to tilt, biased in one direction due to the geometry of it, and the pendulum swings to a neutral state. If the roller is lowered too much or the truck is raised, the duck will lie down flat on the roof and the second sensor will be activated, telling the PLC that it needs to raise the roller. Both the lower and upper holes of the duck were going to be weighted to apply the proper tension to the roller and proper force on the roof of the truck. The specific weights were decided to be calculated if this concept was chosen as the winner, once again to save time and make the development process more streamlined and efficient.

Since the interface between the sensors and the pendulum was crucial for this concept, it was decided to test with a few different types of sensors in this stage, to get as good information of the system as possible. Therefore, three types of sensors were chosen: reed relays (switching), photo-electric sensors (switching), and a hall effect sensor (analog), see Appendix A.3.1. Unfortunately, the hall effect sensor delivered was not the correct one, and only had switching capabilities. Since the hall effect sensor and the reed relays both utilized a magnetic field as working principle, the hall effect sensor was discarded at this stage due to it being physically larger than the reed relays. Pictures of the sensors mounted in two 3D-printed duck-prototypes can be seen in Figure 4.8 and Figure 4.9 below.

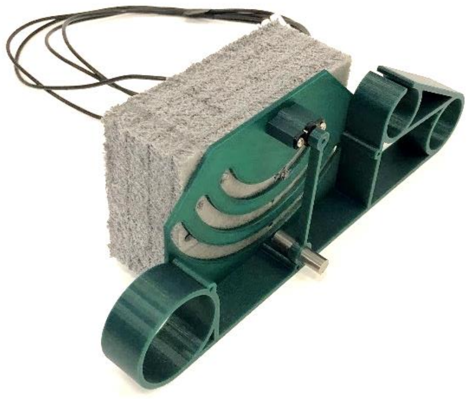


Figure 4.8. Reed relays and pendulum mounted in the duck.

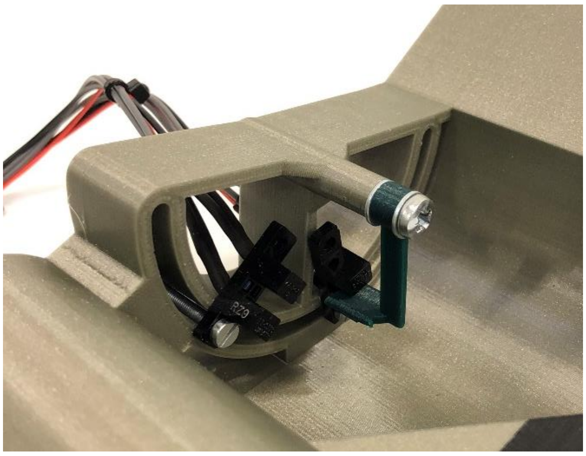


Figure 4.9. Photo-sensors and pendulum mounted in the duck.

Initial testing of the duck resulted in oscillations of the pendulum due to no damping of the swing. At first, these were handled with software hysteresis, in a way that a signal had to be active for a certain period to be considered a true signal, however this introduced a delay to the system. When a truck is loaded with heavy goods, the suspension is compressed, and the truck rapidly lowers. This step change means that the motor must react fast enough to keep the roller in contact with the roof of the truck, and the delay introduced was a potential issue. Therefore, damping of the pendulum's swing was investigated as well. Magnetic damping and rotary dampers were both tested and pictures of these setups can be seen in Figure 4.10 to Figure 4.12. The rotary damper uses silicone fluid resistance for mechanical motion damping (Components, 2022). Mounting the damper on the base of the pendulum, which can be seen in Figure 4.8, decreases the oscillations of the pendulum.

Figure 4.10. Parallel mounted metal plate.

Figure 4.11. Radially mounted metal plate.

Figure 4.12. Rotary damper.

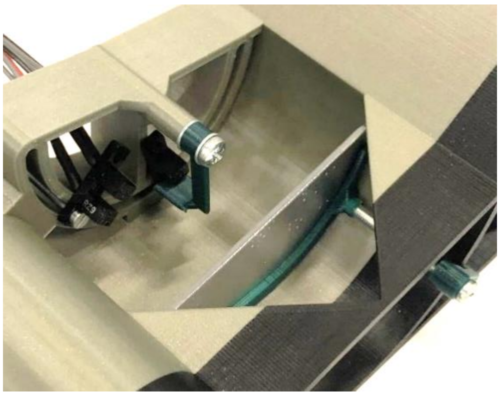


Figure 4.13. Mounted parallel magnetic brake.

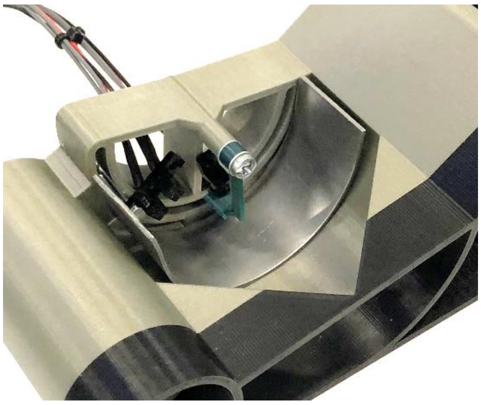


Figure 4.14. Mounted radial magnetic brake.

The mounting orientation of the magnet (see Figure 4.8) and its poles made it so that the radially mounted sheet of metal (Figure 4.14) did not dampen the swing enough, and therefore that option was discarded. The parallel mounted sheet dampened the pendulum sufficiently, however the attractive force of the magnet towards the plate negatively affected the mounting, being non-symmetric. The rotary damper worked as desired and was chosen as the way to go for this concept.

4.3.1.3 Concept 12: Accordion door

This concept was based on the idea of a folding curtain with eyelets along the edges that the guiding wires run through. Another key factor for this concept was that the raising and lowering was done in a way that no matter the height of the truck, the motor would always go to the same position. Therefore, the issue of continuous control is eliminated from the system since the roller could run freely up and down the guiding wires, thus letting gravity completely take care of the contact between the roller and the roof of the truck. This was done by instead of rolling up the roller on the output shaft of the motor, two lifting lines were use. The lines ran from the shaft to the bottom of the roller, through a hole in a ledge attached to the roller, and then fixed to a free-hanging weight. This allows for the line to continue to unroll even though the roller has stopped moving (come in contact with a truck), and the motor, as previously mentioned, to only have two positions to go to no matter the height of the truck. A picture of this system can be seen in Figure 4.15.

Furthermore, if even more rigidity was needed, this system allowed for the guiding wires to be replaced by steel tubes or similar.

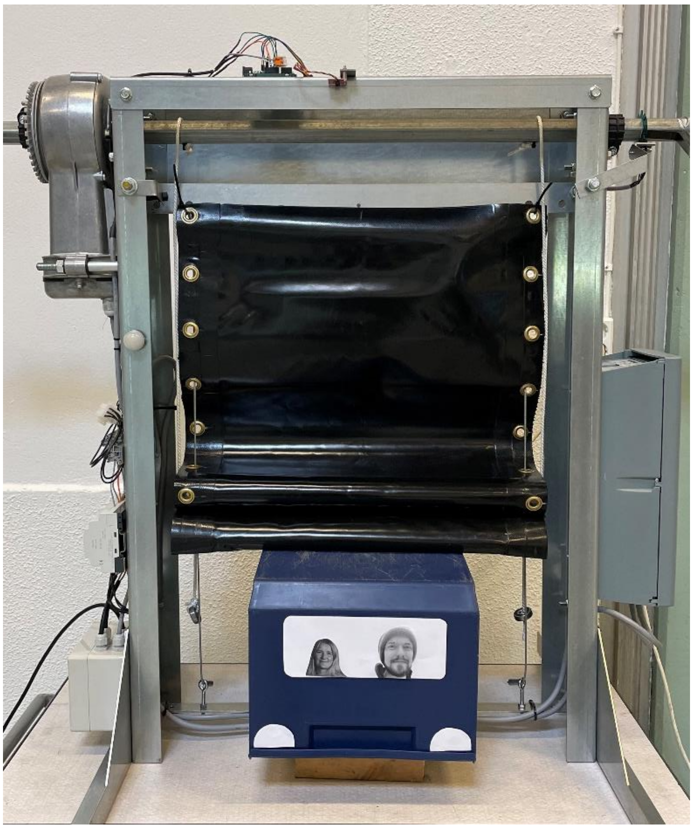


Figure 4.15. Assembled accordion test rig.

A decision to make the concept in a larger scale was made, since the concept on this smaller test rig was not sufficiently representing full scale. There was mainly one thing that needed to be evaluated: the roller’s behavior when being 3.5m wide. Drawings of larger sheet metal parts, roller and a bottom damping in cellular polyethylene were sent to external suppliers. Once the products were delivered the new test rig could be assembled, shown in Figure 4.16. A picture of the bottom damping and the lifting mechanism can be seen in Figure 4.17.

Figure 4.16. Assembled larger rig.

Figure 4.17. Close-up picture of assembled larger rig.

Testing this larger version immediately visualized the issue at hand. The roller had trouble with folding the way it was intended since it was too wide, causing it to completely fall to one side, see Figure 4.18. This issue was fixed and will be further discussed in the detail design section.

Figure 4.18. Roller falling to one side.

4.3.1.4 Communication with the motor

To get the concepts communicating with the motor, different solutions needed to be implemented. The distance measuring concept (concept 1) needs some sort of microcontroller to interpret the sensor readings and be working as another node in the RS485 serial system present in the control unit (outside the scope of this thesis). The angle measurement concept (concept 7) is simpler, where only two digital signals are needed. This could be performed with one single port on the CDM9, with different rectification or Zener diodes to modify the 24VAC into unique signals. The accordion concept (concept 12) is the simplest one since it does not require any additional electronics due to the motor only working between two fixed positions. The implementations of the communication were decided to be prioritized the least since it brought the least value to the concept development process.

4.3.2 **Concept Selection**

To select the winning concept out of the three remaining, another workshop with the same attendees as the original workshop was held. In preparation to this, a concept selection matrix was created and presented along with the physical prototypes. Concept 7 was used as a reference concept, meaning that all metrics was set to 0 for this concept. To compare the concept with the other two, +/++ was used for a performance better than the reference concept, and -/-- was used for a performance worse than the reference concept. The metrics with importance one was weighted as two (++ or --) and metrics with importance two as one (+ or -). The concept selection matrix (see Table 4.7) was used as a tool to help visualize the different strengths and weaknesses of the concepts, but the final decision was done by a vote.

Table 4.7. Concept selection matrix

Metric number	*Metric*	*Concept 1*	*Concept 7 (reference)*	*Concept 12*
	The new system functions the same way as the current system			
1	The system detects if there is no truck in the shelter and retracts	0	0	0
2	The top roller follows the truck throughout the (un)loading procedure	--	0	++
3	The top roller is stretched by a force of	0	0	0*
4	The new system is operated the same way as the old system	0	0	0
5	The top roller is unwound in less than	0	0	0
6	The open area between roller and shelter is less than for the current system	0	0	++
	The system is designed for outdoor use			
7	The top roller withstands the wind pressure specified by SS-EN 13561:2015		Not evaluated	
8	The system is tangle-free	0	0	--
	The system has high compatibility			
9	The motor detects if it is an SIR-unit automatically	0	0	0
10	The system is retrofittable	0	0	-
11	The motor system can be used in other products without manual modifications	0	0	0
	The system is easily serviced			
12	The system has few parts	+	0	0
13	The motor is easily replaced	0	0	+
14	The system is easily assembled	+	0	-
	The system is safe			
15	The top roller operates normally after a truck drives away while the roller is down		Not evaluated	
16	The system fulfills all current and applicable safety regulations		Not evaluated	
	The new system is economically viable			
17	The new system is cheaper than the old		Not evaluated	
	Result	0	0	+

*Not relevant for this concept.

Metric number 3 was not considered for concept 12, since the construction of the accordion roller meant that it was supported by the guiding wires along its entire length, therefore not requiring the same stretching force to be kept from bulging under wind load.

Metric number 7 was not evaluated. However, the accordion door concept's ability to withstand wind could be compared with the current weather shelter. This was compared by simply pushing the current weather shelter by hand, and then doing the same with the accordion door concept. There was a large difference in how much the roller moved horizontally, and therefore the conclusion could be made that the accordion door was better at withstanding wind.

Strengths and weaknesses not clearly visualized by the concept selection matrix were also discussed during the workshop for each concept and are briefly summarized in Table 4.8 below.

Table 4.8. Pros and cons discussed during the workshop

Concept	***Pros***	***Cons***
1 (distance sensor)	No wires in roller No truck-in-place sensor required Protected placement of sensor Reading not affected by wind Retrofittable	Microcontroller necessary Sensor affected by dirt Roller not robust Step response is poor
7 (the duck)	Cheap parts No microcontroller needed Retrofittable	Exposed placement Wires in roller Roller not robust Step response is poor Sensor reading affected by bulging due to wind load
12 (accordion)	No continuous control needed Free motor placement Seals the best Rigid and robust	Lifting lines may tangle Complex roller design Not retrofittable

The results from the vote can be seen in Table 4.9 and meant that concept 12, the accordion, was the one to be continued with. However, all concepts were discussed thoroughly, and the other two concepts were not scrapped but put on pause until the final testing of the winning concept was done.

Table 4.9. Results from the second concept selection vote

Concept	*Result*
12 (accordion)	1
7 (the duck)	2
1 (distance sensor)	3

During the workshop, discussions on how the winning concept would behave in a cold climate arose. For this reason, a decision to perform a cold chamber test was made (more on this in section 6, Testing and Refinement). Discussions on testing the concept at customers' docking systems were also held but chosen to not be done due to lack of time.

It was also brought to attention that the system would preferably be able to be mounted by a single technician, while the old system required two. Different solutions for this issue were discussed and deemed plausible, but no further effort was made to prototype and test them at this stage.

Furthermore, a retrofittable version of the winning concept was suggested at the workshop. This was not included in the time frame available but more information regarding this can be found in section 8.3, "Future Work".

4.4 Set Final Specifications and Plan Downstream Development

To set the final specifications, the target specifications were translated to final specification and adapted to the winning concept's performance, see Table 4.10. Due to the design of the winning concept, metric number 3 was irrelevant, but kept for consistency.

To finalize the large-scale prototype on time, the remaining development work was planned. What was planned to be done the remaining time of this thesis is as follows.

- Cold chamber test of the prototype
- Creating a bill of materials (BOM)
- Assembly of final concept in SolidWorks
- Finalizing electronics and software signaling
- Documenting the work (report writing)

Table 4.10. Final specifications.

Metric number	*Need numbers*	*Metric*	*Target value*	*Unit*
		The new system functions the same way as the current system		
1	1	The system detects if there is no truck in the shelter and retracts	Yes	Binary
2	3	The top roller follows the truck throughout the (un)loading procedure	Yes	Binary
3	3	The top roller is stretched by a force of	81	N
4	5	The new system is operated the same way as the old system	Yes	Binary
5	6	The top roller is unwound in	< 10s	Seconds
6	7	The open area between roller and shelter is less than for the current system	<300	cm^2
		The system is designed for outdoor use		
7	2	The top roller withstands the wind pressure specified by SS-EN 13561:2015	2	Wind class
8	13	The system is tangle-free	Yes	Binary
		The system has high compatibility		
9	8	The motor detects if it is an SIR-unit automatically	Yes	Binary
10	11	The system is retrofittable	Yes	Binary
11	12	The motor system can be used in other products without manual modifications	Yes	Binary
		The system is easily serviced		
12	4	The system has few parts	32	Pieces
13	9	The motor is easily replaced	1	1-5
14	10	The system is easily assembled	1	1-5
		The system is safe		
15	14	The top roller operates normally after a truck drives away while the roller is down	Yes	Binary
16	15	The system fulfills all current and applicable safety regulations	Yes	Binary
		The new system is economically viable		
17	16	The new system is cheaper than the old	Yes	Binary

5 Detail Design

In this section, the digital prototype is presented. A detailed design of the final prototype was constructed, and certain design decisions were taken to fix problems that arose. The custom parts described in this section are used in the final prototype but are also designed to be used in the final product. These parts could be used directly in the real weather shelter, but possible further detail design for better result is described. A BOM was also created with the unique parts for this concept along with a conclusion regarding the cost compared to the original weather shelter.

5.1 Digital prototype

A digital model of the prototype is shown in Figure 5.1, to give the reader an overall picture of the prototype before describing the components in detail.

Figure 5.1. Digital model of prototype.

5.2 Standard Parts Used

Several already available in-house components, which are a part of the standard product range, were used for the winning concept. The reason for this was to reduce the amount of work needed with designing or ordering new parts. Using these, the number of unique parts in the company portfolio is lower than if new parts were designed or ordered, which is positive from an administrative, warehousing, and serviceability perspective, but potentially negative from a functionality optimization perspective. These parts are presented in Table 5.1.

Table 5.1. In-house parts that were used for the prototype

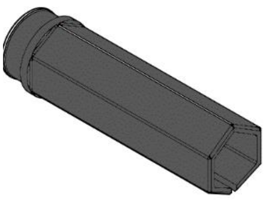
Image	***Description***
	Pulley

Shackle

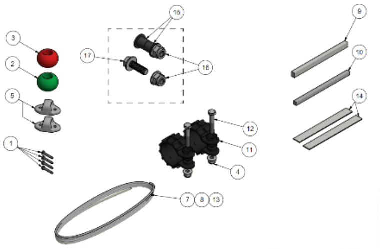
Cable drum

Guiding wire, 3mm

Hex shaft, L=230mm



Adapting sleeve



CDM9 Assembly kit

CDM9 Mechanical Unit

5.3 Custom Parts

Some components needed were not a part of the standard product range. These parts were either found in-house or designed and ordered from a supplier. These parts will be described below.

5.3.1 **Line Weights**

To keep the lines tight when not lifting the roller, steel weights were used, which were available in-house, but not a part of the standard product range. These also served another purpose: as stoppers to lift the roller during retraction. The masses of the weights were not critical if the lines were kept reasonably tight so that they were wound around the drum properly, and the masses were negligible compared to the entire roller assembly. Therefore, no effort was made testing different masses or sizes. The mass of them was 465 grams per weight, and the weight can be seen in Figure 5.2.

Figure 5.2. Digital model of line weight.

5.3.2 **Motor and Roller Mount**

To get the roller to seal as tightly as possible to the weather shelter, the idea of mounting the motor not in line with the roller but on a wall inside the shelter arose. Thanks to the design with the lifting lines, the use of pulleys was introduced to be able to direct the lines wherever wanted and the balance shaft could be removed. This allowed for the motor to be mounted for example on the wall inside the shelter, allowing for the roller to be wider, not having to leave space for the motor on the side, thus sealing better towards the shelter.

Therefore, a motor mount had to be designed and ordered from a supplier. In line with the rest of the prototype this was designed out of 3mm sheet metal, and the digital model can be seen compared to the real part in Figure 5.3.

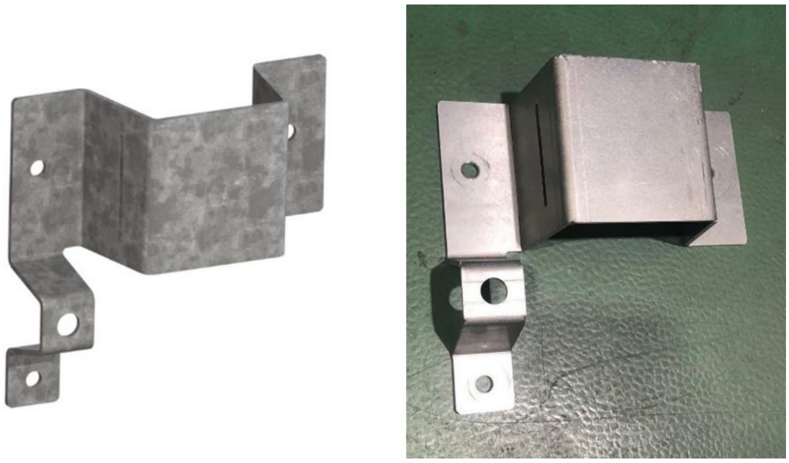


Figure 5.3. Motor mount, digital and real part.

The mount can be attached to any flat surface, and then the motor is strapped to it. This design helps with serviceability as well since the technicians can more easily access and replace the motor if it is mounted slightly inside the weather shelter instead of on the balancing shaft as today.

This bracket could still be optimized a bit, since it was noticed during testing that the tension from the strap was not high enough for keeping the motor from moving a bit between load cycles. This motion could cause the strap to wear and tear off in the slit in the sheet metal. In Figure 5.4 the motor can be seen mounted to the bracket, with the area of concern marked.

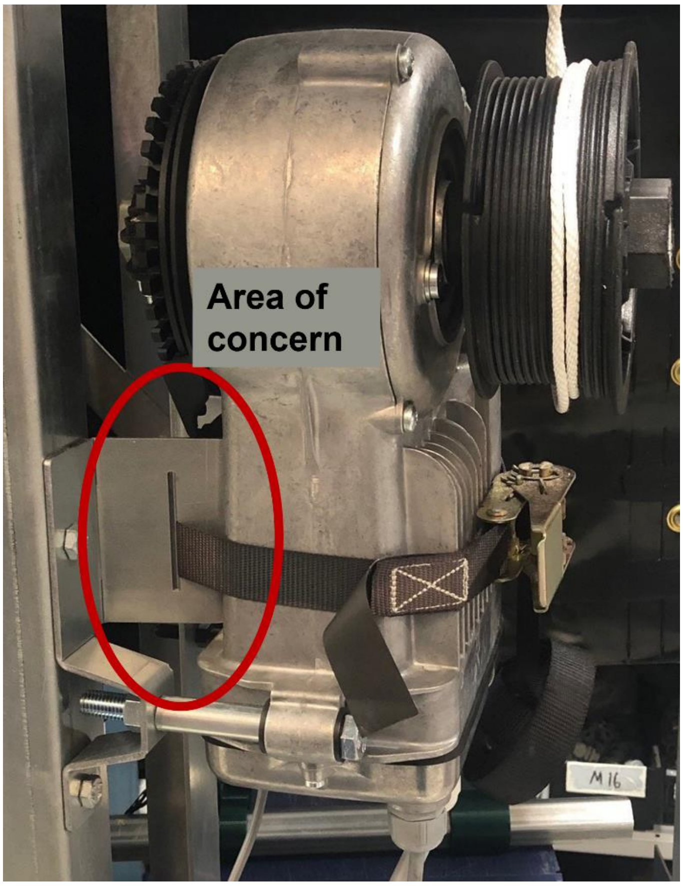


Figure 5.4. Motor mounted on bracket.

Since the balance shaft of the system was removed for this concept, a way to mount the roller to the weather shelter was needed. A simple angled bracket was designed with the intention of mounting it under the roof of the weather shelter, with holes for the roller to mount into, see Figure 5.5. This bracket was used in the prototype and is intended to be used in the product as well. However, to be able to install the roller single-handedly, an idea of another bracket was introduced. This bracket would be mounted to the roof firstly, and then the roller package with the second bracket mounted to it would be lifted into place and hanged from the first bracket, and then bolted together. This idea was not realized during the time frame available and therefore needs to be investigated further.

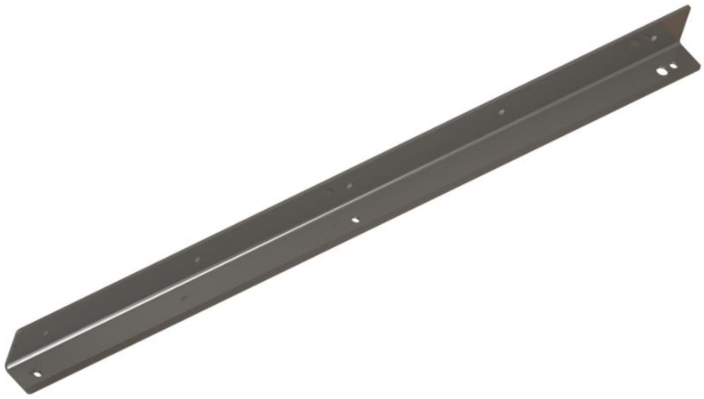


Figure 5.5. Roller mount.

5.3.3 Foamed Covered Impact Protector

The polyethylene (PE)-foamed damper in the bottom of the roller was designed and ordered from a supplier. It was iterated a couple of times to make it as good as possible while keeping the estimated cost down. To do so, scrap wood packing material was used to create the lifting mechanism and the crate that goes along the width of the damper. This can be seen as a digital model in Figure 5.6 and the real part in Figure 5.7. This provided enough rigidity to keep the damper from bending and therefore obstructing the folding of the roller. No iterations of the design of the PE damping foam have been done, but there are a few things that could be optimized and tested. The dimensions of it could possibly be minimized for cost reductions, and the overall design could be investigated further to facilitate the assembly process and serviceability.

Figure 5.6. Digital model of PE-foam covered impact protector.

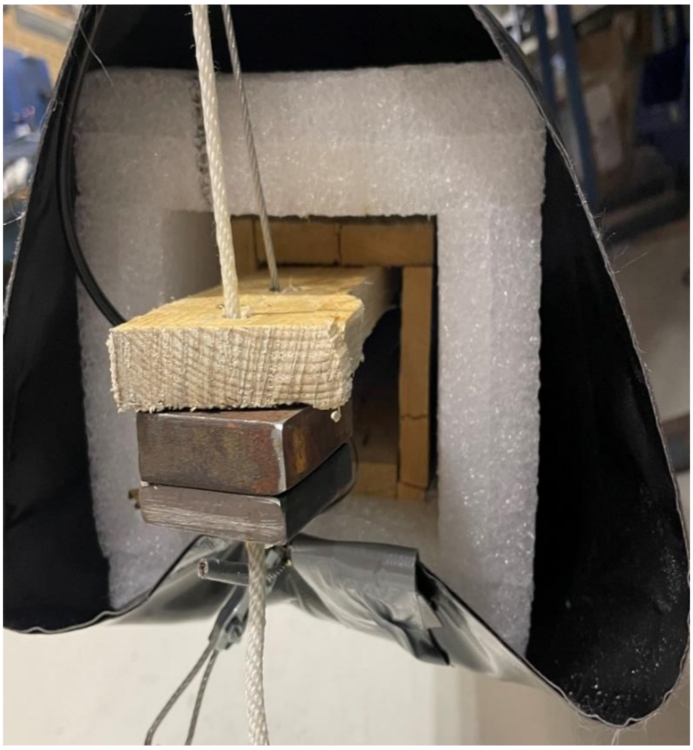


Figure 5.7. Close-up picture of the lifting mechanism.

5.3.4 **Roller Design**

The main strength of the winning concept was its roller design and functionality. During initial testing, the suspicion of the roller failing to fold as intended was confirmed (see Figure 4.18 in section 4.3.1.3).

To fix the problem with the roller falling to one side, thin plastic sheets for stiffening the roller were designed and introduced to the concept. Iterating over different solutions, the best one turned out to be horizontal wooden round bars along the width of the roller in combination with smaller vertical strips of plastic to guide the folding behavior. This can be seen prototyped in Figure 5.8.

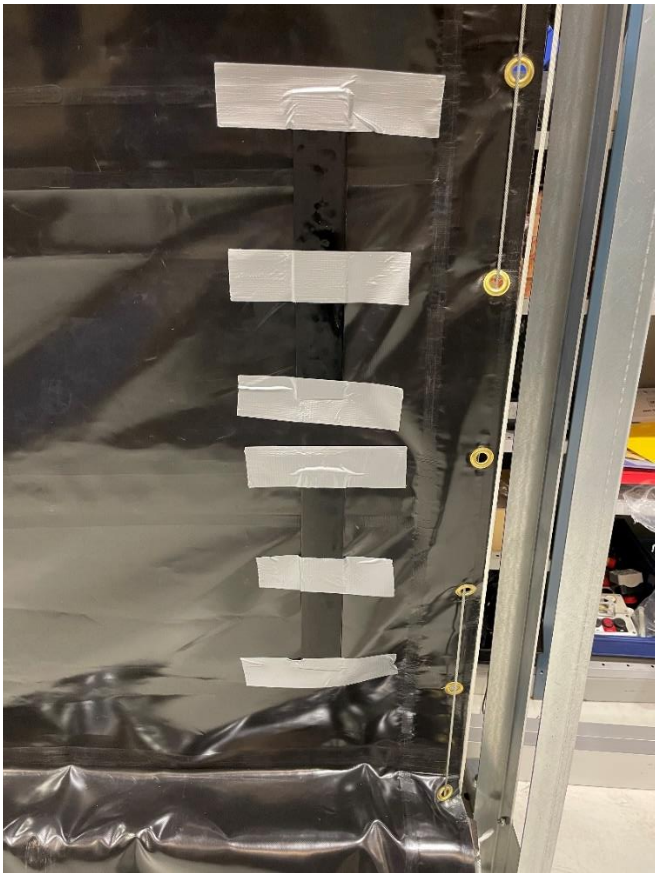


Figure 5.8. Plastic strips for guidance.

However, the vertical plastic strips only slightly improved the folding behavior, and the decision whether to keep them or not should be taken after analyzing the manufacturing cost, which is not included in the scope of this thesis. When not using the vertical plastic sheets, some creasing occurred at the edges of the roller, which can be seen in Figure 5.9. The creases are circled in red.

Figure 5.9. Folding behavior without vertical plastic sheets.

These changes resulted in the roller folding the way it was intended, which can be seen in Figure 5.10. The crease seen in Figure 5.10 is due to the eyelets being in line with the line of the fold. These eyelets were initially used to decide the correct spacing, allowing for testing with much smaller but higher number of folds, and will therefore be removed for the final version.

Figure 5.10. Improved folding behavior.

5.4 Bill of Material and Estimated Cost

A BOM is presented in Table 5.2. Based on discussions with supervisor Anders Löfgren, the new system is estimated to be equally priced or cheaper than the old.

Table 5.2. Bill of materials.

Parts	***Quantity***
Line pulley	3
Shackle	3
Cable drum	1
Hex shaft, L=230mm	1
Retaining sleeve	1
Guiding wire, 3mm	1
Roller mounting bracket	1
Steel thimble	2
Eye bolt	2
Duplex wire clamp	2
Adapting sleeve	1
CDM9 Assembly kit	1
CDM9 MU	1
CDM9 mounting plate	1
PE foamed crate	1
Wood stiffener	3
Vertical stiffener	4
Roller	1
Line weights	2

6 Testing and Refinement

This section describes the execution of the cold chamber test of the prototype. The testing resulted in no further refinement of the concept. No additional testing was made since the delivery time of some components took longer time than expected.

In this phase, the full-scale prototype of the winning concept, the accordion door, was tested to verify the functionality of the product. The entire prototype of the winning concept was placed in a cold chamber and cooled to minus 20°C. After waiting for a few hours to ensure that the entire prototype was cooled down to the right temperature, the prototype was tested and evaluated. The test was made in two parts: 1) when having the roller in the lowest position for a few hours before performing the test; 2) when having the roller in the top position for a couple of hours before performing the test. The result for both sets was that the roller fabric stiffened, but the folding behavior worked at least as good as before and is shown in Figure 6.1. In other words, the roller folded in a controlled manner without creasing. Due to this result, no further refinement of the concept was made.

As previously mentioned, additional testing was also planned for this phase of the development process, but due to the delivery time of the custom parts took longer than expected, these could not be performed. More information regarding these tests can be found in section 8.3.

Figure 6.1. Cold chamber testing the prototype.

7 Results

This section includes the result of the thesis with regards to the goals specified in section 1.4. Furthermore, it presents a physical prototype of the winning concept.

To meet the high requirements of robustness, the new motor package can be integrated with the existing platform as shown in Figure 7.1. Mounting the motor on the wall on the inside of the docking system, resulting in a wider roller and therefore better separation of inside climate from outside climate, also allows for easier access by the service technicians, increasing serviceability. Furthermore, letting the guiding wires run through the roller eyelets in combination with the horizontal stiffeners provides significantly increased rigidity compared to the original product.

Since this concept means mechanical position control of the roller, no sensors need to be integrated with the platform. If sensors were to be used, a solution such as concept one (distance measurement) or concept seven (the duck) are recommended. Since these concepts were put on pause once the winning concept was chosen, an unambiguous answer to the question “What type of sensors are best suited?” cannot be given.

Figure 7.1. Physical prototype of the winning concept.

8 Discussion

This section includes discussions regarding the methodology, result, future work, and project evaluation. With regards to the goals stated in section 1.4, a conclusion of the thesis is presented.

8.1 Methodology

The adaptation of Ulrich and Eppinger (2008)'s methodology used by the authors worked out well. Incorporating the "Discover" phase from the Double Diamond methodology into the research phase suited this project, since the knowledge about the product beforehand was minimal. To take the time to investigate and understand the issues at hand helped pave the way for a concept development phase without detours.

Since the product worked on in this thesis was technically well-defined, and already designed (the entire weather shelter), the process of collecting needs and establishing target specifications might have wasted some time. Focusing more on the concept development earlier in the process could have allowed for the concepts to be finalized sooner, giving more time for testing, and refining of the winner. On the other hand, collecting needs and establishing target specifications was helpful since the authors became familiar with the product.

To save additional time, instead of creating physical prototypes for the top three concepts, digital prototypes could have been made. This would have saved a lot of time, but the possibility to see, touch, and test the concepts as physical prototypes proved very valuable for the development process and was considered the right choice.

Having workshops together with employees with a lot of knowledge about the current weather shelter was very helpful and supported the work moving forward. Having a clear goal, which was stated to the participants in the beginning of each session, on what should be the outcome contributed to the successful result of the workshops. However, the list of participants could have been reconsidered. No service technician or end user of the weather shelter participated in the workshops to give their insight. On the other hand, the participants had a long experience with the weather shelter, giving them a good insight in what the service technicians and users saw as problematic.

8.2 Result

In the beginning of the thesis, it was not realized that the winning concept could be using mechanical position control. The two issues described in section 1.4 were therefore established with the intention of using some sort of sensors. Since the winning concept does not use any sensors, the thesis went another way than expected. However, the mechanical position control was one of the most important advantages with the winning concept compared to the two other concepts since it eliminated the issue with a slow response to a step change. A disadvantage with the winning concept is that the system probably will not handle trucks with canvas roofs. These types of trucks have beams on the roof along the width of the truck that hold up the soft fabric. If the truck were to drive away before the roller being retracted, there is a risk that the roller will get stuck in between these frame sections and brake something. However, this is a disadvantage with the old system as well and is therefore considered as not too problematic.

The design of the winning concept, compared to the other two concepts, was more suited for making a prototype. The result could have been different due to this reason. For example, not being able to get into the software of the motor resulted in having to create a separate encoder used for position control for concept one (distance measurement). This led to lower resolution and a prototype not showing concept 1's full potential. Furthermore, implementing a PID-regulator instead of the current on-/off-control could greatly increase the performance, minimizing the delay in the step response. These differences in the prototypes' performance might have given the winning concept an unfair advantage, with the perception of working better.

8.3 Future Work

8.3.1 **Prototype Testing**

To test the decisions made in this thesis in real-life applications, the concept could be tested at a customer's docking systems. Therefore, beta prototypes need to be manufactured. Once these prototypes are done, the weather shelter can be mounted and tested on real docking systems. What should be tested is the concept's ability to withstand wind and to see what happens in rainy weather. A life cycle test is also recommended, as well as testing what happens if used incorrectly or hit with a truck to validate the safety.

8.3.2 **Detail Design**

Depending on the outcome of the testing described above, further refinement of the custom parts might be needed. Furthermore, what is suggested in the detail design section also needs to be done. These suggestions are presented below.

- Motor bracket functionality and rigidity improvements
- PE-foamed damping design and cost optimization
- Mounting bracket for mounting the system single handedly
- Horizontal stiffener wood quality and shape

Designing parts for retrofitting the concept on current weather shelters at customers' docking systems was suggested at the last workshop as well. This was discussed to be a chain drive system with a clutch mechanism, similar in design as to simple rotating combination locks, so that the current motor could be replaced with the CDM9, but the same roller and balancing shaft as already mounted could be used. No further investigations into this solution were included in this thesis.

8.3.3 **Cost Analysis**

Before the product is manufactured, a complete cost analysis should be done. This needs to be done to set a fair price towards the customer and to see if the product gives profit to the company. As previously mentioned, the new system is estimated to be equally priced or cheaper than the old system.

8.3.4 **Production Planning**

Another thing to be done later is production planning. Production planning contributes to more efficient use of resources and minimize the risk of, for example, delays in the production system. This was outside the scope of the thesis, but during discussions regarding serviceability the following idea was discussed.

Regarding the production of the roller, the roller should preferably come out of the production line as a package together with the bottom damper, guiding wires, lines, and weights all bundled up. This will facilitate the assembly of the weather shelter since the service technician can easily mount these components as one part. But how this should be done efficiently in production is something that needs to be investigated further.

8.4 Project Evaluation

The first few weeks of the thesis was spent at LTH, because of the restrictions at ASSA ABLOY due to the Covid-19 pandemic. This resulted in having a lot of time to spend on report writing since no practical work could be done at LTH. It complicated the research phase since it was harder to acquire information regarding the current weather shelter properly, and not being on site to talk to people working with the product daily. When the restrictions eased and time could be spent at ASSA ABLOY, there was no proper workstation for the authors which slightly impeded the work, but this was solved shortly. Thus, the start could have been more effective even though the time spent deriving the methodology was not in any way wasted.

Something that has been very appreciated is the trust and faith in our work, depicted in the full social and economic support of the development of the prototypes. This, in combination with the aim to work as much as possible together on-site instead of dividing the work and working remotely, has greatly contributed to the experience of this project.

For the work distribution, time management and other project planning-related information, see Appendix D.

8.5 Conclusion

Even though additional testing and validation remains, a promising and well worked-through solution to integrating the new motor with the existing weather shelter has been proposed. The prototype provides value both to the end user for its increased rigidity and sealing capabilities, and the company by modernizing the equipment and keeping the cost equal to or lower than the current product. Since the proposition utilizes mechanical control, no specific sensors can be recommended without further development of the secondary and tertiary concepts.

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Appendix A Electrical Components and Control Theory

This appendix presents basic information regarding discrete components, sensors and controllers used in this thesis.

A.1 Discrete Components

A.1.1 Ideal Diode

The ideal diode model depicts the diode like a hydraulic check valve, on or off. The diode only allows the current to flow in one direction. In the ideal case there is no voltage drop over the diode but in reality, there is. (Rizzone & Kearns, 2016)

A.1.2 Zener Diode

Another property of the semiconductor diode is that when a sufficiently large reverse-bias voltage is applied, the diode conducts current again, but in the reversed direction. This phenomenon is known as Zener breakdown and is useful since the characteristics allows for an almost constant voltage across the diode for a wide band of currents. The Zener-diode is a class of diodes taking advantage of the reverse-breakdown characteristics of a semiconductor diode. The Zener diode is for example used in voltage regulator circuitry. (Rizzone & Kearns, 2016)

A.2 Integrated Components

A.2.1 Opto-coupler

The opto-coupler, or opto-isolator as it is also known, uses LEDs and photodiodes to transfer signals between two circuits without wires. This electrical insulation is used to separate and protect a sensitive system such as a computer from for example power electronics that run a motor, that otherwise could damage the computer. The non-linear properties of diodes means that an opto-isolator is very bad at transferring analog signals, but very good at digital ones. The opto-coupler can be used in an inverting configuration, meaning that a high signal on one side is a low signal on the other. (Rizzone & Kearns, 2016)

A.3 Sensors and Controllers

This section presents theory regarding sensors and two types of controllers.

A.3.1 Sensors

A sensor is a device that generates an output based on an input, which is generally called a measurand. Transducer and sensitive interface are the two major components of a sensor. The sensitive interface interacts with a measurand, which causes a change in how the transducer operates. This change makes the transducer produce a signal, which is translated into information that the data acquisition system can read. The transducer converts one form of energy to another form of energy through a transduction process. (Kalantar-zadeh, 2013)

An example of a sensor is the reed switch. Normally, a reed switch consists of two overlapping surfaces in a tube filled with inert gas. These surfaces attract each other and completes the circuit when being exposed to a permanent magnet. Retracting the magnet will make the surfaces lose contact and break the circuit. (Zhang, 2008)

Photoelectric sensors are widely used in industrial applications today. Most of the photoelectric sensors consists of an emitter, such as a light emitting diode, and a receiver to detect the light source. This beam of light can be used to detect the presence or absence of an object. Photoelectric sensors can be categorized in three different categories: through beam, retroreflective and proximity. Through beam photoelectric sensors have the emitter and detector placed on the opposite path of the target, and sense presence when the light beam is broken. Retroreflective photoelectric sensors have the emitter and detector in the same housing and a reflector that reflects the light beam across the path of the target. Proximity photoelectric sensors have the emitter and detector in the same housing and relies on the reflection of the surface of the target. (Zhang, 2008)

Another type of sensor is the hall effect sensor, which have a wide range of applications and are commonly used in industrial applications to sense position, distance, and speed. Detection of presence and magnitude of a magnetic field is done using the Hall effect, and the sensors are available with both analog and digital outputs. Two advantages with hall effect sensors are that they are not affected by ambient conditions, such as humidity and dust, and that they work over a wide temperature range. A disadvantage with hall effect sensors is that since they work on the principle of a magnetic field, external magnetic fields may affect the sensing. (AZoSensors, 2022)

A.3.2 Controllers

To make use of the sensor, its signal needs to be processed. This can be handled by for example a microcontroller, which is a compact integrated circuit included in many engineering applications today. With built in memory, clock, A/D-conversion, and other functions they offer a lot of functionality for a small prize, and they are used in embedded systems, control systems, the automotive industry, and many more. Microcontrollers provide the possibility to incorporate advanced logic to the application, having many ports and being programmable. (Rizzone & Kearns, 2016)

A programmable logic controller (PLC) is a ruggedized computer used for industrial automation. PLC's process data received from input devices, which triggers outputs based on pre-programmed parameters. The input and output modules can be either analog or digital. Sensors are an example of an input device and relays an example of what the outputs might include. PLCs provide a flexible and robust control solution and are adaptable to almost any industrial application, for example monitoring and recording run-time data or automatic start and stop of processes. (Unitronics, 2022)

A.4 Control theory

There are a couple of different control theories touched on in this thesis. They are briefly presented below, in an order from simplest to most complex. Note that there are other controllers available, like feed forward and LQR-controllers, but these are outside the scope of this thesis.

A.4.1 Open-/Closed-Loop Control

Open loop control means that that no feedback from the system to be controlled exists. An example of this could be a temperature controller controlling the power of a heater based on the outdoor temperature and a look-up table or a mathematical formula, meaning that the measured variable is independent from the process variable. The open loop control system is simple and, in many situations, enough, but sensitive to discrepancies in the formula/look-up table and disturbances. To deal with the drift over time caused by such issues, some form of calibration needs to be done at certain intervals. An example of an open loop controller with regards to this thesis could be as follows.

1. The height of the roof of the truck is measured
2. Based on a look-up table the motor is spun as many turns as it says, meaning that the top roller is rolled down a pre-programmed distance

This system might be enough in some cases, but has no way of knowing if the roller ever got to the top of the truck or not, since there is no feedback built in.

The opposite to open loop control is closed loop, or feedback control as it is also known. The physical quantity to be controlled, the measured variable, is measured and through negative feedback summated with the reference value. The result is the control error, e. The control signal u is based on the error one way or the other. (Hägglund, 2019)

A.4.2 On/Off Control

The on/off controller (bang-bang controller) is the most basic type of controller, and its control signal is decided simply by looking at the error in equation (0.1). The control signal, u, can also be displayed graphically, see Figure A.1.

$$u = \begin{cases} u_{max} & e > 0 \\ u_{min} & e < 0 \end{cases} \tag{0.1}$$

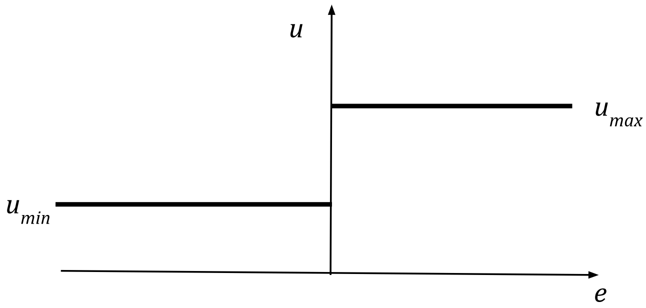

Figure A.1. Control signal of an on/off controller.

One issue with the on/off controller is that it causes oscillations for small control errors. One way of dealing with that is to lower the gain of the controller for small errors. (Hägglund, 2019)

A.4.3 Hysteresis

When an on/off-controller is used, any noise around the setpoint causes the control electronics (usually a relay) to switch on and off with a high frequency. This induces wear and shortens the lifespan of the components. To avoid this, the setpoint is split into two and a band in between is created, see Figure A.2 below.

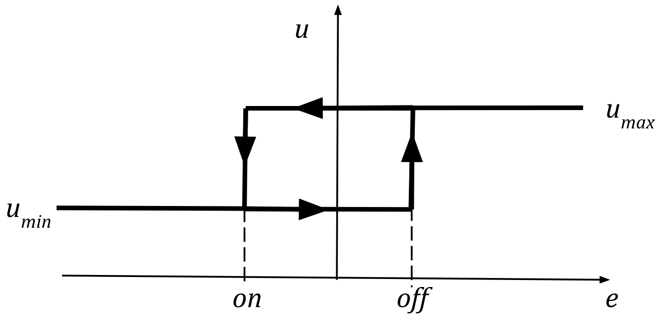

Figure A.2. Hysteresis in an on/off controller.

The purpose off this is to reduce chattering (high frequency switching) to prolong the lifespan of the system, but the drawback is that the amplitude of the oscillations around the setpoint increases. (Omron, 2022)

A.4.4 P-controller

By setting the control signal to be proportional in relation to the control error, the gain is efficiently reduced within the range. For large control errors however, the P-controller behaves just like an on/off controller. The control signal is described in equation (0.2) and can be seen graphically in Figure A.3.

$$u = \begin{cases} u_{max} & e > e_0 \\ K * e & -e_0 < e < e_0 \\ u_{min} & e < -e_0 \end{cases} \tag{0.2}$$

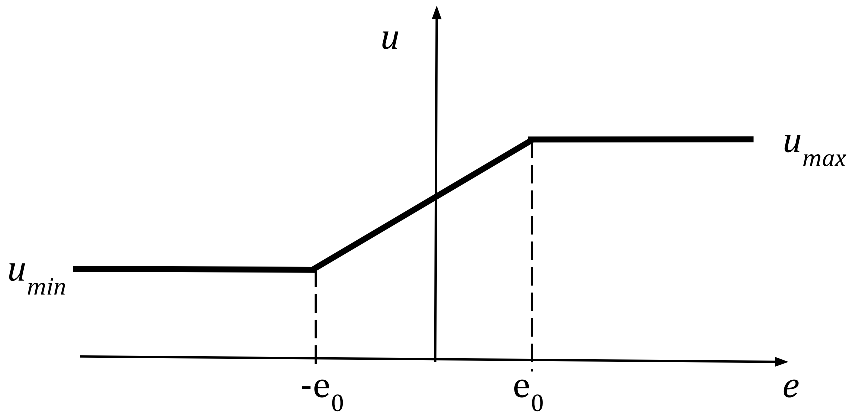

Figure A.3. Control signal of the P-controller.

This causes the oscillations to go away, but the P-controller has another issue instead, the static error. The derivation will not be presented in this thesis. (Hägglund, 2019)

A.4.5 PI-controller

An integral term is added to P-controller, causing the static error to go away. It works by integrating the error over time and is added to the P-part to form the control signal. The new governing law for the control signal can be seen in equation (0.3).

$$u = K(\frac{1}{T_i}\int e(t)dt + e) \tag{0.3}$$

For a static error to exist, both u and e must be constant, and since the integrating part increases/decreases u over time if e is separated from zero, this cannot be true.

Therefore, the static error goes away when using an integrating term. (Hägglund, 2019)

Appendix B Simulation of Signals

This section presents the example signals simulated in the free software LTspice and the schematics for the circuits built in these simulations.

The free circuit simulation “LTspice” was used to simulate example signals of 24VAC from the sensors to the CDM9 motor system. These circuits do not represent the real ones but are merely for presentation of the principle of modifying a wave form to increase the resolution of each port from binary.

Firstly, the open circuit (no signal) was simulated using the circuit in Figure B.4, which resulted in the waveform in Figure B.5, with the output probed between the resistor R1 and the outputs of the opto-couplers. Note that the opto-coupler is inverting, and the CDM9 has an extra inverter after the opto-coupler to deal with this, but that was not included in the simulation. Note that the CDM9 uses an opto-coupler with double diodes, one in each direction, paralleled within the opto-coupler. Such a component was not available in the LTspice software; therefore, two opto-couplers were paralleled with inverted input to simulate this. The switch on the left-hand side was included to simulate an open or closed switching sensor.

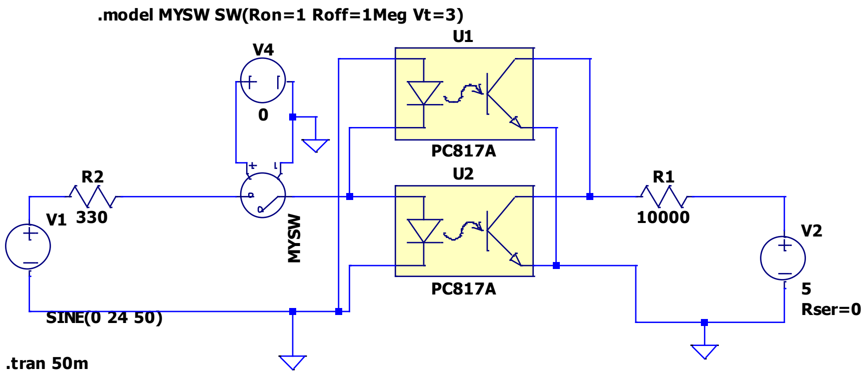

Figure B.4. The circuit diagram of simulation of a 24VAC signal to the opto-coupler in the CDM9.

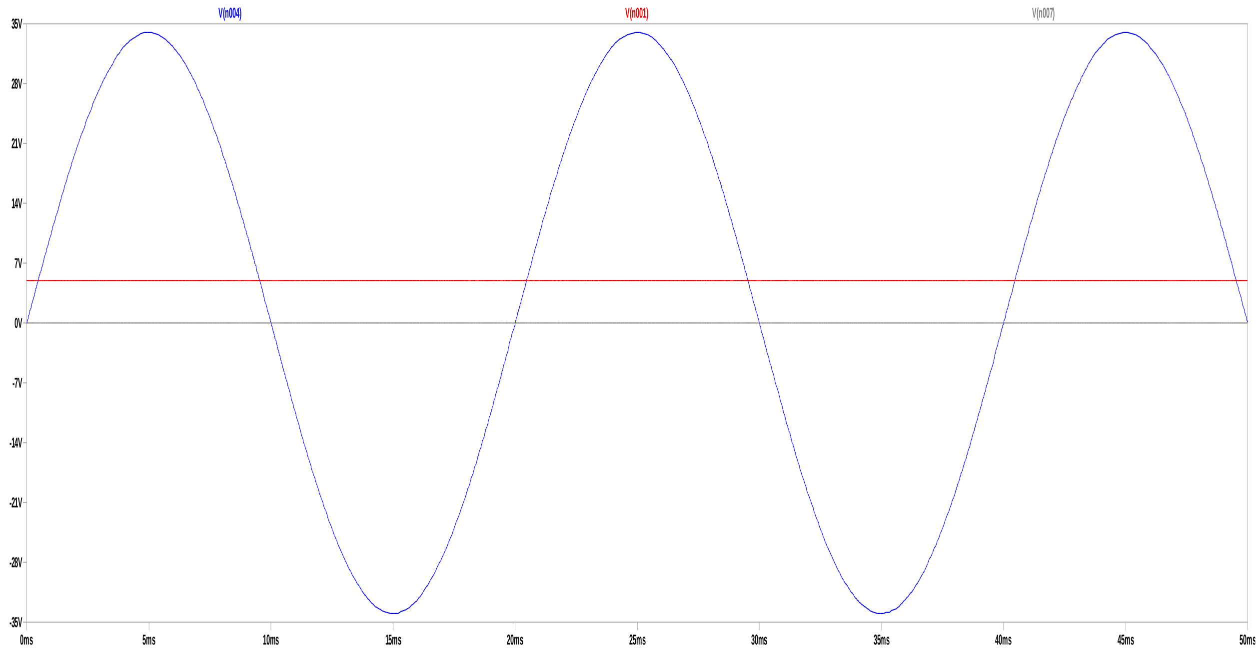

Figure B.5. Open circuit resulting in an inverted output signal.

Appendix C Calculations of metric number 3

This Appendix presents the calculations for some of the metrics for the target specifications.

The value for metric number 3, “the top roller is stretched by a force of”, was defined not as the lifting force on the entire roller, but as the lifting force on the lower, weighted, edge of the roller (see Figure C.6).

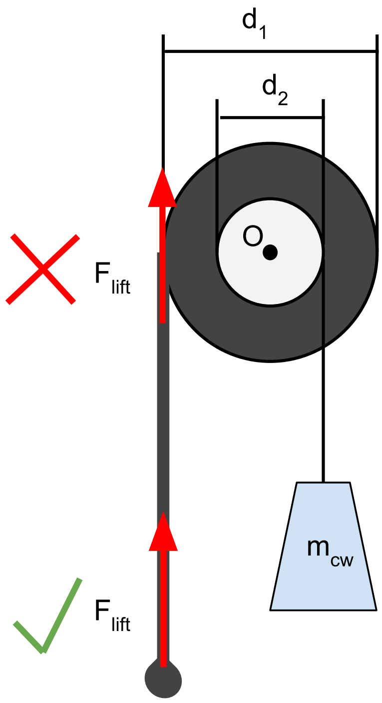

Figure C.6. Definition of the lifting force.

A free body diagram of the weighted section is presented in Figure C.7, and equation (C.4) depicts the lifting force derived from it.

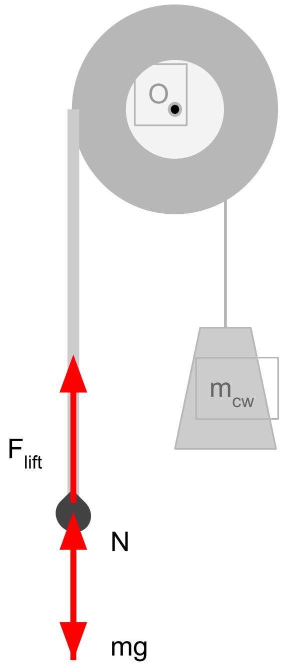

Figure C.7. Free body diagram of the weighted section only.

$$F_{lift} + N - mg = 0 \xrightarrow{yields} F_{lift} = mg - N \qquad \text{(C.4)}$$

By doing this, a situation where the specified lifting force on the roller was met, but the requirement for tension at the bottom was not met, could be avoided. This situation could arise since the opposing torque from the counterweight is constant (mass of thread neglected), but the mass of the roller is varying (mass of fabric not negligible).

Since how much of the roller that was unrolled affected how much lifting force was applied to the bottom edge, the measurements and calculations were performed for the lowest and highest positions of the current system. This provided the upper and lower marginally acceptable limits of "tension".

The free body diagram of the system was drawn and is presented in Figure C. The free body diagram led to the equilibrium equations (C.5) and (C.6), which could be rearranged to the equations **(C.7)** and **(C.8)** respectively. The assumptions that were made for these calculations were as follows.

- Frictionless bearing
- No slack in the roller
- Forces *f* and *R* below are equal

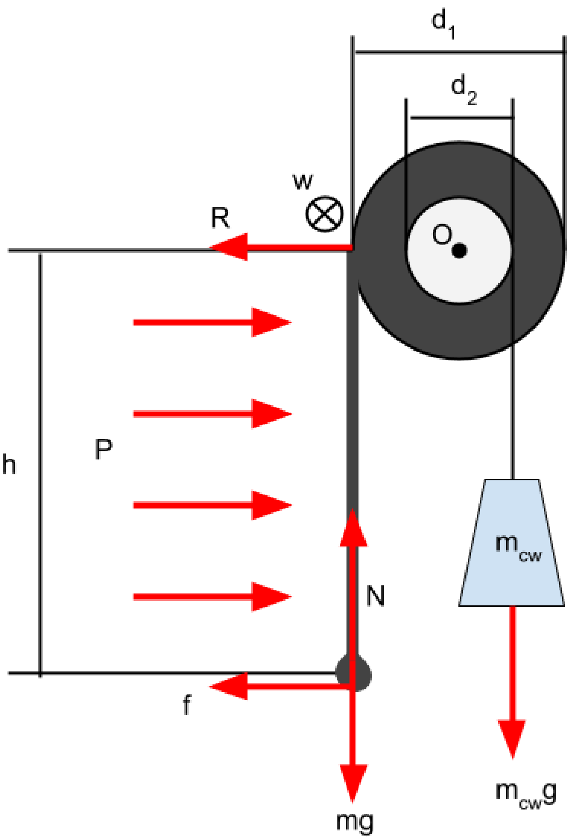

Figure C.8 Free body diagram of the current setup.

$$(O): (mg - N)\frac{d_1}{2} - m_{cw}g\frac{d_2}{2} = 0 \qquad \text{(C.5)}$$

$$(\rightarrow): P - (f + R) = P - (2f) = p_s bh - 2\mu_s N = 0 \quad \text{(C.6)}$$

$$N = g(m - m_{cw}\frac{d_2}{d_1}) \quad \text{(C.7)}$$

$$N = \frac{p_s bh}{2\mu_s} \quad \text{(C.8)}$$

Note that in equation (C.7) the mass m is dependent on how far the top roller is unrolled. This equation was used to calculate the limits of the normal force when the roller is in its lowest and highest operating position in the current system. Equation (C.4) then provides the lifting force. Equation (C.8) gives the required normal force to withstand the safety pressure p_s given the coefficient of friction μ_s and the position of the roller. The maximum amount of force needed occur when the area of the roller is maximized, which means when it is in its lowest position. With the values given in Table C.1 equation (C.7) solves for the normal force present in the system, and equation (C.8) for the normal force required for the specified wind load. Since the roller mass m varies with the position of the roller, it is calculated according to equation (C.9) as the total weight of the roller, minus the rolled up weight. The results are presented in Table C.2. Note that even when the roller is in its top position, the roller extends approximately 0.5m due to the design of the system.

$$m = 27kg - \rho bh_{rolled-up} \quad \text{(C.9)}$$

Table C.1. Variables and constants used.

Variable/Constant	*Value top position*	*Value bottom position*
m	24.4kg	27kg
m_{cw}	18kg	18kg
d_1	77.4mm	50mm
d_2	35mm	45mm
p_s	84N/m^2 (W.C. 2)	84N/m^2 (W.C. 2)
b	3.1m	3.1m
h	0.5m	1.8m
μ_s	0.6	0.6
g	9.8m/s^2	9.8 m/s^2

Table C.2. Equation results.

Equation	*Result top position*	*Result bottom position*
(C.4)	81N	80N
(C.7)	159N	184N
(C.8)	109N	391N

To perform these calculations, the coefficient of friction μ_s had to be specified. To do this, a test was set up with an inclined plane and the materials to be used. The plane used was a sandwich material with a painted aluminum surface to simulate a truck as closely as possible. The roller fabric with a weight on top was placed on the plane which was then lifted until the weight and fabric started sliding. At this point, the angle of the plane from the horizontal plane was measured, and through the free-body diagram in Figure C.9 and equation (C.13) the frictional coefficient was derived. The test was performed five times to get an average result, and the values can be seen in Table C.3. The resulting coefficient of friction was rounded down to the closest decimal.

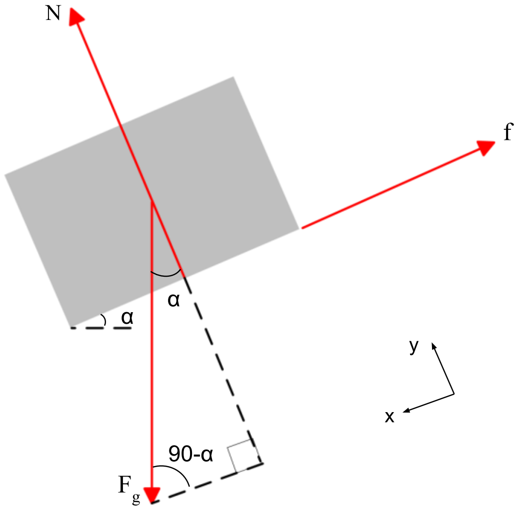

Figure C.9. Free-body diagram for defining the frictional coefficient.

$$(\rightarrow): F_g \cos(90 - \alpha) - f = 0 \tag{C.10}$$

$$mg\cos(90 - \alpha) - N\mu_s = 0 \tag{C.11}$$

$$mg\cos(90 - \alpha) - mgcos(\alpha)\mu_s = 0 \tag{C.12}$$

$$\mu_s = \frac{mgcos(90 - \alpha)}{mgcos(\alpha)} = \frac{\cos(90 - \alpha)}{\cos(\alpha)} \tag{C.13}$$

Table C.3. Friction test results

Test	***Measured angle (deg)***	***Coefficient of friction***
1	33.19	
2	31.18	
3	29.90	
4	31.10	
5	31.20	
Average result	**31.31**	**0.61**

These results shows that the assumption that the guiding spring does not help with rigidity is false, and that the frictional addition to wind resistance is smaller than required to on its own be able to handle the wind load of wind class 2. This means that if a system is to be designed with guiding wires that can handle the entire wind load, the mass of the weight in the bottom of the roller is not important, if the difference between the mass of the roller and the counterweight is the same, to have the same “tension”. Note that these calculations only apply for trucks with a solid roof, and not the canvas variants.

Appendix D Work Distribution and Time Plan

This section presents the work distribution among the students, the project plan and project outcome.

D.1 Work Distribution

In its entirety, the work during this master thesis has not been divided between the two authors. Every part of the work was done in collaboration and considerable decisions was discussed with the other part throughout the process. As an example, designing the final prototype was done sitting next to each other, but both working on different parts on respective computer. This has been the case for all phases of the thesis, working together with the same subject, but not necessarily the exact same thing.

D.2 Project Plan and Outcome

This thesis started with a project planning phase, and a plan was established to define the problem and execution. Table D.4 shows a Gantt-chart including the different project tasks scheduled over time. The time needed for the different stages was approximated but creates a perception of how much time was available for each stage. Throughout the weeks, another Gantt-chart was made and filled with the activities performed to be able to compare the outcome and evaluate the planning. This can be seen in Table D.5.

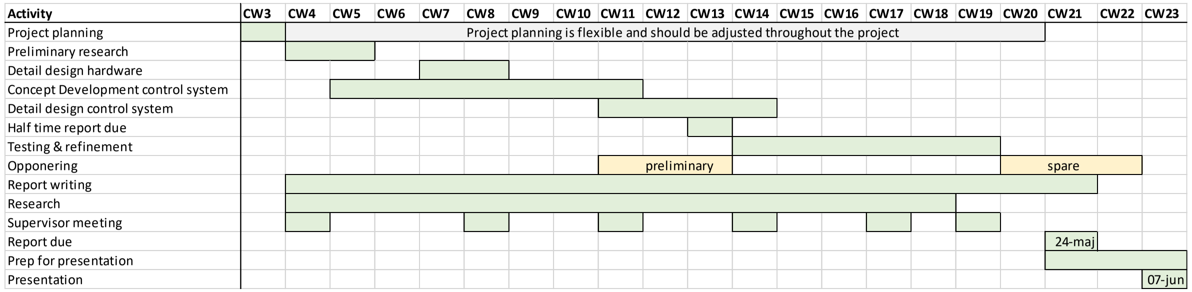

Table D.4. Planned activities in a Gantt-chart.

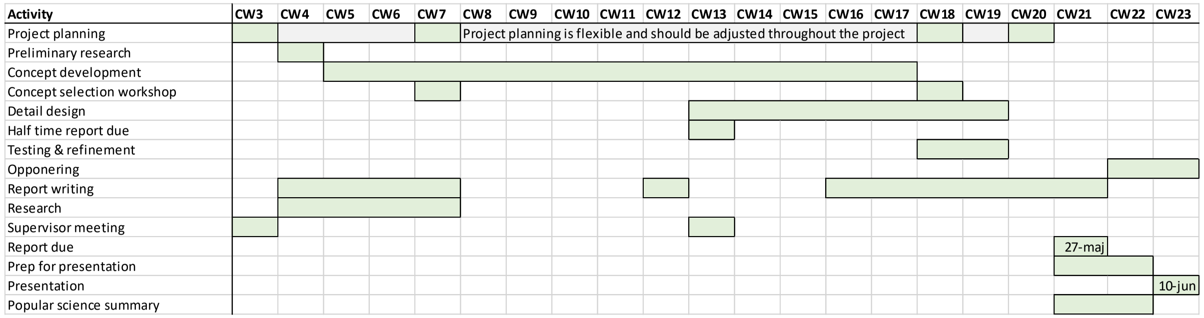

Table D.5. Activities performed, Gantt-chart.

The main differences between the planned activities and the performed activities are that the concept development phase took much longer time than anticipated. This mirrors the decision to construct another, larger testing rig which proved very useful in evaluating the functionality of the winning concept as well as the detail design phase, but also removed the possibility to be able to test the winning concept in a real-world scenario.

The activity named “Detail design hardware” in the planned Gantt-chart was incorporated into the “Concept Development”-activity, since this was supposed to be the design of the test rig. The same applies to “Concept Development control system”, which was split into “Concept Development” and “Detail Design” to better illustrate what was done.

The activities “Report writing” and “Research” shows a large difference as well. Since the prototyping in the concept development phase was iterative work, got prolonged, and all the iterations unnecessary to be disclosed in the report, the report writing took a pause and concentrated to calendar week 12.

Furthermore, the supervisor meetings which were planned to take place every third week were also reduced. This is partly due to the concept development phase working smoothly although prolonged, and partly since the company supervisor was very dedicated to supporting the progress of the work. The need for the planned meetings was therefore removed and the work progressed.

Appendix E Result of Multi-voting

This Appendix presents the result of the multi-voting when selecting and testing concepts.

The concepts that every member of the workshop voted for can be seen in Table E.6.

Table E.6. The votes of each member.

Person	*Highest ranked concept*	*Second highest ranked concept*	*Lowest ranked concept*
1	7	1	9
2	7	9	1
3	7	1	9
4	7	1	9
5	1	7	3

As mentioned before, the votes were weighted when calculating the total amount of points for each concept, using the largest weight for each member's top vote and the least weight for the least prioritized vote. The largest weight was three, the second largest weight was two, and the lowest weight was one. Summing up the votes for the different concepts using these weights, gave the result of the multi-voting, and is shown in Table E.7.

Table E.7. The total amount of points for the concepts.

Number	***Concepts***	***Points***
1	Measure distance from roof above using ultrasonic, radar or laser	10
2	Measure truck height horizontally using array of photocell detectors	0
3	Measure truck height horizontally using contact sensor	1
4	Measure relative distance from roller using ultrasonic, laser or radar	0
5	Measure relative distance from roller using safety edge	0
6	Measure relative distance from roller using load cell	0
7	Measure relative distance from roller tilt sensor	14
8	Mechanical control: horizontal weighted sections	0
9	Mechanical control: tensioning roller	5
10	Measure extension of guiding spring	0
11	Motor pulling the roller down instead of unwinding	0
12	Accordion door instead of roller	0
13	Telescopic sheet door instead of roller	0
14	Hard door that goes above the shelter instead of roller	0
15	Measure strain in roller	0
16	Measure torsional strain	0
17	Measure tension using sheet tension roller	0