Design of a Cable Sealing Solution

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MASTER THESIS

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Design of a Cable Sealing Solution Used in an Outdoor Camera

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Abstract

To seal a cable going into the chassis of a camera, a cable gasket is placed between the chassis and the gasket. This type of gasket is called a grommet. For this project, these grommets needed to be able to withstand a modular plug being pulled through and at the same time be as small as possible to fit into a small space. The purpose of this master thesis was to investigate how to make a grommet smaller, than existing solutions, while still being easy to install with an attached modular plug. The grommet is to be used in an outdoor environment and therefore had to fulfill the sealing requirement of IP67.

The Ulrich and Eppinger methodology was used as a foundation for the development process and an iterative approach was integrated. Background information was gathered from interviews and similar solutions were benchmarked to get more insight into grommets. Together with needs and requirements, concepts were generated, prototyped, tested and then selected. A material evaluation was also conducted. This resulted in four concepts being prototyped in silicone rubber.

The project ended up with two grommets that both used a slit. The result showed that a grommet with a slit was the most promising concept since this could be made smaller and was the easiest to install. Testing of the prototypes also showed that some concepts with specific hardnesses and certain hole dimensions in the chassis fulfilled the IP67 requirements. This meant that the resulting grommet could be implemented in future cameras that would need a sealing solution that is small and easy to install with an attached modular plug.

Keywords: Cable gasket, grommet, prototyping, additive manufacturing, IP67-testing, design of experiments, material evaluation, silicone rubber.

Sammanfattning

För att kunna täta en kabel som går in i ett chassi på en kamera placeras en kabelpackning mellan chassit och packningen. Denna typ av packning kallas genomföring. I detta projekt behövde genomföringen tåla att en modularkontakt drogs igenom. Samtidigt skulle genomföringen vara så liten som möjligt för att passa in i ett litet utrymme. Syftet med examensarbetet var att undersöka hur man kan göra en genomföring mindre än befintliga lösningar, samtidigt som den är enkel att installera med en modularkontakt. Genomföringen ska användas i utomhusmiljö och var därför tvungen att uppfylla tätningskravet IP67.

Ulrich och Eppingers metodik användes som grund för utvecklingsprocessen och ett iterativt tillvägagångssätt integrerades. Bakgrundsinformation samlades in från intervjuer med personer på Axis och liknande lösningar benchmarkades för att få mer insikt om genomföringar. Tillsammans med behov och krav, genererades koncept, prototyper testades och valdes sedan ut. En materialutvärdering gjordes också. Detta resulterade i att fyra koncept tillverkades i silikongummi.

Projektet slutade i två genomföringar som båda använde en slits. Resultatet visade att en genomföring med slits var det mest lovande konceptet eftersom denna kunde göras mindre och var enkel att installera. Testning av prototyperna visade också att vissa koncept med specifika hårdheter och vissa håldimensioner i chassit uppfyllde IP67-kraven. Detta innebar att den resulterande genomföringen kan implementeras i framtida kameror som skulle behöva en liten och lättinstallerad lösning.

Nyckelord: Kabelpackning, genomföring, prototypframställning, additiv tillverkning, IP67-testning, design av experiment, materialutvärdering, silikongummi.

Acknowledgments

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Lund, June 2022

Oliver Dropuljic and Axel Wiktor

Contents

List of Acronyms

ANOM	analysis of means
ANOVA	analysis of variance
BL	benchmarking leader
CG	concept generation
CS	concept selection
DfM	design for manufacturing
DoE	design of experiments
EE	experienced engineer
EPDM	ethylene propylene diene monomer
FFF	fused filament fabrication
MJP	multijet printing
OA	orthogonal arrays
PLA	polylactic acid
PMMA	polymethyl methacrylate
PO	product owner
SEBS	styrene–ethylene–butylene–styrene
SiR	silicone rubber
TP	twisted pair
TPE	thermoplastic elastomers
UV	ultraviolet

1 Introduction

1.1 Problem Description

1.1.1 Background

When developing a product, there are many requirements that must be met for the product to work in different conditions to which it will be exposed. These requirements are there to guarantee that the product can withstand the circumstances but also to assure customers that the product they buy meets the standards that the customer wants. These requirements are different depending on what the product is, how the product is used and what environment it is exposed to.

Products, such as electronic surveillance cameras, often need to meet specific IP requirements that state, among other things, how water-resistant the product is. If a camera is not properly sealed, both the electronics as well as the camera lens can be ruined. This report will be dealing with the design aspects of a cable gasket that seals between a cable, that goes into a camera, and a camera chassis. This type of cable gasket is called a grommet. The project will focus on how to make a camera water-resistant to meet IP67 and how to, at the same time, make it as easy as possible to install. Some definitions of the parts of a grommet can be seen in figure 1.1. A detailed time plan for the project can be seen in E Appendix – Gantt Chart, and the project was distributed equally among the project team.

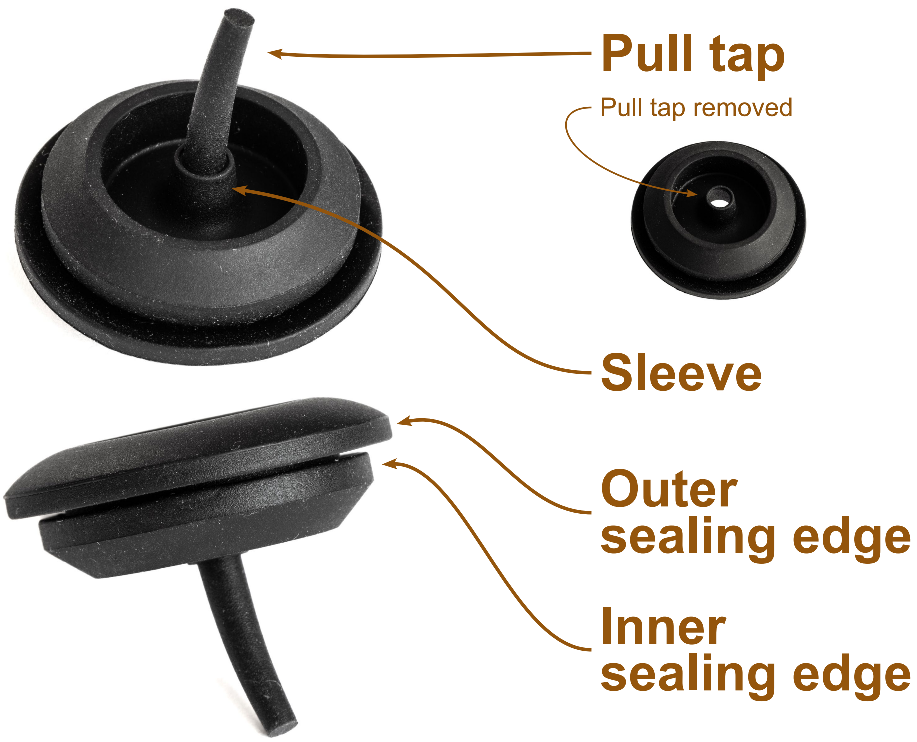

Figure 1.1: The figure shows different parts of a grommet that will be mentioned in the project.

1.1.2 Goals and Objectives

The two main objectives of this master thesis are to investigate how different solutions, for the sealing of a cable going into a camera, behave as well as investigate how easy it is to assemble the solution with the camera. The goal is to find and develop a final concept that meets all the required product specifications. This will be achieved by following the methodology of Ulrich and Eppinger with some minor adjustments made by the project team. Additional goals are to design, produce and test prototypes, resulting in a final solution for the project. The result of the IPX7 testing will be analyzed using a method called Design of Experiment.

1.1.3 Stakeholders

The stakeholders are defined as the groups of people who are affected by the success or failure of the product [1, p. 68]. For this project, the stakeholders include the end-users, sales force, product owner and development team. Axis's business model is selling its products to distributors and not directly to the end-user [2]. This makes the distributors included as stakeholders.

1.1.4 Assumptions

Since this master thesis handles the early stages of a project at Axis, some assumptions will have to be made. Firstly, it will be assumed that some sort of plastic or metal cover will be placed over the camera. Furthermore, after some discussions with the product owner, it will be assumed that the lifetime of the product will be the same as similar products at Axis. Regarding the cable going into the camera, it will be assumed that the maximal diameter of the modular plug (which is attached to the end of the cable) will be 17 mm. Finally, the grommet is installed in a chassis where the wall thickness will be assumed to be 2 to 3 mm.

1.1.5 Delimitations

This report will not handle any production preparations nor a cost analysis since this information is classified to Axis. There will also be some limitations regarding the prototyping of the solutions, and due to lack of time, the project team will only be able to order prototypes once from the supplier.

This project is a pilot study of the camera that will use the developed grommet. Therefore, the design of the chassis used in the project may change which can alter the way the grommet will be installed. However, the project team will base the design of the grommet to fit on the original chassis.

1.2 Axis Communications AB

This master thesis was made in collaboration with Axis Communications AB. Axis is a technology company working with network solutions for security, including video surveillance solutions, access control solutions, intercom and audio solutions. The company is based all over the world with the headquarters in Lund. Axis was founded in 1984 and started with an idea of using network technology to connect storage, print and scanner servers and later moved on to connecting cameras to the networks [3]. Now, they are the market leaders in network video solutions.

2 Theory

2.1 Material

Common materials for sealing two or more parts are some form of elastomer. Elastomer is a class of polymer with rubber-like elasticity which means that it can elastically spring back from large deformations [4, p. 226]. When relaxed, elastomers are amorphous and composed of cross-linked molecules [4, p. 293]. Cross-linked molecules are molecules where the chains are coiled and highly twisted. Under tensile stress, the chains are untwisted resulting in an elongation effect in the direction of the applied stress. When the stress is removed, the chains will retwist and recoil into, or close to, its original form. The cross-linked structure is achieved by curing of the material, and for rubbers, the curing process is called vulcanization.

Vulcanization is the chemical process where rubber is heated with sulfur (or other cross-linking agent) at 140 to 160 °C [5]. In the vulcanization process, cross-links are formed between long rubber molecules resulting in improved elasticity, tensile strength, hardness and weather resistance [5]. Unvulcanized rubber does not return to its original form after large deformations and is generally not strong and can be sticky [6, p. 337]. In other words, a consistency like a chewing gum.

Two elastomers that were investigated as materials for the grommets were ethylene propylene diene monomer rubber (EPDM) and silicone rubber (SiR). As an alternative, thermoplastic elastomers (TPEs) were also investigated.

2.1.1 EPDM

EPDM is a synthetic elastomer where ethylene, propylene and diene are irregularly bonded [7]. The material's properties are characterized by excellent mechanical properties, heat and water resistance, as well as high flexibility and elasticity [8].

In *Electronic Applications of Ethylene Propylene Diene Monomer Rubber and Its Composites* Athawalw and Joshi write that EPDM is a low-cost material with good ultraviolet (UV), fatigue, moisture and weather resistance, as well as a material that has very good electrical insulating properties and aging characteristics [9, p. 305-309]. Two main application areas for EPDM are outdoor usage and in environments with elevated temperatures (the heat resistance of EPDM is up to around 121 °C in air). The reason for this is that EPDM's saturated structure provides stability in these environments, according to Athawalw and Joshi. They explain that the good electric resistivity for EPDM comes from it being a non-polar elastomer which results in the material having a high resistance towards polar solvents such as dilute acids and alkaline solutions.

Furthermore, EPDM is characterized by good compression set, but poor flame resistance [10, p. 3-74]. Compression set is described by ISO standard 815 as the ability of rubber to return to its original dimensions after releasing an applied compression force [11]. The density of EPDM is $0.86\,\mathrm{g/cm^3}$ [10, p. 3-74–3-75]. Regarding the manufacturing process of parts in EPDM, they can be fabricated using injection molding [8].

2.1.2 Silicone Rubber (SiR)

Silicone rubber (SiR) is another synthetic elastomer where the chain consists of alternated silicon and oxygen atoms as the backbone. These are linked to side-bonded hydrogen atoms or atom groups like a methyl group CH_3 [4, p. 582]. The characteristic properties of SiR is its excellent resistance to high and low temperature, good compression set, excellent electrical properties and relatively low strength [10, p. 1-113].

Acid rain, including fog and snow that is acidic, can have a negative impact on the mechanical properties of SiR since SiR is mostly organic [12]. Rain is considered acid rain with a pH < 5.6 and the primary cause of the acidity is sulfur dioxide SO_2 and nitrogen oxides (NO_x) [12].

For SiR, the vulcanization is often done in two steps. First, preliminary vulcanization in a mold, followed by a high temperature (around 180 °C) postcure in air [6, p. 375]. Furthermore, the density of silicone is around 1.1 to $1.6\,\mathrm{g/cm^3}$ [10, p. 3-72–3-73].

2.1.3 Thermoplastic Elastomer

According to the ISO standard 18064, TPEs are defined as a "polymer or blend of polymers that has properties at its service temperature similar to those of vulcanized rubber but can be processed and reprocessed at elevated temperature like a thermoplastic" [13]. Thermoplastics and TPEs can easily be manufactured with traditional methods, without the need for vulcanization, which is a required operation for elastomers [14].

In *Handbook of Thermoplastic Elastomers*, Drobny describes that whereas entanglements in cross-linked elastomers are permanently locked, the physical cross-links are not permanent in TPEs and may disappear with increased temperature [15, p. 1-7]. The thermoreversible networks allow the TPEs to be processed as thermoplastics, but at the same time show the same characteristics as vulcanized rubber when cooled down to a certain temperature. Drobny writes that compared to conventional thermosets, TPEs' simpler processing method leads to a more efficient and less costly manufacturing process resulting in a lower cost of the final product. Drobny also points out the possibility of reusing TPE scrap as a regrind, whereas scrap from thermosets rubbers is often discarded. TPEs also have a lower density than conventional rubber compounds, he mentions. One disadvantage to TPEs, according to Drobny, are their maximum service temperature being well below their melting point. However, he mentions that recent development has introduced TPEs that are capable of being used at 150 °C or higher.

The density of TPEs varies a bit depending on what kind of TPE is used, what kind of filler as well as the proportion of filler. One standard TPE for injection molding from Hexpol has a density of 0.89 to $1.18\,\mathrm{g/cm^3}$ for unfilled respective filled material [16].

2.1.4 Material Hardness

The hardness of elastomers and plastics are described by ISO standard 868 and ISO 48-4. The hardness is measured in Shore and to measure Shore hardness, a shore durometer is used [17, 18]. The durometer measures how much penetration depth a steel rod makes on a test material. The hardness is then described in different Shores with a number between 0 and 100. The two main Shore hardnesses are, Shore A, for softer materials, and Shore D, for harder materials. The number before the Shore indicates how hard the material is. A number of 100 means that there has been zero penetration and the material is very hard. A number of 0 instead means that there has been maximum penetration and the material is very soft.

2.2 Prototyping

Prototyping is a step in the development process of a product and is used to evaluate and see how ideas and concepts behave and if they behave as intended. There are many different ways of prototyping concepts but in this project, additive manufacturing, also known as 3D printing, and compression molding were used.

2.2.1 Additive Manufacturing

Additive manufacturing is a term that includes building 3D physical models [19, p. 3] and is often associated with 3D printing where 3D parts are built layer by layer. 3D printing is often associated with rapid prototyping and the two terms are often used together [19, p. 3]. 3D printing technology can build small prototypes very quickly, often in a matter of hours, and make complex parts with few constraints on the shape [19, p. 3]. This makes 3D printing very useful for prototyping various concepts in the development process.

2.2.1.1 Fused Filament Fabrication and Multijet Printing

In this project, two additive manufacturing techniques were used, fused filament fabrication and multijet printing.

Fused filament fabrication (FFF) is an additive manufacturing technique that uses a thermoplastic material that is fed into a heating chamber, brought up to its melting temperature and then pressed out through a nozzle onto a flat surface. The plastic then cools quickly and hardens at room temperature [20, p. 47]. The filament is extruded layer-by-layer creating several 2D-layers until a 3D shape is generated [20, p. 47]. This technique is used to produce complex 3D shapes at a low cost [20, p. 47].

Multijet printing (MJP) is another additive manufacturing technique that uses a photosensitive polymer to print layer-by-layer on a flat surface [21, p. 1]. The polymer is then hardened with UV light and a roller moves across each layer, disposing of excess material to assure that even layer thickness is attained [21, p. 1]. This technique allows for both hard and soft materials to be printed at the same time [21, p. 1].

2.2.2 Compression Molding

In the book *Applied Plastics Engineering Handbook (Second Edition)*, Tatara describes that compression molding is one of the oldest processing techniques and that it is used to produce both small products and very large parts [22, p. 291]. Tatara explains that the technique uses pressure and heating to cure a resin (placed inside of two mold halves) with a chemical reaction and hardens it into the desired shape. Tatara continues describing that the process can be divided into four different steps. Firstly, the resin is placed into the lower mold half. The second step is that force is applied and, together with heating, compresses the resin. In the third step, the pressure and heating are maintained which further cures the resin. Lastly, the molds open and the part is released.

The tools used for producing parts can be divided into hard tooling and soft tooling. Tools that can only produce few parts before it wears are referred to as soft tools as supposed to hard tooling which can produce thousands of parts [23, p. 2]. Soft tooling, which will be used in this project, is therefore applied to low-volume production and is relatively cheap which makes it suitable for producing prototypes [23, p. 13].

2.3 Ethernet Cables

The main data transfer to and from the camera is done through an Ethernet cable. Different cable and connector variants exist on today's market and the most common cables used today are standardized twisted pair cables (TP). These can be configured as shielded or unshielded [24, p. 18]. Shielded cables protect the signal from unwanted signals and noise [25].

Common connectors for Ethernet cables are called modular connectors where the male end is called modular plug and the female end is called modular jack [25]. There are different variants of modular connectors, but commonly 8-pin (8 position

8 contact, 8P8C), connectors are used [24, p. 132]. Modular plugs are often improperly referred to as “RJ-45”, which is designated for an interface often used for programmable analog modem connections [24, p. 219]. In this thesis, 8P8C connectors will be referred to as 8-pin modular or simply modular.

For short distance connections, patch cords are often used. Patch cords are shorter flexible cables terminated by an 8-pin modular plug in both ends [24, p. 202]. See a typical patch cord to the left in figure 2.1 and note that the modular plug uses a strain relief to allow for greater bending between the cable and plug. Sometimes bulk cables are used where the termination of the cable is done with a modular plug installed by an integrator, see the right plug in figure 2.1.

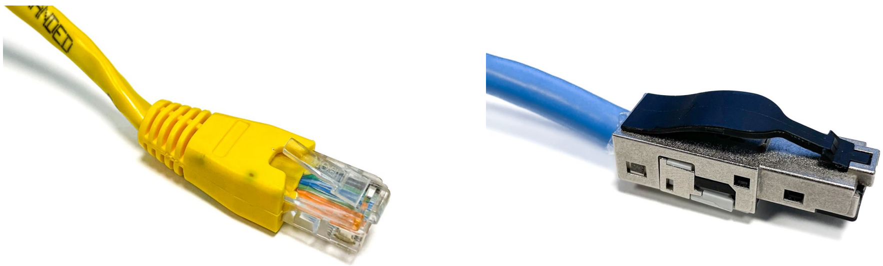

Figure 2.1: The cable to the left shows the end of a typical patch cord which is terminated by an 8-pin modular plug with a strain relief. The TP cable to the right shows a bulk cable which is terminated by a modular plug installed by an integrator. The modular plug to the right is called a Field Connector.

2.4 IP Code – Protection Provided by Enclosures

The industry standard EN 60529 describes the degree of protection provided by enclosures for electrical equipment with a rated voltage not exceeding 72.5 kV [26]. The classification provided by the standard starts with the two letters “IP” which are followed by two digits.

The first digit describes the protection of the inside of the enclosure against ingress of solid foreign objects, like dust. IP6X means that it is completely protected against dust. The “X” indicates that this digit is omitted.

The first digit also describes the degree of protection for persons, where IP5X and

IP6X mean that hazardous parts are protected from contact with a wire held by a person. The wire is defined as having a diameter of $1.0\,\mathrm{mm}$.

The second digit describes the protection of the equipment inside the enclosure against harmful effects due to ingress of water. Digits between 0 and 9 indicate different levels of exposure to water. For example, IPX6 means that the enclosure is protected against powerful water jets from any direction. IPX7 means that the enclosure is protected against immersion in water for a short period.

In this master thesis, the IP requirement was IP67. To test a product for IPX7, the product is submerged $1\,\mathrm{m}$ underwater and stays there for $30\,\mathrm{min}$. If no water has leaked through during this time period, the product has met the IPX7 requirement. IP6X is tested by putting the product in a dust chamber for $2\,\mathrm{h}$ with a negative pressure of $2\,\mathrm{kPa}$ inside the product. The IP6X test is passed if no dust leaks in. IPX6 is another rating that is tested by jetting the product with $100\,\mathrm{L/min}$ of water for at least $3\,\mathrm{min}$.

3 Methodology

3.1 Approach

In this master thesis, a variant of the Ulrich and Eppinger methodology was used as a foundation for the development process. Various steps in the process were used, however, steps that were deemed unnecessary for this project were left out. Together with the traditional Ulrich and Eppinger methodology, an iterative approach was also used. The steps; concept generation, concept selection, prototyping and testing were iterated in three iterations to find the best possible solution.

3.2 Ulrich and Eppinger

Ulrich and Eppinger are two professors at University of Pennsylvania and Massachusetts Institute of Technology that decided to write a book about product development entitled *Product Design and Development* [1, p. iv-v]. The traditional Ulrich and Eppinger methodology can be seen in figure 3.1 which is the overall structure that will be used in this project. However, the focus will be on the concept development phase and the different steps that Ulrich and Eppinger present. These steps can be seen in figure 3.2 and will be described in detail below.

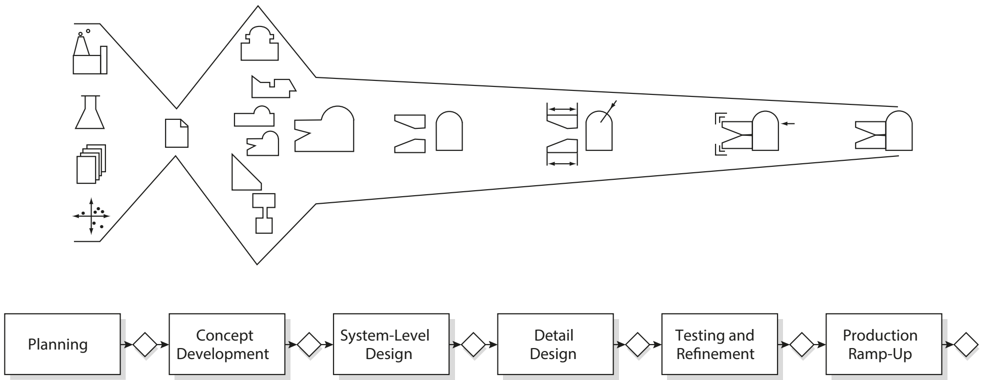

Figure 3.1: The figure shows Ulrich and Eppinger's product development process. [1, p. 14]

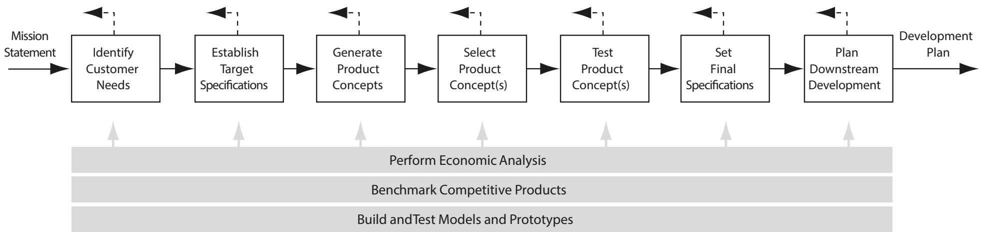

Figure 3.2: The figure shows Ulrich and Eppinger's concept development phase. [1, p. 16]

3.2.1 Identify Needs

The first step in the concept development process is to identify the customer needs. However, in this case, the sealing solution will not be handled by an end-user, it will be used by an installer. Therefore, this section will only be called Identify Needs. The main purpose of this step is to understand what the user wants in order to produce a satisfactory product for them [1, p. 75]. These needs, together with the requirements from the company, will form a basis for the design process. Ulrich and Eppinger present some steps in this phase and the steps that will be used are:

- Gather raw data from customers.
- Interpret the raw data in terms of customer needs.
- Establish the relative importance of the needs.
- Reflect on the results and the process.

3.2.2 Establishing Requirements

The second step in the concept development process is to establish target specifications. However, instead of calling them target specifications, they will be named requirements in this report. The requirements describe what the product has to do [1, p. 92] and are provided by the company. One step presented by Ulrich and Eppinger is to set ideal and marginal values. However, in this report only marginal values are used. Ulrich and Eppinger present different steps in this phase and the ones that will be used are:

- Prepare the list of metrics.
- Set marginal target values.
- Reflect on the result and the process.

3.2.3 Concept Generation

During the concept generation step, various product concepts are generated and explored with the customer needs and target specifications in mind [1, p. 118]. Ulrich and Eppinger present a list of activities in this step, however, some of these activities were made earlier in this project, such as searching externally, and others were deemed unnecessary for the project, such as exploring systematically. Thus, the focus for this step will be generating new concepts and solutions in the search internally step. The steps that will be taken are:

- Clarify the problem.
- Search internally.
- Reflect on the result and the process.

3.2.4 Concept Selection

The fourth step in the development process is to select concepts from the generated solutions. Ulrich and Eppinger present numerous activities such as decision matrices and pros and cons lists to evaluate and eliminate concepts [1, p. 145]. Following the concept selection, a concept refinement is made where refinements and combinations of the concepts take place.

3.2.5 Concept Testing

The next step in the development process is the testing of concepts. Prototypes are made and tested to verify that the target specifications and customer needs have been met [1, p. 166]. From the testing step, further development is made if needed. Ulrich and Eppinger present seven steps when testing the concepts:

- Define the purpose of the concept test.
- Choose a survey population.
- Choose a survey format.
- Communicate the concepts.
- Measure customer response.
- Interpret the results.
- Reflect on the results and the process.

3.3 Iterative Process

As mentioned in section 3.1 Approach an iterative process will be integrated with Ulrich and Eppinger's generic development process. The steps concept generation, concept selection and testing of the prototypes will be iterated to find the best concept. A total of three iterations were made and it is noteworthy to mention that the three steps mentioned above did not always follow after each other. Furthermore, instead of doing "Reflect on the result and the process" after each concept generation, selection and testing, this was made at the end of each iteration. The whole process can be seen in the flow chart in figure 3.3.

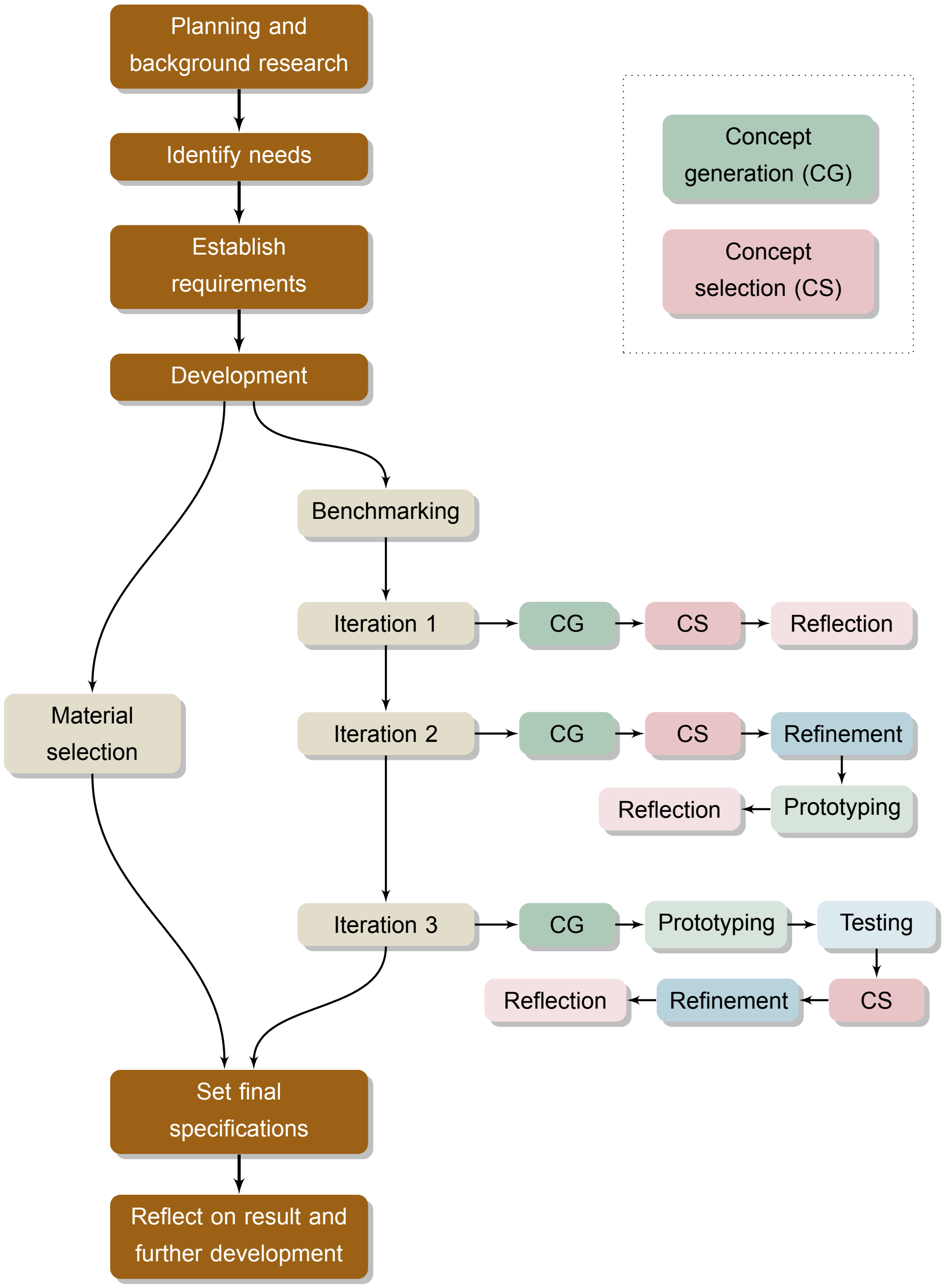

Figure 3.3: Flow chart illustrating the development process for the project. The dotted box shows the acronyms used in the flow chart.

3.4 Design of Experiments

To get a better understanding of how the input parameters in the system affect the performance of the product, Design of experiments (DoE) will be used. DoE is described by Souza et al. in *Robust Design and Taguchi Method Application* as a way to get a better understanding and optimize the parameters of a product or process [27]. Souza et al. describe that DoE can be set up with orthogonal arrays (OA) first used by Fisher and later Taguchi. With these OA, controllable input factors are decided as input variables called factors. The factors can be investigated at different levels, Souza et al. write. They continue by describing that an output variable must be chosen to evaluate the result and to see how the different parameters affect the output variable. When this is decided, the tests are executed and the results evaluated. The last step is to calculate the reliability of the test with analysis of variance (ANOVA). ANOVA answers if one of the groups are statistically significantly deviates from the whole population and not just random noise [28].

To see if the result is significant, a null hypothesis, H_0, is used to represent a null effect and an alternative hypothesis, H_a, represents the opposite [29]. To test the null hypothesis, the p-value is used. The p-value is defined as the probability, under the assumption of no effect or no difference, of observing a result equal to or greater than what was observed [29]. A small p-value means that it would be very unlikely to observe such a result in the null hypothesis. The p-value is compared to a threshold value α which by Fisher was set as standard 0.05 [30]. If the p-value is less than or equal to α, the null hypothesis is rejected.

4 Identify Needs

4.1 Data Gathering

To find and create product needs, data regarding the existing solutions needed to be gathered. The data was gathered through four different interviews. One interview with the product owner (PO), one with a benchmarking leader (BL) and two with experienced engineers (EE) that have previously worked with and developed grommets at Axis. The questions from the interviews can be seen in A Appendix – Interview Questions.

4.1.1 Interview with Product Owner

To get a better understanding of the background of the project, an interview was held with the PO who is the link between the market and technology. From the market and technology, the PO creates an understanding of the camera series at Axis and what the next product should be. The products are then ordered from R&D.

The PO said that the connector that would be pulled through the grommet was going to be an 8-pin modular plug and not the bigger modular Field Connector. The PO mentioned that some cameras have a cable buffer underneath the camera base, but for this camera, it was not a must with the standard camera configuration.

4.1.2 Interview with Benchmark Leader

To get a better insight into how installers install cameras and to get more information regarding competitors, a benchmarking leader (BL) at Axis was interviewed. The BL worked as an expert on integration of Axis's products and worked closely with the customers to get feedback regarding the installation of the cameras. In addition to this, the BL had worked with camera installation over numerous years and had a lot of experience handling different types of cameras.

When asked about the current grommet, the BL mentioned that the grommet worked well. He added that the current solution also worked well with the help of the Hannibal tool developed at Axis, see figure 4.1. However, BL mentioned that grommets made of silicone can get stiff at cold temperatures and break easily if the installer was not careful or did not use the Hannibal tool. In a harsh environment it could take a couple of minutes to get the cable through a grommet and the BL mentioned that it was important for the cable to easily be pulled through the grommet. Furthermore, the BL added that it was important that the current grommet was only going the be used once since further use could create damage and play. Lastly, the BL mentioned that the latest version of the current grommet allows for cables to be bent to more extreme positions.

Figure 4.1: The figure shows a picture of the Hannibal tool which is mounted onto a modular plug when pulling the plug through the existing grommets (Cable Gasket 1 and Cable Gasket 2).

4.1.3 Interview with Experienced Engineer – EE1

Two interviews were held with experienced engineers (EE) from Axis, EE1 and EE2, who both have worked with different projects developing cable gaskets that are used today at Axis. The reason for interviewing these people was to get more information regarding the development of grommets and the sealing of cables going into the cameras.

The first interview was held with mechanical engineer EE1 that worked with the development of one of the first cable gaskets at Axis. According to EE1, the previous solution for cable sealing was to use a more expensive cable gland. The new solution with a cable grommet was developed 9 to 10 years ago, to reduce the cost and make the camera easier to install. The grommet is called Cable Gasket 1 and can be seen in figure 4.2.

Figure 4.2: The figure shows the grommet, called Cable Gasket 1, that was developed by EE1.

Silicone was chosen as the material of the grommet, mainly because EE1 had much experience with that material and knew that it was a good material for the application since it can stretch 200 %. EE1 also mentioned that silicone has great temperature properties and is easy and cheap to manufacture.

The grommet developed by EE1 had been tested against IP66 and IP67. Furthermore, EE1 mentioned that grommets need to be robust against angled cables (cables that enter the grommet with an angle to the axial line in the grommet) to prevent water leakage.

Regarding the biggest risks in a grommet made from silicone, EE1 mentioned that a grommet could crack when the cable is installed in the camera. Cable Gasket 1 is designed for the ability to pass through a modular plug, however, to reduce the risk of getting cracks in the grommet, a Hannibal tool could be used to cover the top of the plug.

According to EE1, one advantage with the current grommet, in comparison to previous solutions, was that it has reduced the weight and volume of the package. It was easier and cheaper to include a grommet instead of a gland. EE1 also acknowledged that cables are not always perfectly round, which makes it harder to get a good seal between the cable and grommet.

4.1.4 Interview with Experienced Engineer – EE2

The second interview with an experienced engineer was with EE2, who developed a new version of Cable Gasket 1. The new version was developed 1.5 to 2 years ago and is called Cable Gasket 2, see figure 4.3. The main improvement in the new version of the grommet was that it handled angled cables better.

Figure 4.3: The figure shows the grommet, called Cable Gasket 2, that was developed by EE2.

Furthermore, another improvement with the grommet was the change in how the pull tap was attached to the gasket resulting in a finer surface on the inside of the sleeve. Moreover, the diameter of the grommet, which pushes against the inner edge of the hole in the camera wall, was increased, making the radial seal tighter.

4.2 Product Needs

The product needs were produced from the data gathered from the interviews with EE1, EE2, BL and PO. The data was interpreted and documented as "interpreted need" in table 4.1 where they were also rated regarding their relative importance. The needs were rated as "Must have", "Should have" or "Nice to have". Many of the needs regarding the environment, water and temperature were deemed to be "Must have"-needs. Other needs such as the cable being bent through the hole and having an uneven cross-sectional area were brought up in the interviews. Easy to assemble was important and included that the sealing solution stayed in its position during assembly. Being able to make a grommet smaller would also result in being able to make smaller cameras. This could be of interest to the customer, especially when buying large volumes of cameras for bigger systems.

Table 4.1: The table shows the interpreted needs as well as the relative importance of the needs.

Need	*Interpreted Need*	*Relative Importance*
1	Withstand low temperatures in cold climate.	Must have
2	Withstand high temperatures in hot climate.	Must have
3	Withstand outdoor climate.	Must have
4	Seal against cables with an uneven cross-sectional area.	Must have
5	Withstand the cable being in extreme positions (bent cable).	Should have
6	Stays in its position during installation.	Should have
7	Easy to pull through big cables.	Should have
8	Easy to assemble.	Should have
9	Keep its mechanical properties during its lifetime.	Should have
10	Small size	Nice to have

4.3 Reflect on the Result and the Process

In total, four different interviews with people at Axis were held. In retrospect, these four were enough to get the most important needs. A lot of useful information was gathered which helped the project team to move forward. However, even though a lot of useful information was gathered, not a lot of needs were generated. The reason for this is that the project focuses on sealing cables which is a small part of the whole camera. Most needs that were constructed were from an installation perspective since that was where the product was going to be used.

The interview with the product owner provided good and important information regarding the project. However, this interview was held last and it would probably have been better to start with this interview and in that way get a better picture of the project before having the rest of the interviews.

5 Establishing Target Requirements

5.1 Target Requirements

The target requirements that can be seen in table 5.1 and 5.2 were made from requirements provided by Axis. These requirements are characteristics that Axis want the product to have together with some desired attributes interpreted from the customer needs.

5.2 List of Metrics

The requirements that are listed in table 5.1 were all divided into categories and had been given both a number and a unit. The unit “Binary” consisted of either a “Yes” or a “No” and explained if a design solution had met the requirement. The unit “Subj.” was subjective to the testers and was set when the design solutions were tested.

Since the camera, on which the project is based, was supposed to be used in an outdoor environment, Axis chose to apply IP67 as the IP requirement. This meant that sealing solution had to be able to fulfill IP67.

Table 5.1: The table shows all metrics that were used to set marginal values for different requirements. The requirements were divided into four categories; General, Physical, Installation and Environmental.

No	***Metric***	***Unit***
	General	
1	Cost-efficient	Subj.
2	Lifetime	year
	Physical	
3	Average Ethernet cable diameter	mm
4	Max modular plug diameter	mm
	Installation	
5	Ease of installation in camera	Subj.
6	Ease of pulling through cable with modular plug	Subj.
	Environmental	
7	Withstand IP67	Binary
8	Operating temperature	°C
9	Storing & transport temperature	°C

5.3 Marginal Values

From the list of metrics, table 5.2 was created where marginal values were set for all specifications. In Ulrich and Eppinger's design process, both marginal and ideal values are mentioned. The marginal values are the minimum accepted values [1] and should not be lower than what is stated in the table. They continue by describing the ideal values as the most desirable values for the specifications and for the final design to have. However, Axis does not use this method and only sets marginal values for their requirements. Therefore, no ideal values were set for the requirements.

Most values for the specifications had been set by Axis, for instance, the operating temperature, storing and transport temperature as well as IP67. However, some other values were generated by the project team after discussions with the supervisors from Axis as well as the product owner.

Table 5.2: The table shows marginal values for the target requirements.

No	*Metric*	*Unit*	*Marginal value*
	General		
1	Cost-efficient	Subj.	Yes
2	Lifetime	year	9
	Physical		
3	Average Ethernet cable diameter	mm	6 to 7
4	Max modular plug diameter	mm	17
	Installation		
5	Ease of installation in camera	Subj.	Yes
6	Ease of pulling through cable with modular plug	Subj.	Yes
	Environmental		
7	Withstand IP67	Binary	Yes
8	Operating temperature	°C	-30 to 55
9	Storing & transport temperature	°C	-40 to 65

5.4 Reflect on the Result and the Process

Similar to the needs, not a lot of requirements were gathered. The reason for this was again that the project handled a small part of the whole camera. The interview with the product owner and the glance at other outdoor cameras at Axis generated good results and requirements that were most important.

Since the project was in a very early stage, some requirements had not yet been set by Axis. These had to be generated by the project team together with the product owner and could be changed later which led to some uncertainty with the requirements.

6 Development

6.1 Existing Solutions at Axis

The existing solutions currently at Axis have been mentioned before in section 4 Identify Needs but will be described more in detail below. The two grommets can be seen in figure 6.1. Both grommets have a sleeve that tightens the grip around the cable, as well as a tag that needs to be pulled off to bring a cable through. Both grommets use silicone as material. The first grommet that was developed was Cable Gasket 1 which had a bigger hole for the cable than Cable Gasket 2 and used more material around the sleeve. Cable Gasket 2 was then developed and had both a smaller hole and used less material around the sleeve. The biggest change from Cable Gasket 1 was that Cable Gasket 2 had a bellow built into it to make it handle bent cables better.

Figure 6.1: The figure shows Cable Gasket 1 and Cable Gasket 2.

6.2 Benchmarking

To gather more insight into current solutions for grommets as well as for solutions regarding cable sealing, a benchmarking was made. In the benchmarking, similar solutions as well as other kinds of sealing solutions were investigated. The project team focused on finding solutions for grommets, however, as stated, other solutions for cable sealing were also investigated. The benchmarking solutions were then evaluated in a pros and cons list.

6.2.1 Similar Solutions

Three similar solutions were benchmarked and investigated. Their respective sealing solutions can be seen in figure 6.2. The first solution (1) did not have a sleeve but instead had a triangular hole in which the cable was brought through. Both solution (2) and (3) were smaller grommets with one of the grommets having two holes for two cables. Lastly, solution (3) did not have a tag that needed to be pulled off. In table 6.1, advantages and disadvantages of solution (1) to (3) are listed.

Figure 6.2: The figure shows similar solutions that were studied in the benchmarking process.

Table 6.1: The table shows advantages and disadvantages of similar solutions that were investigated.

Sol.	*Advantage*	*Disadvantage*	*Comment*
1	• Easy to pull through modular plug	• Leaves three gaps in the seal	The gasket is installed at an angle. It says IP67 and IP68 but this is debatable. Material silicone 60A.
2	• Small • Multiple cables	• Not possible to pull through modular plug (gasket with two holes) • Not IP67	IP66. No markings on grommet.
3	• Small • Multiple cables	• Not possible to pull through modular plug (gasket with two holes) • Not IP67	IP66. The grommet is installed at an angle. No markings on grommet.

6.2.2 Other solutions

When other solutions were investigated, grommet solutions were mainly found, these can be seen in figure 6.3. Both solution (4) and (8) had a slit on their side where the cable could be inserted. The grommets were then sealed when put in their position. This solution with a slit did not require a modular plug to be detached from the cable during installation. Solution (5) had a longer sleeve than Axis's current solution and needed a wrench to be put together (not visible in the figure). Solution (6) was a cable gland and consisted of multiple parts that were screwed together. Lastly, solution (7) was a grommet that could have three cables installed at the same time.

The solutions (4) to (8) were evaluated by listing their main advantages and disadvantages, see table 6.2.

Figure 6.3: The figure shows other solutions that were found. [31, 32, 33, 34, 35]

Table 6.2: **The table shows advantages and disadvantages of other solutions that were investigated.**

Sol.	*Advantage*	*Disadvantage*	*Ref.*
4	• Easy to pull through cable • Easy to assemble • Fulfills IP67	• Not designed for thinner walls • Needs more material than current solution, added weight	[31]
5	• Handles cables at angles • Handles cables with different diameters • Good operating temperature • Fulfills IP67	• Multiple parts • Needs tool to be put together	[32]
6	• Tough • Great water protection • Fulfills IP67	• Advanced to install • More expensive material than current solution • Multiple parts	[33]
7	• Can handle multiple cables	• Cannot handle bigger cables • Does not fulfill IP67	[34]
8	• Good for wall • Easy to pull through modular plug • Easy to assemble	• Cannot handle smaller cable sizes • Does not fulfill IP67	[35]

6.3 Iteration 1

6.3.1 Concept Generation

After gathering all the necessary information needed to continue, Iteration 1 and the first concept generation were initiated. The concept generation consisted of a brainstorming session where each member of the project team generated as many concepts as possible during one hour. The team then gathered to combine and discuss the best concepts. The generated concepts can be seen in figure 6.4 and descriptions of the concepts can be seen in table 6.3 below.

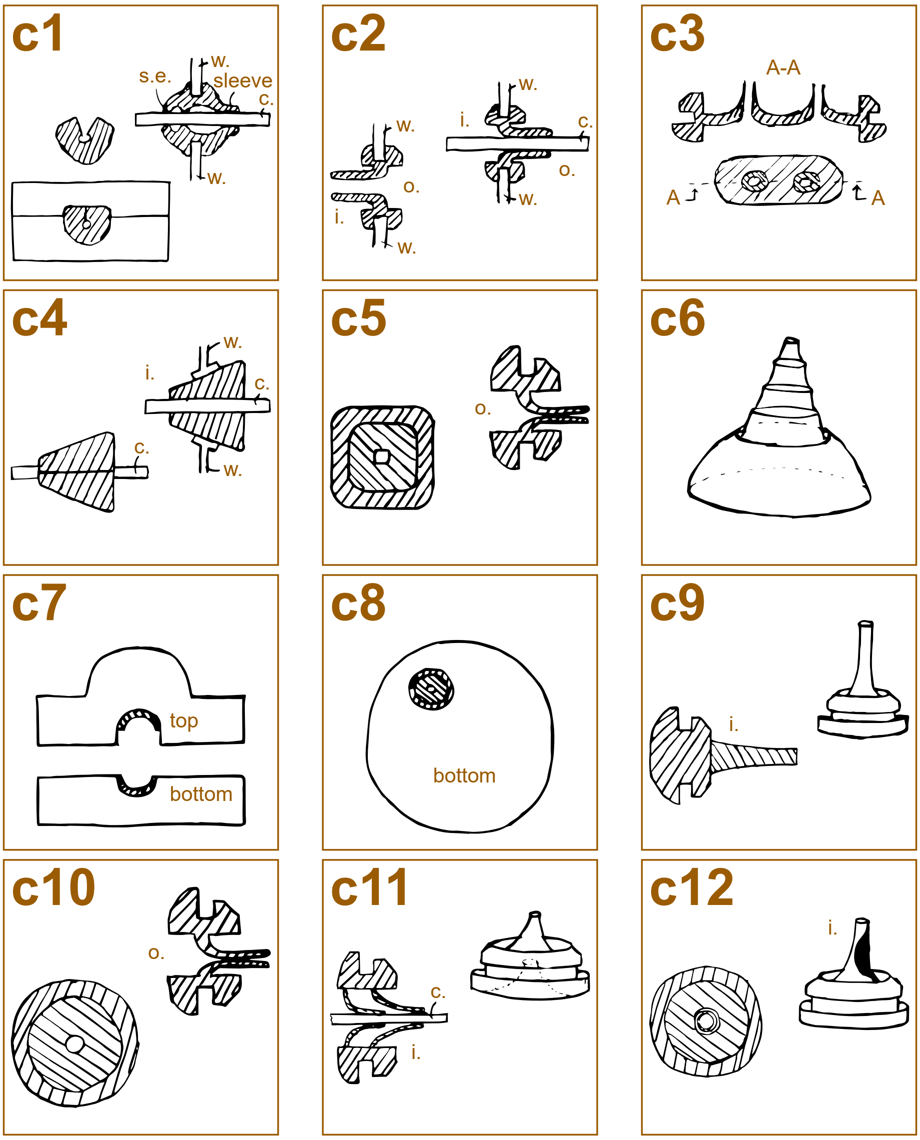

Figure 6.4: The figure shows the concepts that were generated in Iteration 1. The following abbreviations are used in this figure: sealing element (s.e.), wall (w.), cable (c.), inside of the camera house (i.) and outside of the camera house (o.). Descriptions for all concepts can be seen in table 6.3.

Table 6.3: The table describes all concepts that were developed during the concept generation in Iteration 1. All concepts can be seen in figure 6.4.

Concept	*Description*
c1	Grommet with a slit which is opened when a cable is installed. Sealed between top cover and base. Uses two sealing elements and a sleeve for water protection.
c2	Similar to current solution (Cable Gasket 1) where the sleeve is first faced inwards. After the cable has been pulled through, the cable is pulled back letting the sleeve face outwards.
c3	Similar to current solution (Cable Gasket 1), but uses a profile that has been stretched out making it possible to install two cables in one grommet.
c4	Grommet with a slit which is opened when a cable is installed. It uses a profile as a wedge allowing it to be pushed into the hole more easily making a good seal around cables with different diameters.
c5	Similar but smaller than current solution (Cable Gasket 1). Uses a rectangular shape to better fit modular plug.
c6	Similar to current solution (Cable Gasket 1), but uses steps in the sleeve which is cut to be optimized for different cable diameters.
c7	Sealing elements are integrated with the top cover and base and then sealed together when camera is installed.
c8	The idea of having the sealing solution positioned on the bottom of the camera base.
c9	Similar to current solution (Cable Gasket 1) but smaller and uses a longer sleeve with a bigger diameter. Not possible to pull through plug.
c10	Similar to current solution (Cable Gasket 1) but smaller. Not possible to pull through modular plug.
c11	Similar to current solution (Cable Gasket 1) but smaller and uses two sleeves for a better seal around the cable. Not possible to pull through modular plug.
c12	Grommet with a slit which is opened when a cable is installed. The sleeve can be wrapped around the cable for a better seal.

6.3.2 Concept Selection

To select the most optimal concepts for further development, a concept screening was performed where the generated concepts were evaluated based on criteria developed from the product needs and requirements. The screening together with the selected criteria can be seen in table 6.4.

6.3.2.1 Selection of Criteria Used in Concept Screening

As mentioned before, the criteria used in the first concept screening were based on the gathered product needs and requirements. Since the concepts were at an early stage at this point, no criteria regarding specific numbers were chosen. Instead, more general criteria that were deemed suitable for the first concept screening were used.

The "Sealing capability" criterion was based on the IP67 requirement and the "Manufacturability" criterion was based on the cost requirement as well as how easy it would be to manufacture the part. All other criteria were taken directly from the requirements and needs, such as the "Ease of installing cable with/without modular plug" and the "Small size" criterion.

6.3.2.2 Concept Screening

All concepts in the concept screening, together with a reference, were listed and evaluated based on the selected criteria and were scored in relation to the reference. In this screening, Cable Gasket 2 was chosen as a reference. First, the reference got a score of "0" for all criteria. Then the concepts got a score of either a "–" if it was deemed to be worse than the reference for the specific criterion, a "0" if it was deemed equal to the reference or a "+" if it was deemed better than the reference. The sum of all "–", "0" and "+" were then calculated and from this and a net score was generated. Each concept then got a rank based on its net score. The concepts that got a rank of either 1, 2 or 3 moved on to Iteration 2 and the first workshop. The concepts that moved on can be seen in table 6.4.

Table 6.4: The table shows the screening of all concepts that were generated in Iteration 1, see figure 6.4. The reference (Ref.) is the current solution at Axis, Cable Gasket 2. The concept is marked yes (Y) if it will continue to Iteration 2 and no (N) if it will not.

Selection criteria	*Ref.*	*c1*	*c2*	*c3*	*c4*	*c5*	*c6*	*c7*	*c8*	*c9*	*c10*	*c11*	*c12*
Ease of installing in chassis	0	-	0	0	+	0	0	-	0	0	0	0	0
Ease of installing cable with plug	0	+	-	0	+	0	0	+	0	-	-	-	-
Ease of installing cable without plug	0	+	-	0	+	0	+	+	0	0	0	-	+
Manufacturability	0	-	0	0	+	0	0	0	0	0	0	-	-
Cable diameter flexibility	0	0	0	0	+	0	+	-	0	0	0	0	0
Small size	0	0	0	0	0	+	0	+	0	+	+	+	+
Sealing capability	0	+	+	0	+	0	0	0	0	0	0	0	0
Angled cable flexibility	0	0	-	-	0	-	-	-	0	0	-	0	-
Sum +	0	3	1	0	6	1	2	3	0	1	1	1	2
Sum 0	9	4	5	8	3	7	6	3	9	7	6	5	4
Sum –	0	2	3	1	0	1	1	3	0	1	2	3	3
Net score	0	1	−2	−1	6	0	1	0	0	0	−1	−2	−1
Rank	3	2	5	4	1	3	2	3	3	3	4	5	4
Continue?	–	Y	N	N	Y	Y	Y	Y	Y	Y	N	N	N

6.3.3 Reflect on the Result and the Process

The brainstorming session, carried out in the concept generation, had a duration of about one hour. At the time, the team did not feel the need for additional time. However, in retrospect, increasing the duration of the brainstorming session could have been beneficial in the generation of concepts and may have generated more potential concepts.

As for the concept selection method, the team chose to use a concept screening. The reason for this was that, at this stage, the relative importance of the concepts was not significant since there were a lot of concepts. To sort out some of the concepts with the least promise, the screening was chosen. The choice of criteria used in the screening was also good and helped determine which concepts that moved on.

At the end of Iteration 1, the team was satisfied with the concepts, several of them were interesting and had the potential of continuing to Iteration 2.

6.4 Iteration 2

6.4.1 Concept Generation

The concept generation in Iteration 2 started off with discussions about the chosen concepts from Iteration 1. From the discussions, one concept was created, c13, as a variant of concept c1. The difference was that c13 was installed directly into the chassis and not fixed by the top cover, see c13 in figure 6.5.

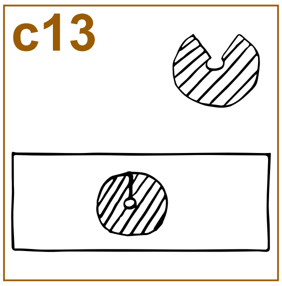

Figure 6.5: The figure shows concept c13 that was generated at the beginning of Iteration 2.

6.4.1.1 Workshop 1

To get professional feedback and help with choosing the most promising concepts, a one-hour workshop was held with selected engineers from Axis. The main purpose of the workshop was to find strengths and weaknesses with the concepts as well as risks and opportunities.

In workshop 1, eight concepts (c1, c4–c9 and c13) were briefly presented to the group. After the presentation, the participants were allowed to verbally express their opinions about the different concepts.

During the latter part of the workshop, some concepts were combined and new concepts (c14–c18) were introduced. The new concepts are described in table 6.5 and presented in figure 6.6.

Comments from the participants, regarding all concepts, were compiled in table 6.6. These comments formed the base for the concept scoring that was done next.

Table 6.5: **The table shows descriptions for concept c14–c18. These concepts were developed during workshop 1.**

Concept	*Description*
c14	Some form of memory foam that expands after the cable has been pulled through.
c15	Expanding spray foam.
c16	Twist solution. Like an aperture in camera lens, the solution is rotated in one direction to increase the hole diameter and in the opposite direction to decrease the hole.
c17	Spinning solution. Like a reflective strip. Strip is added, then pushed into the hole and last released.
c18	Opened gland with a slit. Uses a hinge to close the opening.

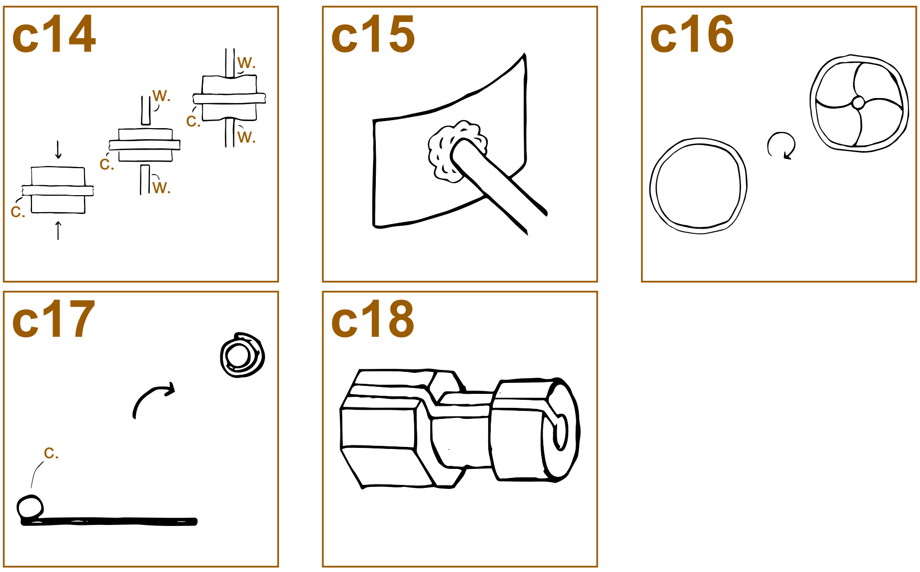

Figure 6.6: The figure shows concept c14–c18 that were generated during workshop 1.

Table 6.6: The table shows comments from the participants about the different concepts that were discussed in workshop 1.

Concept	*Comment*
c1	Difficult to make a good seal. Possibly better with a locking profile close to cable. Difficult for various cable dimensions for slit solution. Could be good with sealing elements to put pressure on the gasket and let the silicone expand.
c4	Steps and threads. Interesting to further investigate. Tighten with nut on outside. Difficult with different cable dimensions. Possibly human error when pushing it in (too much or too little). Possibly different profile with a wedge profile on inside.
c5	Difficult to make tight around corners and middle of sides. Possibly not much smaller than current solution.
c6	Human error, cut too much or too little. Difficult to pull through modular plug.
c7	Difficult to seal tightly. Could use a locking profile. Bad for different cable dimensions.
c8	Could be combined with other concepts and the usage of a backbox. Often do not want to make a hole in the wall.
c9	Did not arise too much interest in this concept. Must pull through modular plug.
c13	No need for a cover that provides pressure. Similar to c1.
c14	Similar characteristics as an earplug. Difficult to select watertight material.
c15	Perhaps a bit messy. More work for installer.
c16	Bigger solution. Needs to be twisted the right amount by installer.
c17	Difficult to make a good seal at the end. No solutions regarding how to attach it to the camera.
c18	Advanced solution, multiple parts and multiple materials.

6.4.2 Concept Selection

After the workshop, another concept selection was constructed, see table 6.7. However, for this concept selection, a concept scoring was used instead of a concept screening.

The criteria used in the concept scoring were the same as used in the first concept screening. All concepts then got a score from 1 to 5 depending on how well a specific criterion was fulfilled relative to the reference. Cable Gasket 2 was again used as a reference and got a score of 3 for all criteria. Regarding the criterion “Ease of installing in housing”, a concept got a higher score if it was deemed not to take a long time to install. For the next two criteria, “Ease of installing cable with plug” and “Ease of installing cable without plug”, a concept got a higher score if it was considered to not get damaged when installing a cable. Furthermore, if a concept was deemed to be easy to manufacture it got a higher score on the “Manufacturability” criterion. Regarding the criteria “Cable diameter flexibility” and “Angled cable flexibility”, concepts got a higher score if they were considered to handle different cable diameters and if they handled angled cables better while still maintaining their sealing capabilities. Moreover, if a concept was smaller than the reference, it got a higher score on the “Small size” criterion. Lastly, a concept got a higher score on the “Sealing capability” criterion if it was deemed to have robust sealing capabilities which would prevent water and dust from entering the chassis. If a concept was considered not to fulfill a specific criterion, it received a lower score than the reference.

All criteria got a weight between 0 and 1, depending on their importance, where the sum of all equaled 1. The “Sealing capability” and “Ease of installing cable with plug” criteria were considered to be the most important ones since the main purpose of the grommet would be to seal against water and dust. Another important requirement from Axis was that the grommet would be able to handle a modular plug being attached to the cable. Both the “Small size” and “Manufacturability” criteria got the third highest rating since it would be beneficial for the grommet to be small as well as easy to manufacture. The “Ease of installing cable without plug”, “Ease of installing in housing” and “Angled cable flexibility” criteria all got lower weighted scores since, firstly, the project would not prioritize cables without a modular plug and secondly, as mentioned before, changes could be made to the chassis in the future which would alter the way the grommets would be installed. Lastly, the "Cable diameter flexibility" criterion got the lowest weighted score since the concepts could, in worst case, be scaled to a size that could handle a specific diameter interval.

The concepts that got the highest scores were concept c1, c4 and c13. However, the team saw potential in concept c14 and c17 and therefore chose to combine these two for further development.

Table 6.7: The table shows the scoring of all concepts that were generated in Iteration 2, see figure 6.4, 6.10 and 6.6. The reference (Ref.) is the current solution at Axis, Cable Gasket 2. The concept is marked yes (Y) if it will continue to Iteration 2 and no (N) if it will not. The concepts have a rating (R.) and weighted score (W.s.) for each selection criteria.

			Ref.		*c1*		*c4*		*c5*		*c6*	
No	***Selection criteria***	***Weight***	***R.***	***W.s.***	***R.***	***W.s.***	***R.***	***W.s.***	***R.***	***W.s.***	***R.***	***W.s.***
1	Ease of installing in housing	0.11	3	0.3	3	0.3	4	0.4	3	0.3	3	0.3
2	Ease of installing cable with plug	0.16	3	0.5	5	0.8	5	0.8	3	0.5	4	0.6
3	Ease of installing cable without plug	0.11	3	0.3	4	0.4	4	0.4	3	0.3	3	0.3
4	Manufacturability	0.13	3	0.4	3	0.4	3	0.4	3	0.4	3	0.4
5	Cable diameter flexibility	0.07	3	0.2	3	0.2	3	0.2	3	0.2	5	0.3
6	Small size	0.13	3	0.4	4	0.5	4	0.5	4	0.5	3	0.4
7	Sealing capability	0.20	3	0.6	3	0.6	3	0.6	3	0.6	2	0.4
8	Angled cable flexibility	0.09	3	0.3	3	0.3	3	0.3	2	0.2	2	0.2
	Total score	1.00	3.0		3.6		3.7		3.0		3.0	
	Rank		9		2		1		8		9	
	Continue?		-		Y		Y		N		N	

	c7		*c8*		*c9*		*c13*		*c14*		*c15*		*c16*		*c17*		*c18*	
No	***R.***	***W.s.***	***R.***	***W.s.***	***R.***	***W.s.***	***R.***	***W.s.***	***R.***	***W.s.***	***R.***	***W.s.***	***R.***	***W.s.***	***R.***	***W.s.***	***R.***	***W.s.***
1	4	0.4	3	0.3	3	0.3	3	0.3	4	0.4	1	0.1	2	0.2	3	0.3	2	0.2
2	5	0.8	3	0.5	3	0.5	5	0.8	4	0.6	5	0.8	4	0.6	5	0.8	4	0.6
3	4	0.4	3	0.3	3	0.3	4	0.4	4	0.4	4	0.4	4	0.4	4	0.4	4	0.4
4	4	0.5	3	0.4	3	0.4	3	0.4	3	0.4	4	0.5	2	0.3	2	0.3	1	0.1
5	3	0.2	3	0.2	3	0.2	3	0.2	5	0.3	5	0.3	4	0.3	4	0.3	2	0.1
6	4	0.5	3	0.4	4	0.5	4	0.5	4	0.5	2	0.3	1	0.1	4	0.5	1	0.1
7	1	0.2	3	0.6	3	0.6	3	0.6	1	0.2	3	0.6	2	0.4	2	0.4	4	0.8
8	2	0.2	1	0.1	3	0.3	3	0.3	2	0.2	3	0.3	2	0.2	2	0.2	2	0.2
	3.3		2.8		3.1		3.6		3.2		3.3		2.5		3.2		2.7	
	4		10		7		2		6		3		12		5		11	
	N		N		N		Y		N		N		N		N		N	

6.4.3 Refinement

As stated in the concept selection, the concepts that moved on were concepts c1, c4, c13 and a combination of concepts c14 and c17 that was be called c19, see figure 6.7. These concepts were refined and 3D models were constructed in Creo Parametrics. The 3D models of concept c1, c4, c13 and c19 can be seen in figure 6.8, 6.9, 6.10 and 6.11.

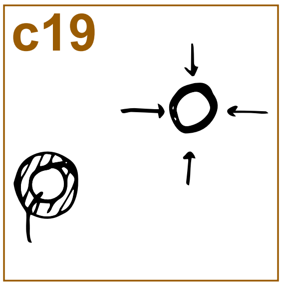

Figure 6.7: The figure shows concept c19 which is a combination of concept c14 and c17.

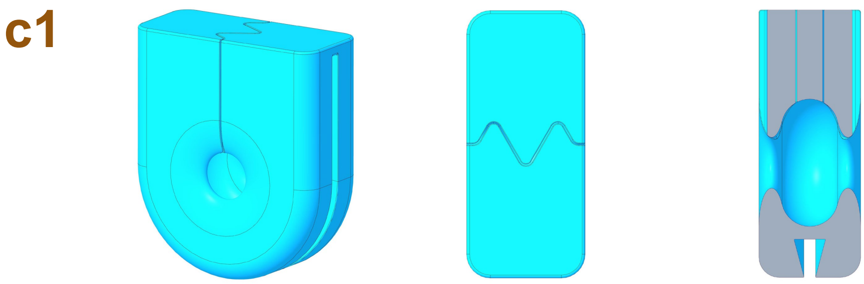

Figure 6.8: The figure shows a 3D model of concept c1 with straight sides.

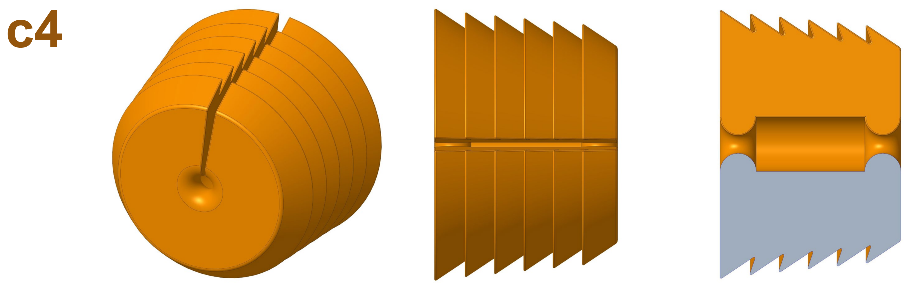

Figure 6.9: The figure shows a 3D model of concept c4.

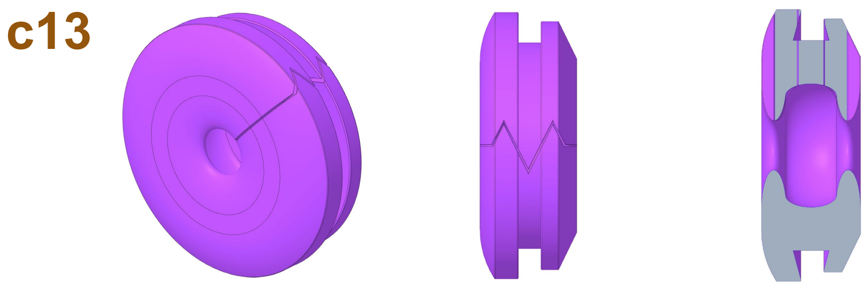

Figure 6.10: The figure shows a 3D model of concept c13.

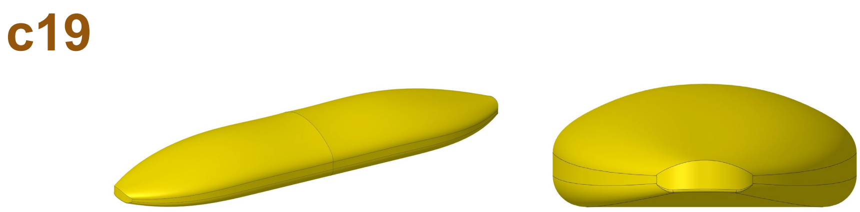

Figure 6.11: The figure shows a 3D model of concept c19.

After some discussions within the project team, a fourth concept was developed and refined. The concept, which will be called c20, can be seen in figure 6.12 and was constructed with concept c13 as a reference. The difference between c13 and c20 was that c20 had a longer axial depth to improve the radial sealing.

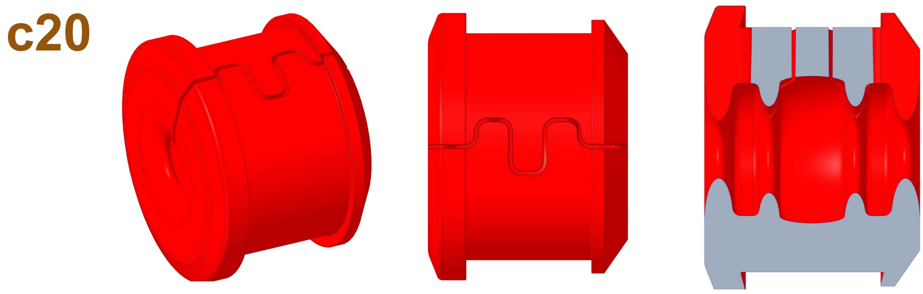

Figure 6.12: The figure shows a 3D model of concept c20.

All concepts were constructed in Creo and they got a detailed “inside”, except for concept c19. At this stage, the size of the concepts was determined. All concepts got small ridges called sealing elements and the idea was that the sealing elements would help prevent water from leaking between the cable and grommet. The sealing elements can be seen in figure 6.8, 6.9, 6.10 and 6.12 to the far right. The plan was to give the concepts slightly different sealing elements to find the most optimal when testing the grommets later on. Similar to the current solution, concept c1, c13 and c20 got tilted inner and outer sealing edges (that seals between the grommet and chassis) to improve the axial sealing capabilities, these can also be seen in figure 6.8, 6.10 and 6.12.

One requirement with the sealing solution was that a cable with attached modular plug must be possible to pull through the chassis. This was the main parameter that controlled how small the sealing solution could be made. This meant that the concepts that had to be placed inside of a hole could not have an outer diameter smaller than 17 mm since the outer diameter of the modular plug was 17 mm. However, unlike the other concepts, the idea for concept c1 was to place the grommet in a U-shaped profile. This meant that the modular plug did not have to be pulled through a hole which in turn made it possible to make concept c1 smaller than 17 mm. In addition to making c1 smaller, it also got some extra material between the top and the sealing edge, see figure 6.8. The idea was that the grommet would be pushed further down, creating a tighter seal between the cable and the grommet. After additional discussions, concept c1 got tilted sides. It was considered that the tilted sides would provide a better seal since the sides would be pushed in as the grommet was placed in the chassis. The updated concept can be seen to the right in figure 6.13.

Figure 6.13: The figure shows a 3D model of concept c1. To the left is the first version with straight lines and to the right is the updated version with tilted sides.

The main idea for all concepts was to use a slit in the grommet to allow for the cable to be installed from the side instead of pulling the cable with attached modular plug through the hole in the grommet. The slit can be seen in figure 6.8, 6.9, 6.10 and 6.12. The concepts got a unique slit to find the best seal when testing the concepts as prototypes.

As for concept c19, it was discovered that it would be hard to prototype because of its desired properties, especially with the time frame the project team had. After a lot of material research as well as a discussion with a material specialist, no suitable material was found for the concept. One material specialist mentioned that a material with the desired settling properties would get worse over time. For that reason, the project team chose not to continue with concept c19 and instead focus on the other concepts.

6.4.4 Prototyping

To get a better perspective of the size and look of the concepts, the concepts were 3D printed using FFF technique. The prototypes were made of polylactic acid (PLA) and therefore had no resemblance to the material characteristics of a rubber material. Sliced versions of all concepts were 3D printed for a better look inside of the holes. The 3D printed parts can be seen in figure 6.14. When seeing the prototypes, it was discovered that the inside hole diameter was probably too small which prompted a change in the 3D model making the diameter bigger.

Figure 6.14: The figure shows 3D printed prototypes of concept c1, c4, c13 and c20. The parts were printed in PLA using FFF.

6.4.5 Reflect on the Result and the Process

The workshop used in the concept selection phase during Iteration 2 was very helpful and generated a lot of good feedback. It was insightful to hear what some experienced engineers had to say about the concepts which also generated additional ideas and concepts that had not been contemplated before.

For the selection method in Iteration 2, a concept scoring matrix was chosen. The reason for this was that at this stage, specific criteria became more important and the matrix helped to reduce the number of concepts since the score differed more.

The 3D modeling of the four concepts that had moved on was very helpful and gave a more detailed picture of the concepts and made it easier to visualize them. The prototyping was helpful since the real size of the concepts could be easier visualized than on a computer screen.

The concepts at the end of Iteration 2 were very promising and the refinements resulted in good results with concepts that fulfilled a lot of needs and requirements.

6.5 Iteration 3

6.5.1 Concept Generation

For Iteration 3, the concepts were further refined. It was deemed that the sealing elements were too narrow and were therefore made wider to absorb the axial force better from cables being pulled. The new insides of the 3D models can be seen in figure 6.15.

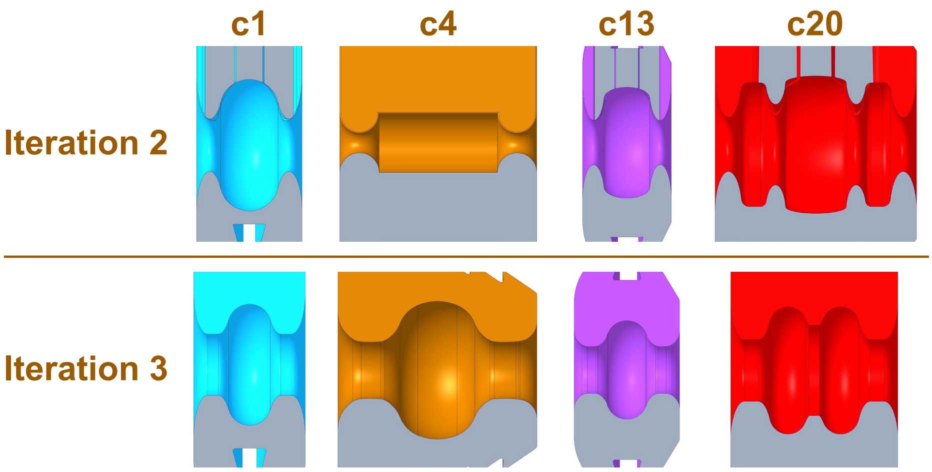

Figure 6.15: The figure shows the profile of the sealing elements of the 3D models for all concepts (c1, c4, c13 and c20) from Iteration 2 and Iteration 3. The gray area is where the 3D model has been sliced since this is a cross section.

6.5.2 Prototyping

The next step in the process was to produce prototypes which would be used to test the concepts. The chosen material for the prototypes was SiR since it would be cheap to fabricate soft tools and it would only take a couple of weeks to get the samples. SiR is also a material with excellent weather resistance. See chapter 7 Material for a deeper analysis of the most suitable material for the prototypes and future large-scale production.

Before making the prototypes, discussions were held with the supplier regarding the design for manufacturing (DfM). Some parts of the concepts had to be changed to make them manufacturable. One change that had to be made was regarding concept c4. The supplier commented that the draft angle for the steps/ridges was too big and had to be reduced to separate the prototype from the tool, see figure 6.16.

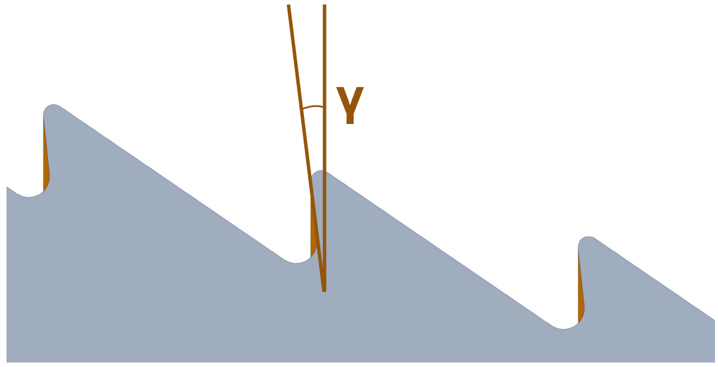

Figure 6.16: The figure shows angle γ which represents the angle of the steps/ridges in concept c4. Angle γ was reduced to create a smaller negative draft angle.

One major change that needed to be made was the slit. According to the supplier, the slit was made after the molding of the prototypes. Hence, only straight slits could be made and the more advanced slits that the concepts had were changed. The final 3D models for the prototypes can be seen in figure 6.17, 6.18, 6.19 and 6.20. Note the new straight slits for all concepts. After these changes were made, the prototypes could be manufactured according to the supplier.

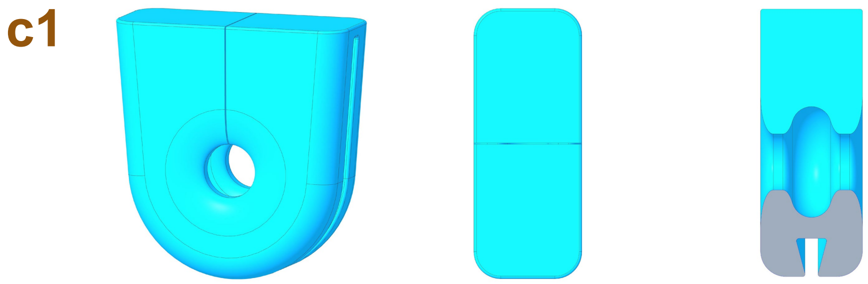

Figure 6.17: The figure shows the final 3D model of concept c1 before being prototyped.

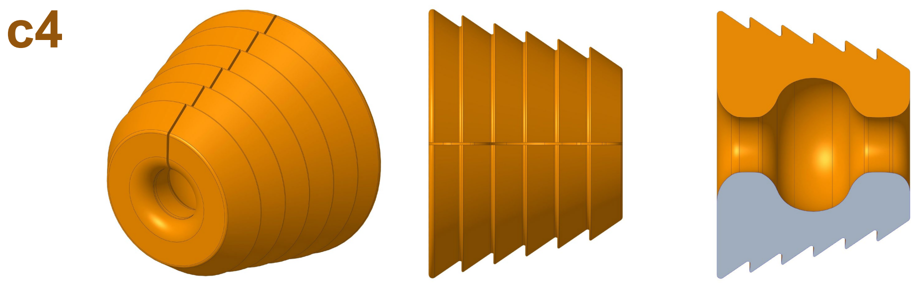

Figure 6.18: The figure shows the final 3D model of concept c4 before being prototyped.

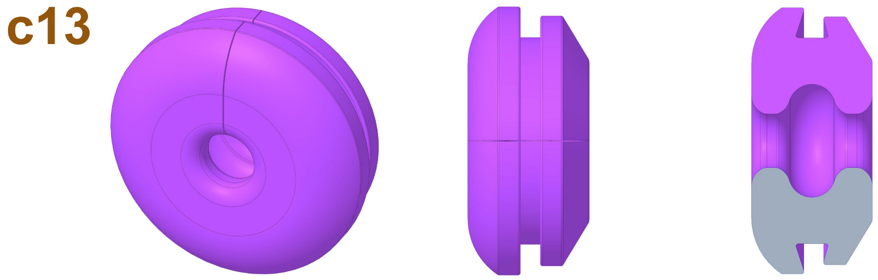

Figure 6.19: The figure shows the final 3D model of concept c13 before being prototyped.

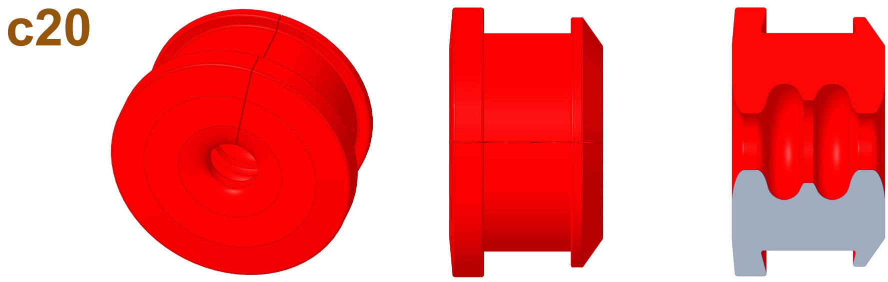

Figure 6.20: The figure shows the final 3D model of concept c20 before being prototyped.

It was proposed to the supplier that a family tool would be used to produce all four parts. Since concept c1 differed from the other concepts, as it was not symmetrical around its axis, the supplier argued that it would be safer to have a separate tool for this concept. In the end, a family tool was fabricated for concept c4, c13 and c20, see the tool in figure 6.21. A separate tool was manufactured for concept c1, see tool in figure 6.22. Pictures from the prototyping process can be seen in figure 6.23 and 6.24 below.

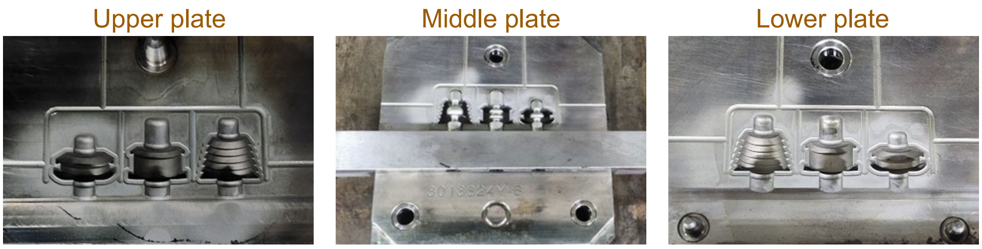

Figure 6.21: The figure shows the family mold used to fabricate prototypes in SiR for concept c4, c13 and c20. The pictures were provided by the supplier.

Figure 6.22: The figure shows the mold used to fabricate prototypes in SiR for concept c1. The pictures were provided by the supplier.

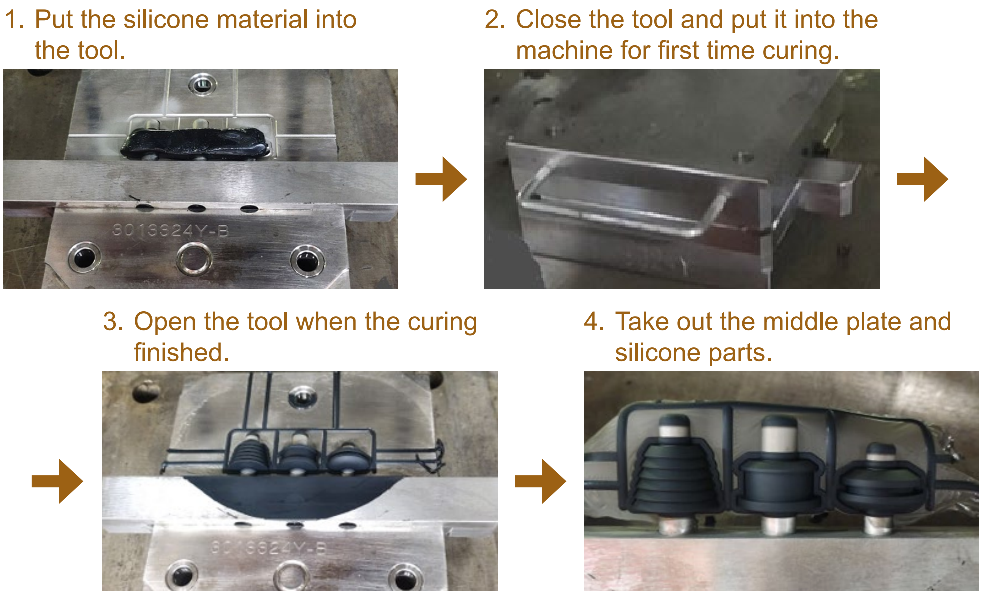

Figure 6.23: The figure shows the manufacturing process for concept c4, c13 and c20. The pictures were provided by the supplier.

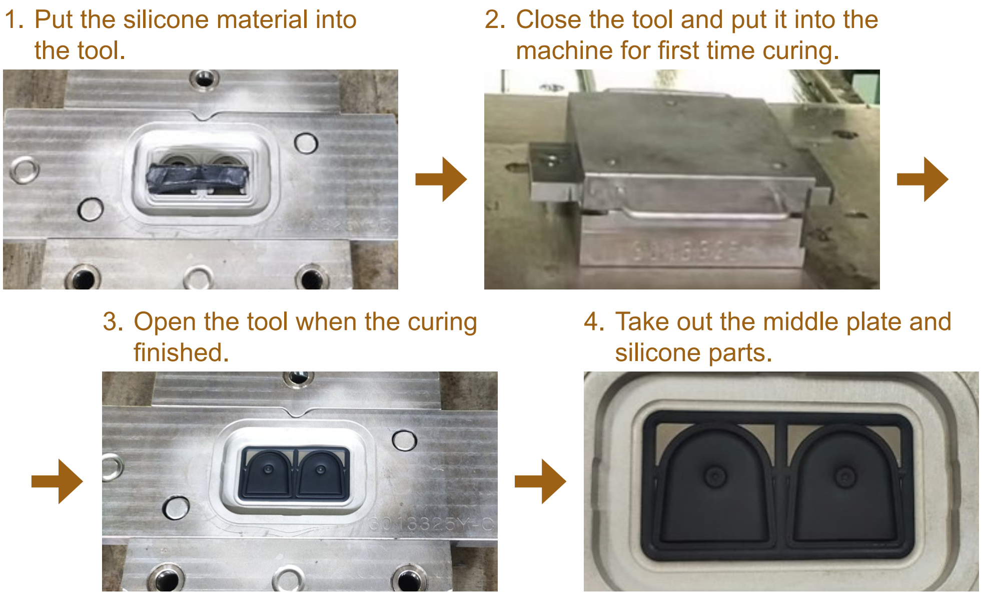

Figure 6.24: The figure shows the manufacturing process for concept c1. The pictures were provided by the supplier.

The ordered quantity of each concept hardness was 30, making the total amount of prototypes 360. All prototypes can be seen in figure 6.25.

Figure 6.25: The figure shows the finished prototypes that were produced.

6.5.3 Testing

6.5.3.1 IP67 Testing

IP67 was one of the product requirements and the different concepts were tested to see if they would fulfill the IP67 requirements. The tests were done with different hole dimensions, wall thickness, cable sizes and with bent cables. How the tests were made and the result for each test can be seen in chapter 8 Testing. The result from the testing showed that concept c4 performed the best and c1 showed great potential. Concept c13 and c20 did not perform as well and many of the concept configurations had a difficult time preventing some form of leakage.

6.5.3.2 Workshop

To further test the grommets, an installation workshop was held with engineers at Axis. The reason for the workshop was to evaluate how easy it was to install and handle the grommets. Each person got to test to install the grommets in three different 3D printed chassis designed for the different grommets, these can be seen in figure 6.26. During the workshop, the participants got to fill in a questionnaire which can be seen in B Appendix – Workshop Form. The answers can be seen in table 6.8.

The feedback was mainly positive, the slit was appreciated and made it easy to install a cable with a modular plug. Concept c1 was perceived to be the easiest to use, since this was easy to slide into the chassis and it was symmetrical, with no risk of installing it backwards. Concept c13 and c20 were easier to install with a softer material, whereas the material hardness did not matter as much for concept c1 and c4.

Figure 6.26: The figure shows 3D printed chassis to be used for testing the prototypes.

Table 6.8: The table shows the answers from the second workshop. The hardness is marked to the right of the concept name. Positive feedback is marked "+", negative "–" and other "•". The number to the right of the concept name is hardness measured in Shore A.

Concept		*Feedback*
c1	+	Concept c1 was easy and smooth to install since it is symmetrical.
	+	I like concept c1 but it can be hard to incorporate with the gasket around the chassis.
	+	Concept c1 is most practicable, if the sealing works it should be the simplest.
	+	Concept c1 was better with harder rubber.
	–	Unsure whether c1 had to be smoothed out at the bottom when installed.
c4	+	Concept c4 was the easiest to know which direction to put it and it was also easy to take off.
	+	Concept c4 was easy and intuitive to install. I liked c4 with hardness 40 the most.
	+	Installing concept c4 with all hardnesses was pretty easy.
	–	Concept c4 is hard to know how much it should be pushed in.
	–	c4 with hardness 50 was impossible to install.
	–	It was hard to get concept c4 in the right position.
c13	+	Concept c13 was easy to know how to install.
	+	The soft concepts for c13 are good.
	–	There is a risk of concept c13 being installed in the wrong way.
	–	I could not install c13 with hardness 50.
	–	Harder material was harder to install, some were unable to install concept c13 with hardness 50.
	•	With concept c13 with hardness 30 I would make the inner (front) sealing edge longer for an easier installation.
c20	+	I liked concept c20 with the long waist, it felt stable.
	+	The soft concepts for c20 are good.
	–	c20 is a little unclear regarding in which way it should be installed.
	–	The sealing edge on the inside of the chassis gets folded with c20.
	–	c20 with hardness 50 is very hard to install.
	–	Concept c20 was hard to get into the right position.
General	+	It was easy and intuitive to install the white cables in the concepts.
	+	Generally, hardness 40 worked best for all concepts.
	–	The majority of the hard materials were hard to install.
	•	The thickness of the cable was important in all concepts, slimmer or thicker cable worked less well.

6.5.4 Concept Selection

After conducting both the IP testing and the installation workshop, it could be concluded that concept c1 and c4 performed best. Both concepts were able to fulfill the IPX7 requirement with the smaller cable. When looking at the result for the bigger cable, concept c4 performed better. Concept c4 also performed better with a bent cable. Concept c4 (with hardness 40 Shore A) passed the IP6X and IPX6 tests, but it was also the only concept to be tested for these two tests.

Although concept c4 performed better in the IP testing, the project team chose to move on with c1 as well since it got the best feedback in the workshop. Therefore, the team chose to move forward with concept c1 and c4 as final concepts and create a final design for them.

6.5.5 Refinement

The feedback from the installation workshop together with the result from the IP67 testing helped the team see flaws in the design of the grommets. These flaws were studied and refinements were made for concept c1 and c4.

The biggest refinement for concept c1 was that a gasket, sealing around the chassis and the dome of the camera, was implemented in the design, see figure 6.27.

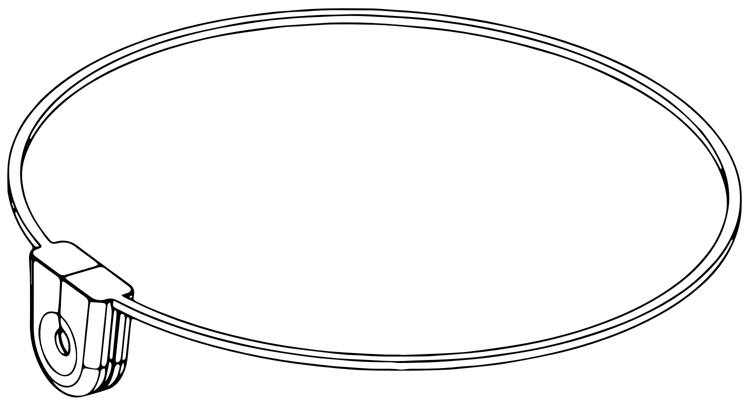

Figure 6.27: The figure shows the refined concept c1. The grommet has been integrated with the chassis seal.

The first refinement for concept c4 was to make the ridges (on the outside) a bit longer and bigger, see figure 6.28. This would allow the ridges to fully cover the inner wall around the hole. This would also allow for the grommet to be pulled harder without accidentally being pulled out. The two ridges with smallest diameter were also removed since it was discovered that they did not do anything for the sealing, the inner sealing element was barely used when pushed into the chassis hole. The last refinement that was implemented was a stop at the end of the grommet. This would prevent the grommet from accidentally being pushed in too much and would also improve the axial seal around the outside of the hole.

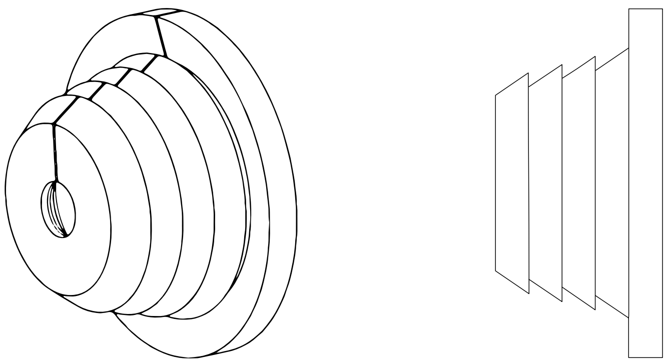

Figure 6.28: The figure shows the refined concept c4. Two smaller ridges have been removed and a bigger stop ridge has been added.

6.5.6 Reflect on the Result and the Process

The whole process for Iteration 3 went well but with slight delays. To do the IP67 testing, the test boxes had to be sealed properly so that if any water had leaked in, the team would know that it came from the grommet. However, this took longer time than expected because the first 3D printed boxes, made from a printer using FFF, leaked and could not be made completely sealed. Therefore, a printer, using MJP technique was used instead. The boxes which had been printed with MJP had no leakage problems.

Furthermore, both the IP67 testing as well as the installation workshop was very helpful and allowed the team to find the best concepts. The IP67 testing also took a longer time than the team thought with all the unique tests that were made.

7 Material

In this chapter, the choice of material for the sealing solution will be discussed. Three types of materials were investigated, SiR, EPDM and thermoplastic elastomer (TPE). The focus of the investigation was to find a suitable material for prototypes as well as the final product used for large volume production. The first step was to confirm the material needs and requirements.

7.1 Material Needs and Requirements

The needs have been researched in chapter 4 Identify Needs and most of the needs are regarding the outdoor environment in which the product is supposed to be installed. In chapter 5 Establishing Target Requirements the environmental requirements are specified as withstanding IP67, having an operating temperature of -30 to 50 °C and storing and transport temperature of -40 to 65 °C. General requirements that effect the material are being cost-efficient and having a lifetime of 9 years. The product should also be easy to install in the camera chassis and a cable with a modular plug should be easy to pull through.

7.2 Material Types

7.2.1 Silicone Rubber

From chapter 2 Theory, it is known that SiR is characterized by excellent resistance to high and low temperature, good compression set, excellent electrical properties and low strength.

SiR is a common gasket material at Axis today and both the existing solutions Cable Gasket 1 and Cable Gasket 2 are made of SiR. From the interview with engineers at Axis (in chapter 4 Identify Needs), the material choice was mostly based on their experience from working with SiR and the fact that they found it a good material choice for Cable Gasket 1. They mentioned that SiR has good temperature properties and that it is relatively fast and cheap when it comes to producing tools for manufacturing. However, one engineer pointed out the risk of cracks forming and propagating in products made of SiR. The choice of using SiR for Cable Gasket 2 was based on the previous solution (Cable Gasket 1). The engineers did not see any need of changing the material since it worked.

To get a better understanding of suitable materials for the sealing solution, a discussion was held with a material expert engineer at Axis. The engineer mentioned that a disadvantage of using SiR is that it needs to be heat treated after the molding to prevent volatile outgassing from the material. This post-cure process takes around four hours. The engineer described the need of using certified materials, such as UL certification. This certification guarantees that the product has been tested for the relevant standards [36]. Getting a material UL certified can be costly for the manufacturer, according to the engineer. Lastly, the material expert pointed out SiR's good weather resistance against rain and UV light, especially black SiR.

Further material discussions were held with another engineer at Axis that agreed that SiR is a good option for grommets. However, this engineer also added that the post-cure process (preventing volatile outgassing) needs to be performed with care to get a good result. During the heating, the parts need to be separated for the gas to escape properly and sometimes the parts are faultily stacked in a pile during the treatment preventing the post-cure to work as expected. When comparing SiR and TPEs, the engineer concluded that SiR has better compression set characteristics than TPEs.

A discussion was held with a supplier regarding lead time for producing soft tools for the fabrication of prototypes in SiR. According to the supplier, the tools would take ten calendar days to manufacture and 60 samples would take three calendar days to produce. The proposed material was a general-purpose SiR which was available in different hardnesses ranging from 30 to 80 Shore A, but the supplier pointed out that 40 Shore A is the hardest material they could do according to their experience for this type of part. However, they mentioned that they could try with 50 Shore A. Material data for the proposed SiR can be seen in table 7.1.

Table 7.1: The table shows material data for the SiR proposed by the supplier. The data was provided by the supplier.

Property	*SiR*
Hardness (Shore A)	30, 40 and 50
Service temperature	−40 to 200 °C
Recyclable	No
Density	1.08, 1.10 and 1.13 g/cm^3
Elongation at break	660, 640 and 600 %

The advantages and disadvantages of SiR are summarized:

Advantages

- Excellent temperature properties.
- Fast and cheap to produce tools.
- Some SiRs are already certified and therefore easy to use by the manufacturer.
- Good compression set characteristics.
- Good weather resistance against rain and UV light (black SiR).
- Excellent electrical properties.

Disadvantages

- Poor crack initiation resistance.
- Time-consuming post-cure process to prevent volatile outgassing.
- Process involves vulcanization which is a time-consuming process.
- Not possible to recycle.

7.2.2 EPDM

As mentioned in chapter 2 Theory, the low-cost material EPDM is characterized by excellent mechanical properties, good heat, moisture and UV resistance as well as high flexibility and elasticity. EPDM is also characterized by good compression set, very good electrical insulation, but poor flame resistance. This makes it a good material choice when producing watertight solutions for outdoor usage. The density of EPDM is $0.860\,\mathrm{g/cm^3}$ which is lower than SiR with 1.10 to $1.60\,\mathrm{g/cm^3}$.

From the discussions that were held with the experienced engineers at Axis, it was clear that EPDM was not often used for grommets. When asked why EPDM was not considered as an alternative to today's existing grommets, they described that they saw no reason to change to EPDM since Axis had few suppliers of EPDM material. One engineer mentioned that EPDM had been used on a previous grommet solution but was changed to SiR since it felt like a safer material choice.

The advantages and disadvantages of EPDM are summarized:

Advantages

- Good weather resistance.
- Good compression set.
- Good temperature properties.
- Very good electrical insulation.
- Lower density than SiR.
- Inexpensive material.

Disadvantages

- Poor flame resistance.
- Process involves vulcanization which is a time-consuming process.

7.2.3 Thermoplastic Elastomer

TPEs are used today at Axis, but they are not as common for grommets as SiR. As mentioned in chapter 2 Theory, one big advantage of TPEs is the possibility to process the material as a thermoplastic, resulting in a lower cost of the final product. TPE scrap can be reused as a regrind, whereas scrap from thermoset rubbers is often discarded.

To get a better understanding of how TPEs would work for the project's sealing solution, a discussion was held with a development engineer from a Swedish material supplier. The development engineer is the link between the customer's products and the company's materials. Regarding the service temperature, the engineer explained that normal TPEs are not suitable for usage above 80 to 90 °C and higher temperatures can lead to compression set in the material over time.

Regarding the price of the material, the development engineer said that TPE probably is a lot cheaper than SiR. According to the engineer, 450 kg TPE would cost around 35 SEK/kg if bought from the supplier. However, one disadvantage to using TPEs is the long, complicated and expensive tool-making process for injection molding. The engineer mentioned that making the tool will take a couple of months, but this is often fine for large volume production.

The engineer from the material supplier proposed two TPEs for the grommet; Dryflex CS and Dryflex DFG. Both are based on a TPE family called styrene–ethylene–butylene–styrene (SEBS) and they can be delivered with different hardnesses. According to the supplier, their Dryflex materials are characterized by excellent weathering, UV and ozone resistance [37]. Dryflex CS is optimized for compression set and is available in hardnesses 40 to 90 Shore A [38]. Two hardnesses of Dryflex DFG were proposed by the supplier, 53 and 64 Shore A. For Dryflex CS, hardness 70 Shore A was the hardest version of the material that was considered.

Both Dryflex CS and Dryflex DFG are great for injection molding as a processing method according to the engineer. Data regarding hardness, service temperature, recyclability, density and elongation at break are summarized in table 7.2.

Table 7.2: The table shows material data for two TPEs from the material supplier, Dryflex CS and Dryflex DFG. The data for Dryflex CS was provided by the supplier [38]. The development engineer from the supplier provided the data for Dryflex DFG.

Property	***Dryflex CS***	***Dryflex DFG***
Hardness (Shore A)	40, 50, 60 and 70	53 and 64
Service temperature	−40 to 100 °C	−50 to 125 °C
Recyclable	Yes	Yes
Density	0.89 g/cm^3	1.21 g/cm^3
Elongation at break	850, 800, 850 and 900 %	500 and 600 %

Finally, outgassing can also be a problem with TPEs, according to engineers at Axis. They explained that outgassing can lead to condensation on optical parts. However, outgassing could be reduced by heating the TPE parts to around 70 °C, one engineer said.

The advantages and disadvantages of TPEs are summarized:

Advantages

- Simple and fast manufacturing process.
- Possible to reuse scrap.
- Cheap material.
- Good weather resistance.

Disadvantages

- Service temperature well below melting point.
- Long time to manufacture tools for injection molding.
- Expensive tools for injection molding.
- Risk of outgassing.

7.3 Material Selection

SiR is currently used in many gaskets and grommets made by Axis which makes it a strong candidate for the material selection. However, the three material types that were considered (SiR, EPDM and TPE) all have their advantages and disadvantages for prototypes and large volume production. The material characteristics of SiR and EPDM are similar and both would probably work for prototypes.

7.3.1 Prototypes

Prototypes were created in this thesis and the project's timeline sets certain limits to which materials and manufacturing techniques could be used. The time limit made it impossible to use manufacturing techniques like injection molding which ruled out TPEs as feasible materials for prototypes. Both SiR and EPDM have similar and good properties that fit or outperform the material requirements. SiR has poor crack initiation resistance, but the concepts that were prototyped did not have any thin walls which probably was the area with the highest risk of cracks forming. The short lead time for producing parts with soft tools and SiR made it suitable for the project's timeline. The low cost of manufacturing soft tool was also good when ordering prototypes since multiple concepts could be tested before choosing the final design for large volume production.

EPDM was also a good candidate for material selection, but since there were not many active suppliers of EPDM, it would take a longer time to find a suitable supplier with a certified material. To get the prototypes as fast as possible to be able to have time to test and evaluate the different concepts, it was decided to produce the prototypes in SiR using soft tooling from the supplier.

From the obtained information, a black material was best for UV resistance. It is important to make sure the product is weather-resistant and the prototypes were not tested against UV radiation. However, black material is often the standard color choice and it is better at handling UV light, which leads to the prototypes being ordered in black.

The hardness of the material would impact how easy it was to install the cable in the grommet and the grommet in the chassis. It would also affect how tolerant the grommet was against different cable diameters since a softer material would better shape itself around the cable. Existing solutions like Cable Gasket 1 are 40 Shore A, making this hardness a good starting point for the prototypes. To test if a harder or softer material would be better, 30 and 50 Shore A were also tested. Therefore, the chosen material for the prototypes was black SiR in hardness 30, 40 and 50 Shore A.

7.3.2 Large Volume Production

For large volume production, it is of interest to investigate manufacturing techniques suitable for this kind of operation. Regarding the properties of all considered materials, SiR, Dryflex CS and Dryflex DFG all have excellent weather and temperature resistance. Both the operating and storing temperature requirements are met for these materials. Good compression set characteristics are important over time, which makes Dryflex CS a good TPE candidate. It is however unknown if the considered TPEs are UL-certified and it needs to be investigated if the material is to be used.

When it comes to the manufacturing process, TPEs have the advantage over SiR since TPEs can be injection molded and they do not need to go through the time-consuming vulcanization process. The fast and simple manufacturing process leads to a cost-efficient product. This, combined with the fact that TPEs are generally cheaper than SiR and the possibility of reusing TPE scrap material, makes TPE even more cost-efficient.

EPDM can also be processed with injection molding, however, the material still needs to cure, making the process not as simple and fast as TPEs. It is also not possible to reuse the scrap material of EPDM.

One disadvantage to TPEs over SiR is the expensive tools and the tools taking a long time to manufacture for injection molding. However, for large series, the tool cost is divided over many parts making injection molding a suitable manufacturing technique for large volume production.

In summary, all three material types are good candidates with excellent weather resistance. TPEs and EPDM are the most interesting for large volume production since they can be processed with injection molding and possibly result in cheaper parts than using SiR with compression molding as a process technique. TPEs have the advantage over EPDM of not needing to cure and the scrap material can be reused. SiR has excellent temperature properties and handles temperatures up to $200\,°C$. However, since the required storing/transport temperature range is -40 to $65\,°C$, the considered TPEs will probably work just as fine. TPEs also have the advantage over SiR with lower material cost.

8 Testing

8.1 Hole Fitting Test

Concept c1 was designed for a hole with a depth of 17 mm, a radius of 6 mm and a wall thickness of 2 mm. See the hole depth defined as D in figure 8.1 for concept c1. For the rest of the three concepts, D is defined as the hole diameter. To see what hole and wall dimensions worked best from an installation perspective, a simple hole fitting test was performed. Three parameters were changed in this test, the hole depth, the hole diameter and the wall thickness. The idea for this test was to get an overall feel for how easy it is to insert the grommet in the hole and see how tightly it fits.

For concept c1, three depths were tested, 16, 17 and 18 mm, and three wall thicknesses 1.5, 2 and 2.5 mm. A 3D printed part was designed and printed with the different configurations (in total nine), see figure 8.1.

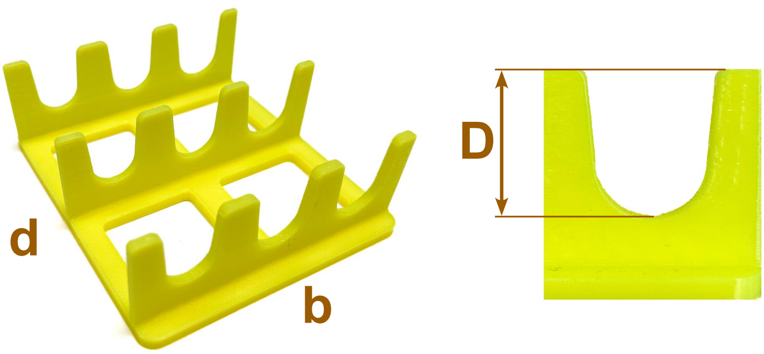

Figure 8.1: The figure shows the 3D printed plate with different hole configurations. It was used to test hole fitting for concept c1. The plate dimension is 70 mm × 80 mm (b x d). D is the hole depth.

Concept c4 and c13 were designed for a hole diameter of 17 mm and a wall thickness of 2 mm. Four diameters were tested, 16, 16.5, 17 and 17.5 mm, as well as four wall thicknesses 1.5, 2, 2.5 and 3 mm. To test the different configurations (in total 16), a 3D printed part was designed and printed, see figure 8.2.

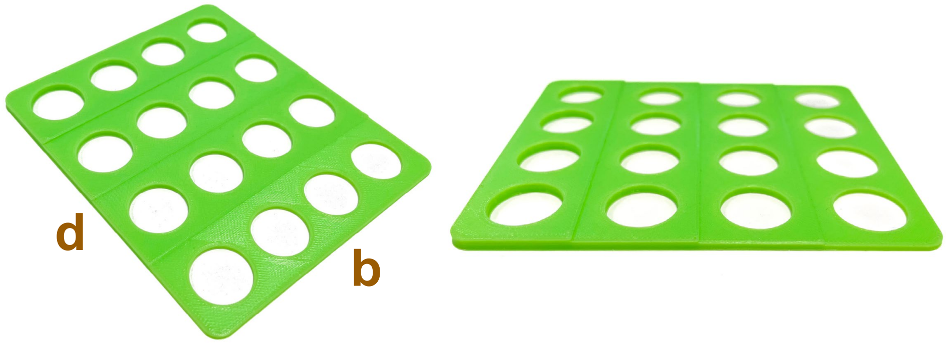

Figure 8.2: The figure shows the 3D printed plate with different hole configurations. It was used to test hole fitting for concept c4 and c13. The plate dimension is 92 mm × 110 mm ($b\ x\ d$).

Concept c20 was similar to c13 but used a deeper hole (the length in the axial direction) which was designed to be 7.5 mm. The hole diameter was tested for four dimensions, 16, 16.5, 17 and 17.5 mm. Three depths were tested, 6.5, 7.5 and 8 mm. A combination of all dimensions (12 in total) was 3D printed on a plate, see figure 8.3.

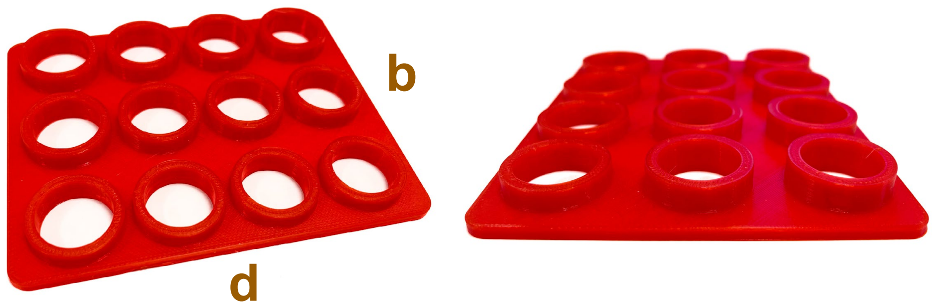

Figure 8.3: The figure shows the 3D printed plate with different hole configurations. It was used to test hole fitting for concepts c20. The plate dimension is 82 mm × 102 mm ($b\ x\ d$).

The prototypes were tested in the plates and the fit for each variant was scored from 0 to 3 where 0 was the worst and 3 the best. The evaluation focused on how easy it was to install the grommet into the chassis and not if it was IP67 compatible. The description for each score is presented in table 8.1.

Table 8.1: The table describes the scoring that was used for the hole fitting test. The score was set by starting from 3 to see if the description is fulfilled, if not, continue down to 2 and so on.

Score	*Fit*	*Description*
0	Bad	Impossible to install or possible to see through when installed.
1	Ok	Possible to install, not good with bent cable.
2	Good	Good axial and radial seal, ok with bent cable.
3	Excellent	Tight axial and radial seal, good with bent cable.

The result from the hole fitting test can be seen in table C.1, C.2, C.3 and C.4 in C Appendix – Hole Fitting Test. The result gave an interval of possible hole dimensions that would be used later for the IP67 testing. The hole fitting test also gave a feeling for what dimensions that could not be possible to have. For instance, a hole diameter of 16 mm and a depth of 8 mm for concept c20 was not possible to install and for concept c1, a depth of 18 mm was too big.

8.2 IP67 Testing

Before conducting the IP67 testing, test boxes were designed and were later used to see if the grommets met the IP67 requirement. The test boxes had extrusions on the sides to assemble the boxes so that several boxes could be tested at once. The boxes were first iterated a few times with FFF technique. However, these boxes could not be made completely sealed. Therefore, when the design was set, all test boxes were printed using MJP with VisiJet® M2R-WT as the printing material and VisiJet® M2 Sup as the support material. On the top of the boxes, a cover made of polymethyl methacrylate (PMMA) was added to see inside the box after the testing to identify any leakage. To seal between the box and the PMMA cover, Casco MultiTech (a glue and sealant) was placed between the two parts. After being glued, the box was left to dry for at least two days. A test box for concept c13 and c4 can be seen in figure 8.4 before and after assembly. Concept c20 used a similar box, but with added wall thickness. For concept c1, the grommet had to be installed directly in the box assembly since the grommet would be glued. The boxes for concept c1 used a thicker PMMA layer to not flex as much when screwed together to push the grommet down, see figure 8.5.

Figure 8.4: The figure shows a test box that was used for concept c13 and c4.

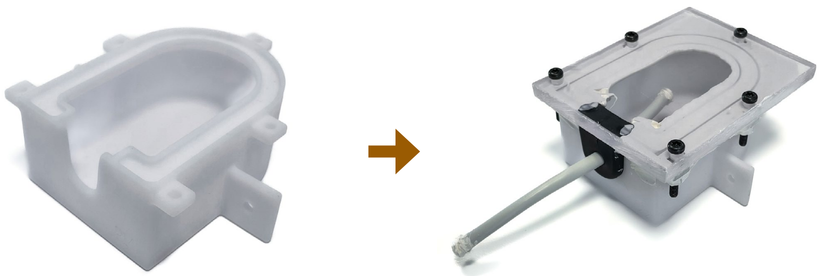

Figure 8.5: The figure shows a test box that was used for concept c1.

The used cables in the tests were not perfectly round and the cables were therefore measured at a few spots to get the average cable diameter. The average cable diameter will simply be referred to as the cable diameter in the report. Two cables were used, a small and a medium-sized, see table 8.2. The ends of the cables were glued (not glued together) with Casco MultiTech to prevent water from leaking inside the cable.

The boxes together with the grommet and the cable were weighed, with a scale with a tolerance of 0.1 g, before the submersion. After the test was done, the boxes were dried with paper and compressed air before being studied to see if any water leakage had occurred. The boxes were then weighed again to see if the weight had increased. Each test was scored based on the average amount of water leakage, see the scoring matrix in table 8.3. The top-performing boxes and grommets then moved on to the next step of the testing.

There was a risk of the boxes not being completely dried after testing and that the material would absorb water and affect the weight measurement. Therefore, a control box without a hole and grommet was tested with the same procedure. This time a more precise scale with a tolerance of 0.0001 g was used. The weight before was measured to be 71.9050 g and after 71.9102 g resulting in a weight increase of 0.0052 g. This small weight increase was neglected when calculating the weight increase of the test boxes.

Table 8.2: The table shows the two cable types that were used in the workshop and the IP testing.

Cable name	***Min cable diameter*** [mm]	***Max cable diameter*** [mm]	***Average cable diameter*** [mm]
Small	4.0	5.0	4.5
Medium	5.5	5.9	5.7

Table 8.3: The table shows a scoring scale based on weight increase and visible water leakage where the weight increase was less than 1 g. A lower score is better.

	Weight increase [g]		
Score	*Equal or bigger than*	*Less than*	*Visible water leakage*
1	0	1	No water at all.
2	0	1	One drop.
3	0	1	Several drops.
4	1	2	
5	2	5	
6	5	10	
7	10	15	
8	15	20	
9	20	30	
10	30		

For the IP67 testing, a total of six test setups were conducted, see table 8.4. Test 1 to 4 tests IPX7, Test 5 IP6X and Test 6 IPX6.

Table 8.4: The table shows the six different tests that were conducted to test the sealing capability of concept c13, c4, c20 and c1.

Test	*Type*	*Description*
1	IPX7	Small cable with no bending angle.
2	IPX7	Medium cable with no bending angle.
3	IPX7	Small cable bent against the slit in the grommet.
4	IPX7	Small cable bent away from the slit in the grommet.
5	IP6X	Small cable with no bending angle.
6	IPX6	Small cable with no bending angle.

8.2.1 Test 1-4 – IPX7 Testing

8.2.1.1 Test 1 – Small Cable with no Bending Angle

The project team wanted to see how different wall thicknesses and hole diameters affected the sealing capability of the different concepts. First, the sealing capability was tested with IPX7 water test and prototypes combined with small cables which were placed to go through the grommet without a bending angle.

Test 1 was tested with a full factorial analysis to study different wall thicknesses, material hardnesses and hole diameters for each concept. The full factorial analysis was conducted to see if any configurations would pass the test and to get data for further development. Four concepts, three hardnesses, two wall thicknesses and two hole diameters resulted in 48 test configurations. Each configuration was tested three times to get a more reliable result which resulted in a total of 144 tests. For each test, a new grommet prototype was used. This was true for all concepts except for concept c1 since these grommets were permanently placed in the test boxes.

For concept c13, the top six configurations had a chassis diameter of 16 mm (see table 8.5). The hardness and wall thickness did not seem to affect the result as much as the diameter. The best configuration of concept c13 was hardness 50 Shore A, diameter 16 mm and thickness 2.5 mm, however, the average score of 2.3 shows that on average, the concept leaked a few droplets. The total average score for concept c13 was 5.2 and water leakage was 8.7 g.

Table 8.5: The table shows the result from the IPX7 tests for concept c13. Small cables (see table 8.2) with no bending angle were used. The hardness is measured in Shore A.

Hardness	***Diameter*** [mm]	***Thickness*** [mm]	***Average water leakage*** [g]	***Average score***
50	16.0	2.5	0.2	2.3
30	16.0	2.0	0.5	2.7
50	16.0	2.0	0.7	2.7
40	16.0	2.0	0.4	3.0
40	16.0	2.5	0.8	3.3
30	16.0	2.5	1.1	3.7
50	17.5	2.5	6.9	5.7
40	17.5	2.5	8.1	6.0
30	17.5	2.5	10.9	6.7
30	17.5	2.0	15.2	7.3
40	17.5	2.0	29.2	9.3
50	17.5	2.0	30.8	9.7
Average			8.7	5.2
Average top five			0.5	2.8

Three configurations of concept c4 passed the test with no water leakage, all with a hole diameter of 16 mm, see table 8.6. The three configurations had hardness 30 Shore A with a wall thickness of 2.5 mm, hardness 40 Shore A with a wall thickness of 2.5 mm and hardness 50 Shore A with a wall thickness of 2.0 mm. The average score was 1.9 and the average water leakage was 0.4 g.

No configurations of concept c20 passed the IPX7 test and the best configuration got an average score of 1.7 meaning it leaked a few drops, see table 8.7. The best configuration had hardness 40 Shore A, a hole diameter of 16 mm and a wall thickness of 7.6 mm. For concept c20, the average score was 3.6 and the average water leakage was 3.4 g.

Table 8.6: The table shows the result from the IPX7 tests for concept c4. Small cables (see table 8.2) with no bending angle were used. The hardness is measured in Shore A.

Hardness	*Diameter* [mm]	*Thickness* [mm]	*Average water leakage* [g]	*Average score*
30	16.0	2.5	0.1	1.0
40	16.0	2.5	0.1	1.0
50	16.0	2.0	0.1	1.0
50	16.0	2.5	0.1	1.3
40	17.5	2.5	0.1	1.7
30	16.0	2.0	0.1	2.0
40	16.0	2.0	0.1	2.0
40	17.5	2.0	0.1	2.0
50	17.5	2.0	0.7	2.3
50	17.5	2.5	3.0	2.7
30	17.5	2.0	0.1	3.0
30	17.5	2.5	0.1	3.0
Average			0.4	1.9
Average top five			0.1	1.2

Table 8.7: The table shows the result from the IPX7 tests for concept c20. Small cables (see table 8.2) with no bending angle were used. The hardness is measured in Shore A.

Hardness	*Diameter* [mm]	*Thickness* [mm]	*Average water leakage* [g]	*Average score*
40	16.0	7.6	0.2	1.7
30	16.0	7.6	0.1	2.3
50	16.0	7.0	0.4	2.3
40	16.0	7.0	0.7	2.7
30	16.0	7.0	3.2	4.0
50	16.0	7.6	3.1	4.3
30	17.0	7.0	8.8	6.0
30	17.0	7.6	8.6	6.0
40	17.0	7.0	8.7	6.0
40	17.0	7.6	8.6	6.0
50	17.0	7.0	8.9	6.0
50	17.0	7.6	8.9	6.0
Average			5.0	4.4
Average top five			0.9	2.6

Concept c1 was the final concept to be tested and four configurations with a hole depth of 16 mm passed the test with no water leakage. The four configurations had hardness 30 Shore A with a wall thickness of 1.5 mm, hardness 50 Shore A with a wall thickness of 1.5 mm, hardness 40 Shore A with a wall thickness of 2.2 mm and hardness 50 Shore A with a wall thickness of 2.2 mm. For all configurations of concept c1, the average score was 3.6 and the average water leakage was 3.4 g.

Table 8.8: The table shows the result from the IPX7 tests for concept c1. Small cables (see table 8.2) with no bending angle were used. The hardness is measured in Shore A.

Hardness	***Depth*** [mm]	***Thickness*** [mm]	***Average water leakage*** [g]	***Average score***
50	16.0	2.2	0.0	1.0
30	16.0	1.5	0.1	1.0
40	16.0	2.2	0.1	1.0
50	16.0	1.5	0.2	1.0
30	16.0	2.2	0.1	1.7
40	16.0	1.5	0.2	1.7
40	17.5	1.5	6.5	6.0
50	17.5	1.5	6.6	6.0
50	17.5	2.2	6.6	6.0
30	17.5	2.2	6.8	6.0
30	17.5	1.5	6.9	6.0
40	17.5	2.2	7.0	6.0
Average			3.4	3.6
Average top five			0.1	1.1

The average score of each concept and the average score for the top five configurations of each concept are shown in figure 8.6. For both concept c4 and c1, the average top five had a better score than the other two concepts. For the average of all configurations, c4 stood out with the best score whereas the rest got a similar result.

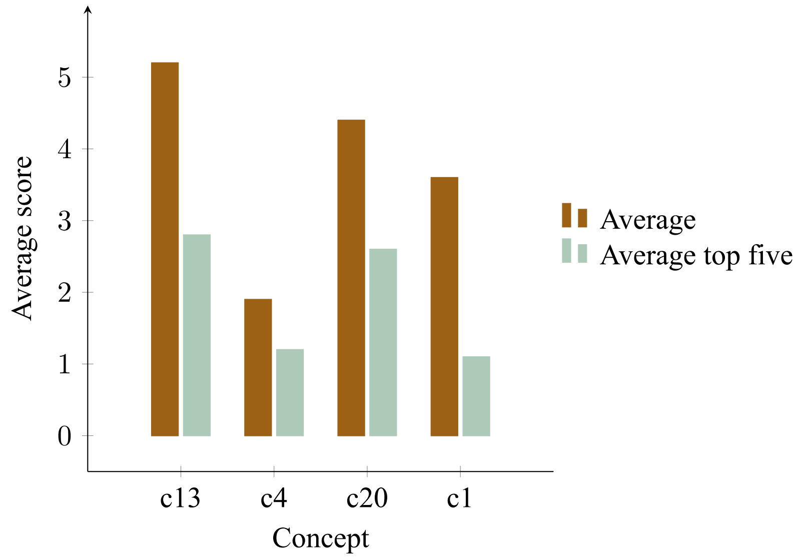

Figure 8.6: The plot shows the average score from the IPX7 test for each concept from table 8.5, 8.6, 8.7 and 8.8. A lower score is better where 1 is the lowest possible, see table 8.3 for score description.

8.2.1.2 Test 2 – Medium Cable with no Bending Angle

Test 2 was done similar to Test 1 but with a medium cable. This was not a full factorial analysis, instead, the best performing configurations from Test 1 were further tested.

The result from Test 2 can be seen in table 8.9. Two concept configurations passed the test with no water leakage, the first was c20 with hardness 40 Shore A, a hole diameter of 16.0 mm and a wall thickness of 7.6 mm. The second was c4 with hardness 40 Shore A, a hole diameter of 16.0 mm and a wall thickness of 2.5 mm. The average score was 3.6 and the average water leakage was 3.2 g.

Table 8.9: The table shows the result from the IPX7 tests for the chosen concept configurations. Medium cables (see table 8.2), with no bending angle, were used. The hardness is measured in Shore A.

Concept	***Hardness***	***Diameter/depth*** [mm]	***Thickness*** [mm]	***Water leakage*** [g]	***Score***
c20	40	16.0	7.6	0.1	1.0
c4	40	16.0	2.5	0.3	1.0
c1	40	16.0	2.2	0.0	2.0
c4	30	16.0	2.5	0.2	2.0
c4	50	16.0	2.0	0.7	3.0
c13	30	16.0	2.0	3.9	5.0
c1	30	16.0	1.5	6.3	6.0
c13	50	16.0	2.5	8.5	6.0
c20	30	16.0	7.6	8.6	6.0
Average				3.2	3.6

8.2.1.3 Test 3 & 4 – Small Cable with Bending Angle

Test 3 and 4 tested how the concepts performed with bent cables. In Test 3, the cable was bent around 45° against the slit in the grommet. Similarly, in Test 4, the cable was bent around 45° away from the slit in the grommet. See figure 8.7 for how the cable was bent in the test box. These two cable positions were thought to put the biggest stress on the outside respective inside of the slit in the grommet. Like Test 2, only the top-performing configurations from Test 1 were tested.

Figure 8.7: The figure shows a test box and how the cable was bent in Test 3 and 4. The slit in the grommet was always positioned up.

The resulting water leakage and score from Test 3 can be seen in figure 8.10. Two configurations passed the test, both concept c4 with a hole diameter of 16 mm. One of the passing configurations had hardness 50 Shore A with a wall thickness of 2.0 mm and one with hardness 40 Shore A with a wall thickness of 2.5 mm. The tested concepts c20 and c1 did not pass the test.

Table 8.10: The table shows the result from the IPX7 tests for the chosen concept configurations. Small cables (see table 8.2) bent against the slit were used. The hardness is measured in Shore A.

Concept	***Hardness***	***Diameter/depth*** [mm]	***Thickness*** [mm]	***Water leakage*** [g]	***Score***
c4	50	16.0	2.0	0.1	1.0
c4	40	16.0	2.5	0.2	1.0
c1	30	16.0	1.5	6.1	6.0
c1	40	16.0	2.2	6.2	6.0
c20	40	16.0	7.6	8.3	6.0
Average				4.2	4.0

The result from Test 4 showed a similar result as Test 3, see table 8.11. Once again, the two concept c4 configurations with a wall diameter of 16 mm passed the test.

One configuration had hardness 40 Shore A with a wall thickness of 2.5 mm and the other one hardness 50 Shore A with a wall thickness of 2.0 mm. The three concept configurations with c20 and c1 did not pass the test since they had water leakage.

Table 8.11: The table shows the result from the IPX7 tests for the chosen concept configurations. Small cables (see table 8.2) bent away from the slit were used. The hardness is measured in Shore A.

Concept	***Hardness***	***Diameter/depth*** [mm]	***Thickness*** [mm]	***Water leakage*** [g]	***Score***
c4	40	16.0	2.5	0.0	1.0
c4	50	16.0	2.0	0.0	1.0
c20	40	16.0	7.6	0.0	2.0
c1	30	16.0	1.5	6.5	6.0
c1	40	16.0	2.2	6.7	6.0
Average				2.6	3.2

8.2.1.4 Comparison

Five concept configurations were tested for all four IPX7 tests that were conducted. The resulting score for these configurations is presented in figure 8.8 where the data is obtained from table 8.9, 8.10 and 8.11. Only one configuration passed all four tests, c4 with hardness 40 Shore A, a hole diameter of 16 mm and a wall thickness of 2.5 mm. Concept c4 with hardness 50 Shore A, a hole diameter of 16 mm and a wall thickness of 2.0 mm was the second best configuration passing all tests except Test 2 with a medium cable.

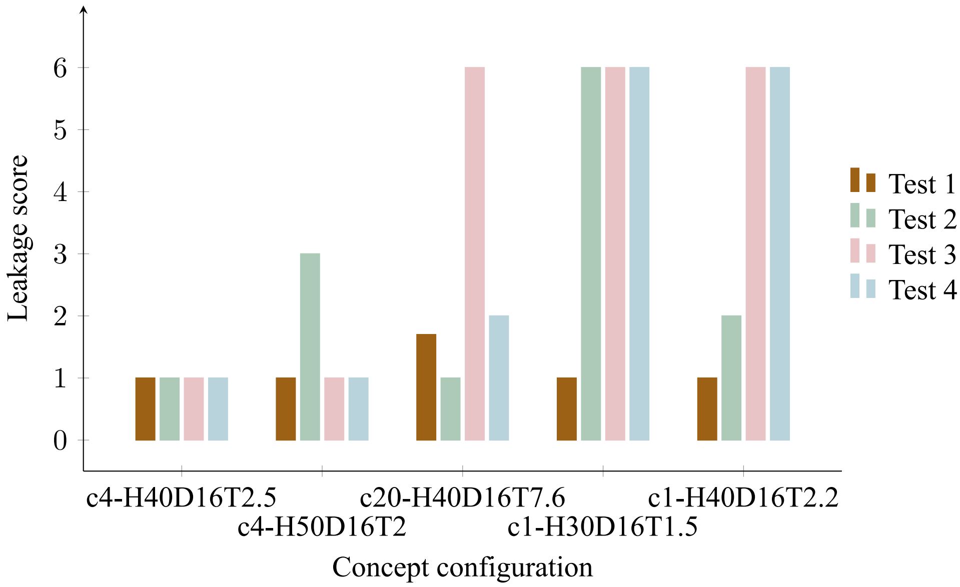

Figure 8.8: The plot shows the leakage score of the five concept configurations that were used for all four IPX7 water tests. Test 1–4 are described in table 8.4. A lower score is better where 1 is the lowest possible, see scoring description in table 8.3. On the x-axis, the number to the right of H is the material hardness in Shore A, the number to the right of D is the hole diameter [mm] and the number to the right of T is the wall thickness [mm].

8.2.2 Test 5 – IP6X Testing

The IP6X was tested in a dust testing machine for two hours. Due to limited time, only the best performing concept configuration from the IPX7 testing was tested, c4 with hardness 40 Shore A, a hole diameter of 16 mm and a wall thickness of 2.5 mm. The test box was used to test the prototype, but for this test, a 6 mm hole was drilled in the box where a tube was attached and sealed with Casco MultiTech, see test box in figure 8.9. The test was only done once.

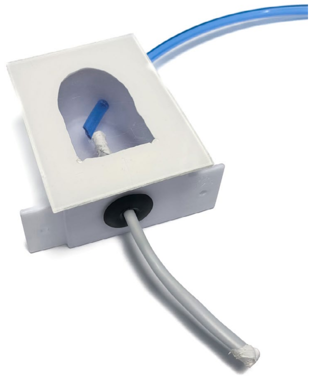

Figure 8.9: The figure shows the test box that was used for the IP6X test. The blue tube sucks air from the box resulting in a negative pressure inside the box.

After the test, the dust was wiped off and it was clear that no dust had leaked in. Therefore, the selected concept configuration passed the IP6X test.

As described in chapter 2 Theory, IP6X includes protection for persons. The standard states that a person holding a wire with a diameter of 1 mm should not be able to penetrate the product. It was not possible to penetrate the chosen concept configuration of c4 since it was tightly sealed.

8.2.3 Test 6 – IPX6 Testing

IPX6 was not a requirement for the product. However, this test makes a better real-world test of the camera, since the camera is not likely to be placed underwater, but is likely to be washed with a pressure washer. Like Test 5, concept c4 with hardness 40 Shore A was used and the test was only done once. This time, the prototype was installed in a real camera (tested for IP66 and IP67) with a hole diameter of 17 mm and a wall thickness of 2 mm. This camera had a protective cover over parts of the camera, but the pressurized water could still make its way to the grommet.

After the test, the camera was disassembled to see if any water had leaked in. No water could be seen, so concept c4 with hardness 40 Shore A passed the IPX6 test.

8.2.4 Summary from IP Testing

The result from Test 1 (IPX7) showed that concept c4 got the best average score. For the average top five concept configurations, both concept c1 and c4 showed a good result with a score close to one, meaning that they did not leak at all or very little. Concept c13 and c20 got a score close to three for their average top five concept configurations, which implied that they leaked a few drops or more.

The top five concept configurations from Test 1 were further tested (Test 1 to 4) and the result showed that only one concept configuration passed all tests without leakage, concept c4 with hardness 40 Shore A, hole diameter 16 mm and wall thickness 2.5 mm. Concept c20 with hardness 40 Shore A, hole diameter 16 mm and wall thickness 7.6 mm worked good as well but had problems when the cable was bent against the slit. The best concept configuration for c1 was hardness 40 Shore A, hole depth 16 mm and wall thickness 2.2 mm. This configuration worked good with a small and medium cable but had problems with a bent cable.

Due to time limitations, only the top-performing concept configuration from Test 1 to 4, concept c4 with hardness 40 Shore A, hole diameter 16 mm and wall thickness 2.5 mm, was tested in Test 5 (IP6X testing). The test was passed for this concept configuration.

The last test, Test 6 (IPX6), was done as a bonus test to confirm that the top-performing concept configuration worked with water being jetted. This test was also passed for this concept configuration.

In summary, the IP testing showed that concept c4 with hardness 40 Shore A, hole diameter 16 mm and wall thickness 2.5 mm was the best performing concept configuration with no leakage. However, this concept configuration was the only one to be tested for IP6X and IPX6. Concept c1 and c20 showed promises, but they leaked a bit with bent cables.

8.3 Design of Experiments

To get a better understanding of how the different parameters affected the amount of water leakage, a DoE was conducted. Due to time limitations, DoE was only done for concept c1 and c4. These two concepts were chosen due to them showing promising result from the early full factorial IPX7 testing, see table 8.6.

8.3.1 DoE – Concept c4

The first DoE was done for concept c4. Three factors were used for the L8 test, material hardness (A), hole diameter (B) and wall thickness (C). Two levels were used, see the values for each level in table 8.12. The three factors were placed in a Taguchi orthogonal array L8, see table 8.13.

Table 8.12: The table shows the factors that were studied in the DoE. The hardness is measured in Shore A.

Factor	*Factor description*	*Unit*	*Level 1*	*Level 2*
A	Material hardness		30	50
B	Hole diameter	mm	16.0	17.5
C	Wall thickness	mm	2.0	2.5

Table 8.13: The table shows the L8 array that was used for the DoE.

Sample number	*A*	*B*	*AxB*	*C*
1	1	1	1	1
2	1	1	1	2
3	1	2	2	1
4	1	2	2	2
5	2	1	2	1
6	2	1	2	2
7	2	2	1	1
8	2	2	1	2

After the tests had been placed in the L8 table, the influence of the parameters was studied. Finally, the interaction between the parameters was investigated to see if there was any interaction present.

Data from the IPX7 Test 1 for concept c4 (see D Appendix – Test 1 Result) was inserted in the L8 array, see table 8.14.

Table 8.14: The table shows the result of the DoE for concept c4. The measurements and average water leakage show the amount of water leakage [g] into the test box for the IPX7 test. The factors and levels are described in table 8.12.

					Measurement			
Sample number	***A***	***B***	***AxB***	***C***	***1***	***2***	***3***	***Average water leakage*** [g]
1	1	1	1	1	0.0	0.2	0.0	0.1
2	1	1	1	2	0.0	0.1	0.1	0.1
3	1	2	2	1	0.0	0.1	0.1	0.1
4	1	2	2	2	0.1	0.1	0.0	0.1
5	2	1	2	1	0.3	0.1	0.0	0.1
6	2	1	2	2	0.3	0.0	0.0	0.1
7	2	2	1	1	0.2	1.8	0.0	0.7
8	2	2	1	2	8.9	0.1	0.0	3.0

8.3.1.1 Analysis of Means

The resulting average water leakage was used to study the analysis of means (ANOM) for factor A, B and C, see figure 8.10. As seen in the figure, A and B had the biggest influence on the water leakage. Factor C also influenced the result, but not as much as the other two.

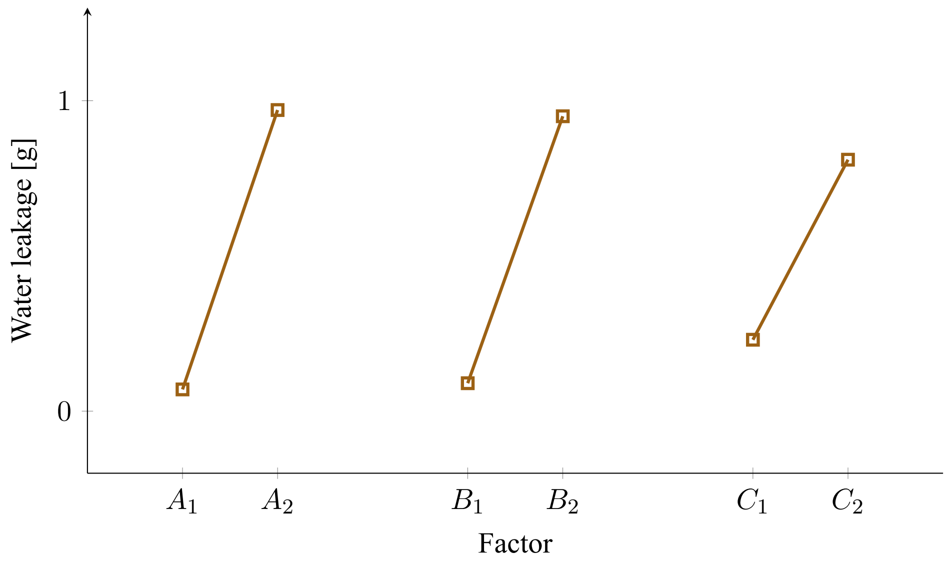

Figure 8.10: The plot shows the ANOM of the DoE of concept c4 for factor A, B and C. A_1 is material hardness 30 Shore A and A_2 is 50 Shore A. B_1 is hole diameter 16.0 mm and B_2 is 17.5 mm. C_1 is chassis wall thickness 2.0 mm and C_2 is 2.5 mm. The result shows the amount of water leakage [g] into the test box for the IPX7 test.

8.3.1.2 Interaction Between Factors

When studying the interaction between factor A and B, there was some interaction present, see figure 8.11. B_1 seemed to work well with both levels of A. However, B_2 performed better in combination with A_1 than A_2.

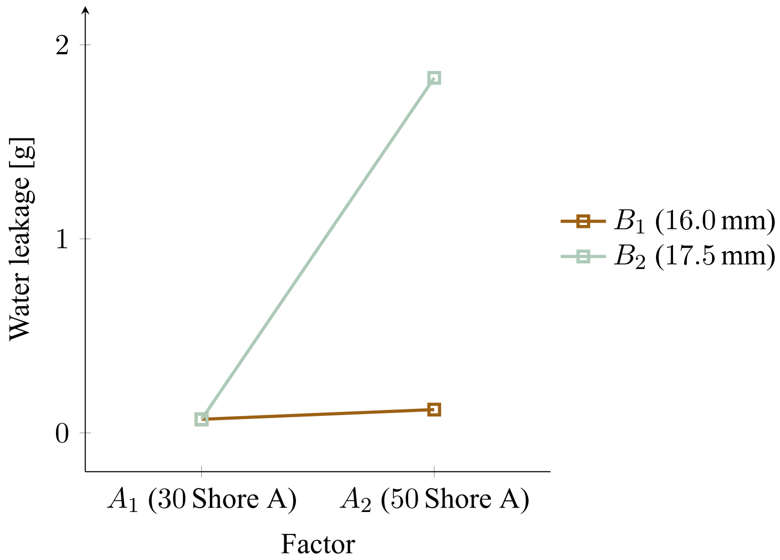

Figure 8.11: The plot shows the interaction between parameter A and B from the ANOM of concept c4. A_1 is material hardness 30 Shore A and A_2 is 50 Shore A. B_1 is hole diameter 16.0 mm and B_2 is 17.5 mm. The result shows the amount of water leakage [g] into the test box for the IPX7 test.

Furthermore, the interaction between factor A and C were studied and the result is shown in figure 8.12. The result showed that there was a small interaction between A and C. For both C_1 and C_2, the combination with A_1 was the best option. A_2 was better with C_1 than C_2, but overall not as good as A_1.

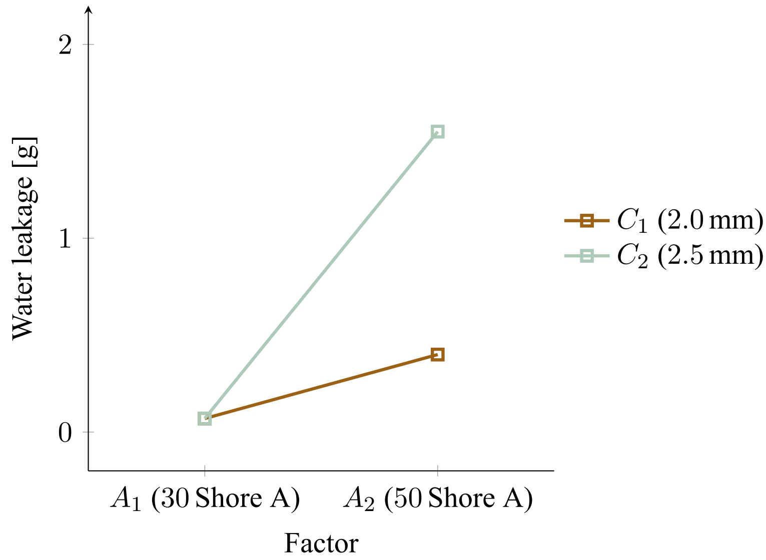

Figure 8.12: The plot shows the interaction between parameter A and C from the ANOM of concept c4. A_1 is material hardness 30 Shore A and A_2 is 50 Shore A. C_1 is chassis wall thickness 2.0 mm and C_2 is 2.5 mm. The result shows the amount of water leakage [g] into the test box for the IPX7 test.

The last interaction to be studied was factor B and C. A smaller interaction between the factors can be seen in figure 8.13. B_1 was better than B_2 for both C_1 and C_2. C_2 was better than C_1 when combined with B_2.

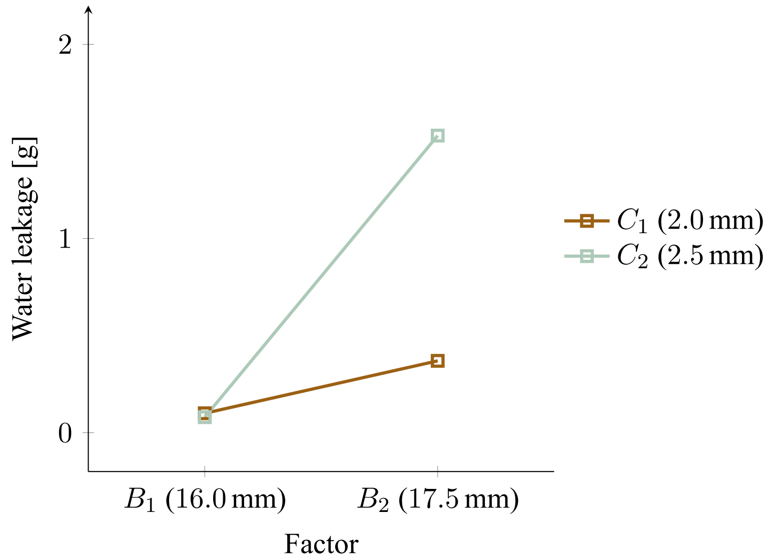

Figure 8.13: The plot shows the interaction between parameter B and C from the ANOM of concept c4. B_1 is hole diameter 16.0 mm and B_2 is 17.5 mm. C_1 is chassis wall thickness 2.0 mm and C_2 is 2.5 mm. The result shows the amount of water leakage [g] into the test box for the IPX7 test.

To summarize the DoE, all three investigated parameters affected the water leakage. Factor A and B influenced the result equally, whereas C did not influence the amount of water leakage as much. The leakage was better with B_1 than B_2 indicating that a smaller hole diameter is preferred. A softer material for A_1 performed a bit better than A_2, however, with the right hole diameter it worked with any level of hardness, as seen in figure 8.11. Factor C also affected the amount of water leakage and C_2 performed better than C_1, but when combined with a smaller hole diameter or a softer material, the water leakage was minimal, see figure 8.12 and 8.13.

8.3.1.3 Analysis of Variance

To test the reliability of the result, analysis of variance (ANOVA) was used. To see if the result was significant, a null hypothesis, H_0, was created that stated that all samples leaked the same amount of water. The alternative hypothesis, H_a, stated that all samples did not leak the same amount. H_0 was then tested to see if it was true, if not, H_0 was rejected and H_a true with a certain significance. The null hypothesis was tested with a significance level $\alpha = 0.05$.

H_0 was then tested with an ANOVA test using Excel. In Excel, *Data Analysis* and

Anova: Single Factor were used with data from table 8.14. A summary of the ANOVA can be seen in table 8.15 for each sample. Especially sample 8 stood out with high variance, but sample 7 also stood out in comparison to the rest of the samples.

Table 8.15: The table shows a summary of the ANOVA that was done for concept c4. Data is from table 8.14 and the ANOVA was calculated in Excel.

Sample	*Count*	*Sum*	*Average*	*Variance*
1	3	0.2	0.067	0.013
2	3	0.2	0.067	0.003
3	3	0.2	0.067	0.003
4	3	0.2	0.067	0.003
5	3	0.4	0.133	0.023
6	3	0.3	0.1	0.03
7	3	2	0.667	0.973
8	3	9	3	26.11

The rest of the ANOVA can be seen in table 8.16 and the calculated p-value was 0.514. This meant that the result was not significant and the alternative hypothesis was rejected. It was therefore not possible to conclude if any sample was significantly better than the rest. This was mostly because the average result did not differ that much for the different samples and that two sample measurements stuck out.

The sum of squares (SS) is 28.8 % variation between groups and 71.2 % within groups. This means that the input parameters control 28.8 % of the variation and 71.2 % is noise. Sample 8 influences the variation a lot since it has a lot of variation within its group.

Table 8.16: The table shows the result from the single factor ANOVA that was done for concept c4. Data is from table 8.14 and the ANOVA was calculated in Excel.

Source of variation	*SS*	*df*	*MS*	*F*	*p-value*	*F critical*
Between groups	21.96	7	3.137	0.924	0.514	2.657
Within groups	54.32	16	3.395			
Total	76.28	23				

8.3.2 DoE – Concept c1

The second DoE was done with concept c1. The same factors were used for the L8 test but the two levels were updated, see table 8.17. The three factors were placed in a Taguchi orthogonal array L8 like concept c4, see table 8.13.

Table 8.17: The table shows the factors that were studied in the DoE. The hardness is measured in Shore A.

Factor	*Factor description*	*Unit*	*Level 1*	*Level 2*
A	Material hardness		30	50
B	Hole depth	mm	16.0	17.5
C	Wall thickness	mm	1.5	2.2

After the tests had been placed in the L8 table, the influence of the parameters was studied. Finally, the interaction between the parameters was investigated to see if there was any interaction present. Data from the IPX7 Test 1 for concept c1 (see D Appendix – Test 1 Result) was inserted in the L8 array, see table 8.18.

Table 8.18: The table shows the result of the DoE for concept c1. The measurements and average water leakage show the amount of water leakage [g] into the test box for the IPX7 test. The factors and levels are described in table 8.17.

					Measurement			
Sample number	*A*	*B*	*AxB*	*C*	*1*	*2*	*3*	*Average water leakage* [g]
1	1	1	1	1	0.0	0.1	0.1	0.1
2	1	1	1	2	0.1	0.0	0.1	0.1
3	1	2	2	1	7.2	6.8	6.7	6.9
4	1	2	2	2	6.4	7.2	6.7	6.8
5	2	1	2	1	0.1	0.0	0.5	0.2
6	2	1	2	2	0.1	0.0	0.0	0.0
7	2	2	1	1	6.2	6.9	6.6	6.6
8	2	2	1	2	6.6	6.3	7.0	6.6

8.3.2.1 Analysis of Means

The resulting average water leakage was used to study the ANOM for factor A, B and C, see figure 8.14. As seen in the figure, B had the biggest influence on the water leakage. Factor A and C had minimal influence on the result.

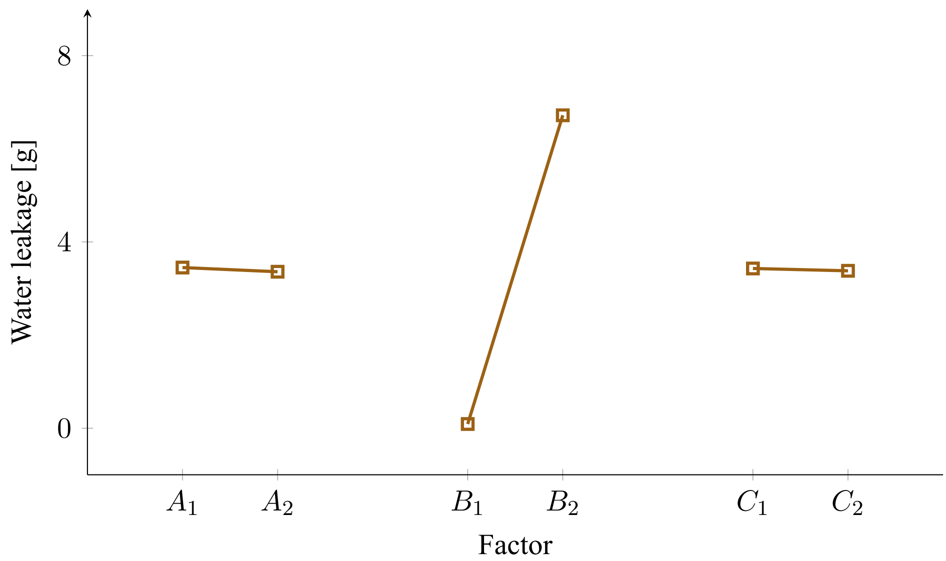

Figure 8.14: The plot shows the ANOM of the DoE of concept c1 for factor A, B and C. A_1 is material hardness 30 Shore A and A_2 is 50 Shore A. B_1 is hole depth 16.0 mm and B_2 is 17.5 mm. C_1 is chassis wall thickness 1.5 mm and C_2 is 2.2 mm. The result shows the amount of water leakage [g] into the test box for the IPX7 test.

8.3.2.2 Interaction Between Factors

When studying the interaction between factor A and B, there was no obvious interaction present since the lines are almost parallel, see figure 8.15. B_1 seemed to work well with both levels of A with minimal leakage. B_2 was a lot worse with similar leakage for both A_1 and A_2.

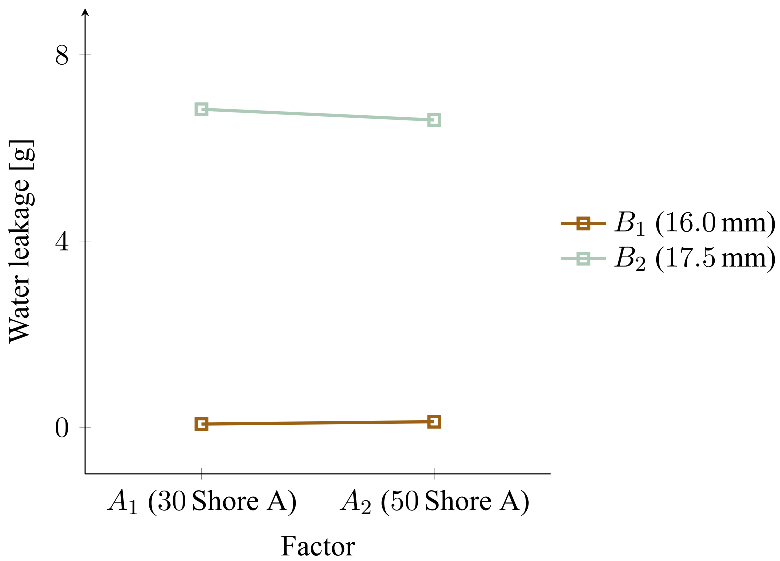

Figure 8.15: The plot shows the interaction between parameter A and B from the ANOM of concept c1. A_1 is material hardness 30 Shore A and A_2 is 50 Shore A. B_1 is hole depth 16.0 mm and B_2 is 17.5 mm. The result shows the amount of water leakage [g] into the test box for the IPX7 test.

Furthermore, the interaction between factor A and C was studied and the result is shown in figure 8.16. The result showed that there was a no visible interaction between A and C. All levels showed a similar water leakage.

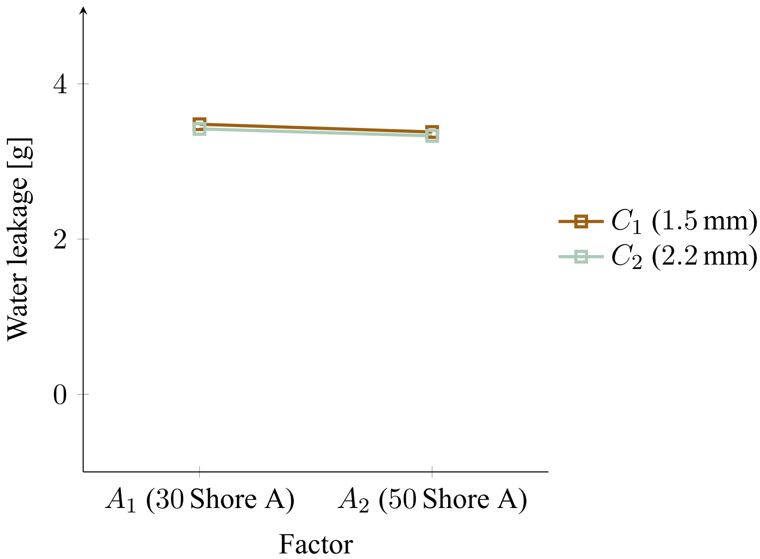

Figure 8.16: The plot shows the interaction between parameter A and C from the ANOM of concept c1. A_1 is material hardness 30 Shore A and A_2 is 50 Shore A. C_1 is chassis wall thickness 1.5 mm and C_2 is 2.2 mm. The result shows the amount of water leakage [g] into the test box for the IPX7 test.

The last interaction to be studied was factor B and C. No apparent interaction between the factors can be seen in figure 8.17 since the lines are parallel. B_1 was equally better than B_2 for both C_1 and C_2.

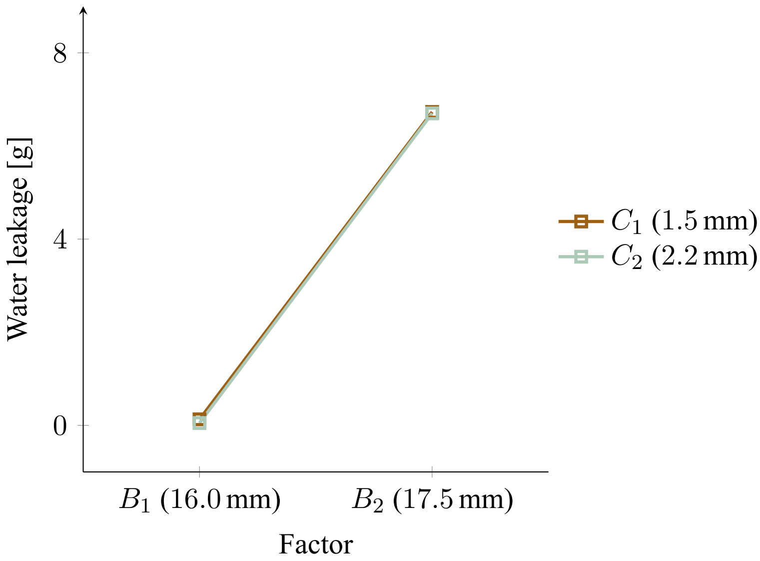

Figure 8.17: The plot shows the interaction between parameter B and C from the ANOM of concept c1. B_1 is hole depth 16.0 mm and B_2 is 17.5 mm. C_1 is chassis wall thickness 1.5 mm and C_2 is 2.2 mm. The result shows the amount of water leakage [g] into the test box for the IPX7 test.

To summarize the DoE, only one factor influenced the result, factor B. Factor A and C had no obvious influence on the system. With B_1, the leakage was none or minimal, whereas with B_2 there was some leakage regardless of the different levels of A and C. This meant that the material hardness and wall thickness did not impact the amount of water leakage.

8.3.2.3 Analysis of Variance

To test the reliability of the result, ANOVA was used once again. To see if the result was significant, the same hypothesis, H_0 and H_a, were used and tested as in the ANOVA for concept c4.

H_0 was then tested with an ANOVA test using Excel like the prevois ANOVA. This time the tool *Anova: Single Factor* was used with data from table 8.18. A summary of the ANOVA can be seen in table 8.19 for each sample. No sample stood out with a high variance.

Table 8.19: The table shows a summary of the ANOVA that was done for concept c1. Data is from table 8.18 and the ANOVA was calculated in Excel.

Sample	*Count*	*Sum*	*Average*	*Variance*
1	3	0.2	0.067	0.003
2	3	0.2	0.067	0.003
3	3	20.7	6.900	0.070
4	3	20.3	6.767	0.163
5	3	0.6	0.200	0.070
6	3	0.1	0.033	0.003
7	3	19.7	6.567	0.123
8	3	19.9	6.633	0.123

The rest of the ANOVA can be seen in table 8.20 and the calculated p-value was 0.000. This meant that the result was significant and the null hypothesis was rejected, meaning that the samples did not leak the same amount. Therefore, it was possible to conclude that some sample or samples were significantly better than some other or others.

The sum of squares (SS) is 99.6 % variation between groups and 0.4 % within groups. This means that the input parameters control 99.6 % of the variation and 0.4 % is noise.

Table 8.20: The table shows the result from the single factor ANOVA that was done for concept c1. Data is from table 8.18 and the ANOVA was calculated in Excel.

Source of variation	*SS*	*df*	*MS*	*F*	*p-value*	*F critical*
Between groups	263.590	7	37.656	537.938	0.000	2.657
Within groups	1.120	16	0.070			
Total	264.710	23				

9 Result

9.1 Final Design

As mentioned at the end of section 6.5 Iteration 3, the final concepts were concept c4 and c1. The chosen material for the prototypes was SiR with hardness 40 Shore A since this hardness seemed to work best in the IP tests and got the best feedback in Workshop 2. The final design of concept c4 and concept c1 can be seen in figure 9.1 respective figure 9.2 with refinements. For concept c1, an arbitrary gasket for the chassis has been integrated with the grommet.

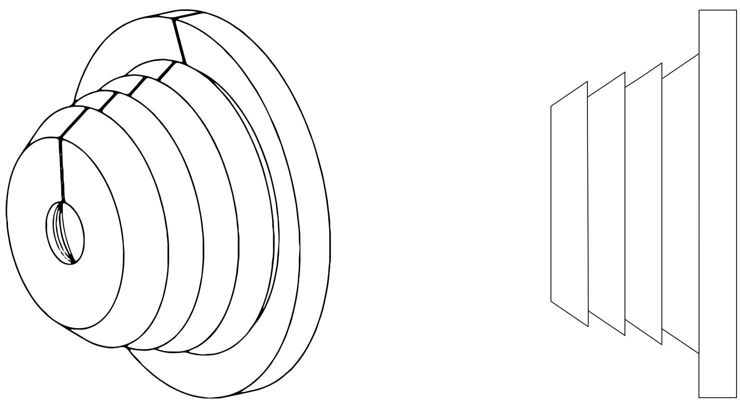

Figure 9.1: The figure shows the final design of concept c4 after refinements had been made.

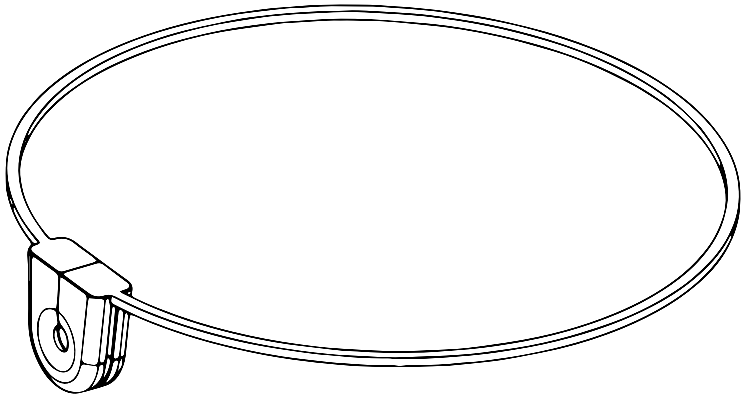

Figure 9.2: The figure shows the final design of concept c1 after refinements had been made.

9.2 Final Specifications

To ensure that the final solutions worked and had met the marginal requirements, established at the beginning of the project, a comparison was made between the solutions and the requirements. In table 9.1 all final values together with their corresponding marginal values can be seen. Here, the final values for concept c4 and concept c1 can be seen on the far right of the table. It can be concluded that almost all requirements have been met except for the cable diameter. It is noteworthy to mention that not all requirements were tested, like with IP6X for concept c1. The reason for this was either time limitations, or that the outcome was already known for the requirement. For example the operating temperature was acceptable since the material is used for existing outdoor solutions at Axis.

Table 9.1: The table shows marginal and final values for concept c1 and c4.

No	Metric	Unit	Marginal value	*Final value*	
				c1	***c4***
	General				
1	Cost-efficient	Subj.	Yes	Yes	Yes
2	Lifetime	year	9	9	9
	Physical				
3	Average Ethernet cable diameter	mm	6 to 7	4.5 to 5.7	4.5
4	Max modular plug diameter	mm	17	17	17
	Installation				
5	Ease of installation in camera	Subj.	Yes	Yes	Yes
6	Ease of pulling through cable with modular plug	Subj.	Yes	Yes	Yes
	Environmental				
7	Withstand IP67	Binary	Yes	Yes	Possibly*
8	Operating temperature	°C	−30 to 55	−40 to 200	−40 to 200
9	Storing & transport temperature	°C	−40 to 65	−40 to 200	−40 to 200

* Fulfills IPX7, not tested for IP6X.

10 Discussion and Conclusion

10.1 Identify Needs

As mentioned in chapter 4 Identify Needs, the interviews that were held gave a lot of valuable information to the project. The interviews with the benchmarking leader as well as with the experienced engineers were essential for the creation of the needs. The interview with the product owner provided better insight into the project and the problem at hand. However, it would have been preferable to have the interview with the product owner sooner than what the team had since additional information regarding the project was updated or added after the discussion.

10.2 Requirements

The requirement step in the project went by fast and was rather straightforward. The requirements were provided by Axis and then organized by the project team. As mentioned in chapter 5 Establishing Target Requirements, not a lot of requirements were created. The reason for this was that the project handled the sealing of a cable going into the camera which is a relatively small part of the entire camera.

10.3 Development

The prototypes created in the development phase were very valuable for the testing and the project team learned a lot from them. Prototyping the concepts fast with FFF gave a better picture of what the concepts would look like and if there were anything that needed to be changed. The 3D printed chassis also helped a lot and gave a clearer picture of how the prototypes could be installed and what the installation felt like.

The test boxes took longer than expected to construct. When the project team first used the FFF method, the boxes still leaked. It took a lot of generations and switching to an MJP until a box that was fully sealed was created.

The two different workshops sparked a lot of good discussions, both between the participants and between the project team and the participants. It was from these conversations that the refinements, and especially the refinements for the final design, were invented.

10.4 Result

The IP67 testing and the workshops resulted in two winning concepts, concept c4 and concept c1. The best performing concept was c4 with hardness 40 Shore A. From the results, it can be seen that shore 40 worked best for almost all concepts. The reason for this could be that the softer material did not push against the wall and cable hard enough. The reason for the harder material not performing as well could be that this material resulted in the grommet not being able to flex and seal completely around the cable. Shore 40 became the best of both worlds with it both pushing hard enough and completely sealing around the cable.

There are some sources of error that could have affected the result. Firstly, to test concept c1 the grommets had to permanently be placed in the test box. This restricted the change of grommets when a new test was made and because of this, the same grommet had to endure many extractions and insertions of cables which could have worsened the sealing capability of the grommet. Another source of error was the 3D printed test boxes. Since these were 3D printed, the surface finish was very poor and small ridges were found near the hole of the box. The area around the hole was sandpapered down but it could still have affected the result. To be sure the test boxes were sealed, a first version of the test box was created. When it was established that the box was sealed, the same sealing method of putting glue and sealant between a PMMA glass and the box was applied to all test boxes. However, the sealant was applied by hand, this created some uncertainty about whether all boxes were completely sealed. Lastly, when the IP6X test was conducted, the negative pressure varied a lot and could not be stabilized. This source of error could have affected the results of the specific test.

In chapter 9 Result, it can be seen that almost all requirements were met except for the cable diameter. The reason for this requirement not being met is that the project team used standard cables that were at hand and due to the time frame, was not able to test bigger cables. Furthermore, the product owner mentioned that smaller cables would in all probability be used in the camera.

To improve and get more reliable results, additional tests could have been made. The results would have been improved if additional dimensions for the holes would have been tested. In this way, the project team could have found the most optimal dimensions for the hole and wall. Furthermore, another thing that could have made the result more reliable was to have a box that was guaranteed to be sealed, this would have made the results more trustworthy. For concept c1 it would be nice with a test box that uses a gasket for sealing between the box and PMMA, this would allow for the prototype to be changed between each test.

10.5 Conclusion

This master thesis aimed to construct and design a sealing solution for a cable going into a camera. This sealing solution had to meet the IP67 requirement and be easy to install. After months of work, it can be concluded from the result that this has been achieved. However, some things need to be taken into consideration. This master thesis is a pilot study for a cable sealing solution, therefore, it is unclear how exactly it will be integrated into a future camera. The exact dimensions, how big the chassis is and how much space there is in the camera need to be taken into consideration.

The final sealing solutions are very easy to handle, the cable can easily be installed in the slit in the grommets. With these solutions, it does not matter whether the modular plug is attached or not. The grommets can also be reused several times, however, if the grommets are detached and then reattached again, they cannot be guaranteed to have the same sealing capabilities, since this was not tested.

The material used for the grommets, SiR, has performed well, especially with 40 Shore A. The temperature span of SiR is good and it has excellent weather properties. However, it is unknown how the grommet will age and how well it will perform over time, but it is assumed that it will age like Axis's current solutions since it is the same material that is used today.

10.5.1 Design of Experiments

Three design parameters were tested, hardness, wall thickness and hole diameter/depth. After systematic testing, the understanding of the impact of the three parameters has increased. Hardness and hole diameter affected the amount of leaked water the most for concept c4. However, the ANOVA showed no significant difference between the different concept configurations that were tested. The insignificant result was mostly because all concept c4 configurations performed well in the IPX7 test without much leakage.

The DoE for concept c1 showed a completely different result thanks to a larger variation between the groups and a smaller variation within the groups. Here, the ANOVA showed a significant difference between the concept configurations. The DoE showed that the hole depth had a large impact on the amount of leaked water, whereas the material hardness and wall thickness did not impact the result. This showed that the radial seal was more important than the axial seal. However, it could also be that the level interval for the wall thickness was too small to affect the amount of leaked water. Concept c1 was designed to be pressed together when installed to seal between the cable and grommet, grommet and chassis, and close the slit in the concept. So, it is not a surprise that the depth affects how much the grommet is being pressed together creating a good or bad seal.

The DoE setup showed some problems, where the biggest problem was that the output variable measured the weight increase of the box. If the box leaks a few drops, that could have a huge impact on the electronics inside the camera. This would at the same time have little impact on the weight increase. A different option could be testing to change the values for level 1 and level 2. From Axis's side, the focus was to develop a sealing solution that passed the requirements of IP67 and therefore a lot of the testing focused on the IP67 test. Perhaps measuring the weight increase as the output variable from the IPX7 tests is not the best way to learn about the parameters of the system. One option could be to measure at what water pressure a concept configuration starts leaking. This would however need a more advanced test setup.

10.6 Future Work

The project team has identified some potential future work that could be made for the project. Firstly, more investigation regarding the material would be valuable, especially for large volume production with TPE. This would allow Axis to see if any cost savings can be made since TPEs have a more efficient production process and cheaper material cost than SiR.

Another future investigation would be to test more cables with different thicknesses to see how big cables the grommet can handle. If Axis is interested in making the grommet work for other cable sizes, the grommet could be optimized for different cable sizes. Two or more grommets could then be sent out in the packaging, and the installer could choose the right grommet for a specific cable size interval.

Furthermore, earlier in the project, discussions were made with the supplier of the prototypes regarding the slit. The supplier said that they could only do a straight slit which resulted in the grommet having a straight line as a slit. Further investigation regarding the slit would be advantageous. If the slit could be varied with different patterns, it could potentially improve the sealing capabilities of the grommet. However, one advantage with a straight slit is that the two sides matches perfectly, creating a good seal, but there is a risk of the two sides sliding creating small gaps.

Lastly, in chapter 6 Development, refinements were discussed for the final solutions for concept c4 and c1. The future steps that need to be taken here are to produce prototypes for the refined concepts and test these prototypes for both IP67 in real cameras and test the ease of installing them to see if the refinements have improved the grommets.

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A Appendix – Interview Questions

A.1 Interview with Benchmark leader

Inledning:

1. Vad jobbar du med?
2. Hur länge har du jobbat med det?

Produktspecifika frågor:

3. Vilken typ av kameror brukar du montera?
4. Ungefär hur lång tid ta det att trä igenom samt fästa den i kameran?
5. Har du sett några problem med hur de åldras?
6. Vad tycker du fungerar bra med nuvarande lösning (Cable Gasket 1 samt Cable Gasket 2)?
7. Vad tycker du kan förbättras med nuvarande lösning (Cable Gasket 1 samt Cable Gasket 2)?
8. Vad ser du för risker med en kamera som ska fungera utomhus?
9. Har du några idéer kring en möjlig lösning för vårt projekt?
10. Kan nuvarande plugg återanvändas?
11. Hur ofta går pluggarna sönder vid installation?
12. Finns det något du vill tillägga?

A.2 Interview with Experienced Engineer

Inledning:

1. Vad jobbar du med?
2. Hur länge har du jobbat med det?
3. Vad gör du en vanlig arbetsdag?

Produktspecifika frågor:

4. Vilken typ av pluggar har du varit med och utvecklat?
5. Har ni gjort några tester för IP-krav?
6. Vad anser du är de viktigaste egenskaperna hos pluggen?
7. Ska pluggen klara av att en kabel med RJ45 dras igenom?
8. Vilka var era största risker i projektet?
9. Hur har era tankar sett ut angående materialval?
10. Från vad du vet, vad har fungerat bra med den slutliga produkten?
11. Fanns det några krav på installationstid?
12. Från vad du vet, vad hade kunnat förbättras med den slutliga produkten?
13. Har ni sökt patent för pluggen?
14. Har du några idéer kring en möjlig lösning för vårt projekt?
15. Hur fick ni idéer till ert projekt? Kollade ni på patent eller tidigare Axis-lösningar eller konkurrenter?
16. Vet du andra personer som hade varit intressanta för oss att prata med?
17. Finns det något du vill tillägga?

A.3 Interview with Product Owner

Inledning:

1. Vad jobbar du med?

Projektrelaterade frågor:

3. Hur ser bakgrunden ut för det här projektet?
4. Hur stor kommer tillverkningsvolymen bli?

Produktspecifika frågor:

3. Vilka temperaturkrav finns på kameran?
4. Behöver kameran ha en kabelbuffert undertill?
5. Vilka kablar ska gå in i kameran?
6. Hur ser möjligheterna ut att göra kamerabasen större?
7. Finns det krav på installationstid?
8. Finns det krav på hur länge kameran ska hålla?

B Appendix – Workshop Form

AXIS COMMUNICATIONS

Workshop - Formulär del 1

3 maj 2022

Personlig identifierare (t.ex. Hannibal Lecter): ____________________________

Jobbtitel (t.ex. mekanikkonstruktör): ____________________________

Svara på följande påstående där:
- 1 - Instämmer **inte alls** med påståendet
- 6 - Instämmer **helt** med påståendet

Beteckning för exempelvis **Koncept U med hårdhet 40** är **U40**.

		Koncept I			**Koncept K**			**Koncept L**			**Koncept U**		
Nr	**Fråga**	**I30**	**I40**	**I50**	**K30**	**K40**	**K50**	**L30**	**L40**	**L50**	**U30**	**U40**	**U50**
0	Exempel: Konceptet luktade gott.	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6
1	Det var enkelt att installera sladden i konceptet.	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6
2	Konceptet var smidigt att installera i chassit.	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6
3	Det var intuitivt hur konceptet skulle installeras.		1 2 3 4 5 6			1 2 3 4 5 6			1 2 3 4 5 6			1 2 3 4 5 6	

	Fråga
0	Exempel: Konceptet luktade gott. Kommentarer? *K30 luktade ros, nice. U40 luktade lite illa, inte önskvärt.*
1	Det var enkelt att installera sladden i konceptet. Kommentarer?
2	Konceptet var smidigt att installera i chassit. Kommentarer?
3	Det var intuitivt hur konceptet skulle installeras. Kommentarer?

Workshop - Formulär del 2

Nr	Fråga
4	Tyckte du något koncept och hårdhet fungerade extra bra? Vilket och varför?
5	Tyckte du något koncept och hårdhet fungerade dåligt? Vilket och varför?
6	Vilket koncept och hårdhet känns mest realiserbart? Vilket och varför?
7	Vad skulle du vilja förbättra med det koncept du tyckte var mest realiserbart? Vilket och varför?
8	Något övrigt du vill tillägga om koncepten, chassin eller sladdtjocklek?
9	Vad tyckte du om den här workshopen? (vi är inte rädda för röd färg)

C Appendix – Hole Fitting Test

Table C.1: The table shows the result from the hole fitting test of concept c13. Three different parameters were tested, wall thickness of the chassis [mm], hole diameter [mm] and material hardness in Shore A. Each variant was scored 0 to 3 where 0 is worst and 3 best, see score description in table 8.1. The minimum score shows the lowest score of all hardnesses for a specific hole diameter and wall thickness. The average score is the average of all hardnesses for a specific hole diameter and wall thickness.

		Wall thickness [mm]			
Hardness	***Hole diameter*** [mm]	1.5	2.0	2.5	3.0
30	16.0	2	2	3	2
	16.5	2	2	2	2
	17.0	1	1	2	1
	17.5	0	0	0	0
40	16.0	1	2	1	1
	16.5	1	2	2	2
	17.0	0	0	0	2
	17.5	0	0	0	0
50	16.0	0	0	0	0
	16.5	1	3	2	2
	17.0	0	1	1	1
	17.5	0	0	0	0
Minimum score	16.0	0	0	0	0
	16.5	1	2	2	2
	17.0	0	0	0	1
	17.5	0	0	0	0
Average score	16.0	1.0	1.3	1.3	1.0
	16.5	1.3	2.3	2.0	2.0
	17.0	0.3	0.7	1.0	1.3
	17.5	0.0	0.0	0.0	0.0

Table C.2: The table shows the result from the hole fitting test of concept c4. Three different parameters were tested, wall thickness of the chassis [mm], hole diameter [mm] and material hardness in Shore A. Each variant was scored 0 to 3 where 0 is worst and 3 best, see score description in table 8.1. The minimum score shows the lowest score of all hardnesses for a specific hole diameter and wall thickness. The average score is the average of all hardnesses for a specific hole diameter and wall thickness.

		Wall thickness [mm]			
Hardness	***Hole diameter*** [mm]	1.5	2.0	2.5	3.0
30	16.0	1	1	1	2
	16.5	2	2	2	1
	17.0	1	1	1	1
	17.5	0	0	0	0
40	16.0	2	2	3	1
	16.5	2	3	3	1
	17.0	2	3	2	3
	17.5	1	1	1	1
50	16.0	1	2	2	3
	16.5	3	3	3	3
	17.0	3	3	3	2
	17.5	3	3	2	3
Minimum score	16.0	1	1	1	1
	16.5	2	2	2	1
	17.0	1	1	1	1
	17.5	0	0	0	0
Average score	16.0	1.3	1.7	2.0	2.0
	16.5	2.3	2.7	2.7	1.7
	17.0	2.0	2.3	2.0	2.0
	17.5	1.3	1.3	1.0	1.3

Table C.3: The table shows the result from the hole fitting test of concept c20. Three different parameters were tested, wall thickness of the chassis [mm], hole diameter [mm] and material hardness in Shore A. Each variant was scored 0 to 3 where 0 is worst and 3 best, see score description in table 8.1. The minimum score shows the lowest score of all hardnesses for a specific hole diameter and wall thickness. The average score is the average of all hardnesses for a specific hole diameter and wall thickness.

		Wall thickness [mm]		
Hardness	***Hole diameter*** [mm]	6.5	7.5	8.0
30	16.0	1	3	1
	16.5	1	2	3
	17.0	0	2	1
	17.5	0	0	0
40	16.0	1	1	0
	16.5	1	3	3
	17.0	1	3	3
	17.5	0	0	1
50	16.0	0	0	0
	16.5	2	3	1
	17.0	1	3	3
	17.5	0	0	0
Minimum score	16.0	0	0	0
	16.5	1	2	1
	17.0	0	2	1
	17.5	0	0	0
Average score	16.0	0.7	1.3	0.3
	16.5	1.3	2.7	2.3
	17.0	0.7	2.7	2.3
	17.5	0.0	0.0	0.3

Table C.4: The table shows the result from the hole fitting test of concept c1. Three different parameters were tested, wall thickness of the chassis [mm], hole depth [mm] and material hardness in Shore A. Each variant was scored 0 to 3 where 0 is worst and 3 best, see score description in table 8.1. The minimum score shows the lowest score of all hardnesses for a specific hole diameter and wall thickness. The average score is the average of all hardnesses for a specific hole diameter and wall thickness.

		Wall thickness [mm]		
Hardness	***Hole depth*** [mm]	1.5	2.0	2.5
30	16	3	3	2
	17	2	2	2
	18	0	0	0
40	16	3	3	1
	17	2	3	2
	18	0	0	0
50	16	3	3	3
	17	2	3	3
	18	0	0	0
Minimum score	16	3	3	1
	17	2	2	2
	18	0	0	0
Average score	16	3.0	3.0	2.0
	17	2.0	2.7	2.3
	18	0.0	0.0	0.0

D Appendix – Test 1 Result

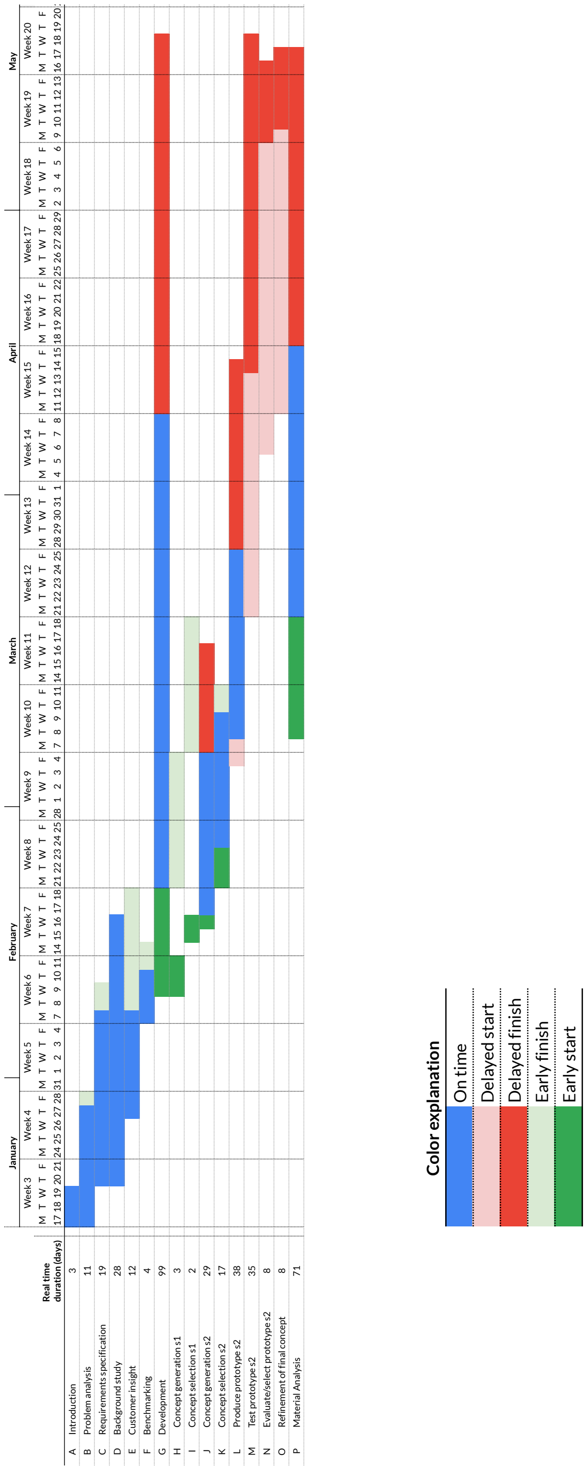
Table D.1: The table shows the result from Test 1 for concept c13 and c4. In this table, c13 is called I and c4 is called K.

				Measurement 1				*Measurement 2*				*Measurement 3*					
Concept	***A – Hardness***	***B – Diameter/depth***	***C – Thickness***	***Weight before*** [g]	***Weight after*** [g]	***Weight increase*** [g]	***Score***	***Weight before*** [g]	***Weight after*** [g]	***Weight increase*** [g]	***Score***	***Weight before*** [g]	***Weight after*** [g]	***Weight increase*** [g]	***Score***	***Average score***	***Average weight increase*** [g]
I	1	1	1	74.5	74.9	0.4	3	74.1	74.5	0.4	3	73.7	74.3	0.6	2	2.7	0.5
I	1	1	2	74.0	74.2	0.2	3	74.5	75.2	0.7	3	73.9	76.3	2.4	5	3.7	1.1
I	1	2	1	72.9	84.2	11.3	7	72.9	98.6	25.7	9	72.7	81.3	8.6	6	7.3	15.2
I	1	2	2	74.9	90.1	15.2	8	74.8	84.4	9.6	6	74.9	82.8	7.9	6	6.7	10.9
I	3	1	1	74.1	74.2	0.1	3	74.0	74.7	0.7	3	74.2	74.5	0.3	3	3.0	0.4
I	3	1	2	74.2	75.0	0.8	3	74.1	74.4	0.3	3	74.0	75.4	1.4	4	3.3	0.8
I	3	2	1	73.2	98.8	25.6	9	72.8	102.0	29.2	9	73.0	105.8	32.8	10	9.3	29.2
I	3	2	2	74.9	83.2	8.3	6	74.8	82.5	7.7	6	74.7	83.1	8.4	6	6.0	8.1
I	2	1	1	74.3	75.9	1.6	4	74.3	74.4	0.1	2	74.0	74.4	0.4	2	2.7	0.7
I	2	1	2	74.3	74.3	0.0	1	74.2	74.5	0.3	3	74.2	74.5	0.3	3	2.3	0.2
I	2	2	1	73.0	106.9	33.9	10	73.1	97.2	24.1	9	73.0	107.4	34.4	10	9.7	30.8
I	2	2	2	74.9	83.3	8.4	6	74.7	83.3	8.6	6	74.8	78.4	3.6	5	5.7	6.9
K	1	1	1	75.1	75.0	0.0	1	74.5	74.7	0.2	3	74.6	74.6	0.0	2	2.0	0.1
K	1	1	2	74.4	74.2	0.0	1	74.3	74.4	0.1	1	74.9	75.0	0.1	1	1.0	0.1
K	1	2	1	73.3	73.3	0.0	3	73.4	73.5	0.1	3	73.5	73.6	0.1	3	3.0	0.1
K	1	2	2	75.3	75.4	0.1	3	75.1	75.2	0.1	3	75.1	75.1	0.0	3	3.0	0.1
K	3	1	1	74.8	74.8	0.0	3	74.7	74.7	0.0	1	74.5	74.7	0.2	2	2.0	0.1
K	3	1	2	74.6	74.6	0.0	1	74.7	74.7	0.0	1	73.8	74.0	0.2	1	1.0	0.1
K	3	2	1	73.8	73.9	0.1	3	73.4	73.4	0.0	1	73.4	73.5	0.1	2	2.0	0.1
K	3	2	2	75.4	75.4	0.0	2	75.5	75.7	0.2	1	75.3	75.5	0.2	2	1.7	0.1
K	2	1	1	74.7	75.0	0.3	1	74.7	74.8	0.1	1	74.9	74.9	0.0	1	1.0	0.1
K	2	1	2	74.9	75.2	0.3	1	74.7	74.7	0.0	2	74.8	74.8	0.0	1	1.3	0.1
K	2	2	1	73.6	73.8	0.2	2	73.5	75.3	1.8	4	73.5	73.5	0.0	1	2.3	0.7
K	2	2	2	75.4	84.3	8.9	6	75.3	75.4	0.1	1	75.3	75.3	0.0	1	2.7	3.0

Table D.2: The table shows the result from Test 1 for concept c20 and c1. In this table, c20 is called L and c1 is called U.

				Measurement 1				*Measurement 2*				*Measurement 3*					
Concept	*A – Hardness*	*B – Diameter/depth*	*C – Thickness*	*Weight before* [g]	*Weight after* [g]	*Weight increase* [g]	*Score*	*Weight before* [g]	*Weight after* [g]	*Weight increase* [g]	*Score*	*Weight before* [g]	*Weight after* [g]	*Weight increase* [g]	*Score*	*Average score*	*Average weight increase* [g]
L	1	1	1	75.1	75.3	0.2	3	75.1	84.3	9.2	6	75.2	75.5	0.3	3	4.0	3.2
L	1	1	2	75.5	75.7	0.2	3	75.5	75.6	0.1	1	75.4	75.4	0.0	3	2.3	0.1
L	1	2	1	74.0	82.9	8.9	6	75.2	83.8	8.6	6	74.1	83.1	9	6	6.0	8.8
L	1	2	2	74.4	83.4	9	6	74.6	83.0	8.4	6	74.2	82.7	8.5	6	6.0	8.6
L	3	1	1	75.1	75.2	0.1	1	74.8	76.1	1.3	4	74.3	75.1	0.8	3	2.7	0.7
L	3	1	2	75.7	75.7	0.0	2	75.0	75.7	0.7	1	75.9	75.9	0.0	2	1.7	0.2
L	3	2	1	74.1	82.3	8.2	6	74.0	83.3	9.3	6	73.9	82.4	8.5	6	6.0	8.7
L	3	2	2	74.3	82.9	8.6	6	74.0	82.3	8.3	6	74.4	83.4	9	6	6.0	8.6
L	2	1	1	75.1	75.2	0.1	1	75.2	75.8	0.6	3	75.4	75.8	0.4	3	2.3	0.4
L	2	1	2	75.1	76.1	1	4	75.6	83.5	7.9	6	76.1	76.4	0.3	3	4.3	3.1
L	2	2	1	74.7	83.9	9.2	6	74.1	82.1	8	6	74.2	83.6	9.4	6	6.0	8.9
L	2	2	2	74.5	83.9	9.4	6	74.8	83.0	8.2	6	74.2	83.3	9.1	6	6.0	8.9
U	1	1	1	102.0	102.0	0.0	1	101.7	101.8	0.1	1	101.7	101.8	0.1	1	1.0	0.1
U	3	1	1	99.7	99.9	0.2	1	99.8	100.0	0.2	3	99.7	99.9	0.2	1	1.7	0.2
U	2	1	1	101.8	101.9	0.1	1	101.5	101.5	0.0	1	100.8	101.3	0.5	1	1.0	0.2
U	1	2	1	87.7	94.9	7.2	6	87.9	94.7	6.8	6	87.9	94.6	6.7	6	6.0	6.9
U	3	2	1	79.4	85.8	6.4	6	79.4	86.1	6.7	6	80.0	86.5	6.5	6	6.0	6.5
U	2	2	1	85.6	91.8	6.2	6	85.7	92.6	6.9	6	86.5	93.1	6.6	6	6.0	6.6
U	1	1	2	102.6	102.7	0.1	1	102.7	102.6	0.0	1	102.6	102.7	0.1	3	1.7	0.1
U	3	1	2	101.4	101.3	0.0	1	101.6	101.7	0.1	1	101.2	101.3	0.1	1	1.0	0.1
U	2	1	2	102.0	102.1	0.1	1	102.5	102.5	0.0	1	102.1	102.1	0.0	1	1.0	0.0
U	1	2	2	87.1	93.5	6.4	6	87.3	94.5	7.2	6	87.3	94.0	6.7	6	6.0	6.8
U	3	2	2	86.9	93.6	6.7	6	87.4	94.2	6.8	6	88.1	95.5	7.4	6	6.0	7.0
U	2	2	2	92.3	98.9	6.6	6	92.8	99.1	6.3	6	92.8	99.8	7	6	6.0	6.6

E Appendix – Gantt Chart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E Customer insight 12
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Early start