# Designed solution for automatic grinding handling of casted iron

Konceptstudie för automatrensnings hantering av gjutet järn

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# Abstract

The casting process results in products with several rest materials such as mold and cast iron feeders. The rest material is needed to be removed for the product to be in its final phase. Usually, the grinding process is being done manually. The current process of manual grinding is demanding and dangerous for the operators. To increase the safety and precision of the operation. Thus, a new constructed gripper that carry the castings from a conveyor belt to an automatic grinding machine is proposed in the present effort.

To get a larger perspective of the current procedures of the manufacturing process, visits and meetings were carried out weekly. A pre-study along with a survey was carried out to help identify what products would have a positive impact on being grinded automatically. A product family was chosen and a requirement specification was made with the information collected. A brainstorming event was held at Karlstad University with master thesis students. Finally, the concepts generated during the meeting was combined and evaluated with elimination matrices.

The highest ranked concept is designed to have a high point on contact to the casting to increase stability and have a safe pick up and drop of. The gripper will perform the lift by pressing against the inner walls of the casting, with the use of the coefficient of friction.

The final concept was modeled in more detail with, while stress analysis was performed to finalize the dimensions of the gripper beam to withstand the stresses of the gripping process.

# Sammanfattning

Tillverkning med gjutning resulterar i produkter med mycket restmaterial såsom form sand och gjutjärnsmatare. Resten av materialet måste tas bort för att färdigställa produkten. Den nuvarande processen med manuell slipning är krävande och farlig för operatörerna. Automatisering av denna process ökar säkerheten och precisionen i driften. De manuellt slipade produkterna ska bli utvärderade och en nykonstruerad gripare som transporterar gjutgodset från ett transportband till en automatisk slipmaskin.

För att få ett bredare perspektiv på de nuvarande rutinerna i tillverkningsprocessen genomfördes besök och möten varje vecka. En förstudie tillsammans med intervjuer genomfördes för att hjälpa till att identifiera vilka produkter som skulle ha en positiv inverkan på att slipas automatiskt. En produktfamilj valdes med hjälp av en jämnförelse mellan ett betygsystem och arbetestimmar per år. En kravspecifikation gjordes med den insamlade informationen. Ett brainstorming-event hölls på Karlstads universitet med mastersuppsatsstudenter. De koncept som genererades under mötet kombinerades och utvärderades med elimineringsmatriser.

Det högst rankade konceptet designades för att ha en hög kontaktpunkt med gjutgodset för att öka stabiliteten och ha en säker upptagning och släpp. Griparen kommer att förforma lyftet genom att trycka mot gjutgodsets innerväggar, med användning av friktionskoefficienten.

Det slutgiltiga konceptet modellerades i högre detalj. Spänningsanalyser utfördes för att fastställa dimensionerna av griparens balk och säkerställa att dimensionerna motstår spänningen av gripar processen. För att möjliggöra att hantera gjutgodsen automatiskt.

# Contents

# Chapter 1

# Introduction

## 1.1 Background

Metal casting is a process of making objects by pouring molten metal into empty shaped space, and allowing the metal to cool and harden into a specific form given by its shaped mold [1]. The forms that shape the casting can be disposable or a permanent form, with the disposable form is consumed with the casting process and the permanent form being used for more casting cycles [2]. The most widely used engineering metal in casting, is iron, which is the main constituent of the iron-based alloys termed steels. The most common of the different casting techniques in case of cast iron, is sand casting [1].Generally the composition of grey iron consists of 95% Fe, 2.1-4 % C and 1-3 % Si by weight. The increase of silicone in the melt is the main reason for the characteristics, graphite that is formatted and gives the grey iron its grey color. The carbon is responsible for the tensile strength and the hardness [3].

The sand-casting technique is also used in Arvika gjuteri for the production of grey cast iron and ductile iron components. After the solidification, rest material and other remains such as feeders and rest sand are necessary to be removed. Usually, this step includes the blasting and the grinding of the product in order to be characterized as a finished product.

The griding step, is the most difficult step due to the fact that the majority of the components, basically because of their geometry or their weight, are being grided manually. The manual grinding comes with complications, one of them is that it is a very hazardous process and often comes with the serious risk of a workplace accident to happen. The other is that it is a time-consuming process and the repeatability of the process cannot be assured. Thus, it is crucial for a more automatic handled process to be developed.

The present study, is being conducted with the collaboration of Arvika gjuteri and one of the main goals is for the trimming cell to be automated. The first task to that direction, is the evaluation of the different types of products that could be suitable to go through this cell. After the evaluation of the potential products, a focus on product development of a gripper to lift the components with the help of a robot to the grinding machines, will be developed.

## 1.2 About Arvika Gjuteri

Arvika Gjuteri is a large manufacturer of grey cast iron and ductile iron products, since 1971. Arvika gjuteri consists of an automatic machine form line, and is still a large supplier of components for the heavy automotive industry ranging in weight from 20 to almost 400 kg, and numbers of units beyond 100 000 [4].

## 1.3 Basis of the Project

Due to sand casting, the products may have rest material and other remains that is needed to be removed, this includes feeders to the product and rest sand and mold. The process of removal is done by blasting and grinding the product to its finished state. Blasting being done in a blasting machine but a large proportion of the products being trimmed manually. The manual grinding comes with complications such as personal damages, with a total number of 33 damages to employees with 10 of the injuries resulting in sick leave (not including long-term illnesses). Also, the damages caused to the products, if grinding has been done to deep, is also a large factor that contributes to the project. The manual grinding is also very time consuming, with many products having different features and small spaces to grind on.

## 1.4 Purpose and Goal

Arvika Gjuteris wish that the project will narrow down the product field and also the development of the gripper/grippers for the different products to the great extent. The purpose of the thesis is therefore to conduct a study and conclude about the type of products which are possible to be automatically grinded, and also the evaluation of automatic robots that can lift these products. A gripper should be constructed to allow the production to become fully automatic. With the focus on the gripper as a product development.

## 1.5 Current Procedures

### 1.5.1 Sand casting

Sand casting is a low cost and low maintenance manufacturing method, the method goes through six steps to get the finished product. The first step is the mold making and the placement of mold patterns in the sand, which is done for each casting. The sand is then packed in a replica of the external shape of the casting and if necessary, it contains cores that will control any internal features [5].

The second step, known as clamping, is prepared for the molten iron to be poured, here the surface of the mold gets lubricated to ensure an easy removal of the casting, and then the cores are positioned and the two mold halves are closed and safely clamped with each other. It is important that the molds are securely closed to ensure that the casting and material does not get discarded [5].

The molten iron is maintained at a fixed temperature and is possible to pour at the third step. It is important to pour enough iron to fill the entire shape plus the channels of the mold,in order to prevent early solidification is this procedure done in a short time [5].

The fourth step is the cooling of the iron. When the entire shape of the mold is filled and solidified the final shape of the casting has formed. However the mold is not opened before the cooling time has elapsed in order to not ruin the casting. The cooling time is different from casting to casting. The fifth stage is the removal of the mold and other additional material that is adhered to the surface. The removal is typically done with a vibrating machine combined with a blasting machine [5].

The sixth and last procedure done is the trimming, where the left-over material from the channels(also known as feeders) are trimmed off the casting. This can be done automatically or manually and it is dependent on the final form of the casting product. A large casting is typically trimmed manually and requires a longer trimming time compared to smaller castings done in a trimming machine [5].

### 1.5.2 Handling

The current procedure of handling cast iron products at Arvika Gjuteri is done manually. The products arrive on pallets after being blasted. The lifting is supported by a smaller overhead crane to allow the user to safely lift the casting on a workbench, with the help of a hook. While the product is on the workbench, trimming is preformed manually with a grinding tool. After the casting is cleared of all rest material, it is lifted to a separate pallet with similar finished products.

### 1.5.3 Dangers of manual handling

The manual grinding feed rate causes a three dimensional force variation on the work tool. These forces have a direct impact on the user of the tool [6].The dangers of having a uncontrollable high speed power tool in your hands could in several cases lead to personal damages but also damages to the casted product. Manual handling may result in, personal damages such as Hand Arm Vibration Syndrome (HAVS) and Vibration White Fingers (VWF), as well as cutting damages [7]. Finally, the risk of grinding a heavy product on a bench without being securely clamped is also high.

## 1.6 Limitations

The aim of this thesis is to investigate the current products and develop a gripper that can fit the castings to an automatic grinding machine. Since the project is treated as a concept development some phases will not be addressed in this project. The manufacturing of the designed gripper and the cost of the design will not be studied or taken into account.

# Chapter 2

# Material handling

Material handling is the movement, protection, storage and control of materials and products through the process of manufacture and distribution, consumption and disposal [8]. It is important that the handling of material is performed safely and efficiently, to ensure a low cost and with low scrap rates. If material handling is overlooked the cost can take up a substantial proportion of the total production cost [9]. In order to improve the logistics of the industries, robots have to become integrated into material handling and processing operations to raise efficiency and lower cost, as the robot can work tirelessly and with high accuracy [9].

## 2.1 Industrial Robotic

The definition of a industrial robots states that an industrial robot is a automatically controlled and programmable in three or more axes, and being either fixed or mobile for use in industrial applications [9]. It is a machine that possesses certain human like characteristics with the most recognizable to be a robotic arm. The robots other characteristics are its ability to respond to sensors, communicate with other machines and make decisions. These capabilities make the robots suitable for industrial applications, since they are also favorable in environments that are hazardous for the human operator [9]. The applications of robots are many, from material handling to production spot welding and machine loading. Since the robots perform the work cycle with a high consistency and repeatability compared to humans, they are a good solution to lower cycle time, and increase quality [9].

The most common configurations of robots used in industry are:

1. Articulated robot
2. Polar configuration
3. SCARA
4. Cartesian coordinate robot
5. Delta robot

The articulated robot is mostly known as the joint-arm robot. It has the similarities to the human shoulder and is also the most common type of industrial robot. The arm design allows for a wide range of rotation and reach with the advantage of high precision [10]. The typical application for articulated robot is assembly, arc welding, material handling, machine tending [11].

The polar configuration is also known as spherical configuration. It is buildup of an arm with a twisting joint combined with one linear joint and two rotary joints [12].

The SCARA robot stands for ”Selective Compliance Articulated Robot Arm” and is functioning on a 3 axis system (X,Y,Z). It is most commonly used in assembly and palletizing [11].

The cartesian coordinate robot is most commonly known as Gantry robot. As the name suggests, it uses cartesian coordinates to move in a straight line over 3 axes. It is a popular choice because of its high flexibility and is mostly used in CNC (Computer Numerical Control) machines and 3D printing [11].

The delta robot is a parallel industrial robot. It is built up of three arms connecting to a single base. Each arm is articulated and often consisting of two rotational joints. This allows the robot to move smaller products with high speed and high precision. The most common applications of the delta robot is pick-and-place, assembly, sorting and packing [9, 13].

### 2.1.1 Applications

Material handling is a common application for industrial robotics. It involves the movement of materials or products from one place to another including material transfer and machine loading. The robot is usually equipped with a uniquely developed gripper to accomplish the movement of the product [9]. The loading and transferring of material increase the production speed, and also protects the operator from damages, such as monotonous loading on and of a machine can be very demanding and with high pace [14].

## 2.2 Robotic Grippers

Robotic grippers are the universal component in automation and they are the active link between the handling equipment and the workpiece. The function of the gripper is dependent on the application of the industrial robot which it is attached to [15]. The book Robot Grippers by Garetj J. Monkman give a classification of four different categories of grippers, as below:

1. Impactive
2. Ingressive
3. Contigutive
4. Astrictive

Depending on if the gripper is penetrating or non-penetrating, more designs and solutions can be developed to grip a specific product geometry [15].

The impactive gripper requires motion of a solid jaws to produce the necessary gripping force. This would be classed as a non-penetrating feature. A penetrating feature it would consist of pincers with pinch mechanism. The ingressive non-penetrating gripper uses a featured hook to lift the desired object. The contigutive gripper uses chemical adhesion with a direct contact to the product to facilitate a grip. Lastly, the astrictive methods to facilitate a grip are magnetic adhesion or vacuum suction [15].

### 2.2.1 Stability of grip

The element of stability is of great importance to the gripper. Without this, it would mean that the product has a higher probability to be dropped and break. Figure 1 illustrates the level of stability by increasing the point of contact to the product and increasing the number of fingers gripping. As it can be seen, a large active surface is the main reason for the stability of the lifted product to be increased along with a reduction of required gripping force [15].

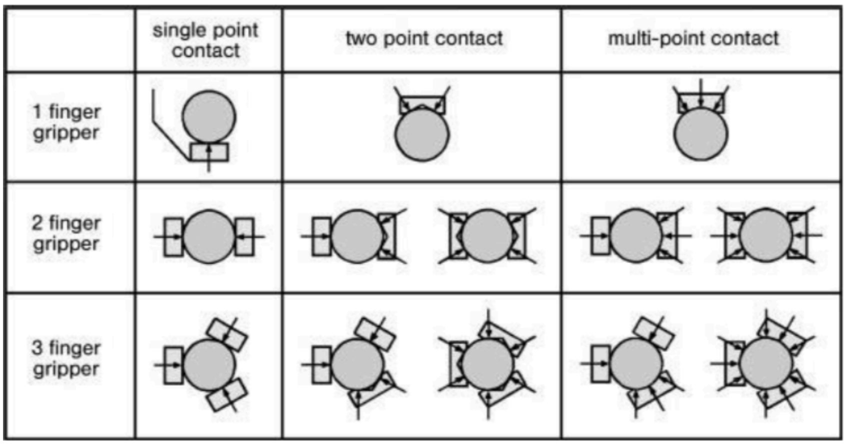



Figure 1: Gripping methods depending on the number of fingers and contact points [15].

# Chapter 3

# The Product Development Process

The product development process consists of a series of steps that guide the developer to design and commercialize a product. The development process could be seen as the creation of many alternative concepts followed by a narrowing down of the concepts. The method lead to a reduced risk that the project continues with unrealistic and unsatisfied concepts to the customer [16].

The product development process could be categorized in six different stages [17].

1. Feasibility study phase
2. Product specification phase
3. Concept generation phase
4. Concept valuation and choice of concept
5. Configuration and detail design
6. Prototype testing
7. Adjustments for manufacturing
8. Market introduction

These stages are designed to guide the developer in a methodical approach to the problem. The logic to this is to ensure that the project is always in a specific phase. Along to the systematic method, many other positive effects could arise. One major advantage is the better documentation, which could be helpful in the future development of the project, therefore the chance of a successful project is being raised [16]. In the present project, only phases 1 to 5 will be addressed because of limitations that are being involved, and have been described at in section 1.6.

## 3.1 Feasibility study phase

Over the feasibility study phase, the project has its outset. During that phase the gathering of information is important, different areas of competence should be addressed to ensure that the issues that might arise can be predicted. It is important during the study phase to uncritically investigate different possible solutions and also various presumptions to ensure that the project has enough information before going forward with wrong premises. The outcome of a well preformed feasibility study is a clear requirement specification, where the functional requirements are established [17].

### 3.1.1 Identifying customer needs

The importance of identifying the customer needs in a product development project is significant. Therefore, it is important to not make rash decisions and forget critical needs. The five-step method is an effective way to help the project reach to a favorable starting point [16]. The steps are as follows:

1. Gather raw data from customers.
2. Interpret the raw data in terms of costumer needs.
3. Organize the needs into a hierarchy.
4. Establish the relative importance of the needs.
5. Reflect on the result and the process.

In the first step, it is suggested that three methods are suitable to gather raw data from the customer. The first method is to conduct interviews and discuss the needs with one person of interest at the time. The second method is the use of a focus group of commonly 8-12 people, where the focus group is observed by the development team with the use of a transparent mirror. The method is more costly compared to the first because it requires that the participants are compensated for the participation. The third method is observing the product in use, with the observation being passive or active and preferably in the actual environment [16].

The second step is the interpretation of raw data in terms of costumer needs. A translation is done with information and observation from the previous step. Karl T. Ulrish presents five guidelines for writing needs statements [16].

- Express the need in terms of what the product has to do, not in terms of how it might do it.
- Express the need as specifically as the raw data.
- Use positive, not negative phrasing when expressing the needs.
- Express the need as an attribute of the product.

- Avoid using the words ”must” and ”should”.

The third step is to organize the needs into an hierarchy, with the goal to have a collection of sets. The sets should consist of primary needs, followed by secondary needs, and sometimes lastly followed by thirdly needs (usually consists of broken-down secondary needs). This is done by writing each need on a separate card, following with redundant cards being stapled together and treated as a single card. The cards should then be grouped and labeled into similarity aspects of the product. The fourth step establishes the relative importance of the previously grouped needs from step one to three. This is because the previous step does not address the importance's of the grouped cards. This can be done in two basic approaches. The first is to depend on the coherence of the team members based on experience while the second, relying on surveys to finalize the evaluation. The fifth and last step is the reflection on the result and process. With the challenging of the results generated to certify that the team has been persistent with the knowledge gathered from the customer surveys [16].

### 3.1.2 Analysis of production data

In many production facilities there are cramped spots. These spots are known as bottlenecks, as they are guilty of producing the minimum amount of workflow rate and affecting the total lead time of the production. It is therefore important to focus on improving the bottlenecks, so to allow higher production by the company. To level the flow of product a tact time is introduced to allow the operator to know how many products should be finished in each cycle [18]. Depending on each specific product, these times may vary. A sectioning of the product with similarities is therefore a good way to get an overview of the variations between the ”product families”. This is best done with the use of diagrams [18]. The comparison of products are important to determine the degree of automation possibility. An inspection of production data has the advantage to be quick [9], which is important to the projects later phases.

## 3.2 Product specification phase

The task in the product specification phase is to establish a requirement specification of what should be accomplished by the finished product. This is done so the in going information can be used as a starting point for the construction development solutions. The requirement specification should also be used to evaluate the different solutions and the final solution. It is important that the requirement specification is an open document under development throughout the project, as more knowledge about the specific field becomes known to the developer. Starting with a requirement goal specification to generate concepts and ending with the final requirement specification. After the construction process is finished, the specification is supposed to describe the finished product. It is important to the project that the requirement goal specification is well structured from the beginning of the project to ensure minimum setbacks during later project stages [17].

The requirement specification is divided into two criteria. The first is the criteria related to the products function, and the second is the criteria that set limitations to the product solutions. With the first criteria being the standpoint to creating some concepts and the limitations to narrow the allowed concepts. This can be strengthened by division, by demands and by wishes. With the demands to be a criterion that always should be fulfilled by all concepts, but the wishes of the customer can vary depending on each specific concept [17].

It is important for the requirement specification to address all stakeholders, life cycle phases and aspect that the product might experience. One way to fully address this is with the use of Olsson´s matrix of criteria. The matrix is divided into different life cycle phases of the product, as can be seen can be seen over the rows in Table 1, and the different aspects of the product that are important to be considered. A well-developed requirement specification leads to a shorter development time and fewer adjustments and lower development costs in a later stage of the project [17].

Table 1: Olsson´s matrix of criteria [17].

| | **Aspects** | | | |
|---|---|---|---|---|
| **Life Cycle Phase** | **Process** | **Environment** | **Human** | **Financial** |
| **Development** | **1.1** | **1.2** | **1.3** | **1.4** |
| **Production** | **2.1** | **2.2** | **2.3** | **2.4** |
| **Disposal** | **3.1** | **3.2** | **3.3** | **3.4** |
| **Usage** | **4.1** | **4.2** | **4.3** | **4.4** |
| **Destruction/Re-use** | **5.1** | **5.2** | **5.3** | **5.4** |

## 3.3 Concept generation phase

In the concept generation phase the potential solutions are invented. This is done with the help of what extent the different concepts fulfill the requirement specification. In order to invent as many concepts as possible, it is important to start with the concepts generation at the functional requirements to ensure that the concepts developed are within the aspects of the requirement specification[17].

To allow the concept generation to produce as many concepts as possible, a systematic solution search is used that includes the following steps [17].

1. Reformulate the problem in a broader, abstract and neutral form
2. Produce a function analysis and divide them into product functions and sub-functions.
3. Generate solutions to the sub-functions
4. Combine sub-functional with total solutions
5. Sort the potentially approved total solutions.

### 3.3.1 Reformulate the problem

The problem description in the requirement specification, have more detail and should be reformulated into a more abstract and broader form. The purpose is to allow for more general solutions to be produced that could potentially result in an improved solution [17].

### 3.3.2 Function analysis

When a broader description of the requirement specification has been done, a function analysis is being conducted. The structure of the intended product is then more clear. This is done by defining the main function and breaking it down into sub-functions and combine them. The result of the functional analysis is to show a clear function structure. The sub-functions that simplify the concepts generation are in the coming step [17].

### 3.3.3 Generate solutions

There are a lot of alternatives to generate the concepts of the sub-functions. The concepts can be generated with a systematic approach or a creative approach. In the systematic approach the focus is on finding solutions that are already existing with the help of literature and patent or with the analysis of competitors products. A common creative method that is used is brainstorming. Where a group of 5 to 15 people are in with one person as an assigned leader, the group's task is to generate as many concepts as possible without focusing on the quality of the product, and instead focus on generating new ideas with the collaboration of the group [17].

### 3.3.4 Combine sub-functions

The different sub-solutions that were generated to solve the sub-functions should be combined and be put together for a total solution. The process can be done with the help of a morphological matrix. This matrix consists of the sub-functions on the rows and the sub-solutions on the columns. To find the most total solutions, all the sub-solutions are combined to address all possible outcomes of the total solutions, the total solutions are dependent on the number of sub-functions and sub-solutions generated in to previous step [17].

### 3.3.5 Sort the approved solutions

With this method many concepts will be developed. It is therefore important to eliminate unrealistic concepts that do not follow the requirement specification at the final stage of the concept generation. The remaining solutions that show a promise are proceeding into the final concept valuation.

## 3.4 Concept valuation and choice of concept

The concepts generated in the previous method are evaluated to narrow the field of concepts down to fewer amounts. The concepts are valuated to the aspects of the elimination matrix shown in Table 2. The concept that fulfill the aspects of the elimination matrix are marked with (+), and the ones not fulfilling the aspects are marked as (-), if more information is needed, they are marked with (?), and if a control of the product specification is fulfilled is marked as (!). The concepts that need further information are marked as (?) at the decision box. However, if a concept is marked with (-) in any aspect, it is automatically marked as (-) in the decision box and eliminated. The final decision of the concepts that should proceed to a further valuation are marked as (+) [17].

The next step of the valuation is the use of the relative decision matrix, where the evaluation between the concepts is done. A reference solution is used as a datum for the comparison, where the datum can be an existing product or a basic solution. All solutions are then compared with the reference alternative. The concepts that are believed to be greater than the datum concept are marked as (+). In case of the concept would be poorer its marked (-), and if it is considered to be equal it is marked as (0). The valuations are summed and compared to rank what concept has the highest score of the net value [17]. The relative decision matrix can be seen below in Table 3.

Table 2: Elimination matrix by Pahl and Beitz

| Elimination matrix for: Handeling of castings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Concepts | Fullfills the main requirements | Fullfills all demands | Realizable | Within the budget* | Suites the company | Enough information | Elimination criteria:<br>(+) Yes<br>(-) No<br>(?) More information needed<br>(!) Control product specification<br>Decision:<br>(+) Approved<br>(-) Not Approved<br>(?) More information needed<br>(!) Control product specification | |
| | | | | | | | **Comment** | **Decision** |
| **1** | + | + | - | | | | | - |
| **2** | + | + | ? | + | + | + | | ? |
| **3** | + | + | + | + | + | + | | + |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

*Because of limitations the cost/budget is not taken into acount.

Table 3: Relative decision matrix by Pugh.

| **Criterium** | **Concept No.** | | | | |
|---|---|---|---|---|---|
| | 1(ref) | 2 | 3 | 4 | 5 |
| Wish A | | | | | |
| Wish B | D | | | | |
| Wish C | a | | | | |
| Etc.. | t | | | | |
| Wish D | u | | | | |
| Wish F | m | | | | |
| Etc.. | | | | | |
| Sum + | | | | | |
| Sum 0 | | | | | |
| Sum - | | | | | |
| Net worth | | | | | |
| Rank | | | | | |
| Further developing | | | | | |

## 3.5 Configuration and detail design

### 3.5.1 Bending force and Stress of the gripper

The bending force in a beam is described in Equation 1, where M is the maximum moment, I is the moment of inertia, and z is the maximum distance from the neutral plane [19]. The second moment of inertia can be calculated according Equation 2 for a


Figure 2: Schematic Load case 2 [20].

square rod [20].

$$\sigma_{max} = \frac{M}{I} z_{max} \tag{1}$$

$$I = \frac{bh^3}{12} \tag{2}$$

The displacement for the gripper beam can be simplified as a straight beam with the load of the casting seen in Equation 3.

$$\delta = \frac{FL^3}{3EI} \tag{3}$$

$$W_v = 0,208a^3 \tag{4}$$

$$\tau_{max} = \frac{M_v}{W_v} \tag{5}$$

The maximum torsional stress of the gripper bar can be described by Equation 5, where $M_v$ is the torsional moment and $W_v$ is the torsional resistance for the cross section described in Equation 4 for a square rod. The equation follows the Saint-Venants theory of pure torsion [20].

# Chapter 4

# Methods

## 4.1 Feasibility study phase

At the beginning of the project, a visit to Arvika Gjuteri took place. During the visit, meetings were held and the problem description was discussed. A guided tour was held to show the manufacturing process leading to the final finishing processing of the products. After the visit, a project plan was done with descriptions of what would be done in each development phase. A GANTT-schedule, can be seen in appendix A, and was done to acquire a good overview of the timeline with different tasks of the project.

The term working hours was calculated seen in Equation 6 . This was done by dividing the expected yearly production of each piece of product [PCE] with the cycle time of each product at the manual trimming station [PCE/h].

$$\frac{PCE}{\frac{PCE}{h}} = h \tag{6}$$

Working hours calculated shows the total time that is spent on manual grinding yearly on each product family or individual product. An inspection to determine which products are possible to automatically grind was essential to the development of the gripper. A grading system from 1 to 5 was introduced to be able to determine what product should be automatically grinded. The grading included the weight of the castings before grinding, with a low grade means the product are heavy and hard to handle and a high grade that they are easy to handle. The operation guides for manual grinding were also studied to find information on how the different products were grinded. The instructions were analyzed to identify operations performed on each specific product. This involved rotation of the product, turning, cutting, total grinding and tight space grinding. The operations of the manual grinding were concluded in a final grade labeled complexity. With a high-grade is shown the products that proved promising for automatically grinding. Low grade correlates to a low promise of being automatically grinded. To conclude what products and product families have the highest possibility of automation, the analysis was summed into a final grade with a mean value for the products within families, with the maximum points being 10.

With the grading system, it was possible to determine what products would be best suited to be automatically trimmed, as most of the products have totally different shapes and operations. This was the main path to be determined, with the product scoring highest showing a good promise of being automatically trimmed and the lowest showing low promise.

The sectioning of the many products into specific families was done depending on their similarities. The sectioning along with grading allowed for a mapping of what product take up the largest time yearly and if it would be possible to be automatically grinded, can be seen in Figure 6.

## 4.2 Product specification phase

The product specification phase was started by investigating further on what products would be best suited to be trimmed automatically. A survey was written to get the important aspect of the operators. The answers from the survey were then sorted according to the method by Karl T. Ulrish in section 3.1.1. With the results of the evaluation, a requirement specification started to become developed for a gripper and also for a handling robot that should lift the products. With more information gathered from the product evaluation and survey, the requirements specification was completed, as it can be seen in Table 5. With the permission of Arvika gjuteri the project could move advance into the concept generation phase.

## 4.3 Concept generation phase

The concept generation was started by reformulating the specification to broader and more abstract form, as described in section 3.3.1. A function analysis was made, as well as and three sub-functions were thought of. More specific, lifting the casting from a spot, turning the casting upside down, and rotating the casting. (Figure 3).

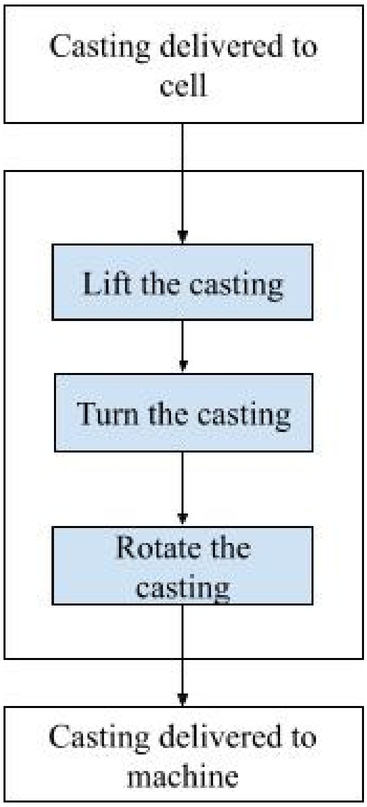



Figure 3: Function analysis with sub-functions to the gripper and handling system.

To find the sub-solutions to the sub-functions a brainstorming meeting was held at Karlstad University with four master thesis students attending. The event was started by introducing the different types of grippers showed in section 2.2, so to let the attending students get a good overview of the subject. The group later continued and answered the questions from the function analysis below.

1. How to lift the casting?
2. How to turn the casting?
3. How to rotate the casting?
4. How to set down the casting?

The ideas generated before came together with the result of the brainstorming event and sub-solutions and fresh ideas were added into the morphological matrix to find maximum numbers of solutions.

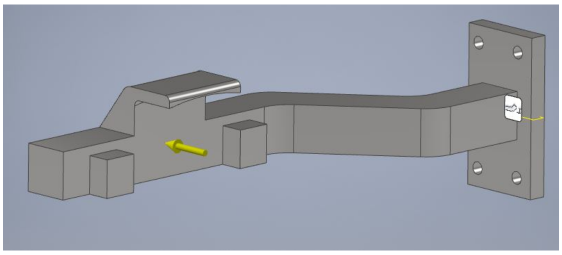
## 4.4 Concept valuation and choice of concept

The function analysis consists of three sub-functions as described above. Before adding the sub-functions and sub-solutions together in the morphological matrix, it was realized that the function analysis questions 2 and 3 in Figure 3 was solved by the handling system. With that knowledge the first question, (lifting the casting) was focused on. The main question to be, at this point, is referred to as the possible method of lifting the castings. Various lifting methods for the gripper were established and put into the morphological matrix as sub-functions. The sub-solutions established was the lifting spot of the gripper on the casting. In addition, the possible solutions of the grippers design were also added into the morphological matrix to generate the most possible concepts.

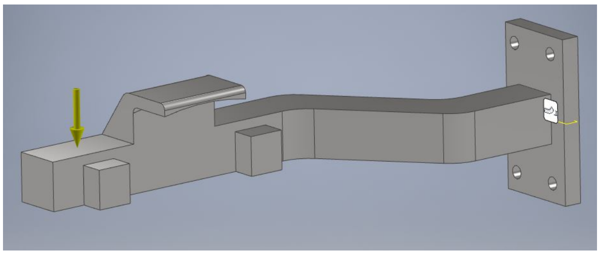
With the morphological matrix, the maximum concepts would be one hundred. Due to the high number of concepts, a sorting out of the morphological matrix was done to narrow down the concept numbers. This was done by over viewing if it would be realistic for the product to be gripped at the possible lifting spot. After the overview, a total number of concepts where narrowed down into 23, and are described in Table 6. These concepts where put into an elimination matrix for evaluation. The concepts that were given a positive decision continued in the process and was put into the Pugh's relative decision matrix. The requirements with high importance to the gripper was added into the relative decision matrix. One concepts added from the approved concepts in the elimination matrix was chosen as a reference concept, the remaining concepts added were evaluated compared to the reference concept based on its better performance compared to the reference on the specific requirement.

## 4.5 Configuration and details of the design

### 4.5.1 Calculation



(a) Loading case 1



(b) Loading case 2

Figure 4: Loading cases for stress and displacement

The maximum stress and displacement of the gripper beams where calculated for the most promising concept, in closest resemblance to a beam according to equation 1 and 3. The loading cases can be seen in Figure 4a, the force experienced by the beam is approximated to be 2000 N. Loading case 2 sen in Figure 4b is experiencing a force of 250 N. The purpose is to determine a beam size that would experience the favorable low stress and low displacement. The result can be seen in Table 10.

The concepts for the grippers were setup for an additional loading case where the casting was set at approximately 500 N. The aim being to find the minimum coefficient of friction between the casting and the gripper.

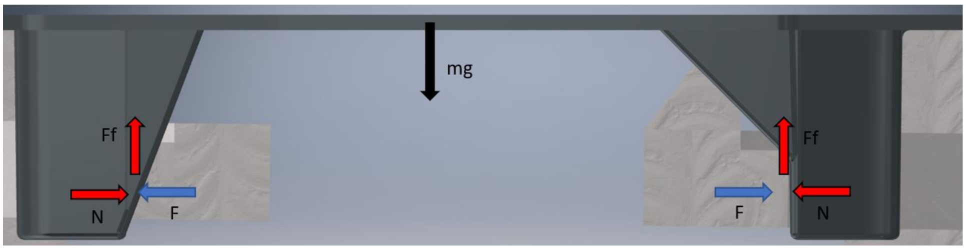



Figure 5: The load case 3 of the gripper

$$\uparrow \sum F_y : -m * g + 2F_f = 0 \tag{7}$$

$$\rightarrow \sum F_x : 2N - 2F = 0 \tag{8}$$

$$F_f = N * \mu \tag{9}$$

The force equilibrium for the grippers two planes showed in figure 5 are showed in Equations 7 and 8. Where m is the mass of the casting [Kg], g is the acceleration of gravity [m/s$^2$], N is the normal force from the casting and F is the applied force of the gripper. By solving equation 8 and substituting 9 in 7 we establish equation 10. Where μ is the coefficient of friction.

$$\mu = \frac{m * g}{2 * N} \tag{10}$$

### 4.5.2 Material selection

A material selection for the beam was done with Granta Edupack 2021 to find well suited materials that has sufficient yield strength, a high Young's modulus and moderate toughness. The result from the software can be seen in appendix E.

Equation 10 was used as a material recommendation of a suitable material that could enhance the coefficient of friction to support the castings weight and ensure no casting has a possibility of being dropped.

### 4.5.3 Final design

The modeling of the final concept was done with *Autodesk Inventor Professional 2020*. A rough design of a gripper was done by observing the castings that should be lifted. The castings were later added into the CAD module and a more detailed design was constructed on the gripper. A beneficial feature was found on all castings which was used to allow one gripper to grip and place all products in the product family. The feature will allow for a safe lift and flip along with removal of the gripper without interfering with feeders or fixtures.

# Chapter 5

# Result

## 5.1 Feasibility study phase

The results of the feasibility study generated are depicted in Figure 6. The products that have a good possibility to become automatically grinded can be seen in the graph. The GANTT schedule and risk analysis along with a work breakdown structure for the project can be observed and analyzed in Appendix A, B and C. In addition, the operators were asked questions about manual grinding and the goal was to get suggestions on what product they believed should fit for the automatic cell. The result of the survey can be seen in Appendix D.

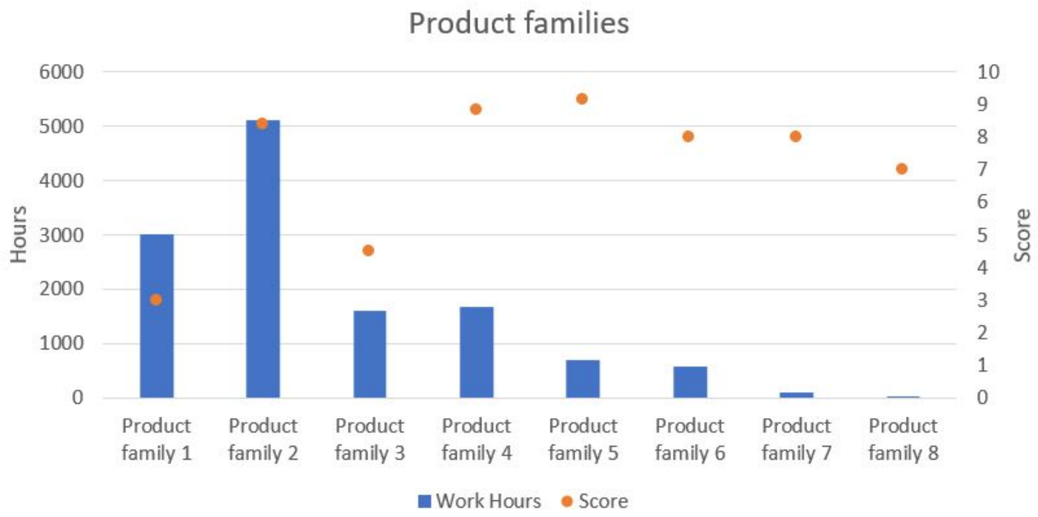



Figure 6: Result of the evaluation of products comparison to work hours.

The graph shows product families with high scores. However, because most of them show a low number of working hours they are still not well suited to automatically grinding, as higher number of hours products like product family 2, that have a correlating high working hours and a high grade. The product family 2 were therefore chosen to develop a gripper to feed the automatic grinding machine.

## 5.2 Product specification phase

From the feasibility study phase, it was found that the product family 2 where the most suited to be automatically trimmed. A requirement specification was developed for the handling system and gripper (Table 4 and 5 respectively). The information from product family 2, demand a minimum lifting capacity for the handling and gripper of 50 kg (criterion number 3, Table 4, and criterion number 4, Table 5).

Table 4: Requirement specification for handling system

| **Product Requirement specification** | | | Issued: 20220307 | | |
|---|---|---|---|---|---|
| | | | Reviewd: 20220407/Theodor Hansson | | |
| Product: Handeling system | | | Approved by: Arvika Gjuteri AB | | |
| Criterion number | Cell | Criterion | Function(F)/ Limitation(L) | Demand(D) /Wish(W) | Weighting (1 min, 5 max) |
| 1 | 1.1 | CE Marking. | L | D | |
| 2 | | Heat resistant. | L | D | |
| 3 | 2.1 | Handleing weights to 50kg. | F | D | |
| 4 | 4.1 | Be able to handle induvidual products. | F | D | |
| 5 | | Automatic operation. | F | D | |
| 6 | | Lift on and off the conveouy belt. | F | D | |
| 7 | | Allow for a simple tool change. | F | W | 2 |
| 8 | | Electrically powerd | L | D | |
| 9 | | Allowed to flip the casting 180 degrees. | F | D | |
| 10 | | Allowed to rotate 360 degrees. | F | D | |
| 11 | | Able to move the casting 1.5-3m. | F | D | |
| 12 | 4.2 | Take up minimal space. | L | D | |
| 13 | | Flexible movment if needed. | L | W | 2 |
| 14 | 4.3 | Operator protection. | L | D | |
| 15 | | User friendly. | L | W | 2 |
| 16 | | Easy Maintenance. | L | W | 1 |

## 5.3 Concept generation phase

Function analysis aid the development of concepts by allowing the brainstorming to have a clear goal. The brainstorming, was clear that the second and third sub-function of the function analysis was solved by the handling system. Although, the second and third sub-function was solved by the handling system further sub-functions were added into the morphological matrix along with sub-solutions on where a gripper could lift the castings. By combining the sub-functions and sub-solutions in the morphological matrix a total number of 100 concepts were possible. However, not all the concepts are physically possible. The group analyzed the concepts individually and concluded that a total number of 23 concepts were physically possible. This allowed for a good variety between the different grippers. The result of the morphological matrix is depicted in Table 6.

Table 5: Requirement specification for gripper

| **Product Requirement specification** | | | Issued: 20220303<br>Reviewd: 20220412 / Theodor Hansson | | |
|---|---|---|---|---|---|
| Product: Gripper | | | Approved by: Arvika Gjuteri AB | | |
| Criterion number | Cell | Criterion | Function(F)/ Limitation(L) | Demand(D) /Wish(W) | Weighting (1 min, 5 max) |
| 1 | 1.1 | Usage of ISO-standards. | L | D | |
| 2 | | Handle feeding and removal of the castings. | F | D | |
| 3 | | Be able to flip the castings 180 degrees. | F | D | |
| 4 | | Handleing weights to 50kg. | F | D | |
| 5 | | CE Marking. | L | D | |
| 6 | | Allowed to rotate 360 degrees. | F | D | |
| 7 | | Heat resistant. | L | W | 1 |
| 8 | 2.1 | Be able to handle induvidual products. | F | D | |
| 9 | | Automatic operation. | F | D | |
| 10 | 4.1 | Handle different products within a product family. | F | W | 1 |
| 11 | | Allow for a simple tool change. | F | W | 1 |
| 12 | | Dont drop the castings. | L | W | 4 |
| 13 | | Easy Instalation. | L | W | 1 |
| 14 | 4.2 | Not hinder the fixture from going into the machine | L | W | 5 |
| 15 | 4.3 | Easy Maintenance. | L | W | 1 |
| 16 | | Easy to handle | L | W | 1 |

Table 6: Morphological matrix for the gripper

| **Sub functions/Type of grippers** | **Lifting spot/Sub solutions** | **Possible solutions** | | | | |
|---|---|---|---|---|---|---|
| | | **Single gripper** | **Double gripper** | **Triple gripper** | **Quad gripper** | **Round gripper** |
| **Mechanical grippers** | Above lift | | C1 | C2 | C3 | |
| | Under lift | | C4 | C5 | C6 | |
| | Side lift | | C7 | | | |
| | Above and Under lift | | C8 | | C9 | |
| **Vacuum grippers** | Above lift | C10 | | | | |
| | Under lift | C11 | | | | |
| | Side lift | | | | | |
| | Above and Under lift | C12 | | | | |
| **Magnetized devices** | Above lift | C13 | | | | C14 |
| | Under lift | | | | C15 | C16 |
| | Side lift | | | | C17 | |
| | Above and Under lift | | | | | |
| **Adhesive devices** | Above lift | C18 | | | | |
| | Under lift | C19 | | | | |
| | Side lift | C20 | | | | |
| | Above and Under lift | | | | | |
| **Simple mechanical devices (Hook, or scoop)** | Above lift | C21 | | | | |
| | Under lift | C22 | | | | |
| | Side lift | C23 | | | | |
| | Above and Under lift | | | | | |

## 5.4 Concept valuation and choice of concept

The concepts possible for the handling system were evaluated in the elimination matrix (Table 7). Agv (Automated Guided Vehicle) trucks, Scara robot and collaborative robot did not fulfill the main requirements of the requirement specifications, mainly because the concepts are not possible to deliver the castings to the grinding machine. The concept overhead crane, and Gantry robot are fulfilling the main requirements but as they need a large volume, they do not fulfill the main requirement. The parallel robot fulfills the main requirements and demands but does not suite the company as it is oversized for the handling operation. The only handling system that was approved was the articulated robot. Since no other handling concept was approved it was not necessary to evaluate the concepts further. And the articulated robot was chosen as the final handling concept.

Table 7: Elimination matrix of handling system

| Elimination matrix for: Handeling of castings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Concepts | Fullfills the main requirements | Fullfills all demands | Realizable | Within the budget* | Suites the company | Enough information | Elimination criteria:<br>(+) Yes<br>(-) No<br>(?) More information needed<br>(!) Control product specification<br>Decision:<br>(+) Approved<br>(-) Not Approved<br>(?) More information needed<br>(!) Control product specification | |
| | | | | | | | **Comment** | **Decision** |
| Overhead crane | + | - | | | | | Does not fullfill all demands | - |
| Articulated robot | + | + | + | ? | + | + | | + |
| Agv Trucks | - | | | | | | Does not fullfill the main requirements | - |
| SCARA Robot | - | | | | | | Does not fullfill the main requirements | - |
| Gantry robot | + | - | | | | | Does not suite the company | - |
| Collaborative robot | - | | | | | | Does not fullfill the main requirements | - |
| Paralell linkage robot (e.g Tricept) | + | + | + | ? | - | | Does not suite the company | - |

*Because of limitations the cost/budget is not taken into acount.

The possible gripper concepts were imported into the elimination matrix (Table 8). Although, all concepts generated in the morphological matrix was deemed possible, when evaluated in the matrix of elimination some concepts did not fulfill the requirements to be further developed. Concept C10, C11, C12 was eliminated due to the fact that the concepts involved the use of a vacuum gripper, which has a maximum weight capacity of 50 kg. However, it would require that the lifting surface of the casting would be perfectly flat. Therefore, it is not realizable to the company. Concept C13 was eliminated on the same principle that there is little space for a magnetic gripper on the upper side of the castings and it is therefore discarded. Concept C18, C19, C20 were all concepts with a adhesive device as a lifting mechanism for the gripper. Unfortunately, the adhesive mechanism does not fulfill the main requirements because of its low lifting weight capacity, so it is eliminated. Concepts C21, C22 and C23 all contained a simple mechanical device, concept C21 would lift the casting from above, this would mean that the concept does not fulfill all demands of the requirement specification. Concept C22 would require that the device would lift the casting from underneath. The concept would therefore not be possible to fulfill the main requirements of the gripper, which was the turning of the casting 180 degrees. Concept C23 would use a similar solution as in concept C22. In that case, even if it would be possible to fulfill the main requirements of the gripper, it would not be realizable to the company, so it is given a negative decision. From the finished elimination matrix, a total of 13 concepts were approved to go forward into the relative decision matrix.

Table 8: Elimination matrix of gripper concepts

Elimination matrix for: Handeling of castings

Elimination criteria:
(+) Yes
(-) No
(?) More information needed
(!) Control product specification

Decision:
(+) Approved
(-) Not Approved
(?) More information needed
(!) Control product specification

| Concepts | Fullfills the main requirements | Fullfills all demands | Realizable | Within the budget* | Suites the company | Enough information | Comment | Decision |
|---|---|---|---|---|---|---|---|---|
| C1 | + | + | + | ? | + | + | | + |
| C2 | + | + | + | ? | + | + | | + |
| C3 | + | + | + | ? | + | + | | + |
| C4 | + | + | + | ? | + | + | | + |
| C5 | + | + | + | ? | + | + | | + |
| C6 | + | + | + | ? | + | + | | + |
| C7 | + | + | + | ? | + | + | | + |
| C8 | + | + | + | ? | + | + | | + |
| C9 | + | + | + | ? | + | + | | + |
| C10 | + | + | - | | | | Is not realizable to the company | - |
| C11 | + | + | - | | | | Is not realizable to the company | - |
| C12 | + | + | - | | | | Is not realizable to the company | - |
| C13 | + | + | - | | | | Is not realizable to the company | - |
| C14 | + | + | + | ? | + | + | | + |
| C15 | + | + | + | ? | + | + | | + |
| C16 | + | + | + | ? | + | + | | + |
| C17 | + | + | + | ? | + | + | | + |
| C18 | - | | | | | | Does not fullfil the main requirements | - |
| C19 | - | | | | | | Does not fullfil the main requirements | - |
| C20 | - | | | | | | Does not fullfil the main requirements | - |
| C21 | + | - | | | | | Does not fullfill all demands | - |
| C22 | - | | | | | | Does not fullfil the main requirements | - |
| C23 | + | + | - | | | | Is not realizable to the company | - |

*Because of limitations the cost/budget is not taken into acount.

The concepts from the elimination matrix were added into the relative decision matrix. The criterion number from the requirements specification seen in Table 5. In that stage, the concepts are evaluated against the reference concept which was chosen to be concept C2 due to the fact that it is a moderate solution. From the relative decision matrix, it was found that concepts C7 scored the highest score. The concept where therefore chosen for further development.

Table 9: Relative decision matrix of approved concepts

| Criterion | Concept No. | | | | | | |
|---|---|---|---|---|---|---|---|
| | C2(ref) | C1 | C3 | C4 | C5 | C6 | C7 |
| 3 | | - | + | - | 0 | + | + |
| 4 | D | - | + | - | 0 | + | + |
| 6 | a | 0 | 0 | - | - | - | + |
| 7 (1) | t | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 (1) | u | - | + | - | 0 | + | + |
| 12 (4) | m | - | + | - | 0 | + | + |
| 14 (5) | | 0 | - | - | - | - | 0 |
| Sum + | 0 | 0 | 4 | 0 | 0 | 4 | 5 |
| Sum 0 | 0 | 3 | 2 | 1 | 5 | 1 | 1 |
| Sum - | 0 | 4 | 1 | 6 | 2 | 2 | 0 |
| Net worth | **0** | **-4** | **3** | **-6** | **-2** | **2** | **5** |
| Rank | **9** | **12** | **4** | **13** | **11** | **8** | **1** |
| Further developing | **No** | **No** | **No** | **No** | **No** | **No** | **Yes** |

(a) Concepts C1-C7

| Criterion | C2(ref) | C8 | C9 | C14 | C15 | C16 | C17 |
|---|---|---|---|---|---|---|---|
| 3 | | + | + | + | + | + | + |
| 4 | D | + | + | + | + | - | + |
| 6 | a | + | + | 0 | 0 | - | 0 |
| 7 (1) | t | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 (1) | u | 0 | 0 | 0 | + | + | + |
| 12 (4) | m | + | + | 0 | + | 0 | + |
| 14 (5) | | - | - | + | - | - | 0 |
| Sum + | 0 | 4 | 4 | 3 | 4 | 2 | 4 |
| Sum 0 | 0 | 2 | 2 | 4 | 2 | 2 | 3 |
| Sum - | 0 | 1 | 1 | 0 | 0 | 3 | 0 |
| Net worth | **0** | **3** | **3** | **3** | **4** | **-1** | **4** |
| Rank | **9** | **4** | **4** | **4** | **2** | **10** | **2** |
| Further developing | **No** | **No** | **No** | **No** | **No** | **No** | **No** |

(b) Concepts C8-C17

# 5.5 Configuration and detail design

## 5.5.1 Numerical Calculations and Stress Analysis

Table 10: Dimensional calculation of stresses and displacement for loading case in Figure 4a and figure 4b.

| Dimension [mm] | $I$ [$*10^{-7}$ $m^4$] | $\sigma_{max1}$ [MPa] | $\sigma_{max2}$ [MPa] | δ1 [m] | δ2 [m] |
|---|---|---|---|---|---|
| 30*30 | 0,675 | 21,80 | 222,22 | $15,5*10^{-12}$ | 0,00158 |
| 35*35 | 1,25 | 13,73 | 139,94 | $8,37*10^{-12}$ | 0,00085 |
| 40*40 | 2,13 | 9,20 | 93,75 | $4,91*10^{-12}$ | 0,00050 |
| 45*45 | 3,41 | 6,46 | 65,84 | $3,06*10^{-12}$ | 0,00031 |
| 50*50 | 5,2 | 4,71 | 48,00 | $2,01*10^{-12}$ | 0,00020 |

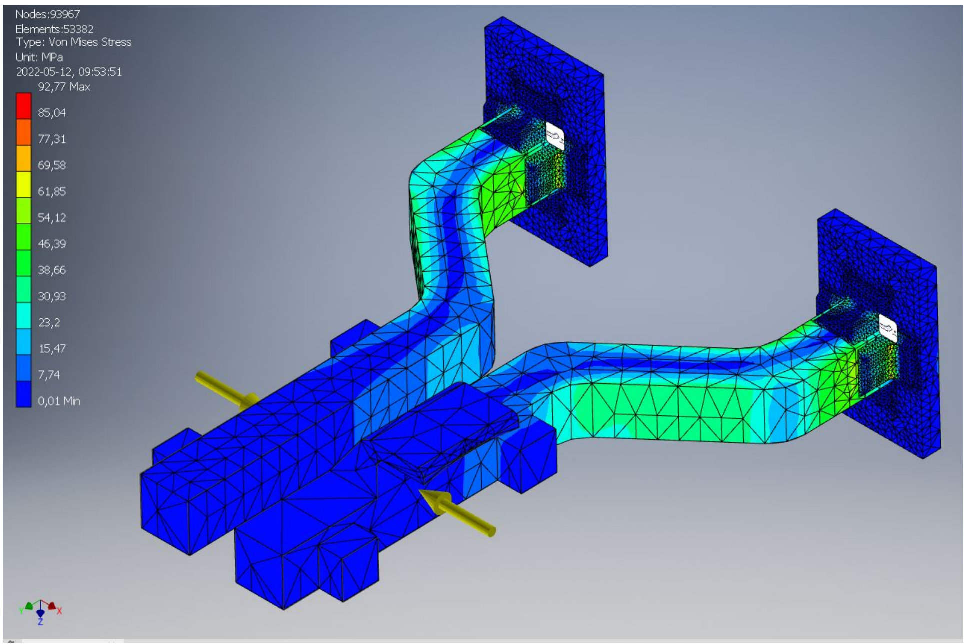



Figure 7: Von Mises stress analysis made with Autodesk Inventor Professional 2020.

Numerical calculations according to theory and Equations 1 and 3 lead to the result of the maximum stress and displacement, which can be seen in Table 10. Additionally, a stress analysis was made to with *Autodesk Inventor Professional 2020*, (Figure 7). The maximum stress was found to be 92,77 MPa and was located at the beginning of the beam. The displacement of the beam with Autodesk was found to be 0,71mm. Although the value of the stresses generated from Autodesk was greater than the numerical calculation it is considered a low displacement.

The normal force was approximated to 2000 N and the coefficient of friction was calculated with equation 10 to be $\mu \geq 0{,}122$. The coefficient of friction between the cast iron and gripper than needs to be greater than 0,122 to support the castings weight.

### 5.5.2 Material selection

The result of the maximum stress and deflection from the loading case 1 and 2 led to the dimension of the gripper beam to be set as 40x40 mm, as it has moderate stress and has a low displacement in the two bending scenarios. The stress of 93,75 MPa (Table 10) is therefore used as reference to a material selection as the materials must be able to handle the maximum stress. The material, therefore needs to have a higher yield strength than the maximum stress, to ensure that there is no plastic deformation occurring in the gripping process. The best material S355J is chosen as the material for the gripper, as it has a yield strength of 355 MPa and Young's Modulus of 210 GPa, the steel is also chosen for its convenience as it possesses high weldability, and is commercially available.

A mild steel like S355J has a static coefficient of friction of 0,4 against cast iron. The value means that the safety factor for the grippers coefficient of friction is 3,27. The safety factor is well enough to carry the casting in the operations needed.

### 5.5.3 Gripper design

The final concept of the gripper can be seen in Figure 8. The solution is the result of the further development of concept 7. The concept also has a beneficial feature as it would suite all products in product family 2 with only minor adjustments.

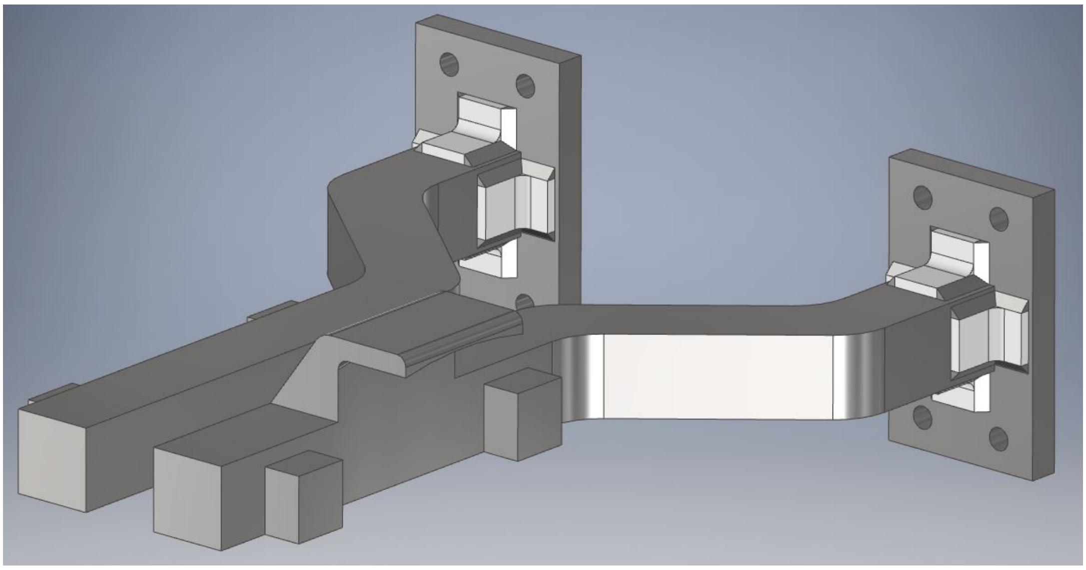


Figure 8: Final gripper design

# Chapter 6

# Discussion

In the present effort, the time plan that was made in the beginning of the project was not followed to an accurate extent. The project started of very front heavy with the process of deciding what product should go through the automatic grinding machine. The grading of products took up more time than planned for, and the outcome was a complex product family. Due to the complexity of the approved castings the concept development would experience a longer time needed to develop sufficient concepts. It was therefore important that the product development process was started as soon as the products where decided.

The structured product development process followed in this project was an important guideline for the project´s success. The theory of the developing process suggests that process should be seen as guidelines and not strict rules [17].

The development process is dependent on the development team in the concept generation and the individual performance in the evaluation in the decision matrix [17]. The content of the result in the evaluation is therefore the what the performer of the evaluation matrix's believes. If the evaluation was done as a group effort the outcome might not have been the same. Although, it is believed that the result are fair. However, the structure of the development process comes with good documentation of the different phases and therefore leads to an increased chance of a successfull project [17]. In particular the feasibility phase, as the gathering of information, is crucial for the project not to encounter small hindrances further into the development process that take up long development time.

As the gripper concept is dependent of the handling system, it was therefore important that the concept valuation and choice of concepts of the handling system was done before the gripper concepts. The outcome was clear as the articulated robot was the only concept approved from the elimination matrix and was therefore the concept to develop the gripper too.

The theory advised that the brainstorming event should consist of five participants or more , to ensure that a variety of ideas can be expressed [17]. In the brainstorming event held on Karlstad University only four master thesis students attended. The function analysis was not to the greatest help as it was concluded by the group that question two and three in figure 3 were solved by the handling system. Although this was of help to the project itself the questions where reformulated by the group that the gripper should support the castings in the turning and rotating moments. The attendance of the master thesis students was below the recommended attendance. The variety and innovative concepts from the event was very successful. The reason to this might be that the all the students have previous experience in the product development process and have a talent for innovative techniques, also the possibility of looking at a problem with an open mind.

The morphological matrix allowed the sub-functions and sub-solutions as well as the possible solutions of the gripper design to be combined. The combination resulted in a total of 100 different concepts, but by the physical limitations most of the solutions were deemed not possible. Finally, a total number of 23 concepts were deemed possible to solve the problem. The fore evaluation was necessary as it would have been a time-consuming process to evaluate all concepts to proceed to the matrix of elimination.

The 23 concepts were evaluated in the relative decision matrix. From the matrix it was found that concept 7 would be ranked at place 1 just before concept 17 and 15, because of concept 7's ability to avoid a fixture compared to most the other concepts. As concept 17 and 15 could not reach the casting without colliding with a fixture or a feeder to the casting. Therefore, the final concept was chosen by scoring in the relative decision matrix. Concept 7 scored the highest. Although, other concepts scored high as well, they would not perform as well as concept 7 according to the relative decision matrix. However, this evaluation is dependent on the performer of the matrix. The final gripper design is a solution that will suite the products of product family 2 to most extent. The mechanism of the concept is a press against the casting to support its weight, with an additional support to secure the castings when they are flipped 180 degrees.

The forces involved in pressing the gripper beam against the casting was approximated to be around 2000 N, the stresses on the beam seen in table 10 was a good overview of how much stress and deflection the gripper beam undergoes in the different loading cases which is important to assure that the beam that is supporting the casting can support the load. The 40x40 mm dimensions were chosen as it made possible for the gripper to reach under the space under the casting as the concept require. The force of the gripper preferably be a hydraulic working gripper as it can product the force required simply.

The material selection of the beam was necessary to find a material with a yield strength able to operate with the stresses produced. The material selection was done with the software Grant EduPack 2021. The material chosen for the gripper was S355J as the steels yield strength and toughness is favorable for the gripper along with its high weldability and quite good performance to fatigue [21].

The coefficient of friction consist of a adhesive component by atomic attraction and ploughing component by deformation of the softest material in the contact. The friction between iron and steel is roughly 0,4 [22] and is enough to support the casting with its weight. However, to enhance the coefficient of friction would result in a higher safety factor. There are different ways to raise the coefficient of friction, one is with the use of a material that can have a high atomic attraction against iron and another could be with the use of a lesser hard material than the iron, to let the contact area become larger due to deformation of the gripper material and therefore increasing the ploughing component, also with the use of a non-metallic material like rubber could raise the coefficient of friction substantially to increase the safety factor for the gripper.

The final design of the gripper is a beam with bent plates and welded parts to increase the stability of the lift and flip. The concept has the possibility to go in under the casting and withstand the stresses produced with the approximated press against the walls. With the articulated robot the concept can successfully handle the castings.

# Chapter 7

# Conclusions and Future Work

## 7.1 Conclusion

The product development process provides good instructions to develop a new constructed component. The phase of feasibility study was an important start to identify customer needs for the requirement specification before proceeding to the concept generation phase. The process decisions made previously of the phases are easily accessible for review if required.

The final design of the gripper can be seen in Figure 8 and could accomplish the task of moving the castings to from a fixture to an automatic grinding machine. The mechanism of the concept requires a hydraulic or pneumatic press, to push against the inner side to generate a force sufficient to lift the casting. The grippers additional stability bar will provide more point of contact in the flipped state, to allow for a safer handling.

## 7.2 Future Work

To start with, the construction would need to be tested in real life. The testing should be done with a prototype and all the different products within product family 2. To answer the main questions. How is the pressing on the inside of the casting affecting the product? Is there any plastic deformation on the casting? Does the pressing lead to a shorter lifetime of the casting? The answers to the questions should lead to a greater understanding of the grippers impact on the product and with the information make changes to the gripping process.

As the tribological properties between cast iron and a high friction material has not been examined during this project, and it is an important step to securing the casting. A higher coefficient of friction against the iron will result in a lower normal force needed to press against the casting. The properties should be done by experimental test with a variety of materials against cast iron to conclude what material could coat the grippers to press against the casting.

Because the castings are not designed to be automatically handled, if the castings were designed with an aspect of the gripper it could help the handling process to have safer operations of lifting, flipping and turning. And not a potential to damaging the castings.

# Chapter 8

# Acknowledgement

I would like to thank Anders Österberg along with Sofia Fagerström at Rejlers AB that made this master thesis possible. I want to give thanks to my supervisors Tore Paulsen and Rolf Andersson for their guidance and the questions they answered along with valuable insight of the iron casting production. A special thanks to the master thesis students that attended the brainstorming-event, their innovative thinking was a great help to the development of the gripper.

Thanks to my supervisor Katerina Chantziara for helping me continuously and guiding me through the thesis.

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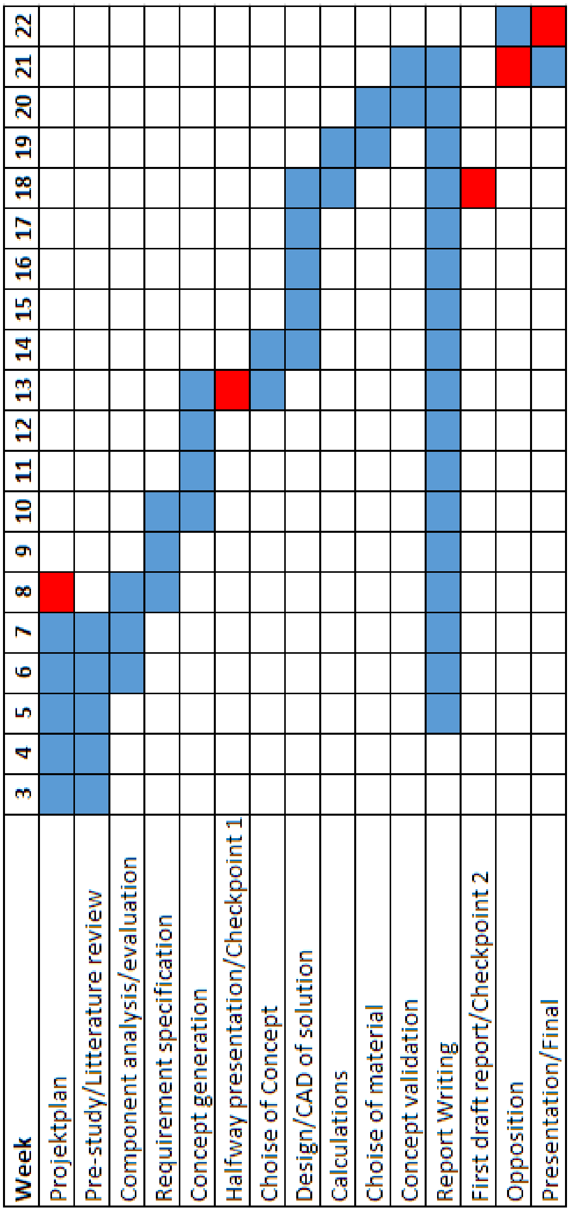
# Appendix - Contents

# Appendix A

# First Appendix- Gantt



# Appendix B

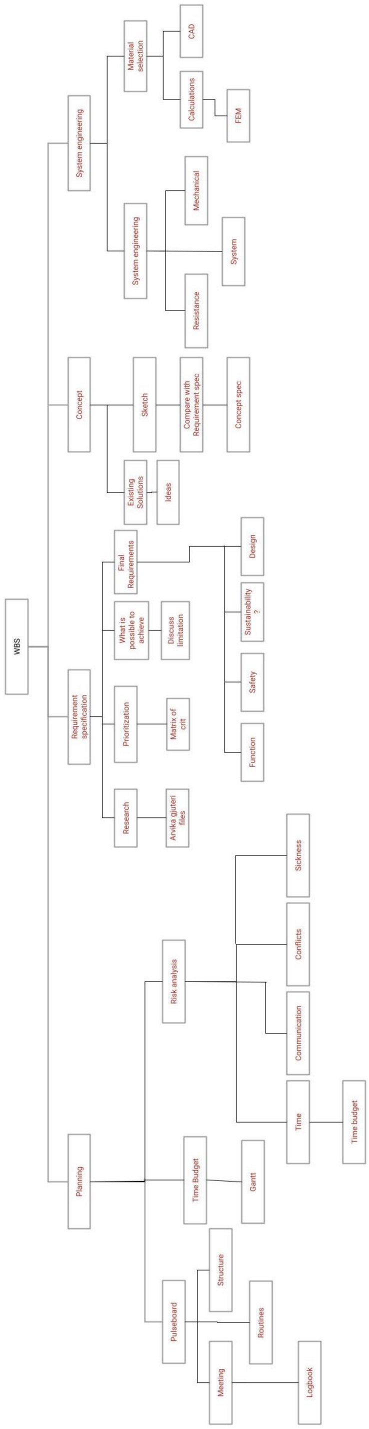
# Second Appendix- Risk analysis

| No. | Risk | P | C | R | Action |
|---|---|---|---|---|---|
| 1 | The project exceeds the time limit | 3 | 3 | 9 | Constantly update the project plan and plan longterm goals that sould be fullfilled |
| 2 | Lack of communication with the customer | 2 | 3 | 6 | Have open communication of rising problems in each meeting with the customer |
| 3 | Lack of communication with the University supervisor | 1 | 3 | 3 | Have continous pulse meetings and prepare questions and adress issues about the thesis |
| 4 | Unpredictable work is vital to fulfill the purpose of the thesis | 4 | 3 | 12 | Plan for a front-heavy project and make time for additional work in the timeplan |
| 5 | Student or coworkers get covid-19 | 3 | 1 | 3 | Follow restrictions to all extent |
| 6 | No concepts fullfill the goal of the thesis | 2 | 5 | 10 | Verify the concepts to the goal of the thesis and have time to make smaller adjustments if needed |
| 7 | The company and Karlstad University has different opinions on what is to be included in th | 2 | 3 | 6 | Keep an open dialogue between the company and the University |

P=Probability
C=Consequence
R=Risk factor (P*C)

# Appendix C

# Third Appendix- Work breakdown structure


WBS
Planning
Requirement specification
Concept
System engineering
Material selection
CAD
Calculations
FEM
System engineering
Mechanical
System
Resistance
Sketch
Compare with Requirement spec
Concept spec
Existing Solutions
Ideas
Final Requirements
Design
Sustainability ?
Safety
Function
What is possible to achieve
Discuss limitation
Prioritization
Matrix of crit
Research
Arvika gjuteri files
Risk analysis
Sickness
Conflicts
Communication
Time
Time budget
Time Budget
Gantt
Pulseboard
Structure
Routines
Meeting
Logbook

# Appendix D

# Fourth Appendix- Survey

**What is good about the manual grinding process today?**

The manual grinding is good today because of its flexibility to easy and quick make adjustments to the products in process.

**What is not good with the manual grinding process today?**

Today a lot of the tolerances of the grinding is depended on the human factor, this means that the operator has a high responsibility to do everything correct and has the right information and are following the right instructions, this makes the manual grinding tough to fail safe. The though work environment also makes it dangerous and can lead to occupational injuries.

**If something goes wrong, what is that typically?** A typical error is when the operator cut of feeders and other remaining material from the casting, it is easy that the operator than cuts into the casting. There is also the human error of forgetting a side to grind and the product have a chance to be delivered unfinished to the customer.

**Does it feel safe to manually clean the products?** There is always an acute risk with manual grinding, although this risk is not very high. The higher risk is in long term work with a vibrating power tool.

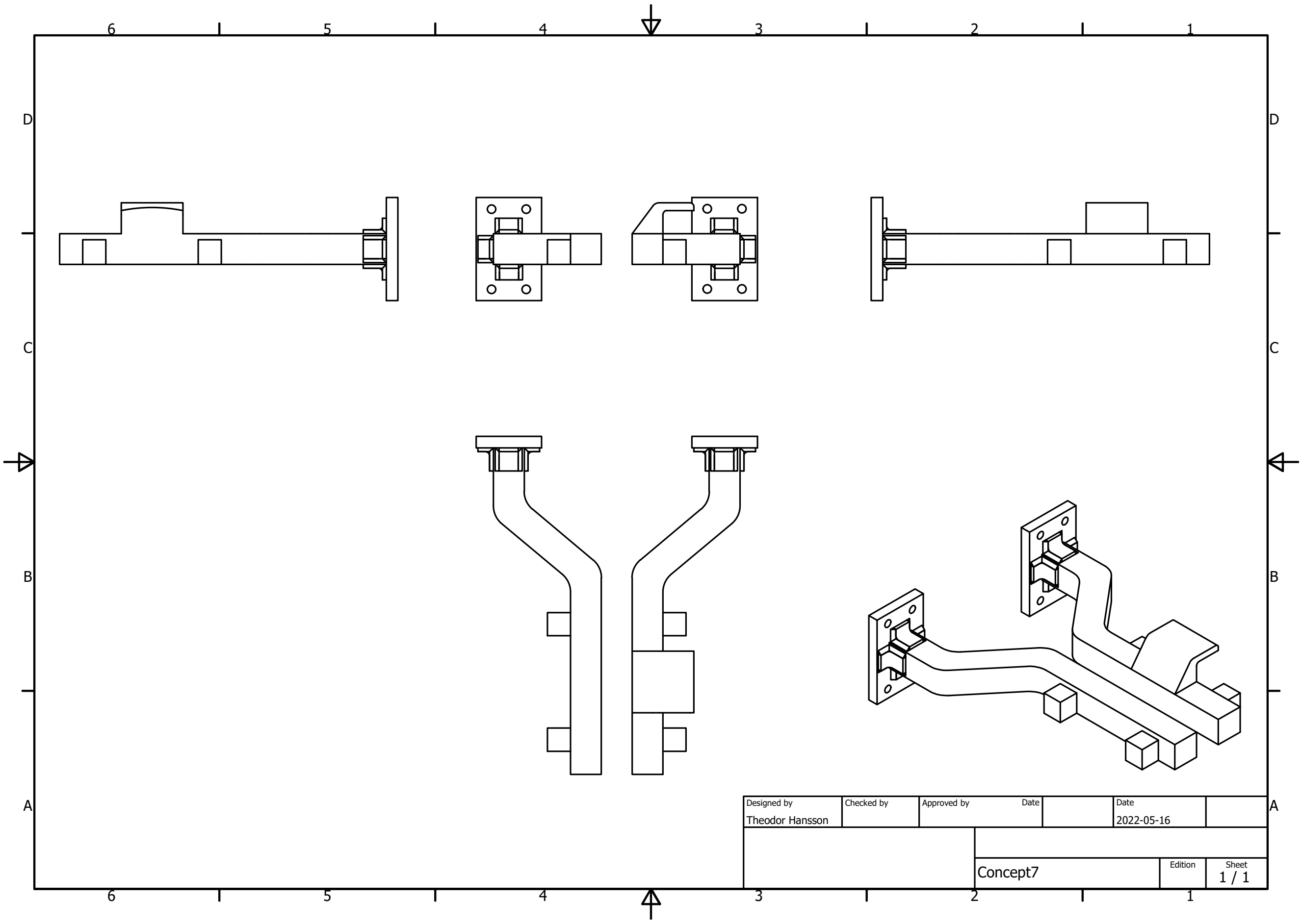
**Which product is the toughest to manually grind?** The operator points out the specific product called Product 1.

**Rank the product on what you would believe is easiest to automate?** The operator points out that product 3 and product 5 would be simple to automate.

**What product would you most like to be grinded automatically?** The operator points out the (Product family 1) with the reason of it being a lot of cutting procedures and a high risk of damaging the product and possibly forgetting a procedure. The operators also point out the product family 2 as it involves tough grinding. And would save the operators a lot of time.

# Appendix E

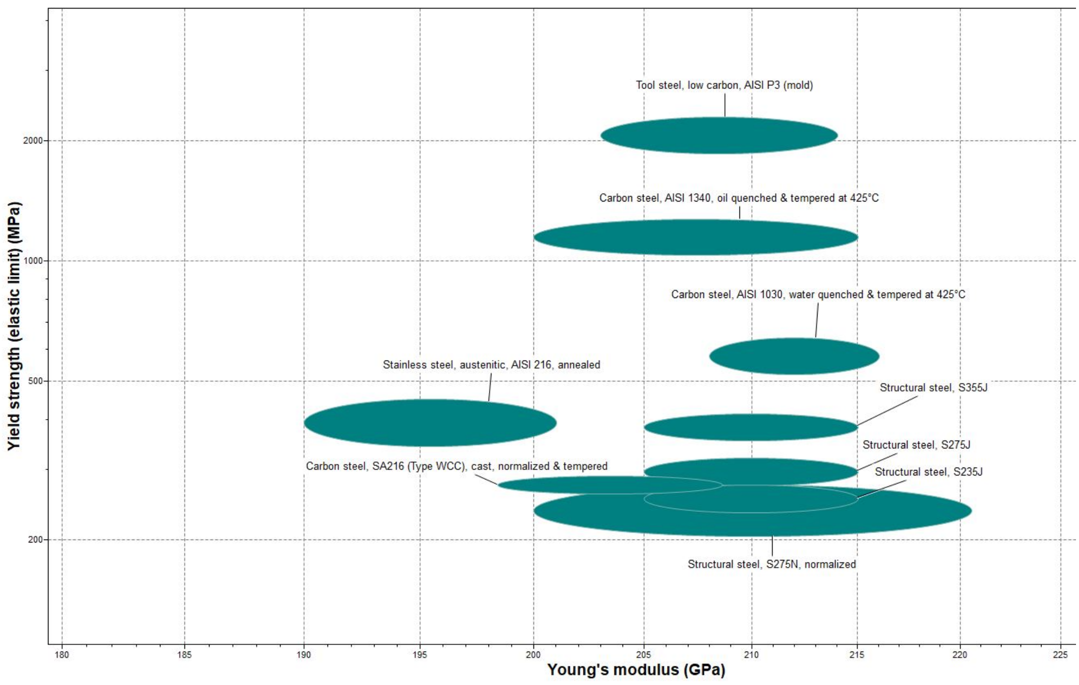
# Fifth Appendix- Drawing

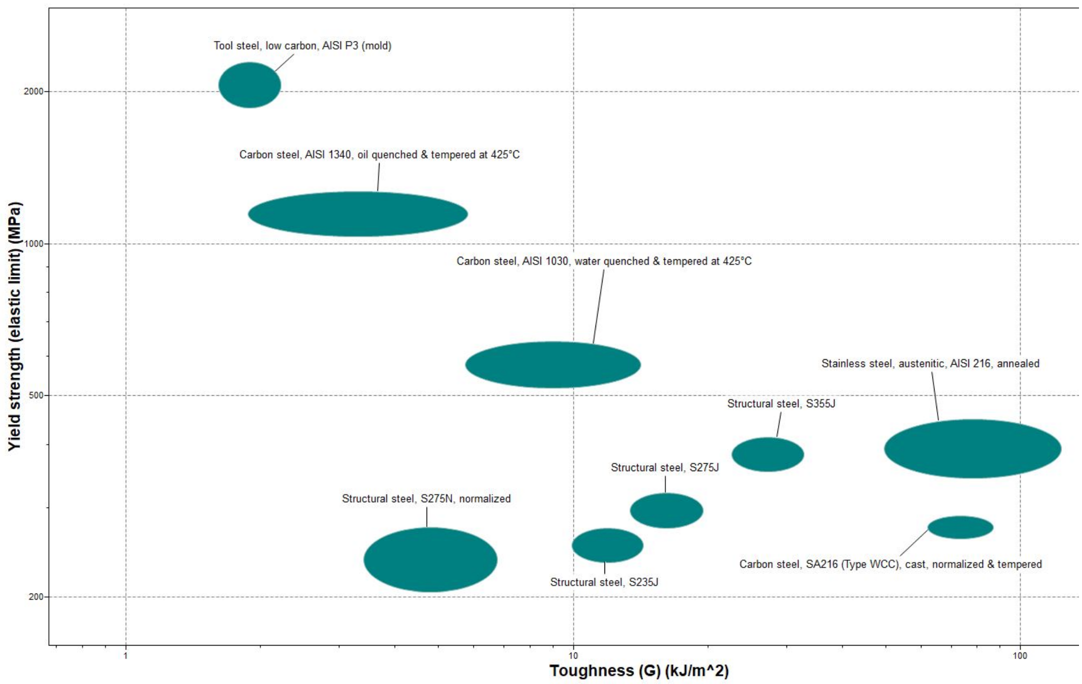


# Appendix F

# Sixth Appendix- Material selection

| | |
|---|---|
| Function | With stand load without plastically deform |
| Constraints | Good weldability<br>Good metal cold forming and hot forming |
| Free variabels | Choice of material |






The materials shown in the diagram are the possible candidates for the gripper beam. The material is chosen as the structural steel S355J as it the best performance in yield strength and toughness and has a favorable Young's Modulus.

# Appendix G

# Seventh Appendix - Concepts

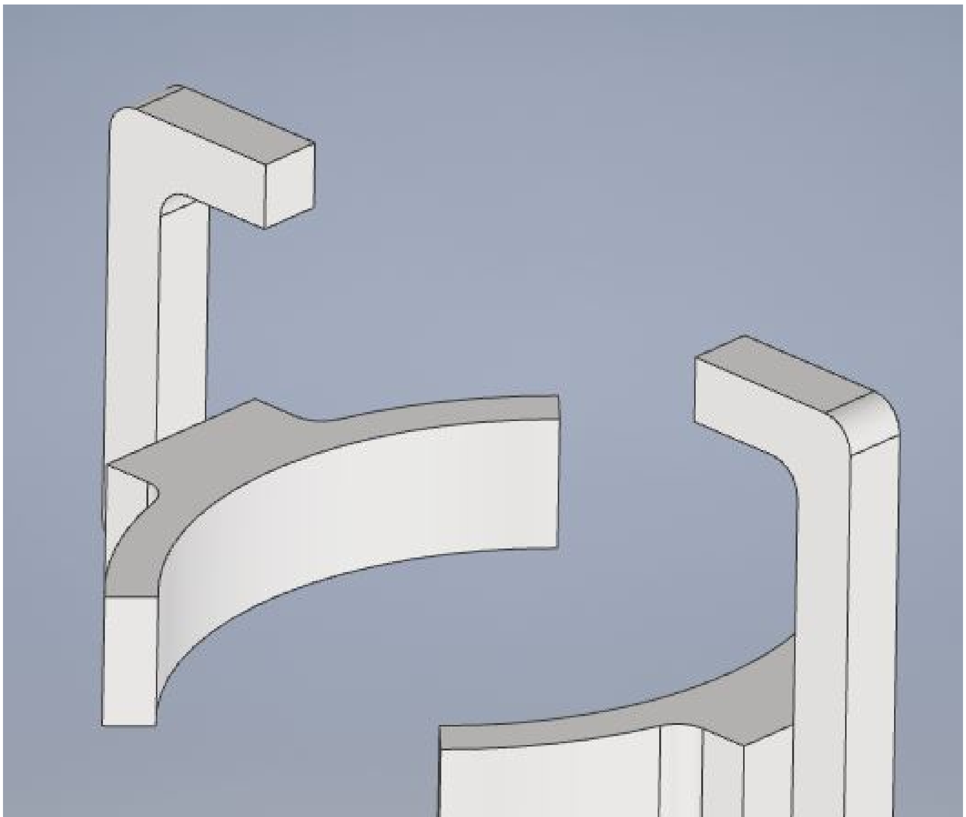


Figure 9: Concept 1

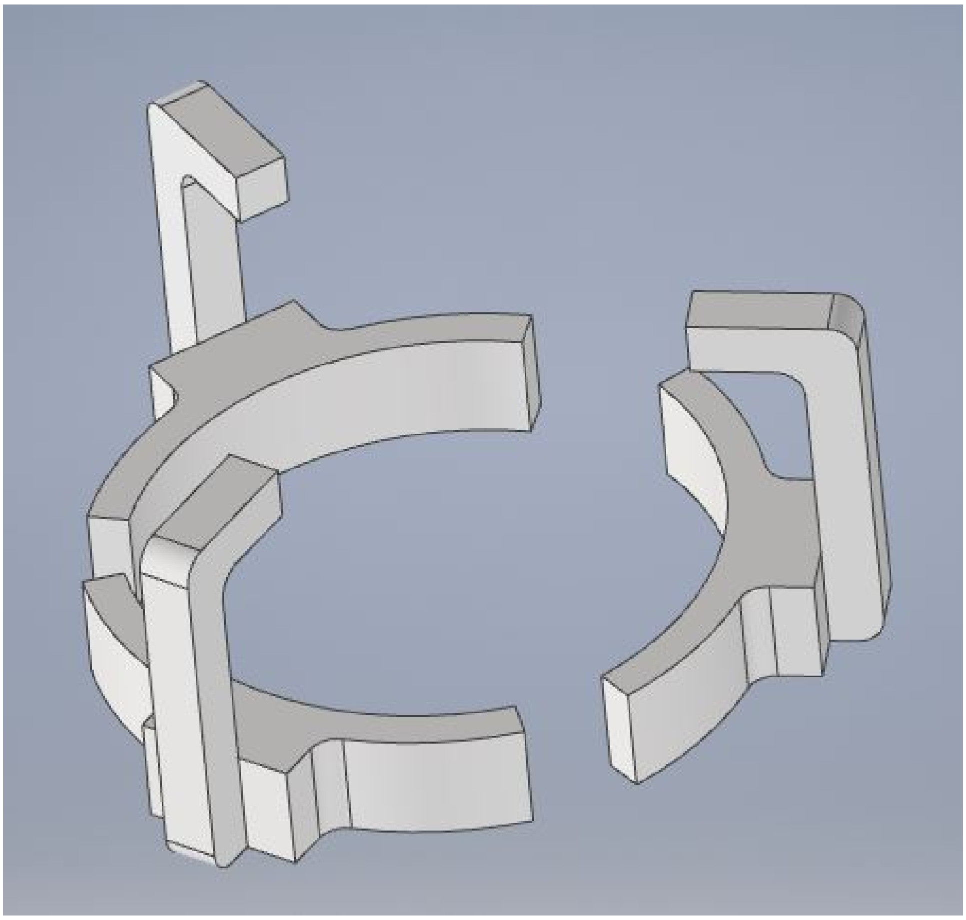


Figure 10: Concept 2

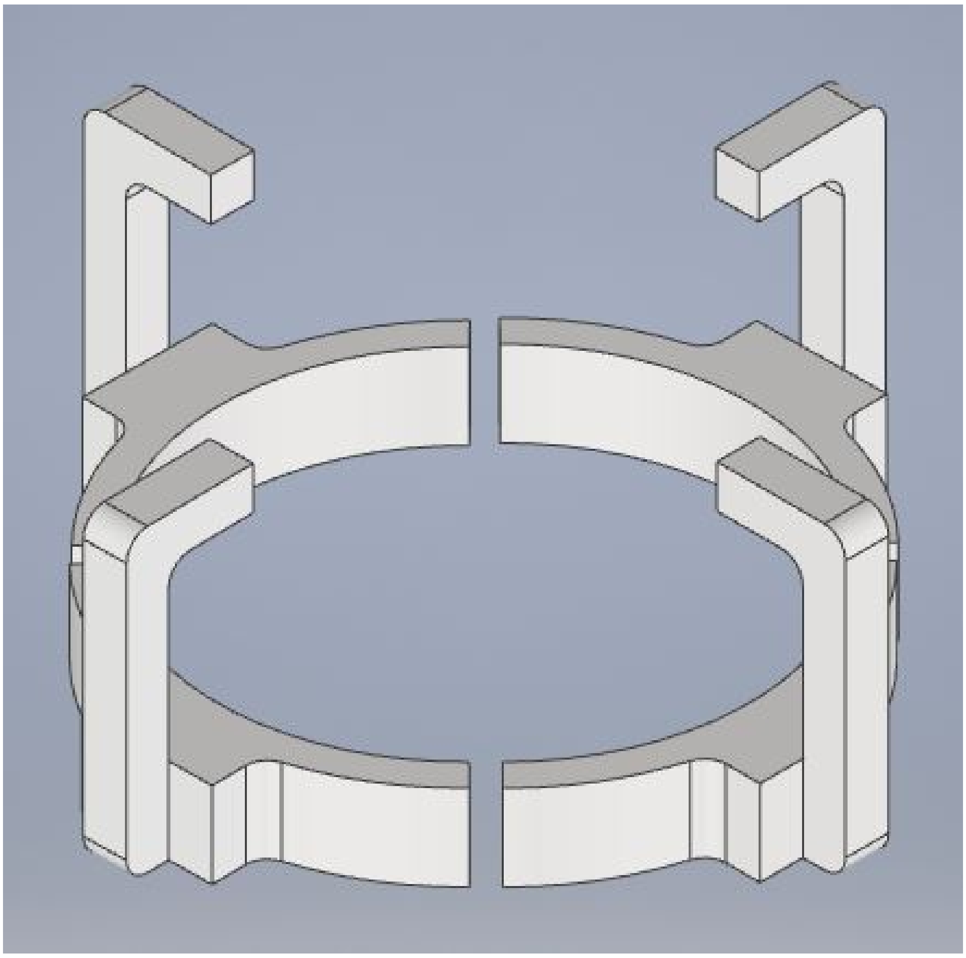


Figure 11: Concept 3

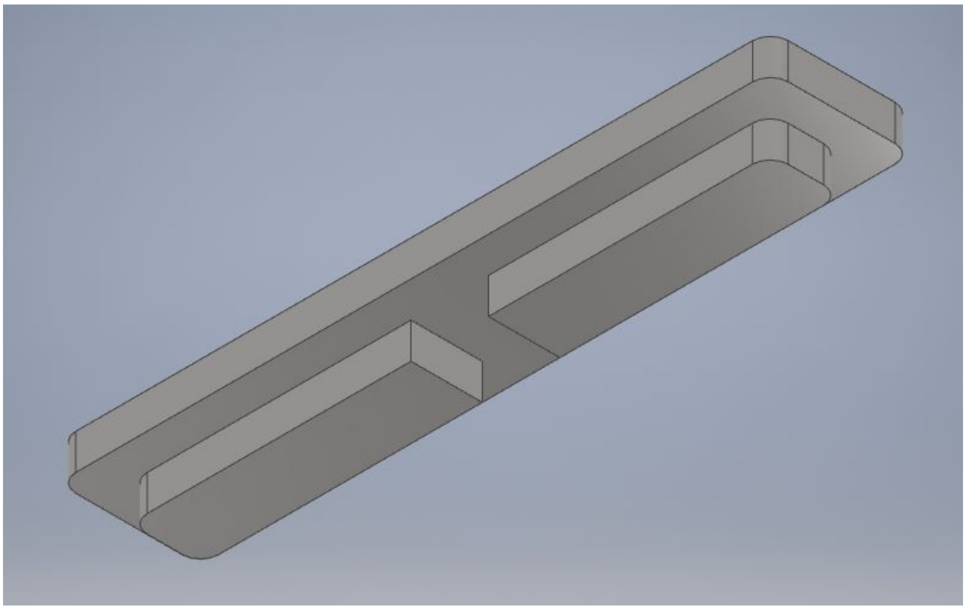


Figure 12: Concept 4

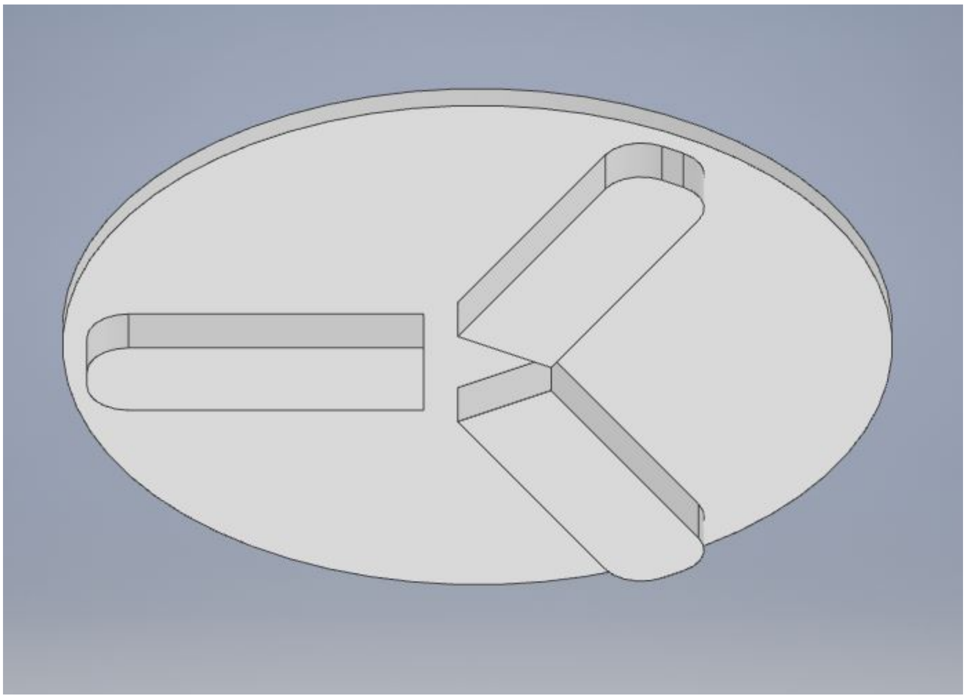


Figure 13: Concept 5

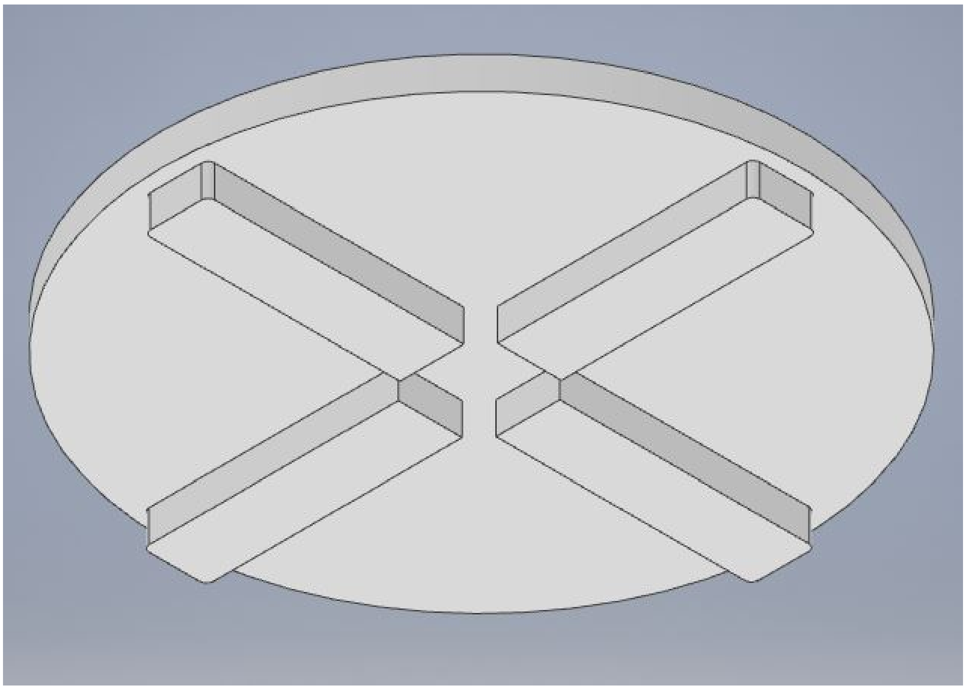


Figure 14: Concept 6

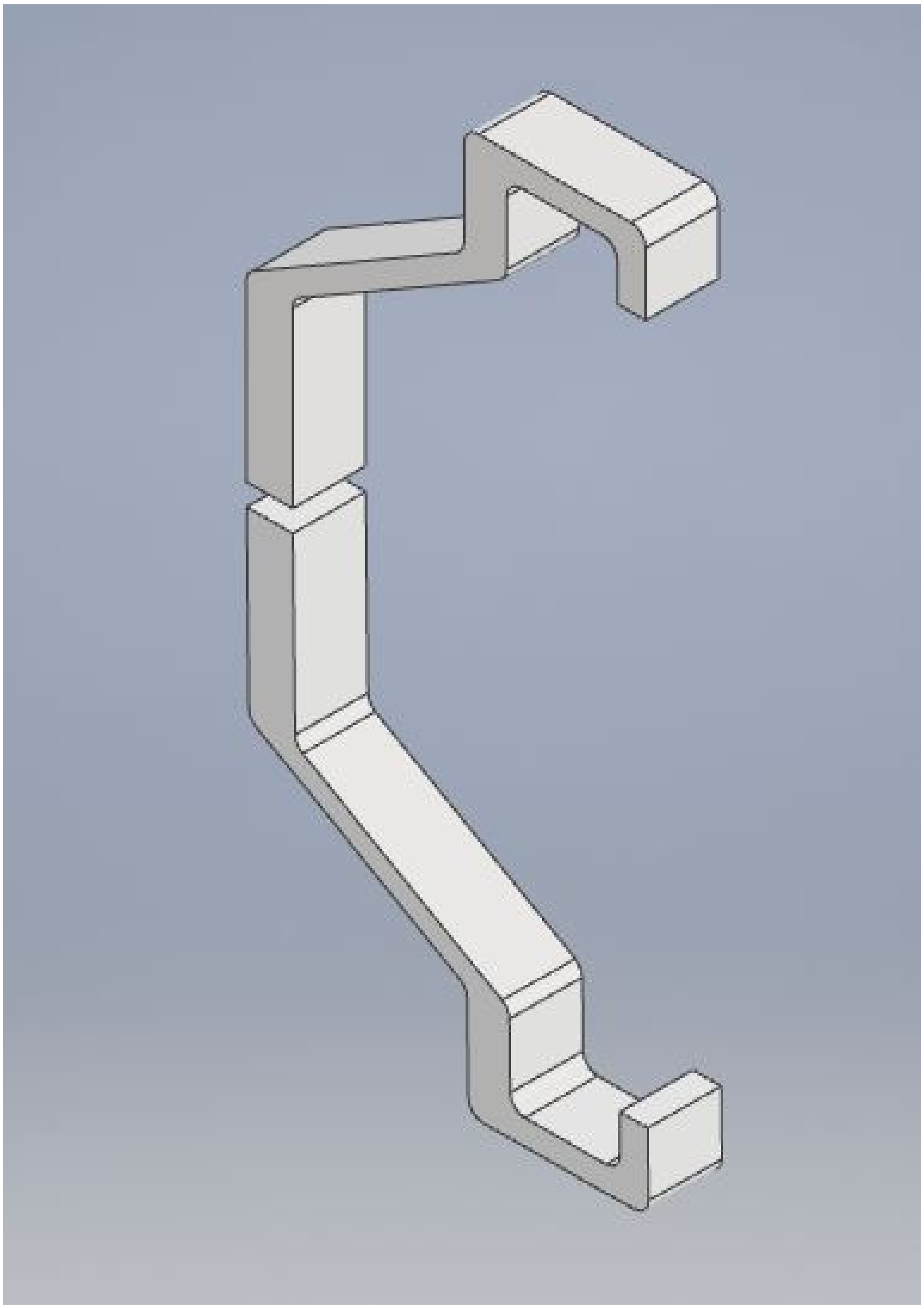


Figure 15: Concept 8

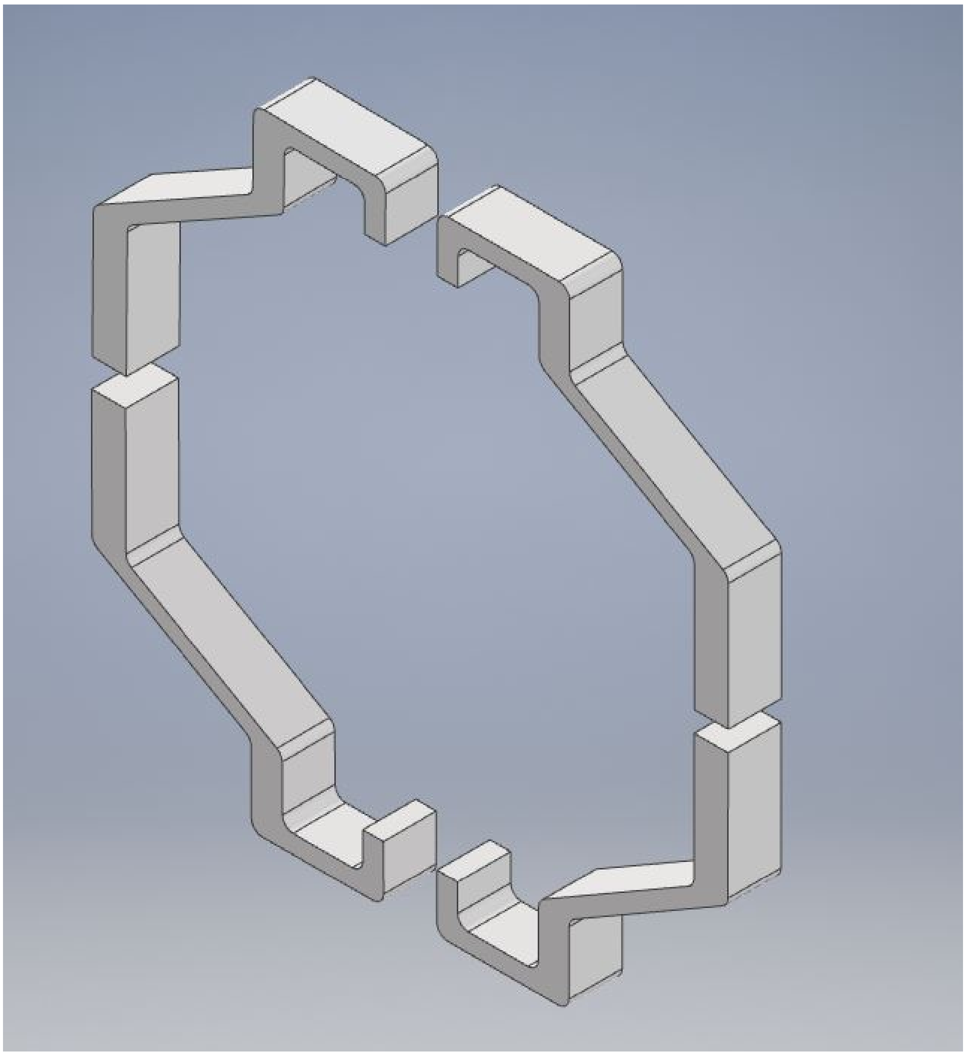


Figure 16: Concept 9

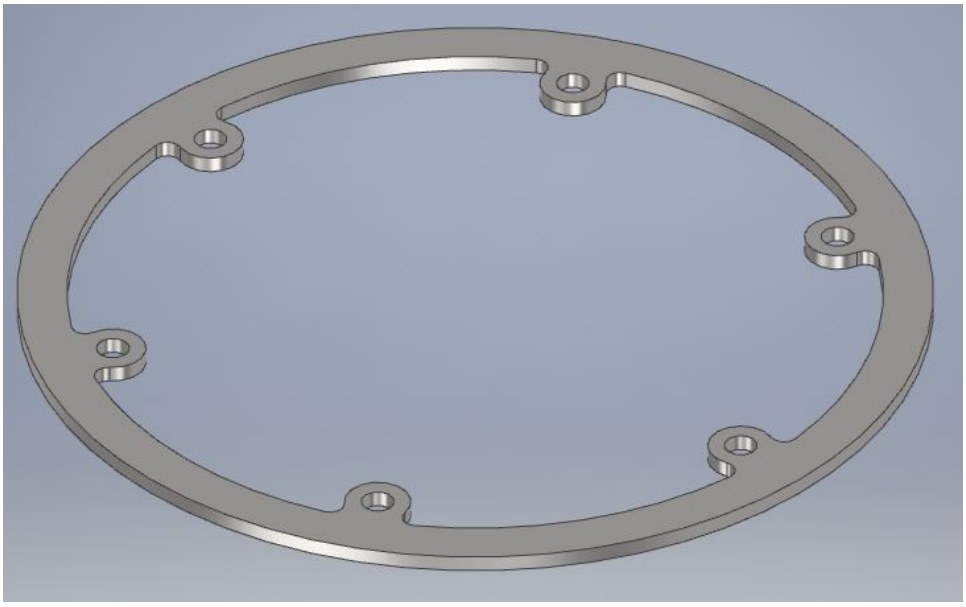


Figure 17: Concept 14

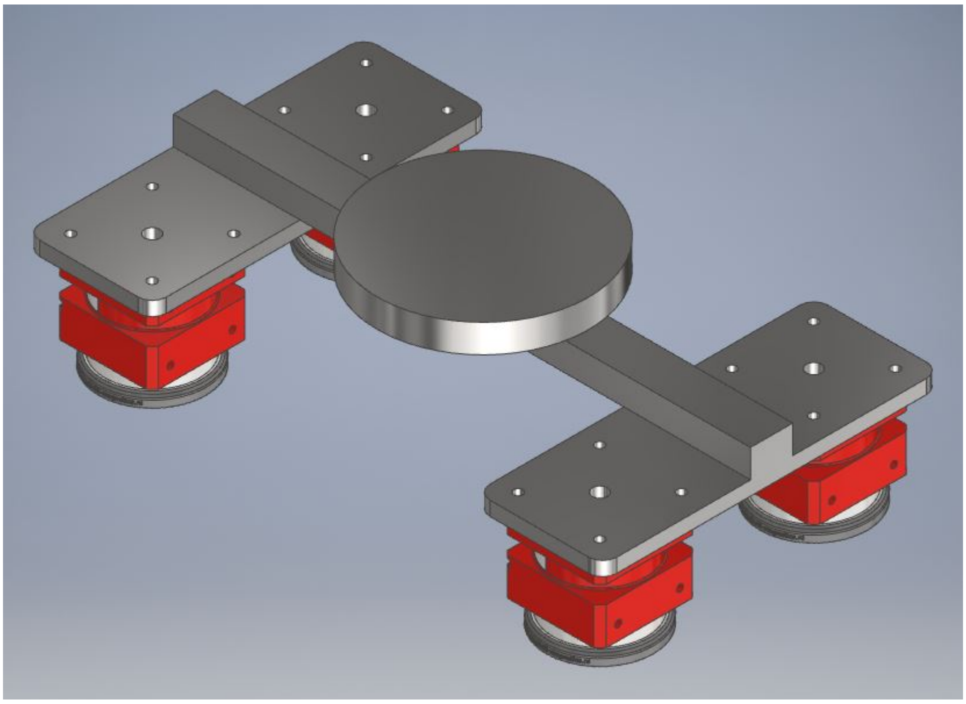


Figure 18: Concept 15

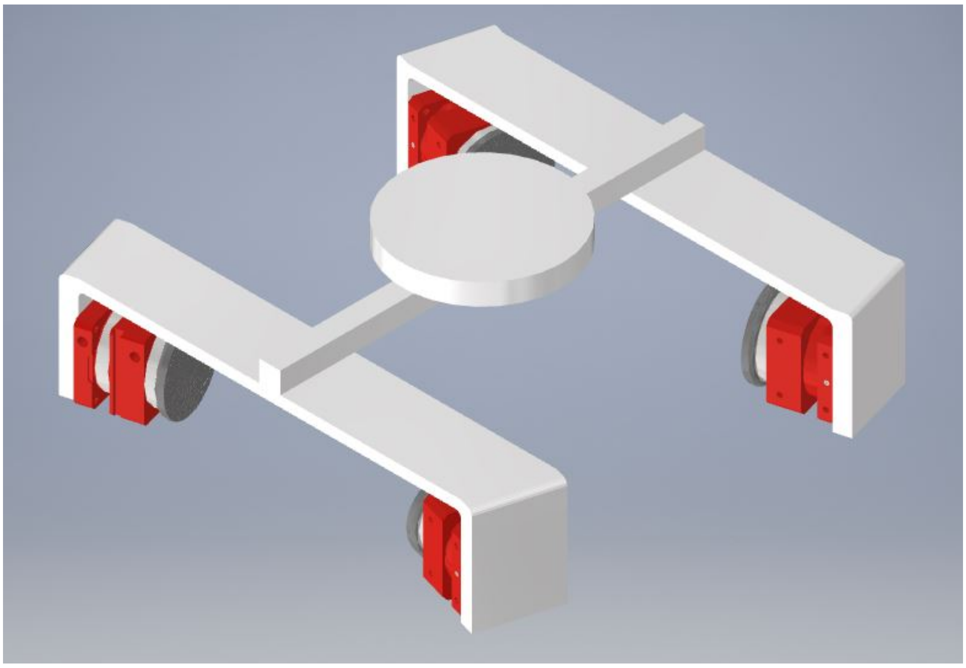


Figure 19: Concept 17