Analysis of an explosion protected cemented flame path

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Abstract

This report covers the master thesis that has been carried out at Axis EX, which focuses on explosion protected cameras. It is assumed that it is impossible to prevent flammable gasses from penetrating an explosion protected product. Therefore, an explosion can occur if an ignition source is present inside the product. The camera housings shall, in the event of an internal combustion of flammable gas, prevent the flames from spreading outside of the housings. To ensure that the examined camera fulfills the set requirements, mainly two standards are used; IEC 60079 and UL 1203.

The purpose of this work was to analyze the installment of a glass window and its cemented flame path, to minimize potential issues noted in the production. During research it became clear that the sealant material used for the cemented flame path must undergo yearly testing. These tests can be avoided provided that the sealant material is classed according to TVLE2 by Underwriters Laboratories, who have issued the applied standard. The approach that was then followed was to partly examine TVLE2-classed materials, and partly analyze the production with the current material in order to contribute with improvement suggestions.

Different methods and approaches were used for the two routes. For the selection of TVLE2-classed material, it was decided to combine the Double Diamond development methodology with Ulrich & Eppingers' general development methodology. The result of the material selection was that only two materials fulfilled the requirements; Peppers T1000 and KQS Celox. Due to uncontrollable circumstances they could not undergo testing within the scope of this work. Similar materials were however tested and it was concluded that new tools and fixtures would be needed for both materials.

For the production analysis with the current material, a process-oriented FMEA was created. Fixtures and tools were constructed and tested iteratively with the FMEA acting as guidance. The team's contribution to the development process resulted in fixtures, tools and work instructions that led to the improvement of the defined objectives.
Keywords: Explosion protected, cemented flame path, product development, camera

Sammanfattning

Denna rapport behandlar det examensarbete som genomförts på Axis EX som inriktar sig på explosionssäkra kameror. Det är förmodat att det är omöjligt att förhindra antändningsbara gaser att penetrera explosionssäkra produkter. Därav kan en explosion ske om en antändningskälla är närvarande i produkten. Dessa kamerahus skall, vid invändig antändning av brandfarlig gas, förhindra att flammorna sprider sig utanför husen. För att säkerställa att produkten uppfyller gällande krav så används, för den undersökta kameran, i huvudsak två standarder; IEC 60079 och UL 1203.

Syftet med arbetet var att analysera infästningen av ett glasfönster och dess “cemented flame path”, för att minimera potentiella problem som noterats i produktionen. Under efterforskningen framkom det att det nuvarande materialet som används till denna cemented flame path behöver genomgå årliga tester. Dessa tester kan undvikas under förutsättning att tätningsmaterialet är klassat enligt TVLE2 av Underwriters Laboratories, som utfärdat gällande standard. Tillvägagångssättet som följdes var dels att undersöka TVLE2-klassade material, dels att analysera produktionen med det nuvarande tätningsmaterialet i syfte att bistå med förbättringsförslag.

Olika metoder och tillvägagångssätt användes för de två spåren. För valet av TVLE2-klassat material kombinerades utvecklingsmetodiken Double Diamond med Ulrich & Eppingers generella utvecklingsmetodik. Resultatet av materialvalet var att endast två material uppfyllde kravspecifikationerna; Peppers T1000 och KQS Celox. På grund av okontrollerbara omständigheter kunde de inte genomgå testning inom omfattningen av detta arbete. Liknande material testades och slutsatsen blev att nya verktyg och fixturer kommer att behövas för båda materialen.

För produktionsanalysen med det nuvarande materialet skapades en processorienterad FMEA. Fixturer och verktyg testades och konstruerades iterativt med FMEA:n som stöttning. Den utvecklingsprocess som genomfördes av teamet resulterade i verktyg, fixturer och arbetsinstruktioner som tillsammans bidrog till förbättringen av de mål som definierats.

Nyckelord: Explosionssäkrad, cemented flame path, produktutveckling, kamera

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Abbreviations

EX – Explosion protected
R&D – Research & Development
UL – Underwriters Laboratories
FMEA – Failure Mode and Effect Analysis
RTV – Room Temperature Vulcanizing
IEC – International Electrotechnical Commission
NFPA – National Fire Protection Association
DD – Double Diamond
NRTL – Nationally Recognized Testing Laboratory

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1 Introduction

1.1 Axis Communications AB

This master thesis was carried out in cooperation with Axis Communications, located in Lund, Sweden. Axis Communications will be referred to as Axis for the remainder of the report. Since 1984, Axis has been developing a range of electrical products such as protocol converters and print servers in the early years, to mainly working on network cameras in recent years. Axis is one of the leading companies in the field of network surveillance and operates in many countries around the world [1].

In recent years, Axis has entered a new market, explosion protected products. A new company, Axis EX, was founded for this purpose. Axis EX has all certificates needed to produce explosion protected products while Axis Communications provides the designs.

1.2 Problem description

1.2.1 Background

This project was defined by the Research & Development (R&D) department of Axis EX, which specializes in explosion protected cameras. The requirements are therefore particularly high, both in terms of the technical design and on the production. As part of the explosion protected design the camera unit is located within an outer housing. Certain conditions must be met to achieve an EX-certification, one of which is sealing passages where gasses otherwise may pass through. Some seals are based on a construction called “cemented joint”, utilizing adhesive sealant. Certain issues may be faced in production when assembling constructions of this type. One such issue can be to acquire seals that are sufficiently homogeneous throughout the sealing joint. When mating the surfaces, there may be areas where this is not the case due to air pockets being trapped. The reason for this could be inadequate distribution, but it could also be due to the inherent stickiness of such a sealant. Another problem faced due to the inherent stickiness is that it may pose smearing problems. This can ultimately lead to lower image quality if the sealant accidentally comes in contact with the glass window, disturbing the field of view. Manual application of sealant is another source of potential issues since it can lead to an unnecessarily large quantity being applied. The problem with this aspect is the increased levels of outgassing that may occur, which also can be detrimental to the image quality. Outgassing is when a substance is evaporated from a material, in this case the sealant material.

This master thesis will be focused on analyzing the installment of a glass window and its cemented joint, to minimize the potential issues mentioned above. The cemented joint is located between a stainless steel outer housing and a circular glass window and can be seen in figure 1. The material used for the cemented joint is a silicone.

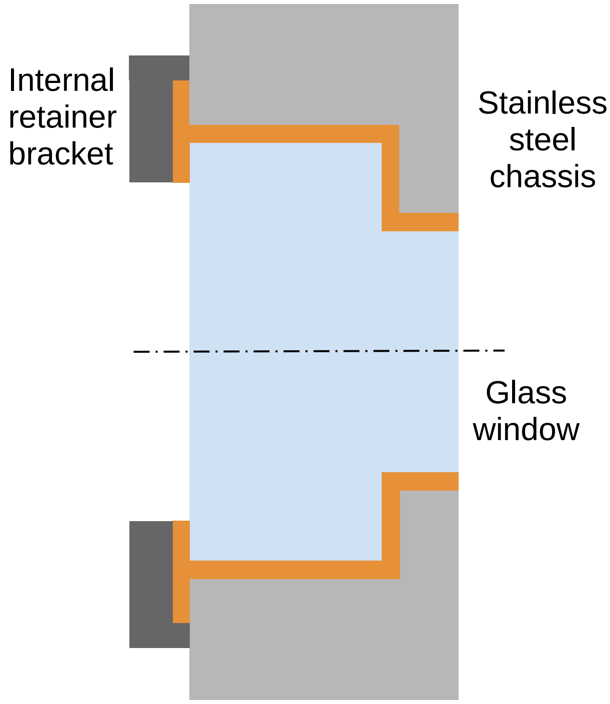


Figure 1: Cross-section illustration of the glass window

1.2.2 Objectives

The overall goal of this master thesis is to find a solution to the possible issues mentioned in the background. The objectives set to achieve this goal are listed below. In order to accomplish this, the entire assembly process, design and the material used will be examined.

Objectives:

- Achieve sufficiently homogeneous sealant joint
- Reduce smearing problems
- Minimize material applied to reduce excess material
- Minimize risk of outgassing
- Develop an improved work procedure for the production with the current material
- Evaluate alternative materials to the current material

1.2.3 Delimitations

The only mentionable delimitation was the decision to solely use a Failure Mode and Effect Analysis (FMEA) as the basis for the concept development regarding the production analysis. It was deemed that Ulrich & Eppingers' methodology would have been too extensive to carry out within the given time frame. Another delimitation was that a rotation table available in production was to be utilized.

1.2.4 Limitations

There were limitations to consider for the entirety of this thesis work, which affected both what could be reported and what could be carried out. One such limitation was that certain pieces of information regarding certifications, classifications and production, are classified and could not be shared in this thesis. If published, it could compromise the integrity of the intellectual property of both Axis and other parties. Some knowledge regarding the production could for the same reason not be shared either. This led to the limitation of not being able to show the full FMEA or the full work instructions. Limitation regarding the certification was that a redesign would lead to a recertification, which would preferably be avoided. The time aspect was also something to take into consideration since the time frame was set, which limited the number of ideas that could be further examined. Another limitation was that the materials could not be tested during the concept development phase. The reason for that was that lead times were too long and therefore only theoretical work will be presented in the report.

2 Theory

2.1 Explosion protected products

Explosion protected products are products designed to be used in hazardous environments, and they will from now on be referred to as EX products. These products must be certified and this is conducted by external companies that are analyzing the production and the mechanical and electrical design. The certification is based on the assumption that it is impossible to prevent flammable gasses from penetrating the product. If the gasses penetrate the product and there is an ignition source present, an explosion may occur. Hence the first objective of an EX certified product is to minimize the risk of having an ignition source. The second objective is to enclose the explosion and retain it, not allowing flames to spread outside of the camera housing [2][3].

2.2 Certification

There are different standards influencing the certification depending on where the product is being sold. The examined product is certified in accordance with numerous standards, but only the standards regarding explosion protection were relevant for this thesis. The product is certified in consideration to hazardous atmospheres in accordance with the European standard EN IEC 60079 by International Electrotechnical Commision (IEC) and the North American standard UL 1203 by Underwriters Laboratories (UL). Hazardous environments can differ leading to EX products being divided into different hazard classifications, area classification, gas/dust group and temperature classification. For the different hazard classification, there can be different standards. The hazard classifications will be further explained in *2.3 Certification in North America* and in *2.4 Certification in Europe*. It is of high importance to understand the hazard classification in order to extract the correct information regarding the product, as it is determined which substandard to use based on the different classifications [2][4].

2.3 Certification in North America

North America is using both the division system and the zone system. The two systems use different structures to describe the hazardous environment. The different structures can be seen in table 1 and 2 [5][6].

Table 1: North American division system to describe the hazardous environment.

Division system	Hazard class	Area classification	Gas/dust group	Temperature classification

Table 2: North American zone system to describe the hazardous environment

Zone system	Hazard class	Area classification	Stamp of approval	Type of protection	Gas/ dust group	Temperature classification	Equipment Protection Level EPL

2.3.1 Hazard class

The hazard class describes the type of explosive or ignitable substances that may be in the area.

Class I: Flammable vapor or gas.
Class II: Combustible dust.
Class III: Ignitable fibers or flyings [5][6].

2.3.2 Area classification

Specifies the likelihood of flammable concentrations of the classified substances. The classification can either be based on zones or on divisions and is summarized in the table 3 below [5][6].

Table 3: Area classification

Area classification	**Description**
Division 1 Zone 0 (gas) Zone 20 (dust)	Where ignitable concentrations of hazards can exist all/some of the time under normal operating conditions
Division 1 Zone 1 (gas) Zone 21 (dust)	Where ignitable concentrations of hazards can exist some of the time under normal operating conditions
Division 2 Zone 2 Zone 22	Where ignitable concentrations of hazards are not likely to exist under normal operating conditions.

2.3.3 Gas/dust group

Specifies what substance that is present in the atmosphere. The different classifications for each system can be seen in table 4 [5][6].

Table 4: Gas/dust group

Substance	**Division system**	**Zone system**
Acetylene	Group A	IIC
Hydrogen	Group B	IIC or IIB
Ethylene	Group C	IIB
Propane	Group D	IIA
Methane	Group D	IIA (for non mining applications)

Combustible metal dust	Group E (Only applicable to class II division 1)	IIIC
Combustible carbonaceous dust	Group F	IIIB
Combustible dust not in groups above (flour, grain, wood, plastics, chemicals)	Group G	IIIB
Combustible fibers and flyings	Not applicable	IIIA

2.3.4 Stamp of approval

The stamp of approval refers to what country the product has been approved in. If it is approved in the US it is marked AEx and if it is approved in Canada it is marked Ex.

2.3.5 Type of protection

The type of protection depends on what the product is designed to withstand and it follows a set standard. The examined product is marked db for gas and tb for dust [6].

Table 5: Type of protection

Type of protection	Symbol	Permitted zone	Definition
Flameproof (gas)	db	1	Contain the explosion and quench the flame
Enclosure (dust)	tb	21	Prevents dust coming into contact with electrical parts

2.3.6 Temperature classification

Specifies the maximum surface temperature allowed [5][6].

Table 6: Temperature classification

Temperature (°C)	**Division system**	**Zone system**
450	T1	T1
300	T2	T2
280	T2A	
260	T2B	
230	T2C	
215	T2D	
200	T3	T3
180	T3A	
165	T3B	
160	T3C	
135	T4	T4
120	T4A	

100	T5	T5
85	T6	T6

2.3.7 Equipment Protection Level (EPL)

According to the National Fire Protection Association (NFPA 70) the Equipment Protection Level (EPL) is designed as G for gas, D for dust and M for mining. It is then followed by letter a, b or c describing the level of protection against ignition of an explosive atmosphere, where a is “very high”, b is “high” and c is “enhanced”. The examined product is marked Gb for gas and Db for dust, meaning that in both gas and dust environments there has to be a high level of protection against ignition of the atmosphere [6, p.390].

2.4 Certification in Europe

Europe is using the zone system and the structure to describe hazardous environments is the following [2].

Table 7: European structure to describe the hazardous environment

Equipment group	Equipment category	Explosion protection	Type of protection	Gas/ dust group	Temperature classification	Equipment Protection Level EPL

2.4.1 Equipment group

The equipment group is either I for mining or II for surface industry [7].

2.4.2 Equipment category

The equipment category is a combination Level of protection, Type of flammable atmosphere and Mining applications [6].

Table 8: Level of protection

Level of protection is assured in	
1	The event of two faults occurring independently of each other
2	The event of one equipment fault
3	Normal operation

Table 9: Type of flammable atmosphere

Type of flammable atmosphere	
G	Gas
D	Dust

Table 10: Mining applications

Mining applications	
M1	Equipment remains energised
M2	De-energised

2.4.3 Explosion protection and Type of protection

The explosion protection is "Ex" and all explosion protected products in Europe will have the same marking. For the type of protection it is the same as the north American classification, see 2.3.4.

2.4.4 Gas/dust group

Same as North American classification, see 2.3.3.

2.4.5 Temperature classification

Same as North American classification, see 2.3.5.

2.4.6 Equipment Protection Level (EPL)

According to EN IEC 60079-0 the equipment protection level is "assigned to equipment based on its likelihood of becoming a source of ignition and distinguishing the differences between explosive gas atmospheres, explosive dust atmospheres, and the explosive atmospheres in mines susceptible to firedamp". The EPL depends on what the product is designed to withstand and it follows a set standard. The examined product is marked Gb for gas and Db for dust.

EPL Gb is "equipment for explosive gas atmospheres, having a "high" Level of Protection, which is not a source of ignition in normal operation or during expected malfunctions".

EPL Db is "equipment for explosive dust atmospheres, having a "high" Level of Protection, which is not a source of ignition in normal operation or during expected malfunction" [2, p.27-28].

2.5 Summary of hazardous atmospheres

The examined product's classification was found in the product's technical data sheet and was needed to acquire correct data from the standards.
The product should have the following European certification in accordance with the European standard EN IEC 60079:

II 2 G Ex db IIC T4-T6 Gb
II 2 D Ex tb IIIC T135°C - T185°C Db

The product should have the following North American certification in accordance with the North American standard UL 1203:

Class I Div1 B,C,D T4-T6
Class II Div1 E,F,G T4-T5
Class III Div 1
Class I Zone A Ex db IIC T4-T6 Gb
Class II Zone 21 A Ex tb IIIC T135°C - T185°C Db

With the information above, substandards from EN IEC 60079 and UL 1203 could be recognized and correct data could be extracted. The primary standards to be used which are relevant for the cemented flame path based on the classification are therefore EN IEC 60079-1 for protection by flameproof enclosures, EN IEC 60079-31 for dust ignition protection and the North American standard UL 1203 [2][4].

2.6 Cemented flame path

A cemented flame path, also referred to as a cemented joint is according to UL 1203 "– A joint which relies upon a cement or other similar compound to prevent the propagation of an explosion to a surrounding atmosphere by filling all voids between the mating parts forming the joint, such that no flame path exists. Intended for joints which are not disturbed after assembly."

When comparing EN 60079-1 to UL 1203 in regards to requirements for a cemented flame path, UL 1203 has stricter requirements. According to UL 1203 a cemented flame path is "When a part that is not intended to be removed after assembly, and that is not required to be opened to install or service the equipment is cemented with a cemented compound".

The length of the cemented flame path must be a minimum of 15.9 mm [4, chapter 10.2]. The mechanical strength in the cemented flame path does not need to fully depend on the adhesion of the sealant. In the examined product the internal bracket is used to mechanically secure the glass window [4, chapter 6.1.2]. The chassis housing is subjected to a pressure test and should withstand at least 25 bar which is based on the internal volume of the chassis housing according to the certification.

2.7 Materials

2.7.1 Silicones

Silicones can because of their characteristics and variability be used for many different applications, such as sealants, electrical insulation, cables and medical products. Some of these characteristics include;

- Usability in wide temperature range
- Durability and water repellency
- Low electrical conductivity
- Low tendency to oxidize
- Biocompatibility

2.7.1.1 RTV Silicone

There are two types of RTV silicones; one-component and two-component, hereafter called RTV-1 and RTV-2 respectively. They differ in the mechanisms that actuate the curing. RTV-1 is, as the name suggests, a silicone that only consists of one component and hence, does not require any other added components to cure. The RTV-1 silicones react with moisture in the air to cure. This process is called hydrolyzation and results in cross-linking between the silicone's molecular chains. The cross-linking yields covalent bonds making the silicone stronger and harder. RTV-2 silicone on the other hand requires the use of two components, a base and a curing agent, which mixed together will actuate the curing process [8, p.664].

Since RTV-1 silicone changes its chemical structure by the influence of external factors, these factors must be allowed to be present. As mentioned the main factor is the humidity of the surrounding air. When moisture comes into contact with the surface of the silicone, diffusion of the moisture into the silicone takes place. At first a skin is formed and this happens after the silicone's tack free time. As time progresses, the depth of which the silicone has cured increases. Humidity is the driving factor of the chemical reaction and the temperature at which it takes place also affects the rate of change. The rate increases with increased temperature, and vice versa. Although RTV-1 is more straightforward than RTV-2 in terms of application, since it can be applied from its container right onto the surfaces to be sealed, these external factors require certain care. The distance from which the air comes into contact with the silicone must not be too long, for the moisture to be able to fully diffuse. Therefore sealed surfaces must be designed with this taken into account. The general recommendation for RTV-1 silicones is that such depths should not exceed ¼ inch to ensure full cure. If longer distances would be required, one should evaluate the use of RTV-2 [8, p.663].

2.7.1.2 Current silicone

This silicone has the consistency of a paste, is solvent free and of an acetoxy type [9].

Table 11: Values for the current silicone [9]

Type	RTV-1
Color	Black
Tack free time	4 minutes
Time left undisturbed	24 h
Working temperature	-60º C to 300º C
Ideal cure temperature range	20º C to 60º C
Ideal cure humidity	> 40 %
Full cure time, 1 - 5 mm depth	7 days
Full cure time, 5 - 10 mm depth	14 days
Pneumatic dispense pressure range	2,25 to 3,45 bar
Cured tensile strength	2,3 N/mm^2
Young’s modulus	0,7 N/mm^2
Linear shrinkage	0,8 %

2.7.3 Epoxies

The established definition of an epoxy covers both the uncured thermoplastic base resins as well as the cured thermoset plastics [10, p.176]. There are several different areas of use for epoxies, such as; glues, sealings, coatings and reinforcements. They are also suitable for use on many different materials [11]. Epoxies hold several characteristics, making them versatile [12, p.724];

- Cured easily and quickly
- Low shrinkage when curing
- Great chemical resistance
- Strong adhesion capabilities
- High mechanical strength
- Can be altered by chemical composition

The definition of “epoxy resin” is “a molecule containing more than one epoxy group capable of being converted to a thermoset form” [12, p.723]. The epoxy groups are glycidyl and oxirane. There are a variety of different consistencies for epoxies, which all depend on their molecular weight. Epoxies with a higher molecular weight are solid, putty-like substances. With lower weight, their viscosity decreases, making them into thick liquids [13]. The uncured thermoplastic base resins require added material in order to cure, chemically altering the structure rendering them into a thermoset structure [12, p.725]. Most epoxy systems are applied with the base and activator separately in a certain ratio and require manual mixing. Such systems are called two-component epoxies. There are also so-called one-component epoxies which contain both materials premixed. The activator is latent and will only cure the epoxy under increased heat and/or UV-light conditions [14].

2.8 Outgassing

According to internal Axis documentation, outgassing is when a substance is evaporated from an object which in this case is the material in the cemented joint. Outgassing is mostly associated with vacuum, but it can also occur from heat or when a sealant is curing. The evaporated substance will eventually condense onto other components in the camera resulting in fogging, a film or haze. This is particularly problematic if it condensates to the camera lens as it will affect the image quality [15].

3 Methodology

3.1 Approach

The chosen approach was to use the Double Diamond (DD) method as a basis for the thesis. The reason for this was that the DD method was deemed highly suitable to the nature of the issues since there was no pre-defined problem description. With the DD method a clear path from the initial problem to the problem description is formulated.

For the material concept development phase Ulrich & Eppingers' methodology was used. This method was used due to the extensive technical specifications and requirements that apply when developing something within the explosion protection section. With the familiarity and understanding of the Ulrich & Eppinger concept development process from previous experiences, it was desirable to use it as well.

A Failure Mode and Effect Analysis (FMEA) was chosen to act as the basis of the work covering the analysis of the production with the current material and to aid the development. With the production being carried out using several different manual assembly steps, a process-oriented FMEA was seen as highly suitable. After the different steps were identified, the approach was to generate solutions iteratively. The solutions could be both work instructions, tools and fixtures with the mindset to make modifications where needed after each iteration.

The workflow can be seen below in figure 2 and the blue research diamond can be seen as the first diamond in the DD methodology, while the orange diamonds can be seen as the second diamond. The DD methodology will be explained further in the next section.

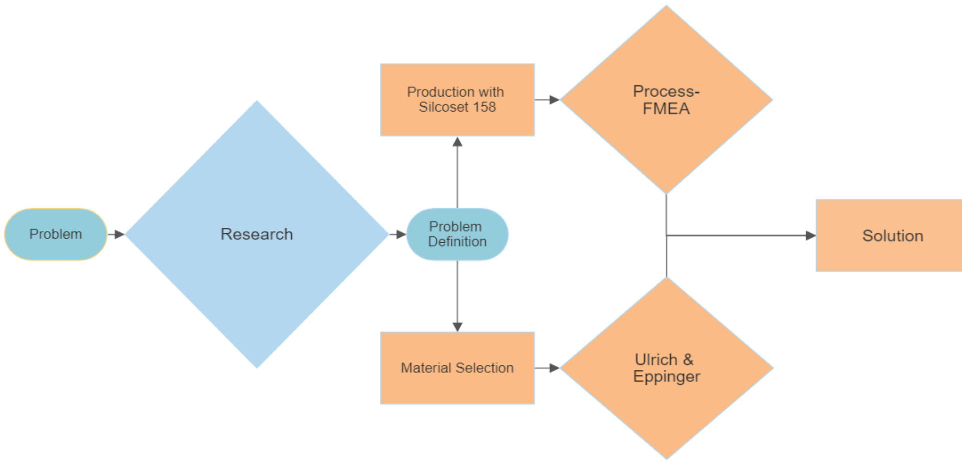


Figure 2: Workflow of the thesis

3.2 Double Diamond

The DD structure is made up out of two diamonds, each containing two different steps which can be seen in figure 3. The first diamond covers the research phase. Once a problem has been identified, the first step is to *Discover* more about it to gain insight. This is conducted in the *Theory* and *Research* sections of this thesis. The theory covers the background information needed to gain a general insight. It is with this information that the team initiates the work procedure. The research, on the other hand, includes more in-depth knowledge related to the actual issues. The information gathered will mainly be through certifications, standards, interviews and literature. After this part, the *Define* step is entered, and the problem is narrowed down and concretized to a problem definition. This is conducted in the *Problem Definition* section of this thesis. The second diamond focuses on the design phase. The *Develop* step aims to generate different concept solutions, which takes place in the *Development* section of this thesis.

In the chosen approach, however, this step is substituted by the steps of the Ulrich & Eppinger method for the material selection. For the production with the current silicone the steps of the second diamond are substituted by a process oriented FMEA. The overall goal to develop and test concepts in the second diamond remains unchanged. The last step is to *Deliver* the final solutions, represented in the *Conclusion* section [16].

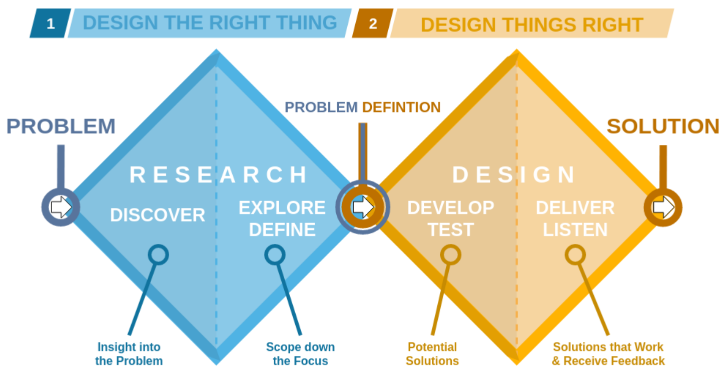


Figure 3: Double Diamond [17]

3.3 Ulrich & Eppinger

The methodology chosen, created by Ulrich & Eppinger, is a part of their general methodology to a product development process. The processes are described in detail in their book *Product Design and Development*. Seen below in figure 4 is the concept development phase of their development methodology. The design and test phase will be cycled iteratively to make improvements if deemed necessary. Its different activities are explained below.

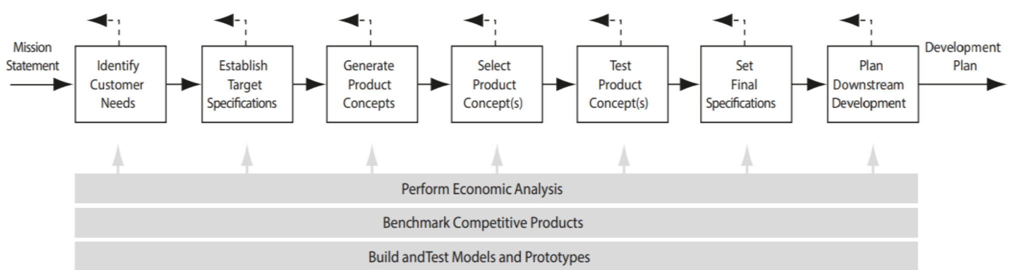


Figure 4: Ulrich & Eppinger Concept Development Phase [18, p.16]

3.3.1 Identify Needs

The first activity after setting a mission statement is to identify the needs for the product. Ulrich & Eppingers' method is adapted to cases where the development process aims to satisfy a customer. This thesis, however, intends to find a solution to the issues presented for an already existing product. Therefore, the aim is to satisfy the specifications stated in the product's certification. The activity called "Identify Customer Needs" above in figure 4 is therefore titled "Identify Needs". Ulrich & Eppinger have formed a five-step guide to successfully achieve this. Adapted to the certification needs, the guide looks as follows [18, p.75]:

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

3.3.2 Establish Target Specifications

This step aims to translate the gathered needs into technical specifications and requirements. Ideally, they should contain metrics, and marginal and ideal values. These requirements form the basis of which further development is conducted. The stated requirements reflect the ambitions and are set well before any concepts have been tested. Therefore, they will most likely be scrutinized at a later stage in the development process, when further technical aspects and limitations have been identified. Ulrich & Eppinger present four steps at this stage [18, p.95]:

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

3.3.3 Concept Generation

This stage of the development phase aims to search the realm of technical concepts. Generally, this activity should generate 10-20 concepts. Each concept is depicted with a sketch or a three-dimensional model, and a short description in text. The things included and depicted should be a description of; the technology, working principles and form. Ulrich & Eppinger present a five step method which include the following steps where steps 2 and 3 are run in parallel [18, p.119]:

1. Clarify the problem - understanding, problem decomposition, critical subproblems
2. Search externally - experts, literature
3. Search internally - individual, group
4. Explore systematically - classification tree, combination table
5. Reflect on the solutions and the process - constructive feedback

3.3.4 Concept Selection

The generated concepts are compared against each other and analyzed. This screening will eliminate concepts that are deemed less promising. Depending on the complexity of the product design, the team can use one or two evaluation stages. Stage one is called *Concept screening* and stage two is called *Concept scoring*. For a product with a more complex design, both stages should be used, whereas more simple designs usually suffice with the first stage. *Concept screening* has its purpose in quickly evaluating concepts and eliminating concepts that are not adequate. *Concept scoring*, however, takes the process further by examining details with more refinement. Both stages include the same six steps [18, p.149]:

1. Prepare the selection matrix
2. Rate the concepts
3. Rank the concepts
4. Combine and improve the concepts
5. Select one or more concepts
6. Reflect on the result and the process

3.3.5 Concept Test

The selected concept(s) is/are tested. The test results are evaluated to ensure that the concept(s) meet the defined needs. The tests are also used to narrow the selection down to one concept if there are more than one. Also, any weaknesses are identified which should be addressed during further development. The following seven steps are recommended in the procedure [18, p.167]:

1. Define the purpose of the concept test
2. Choose a survey population

3. Choose a survey format
4. Communicate the concept
5. Measure customer response
6. Interpret the results
7. Reflect on the results and the process

3.3.6 Set Final Specifications

The target specifications set earlier in the process are scrutinized and refined. At this stage further analysis is made in order to set the final specifications. Aspects such as technical limitations identified during modeling as well as trade-offs are to be evaluated as well. The recommended process is the following [18, p.105]:

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

3.3.7 Plan Downstream Development

A detailed development strategy is created to minimize development time and to identify the resources required to complete the project [18, p.17].

3.4 FMEA

According to the *American Society for Quality* an FMEA is “a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service.” [19]. The FMEA will be oriented towards process development in the production with the goal to identify potential failure modes before they appear. The different steps in the production are to be investigated separately, and failure modes, causes and effects are analyzed. The failure mode describes what the error is, the failure cause is the reason behind the error and the failure effect describes what happens. For each failure cause, a recommended action to take to resolve the error is suggested. Based on the knowledge and estimations within the team ratings on severity, occurrence probability and detection probability are set under each failure effect.

Table 12: Layout of process-FMEA

Process-FMEA for working procedure using the current silicone								
Assembly step	Failure mode (what error)	Failure cause (how/ by what)	Failure effect (what happens)	Severi ty	Occurre nce	Detect ion	Total	Recommende d action

The rating intervals are shown below in table 13. The occurrence value describes the likelihood that the failure takes place. The severity value represents how impactful the failure is. The detection value states how likely it is that the failure is noticed. These numbers are multiplied with each other, and the product is used as an importance factor [19]. For example, a high occurrence, severity, and detection value would indicate that the failure effect in question requires great attention since it occurs often, is serious and easy to miss. With the finalized FMEA, the team will analyze the production process further and carry out process development and make improvements where necessary. These improvements could involve fixtures, tools and work procedures.

Table 13: Layout of the rating intervals

Occurance Value		Severity Value		Detection Value	
Rating	**Value**	**Rating**	**Value**	**Rating**	**Value**
Not present	0	No risk	1	Very high	1
Rare	1	Very low	2	High	2
Possible	2	Low	3	Moderate	3
Likely	3	Moderate	4	Low	4
Almost certain to certain	4	High	5	Very low	5
		Very high	6	No chance	6

4 Research

4.1 Interviews

To gather information three different interviews were carried out. The goal was to get a better understanding of what the actual problem was and to get a better understanding of the working procedure in the production. The key questions asked can be seen in Appendix A.

4.1.1 Interview with Axis Ex R&D mechanical engineers

An interview with the mechanical engineers was carried out with the intention to get a better understanding of the background leading up to this master thesis. The glass window construction was not designed by the R&D department at Axis, but they are responsible for solving issues regarding it.

The key points from the interview was that the silicone is difficult to handle, resulting in a risk of leftover residue from the silicone on the glass window. This can affect the image quality. Further problems occurring with the handling difficulty is the risk of fixating the glass window in a slanted position. This can affect the wipers ability to clean the window, resulting in poorer image quality. Another concern they raised was the risk of trapping air pockets in the silicone joint. The problem with air pockets in the silicone joint is that it disturbs the cemented flame path and can as a consequence affect the certification. They also mentioned that problems could arise with the silicone being outside the internal retaining bracket. There is a phenomenon called outgassing, mentioned under the *Theory* section, that potentially can be a considerable problem. This is however not confirmed to be a problem, but it was brought to the team’s attention.

4.1.2 Interview with Axis certification specialist

An interview with a certification specialist was carried out with the intention to get a better understanding of the certification and what is allowed to modify in the design.

The key points from this interview were that a change in the design would most likely be too extensive to do. It would require a lot of new certification documents and tests which is both time consuming and expensive. Suppliers would also be affected as their manufacturing process would have to be changed. It might however be possible to do a small change like changing the silicone, as long as it is a material approved by UL and it fulfills the criteria set by the certification. If the material was to be changed, it has to be a TVLE2 classified material. The company doing the certification will most likely do an "engineering judgment" meaning that their experts will evaluate the change to see if new tests are necessary.

4.1.3 Interview with Axis Ex production personnel

An interview with the production personnel was carried out with the intention to get a better understanding of the working procedure when installing the glass window.

According to one of the production personnel, the most challenging aspect of the glass window assembly is to apply the silicone on the mantle surface of the glass window. They are not using any fixtures for this and the process was described as an ergonomically challenging part of the assembly. Another problem was the stickiness of the silicone. The risk is that small amounts touch the glass on other places than the mantle surface. The leftover residue requires cleaning but it is difficult to see if the glass is entirely clean after having wiped it off. This can result in the discovery of cured and hardened residue further down the production line, making it even more difficult to wipe off. When asked about other difficulties, another challenging aspect is positioning the glass. One part of this particular issue is the risk that the glass protrudes beyond the front surface of the housing, which can happen when the silicone is squashed too much. The risk is that the wiper blade action is affected. The second part of the issue is that the glass may get slanted when wiping it off, also because of the softness of the silicone. To aid in the application of silicone around the glass, the production team has acquired a rotating table, which can be put to use. The idea is that the personnel can mount the glass and retaining bracket onto the table, whose speed is controlled by a foot pedal. Thereby, when using both hands for the silicone dispenser, the silicone layer can be applied with more stability to attain greater accuracy.

4.2 Clarification of the current work procedure

The following part is based upon the interview with the production personnel and internal production documentation for the front glass window assembly.

4.2.1 Work procedure when installing the glass window

The illustrations are only showing a cross section of the sealing faces as the glass window is circular.

Step 1: Use a suction cup to hold the glass window and coat all seal faces of the glass with RTV silicone.

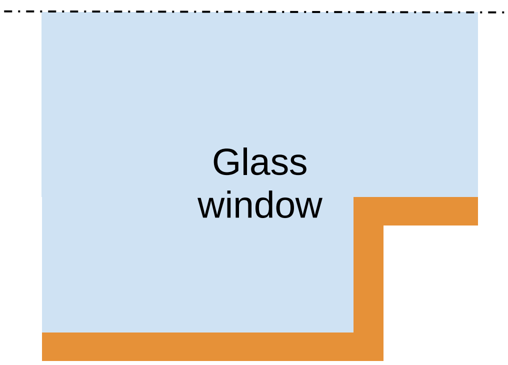


Figure 5: Illustrations of step 1 in the glass window assembly

Step 2: Press the window toward the stainless steel chassis until it is resting on a special tool which is used to ensure that the vertical sealant face is not too compressed. The glass window should be aligned to the outside of the stainless steel chassis.

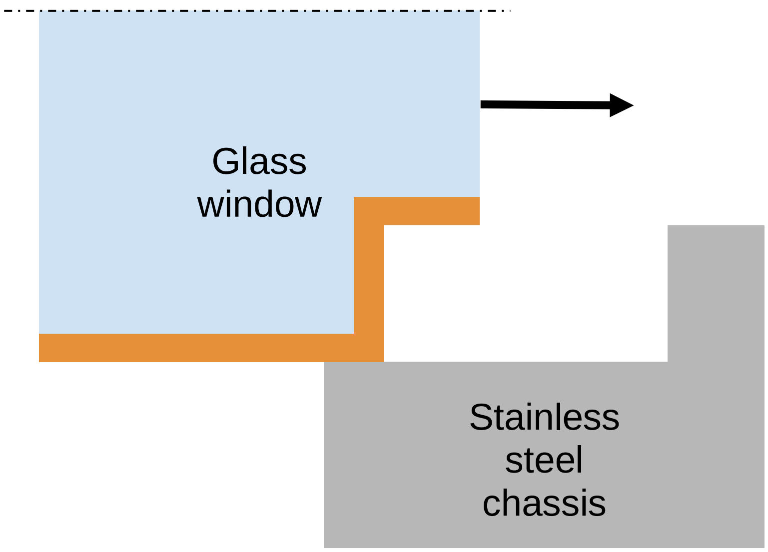


Figure 6: Illustrations of step 2 in the glass window assembly

Step 3: Apply RTV silicone on the internal retainer bracket and secure it in place with screws. Once the retainer bracket is secured, excess material is wiped off the glass window.

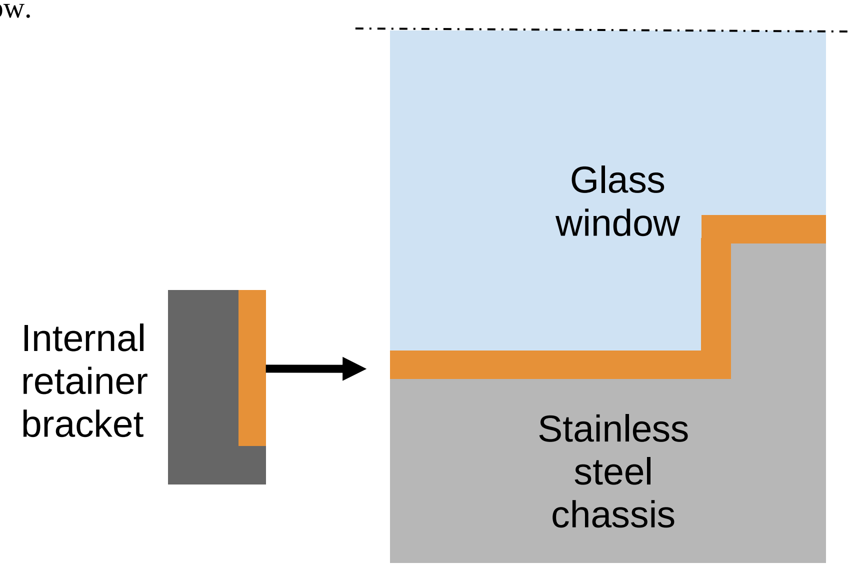


Figure 7: Illustrations of step 3 in the glass window assembly

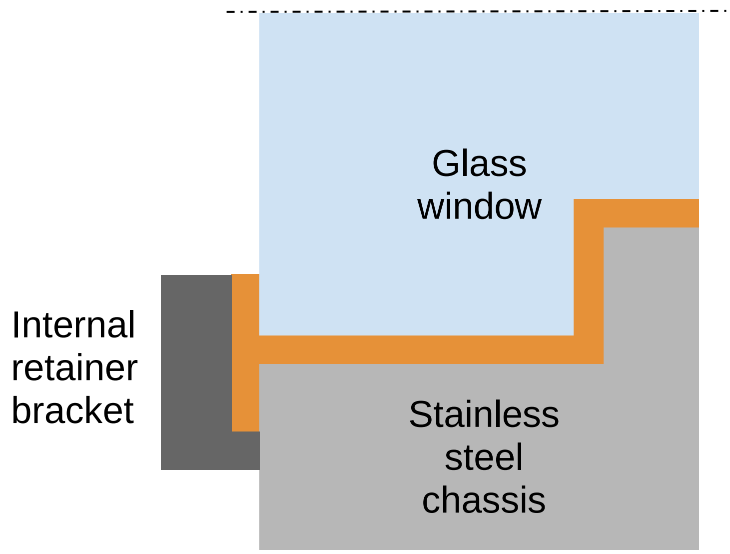


Figure 8: Illustration of the cemented flame path

Once the adhesive sealant has cured the chassis housing is pressure tested.

4.2.2 Result of current work procedure when installing the glass window

The pictures under picture 1 show the current result using the glass window, the suction cup and the applied silicone. They also display the installation of the glass window within the chassis housing as well as the installed retainer bracket.

Figure 9: Pictures showing the result of the current work procedure

4.3 Periodic testing of the current silicone

According to the certification specialist, the current silicone is not a Nationally Recognized Testing Laboratory (NRTL) approved material. It is therefore subjected to periodic testing which is conducted annually, according to the certification for the examined product. The certification highlights three different components subjected to re-testing and there is an associated cost based on the current hourly rate at the time of the test. The approximated re-testing time of the cemented joint according to the certification for the window is 82,8% of the total re-testing time, and thus stands for 82,8% of the cost.

4.4 Alternatives to the current silicone

According to the certification specialist there are other options to the silicone used, as long as the material is classified as TVLE2 in the UL database. TVLE2 is a UL category that covers sealing compounds for use in hazardous locations. These compounds are intended for use in making seals in cable or conduit fittings. The TVLE2 classed materials' resistance to for example solvent vapors and moisture has been investigated. To employ these compounds under this category and with the UL standard, certain "Conditions of Acceptability" must be considered. These conditions cover aspects such as cure temperature, cure time and seal depths. The standard used to inspect products in the TVLE2 category is UL 1203 [20].

It is quite expensive and time consuming to change material but these materials are not subjected to periodic re-testing. Therefore, it is highly interesting to evaluate the usability of the TVLE2 materials. The use of one of these materials would diminish the yearly costs greatly, which over the long term would lead to significant cost reduction, since the material test would not be performed. Also, the possibility of finding a material that performs better than the current silicone is another incentive, to address the potential issues. With these aspects being present, the team will proceed with evaluating these materials under the *Development* section. The following materials are classified as TVLE2 according to UL [20].

Table 14: TVLE2 materials

Number	Product name	Material type
1	Kneadaseal	Epoxy [21]
2	EPOCAP 45137	Epoxy [22]
3	E-40 EXP (Loctite® Product X284644)	Epoxy [23]
4	Peppers T1000 Compound	Epoxy [24]
5	KQS, CELOX, followed by -50, -250, or -any other number, followed by ML or OZ.	Epoxy [25]
6	HQS "Hawke Express", followed by 14, 24, 50, 250, or any other number, followed by ML or OZ.	Epoxy [26]
7	EP41S-6	Epoxy [27]

5 Problem definition

From the research carried out a few conclusions could be made. A redesign would most likely be too extensive to do, but it would be possible to change the material as long as it is TVLE2 classified. The scope of this thesis has been narrowed down to only looking at TVLE2 classified materials, as it is otherwise not deemed necessary to change the material. There is also room for improving the work procedure when assembling the glass window, both with work instructions, tools and fixtures to facilitate the assembly. The development process will therefore focus on both material selection, and the working procedure for production with the current silicone.

6 Development

The development stage aims at investigating both potential sealant materials as well as revised production methods. The material selection process will be carried out first, and thereafter proceed with the production development. The steps of the Ulrich & Eppinger methodology will be implemented to the highest degree possible in the material selection. For the production development, an FMEA will be generated and will act as the foundation of the improvement.

6.1 Material Selection

Following the procedure recommended by Ulrich & Eppinger, the next step was to carry out the material selection process. The purpose of this stage was to evaluate other sealant material options. For this process, the sealant which is currently in use, acted as the benchmark in terms of characteristics. The other materials were graded based on their performance in relation to this material.

The steps recommended by Ulrich & Eppinger were followed to the highest possible extent. But due to the fact that the material selection process is conducted on a predetermined list of materials that are unchangeable, there are certain limitations with regards to what can be carried out. Therefore, some of the steps recommended for the following topics could not be executed.

6.1.1 Identifying Needs

The following table introduces the identified needs for the sealant materials. In the process of formulating the needs, it was established that following the applied standards and the certification was of the highest importance. This formed the basis for the list of requirements. Further on, a discussion was held within the team to broaden the range of needs. When the needs had been identified, the next step was to establish their importance. They were graded in the range from *Must* to *Should* to *Preferable*. This was carried out in collaboration with the R&D team.

Table 15: Identified needs for material selection

Need	Description	Importance
1	Fulfill the requirements set by EN 60079-1, EN 60079-31, UL 1203 and the existing certification.	Must
2	Is a TVLE2 classified material	Must
3	Good adhesion to surrounding materials	Must
4	Does not start to cure during assembly	Must
5	Generates a homogenous cemented joint by filling voids	Must
6	Sufficiently long life-span	Must
7	Can cure in the existing environment	Should
8	Safe to handle by production personnel with limited protection	Should
9	Requires little pre-treating	Should
10	Easy to handle by production personnel	Preferable
11	Low levels of outgassing	Preferable
12	Reasonable cure time	Preferable
13	Reasonable price	Preferable

6.1.2 Target Specification

The needs were at this stage translated into technical metrics and values based upon standards, the certification and test reports. Step 2 of the Ulrich & Eppinger methodology, collecting competitive benchmarking information, was not carried out in this activity as there is no available information about what materials the competitors are using.

An importance factor ranging from 1 (least important) to 5 (most important) was given for each metric. Where applicable, margin values and ideal values were also set for each target specification. These values were partly collected from the standards and the certification, and partly set in relation to the characteristics of the current sealant. It was however not possible to assign values to all metrics since a few were of a subjective nature. For the subjective metrics it was up to the team to make the judgment on how the materials performed.

Table 16: Target specification for material selection

Number	Need	Metric	Unit	Margin value	Ideal value	Importance factor	Source
1	1	Working temperature range	°C	-60 to 155	-60 to >200	5	Certification
2	1	IP66/67/68 rated	Binary	Yes	Yes	5	UL 1203
3	1	Shrinkage	%	<1	0	5	UL 1203
4	1	Pressure test	Bar	25	>25	5	Certification
5	2	TVLE2 classified material	Binary	Yes	Yes	5	Given
6	1,3	Good adhesion to glass	Subj.	-	-	4	Given
7	1,3	Good adhesion to stainless steel	Subj.	-	-	4	Given
8	4	Tack free	min	>3	5 to 10	4	Given

		time					
9	5	Viscosity (at 23 °C)	cps	2000 to 10 000 000	50 000 to 1 000 000	4	Given
10	5	Depth of cure	mm	8	>10	4	Certification
11	6	Life-span	Years	10	>10	5	Certification
12	7	Ideal cure temperature range	°C	10 to 70	20 to 40	3	Given
13	7	Ideal cure humidity	%	30 to 70	40 to 50	3	ESD criteria
14	8	Safe to use	Subj.	-	-	3	Given
15	9	Pre-treatment	Subj.	-	-	3	Given
16	10	Easy to use	Subj.	-	-	2	Given
17	11	Outgassing	Subj.	-	-	1	Given
18	12	Minimum time left undisturbed	Hours	48	<24	3	Given
19	12	Full cure time	Days	14	<7	2	Given
20	13	Price	kr/liter	-	<2000	2	Given

6.1.3 Generate Concepts

The concept generation for the material selection differs a bit from traditional concept generation. Since the material has to be TVLE2 classified, this factor constitutes the initial limitation. The steps recommended by Ulrich & Eppinger could not be entirely followed as there was no possibility to search internally and to explore systematically. The concept generation will therefore be to see which materials that fulfill the *Must* criteria in the target specification. If a material does not meet the *Must* criteria, there is no reason to keep them in the selection and evaluate them further. In table 17 below, the seven materials, that are all TVLE2 classed, are shown. For each material, their compliance with the *Must* criteria are stated and additional comments are given. A few of these seven materials are directly outruled because of either an insufficient working temperature range or an unavailability in Sweden. For material number 5, KQS Celox, its shrinkage when curing is above the guideline of 1 %. However, in guidance with the Axis certification specialist, it may still be used on the prerequisite that the product passes the pressure test. Therefore this material is deemed ok and brought forward to the product selection stage.

Table 17: Material concept generation

Number	**Product name**	**Does it fulfill the must criteria in target specification?**
1	Kneadaseal	No, minimum working temperature is -40 °C.
2	EPOCAP 45137	No, minimum working temperature is -20 °C and maximum is 140 °C.
3	E-40 EXP (Loctite® Product X284644)	No, not available in Sweden.
4	Peppers T1000 Compound	Yes but maximum working temperature is not ideal.
5	KQS, CELOX, followed by -50, -250, or -any other number, followed by ML or OZ.	Yes but shrinkage is 1,8%.
6	HQS "Hawke Express", followed by 14, 24, 50, 250, or any other number, followed by ML or OZ.	No, minimum working temperature is -50 °C and maximum is 60 °C.

7	EP41S-6	Yes.

Peppers T1000 Compound
According to the technical data sheet *Peppers T1000 compound* is a "hand-mixable, UL-approved, epoxy putty sealing compound that mixes easily within minutes and hardens in one hour to provide water, dust and vapor-tight seals for cable fittings and electrical connectors. Its dough-like consistency eliminates drips and runs for a "no mess" application with no tools required for use". Once mixed the material has about 30 to 40 minutes of tack free time before it starts to harden. The joint should be left undisturbed for one hour and is fully cured in 24 hours. It is tested and approved for use at a temperature range between -60 °C and 135 °C. The upper service temperature limit is not ideal, since the current service temperature for the camera is at 155 °C. Using this material the temperature range would have to be re-evaluated [23].

KQS CELOX
According to the manufacturer's specifications sheet, "CELOX KQS Series is an alternative quick sealing compound used extensively for sealing conduit to prevent the spread of explosive gases and vapors. It is a two part epoxy resin that is self-mixed when pushed through a patented static mixing nozzle. CELOX requires no mixing, measuring, stirring, or pumping prior to pouring a seal.". The sealant has a tack free time of 4 minutes and cures in 30 minutes at room temperature. Its shrinkage of 1,8 % is the main drawback of this product, since a maximum allowed shrinkage of 1 % currently is the guideline. Therefore, the use of this product would require re-evaluation [24].

EP41S-6
According to the technical data sheet *EP41S-6* is a two part epoxy that is mixed with a 100 to 25 ratio by weight. Upon mixing it is " a moderate viscosity liquid with good flow properties. It contains no solvents or diluents and is 100% reactive. It has low shrinkage upon curing. This epoxy combines formidable physical strength properties and electrical insulation values. It bonds well to a wide variety of substrates including metals, composites, glass, ceramics, as well as many rubbers and plastics. EP41S-6 is serviceable over a wide temperature range of -80 °F (-62 °C) to +500 °F (260 °C)". EP14S-6 has a specific cure schedule which is to let it cure "overnight at 75 °F followed by 6-8 hours at 150-250 °F. Since applications vary, additional post-curing at 250 °F for another 5-10 hours is beneficial". The quoted price for this product is substantially higher than the other options, and the curing cycle is more complicated as well, which are the main drawbacks of this product [26].

6.1.4 Concept Selection

The general approach following Ulrich & Eppingers' concept selection phase is to first carry out a concept screening, and if needed, also carry out a concept scoring. For this stage however, it was deemed more suitable to make a weighted concept scoring directly. The reason was that there were very few materials to select from and that a concept screening therefore would not yield a result of much interest. With the weighted selection, each material could be scrutinized with greater accuracy, and a more interesting result could be obtained. No information was missed out by not going through with the screening, but the advantages of the weighted scoring were acquired. Binary metrics like IP rating and if it is a TVLE2 material was opted out due to not contributing to the scoring.

Based on discussion within the team, the weighting factors were changed compared to the concept generation weighting factors. Higher weighting factors were given to metrics that are of greater interest to the production personnel, such as usability. The reason for this is that the material properties do not necessarily have to be optimized fully. As long as they pass the must criteria they are deemed satisfactory, which is the reason for the lower weighting factors in these criteria. The materials were thereafter rated from 1 (much worse than the reference) to 5 (much better than the reference). The reference material is the current material. The product of the weight factor times the score yielded the weighted ranking score. The weighted scores were summarized under each material. The concepts with the highest total weighted score were deemed most promising.

The concept scoring can be seen in Table 18. Peppers T1000 and KQS Celox achieved the same score and were selected for further examination, both with a total of 57 points and an average score of 3.344. EP41S-6 achieved a total of 55 points with an average score of 3.245. EP41S-6 was therefore excluded from further evaluation, mostly due to the substantially higher price but also for its more complicated curing cycle.

Table 18: Material concept scoring

Nr	Metric	Importance	Weight	Current material		Peppers T1000		Killark Celox KQS		EP41S-6	
				Score	W. Score	Score	W. Score	Score	W. Score	Score	W. Score
1	Working temperature range	2	0.03278688525	3	0.09836065574	1	0.03278688525	3	0.09836065574	3	0.09836065574
2	Shrinkage	3	0.04918032787	3	0.1475409836	3	0.1475409836	1	0.04918032787	3	0.1475409836
3	Good adhesion to glass	4	0.06557377049	3	0.1967213115	3	0.1967213115	3	0.1967213115	3	0.1967213115
4	Good adhesion to stainless steel	4	0.06557377049	3	0.1967213115	3	0.1967213115	3	0.1967213115	3	0.1967213115
5	Tack free time	5	0.08196721311	3	0.2459016393	4	0.3278688525	3	0.2459016393	4	0.3278688525
6	Viscosity (at 23 °C)	4	0.06557377049	3	0.1967213115	2	0.131147541	2	0.131147541	4	0.262295082
7	Depth of cure	5	0.08196721311	3	0.2459016393	5	0.4098360656	5	0.4098360656	5	0.4098360656
8	Life-span	2	0.03278688525	3	0.09836065574	5	0.1639344262	5	0.1639344262	5	0.1639344262
9	Ideal cure temperature range	3	0.04918032787	3	0.1475409836	3	0.1475409836	3	0.1475409836	1	0.04918032787
10	Ideal cure humidity	3	0.04918032787	3	0.1475409836	5	0.2459016393	5	0.2459016393	5	0.2459016393
11	Safe to use	5	0.08196721311	3	0.2459016393	2	0.1639344262	2	0.1639344262	2	0.1639344262
12	Pre-treatment	5	0.08196721311	3	0.2459016393	2	0.1639344262	3	0.2459016393	2	0.1639344262
13	Easy to use	5	0.08196721311	3	0.2459016393	2	0.1639344262	3	0.2459016393	2	0.1639344262
14	Outgassing	3	0.04918032787	3	0.1475409836	5	0.2459016393	5	0.2459016393	5	0.2459016393
15	Minimum time left undisturbed	4	0.06557377049	3	0.1967213115	5	0.3278688525	5	0.3278688525	3	0.1967213115
16	Full cure time	3	0.04918032787	3	0.1475409836	5	0.2459016393	4	0.1967213115	4	0.1967213115
17	Price	1	0.01639344262	3	0.04918032787	2	0.03278688525	2	0.03278688525	1	0.01639344262
Total Score		**61**		**51**		**57**		**57**		**55**	
Total Weighted Score		**1**		**3**		**3.344262295**		**3.344262295**		**3.245901639**	
Rank						**1**		**1**		**3**	

A cost analysis of the two remaining concept materials were done and compared to the existing material. This analysis was not part of the objectives, but was deemed interesting for Axis and was therefore carried out. An important remark in this cost analysis is that the price for the two remaining materials are based upon small batches and would most likely be less expensive in production.

The cost analysis was performed by comparing the average price per glass window assembly in a year. The material cost per glass window was calculated based upon an approximation of how much material is needed per glass. The two concept materials are more expensive but they do not require the cost for the yearly testing. A break even amount of produced glass window assemblies could therefore be calculated by the formula below.

The result was the following:

- Peppers T1000 is less expensive to use if the amount of produced window assemblies is below 4020 per year.
- KQS Celox is less expensive to use if the amount of produced window assemblies is below 1760 per year.

N.b: Keep in mind that this is based upon approximated values and can only be seen as an indication

6.1.5 Concept test

Due to uncontrollable circumstances, T1000 and KQS Celox could not be tested physically. The lead times to have these materials delivered were too lengthy, as they would have been delivered a month after the deadline of this thesis, rendering this part of the work impossible to carry out within the timeframe.

Testing was however carried out with other materials to get an understanding of how they would act. The viscosity of the materials chosen was as similar to T1000 and KQS Celox as possible, as this is the main metric to be tested. The substitutes were ordinary materials, for T1000 it was play-dough and the substitute for KQS Celox was liquid honey. It was quickly realized that none of the materials will be suitable with the existing tools and fixtures. The play-dough was too viscous to be extracted through a nozzle, and had to be shaped and applied to the glass window by hand. The liquid honey was too runny to be applied to the glass window without spillage. It was also difficult to maintain it inside the joint before it hardened, resulting in more residue material. Both materials therefore require new tools and fixtures before it is possible to implement them in the production.

6.1.6 Set Final Specifications

Since no testing could be completed this step could not be carried out, as there were no test results on which to make adjustments from and to base a selection on. Also, since the materials have unchangeable specifications, the suggested process would be redundant. This entire step would therefore simply be substituted for the selection of the final product, a process that may be carried out as further work.

6.1.7 Plan Downstream Development

If a continued development would have been possible within this thesis, the two materials would have to be bought and tested. New tools and fixtures would be developed as well. The concept testing would be conducted by following the assembly steps described in 4.2.1 with a center of attention to adhesion to the different parts and usability.

The initial step of the testing phase would be to analyze the homogeneity of the sealant joint. The analyses would be used to compare each material's proneness to issues on these points and the team would also take notice of any difficulties or issues in terms of usability of the sealants during this phase. Evaluation of the two remaining concept materials would be done with the production personnel and the R&D team at Axis, and then it would have been assessed if one of the materials could be implemented in the production.

6.2 Production with the current material

This part of the work aims at improving the procedures and tools, and thereby outcome, using the current sealant. Part of the focus is on taking the production personnel's' view on issues into consideration and to develop adjustments accordingly. One request from the personnel is to utilize the rotating table that they have available. Therefore, the use of this table is a prerequisite for the development and procedures using it will be created. A picture of the table in question can be seen below under Figure 10. Another prerequisite for the development is that 3D-printed parts will be acceptable to use as prototypes.

The first step of this development is to conduct a process-oriented FMEA where needed assembly steps are analyzed critically. Thereafter, a concept generation is carried out where the FMEA acts as guidance. All the assembly steps in the FMEA were created from scratch with insights from the current work procedure.

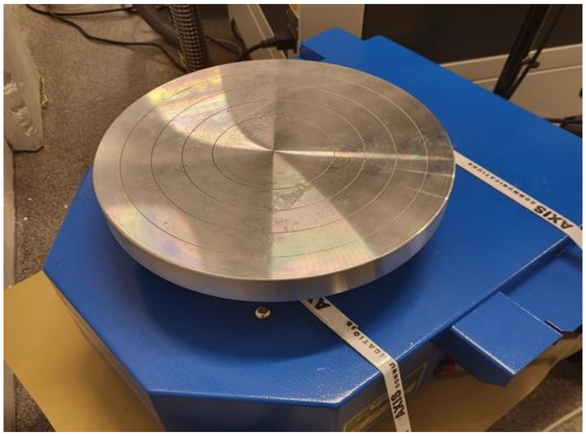


Figure 10: The rotation table

6.2.1 Process FMEA for the current material

The approach used for evaluating and improving the production using this material is a process-oriented FMEA as described in section 3.4 FMEA. The FMEA was created by the team, and was thereafter reviewed with the engineers of the R&D team to gather thoughts and improvement suggestions. The severity, occurrence and detection value were all estimated.

If the product of the severity value times the occurrence value times the detection value was between 0 and 20, the failure effect was deemed safe, but no failure effect was neglected in the concept development. If the product was between 21 and 40, the failure effect was deemed as an increased risk and would be included in the concept development. A product between 41 and 90 was deemed as high risk and likely to be a problem. These failures were therefore of high interest in the concept development. A product between 91 and 144 was deemed as a very high risk and would be very important to address in the concept development.

Due to the integrity of the production procedure, the complete FMEA must not be shared. A summary of the most important failures that will be focused on in the concept development can be seen below in table 19. Failure modes that will be addressed with work instructions are not included in the table. The failure mode "*Difficult to transport glass window after sealant is applied*" was included even though its failure effect scoring was low. The reason for this was that it was deemed as an important step in the assembly.

General for all steps is to develop a work procedure that is as ergonomically friendly as possible and to have a clean workspace throughout the whole assembly process.

Table 19: Most important failures for the concept development

Number	Assembly step	Failure mode	Failure cause	Failure effect
1	Position the glass window on the rotation table	Glass window is held incorrectly or contact surface is not accessible on rotating table	Poor fixture/tool	Uneven layer of sealant - risk of cemented joint not being homogeneous
2	Apply material on the sealant faces	Smearing onto incorrect surfaces	Uncalibrated fixture/tool	Increased risk of residue post-cleaning - image quality compromised
				Increased risk of outgassing - image quality compromised
3		Air pockets in sealant	Uncalibrated fixture/tool.	Risk of cemented joint not being homogeneous
4		Even layer not applied	Uncalibrated fixture/tool.	Risk of cemented joint not being homogeneous
5		Difficult to transport glass window after sealant is applied	Poor fixture/tool	Sealant layer is compromised - risk of cemented joint not being homogeneous
6	Position and secure glass window in chassis housing	Glass window is not centered in chassis housing	Poor fixture/tool	Cemented joint not being equally thick around the glass window circumference

7		Glass window not being aligned with front of chassis housing	Poor fixture	Risk of affecting the flame path
8		Trapping air pockets in the cemented joint	Uncalibrated fixture/tool	Cemented joint not homogeneous
9		Improper set of retainer bracket	Poor fixture/tool	Smearing onto glass window - image quality compromised

6.2.2 Solutions to minimize issues using the current material

This part will be based on the potential failures identified in the FMEA and the issues and requests addressed by the production personnel. The approach is to generate solutions iteratively, and to make tool and fixture modifications where needed after each iteration. Iteration 1 solutions were used together with other iteration 1 solutions, which led to the solution to one issue influencing the solution for another solution. One example is that the nozzle solution to "*Avoid smearing onto incorrect surfaces when applying the material*" and the fixture solution to "*Even layer not applied when applying the material*" were developed in parallel and influenced each other.

The production personnel will be included in this process to ask for input and suggestions. When generating the different possible solutions, the assembly step order is not followed. The reason for this is that the failure mode "*Difficult to transport glass window after sealant is applied*" is deemed very important for how the fixture for assembly step 1 will be designed. This stage will therefore start with a solution to step number 5, which is how to transport the glass window after the sealant has been applied.

6.2.3 Transport the glass window after the material is applied

6.2.3.1 Iteration 1

Main issues

- To securely transport the glass without touching the applied silicone.

Solution

- Suction cup on a handle.

Pros

- Already used in the production today so the personnel are familiar with this tool.
- Can easily let go of the glass by the press of a button.
- Does not scratch the glass.

Cons

- May be a little less secure, since it only uses suction on one side.
- A mock-up will have to be used during part of the development due to the need to use the current one in the production.

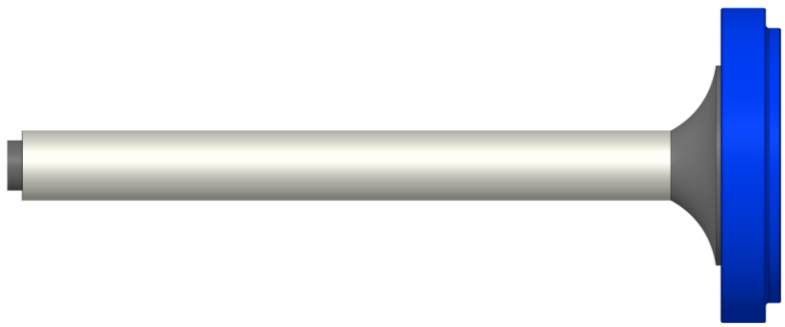


Figure 11: Mock-up of suction cup holding the glass window

Testing

With the extensive usage of the suction cup, and thereby knowledge that it consistently works without issues, no further work will be done at this stage to improve the transportation process. It was however noted that the modeled mock-up dimensions were incorrect.

6.2.3.2 Iteration 2

Main issues

- Still using the mock-up suction cup.

Solutions

- Correct suction cup used.

Pros

- Will be able to do more accurate testing.

Cons

- May be a little less secure, since it only uses suction on one side.

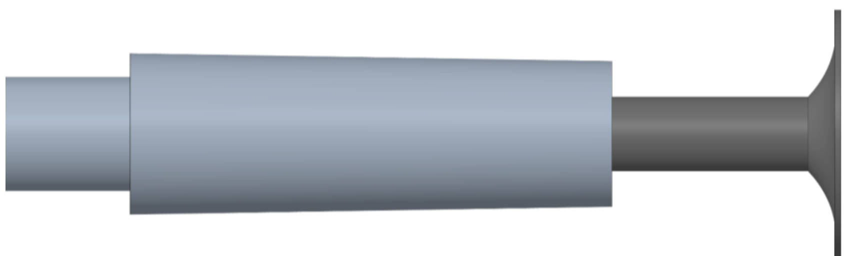


Figure 12: Correct suction cup

Testing

The correct suction cup proved to be easier to operate than the temporary one. It required less force when pressed onto the glass window, since the button was used to generate suction. It was also more stable and precise. This suction cup was deemed to fulfill all criterias and was chosen as the final solution.

6.2.4 Position the glass window on the rotation table

6.2.4.1 Iteration 1

Main issues

- To center the glass on the rotation table and allow for silicone application.

Solution

- It is desirable to use the suction cup from number 5 throughout the whole assembly process. A fixture centering the glass on the rotation table using the suction cup is therefore the solution to the main problem. The fixture will either be attached to the rotation table mechanically or with adhesives.

Pros

- Simple and easy-to-follow work procedure that yields consistent results.

Cons

- Might be unstable.
- The suction cup might not generate enough suction to keep the glass window in the right position.

To center the suction cup on the rotation table a fixture was made that was attached to the rotation table. This solution led to another problem, centering the suction cup on the glass window. If the glass window is uncentered on the suction cup, it will wobble while rotating.
The solution for this will be a mounting fixture seen in figure 13. A guide plate will be attached to the suction cup with the same hole geometry as the mounting fixture and the chassis housing, which can be seen in figure 15. With this solution the same tool can be used throughout the whole assembly process.

The work progress will be the following:
The glass window is placed into the slot in the mounting fixture, with the smaller diameter surface facing down. The fixture secures the glass in the center.

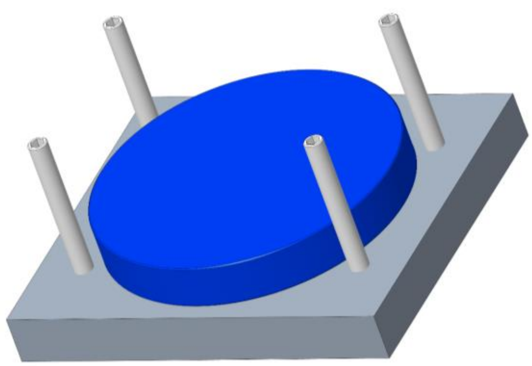


Figure 13: Mounting fixture seen from the side above

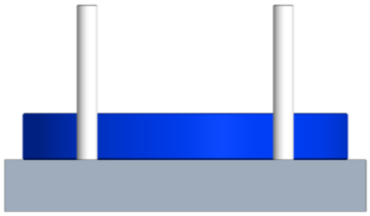


Figure 14: The glass window and mounting fixture seen from the side

The suction cup with its attached guide plate is brought down onto the mounting fixture. The guide pins are entered through the guide plate holes, which centers the suction cup on the glass. The suction cup is then pressed against the glass window which secures it, and picked up from the mounting fixture.

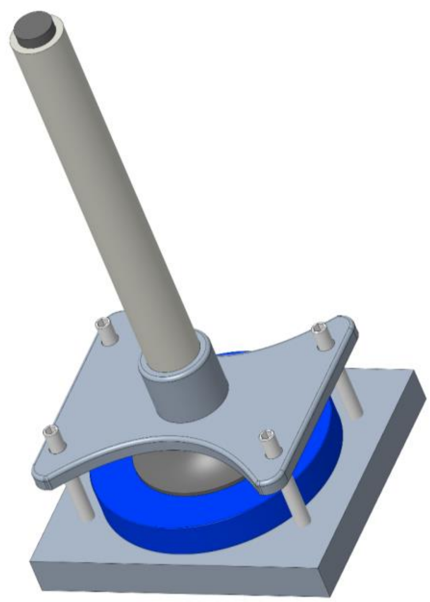


Figure 15: Suction cup tool and mounting fixture seen from the side above

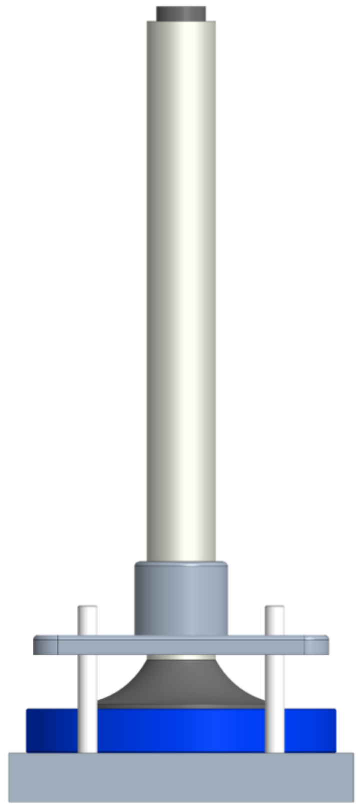


Figure 16: Suction cup tool and mounting fixture seen from the side

The suction cup with the glass window is then flipped so that the glass is facing up, and inserted in a fixture holding around the suction cup handle. This fixture is centered on the rotating table and the positioning of the glass window on the rotating table is now completed.

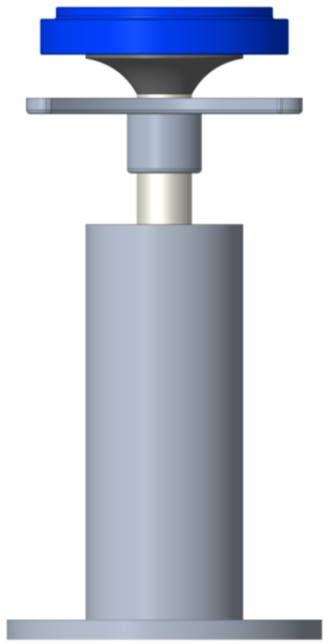


Figure 17: Fixture for the suction cup placed on the rotating table

Testing

The distance between the suction cup guide plate and the glass mounting fixture was longer than expected when testing with the intended suction cup. Therefore it was discussed to add guide pin sleeves to the guide plate and also to extend the pins on the glass mounting fixture further. Problems were also noted locking the suction cup rotationally within the fixture that is to be mounted on the rotation table, as can be seen above in figure 17. Adding a flange or wedge was discussed. The rotation table fixture was not tested on the rotation table at this stage, but was operated manually by hand. Some instability and eccentricity was observed however, which seemed to mainly come from the softness of the temporary suction cup and its tendency to not move completely straight when being pressed onto the glass window. In the next iteration of tests, the correct suction cup will be available for testing.

6.2.4.2 Iteration 2

Main issues

- The guide pins could not align the suction cup tool at far enough distance.
- Risk of suction cup slipping within the rotation table fixture.
- Instability and the tendency of eccentricity of the temporary suction cup.

Solutions

- To steer the suction cup guide plate earlier, it is supplemented with guide pin sleeves.
- The mounting fixture guide pins are also extended.
- Two flanges are added to the suction cup guide plate as well, to eliminate the risk of slippage during rotation. Two matching slots in the rotation table fixture were added.
- Correct suction cup is used and fixtures are adapted.

Pros

- Earlier alignment with better precision.

Cons

- Higher requirements for straight sleeves and pins because of longer distances between the glass window and the location of the guide plate.

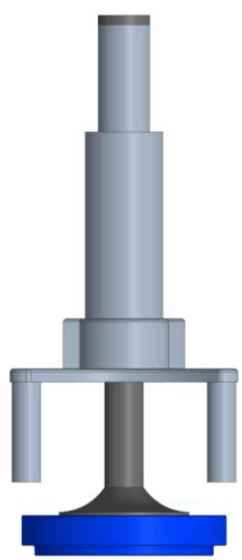


Figure 18: Suction cup with added guide pin sleeves and flanges

Testing
With the guide pin sleeves and the guide pins both being longer, the suction cup tool was centered more accurately on the glass window. A concern about breaking the guide pin sleeves were however raised while testing. The rotation table was, like in iteration 1, not tested with the rotation table fixture at this stage. The fixture was operated by hand instead. The flanges and the slots on the rotation table fixture proved to work very well as the suction cup tool was fitted very securely. It was however noted that there is a risk of not being able to fully center the fixtures on the rotating table.

6.2.4.3 Iteration 3

Main issues

- Risk of breaking the long guide pin sleeves.

Solutions

- The guide pin bracket is moved towards the suction cup for added stability.
- Rotation table fixture created with centering screws for extra adjustability.

Pros

- Will be able to do more accurate testing. More stable construction.

Figure 19: Suction cup with updated dimensions

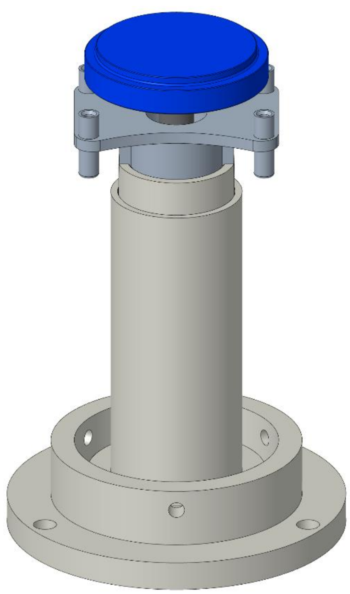


Figure 20: Fixture for suction cup with possibility for centering screws

Testing

The use of the correct suction cup led to a drastically improved centricity of the glass window, with much more consistent results. The more compact construction of this suction cup enabled installing the suction cup guide plate closer to the cup. This also seemed to contribute to better centricity. The rotation table centering fixture worked effectively and did not display any issues. The centering screws held the suction cup fixtures securely in place and made precise centering possible. Apart from making final adjustments to tolerances, these parts do not require further changes. This construction was deemed to fulfill all criteria and was chosen as the final solution.

6.2.5 Avoid smearing onto incorrect surfaces when applying the material

6.2.5.1 Iteration 1

Main issues

- To apply an adequate amount of silicone only on the target surfaces.

Solution

- A nozzle on the silicone dispenser custom-made to follow the contact surface on the glass.
- The dispenser will be set in a fixture that is locking its position to reduce the risk of human error.

Pros

- Does not require manually holding the dispenser, which is strenuous on the body.
- Consistent results.
- The nozzle can easily be redesigned to optimize results further.

Cons

- Not versatile/adjustable.
- Might not distribute the silicone evenly after a few usages.

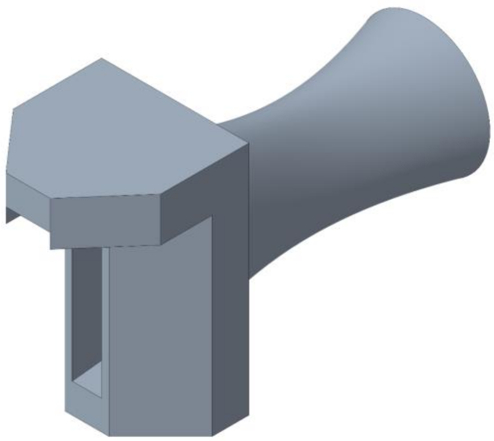


Figure 21: The nozzle seen from the side above

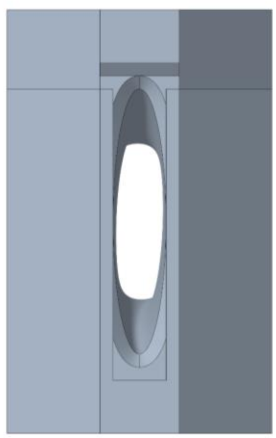


Figure 22: The nozzle seen from the front

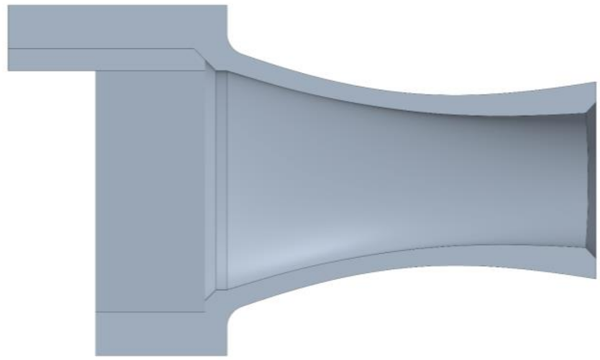


Figure 23: Cross-section of the nozzle seen from the side

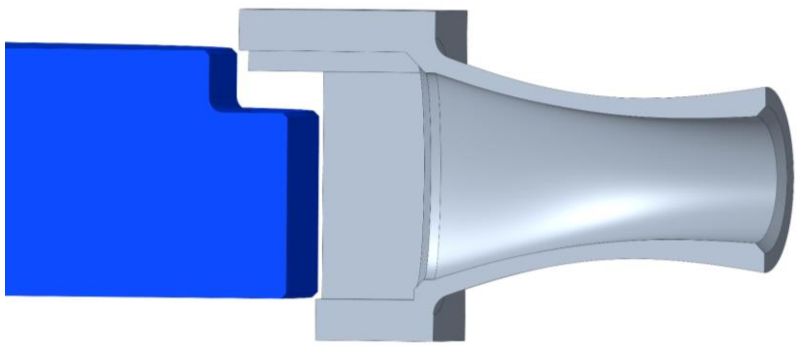


Figure 24: Cross-section of the nozzle in contact with part of the glass window

Testing

During the first test iteration of the nozzle, an electric handheld dispenser gun was used. The nozzle was pressed onto the standard conical nozzle to the point that it was secured. To make the glass window reusable after the early testing, it was decided that it should be wrapped in plastic foil. The foil could follow the contours of the glass decently well, allowing for the silicone to follow the corners of the glass window. During testing, one person held the dispenser gun at a rested and stable position, and the other person held the glass window, focusing on keeping it stable and close to the nozzle. During application, the glass was slowly rotated by hand as smoothly as possible. Seen below in figure 25, is the result. It was noted that the silicone layer at the larger diameter mantle surface was thinner than that of the corner into the smaller diameter. It was discussed that it is not certain that the exit of the nozzle is causing this, as the result relies heavily on other factors such as nozzle stabilization. This discovery is carried over to iteration 2, where an evaluation of this phenomenon is to be conducted and potential changes implemented.

Figure 25: Glass window with a section of silicone

6.2.5.2 Iteration 2

Main issues

- Too unstable attachment to the nozzle fixture.
- Too insecure fit to the dispenser nozzle.

Solutions

- Larger head to make room for attachment.
- Conical attachment to the dispenser nozzle for more secure fit.

Pros

- More secure attachment.

Cons

- Requires more material and takes longer time to print.

For the second iteration of the nozzle, some dimensional changes were made. It was mainly changed to accommodate for the attachment to the fixture holding the nozzle.

The “head” was made larger so that a hole in the bottom for a stabilizing pin could be made. During the first iteration test, it was mentioned that the silicone layer was noticeably uneven. No changes are made during the second iteration to address this, since the result relies heavily on other factors such as nozzle stabilization. If the results are not satisfactory with the nozzle fixed at a constant position in relation to the glass window, further analysis and development of the nozzle is carried out in iteration 3.

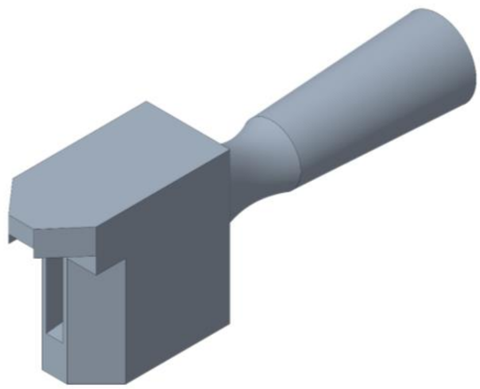


Figure 26: The nozzle seen from the side above

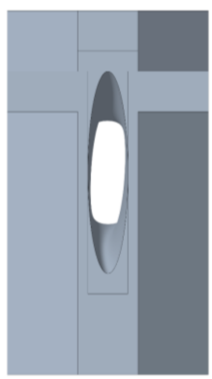


Figure 27: The nozzle seen from the front

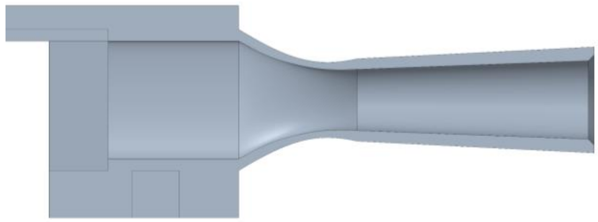


Figure 28: Cross-section of the nozzle seen from the side

Testing
The conical pipe of the nozzle could be securely stuck onto the dispenser nozzle and worked decently well during the entire process. It was however noted that the nozzle became very sensitive to small movement of the dispenser gun. The opening of the nozzle was noted to be wide, yielding a wide and thick layer of the silicone onto the glass window. It was concluded that a more narrow opening could be beneficial to more precisely dispense a suitable amount.

6.2.5.3 Iteration 3

Main issues

- Wide nozzle opening and silicone not directed well enough.

The following issues were discovered in section "*6.2.7 Even layer not applied when applying the material*" iteration 2, which was done in parallel to the previous iteration.

- Dispenser gun attachment, as described during nozzle fixture testing.
- Nozzle attachment to the fixture is not simple enough.
- Overhang on the nozzle requires the nozzle fixture to have moving parts.

Solutions

- More narrow nozzle opening.
- Guide more silicone towards the upper part to ensure an adequate amount towards the glass corner.
- Pipe-like attachment on the nozzle to try a hose between it and the dispenser gun.
- T-groove with a locking screw for the nozzle and its fixture.

- Removed overhang on the nozzle to enable a nozzle fixture with fewer parts and hence greater stability.

Pros

- Better directed application of silicone.
- Simplified process of removal and installation of the nozzle.
- Less instability due to fewer fixture parts.

Cons

- The lack of the nozzle overhang may cause decreased stability of the silicone when exiting the nozzle.

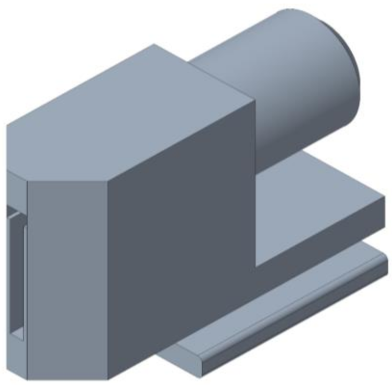


Figure 29: Nozzle seen from the side above

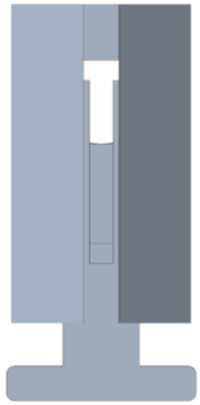


Figure 30: Nozzle seen from the front

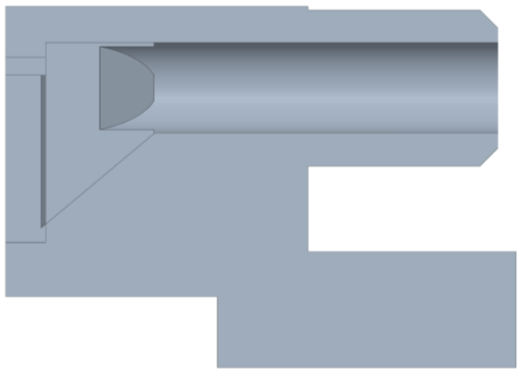


Figure 31: Cross-section of the nozzle seen from the side

Testing

The changes made to address the issues resulted in more consistent results. The redesigned nozzle exit dispensed more silicone towards the glass ledge, filling out this area better. The removed overhang led to a slight difference in the appearance of the silicone layer. The silicone along the glass ledge was not quite as smooth and circular as with the overhang, it displayed a wave-like pattern, but it was however deemed acceptable since the ledge was filled out well. The hose-attachment worked well without any signs of leakage. Adding hose clamps was however discussed to make it fit even more securely. The T-groove and its locking screw was simple to use and precise. The result can be seen in 6.2.7.3. This nozzle was deemed to fulfill all criteria and was chosen as the final solution.

6.2.6 Avoid air pockets in sealant occurring when applying the material

6.2.6.1 Iteration 1

Main issues

- To apply the silicone smoothly without air pockets getting trapped.

Solution

- The silicone will be applied with an electric dispenser to ensure an even layer together with the nozzle.

Pros

- Easy to use with consistent results.
- The electric dispenser has already been purchased.

Cons

- If the electric dispenser is wrongly calibrated there is a risk of inaccurate silicone application.

Figure 32: Milwaukee M12 PCG collected from Milwaukee´s website.

Testing

The electric dispenser worked well and had settings suitable for slowly dispensing the silicone. The silicone was dispensed evenly and no air was trapped. The dispenser was however rather large and heavy to hold by hand, but with the added hose it was made less sensitive to movement and easier to work with. It was therefore deemed to fulfill all criteria.

6.2.7 Even layer not applied when applying the material

6.2.7.1 Iteration 1

Main issues

- To apply a silicone layer with consistent thickness all around.

Solutions

- Fixture for the nozzle, mounted onto the rotation table. Iteration 2 (section 6.2.5.2) of the nozzle is directly implemented into this development step.

Pros

- Stable and easy to use.
- Small compared to a fixture fixated outside the turning table

Cons

- Complicated design with parts moving in relation to each other.

The fixture for the nozzle consists of several different parts, some of which are moveable in relation to each other. To allow for great accuracy, the idea is that a fixture as compact as possible is beneficial, as this should reduce the instability that could otherwise occur. The idea was to have an as stable nozzle as possible. The rotating table is big so having a fixture that is fixated externally could lead to much instability. The solution thus became having a fixation for the nozzle attached to the rotating fixture for the suction cup. To be able to rotate the suction cup while the nozzle remains stationary a bearing was added.

The entirety of the fixture is set onto the rotation table and can be seen in figure 33. The large cylinder will be centered onto the table and has a slot for the suction cup tool. At the upper area of the cylinder is *Part 1,* consisting of a ring with an arm. The ring clamps around the outer ring of a ball bearing. The inner ring of the bearing will be pressed onto the large cylinder that is to be mounted on the table. This construction locks these parts in the axial and radial directions but allows for free rotation. The arm is made with a T-shaped groove and holds a spring. To allow for disassembly, as well as to act as a support on which the spring pushes, the T-shaped *Part 2* is screwed onto the arm of *Part 1*. *Part 3,* also mounted on the same arm with a T-shaped track, is constantly pushed in towards the center of the ring. The reason behind the spring is to be able to with ease retract the nozzle and make room for the glass window and suction cup tool to be removed. The spring will also rebound and push the nozzle assembly forward to the correct position. To secure the nozzle onto *Part 3*, a guide pin locks it in the radial direction, a groove on *Part 3* locks it rotationally and the U-shaped *Part 4* keeps it from moving upwards. *Part 4* slots into two grooves on *Part 3*, and thus it is easily removed when the nozzle needs to be replaced.

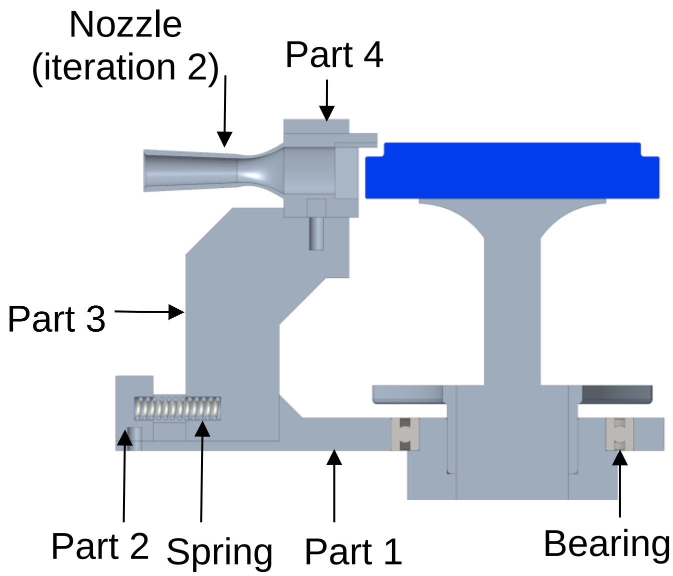


Figure 33: Cross-section of all of the tools and fixtures

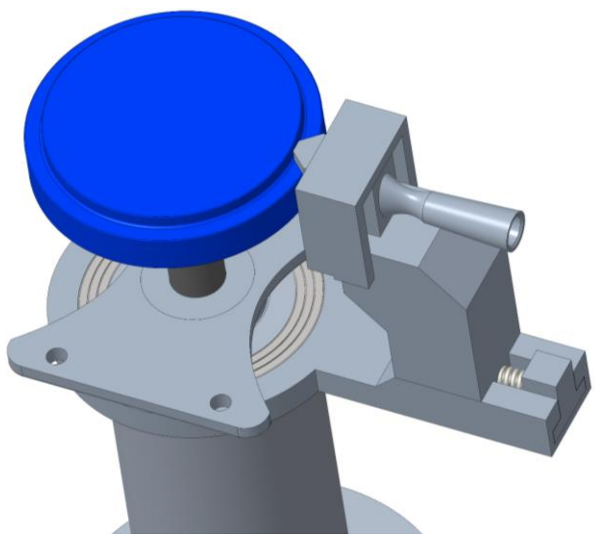


Figure 34: Tools and fixtures seen from the side above

Testing

Since the suction cup guide plate was unsatisfactory and had to be redesigned, the nozzle fixture did not undergo testing. It was however mocked-up to the extent possible for the team to get a visual understanding of its potential, and since it seems promising it is kept for iteration 2. Minor dimensional changes may be made but the features remain the same.

6.2.7.2 Iteration 2

Main issues

- To make guide pin sleeves move freely
- Get the nozzle closer to the glass window.

Solutions

- Part 1 is shortened 1 mm to move the other parts closer to the glass window.
- Part 3 and 4 have cut-outs to make room for guide pin sleeves.

Pros

- More thin layer of the silicone.
- Free rotation of sleeves.

Cons

- Potentially slightly more unstable.

Seen below in figure 35 are the dotted lines where the dimensional alterations have been made.

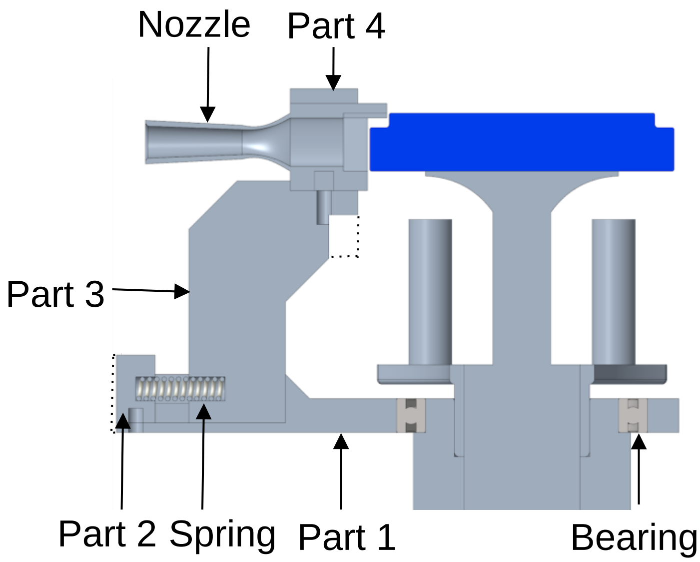


Figure 35: Cross-section of all the tools and fixtures

Testing

Although the nozzle fixture was used and was stable in itself, it could be observed that the movement from the handheld dispenser gun still affected the angle of the nozzle slightly. To minimize the impact of any dispenser movement, the use of a hose between the nozzle and the dispenser was discussed. Also, a fixture for the dispenser gun should be very beneficial in addition to the nozzle fixture. It was also noted that the silicone layer was very thick, a result partly due to distance between the nozzle and the glass window. The evenness was however more satisfactory compared to the fully handheld application, which likely came from the added stability of the nozzle fixture. The part locking the nozzle into position did not provide the stability that was required. A T-groove was therefore considered as a change. The spring-loaded construction was not satisfactory enough either, as it displayed inconsistency with its tendency to slide freely. The required tolerances to allow for a smooth user experience also caused a noticeable movement in unwanted directions. It was discussed to remove the overhang on the nozzle to remove the need of a spring-loaded mechanism. Despite using the temporary suction cup, the team could still evaluate some aspects of the fixture and its function. Any problems, and their potential implications on the fixture, are analyzed with the temporary suction cup's weaknesses taken into account. It does for example not have a release button, and is rather unstable.

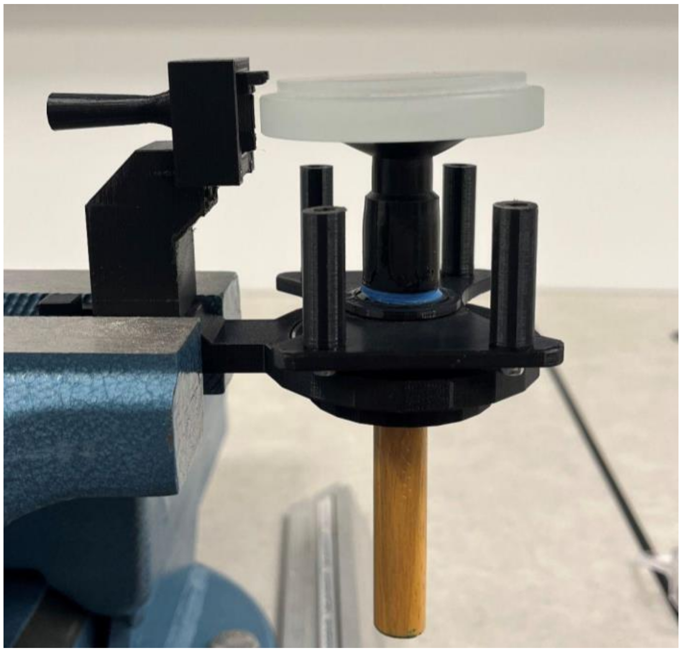


Figure 36: Tools and fixtures seen from the side

6.2.7.3 Iteration 3

Main issues

- Movement from the dispenser gun transferred to the fixture and nozzle causing instability.
- Too thick silicone layer.
- Make adjustments required for the changed nozzle design.

Solutions

- Hose connection between nozzle and dispenser.
- Nozzle brought closer to the glass window.
- T-groove for the nozzle attachment and a stopping screw to lock it.
- Spring-loaded construction for part 3 removed, since the deleted nozzle overhang makes it redundant.

- Fixture parts are made thicker and shorter for added stability.

Pros

- Less sensitive to vibration.
- More even thickness of silicone.

Cons

- The minimized distance to the glass requires even better centricity.

There were several different issues that were discovered during the testing of the second iteration parts. With the complexity of the design, coming for example from the nozzle overhang, and consequently the required spring-loaded nozzle holder, some problems were noted. The tolerances needed to allow for smooth movement of the nozzle holder inevitably causes movement in undesired directions which affects the evenness of the silicone layer. Therefore the nozzle overhang and the spring-loaded construction are removed for the third iteration. This enables making these parts, named part 1 and part 3 in figure 35, into one solid part. Also, to further minimize the flex and thereby movement at the nozzle exit, the parts will be made more compact.

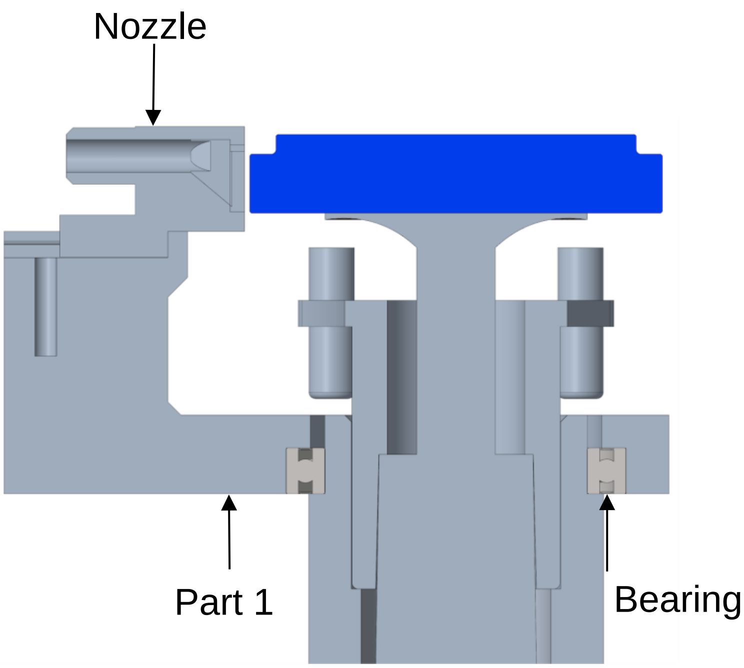


Figure 37: Cross-section of all of the tools and fixtures

Testing

The movement of the nozzle was minimized further without the spring-loaded mechanism and with thicker and shorter parts. The absence of this mechanism also made the entire process more simple. The closer distance between the nozzle and the glass enabled a decrease in the flow rate of the silicone. However, fine adjustments will be made to achieve a layer with better thickness and reach into the glass ledge. The results can be seen below in figure 38. Apart from these minor adjustments, the fixture was deemed to fulfill all criteria and was chosen as the final solution.

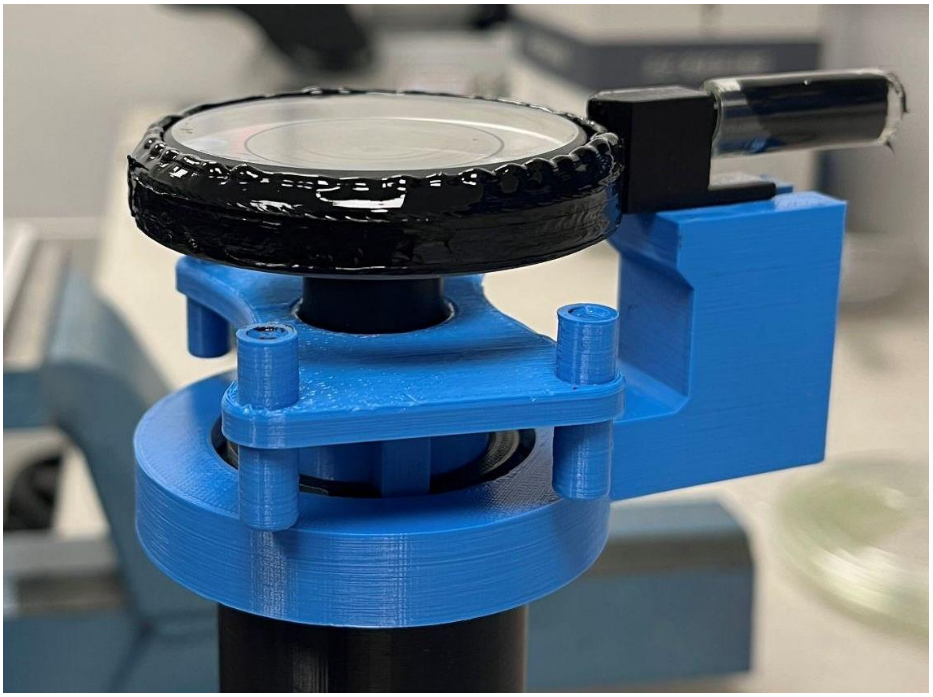


Figure 38: Tools and fixtures seen from the side, with silicone applied

6.2.8 Centering the glass window in the chassis housing

6.2.8.1 Iteration 1

Main issues

- To consistently install the glass window in its intended position.

Solutions

- Guide pins that guide the tool holding the glass window.

Pros

- Pins consistently guide the glass window into the correct position.

Cons

- Extra parts to fiddle with.
- Small risk of affecting the threads in the chassis housing.

To center the glass window in its chassis position, two guide pins are used. They are placed diagonally into two of the four holes intended for securing the retainer bracket into the chassis. The glass window, which is stuck onto the suction cup tool and prepared with silicone, is brought down over the two guide pins. Once fully seated, the suction cup button is pressed, releasing the glass window. The suction cup tool is lifted up and removed. The glass is ready to be secured with the retainer bracket.

Figure 39: Bottom of the chassis housing with guide pins installed

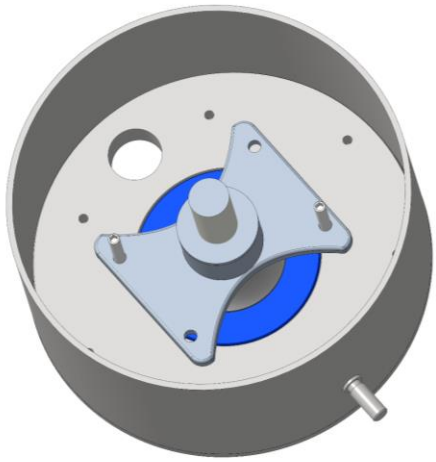


Figure 40: Bottom of the chassis housing with guide pins, suction cup assembly and glass window installed

Testing

The use of diagonally placed guide pins within the chassis housing proved to be of some assistance to mount the glass window centered. This test was carried out using final parts of everything else but is not shown here. Inconsistencies were experienced regarding the ease of dismounting the glass when in position. If solely the release button is pressed, without holding the rest of the suction cup in position whilst releasing, the vacuum seems to run a great risk of increasing, further sticking the glass window to the suction cup. In these cases it was not possible to release the glass without bringing it out of the chassis and manually forcing it off. The suction cup must therefore be at least slightly unloaded against the seat of the housing.

One problem noted was that the guide pins tend to run the risk of getting stuck inside the guide pin sleeves during suction cup removal. The production personnel will be instructed to determine if they want the increased workload of threaded pins to remove this issue. Apart from this potential change, this method was deemed to fulfill all criteria and was chosen as the final solution.

6.2.9 Align the glass window with the front of chassis housing

An existing fixture that is holding the housing when mounting and aligning the glass window will be used. It features a pipe-like sleeve, securing the housing, with two parallel pins in the bottom to which the glass window rests and aligns.

6.2.9.1 Iteration 1

Main issues

- To align the front of the glass with the chassis housing surface.

Solutions

- Use existing fixture. The blue lines in figure 41 below will be the location of the alignment pins

Pros

- Easy to implement as the fixture is already in use in the production.

Cons

- Alignment pins may get slightly out of position since they are removable, which can cause the glass window to get tilted.

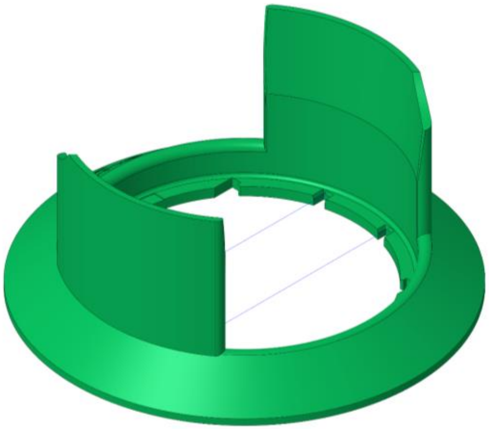


Figure 41: Existing fixture for installing the glass window in the metal housing

Testing

No testing done as this fixture is already used in the production and no modifications were needed in account of the other fixtures.

6.2.10 Avoid trapping air pockets in the cemented joint when positioning the glass window in the chassis housing

6.2.10.1 Iteration 1

Main issues

- To have acquired an even layer of silicone on the glass window, without air pockets.

Solutions

- The primary solution to this problem will be to make sure that an even layer of silicone is applied to the glass window. That will reduce the risk of trapping air in the cemented joint.

Pros

- Easy solution.

Cons

- No way of telling if this solution will actually work every time.

Testing

No testing done for this specific failure mode. This was kept in mind and evaluated in every other failure mode instead.

6.2.11 Improper set of retainer bracket

6.2.11.1 Iteration 1

Main issues

- To avoid unnecessary movement of the bracket which can cause smearing onto incorrect surfaces.

Solutions

- Guide pins that are guiding the retainer bracket.

Pros

- Pins consistently guide the bracket into the correct position.

Cons

- Extra parts to fiddle with.
- Small risk of affecting the threads.

The retainer bracket, prepared with a layer of silicone, is brought down over the two diagonally opposed guide pins, aligning the bracket. The remaining two holes are utilized to lightly lock the bracket in place with two screws. Once the bracket is lightly locked into position, the guide pins are removed and replaced with the remaining two screws. The bracket installation is thereafter finalized by tightening the four screws to specification.

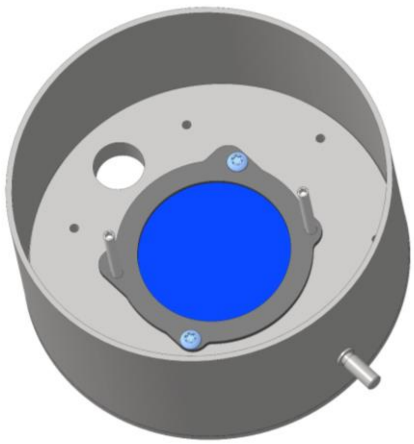


Figure 42: Bottom of the chassis housing with guide pins, glass window, retainer bracket and two screws installed

Testing

There is a risk that the pins become sticky with silicone after each use, leading to them needing cleaning. This will increase the work needed by the production personnel so the use of these will have to be evaluated by the production personnel in a later stage. Apart from the risk that the pins become sticky with silicone, this procedure worked well and aligned the bracket accurately. It was deemed to fulfill all criteria and was chosen as the final solution.

6.2.12 Final optimization

Some final adjustments were made for the optimization. To increase usability and facilitate releasing the glass window easier, a small ring was added to the suction cup handle. This ring proved to help when having the hand in position within the steel housing, making it easier to hold the handle when pressing the button. Other minor adjustments were also made to some of the dimensions of the parts, such as the nozzle. The final result can be seen in the conclusion.

To conclude the development a final FMEA was established. The final FMEA is focused on the new processes and tools with the aim to assess the improved version of the assembly operation. This will however not be shown in this thesis as it is kept internal due to the integrity of the production procedure.

7 Results

7.1 Result of material selection

The objective related to material selection was to evaluate alternative materials to the current material, an objective which was deemed to be fulfilled. The material selection resulted in a tie between two materials, Peppers T1000 and KQS Celox. It could not be decided which of these materials is most suitable for the intended application due to tests not being able to be carried out. Similar materials were however tested and it was concluded that new tools and fixtures will be needed for both materials. Further work would be needed to determine a result and to evaluate if the new material could be implemented in the existing design.

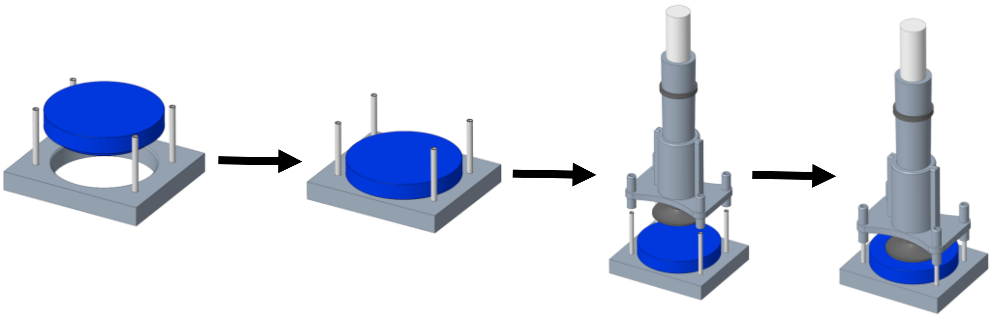
The takeaways from the material selection is that it was deemed unnecessary to change material unless the new material is TVLE2 rated by UL. With a TVLE2 material yearly testing can be avoided, leading to both time and cost savings. A cost analysis was performed to get an approximation for when it is cost-beneficial to change material. The cost analysis carried out under *6.1.4 Concept Selection* proved, with the current yearly production volume, that the use of any of these two materials would be beneficial economically.

7.2 Result of production with the current material

The objectives related to production with was to:

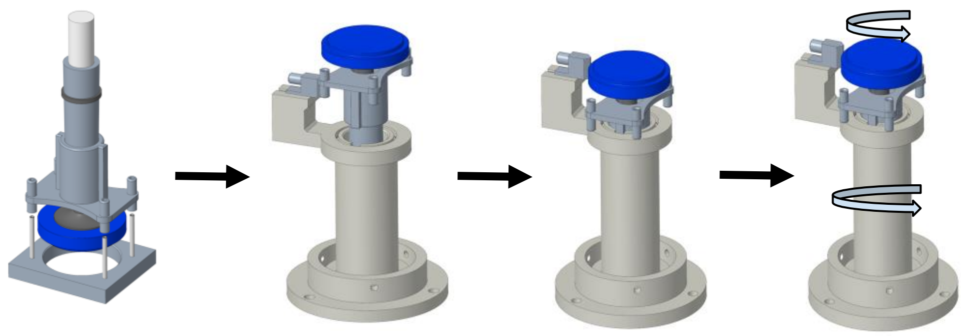
- Achieve sufficiently homogeneous sealant joint
- Reduce smearing problems
- Minimize material applied to reduce excess material
- Minimize risk of outgassing
- Develop an improved work procedure for the production with the current material

Below is a flowchart over the improved assembly process that was deemed to fulfill all objectives and the issues each step aims to minimize.



The glass window is placed into the centering fixture, with the smaller diameter surface down. The goal of this fixture is to center the glass window on the suction cup assembly.

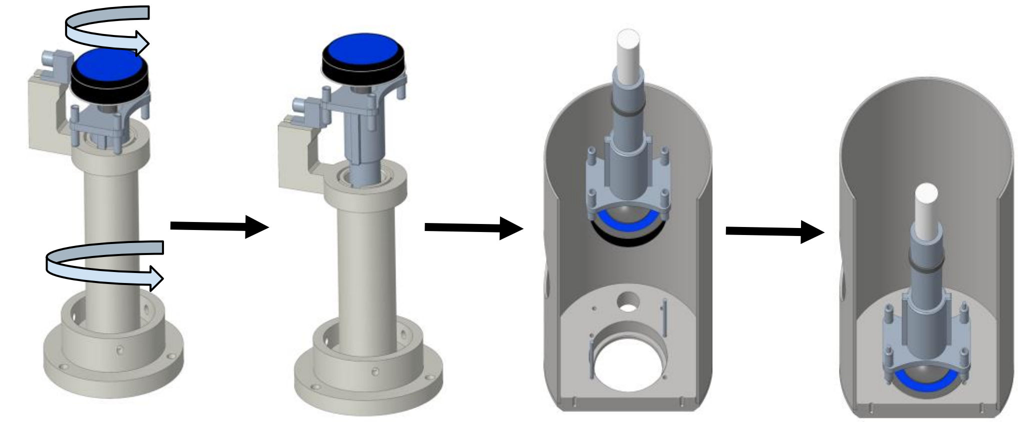
With the suction cup button depressed halfway, the suction cup assembly is brought down over the centering fixture with the guide pins entering the guide pin sleeves.



The suction cup button is released and the suction cup assembly and the glass window are removed.

The suction cup assembly is flipped over, and placed into the rotation table fixture, allowing the flanges to enter into position. The goal of this fixture is to center the suction cup assembly on the rotation table.

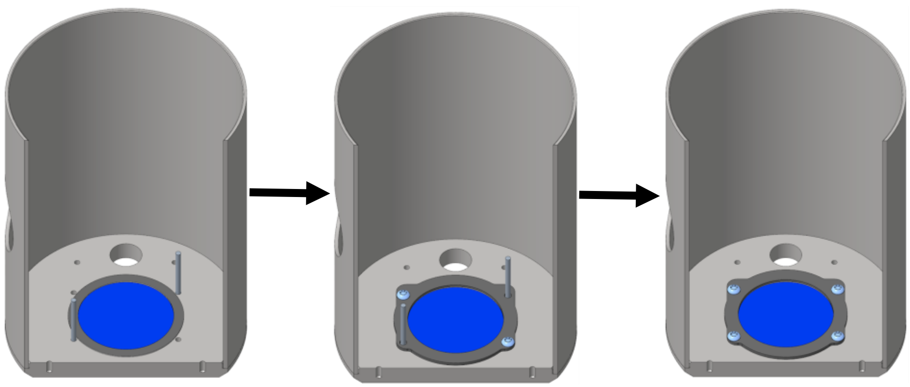
The electrical dispenser is attached to the nozzle with a piece of plastic hose. The rotation table is turned on. The goal of the dispenser and nozzle is to achieve sufficiently homogeneous sealant layer.



The silicone dispenser is engaged. Once a full rotation has been completed, the dispenser is disengaged. The goal of this step is to reduce smearing problems by minimize material applied to reduce excess material. This will also lower the risk of outgassing in the end.

The rotation table is turned off when the suction cup assembly is free from the nozzle vertically. Suction cup assembly is removed.

With the two guide pins diagonally installed in the housing, the glass window is brought down, allowing the pins to enter the guide pin sleeves. Once fully seated, the button is depressed and the suction cup assembly is lifted vertically. An already existing fixture that can be seen in 6.2.9 is used in this step as well. The goal of the guide pins is to center the glass and to minimize smearing problems and thereby lower the risk of outgassing.



The guide pins are left in their positions.

The retainer bracket is guided into position using the two guide pins. It is thereafter locked with two screws. The goal is to minimize smearing problems.

The two guide pins are removed and replaced with the two remaining screws. All screws are tightened to specification.

The pictures below show the results prior to the production development work. A thick and uneven layer is present and considerable smearing can be observed around the edges of the glass window.

Figure 43: Pictures of the installed glass window following the current work procedure

Utilizing the new resources, the results are now as demonstrated in the following pictures. The more controlled sealant application results in less smearing and less excess sealant material. It should be mentioned that any silicone residue on the glass surface is a result of previous testing, and did not originate during the shown installation procedure.

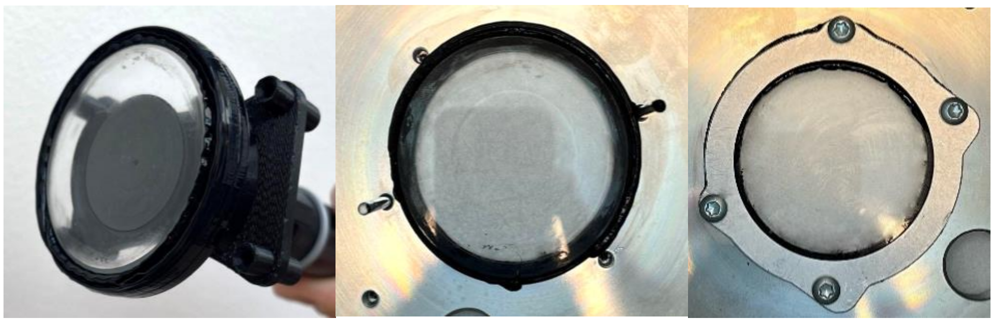


Figure 44: Pictures of the installed glass window using the developed work procedure and tools

8 Discussion

8.1 Material selection

The possibility to minimizing some of the difficulties experienced with the current material were the main incentives to look into alternative materials. Another incentive discovered in the research was the potential cost savings by switching to a TVLE2 classed material. If this would not have been a driving factor for a change, other materials which weren't TVLE2 classified may have been looked into during the concept generation. It should therefore be noted that the two final materials, Peppers T1000 and KQS Celox, are not necessarily the most technically appropriate materials on the market for this specific application. One is a putty, and the other is a relatively free flowing liquid, and these characteristics have their innate challenges to accommodate for. Also, there are other technical specifications that are not ideal. For Peppers T1000, the main technical drawback is the service temperature range where the upper limit is 135 °C, and the certification requires 155 °C. It might however be possible to implement this material but it would require some work as the certification company has to approve it. For KQS Celox it is the shrinkage level of 1,8 % that is its main drawback, exceeding the 1% limit set by UL 1203. It might however be possible to implement this material as long as it fulfills the other criteria set by the standards and that it passes the pressure tests. The Axis certification specialist indicated that both materials might be usable despite these drawbacks, but these uncertainties would have to be looked into further. In the end it will be up to the certification company to approve any changes. However, with the tradeoff required to take advantage of the cost saving aspect with a TVLE2 classed material, the team is confident that the two final materials are the best overall options to go further with, technically and cost wise, if a change is to be made.

As part of the material selection process, quite a few specifications were either subjective, meaning that they were handled intuitively by the team, or simply difficult to set target values for. One such target specification was the optimal viscosity of the material. It is very difficult to intuitively determine what that is, since there are both upsides and downsides with every range. The viscosity is in terms of usability what represents the biggest difference between Peppers T1000 and KQS Celox, and which of these is easier to handle would become more apparent during eventual testing. The putty-like consistency could be useful in the way that it is malleable and could be applied to the surfaces by hand. The main downside however is that the two components must be manually mixed, which if done by hand, may become strenuous. The self-mixing nozzle of KQS Celox would make the application much swifter in that sense. The low viscosity may however make the liquid difficult to contain and to apply in this application.

The implementation of a new material should also be discussed. As mentioned by Axis' certification specialist, the process of successfully changing to a different material is not completely clear. Since the two potential materials in question are TVLE2 rated, the company issuing the certification will most likely re-evaluate the construction with the material by carrying out a so-called "engineering judgment" which includes a chemical resistance test followed by an explosion test. The certification would then be updated with the new specifications, hopefully without issuing an all-new certification. There is however a risk that the certification company would require a new certification. Such a process is costly and takes more time and should therefore preferably be avoided.

The use of the development methodology created by Ulrich & Eppinger may not have been entirely optimal for the faced material selection process. Their methodology is more oriented towards completely new products, where the specifications can be changed more freely. Since the materials examined were unchangeable, some of the recommended steps were redundant and not applicable. The methodology was therefore not used to its full intent but the steps taken were however very useful and provided valuable insights. The chosen methodology was therefore deemed to be applicable to the problem faced in this thesis even though it was not applied to its intended use.

8.2 Production with the current material

To act as the basis of the production improvements for this material, it was decided to carry out a process-oriented FMEA. The FMEA shed light on issues to focus on, and did so based on the score that each issue got. This functionality proved to be helpful, since it became easier to spot the processes that posed the biggest risks. To minimize the risks of such issues occuring, designing processes and tools that would take out the human factor as much as possible became the philosophy of choice. The work was set to iteratively design and 3D-print tools and fixtures that would aid the consistency of the work procedure. As a prerequisite, it was also requested that the process would utilize a rotation table that had been purchased specifically for this task.

The already existing fixture that can be seen figure 41 was left unchanged. The reason for this is that it solved the problem of the protruding glass window and aligned it well with the front surface of the chassis housing. Another reason to leave this fixture as it is was that the production personnel are familiar with it.

As a result of fulfilling the mentioned objectives, another positive result was obtained. By reducing the waste through less applied material, a positive impact on the environmental sustainability was achieved.

The FMEA proved to be of assistance in guiding the team in which issues to focus on. Apart from this analysis, there were no specific methodologies that were used to organize the work procedure. The approach to use the FMEA and come up with ideas and concepts, and iteratively test them, was constructed by the team and worked very well and continuously kept the project moving forward efficiently.

Since the production with this sealant involved a lot of manual steps which issues would have to be solved with work instructions to reduce human errors, it was deemed that a development methodology like the one from Ulrich & Eppinger was not the most optimal to use. It should be noted that following an established methodology, suitable to the tasks that were at hand, probably could have made the process even more streamlined. This was however deemed to be too time consuming to do for each issue, thus development by iterations were used.

Regarding 3D-printed parts, it may also be the case that these parts are not allowed in production. If this is the case, the parts must be manufactured using other methods, something that will surely require work to the tolerances as different manufacturing methods cause different results in terms of for example surface roughness. The team's understanding was however that 3D-printed parts will be acceptable for the intended use and this will therefore not be an issue.

As mentioned before, the entire work of improving the production processes for the current sealant was based on the desire to utilize the rotation table at hand. With the nature of the problem, to apply a sealant around a circular object, this tool is both in theory and in practice very suitable. It should however be said that there are potentially other methods that could be used instead. There is a risk that the team was directly very focused on making use of the rotation table, to the point that other production methods may have been overlooked. That being said, the risk of missing methods that would have been better is deemed very low, since such a table is so widely used in similar applications and yielded such consistent results.

Another issue to take into account was that the assembly process should be safe for the operator. No specific measures were taken to ensure this since every created assembly step did not pose any obvious risks, according to the team. The greatest change from the original assembly process was the introduction of the rotation device. If the operator somehow would get stuck, especially if high speeds accidentally would have been present, the risk of injury would be imminent. It is therefore important that the increased risk is discussed with the production personnel, and then actions could be made by them if deemed necessary. The other risk factors have not changed significantly. The safety measures taken to handle the chemicals will remain the same and are all deemed safe. Minding all these factors, the entire process is by the team considered safe.

9 Conclusion

9.1 Conclusion of material selection

The objective related to material selection was to evaluate alternative materials to the current materials. The possible cost savings each year and the possibility of minimizing some of the difficulties experienced with the current material were the main incentives to look into alternative materials. To assist the process of fulfilling the objective the steps of Ulrich & Eppinger methodology was implemented to the highest degree possible. The contribution of this thesis resulted in a tie between two materials, Peppers T1000 and KQS Celox. It could not be decided which of these materials is most suitable for the intended application due to tests not being able to be carried out. Similar materials were however tested and it was concluded that new tools and fixtures will be needed for both materials. The takeaways from the material selection is that it was deemed unnecessary to change material unless the new material is TVLE2 rated by UL. If the cost saving potential by switching to a TVLE2 classed material would not have been the driving factor for a change, other materials would have been looked into. It should therefore be noted that the two final materials, Peppers T1000 and KQS Celox, are not necessarily the most technically appropriate materials on the market for this specific application. They are however fulfilling all the identified needs set by the team.

9.2 Conclusion of production with the current material

The main goal was to develop an improved work procedure for the production with this material to minimize some of the difficulties experienced with the current work procedure, tools and fixtures. To assist the process of fulfilling all objectives a process-oriented FMEA was created. The approach to use the FMEA and come up with ideas and concepts, and iteratively test them, was constructed by the team and worked very well and continuously kept the project moving forward efficiently. This led to the contribution of this thesis which is a combination of an improved work procedure, tools and fixtures. The more controlled sealant application results in less smearing and less excess sealant material.

9.3 Further work

Some areas that could be worked upon and investigated further have been identified during the course of this work. The most prominent step would be to carry out tests on Peppers T1000 and KQS Celox. The way that the team would initiate this process would be to discuss the materials' characteristics and develop first iterations of tools. Where applicable, inspiration would be drawn from the tools and fixtures created for the current material's production. Thereafter further development would take place, and the usability of these materials would be under investigation. If a material is deemed unsuitable already during this stage, it would be excluded from taking part in further development. If they are both deemed usable, final scrutiny would be carried out where one material is selected.

Apart from the aspects regarding the certificate, if a material change would be initiated, there are other areas that would have to be adapted as well. Firstly, a new risk assessment for the production would need to be carried out, examining the risks that come with the chosen material. Secondly, new work procedures and tools must be created and implemented, which also requires training of the production personnel. Thirdly, routines for a new supplier would need to be established.

One of the issues mentioned in the FMEA for the current sealant's production is the risk of trapping air within the sealing joint, an issue that can compromise its function. This is also one of the issues that are the most difficult to examine, since it would require ejection of the entire seal without rupturing it. To minimize the risk of trapping air, implementing a vacuum cabinet was discussed. The vacuum could potentially draw out the trapped air, leaving a homogeneous joint behind. But with the precision with which the sealant was applied, and in combination with the cost aspect, this was not something that the team advised Axis to pick up on during this stage. It is however something that could be of use, and the potential implementation of another sealant material could change the motives for such a cabinet. It is therefore recommended that Axis contemplate a cabinet of this type if issues are experienced with either the current material or after the potential implementation of another material.

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Appendix A

A1 Key questions for the mechanical engineers

1. Vad har varit mest problemfyllt med glasinstallationen?
2. Vad ser ni för risker med detta?
3. Vad ser ni för risker med nuvarande konstruktion?
4. Har ni några tankar om hur det bör åtgärdas?

A2 Key questions for the certification specialist

1. Hur stor ändring genererar omcertifiering?
2. Måste vi ha RTV silikonet eller kan man ändra fritt så länge det är inom standarden?
3. Vad innebär det att certifiera om?
4. Ändra design/dimension, innebär det mycket extrajobb?
5. Vad får vi lov att dela med oss av?

A3 Key questions for the production personnel

1. Kan du beskriva tillvägagångssättet när ni monterar glaset
2. Vad är det största problemet? Vad är mest besvärligt?
3. Vad ser du för risker med nuvarande konstruktion? Har du några tips på förbättringar?