CHALMERS

Kostnadsreducering för sätestätningen

med hjälp av en ny tillverkningsprocess och nya materialval

Cost reduction for the valve seat

With the help of a new manufacturing process and new material selection

Examensarbete för högskoleingenjörsexamen inom
Maskiningenjörsprogrammet och Mekatronikingenjörsprogrammet

Mikael Mousavi

Viktor Keric

Institution för Material-och tillverkningsteknik
Division of Material and process manufacturing
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden

Examinator: Peter Hammersberg, Examensarbete 171, 2017

EXAMENSARBETE 171/2017

Cost reduction for the valve seat

With the help of a new manufacturing process and new material selection

Mikael Mousavi

Viktor Keric

Cost reduction for the valve seat with the help of a new manufacturing process and a new material choice

MIKAEL MOUSAVI
VIKTOR KERIC

Diploma work 171/2017
Department of Materials and Manufacturing Technology
Chalmers University of Technology
SE 412 96 Gothenburg
Sweden
Telephone: +46 (0)31-772 1000

Preface

This examination thesis was order by the company IMI Hydronic Engineering and was made during the spring of 2017. The work was executed by Mikael Mousavi and Viktor Keric and is the ending part of the three yearlong Mechatronics Engineering and Mechanical Engineering education at Chalmers University of Technology. The work comprises 15 university credits per student. There are many people that have helped us along the way of this examination thesis. Firstly, we would like to thank our supervisor at Chalmers, Peter Hammersberg, who always was able to help us move forward when we hit different obstacles along the way. We would also like to thank Camilla Klässbo at the company Hexpol TPE who took the time and helped us choosing the right material in the later stages of this thesis. Finally, huge thanks go to everyone at the company IMI Hydronic Engineering and especially our supervisor during this examination thesis, Daniel Jilderos, who always had time to answer our questions and help us throughout the project.

Mikael Mousavi

Viktor Keric

Sammanfattning

Det finns både fördelar och nackdelar med att använda sig utav plastmaterial. En nackdel är att plastmaterial har svårt att sammanfogas med andra material såsom gummi. Det är också detta problem som företaget IMI Hydronic Engineering har stött på i en sätestätning i deras produkt TA-Compact. Detta projekt utfärdades då av IMI för att hitta en teoretisk lösning på problemet. Deras problem låg i en sätestätning som består av 5 komponenter (plast komponent, gummi O-ring, gummitätning, mässingsbricka och en skruv av rostfritt stål). Det företaget främst vill göra sig av med är de fästelementen som behövs för att kunna fästa en gummitätning mot en plastkomponent i dagens produkt. Anledningen till varför företaget vill eliminera dessa fästelement beror på tillverkningskostnaden. För att kunna tillverka sätestätning i ett högt tempo så har företaget tvingats att köpa en maskin som monterar gummitätningen, mässingsbrickan och skruven automatiskt på ett löpande band. All information ledde till några frågeställningar som bland annat handlade om vad kostnaden skulle bli för det nya konceptet och hur den skulle kunna tillverkas.

Dessa frågeställningar ledde till att en omkonstruktion av den befintliga produkten utfördes. Fyra koncept togs fram och utvärderades med hjälp utav en urvalsmatris. Det vinnande konceptet valdes och ett materialval utfördes för att uppnå den bästa kemiska bindningen mellan materialen som möjligt. Då det upptäcktes tidigt att gummimaterialet var ett stort problem för att uppnå en kemisk bindning med plast så ersattes gummimaterialet med TPE vilket är ett plastmaterial med gummiliknande egenskaper. Det vinnande konceptet hade också ett välgenomtänkt mekaniskt lås för att ytterligare förstärka bindningen mellan materialen. Sammansättningsmetoden som valdes för den nya produkten var dubbel gjutning eller 2k gjutning som det också kallas. Med hjälp av att gjuta ihop materialen så blir den nya produkten en enda komponent jämfört med den befintliga produkten som består av fem delar. Detta betyder också att kostnaden för den nya produkten kan bli betydligt lägre än den nuvarande kostnaden för sätestätningen.

För detta projekt så fanns det några viktiga avgränsningar. Den ena avgränsningen handlade om dimensionerna för den nya produkten. Eftersom sätestätningen skall appliceras i TA-Compact produkten är det viktigt att de yttre dimensionerna är exakt samma som på den befintliga produkten. Detta gör det svårt för större omkonstruktioner på den nya produkten då det kunde leda till att produkten blir oanvändbar. Den andra avgränsningen handlade om materialen. Även om det var fritt att välja mellan olika materialkombination fanns det ändå några restriktioner i form av krav. Dessa krav var till för att försäkra sig om att den nya produkten bibehöll samma kvalitet som den befintliga produkten.

Summary

There are both advantages and disadvantages when using plastic materials. One disadvantage is that plastic materials are difficulty to join with other materials such as rubber. It is also this problem that the company IMI Hydronic Engineering has encountered in a valve seat in their TA-Compact product. This project was then issued by IMI to find a theoretical solution to the problem. Their problem lied in a valve seat consisting of 5 components (plastic component, rubber O-ring, rubber seal, brass washer and a stainless steel screw). What the company wants to achieve is to eliminate the fasteners that attaches the rubber seal to the plastic component on today's product. The reason for why the company wants to eliminate these fasteners depends on the manufacturing cost. In order to produce the valve seat at a high speed, the company has been forced to purchase a machine that assembles the rubber seal, the brass washer and the screw automatically on an assembly line. All the gathered information led to a few questions that included what the cost would be for the new product and how it could be manufactured.

These questions led to a reconstruction of the existing product. Four concepts were developed and evaluated using a selection matrix. The winning concept was chosen and a material selection was performed to achieve the best possible chemical bond between the materials. At early stages of this project it was discovered that the rubber material was a major problem in order to achieve a good chemical bond with a plastic material. Therefore, the rubber material was completely replaced with a TPE material which is a plastic material but with rubber-like properties. The winning concept also had a well-designed mechanical lock to further strengthen the bonding between the materials. The joining method that was chosen for the new product was double molding or 2k molding as it is also called. By merging the materials, the new product becomes one single component which is a significant reduction as compared to the existing product that consist of five. This also means that the cost on the new product is significantly lower than the current cost of the valve seat.

For this project, there were some important limitations. One limitation was about the dimensions of the new product. Since the valve seat is applied into the TA-Compact product, it is important that the outer dimensions are exactly the same as on the existing product. This made it difficult for major reconstructions for the new product since it could lead to the product becoming unusable. The second limitation was about the materials. Although it was free to choose between different material combinations, there were still some restrictions in terms of requirements. These requirements were in place to ensure that the new product retained the same quality as the existing product.

Table of Contents

1. Introduction

In this first introduction chapter, a background and the reason for why this project was created will be explained. To get further understanding, the goals, purpose and limitations of this project, will be presented.

1.1 Background

IMI Hydronic Engineering is a leading company in HVAC (Heating, ventilation and air conditioning). One of their most popular product is the TA-Compact, a regulator that consist of several different parts. The product in this project works as a sealing component in the TA-Compact. The product contains five different parts: one plastic component, two rubber components, one brass washer and a stainless-steel screw. The problem that IMI Hydronic are facing is that the rubber parts themselves are inexpensive to purchase, but expensive to assemble. The reason for that is the difficulties to assemble rubber parts onto plastic parts without any fasteners. IMI has for many years molded rubber components onto metal, but since the industry is developing, plastic components have replaced metal parts and have become a better and cheaper alternative. Therefore, a solution for molding rubber parts on plastic is necessary. This technology is new for IMI and with the help of this project they would like to gain new knowledge on how a solution for the problem could be realized.

1.2 Purpose and Objectives

The projects task from the company IMI Hydronic Engineering is to modify a part in the product called TA-Compact. This product has a valve seat that consists of a plastic component and rubber components for sealing purposes which makes it possible to shut of the flow through the valve. The sealing component is held in place by a brass washer and a stainless-steel screw. The valve seat also contains a standard rubber O-ring assembled to the plastic part. By combining the rubber seat and rubber O-ring directly to the plastic component it should be possible to reduce an assembly of 5 parts to only one part that has the same functionality. This project will be purely based on information and methods which will result in a theoretical solution for the problem.

1.3 Limitations

Dimensions of the valve seat is a limitation because it is a relatively small product that needs to be able to fit in with all the other products that combined creates the TA-Compact. The valve seat's performance and quality needs to remain the same after all changes are applied. Its ability to handle high temperatures and high pressure are essential to maintain the products efficiency. This is why the material choice is limited and an alternative material needs to reach the requirements of the existing products materials.

1.4 Project Questions

In the beginning of this project a few important questions were asked:

- Will the new product be able to fit in the TA-Compact and maintain same performance rate?
- Will the new product be cheaper than the existing?
- What is the optimal way to produce the new product regarding quality?

These questions will be answered with the help of different analyses. These analyses will be performed on both the existing product and the new concept. By comparing the results, it will be clear if the goals have been reached or not.

1.5 Outline

Method, Result and Discussion will be the three major chapters in this project. The reason for this is to get a structure where the knowledge builds up as the reader follows the project. In the Method chapter, all methods that are necessary for achieving the results will be presented. The Results are presented in chapter four and chapter five will contain a discussion of the result.

2. Theoretical Framework

IMI Hydronic are searching for a way to reduce their cost within production. Their solution for this problem is to find a way where joining plastic with rubber, without any fasteners, is possible. This solution will result in fewer assembly steps which will lead to a cheaper production process.

At the moment, the company has not found a way for how they can achieve this task. The reason for that is the difficulties that exists in merging these two materials. The difficulties lie in finding bindings that not only succeeds in joining plastic with rubber but also succeeds in maintaining the quality and all the requirements of the product.

There are several different solutions on this problem out on the market today. One of these solutions is to use molding and mold together rubber on plastic. However, there are some conditions that needs to be reached. Goodship & Love (2002 p.7) explains that two of these conditions are to choose the right materials that are compatible with each other and choose the right joining method. The joining methods are either chemical bonding, mechanical bonding or a combination of both. To use a chemical bonding, you need to look at both materials on a molecular level while a mechanical bonding is created by a reconstruction of the product to prevent dislocation of components.

2.1 Molding

There are several different methods to mold components together. The method that has been studied in this project is 2k molding or double molding as it's called. It's commonly used to combine different polymer materials in the industry today.

2.1.1 2k Molding

Goodship & Love (2002 p.9-10) explains that the advantages with this method is its ability to achieve certain characters that a specific material itself cannot attain. Because of its abilities to mold together hard parts onto softer parts this method works perfectly for the task in hand. The primary goal to succeed with 2k molding is to achieve good adhesion between the materials that are assembled. There are several ways to achieve this.

- Modify one of the materials so that the materials are compatible with each other or choosing materials that are compatible with each other
- Selecting materials were their surface energies are alike
- Creating mechanical locks. With the right reconstruction in one of the components the second material, when injected, can flow through and around the first component.
- To get the best conditions for processing the materials, a variety of surface treatment methods are needed.

Besides the material properties that needs to be accomplished the processing parameters needs to be taken into consideration because of its significant influence on the quality of the joining. These parameters are:

- The softer materials melting point
- What molding temperatures both materials require
- How much time the cooling process is for the hard material and the delay-time before the soft material can be injected over the hard material component.

2.2 Adhesives

There are other ways to assemble two materials with each other. One of these ways are to use adhesive products and glue together the different components. While it sounds simple, Jon Wingborg (Materials Engineer at Chalmers University of Technology) provided information that this solution requires a lot of processing to make the materials joinable with each other.

For the rubber material processing to make the material compatible with other materials is necessary as it usually consists of different blends of shifted materials and additives. Important aspects for the strength is that both the surface tension of the material is good and that the chosen rubber material has good surface strength. Another significant problem in using adhesive products on rubber materials is that even if a certain rubber material exhibits good strength quality, the gluing result may not achieve an acceptable standard. This is due to the fact that rubber material characteristics varies and is not the same on the surface as it is on the inside.

A general processing of the surface is also performed to give the rubber the best possible conditions for attachment on other materials. Grinding the rubber surface is the most common method. Small rubber particles can be created when using the grinding method and therefor it is important to brush off the detail to remove these particles which will lead to a higher possibility for a strong bonding between the materials when applying glue.

Even for gluing with plastic materials, preliminary work to achieve the best possible results is needed. Klason, Kubát, Boldizar & Rigdahl (2008 p. 286) explains that there are both advantages and disadvantages of using adhesive products as a composition method for the plastic material.

Pros:

- The properties of the glued material are not affected
- Provides good fatigue strength
- Can be used to merge details with large dimensional differences

Cons:

- Increased risk of chemical exposure
- Thermosetting resin cannot be glued to solvents

One of the most important preconditions for using glue is that the joint surface should be clean. The best way to achieve this is to either grind or use abrasive blasting. Even dust and grease must be removed from the surface, to get as good joining as possible, using solvents.

2.3 Materials

2k molding requires that the two materials that are used for the molding are compatible, otherwise no bonding will take place. The task requires to use plastic material for the first component (nowadays manufacturers often use plastic as a main component because of its many advantages versus metal) and a material that have the same sealing properties as a rubber material for the second part. One material group that does achieve the rubber like properties is a material group called TPE. Because TPE is mixture of plastic and rubber, they have a similar surface chemistry as plastic and therefore the TPE, as a replacement for the rubber, has a good compatibility with other plastic materials.

2.3.1 TPE

TPEs are Thermoplastic Elastomers. This material group has been used as a replacement for rubber more frequently in the recent years. Based on the information provided by the company Hexpol TPE the main reason for that is that TPEs are plastics that show rubber like properties. Thanks to this combination TPEs can offer both the properties that rubber materials have and simultaneously the processing efficiencies that plastics are known for. From an environmental aspect, TPEs are an ideal material group since it is 100 percent recyclable. There are other reasons why TPE should be chosen over rubber:

- Parts weigh less
- The cycle time of TPEs are faster than rubbers
- Waste is eliminated due to less scrap
- Superior flexibility of the design aspect

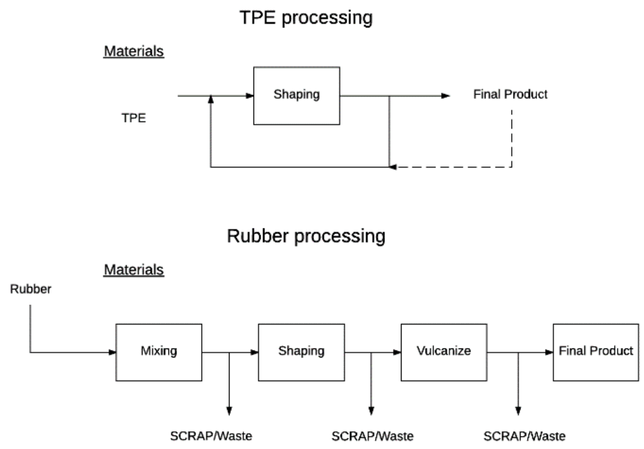


Figure 1. The differences between TPE and rubber processing. Adapted with permission from Hexpol TPE

As earlier mentioned there is a significant difference in the processing of TPE versus the processing of rubber. With the illustration above it is clear that there is a huge difference in the waste aspect since TPE only performs one operation while processing of rubber requires many steps and in each additional operation the waste increases.

The TPE material group consist of various different thermoplastic elastomers. Each type has its own advantages and disadvantages and it is important to choose the right TPE based on what requirements the product needs to fulfill.

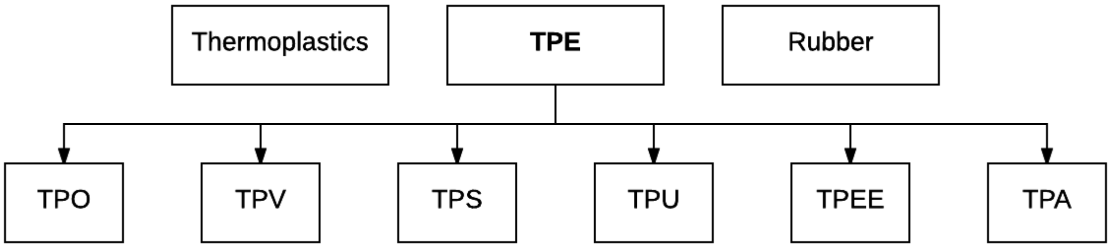


Figure 2. The different variations in the TPE material group, Adapted with permission from Hexpol

2.3.2 Polyoxymethylene

Polyoxymethylene or POM is an acetal plastic material and is frequently used in many areas of the industry today due to its qualities. Klason, Kubát, Boldizar & Rigdahl (2008 p. 113-115) argues that there are many advantages of using this plastic material since it has:

- Excellent combination of toughness, stiffness and fatigue strength
- Good moisture and chemical resistance
- Resistance for a wide temperature range
- Good resistance to stress relaxation
- Good friction and wear characteristics

All of these abilities create a perfect material for the plastic component in the valve seat.

3. Method

Every result requires a method. In chapter three, Method, all methods that will be used in this project, to accomplish a good result, will be presented. The outline for this chapter is going to be divided into three topics: Pre-study, Concept generating and Choosing a concept.

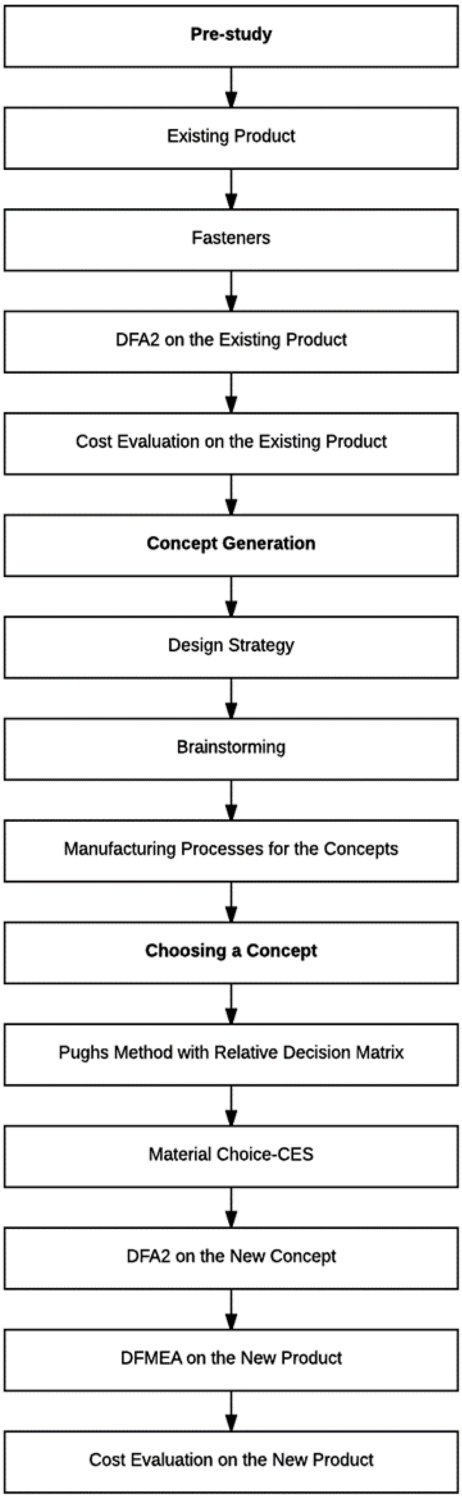


Figure 3. A visualization on how the methods in chapter three will be presented

3.1 Pre-study

With the task in hand and little knowledge about all the aspects that this project requires, a pre-study had to be done. A pre-study is a very important step to make this project as effective as it can be. The main channels of information that were used was literature, gathered knowledge from specialists in specific areas and previous master theses.

With a DFA2 analysis for the existing product a reference showing whether the task has been completed or not at the end of the project will be reached with comparison against the new concept. By comparing what the difference will be for the manufacturing costs between the existing product and the new product a cost evaluation will be performed for the two products. All these comparisons provide a good basis for responding to the project questions that were realized in the beginning of this project.

To gain knowledge about plastic and rubber materials, questions to professors were asked and literature studied. With that information, a foundation to move forward and successfully create a new product was possible.

3.1.1 Existing Product

To get a full understanding of how the product and its parts works, an analysis was needed. The key area was to evaluate how each part interacts with other parts in the product and what their main functions are. To achieve this the existing product was taken apart and studied. A study on how the valve seat looks today and what its main function is was also wanted to get a clear view on why the product looks like it does.

3.1.2 Fasteners

To gain an understanding on how IMI hydronic combines plastic and rubber parts and what machines they use to accomplish that, an observation of their production process was performed. This observation helped to gain knowledge about the current process and what reconstructions could be made without affecting the products functions.

3.1.3 DFA2 on the Existing Product

Johannesson, Persson & Pettersson (2004 p.323-324) explains that DFA2 is a simplified DFA method used to check how a product's assembly steps and time can be reduced. Since this projects main objective is to find a way of removing fasteners from the existing product, this method was considered necessary. With this DFA2 analysis on the existing product a reference showing whether the task has been completed or not at the end of the project will be reached with comparison against the new concept.

The method is implemented by scoring 12 different assembly aspects for each item number (detail, component or module).
For each aspect, points are given by following order:

- 9 points=Best possible solution
- 3 points=Acceptable solution
- 1 point=Undesired solution

When the DFA2 analysis on the existing product is complete an examination of the results is needed. There is one question that needs to be asked.

- Can the item be eliminated or combined with any other detail?

This question is the key to succeed with the task in hand. This analysis will answer the questions on which assembly operations are critical and thus which subsystems and components should primarily be reconstructed.

3.1.4 Cost Evaluation of the Existing Product

By the help of the company a cost evaluation on the existing product will be received and studied.

3.2 Concept Generation

When all observations on the existing product was done, the project moves on to the concept generation phase. In this phase methods like Brainstorming and Design-strategy will help generating different concepts that will all be possible solutions to the task in hand. Throughout these methods concepts that do not reach the required standards will be eliminated and only the best will proceed to the next phase.

3.2.1 Design Strategy

In the method called Design-strategy a match between the attribute profiles of the materials and process is sought. This method requires three phases. Ashby, Shercliff & Cebon, D. (2014 p. 35-36) explains that the first phase is called translation. In this step a translation means that the design requirements are converted into prescriptions to help the choosing of materials. This gates by finding what constraints that the material needs to reach and what objectives the design must fulfill. The design of the product may have free parameters that is not set by the design requirements. These parameters are called free variables. The second phase is called screening. In this step, all materials that are not capable of meeting the set requirements are eliminated from this process. This means that all material groups that are left after phase two are potential candidates for the product. Since only a few strong candidates are preferred a last phase called ranking is required. In this third and final step, all material groups that have survived previous phases are examined to detail. Depending on what objectives (minimum cost, maximum strength etc.) are sought an analysis on specific requirements are performed on each material group. The result of these phases should lead to a clear view on which materials have the best material index for the sought objective. A material index is the greatest value of properties and will identify the materials that are best suited for this task.

3.2.2 Brainstorming

Johannesson, Persson & Pettersson (2004 p.166-167) describes that a common method to generate concepts is to use Brainstorming. The idea of this method is to address as many solutions as possible to the problem over a span of time. Idea quantity goes before idea quality. There are four basic rules to take into consideration when brainstorming.

1. Criticism is not allowed

No comments are allowed during the brainstorming phase, neither positive nor negative. It is also important that the participants are not self-critical of their own ideas, the important thing is to spell out all ideas spontaneously without any restrictions. The main purpose for why this is important is because even if the person's idea may not be so successful, it can inspire someone else in the group for a new idea.

2. Seek quantity

It is important that many ideas are presented, as it increases the chance that some of them are useful. A fundamental principle is that even a bad idea can lead to brilliant ideas through association.

3. Think outside the box

All ideas are welcome even though they may seem unusual or weird. It has been proven numerous times that unusual solutions can with some modifications become an excellent solution to the problem. Just because a solution is unconventional doesn't has to mean that it is bad.

4. Combine ideas

Combine and complement the ideas that have been presented. Listen to the others solutions and associate further from them. Keep in mind that new problems can arise if you combine two solutions.

Based on these steps, many different concepts will be developed. Choose a few concepts that best resolves the issue and move on to the next method phase within concept generation.

3.2.3 Manufacturing Processes for the Concepts

When the concepts are generated from the brainstorming phase solutions on how these concepts will be manufactured is necessary. These manufacturing methods for each generated concept will be presented and explained.

3.3 Choosing a Concept

After generating a few concepts, it is time to eliminate those who do not reach the required standards. As a tool to select the right concept a Pugh Matrix was used. When a final concept is chosen, material choices needs to be applied and final analyses performed to ensure good results.

3.3.1 Pughs Method with Relative Decision Matrix

Johannesson, Persson & Pettersson (2004 p.184) argue that when you try to reach a definitive concept, the work process usually goes through several different methods to achieve the best possible result. After the first method is completed (brainstorming) different concepts that can solve the problem we are facing, have been developed. The next phase in concept generation is in this case the use of Pugh's method to determine which solution meets the set requirements and wishes the best. Pugh's method uses a matrix where the selection criteria and the alternative conceptual solutions are inserted. A solution that acts like a reference is also chosen and inserted into the matrix. Each concept is now compared with the reference. The matrix helps to determine whether or not each concept meets a specific requirement better than (+), as well as (0) or worse than (-) the reference. Once all requirements and concepts have been processed, a summary of all the scores (+, 0 and -) will result in a net value for each individual concept. With this net value a visualization of which concept is best suited for the set requirements and which concepts are eliminated from the next phase can be realized.

3.3.2 Material Choice – CES

When selecting the right materials for the component, the database CES EduPack is used. CES EduPack is a material platform for design, engineering, research and sustainable development. With the help of the method Design Strategies certain requirements are set and materials that do not fulfill them are eliminated. Since all the information of certain materials can be found in the CES EduPack database, it is the perfect tool for analyzing the remaining materials from the Design Strategy method. The analysis should lead to a clear view on which materials are best suited for the product.

3.3.3 DFA2 on the New Concept

The reason for why a second DFA2 analysis is needed is simple. With the help of the first analysis of the existing product, a comparison and a conclusion if the set goals have been reached can be made.

3.3.4 DFMEA on the New Product

Based on the lectures from the course Machine Construction (MMF 092) which is taught at Chalmers University of Technology it was explained that DFMEA stands for Design Failure Mode and Effect Analysis and is a commonly used method in product development projects.

During the construction process this method is used to identify and evaluate where a failure can occur. DFMEA works after a motto “the cheapest failures are those who never occur”. To achieve this there are a few phases that are performed. During construction, it is recommended to try and identify all possible ways in which a product may malfunction during use. After the identification is complete each error needs to be evaluated based on three questions:

- How likely is it that the error occurs?
- How great are the opportunities to detect the errors before they cause problems?
- How serious will the consequences be if the errors occur?

When these questions are answered two more steps needs to be performed. The first step is to determine what actions are necessary to prevent the errors from occurring and the second step is to verify that the actions have been implemented.

A well-executed DFMEA not only helps to ensure proper product features from the very beginning, it also creates a well-balanced risk assessment of the product.

3.3.5 Cost Evaluation of the New Product

One of the tasks was that the new developed product should be cheaper than the existing product. To be able to know if this goal was reached, a cost calculation for the new product will be performed. The cost evaluation will analyze the use of a specific manufacturing process and other external costs that can occur when manufacturing the new product.

4. Results

This chapter will present the results. All results are an outcome from the methods that were presented in the previous chapter.

4.1 Pre-study

The most important step of the pre-study was to gather as much information as possible about the existing product. The whole TA-compact product was studied and an observation was made of what functions the product in this project overall affects. The manufacturing methods for the fasteners were gathered and analyzed to get a reference comparable against the final concept. All the results from these studies will be presented in this chapter and further explored. With the help of the results, knowledge on what's needed of a new product to maintain its functionality and quality is realized.

4.1.1 Existing Product

To get a full understanding on how the existing product functionalizes an analysis was performed.

Number (1) in the picture below is the part where an operator sets in the desired outflow pressure. With the help of that information, a relationship between the regulating valve and the outflow valve is established (2). The pressure from the regulating valve is led into a

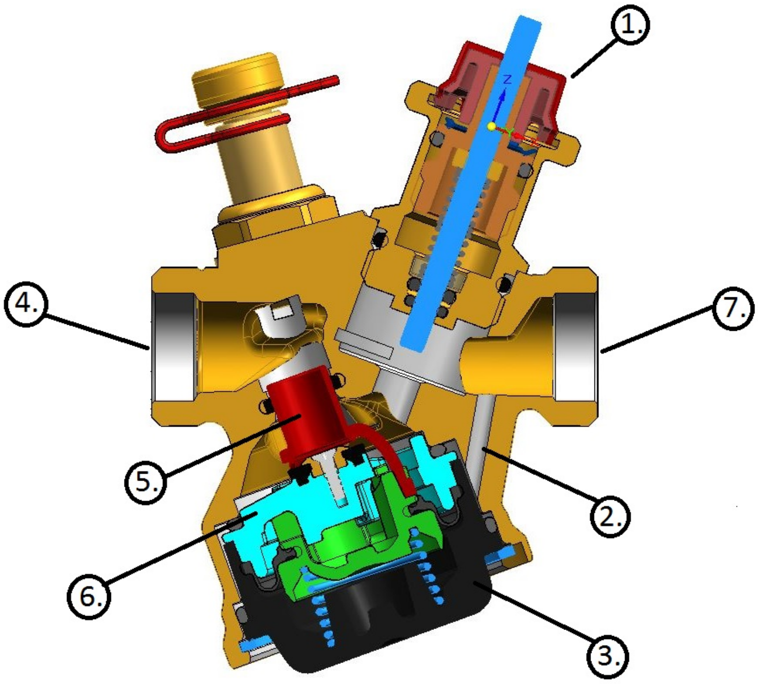


Figure 4. A cross-sectional view on how the components operate in the product TA-Compact

membrane (3) which will make it possible to adjust the inflow pressure. The inflow pressure (4) transports directly to the red cylinder (5), where depending on if the pressure is higher or lower than wanted it will regulate to reach the set goal. The regulation is based on two major principles, if the inflow pressure is higher than wanted then the cylinder will push down and strangle the flow and if the pressure is too low it will open up. Between the cylinder and membrane there is a component (6) that is used as a seal to prevent any leakage. Its outer frame is combined with an O-ring that seals the frame of the TA Compact and the inner rubber component seals the cylinder. Another important function for this part is to hold the cylinder in place when it regulates, so leakage can't occur. Every part in this product has a function in order for it to work. When the pressure has been correctly regulated the desired pressure comes out from the outflow valve (7).

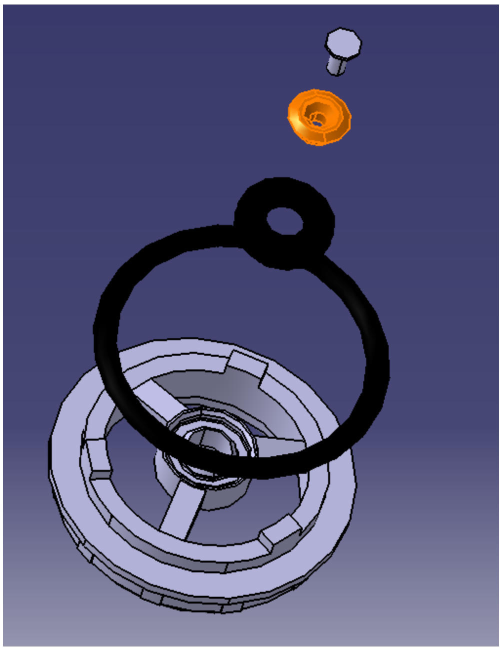
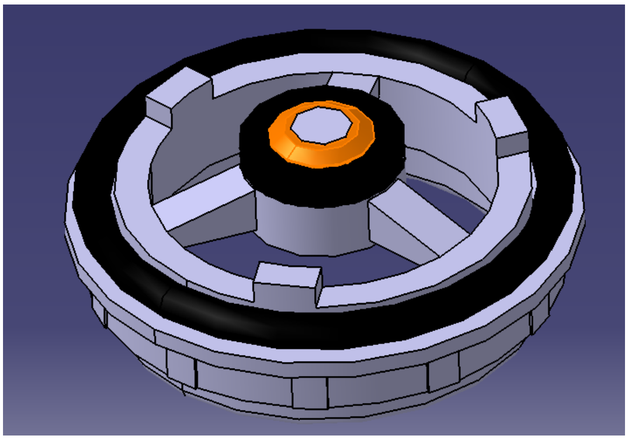


Figure 5. Exploding view on all the valve seat parts created in Catia V5.



Figur 6. A visualization on the existing valve seat product created in Catia V5

The 3D models above show how the valve seat looks today. It consists of 5 separate parts. A plastic frame, an O-ring, a rubber component, a brass washer and a stainless-steel screw. As explained above the main function of this valve seat is to shut of the flow that comes through the valve. That is also why it is important to use sealing components to prevent any leakage.

4.1.2 Fasteners

Since this project main goal is to find a solution on how to combine plastic and rubber parts, a first step was to analyze how IMI Hydronic solve this problem today. With the help of a special machine that the company have purchased only for this specific purpose they manage to combine both parts. The process of this machine starts of by placing the plastic component on a stand which attaches it without the possibility to move. The process then continues to the next phase were a small circular rubber part is placed on top of the plastic component. To ensure that the rubber part is securely placed on the component, a brass washer is added and a screw is applied. The main reason for why the brass washer is needed was because it is impossible to attach a plastic and rubber part directly with a screw.

4.1.3 DFA2 on the Existing Product

In this section the results of the DFA2 analysis on the existing product will be presented. As earlier explained this method will help to visualize which operations are critical and what components should primarily be reconstructed. As the result shows (Appendix 1), there are components like the brass washer and screw that significantly lowers the overall score for the product. Removal of these components is a priority. The analysis also show that difficulties, for the rubber components in both the insertion and gripping aspect, exists. The smaller rubber sealing also requires several operations before it is securely attached and the rubber O-ring is barely attached after it is placed on the plastic component.

The results from the DFA2 analysis shows how well the design fulfills the set assembly requirements. The total aggregated score for the existing product was 240. To get an understanding of what this result means it is converted to percentage. The aggregate score in percent resulted in 67%. Generally, a score between 80-90% means that there is no need for reconstruction, therefor the results of 67% implies that there is room for improvement. The aggregate time for the total assembly was 20 seconds.

4.1.4 Cost Evaluation of the Existing Product

Detail		Detail cost(%)
1		14,9
2		3,5
3		6,6
4		5,4
5		8,3
Manuel assembly		14,9
Automatic assembly		7,9
Total cost		
Manuel assembly		53,4
Automatic assembly		46,6
Total cost per valve seat		100

Table 1. A cost evaluation on the existing product made by the company IMI Hydronic Engineering

The company provided the total cost for the existing product with a table. In this table, all the cost for each detail and the costs for the manual and automatic assembly was presented in a percentage form where the total cost per valve seat represents 100 percent. The manual assembly that is needed to attach the rubber O-ring is the biggest expense of the product and represents 53.4 percent of the total cost. This is a big unnecessary expense that the company hopes to reduce or completely eliminate by the new products solution for the manufacturing process. Thanks to this table a comparison for the costs of the new product can be made.

4.2 Concept Generation

In this chapter, the requirements for the materials will be presented with the help of a Design-Strategy table. All the concepts will also be presented and visualized with 3D models (created in the program Catia V5) with all the information on how they supposedly can be constructed and produced. Each concept will be based on either joining by molding or usage of adhesive products which were the two studied joining methods.

4.2.1 Design Strategy

Before constructing the new product, there are a few requirements that must be met. The requirements of whatever changes that are applied on the new product, is that there cannot be any deterioration of quality or performance in relation to the existing products. In order to assess the material requirements for the new product, an examination on what conditions the existing product can handle now was performed. By using the product sheet for the existing product an observation could be made that the product needs to be able to handle a maximum pressure of 4 bar(400kPa). The product should also handle temperature differences between -10 and 90 degrees. By studying the existing products materials, it was discovered that the rubber part had a hardness of 70 shore. Since it is a requirement to preserve the same quality as in the existing product, a decision was made to maintain the same hardness level. By the help of the company a lifespan of 20 years was set for the product. Since the product is used as a seal in a valve where fluids pass, it was also important to choose materials without any toxic emissions and with great water resistance.

Because the joining between plastic and rubber materials is the most central task in this project, there was not much that could be maximized / minimized except the cost. So, if multiple materials meet all the requirements, the max / min variable will be set to the cost.

The free variable was set to fastening method and weight limit since there are no requirement for these aspects from the company's point of view.

Design Strategy			
Rubber		Plastic	
Function			
	Seal the constructions		Fixates the constructions
Constraints			
	Hardness: >70 Shore		ΔT -10-90˚
	ΔT -10-90˚		ΔP >4 Bar
	ΔP >4 Bar		Life Span: 20 years
	Life Span: 20 years		No toxic emissions
	No toxic emissions		Withstand water
	Withstand water		
Objectives			
	Price		Price
Free Variables			
	Fastening method		Fastening method
	Weight		Weight

Table 2. The result from the method Design-strategy for both material groups

4.2.2 Concepts

All concepts that have been created during the brainstorming method will be presented below. One of these concepts will in the end stand as the final product for this project.

4.2.2.1 Concept 1

During the brainstorming phase an idea emerged based on how inline wheels look.

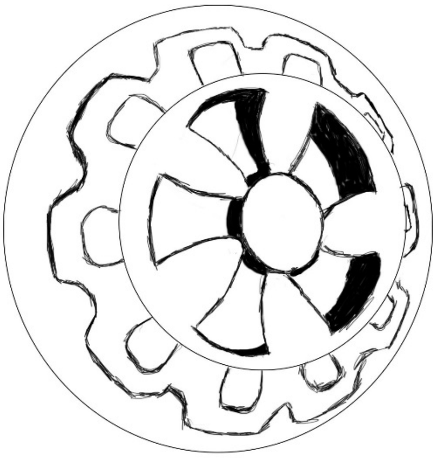


Figure 5.An inline wheel with a mechanical plastic locking inside the transparent rubber material

The idea was to mimic how an inline wheel is constructed but minimize the scale significantly so it could be applied for this project. As seen in the picture above, the rubber part is held together to the plastic material with the help of mechanical locks. This is possible due to the triangular spikes and hollow plastic construction which forces the rubber to mold around and through the component. A first draft inspired by the inline wheel was created.

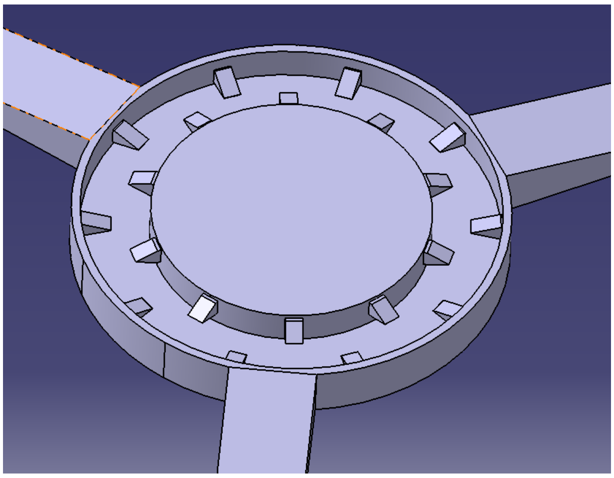


Figure 6. A Catia V5 model for the initial idea for concept 1's mechanical lock

When the first draft was visualized, further discussion led to a conclusion that the dimensions on the triangular spikes were too small and could only be created in theory but not in practice.

This led to a final reconstruction to get rid of that problem.

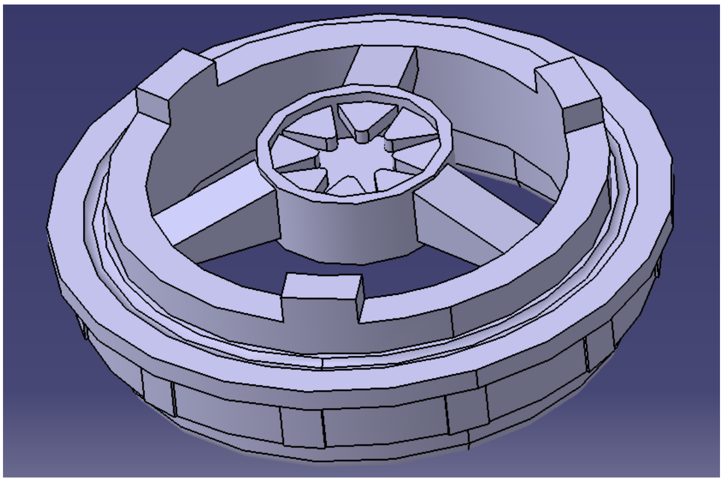


Figure 8. Upper view of concept 1, created in Catia V5

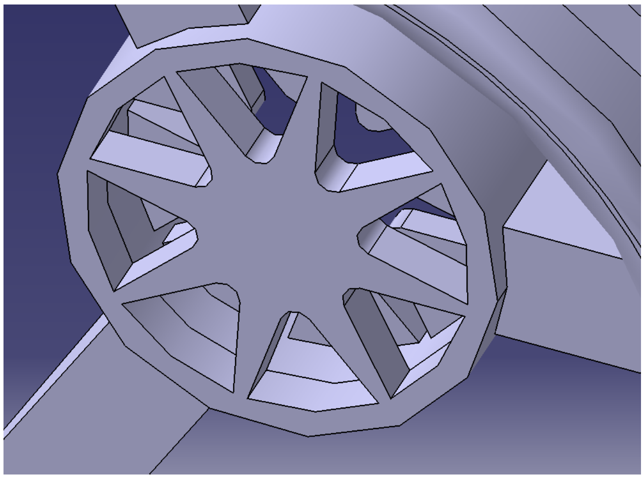


Figure 7. Bottom view of the concept, Catia V5

The final draft for Concept 1 is visualized above. Instead of adapting to what the product looks like today the inner circle was reconstructed. By creating more space to work with it became possible to make the triangular spikes bigger. To reduce the stress concentration at the ends for the triangular spikes, they were rounded. The idea is that the triangular spikes will work as mechanical locks so when the rubber in injected it will solidify around them. In addition to this mechanical lock, a chemical bond between the materials is sought. For the O-ring a trail was created to keep it in place when the rubber is injected. The O-ring will mainly be attached thanks to the chemical bonding.

4.2.2.2 Concept 2

When the first draft for the small triangular spikes was created, the development from that point divided into two separate directions. The first direction was Concept 1 that has been presented. The second direction was Concept 2. As earlier mentioned a big problem with the triangular spikes was the sharp edges, which lead to a high stress concentration. Instead of modifying the spikes a reconstruction on the mechanical lock was made. The triangular spikes were replaced with circular beams.

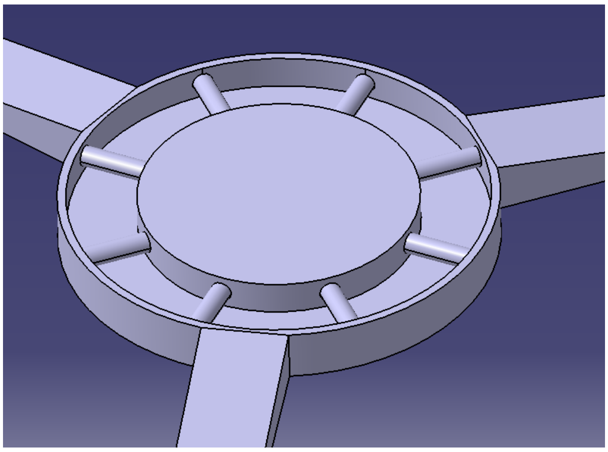


Figure 9. A Catia V5 model for the initial idea for concept 2's mechanical lock

Once again, the discussion lead to a conclusion that the beams dimension is too small to be constructed. A reconstruction of the inner circle lead to the final draft of Concept 2.

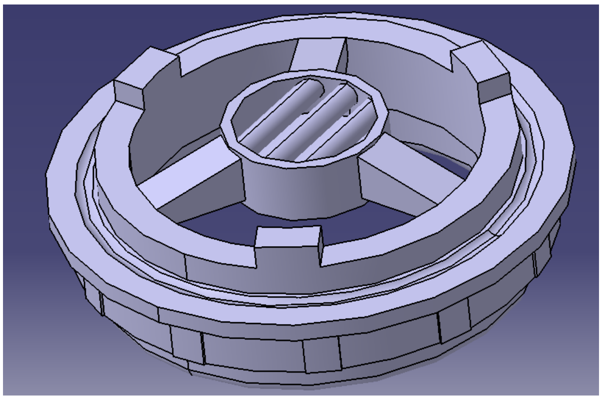


Figure 10. Upper view of concept two created in Catia V5

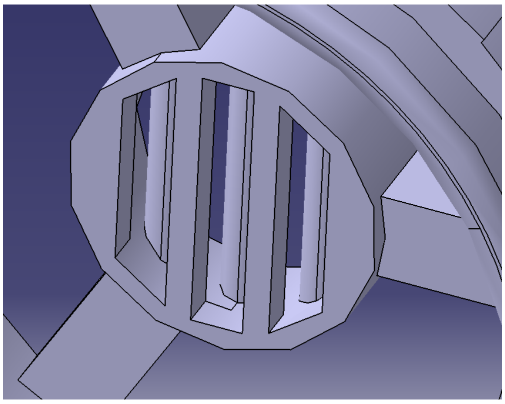


Figure 11. Bottom view of the concept, Catia V5

The reconstruction looks as following. Three circular beams are placed in the inner circle with dimensions that can be manufactured. To be able to construct these mechanical locks in the injection mold phase three holes were created directly underneath the beams which enables the machine to reach them. This solution almost eliminates the stress concentration because of the circular form. As in the previous concept this will mean that after the rubber is injected it will solidify under and around the beams creating a strong mechanical lock to keep the rubber in place. A chemical bond is also going to be sought. The O-ring will mainly be attached thanks to the chemical bond and the trail that guides it to the right place.

4.2.2.3 Concept 3

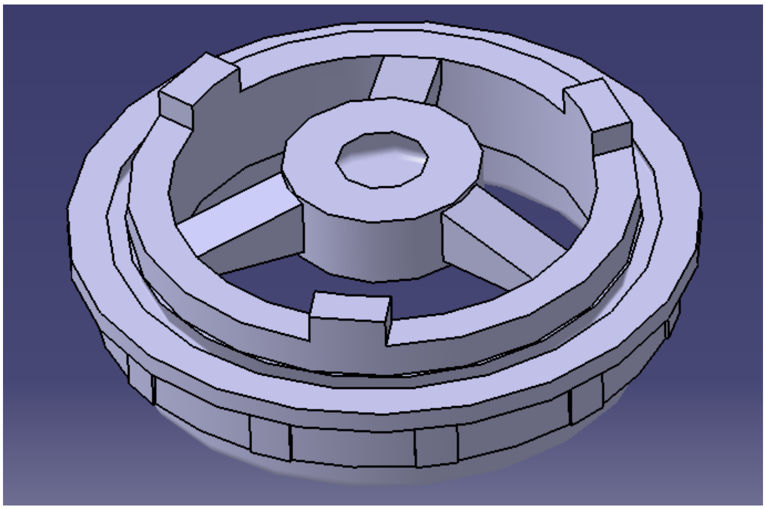


Figure 12. Upper view of concept three created in Catia V5

The third concept was also based on the idea of combining a mechanical lock with a chemical bonding. The difference between Concept 3 against the previous concepts is that the reconstruction directly works as a mechanical lock. A trapezoid cylindrical shape is constructed in the inner circle and a trapezoid trail is created for the O-ring in the outer circle. Both shapes have rounded edges to remove any stress concentrations. This reconstruction makes this concept both a simple solution for the mechanical lock and in the aspect of manufacturing, since the mold for the plastic injection will in theory be possible and easy to create.

The trapezoid trail also gives an opportunity for the O-ring to not only bond chemical but also mechanical.

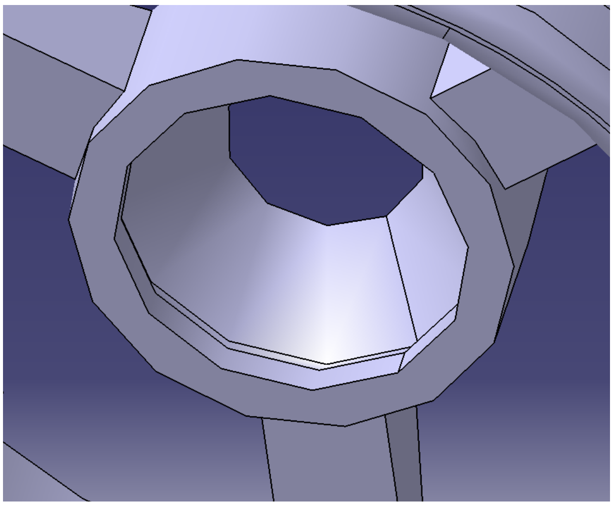


Figure 13. Bottom view of the concept, Catia V5

4.2.2.4 Concept 4

The fourth and final concept that was generated was an adhesive solution. The idea was to retain the existing product and remove the brass washer and the screw. Instead of the fasteners an adhesive product will be used. The adhesive product will be applied between the plastic and rubber material. As there already is a lowering trail in the inner circle on the existing product, it gives the possibility to use that space for the adhesive to harden and establish a good joining. Since the O-ring only needs to be held in place until it is inserted into the TA-Compact a discussion led to that no further reconstructions are necessary.

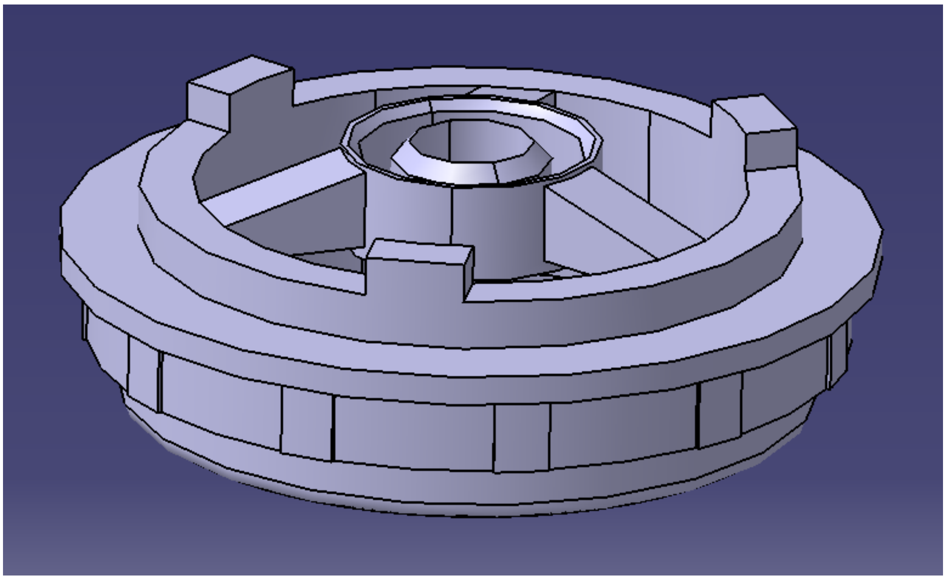


Figure 14. Upper view of concept four created in Catia V5

4.2.3 Manufacturing Processes for the Concepts

In order to successfully manufacture concepts 1, 2 and 3, 2k molding will be used. First the plastic material is injected and hardened and after that the rubber material is injected. The rubber will solidify under and around the individual mechanical locks which will lead to a strong joining. Since the two rubber components are apart and not connected, a customized mold is required. This mold will prevent an extra operation for the process. Instead of injecting the two rubber parts separately the whole process will be finished in two operations, one for injecting plastic and only one for injecting both rubber parts simultaneously. 2k Molding will also allow the possibility for a chemical bond since there are basically no restrictions on what materials can be used in the injection phase. This means that if the right materials are chosen a chemical bond will be achieved.

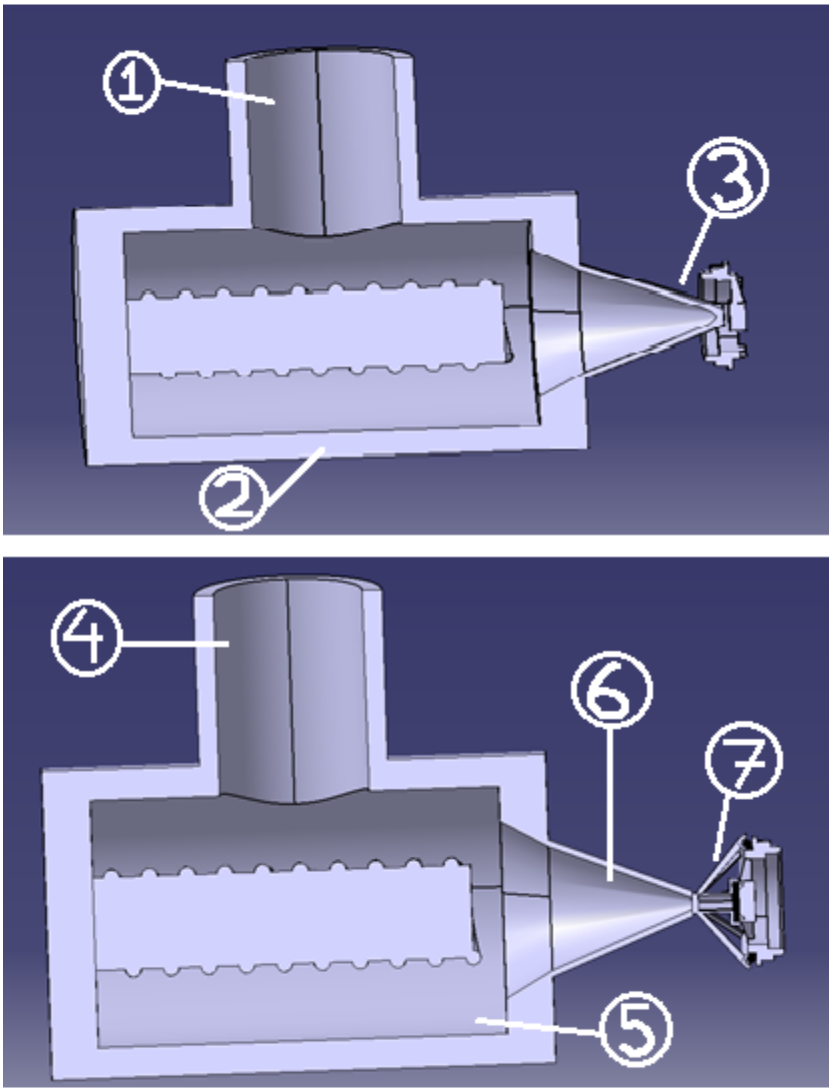


Figure 15. An illustration on the manufacturing process for 2k molding, created in Catia V5

In this picture, a visualization of how 2k molding would work on the concepts is shown. (1) Plastic pellets are loaded in a material hopper. When the pellets are in place they are then feed into the extruding barrel. The plastic pellets are then heated up (2) in the extruding barrel. The process then continuous with the injection (3) for the first material into a closed mold to form the initial part. The part is let to solidify and then transported to the second extruding barrel. The second phase is a replication of the first but with the rubber material instead. The second extruding barrel is equipped with a customized frame mold (7) so when the second phase reaches the injection phase (6) the material is spread through the customized frame mold onto the solidified plastic part. While the second phase is in production, the first phase has already started again which provides an efficient workflow for the production.

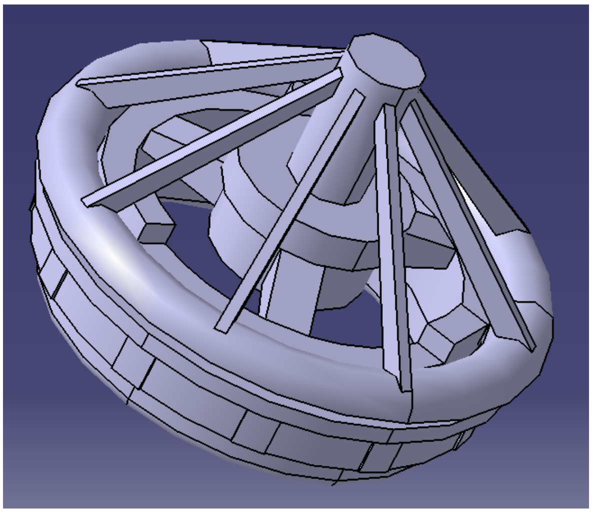


Figure 16.The customized frame mold for the injection molding phase when injecting the sealing material, created in Catia V5

Concept 4 will use adhesive products as its joining method. The manufacturing process will depend on the materials but there are a few phases that always has to be done regardless of the selection. In order to get a good adhesion, several different preparatory work has to be applied. This preparatory work often involves grinding, brushing and many other operating steps to create good adhesiveness on both material surfaces (see chapter 2.2).

4.3 Choosing a Concept

In this phase, the best concept for the valve seat is going to be picked. The choice will be made based on Pugh's matrix and an explanation on why a certain concept is chosen will be presented.

4.3.1 Pugh's Method with Relative Decision Matrix

Criterion	**Alternative**			
	1(ref)	2	3	4
Good mechanical bonding	**Reference**	+	-	-
Good chemical bonding		0	0	-
Stiffness		+	+	+
Fatigue strength		+	+	-
Process (Rubber)		0	+	-
Injection Process (Plastic)		+	+	-
Stress concentration		+	0	+
Sum +		5	4	2
Sum 0		2	2	0
Sum -		0	1	5
Net value	0	5	3	-3
Ranking	3	1	2	4
Further development	No	Yes	No	No

Matrix 1. A presentation of the results using Pughs method with relative decision matrix.

In Pugh's matrix each concept is compared to a reference according to certain criteria. These criteria were chosen after what requirements were set to the final product. Since no materials had been selected it was assumed that every concept had the same material and they were judged only by the constructional benefits. The first criteria that was compare was what probability the concepts had to achieve good mechanical and chemical bonding strength based on their designs. How well the design would achieve a good stiffness was also compared. Since the final product must be able to cope with tough conditions over a long period of time it is of greatest importance that it attains good fatigue strength. The simplicity of the designs to be used in both the plastic and rubber processes was also evaluated. The last criteria that was assessed was the constructions ability to cope with high stress concentrations. After all the comparisons were complete, it was easy to see which concepts showed the best results. Concept two and three were the ones that had the highest score. Since both concepts were based on the same principle were it contains mechanical locks and similar design a decision was made. Concept two was selected as the best solution for the problem in hand due to its superior design in the aspects of both mechanical locking and the ability to repel stress concentrations.

4.3.2 Material Choice-CES

The most important part of this project lies in the material choice. If the wrong materials are chosen it can lead to no chemical bonding and results in a bad adhesion. To get a chemical bonding the materials needs to have similar surface chemistry which is impossible to achieve with the current materials that are used on the existing product. The valve seat today uses PPS (Polyphenylene Sulfide) as its plastic material and EPDM (Ethylene Propylene Diene Rubber) 70 shore for the rubber material. Since the differences between these materials surface chemistries are too significant it was decided that other materials would work better for molding. The main problem lied in the rubber material since it is difficult to make them compatible with plastic materials. The main function of the rubber material was to have a good sealing ability. To solve this problem the rubber material was completely replaced with a TPE material. TPE materials have similar surface chemistry as plastic materials but show rubberlike properties.

The choice was based on how well different materials are compatible with each other and how well they met the set requirement. Since the product operates in a valve the requirements were that it could handle a service temperature between -10 to 90 degrees. Water resistance and good fatigue strength was also crucial. With the help of the program CES EduPack it was possible to find a material that reaches every set requirement.

The first combination of materials that were chosen were Polyoxymethylene with 25 % glass fiber (POM-GF25) for the plastic component and TPS SEBS (TPS-S) for the sealing components. These two materials show great compatibility and their surface chemistry are similar which makes for a strong chemical bond. By studying these materials in CES EduPack it was clear that they passed all the set requirements.

General information				
Designation				
Polyoxymethylene, acetal (copolymer,25% glass fiber, coupled)				
Composition detail (polymers and natural materials)				
Polymer	75			%
Glass (fiber)	25			%
Thermal properties				
Melting point	160	-	180	°C
Glass temperature	-60	-	-50	°C
Maximum service temperature	93	-	107	°C
Minimum service temperature	-50	-	-40	°C
Durability				
Water (fresh)	Excellent			
Water (salt)	Excellent			
Weak acids	Acceptable			
Strong acids	Unacceptable			
Weak alkalis	Excellent			
Strong alkalis	Excellent			
Organic solvents	Acceptable			
Processing properties				
Polymer injection molding	Acceptable			

Table 3. General information about the plastic material POM-GF25, CES EduPack

POM-GF25 shows great characteristics to be used in a valve component. In addition to that it also has similar properties as the currently used plastic material PPS in the existing product.

As seen in the picture above, CES shows that POM-GF25 has Excellent durability in fluids and the Thermal properties confirms that its maximum and minimum service temperatures from -50 to 107 degrees passes the requirements range. The material is also suited for injection molding processes which is what will be used in the production of the product.

General information

Designation

Styrene Ethylene Butylene Styrene Block Copolymer

Composition detail (polymers and natural materials)

Polymer	100	%

Thermal properties

Glass temperature	* -58	-	-42	°C
Maximum service temperature	* 90	-	125	°C
Minimum service temperature	* -41	-	-21	°C

Durability

Water (fresh)	Excellent
Water (salt)	Excellent
Weak acids	Excellent
Strong acids	Limited use
Weak alkalis	Excellent
Strong alkalis	Excellent
Organic solvents	Unacceptable

Processing properties

Polymer injection molding	Acceptable

Table 4. General information about the sealing material TPS-S, CES EduPack

The reason for why TPS SEBS (TPS-S) was chosen lies in its compatibility to plastic material such as Polyoxymethylene. TPS-S also comes in many variation and its flexibility in hardness (range between 0 Shore A - 65 Shore D) makes it a perfect sealing material. Its service temperatures from -41 to 125 degrees are within the set range and its durability in water is Excellent. As the POM-GF25 material, TPS-S also can be used in an injection molding process which allows the use of both materials in a 2K molding process for the manufacturing of the valve seat.

There are many different variations of POM and TPS materials. With the help of Camilla Klässbo from Hexpol TPE and Magnus Harrysson from Celanese, specific data sheet for the materials were provided. The data sheet for the TPS material can be seen in Appendix 2 and the data sheet for the POM can be seen in Appendix 3.

There was a different material combination that was studied in the early stages of the material choice phase. That combination consisted of an impact modified Polypropylene plastic with 30 percent glass fiber (PP-I-GF30) combined with a TPS. By all the data that was gathered about the PP-I-GF30 it was a strong candidate for the material choice but after consulting with the company IMI Hydronic a decision was made to not move forward with this plastic material. The reason for that was that they were questioning the material PP-I-GF30 abilities to maintain its qualities during a long period of time.

4.3.3 DFA2 on the New Concepts

At this stage, a new product has been created. This step is important because it gives a clarification of how the new product compares versus the existing product in the valve seat today.

As the results illustrates (Appendix 4) there were significant differences between this DFA2 analysis versus the DFA2 analysis performed on the existing product (Appendix 1). The biggest change is that the whole product now only consist of two components since the materials are molded together. This result is an improved aggregate score. The new aggregate score is 182 or 84 percent. As earlier explained the searched goal was to get an aggregate score over 80 percent which has been accomplished. The aggregate time for the total assembly is slightly higher than for the existing product, but this can be explained with the fact that a molding process requires more time than manual and automatic assembly process that used today.

4.3.4 DFMEA on the New Product

DFMEA is an important method used when developing a product. It helps the company to evaluate what errors that can occur and prevent them from happening. A DFMEA analysis was made for the new product where different possible failures were evaluated. As the results imply (Appendix 5) there are several different failures that can possibly occur. It's also clear that many of these failures depend on the choice of materials for the product. Therefore, as previously told, it is essential that the material choice is correctly executed and all aspects have been taken into consideration. Testing the materials at the set requirements is essential to ensure that the material maintains its abilities. The results also show that several actions already have been thought of and executed with the help of right reconstructions in the concept generation phase.

4.3.5 Cost Evaluation on the New Product

The cost evaluation on the new product was a challenging phase to complete. The main problem lied in what type of machinery that was desired for the specific shapes of the mechanical locks on the new product. The unit volume per year and other external costs also needed to be taken into consideration when analyzing how much the new product would cost. Thanks to Marika Rudén at PlastInject AB a rough price evaluation was created. The costs are calculated in percentage form based on the total cost of the existing product.

In the pricing, an analysis was made on how much the raw material would cost per detail, how much the process would cost per detail, the tool cost per item and the staff cost for the packing of the product. As the results show (Appendix 6) the total cost for manufacturing this product was calculated to 54.3% of the total cost on the existing product. With this result, it is clear to see that the new product is significantly cheaper than the existing product but as the pricing on the new product is a rough estimate, there may be additional costs that haven't been considered.

5. Discussion

In this chapter, an analysis on the results throughout the entire project will be presented. Discussions about how the work has been carried out and decision-makings will also be included in this chapter.

5.1 Pre-study

The ability of solving difficult problems lies in what knowledge a person has of the problem subject. For that reason, a pre-study was essential for this project. Given that the preliminary study provides a basis for the upcoming work, it was extra important that it was properly executed. The pre-study in this project was aimed into understanding everything about the existing product and its area of work. All the products parts and their functions were analyzed to get as clear a picture as possible about where and why the problem exists. Due to the time limit for this project it was decided that no more analyses will be made on the existing product.

5.1.1 Existing Product

As mentioned the first step was the analysis of the existing product. The results of taking the product apart an observing it was of greatest value due to its importance in later stages of this project. It also resolved in an early observation that there was a possibility to reconstruct the plastic component to gain as much work area as possible for the solution to join plastic with rubber materials. The material choices for the existing product also gave a lot of information on how other material choices needs to adapt in order to maintain the same durability and quality. Since this dimensionally small product consists of 5 separate parts it was also easy to see why this is a problem that IMI wants to get rid of.

5.1.2 Fasteners

The fasteners on the existing product is the main problems in today's production of the valve seat. It consists of a brass washer and a stainless-steel screw. Their function in the valve seat is to keep the small rubber component in place, besides this they are essentially unnecessary. As the results of the observation showed the usefulness of the fasteners versus the difficulties of applying them makes it easy to see that they are not profitable in a long-term perspective. This is due to the fact that the company was forced to buy an assembly lined machinery to be able to execute the work in a high rate. This information also confirmed why this project is important for the company since it can eliminate the machinery completely from the production phase.

5.1.3 DFA2 on the Existing Product

At this stage all the information on the existing product had been gathered and an analysis was executed to determine where the problem lies with the help of the DFA2 method. The result of the DFA2 analysis showed where the valve seat is in the aspect of effective constructing. The results showed that the aggregate score for the whole product lied under

70% which meant that there was room for improvement. As expected the DFA2 analysis helped to answer its main question on what components that can be eliminated. The analysis confirmed that the main problems of the construction is located in the use of fasteners. Now that there was confirmation from both IMI Hydronic and a reliable method, the work could continue to the next phase.

5.1.4 Cost Evaluation of the Existing Product

The costs for the materials and the manufacturing of the existing product showed that the manual assembly was the most expensive part of the production. Since this project main aim is to find a solution to join plastic and sealing materials together this cost should be eliminated. This doesn't mean that the total cost will reduce for the new product but it creates opportunities for a cost reduction.

5.2 Concept Generation

It is a difficult task to generate concepts when there only are two people in a group. Usually when using methods like brainstorming there are groups of 5-10 people which can provide a wider range of ideas and concepts. But detailed discussion led to many different solutions for the concept and even if not all of them were great, four main candidates could move on and eventually a final concept was chosen. For each concept, a 3D model in Catia V5 helped the evaluation of the concepts since it is always easier to discuss and suggest improvements when there is a visualization of it.

5.2.1 Design Strategy

The material choice for the final concept was the most important step of this project. As everybody knows there are hundreds of different plastics and sealing materials which means that a method needed to be applied to shorten the list to just a handful of materials to pick from. To be able to shorten the list of materials a design strategy method was applied. All the requirements were set to the table which showed what a material had to accomplish for it to be applied on the product. As expected the Design-strategy eliminated a large group of plastic and sealing materials which led that the material choice was one step closer to the final goal.

Even if the design strategy did fulfill its purpose there was room for improvement. An improvement could have been to use more constraints which would have eliminated even more materials.

5.2.2 Concepts

The concept generation phase was the most challenging part of this project. The reason for that is simple. The problem in joining plastic with rubber materials is the difficulties in getting a strong bond which meets the qualitative requirements that were set. Thanks to the brainstorming phase the idea of mechanical locks occurred which was fundamental. When the first step of the brainstorming step was complete there was one specific idea that stood out from the rest. Further evaluation of that idea led to three different concept solutions on how a mechanical lock could look on the plastic component.

5.2.2.1 Concept 1

The first concept ascended from the construction of an inline wheel. Inline wheels often uses plastic and rubber material and therefore It was a good first step to see how it could look if the same design was used for the valve seat. As the Result chapter shows the concept is built by triangular shaped mechanical locks which is similar to the mechanical lock in the inline wheel. The overall concept was good but there were a few concerns. The main concerns lied in how well this construction could handle stress concentrations. Another concern was if this constructions dimensions were stable enough to avoid fractures when forces are applied.

5.2.2.2 Concept 2

The second concept was also based on a construction with mechanical locks but there was one big difference between the concepts. The design of the mechanical lock was reconstructed to cylindrical beams instead of the triangular spikes. The reason for that was that this solution could possibly solve the situation for the stress concentrations that the construction is exposed to.

5.2.2.3 Concept 3

As earlier mentioned the first three concept were based on some sort of a mechanical lock. The previous two concepts had mechanical locks constructed into the plastic component. The third concepts mechanical lock was created by the concepts design. The design was constructed in a way which meant that when the sealing material was injected it would solidify in this cylindrical trapezoid. Due to the shape, it wouldn’t be able to move. Since the construction is thin in the middle section, a concern was how well it could handle forces without breaking.

5.2.2.4 Concept 4

Since all the previous concept are based on reconstruction the idea for the fourth concept was simple. Keep everything as it is and use an adhesive product for the joining method. The questions here were if anything needed to be changed or not for it to work and a decision to keep the original design was made.

5.2.3 Manufacturing Processes for the Concepts

When all the concept was presented the next phase was to decide what sort of joining method will be used and how it will be manufactured. For the first three concepts 2k molding was chosen. Even if it is not certain that this molding method will work on these three concepts, it was decided that the possibility for the method to succeed is high by studying other products that have been produced by 2k molding. For the fourth concept the only requirement that needs to be done to get a good adhesion was preparatory work before using adhesive products. Preparatory work is necessary and even if it is a long and difficult process to make the materials compatible it is a process that has been done on many different products on the market today.

As the results show 2k molding is the optimal molding method to manufacture the three first concepts. As presented the molding phase will be performed in two steps. The first step is going to be to inject the plastic material into closed mold and let it solidify. The next step is to perform the exact same operation for the sealing material but there was one small problem. Since the rubber component was not connected to each other, the process would require two operations. One for the small sealing component and one for the sealing O-ring. A solution for this problem was to create a customized frame mold which with the help of channels would spread the sealing material to where both locations at the same time. This solution reduces one operation, which will reduce the manufacturing cost for the 2k molding process. If there were more time for this project all these solutions would have been tested so it could be confirmed that they work on these concepts.

5.3 Choosing a Concept

Now when all the concepts have been generated it was time to choose one of them as a final product for this project. All the results leading to this final concept will now be analyzed and discussed.

5.3.1 Pugh's Method with Relative Decision Matrix

When all the concepts and their manufacturing processes had been presented it was time to choose one of these to as the final product. The Pugh's matrix gave the opportunity to compare each concept to each other and choose the best one. As the results show the concept that was prized as the best was concept two. The main reasons for this was its superiority in good mechanical bonding and its ability to handle stress concentrations. When analyzing the results of the Pugh's matrix it is also easy to see how inefficient the solution of an adhesive products bonding is versus a chemical and mechanical bond by molding. The outcome of the result was also somehow expected since there already was a discussion on how the stress concentration would affect the concepts and it is a logical result that the concept with the circular beams would handle it the best.

5.3.2 Material Choice-CES

To get the chemical bond that was wanted it was crucial to choose the right materials to combine with each other. This was also why this phase was one of the most important parts of the whole project. To get the right materials a study during several weeks was executed.

Early on in this phase it got clearer and clearer that the main problem lied in the rubber materials. The difficulties lied in finding a rubber material with similar surface chemistry as a plastic material and in addition to that reach all the set requirements. Depending on that the rubber material was replaced with a TPE material which is a plastic material with rubberlike properties.

This led to two specific material combinations. At first the two materials that were chosen was impact modified Polypropylene with 30 percent glass fiber (PP-I-GF30) combined with a TPS SEBS plastic. These two material could achieve a great chemical bond and both materials could be used in 2k molding. When this solution was presented to the company IMI Hydronic a concern was raised. The concern lied in the plastic material where they were questioning if Polypropylene could achieve a long service life due to the forces and temperatures that are applied on the product. Therefore, another plastic material was chosen.

The plastic that replaced PP-I-GF30 was a plastic material called Polyoxymethylene with 25% glass fiber (POM-GF25). Since this was a material that IMI Hydronic had worked with before the company knew that this materials quality is good enough to achieve a good result when dealing with temperature differences and keeping a long service life at the same time. Thanks to TPS-SEBS ability to chemically bond with different types of plastic it still worked with a POM-GF25 plastic material.

The final results for the material choice became POM-GF25(Appendix 3) for the plastic component and TPS-SEBS (Appendix 2) for the sealing components. These two materials achieve every possible requirement that was set and can be used in a 2k molding process. They also show great properties in maintaining the same quality as the existing product.

5.3.3 DFA2 on the New Concepts

The results that the DFA2 analysis showed on the new product was expected. Since the task was to eliminate the fasteners it is logical that without them the product scores a higher total aggregate score. The results on aggregate time was also somehow expected since molding components will take longer time than manually assemble the rubber components such as the rubber O-ring. Overall the results from the DFA2 analysis shows that there has been a big improvement when comparing it to the previous DFA2 analysis on the existing product, which suggests that the project has been executed in the right way and accomplished a good result for a final product.

5.3.4 DFMEA on the New Product

As mentioned a DFMEA can help to predict what possible failures can occur with a product and prevent it from ever happening. The results of the DFMEA on the new product showed once again how important the right material choice is. Since this project only bases its results on methods and literature it was clear that tests regarding the materials and manufacturing processes will be needed to ensure that this product not only works in theory but also in real service environment. The tests are also required for some decisions based on recommendations to prevent possible failures. Thanks to right reconstructions in the concept generation phase a few problems have already been evaluated and actions have been implemented to prevent some failures. With more time there is a possibility to improve the construction even more.

5.3.5 Cost Evaluation of the New Product

The pricing of the new product resulted in a significant lower price than the existing product. The new product was 45.7% cheaper than the existing product which is a fantastic result. An important aspect to keep in mind is that when the cost calculation was carried out it was a rough estimate of how much the new product would cost. This results in a grey zone where the actual price of the product can be higher than calculated. After some discussion it was decided that this isn't a problem since even if the price reaches the same cost as the existing product it would benefit the company. The reason for this is that the production today at IMI Hydronic Engineering requires a fitter that assembles the rubber O-ring. The idea for the new product is that it will be delivered completely finished from a sub-contractor to IMI Hydronic which means that even if the price is similar IMI will have a free fitter that can work on other tasks.

6. Conclusion

A last evaluation of the results and what this project has achieved will be presented in chapter six. The question that were realized in the beginning of this project will be answered and discussed. The last part will be a recommendation on future work for the company IMI Hydronic Engineering.

6.1 Evaluation of the Result

In the beginning of this project a discussion with the company was held on what the purpose and objective was for this project. The given information was simple. The task was to find a way to mold together the plastic component with the rubber components to reduce five components that the valve seat consists of to only one part. With no more information on the task it was decided to put together a few questions. The questions were aimed at three subjects: the dimension of the new product, the price of the new product and the manufacturing of the new product (see Chapter 1.3).

To ensure that the questions had been answered a closer look on the final result was performed. Regarding the first question:

- Will the new product be able to fit in the TA-Compact and maintain same performance rate?

The answer was simple. Yes, based on information. One of the most essential and time-consuming phase was to make the concepts as 3D models with the right dimension from the beginning and choosing materials that will be able to provide the same quality in its service life as the existing product. These tasks were completed and both the 3D model in Catia V5 and the material choices of TPS-S and POM-GF25 that have been made will be able to reach the set requirements, but there is one issue. Since this project main goal was to find a solution based on information and methods, no tests have been executed. Therefore, the company IMI needs to perform these tests to ensure that the material choice and the construction, works in practice.

The second question that needed an answer was:

- Will the new product be cheaper than the existing?

Ones again the answer is “Yes”. From the calculations that were made it indicates that the new product will be 45.7% cheaper than the existing product. The only concern here was that to get an exact price for the manufacturing of the product, different analyses from a sub-contractor on different 2k machineries, needs to be executed. Since these analyses haven’t been performed the pricing of the new product have been based on a rough cost calculation. This means that the price for the new product can be higher than calculated. However, this is no major problem as the total cost will still either be lower or at worst, the same as on the existing product. Even if assuming the worst it will still benefit the company since they will be able to replace one fitter that assembles the rubber O-ring to another production area.

The third and final question that was put together was:

- What is the optimal way to produce the new product regarding quality?

2k molding is the optimal manufacturing process for this product. This method is frequently used on many different applications where two different materials are molded together. As Marika Rudhén at PlastInjekt AB explained there are different types of machineries in 2k molding. To get the best possible result of the 2k molding process regarding the quality the right machinery needs to be selected. Since the new product hasn't reached the prototype phase it is impossible to determine what machinery that should be picked. To determine this, different tests needs to be performed and evaluated.

6.2 Recommendations

The solution in this project has been based on research and information from sub-contractors and literature. A recommendation for the company IMI Hydronic is to create a prototype based on the solution presented in this project. This prototype needs to consist of the two materials that were researched, TPS-S and POM-GF25, and the applied joining method should be 2k molding. The mechanical lock isn't necessary in the first prototype phase since the most important step is to evaluate if the molding process will bond the materials and create a strong adhesion. When a prototype is created, tests in a laboratory should be performed to evaluate how well the prototype meets the set requirements. If the tests are successful, a possibility is to examine if this solution can be replicated on other products, which consists of rubber and plastic materials and are forced to use fasteners to join the materials.

7. References

Ashby, M. F., Shercliff, H., & Cebon, D. (2014). *Materials: Engineering, science, processing and design* (2.th ed.). Oxford: Butterworth-Heinemann.

Goodship, V., Love, J. C., Rapra Technology Limited, ebrary, I., & Ebook Central (e-book collection). (2002). *Multi-material injection moulding*. Shrewsbury, U.K: Rapra Technology. Retrieved from http://www.lib.chalmers.se/

Johannesson, H., Persson, J., & Pettersson, D. (2004). *Produktutveckling - effektiva metoder för konstruktion och design*

Klason, C., Kubát, J., Boldizar, A., & Rigdahl, M. (2008). *Plaster: Materialval och materialdata* (6. uppl. ed.). Stockholm: Liber

8. Appendix

Appendix 1

DFA2 analysis on the existing product

Komponent	Need to assemble part	Gripping by hand	Reachability	Insertion	Tolerances	Holding assembled parts	Fastening method	Separate operations	DFA Score Score	Score (%)	Agg Score	Agg Score (%)	Time	Agg Time	Agg Time (%)
Valve seal []									0		240	67%		20	133%
Plastic component [] [1 st]	9	9	9	9	9	9	9	9	72	100%			3		
Rubber sealing [] [1 st]	9	3	9	3	3	3	9	1	40	56%			3,4		
Brass washer [] [1 st]	1	9	9	3	1	3	9	1	36	50%			3,6		
Screw [] [1 st]	1	9	9	3	1	9	3	9	44	61%			6,6		
O-ring [] [1 st]	9	3	9	3	3	3	9	9	48	67%			3,4		

Appendix 2

The data sheet for the material TPS-S provided by Camilla Klässbo from the company Hexpol TPE

Dryflex® TPE

Reg.No *A5 660700*
Issue *1*
Doc.Date *30.01.2017*
Issued by *CC*
Production *HEXPOL TPE AB*

Preliminary datasheet

A5 660700

General

Dryflex A5 660700	Thermoplastic Elastomer
Material Type	TPS-SEBS
Hardness	70 Shore A (4mm)
Service Temperature Range	-50 - +125 °C (unstressed material)
Colour	Natural, but can be available in any colour.
Presentation	Free flowing pellets that can be processed without predrying, when stored under normal conditions.
Weather Resistance	Good
Chemical Resistance	Good (excluding organic solvents, aromatic- and vegetable oils)
Recyclability	100% recyclable

Special Features

The material has good adhesion to POM.

Processing

The material has excellent processing characteristics and can be processed using conventional thermoplastic fabricating methods, including injection moulding and extrusion.

Processing Temperatures	Injection Moulding	Extrusion
Barrel Temperatures °C	210 - 250	210 - 250
Mould Temperatures °C	30 - 60	

Typical Properties

Property	Units	Typical Value	Test Method
Hardness	Shore A (4mm)	70	ASTM D 2240
Specific Gravity	g/cm³	1,12	ASTM D 792
Tensile Strength	MPa	7,5	ASTM D 638
Tear Strength	kN/m	35	ASTM D 624
Modulus at 100% Strain	MPa	2,9	ASTM D 638
Modulus at 300% Strain	MPa	4,2	ASTM D 638
Elongation at Break	%	700	ASTM D 638
Melt Flow Rate	g/10 min 230°C/2,16kg	25	ASTM D 1238
Compression Set			
72 hours at 23°C	%	24,0	ASTM D 395
22 hours at 70°C	%	49,0	ASTM D 395

HEXPOL TPE

info@hexpolTPE.com
www.hexpolTPE.com

Appendix 3

The data sheet for the material POM provided by Magnus Harrysson from the company Celanese.

Celanese
The chemistry inside innovation

HOSTAFORM® C 9021 GV1/30 - POM

Description

Chemical abbreviation according to ISO 1043-1: POM Molding compound ISO 9988- POM-K, M-GNR, 02-003, GF26 POM copolymer Injection molding type, reinforced with ca 26 % glass fibers; high resistance to thermal and oxidative degradation; reduced thermal expansion and shrinkage. UL-registration for all colours and a thickness more than 1.57 mm as UL 94 HB, temperature index UL 746 B electrical 105 °C, mechanical 95 °C (tensile impact) and 100 °C (tensile). Burning rate ISO 3795 and FMVSS 302 < 100 mm/min and a thickness more than 1 mm thickness. Ranges of applications: For molded parts with very high strength and rigidity as well as higher hardness. FMVSS = Federal Motor Vehicle Safety Standard (USA) UL = Underwriters Laboratories (USA)

Physical properties	Value	Unit	Test Standard
Density	1600	kg/m³	ISO 1183
Melt volume rate, MVR	4	cm³/10min	ISO 1133
MVR temperature	190	°C	ISO 1133
MVR load	2.16	kg	ISO 1133
Water absorption, 23°C-sat	0.9	%	ISO 62
Humidity absorption, 23°C/50%RH	0.17	%	ISO 62

Mechanical properties	Value	Unit	Test Standard
Tensile modulus	9200	MPa	ISO 527-2/1A
Tensile stress at break, 5mm/min	135	MPa	ISO 527-2/1A
Tensile strain at break, 5mm/min	2.5	%	ISO 527-2/1A
Tensile creep modulus, 1h	7700	MPa	ISO 899-1
Tensile creep modulus, 1000h	5400	MPa	ISO 899-1
Flexural modulus, 23°C	7800	MPa	ISO 178
Flexural strength, 23°C	165	MPa	ISO 178
Charpy impact strength, 23°C	30	kJ/m²	ISO 179/1eU
Charpy impact strength, -30°C	35	kJ/m²	ISO 179/1eU
Charpy notched impact strength, 23°C	8	kJ/m²	ISO 179/1eA
Charpy notched impact strength, -30°C	8	kJ/m²	ISO 179/1eA
Ball indentation hardness, 30s	200	MPa	ISO 2039-1

Thermal properties	Value	Unit	Test Standard
Melting temperature, 10°C/min	166	°C	ISO 11357-1/-3
DTUL at 1.8 MPa	160	°C	ISO 75-1, -2
DTUL at 8.0 MPa	125	°C	ISO 75-1, -2
Vicat softening temperature, 50°C/h 50N	158	°C	ISO 306
Coeff. of linear therm expansion, parallel	0.4	E-4/°C	ISO 11359-2
Coeff. of linear therm expansion, normal	0.8	E-4/°C	ISO 11359-2
Flammability @1.6mm nom. thickn.	HB	class	UL 94
thickness tested (1.6)	1.6	mm	UL 94
UL recognition (1.6)	UL	-	UL 94
Flammability at thickness h	HB	class	UL 94
thickness tested (h)	3.18	mm	UL 94
UL recognition (h)	UL	-	UL 94

Electrical properties	Value	Unit	Test Standard
Relative permittivity, 100Hz	4.3	-	IEC 60250
Relative permittivity, 1MHz	4.3	-	IEC 60250
Dissipation factor, 100Hz	30	E-4	IEC 60250
Dissipation factor, 1MHz	60	E-4	IEC 60250
Volume resistivity	1E12	Ohm*m	IEC 60093
Surface resistivity	1E14	Ohm	IEC 60093
Electric strength	40	kV/mm	IEC 60243-1
Comparative tracking index	600	-	IEC 60112

Test specimen production	Value	Unit	Test Standard
Processing conditions acc. ISO	9988	-	Internal

Created: 11.May.2016 Source: www.materialdatacenter.com Page: 1/4

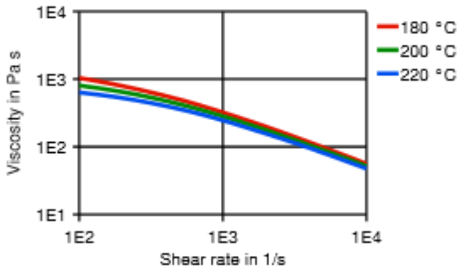
HOSTAFORM® C 9021 GV1/30 - POM

Injection Molding, melt temperature	**205**	°C	ISO 294
Injection Molding, mold temperature	**90**	°C	ISO 294
Injection Molding, injection velocity	**200**	mm/s	ISO 294
Injection Molding, pressure at hold	**90**	MPa	ISO 294

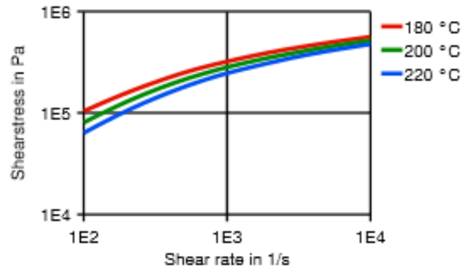
Rheological calculation properties	**Value**	**Unit**	**Test Standard**
Density of melt	**1350**	kg/m³	Internal
Thermal conductivity of melt	**0.215**	W/(m K)	Internal
Spec. heat capacity melt	**1810**	J/(kg K)	Internal
Eff. thermal diffusivity	**6.51E-8**	m²/s	Internal
Ejection temperature	**140**	°C	Internal

Diagrams

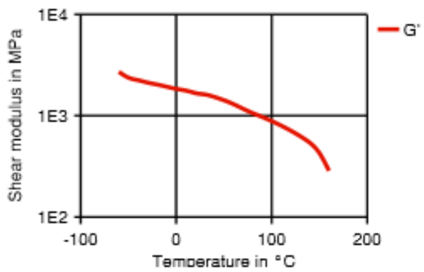
Viscosity-shear rate



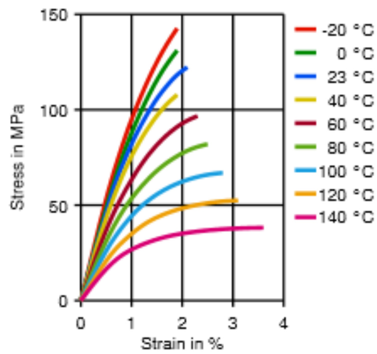
Shearstress-shear rate



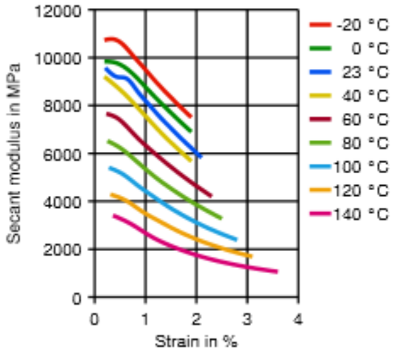
Dynamic Shear modulus-temperature



Stress-strain



Secant modulus-strain



Typical injection moulding processing conditions

Pre Drying	Value	Unit	Test Standard
Necessary low maximum residual moisture content	0.15	%	-
Drying time	3 - 4	h	-
Drying temperature	100 - 120	°C	-
Temperature	**Value**	**Unit**	**Test Standard**
Hopper temperature	20 - 30	°C	-
Feeding zone temperature	60 - 80	°C	-
Zone1 temperature	170 - 180	°C	-
Zone2 temperature	180 - 190	°C	-
Zone3 temperature	190 - 200	°C	-
Zone4 temperature	190 - 210	°C	-
Die temperature	190 - 210	°C	-
Melt temperature	190 - 210	°C	-
Cavity temperature	80 - 120	°C	-
Hot runner temperature	190 - 210	°C	-
Pressure	**Value**	**Unit**	**Test Standard**
Back pressure max.	20	bar	-
Speed	**Value**	**Unit**	**Test Standard**
Injection speed	slow	-	-
Screw Speed	**Value**	**Unit**	**Test Standard**
Screw speed diameter, 25mm	150	RPM	-
Screw speed diameter, 40mm	100	RPM	-
Screw speed diameter, 55mm	70	RPM	-

Other text information

Pre-drying

Drying is not normally required. If material has come in contact with moisture through improper storage or handling or through regrind use, drying may be necessary to prevent splay and odor problems.

Longer pre-drying times/storage

The product can then be stored in standard conditions until processed.

Injection molding

Standard injection moulding machines with three phase (15 to 25 D)
plasticating screws will fit.

Melt temperature 190-210 °C
Mould temperature 80-120 °C

Appendix 4

DFA2 analysis on the new product

Komponent	Need to assemble part	Gripping by hand	Reachability	Insertion	Tolerances	Holding assembled parts	Fastening method	Separate operations	DFA Score						
									Score	Score (%)	Agg Score	Agg Score (%)	Time	Agg Time	Agg Time (%)
Valve Seal []									0		182	84%		25,6	284%
Plastic component [] [1 st]	9	9	9	9	9	9	9	9	72	100%			3		
O-ring [] [1 st]	9	9	9	3	3	9	1	9	52	72%			11,4		
Rubbersealing [] [1 st]	9	9	9	9	3	9	1	9	58	81%			11,2		

Appendix 5

DFMEA on the new product

DFMEA (Failure Mode and Effects Analysis - Feleffektanalys)

Main system	Artikelbenämning/Part name.	Ritn nr/Dwg No.	Leverantör/Supplier
TA-Compact	**Valve seat**	-	-

Funktion/Function	Datum/Date	Utförd av/Issued by	Status - hårdvara/Status - hardware	Projekt/Project	Utgåva/Issue
Sealing	**1931-05-17**	**Viktor Keric &Mikael Mousavi**	-	**Rubber on plastic**	1

ARTIKEL/PART		FELKARAKTÄRISTIK/CHARACTERISTICS OF FAILURE			RATING				ÅTGÄRD-STATUS/ACTION-STATUS						
Nr/ No	Funktion/ Function	Feltyp/ Failure mode	Felorsak/ Causes of failure	Feleffekt på komponent/syst.	Failure probability	Seriousness of the failure	Probability of detecting the failure	RPN	Rekommenderad åtgärd/ Recommendations	Beslutad åtgärd/ Decisions taken	Failure probability	Seriousness of the failure	Probability of detecting the failure	RPN	Ansvar avd/sign
	Mechanical Lock	Deformation of the beams	Internal stress	Shorter service life and deterioration of adhesion	4	7	7	196	Thicker diameter on the beams and testing	Reconstructed the beams with additionally 0,2 mm in diameter	2	7	7	98	Viktor Keric & Mikael Mousavi
			Manufacturing process	Shorter service life and deterioration of adhesion	3	7	5	105	Change manufacering process						
	Plastic component	Breakage	Low tensile strenght on the material	The component can no longer regulate water flow and is therefore unusable	3	10	3	90	Chose material with high tensile strenght	The plastic material POM-GF25 which has a high tensile strenght	2	10	3	60	Viktor Keric & Mikael Mousavi
		Water absorption	Wrong material choice	Degraded properties, leading to breakdown	8	10	6	480	Thorough testing the materials before implementation	Chosen materials by data sheet	4	10	6	240	Viktor Keric & Mikael Mousavi
		Wrong dimensions	Manufacturing process	Unable to fit in the TA-Compact	3	10	2	60	Small tolerances for manufacturing process						
	TPE components	Water absorption	Wrong material choice	Degraded properties, leading to breakdown	8	10	5	400	Thorough testing the materials before implementation	Chosen materials by data sheet	4	10	5	240	Viktor Keric & Mikael Mousavi
		Compression set	Wrong material choice	Degraded sealing ability	8	4	7	224	Thorough testing the materials before implementation	Chosen materials by data sheet	6	4	7	168	Viktor Keric & Mikael Mousavi
		Bad adhesion	Wrong material choice	Degraded adhesion leading to shorter service life	6	6	5	180	Thorough testing the materials before implementation	Chosen materials by data sheet	3	6	5	90	Viktor Keric & Mikael Mousavi

Appendix 6

Cost evaluation of the new product

	Volume (m3)	Weigt (g)	Material cost (SEK/kg)	Material cost per unit (%)	Process cost (%)	Total unit and process cost (%)		Tool cost/detail (%)	Total cost/detail (%)	Salary per unit (%)	Total unit cost (%)
TPE	1,41E-06	1,4	27	0,16	10,5	**10,6**	Additional costs	8,4	**19,1**	14,7	**54,3**
POM	5,00E-06	8.1	32,1	1,1	10,5	**11,6**		8,4	**20,5**		