Design of breast roll retraction system – Valmet

Redesign of keyway solution for positioning of breast roll in tissue machine

Konstruktion för uppbärning av bröstvals - Valmet
Omkonstruktion av kilspårslösning för positionering av bröstvals i tissuemaskin

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22.5 hp
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Abstract

This Thesis has been carried out as a final part of the Mechanical Engineering programme (180 credits) at Karlstad University during the spring semester 2022 and comprises 22.5 credits. The work is carried out on behalf of Valmet AB in Karlstad.

At the beginning of a tissue machine, a mixture of fibres and water is fed into the machine and formed into a sheet using a forming wire and felt. During maintenance work, the wire sometimes needs to be detached from the machine. In order to release the forming wire, the breast roll retraction system needs to be opened up, which is done using an arm with the breast roll attached to it. This arm can rotate upwards, taking the breast roll with it, and when this is opened, the forming wire can be removed. In the hinge that this arm is attached to there is a gap, in addition to the gap the arm can be bent slightly. When the arm is returned to its original position after replacing of the forming wire, this gap and bending creates some problems. The problem is that the arm needs to return to its original position with great precision to avoid unnecessary adjustments. This is currently done using keys with angled walls and to lock the position eye bolts with associated nuts. The manufacturing of this solution has been identified as expensive due to tight tolerances and the angled walls of the keys and keyways. The aim of this project is to make the design cheaper to manufacture through design modification of this positioning and locking mechanism.

Through a feasibility study regarding the current design and manufacturing method a deeper understanding of the function and machining was gained. The project has followed a structured product development process, from pre-study through requirements specification, concept generation and evaluation to detailed design. A requirement specification was developed using the results of the feasibility study together with information from Valmet employees. Two concept generation sessions were conducted, the 6-3-5 method and morphological matrix, these were done together with people at Valmet with different experiences. For concept evaluation and selection, Harris profile and relative decision matrix were used, these were conducted after consultation with experienced people at Valmet.

The best concept is a design change that eliminates the milled angled walls in the keyway on the arm. These are replaced by a cylindrical pocket and a threaded hole. A corresponding change is made to the bracket against which the arm rests. Instead of the keys used today, two turned parts with a conical contact surface between them are proposed. This solution achieves all the requirements of the requirements specification as well as all the wishes except that it should fit similar fastening elements in other sections of the machine. The explanation for this is that the other fastening elements have slightly different functions which the proposed solution does not take into account. The price difference between the current design and the design proposed by the project has been obtained by a subcontractor providing price proposals for both.

Sammanfattning

Detta Examensarbete har genomförts som en avslutande del av maskiningenjörsutbildningen (180 hp) vid Karlstads universitet under vårterminen 2022 och omfattar 22.5 hp. Arbetet utförs på uppdrag av Valmet AB i Karlstad.

I början av en tissuemaskin förs en blandning av fibrer och vatten in i maskinen och formas till ett ark med hjälp av en vira och filt. Vid underhållsarbete behöver viran ibland tas ut från maskinen. För att lossa viran behöver bröstvalsen öppnas upp, detta görs genom att bröstvalsen sitter fastspänd på en arm. Denna arm kan rotera upp och tar då med sig bröstvalsen, när denna är öppnad så kan viran tas ut. I gångjärnet som denna arm sitter på finns ett glapp, förutom glappet kan armen böjas något. När armen, efter att viran bytts ut, ska återgå till sitt ursprungliga läge skapar detta glapp och böjning viss problematik. Problemet är att armen behöver återgå till sitt ursprungliga läge med stor precision för att undvika onödiga justeringar. Detta görs idag med hjälp av kilar med vinklade väggar samt för att låsa fast positionen fäll skruvar med tillhörande mutter. Tillverkningen av denna lösning har identifierats som dyr på grund av snäva toleranser och de vinklade väggarna på kilen och kilspåret. Syftet med detta projekt är att genom designändring av denna positionering och låsningsmekanism få konstruktionen billigare att tillverka.

Genom en förstudie gällande den nuvarande designen och tillverkningsmetoden skapades en djupare förståelse av funktion och bearbetning. Projektet har följt en strukturerad produktutvecklingsprocess, från förstudie genom kravspecifikation, koncept -generering och -utvärdering till detaljkonstruktion. En kravspecifikation togs fram med hjälp av resultatet från förstudien tillsammans med information från anställda på Valmet. Två konceptgenereringssessioner genomfördes, 6-3-5 metoden och morfologisk matris, dessa gjordes tillsammans med personer på Valmet med olika erfarenheter. För konceptutvärdering och val användes Harris profile samt relativ beslutsmatris, dessa genomfördes efter konsultation med erfarna på Valmet.

Det bästa konceptet är en konstruktionsändring som eliminerar de frästa vinklade väggarna i kilspåret på armen. Dessa ersätts av en cylindrisk ficka samt ett gängat hål. Motsvarande ändring görs på konsolen som armen ligger mot. Istället för de kilar som används idag föreslås två svarvade parter med konisk kontaktyta mellan varandra. Denna lösning uppnår alla krav i kravspecifikationen samt alla önskemål förutom att den ska passa liknande förband i andra delar av maskinen. Förklaringen till det är att de andra förbanden har något annorlunda funktion som den föreslagna lösningen inte tar hänsyn till. Prisskillnaden mellan den nuvarande och den av projektet föreslagna designen har tagits fram genom att en underleverantör lämnat prisförslag på båda.

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Appendices:

1. Introduction

This chapter gives an introduction to the thesis with some background about the paper industry and Valmets role in it. This together with problem definition, aims and delimitations for the thesis project.

The thesis has been carried out as a final part of the mechanical engineering programme (180 credits) at Karlstad university during the spring semester 2022 and comprises 22.5 credits. The thesis is carried out on behalf of Valmet AB in Karlstad with supervisor Jenny Nilman. The supervisor at the university is JanErik Odhe and the examiner is Anders Biel.

1.1 Background

The demand for tissue paper is growing at about 3 percent per year. The increase in demand is mainly driven by developing countries, where the driving factor include rising standards and increased purchasing power. The use of tissue paper is also increasing in the western world, where the quality of the product is becoming increasingly important. [1]

1.1.1 About Valmet

The leading global supplier and developer in the pulp, paper, and energy industries is Valmet Corporation. Globally, Valmet has around 17 000 employees, of which approximately 1 500 work in Sweden. The main production and R&D units in Sweden are located in Gothenburg, Karlstad and Sundsvall. Valmet has a strong technology offering in pulp mills and production lines for tissue, paperboard, and paper, including powerplants for bioenergy production. Valmet has a long history in the industry, stretching over 200 years. The company is headquartered in Espoo, Finland, and is listed on the Helsinki Stock Exchange [2]. Valmet places great emphasis on sustainability and is included in the Dow Jones Sustainability Index.

Valmet AB Karlstad manufactures machines that produce tissue paper for the global market. Valmet has delivered over 200 tissue machines worldwide. The machines include technical solutions for the production of high-quality tissue paper such as facial, bath, towel, napkins, hankies and away from home products. Energy, water, and fiber savings, as well as reduced emissions to air, water and landfill are high on the agenda for most tissue manufacturers today, and Valmet is constantly developing its technology to meet the increasing environmental demands.

1.1.2 The tissue machine

In the first part of the tissue machine, the former section is located (left in figure 1.1). In this section the aim is to distribute the fibers evenly over the entire width of the machine with the help of a headbox. The fibers are mixed with water and distributed between a forming wire and a felt, where also parts of the water are separated from the fibers. Remaining on the felt after the forming section is a sheet of fibers, which still contains a large proportion of water. The sheet then enters the next section of the machine, the press section, which has the task of removing water. Thru wet pressing the amount of liquid reduces in the sheet, the press section also has a major impact on the quality of the paper, such as softness and bulk. After the press section, the sheet arrives at the drying section, where water is removed by evaporation. Usually, a yankee cylinder is used for this, or “Thru-Air” drying in combination with yankee. Finally, the sheet reaches the rewinding section, where the sheet, the finished tissue paper, is rolled up on tambour rolls for further processing. [1]

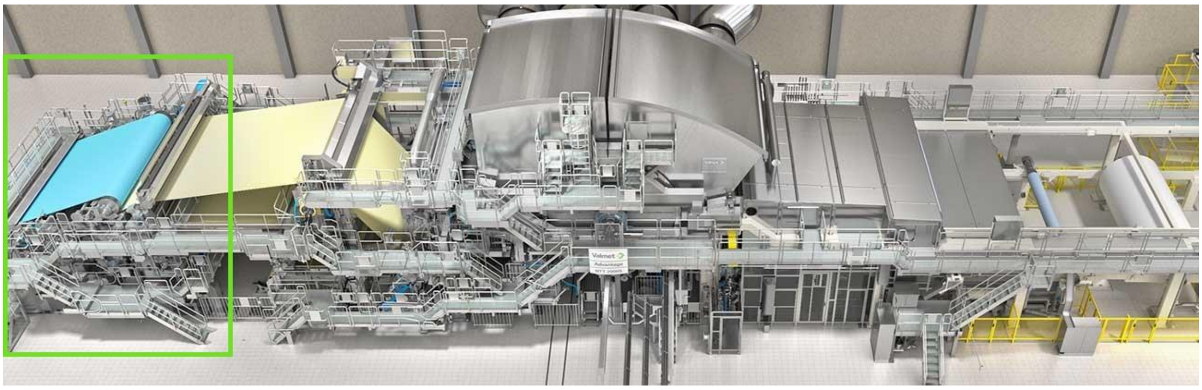

Figure 1.1 Picture of a tissue machine, the process starts on the left with the Forming section [F.1].

The fibers contain 99.8 percent water at the beginning of the process when they enter the forming section of the tissue machine. Through various stages of the process, the water amount is reduced to only around five percent as the sheet is processed through the various sections. The normal width of the sheet is around 5-5.5 meters and it runs through the machine in nearly 120 km/h, which means it takes only 1,5 seconds to pass through all the sections from start to finish and become finished paper.

1.1.3 Problem definition

The breast roll is located in the forming section, which is the first part of the paper machine, where the forming roll also is located. Figure 1.2 below shows the forming section, which in addition to the breast roll shows where, the forming roll, headbox, felt and the forming wire are located in relation to each other.

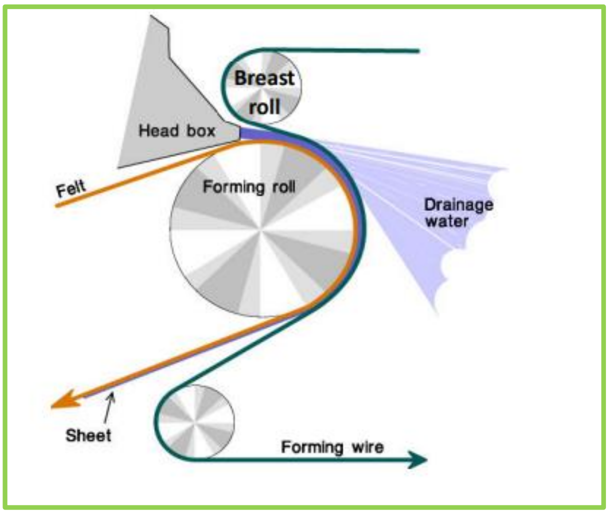

Figure 1.2, picture that shows the former section in the tissue machine. (Internally retrieved from Valmet, with permission)

There is a “nip” between the forming roll and the breast roll that presses the fibers against the felt. The breast roll sits on a bracket on an mechanical arm that also needs to open up to get the forming wire through. This arm is locked by eye bolts and a fitted keyway to avoid movement (see figure 1.3).

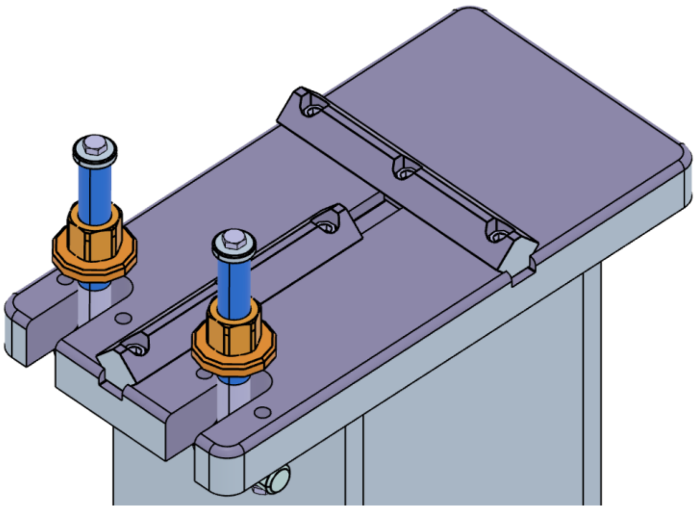

Figure 1.3 The keyways and the eye bolts, the top plate is around 200x400x35mm

The breast roll needs to be carefully fitted against the forming roll, to ensure that the sheet is of correct thickness and that variations in thickness along the sheet are kept to a minimum, so the final paper is of high and consistent quality. The keyways that fixes the position of the breast roll is therefore manufactured to a tight tolerance that is difficult and therefore expensive to produce. The retraction system should have a repeatable position of about ±0,1mm. The tight tolerance also contributes to a small margin when fitting the breast roll. In order to make it easier, and therefore cheaper, to manufacture and fit the breast roll, this positioning and locking mechanism is to be redesigned. By lowering the price of individual parts of the tissue machine, the overall price can be reduced, thus creating a greater competitive advantage.

1.2 Purpose and goals

The aim of the project is to reduce the price of the design that positions the breast roll, without changing the function, and thereby obtain a lower manufacturing price. The new design should contribute to a simpler geometry which leads to a cheaper production and should, if possible, consist of standard parts. It should also be easy to install the breast roll with the new design. In the project description, Valmet presents the expected results of the thesis, which are described as project objectives below. The thesis should also lead to a bachelor's degree in mechanical engineering.

Project objectives:

- Propose a design with a lower cost than the current design.
- Compare the current solution with the improved design.
- Provide a 3D model and drawings for the new proposed design.
- Provide manufacturing method for the new design.

1.3 Delimitations

The project will only investigate the positioning and locking mechanism of the breast roll for a tissue machine. The production of a prototype and testing of it will be excluded from this thesis.

The resources of the project are limited to 600 hours, which corresponds to 22,5 hp.

2. Theory

This chapter describes relevant theories on the product development process, manufacturing methods, different types of fastening elements and materials.

2.1 Tolerances

Allowable variations in dimensions, shape and position from a base dimension are described by tolerances. Both surface roughness and dimensional tolerances are two important quality attributes of a part to ensure that assembly and usage will work as intended. Tighter tolerances and smoother surfaces lead to a more expensive manufacturing cost, and greater control of the manufacturing process is required. [3]

The tolerances is defined by ISO standards and for the standards that apply to the products covered by this thesis are the following ISO tolerances:

Machining: ISO 2768-mK, ISO 2768-2(/EN 22768-2), ISO 2768-1(/EN 22768-1)
Welding: (EN) ISO 13920-BE
Welding quality: (EN) IDO 5817 LEVEL C
Thermal cutting: (EN) ISO 9013-331
Casting: (EN) ISO 8062-3-DCTG 11

A standard is used to uniform and transparent procedures to recurring problems. And it is a way to make sure that buyers and suppliers speak the same language. Some of the benefits using standards is that ensures compatibility and creates a cost-effective process. [4]

2.2 Product development process

The methodology used in this product development is based on Johannesson et al [5] description of the product development process. The process is described as a structured problem solving and describes different phases of product development. In general, the process is described in the following steps, feasibility study, product specification, concept generation, concept selection, detailed design, prototyping and finally manufacturing adaption (see figure 2.1). The use of a well-defined development process helps to create a high-quality product and facilitates planning [6].

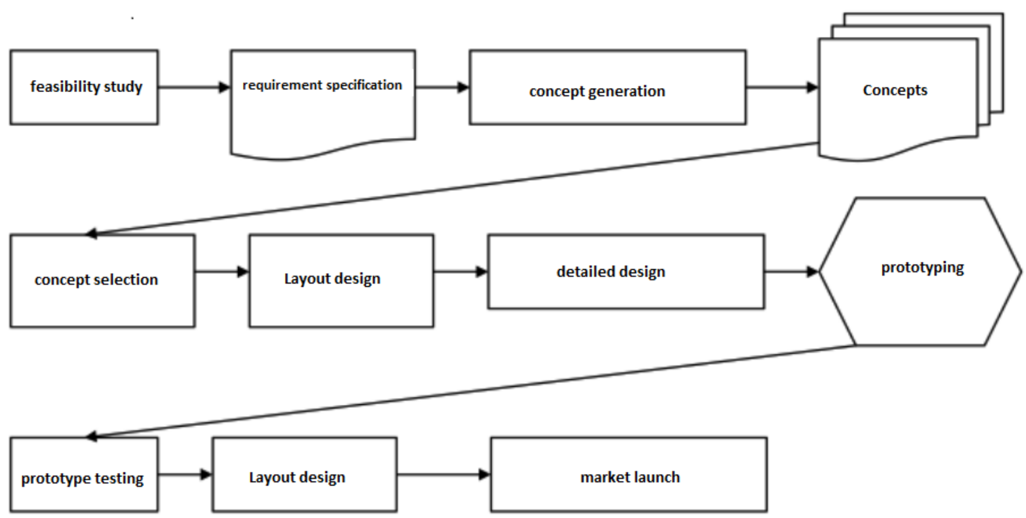

Figure 2.1 Phases of product development Based on Johannesson et al. [F.2] figure.

An important aspect of using a systematic approach to the product development is that the future cost and quality of the product is largely determined during the development. Conditions are thus created in the development process to create a high-quality product with low cost. Using a systematic approach also leads to a shorter development process of the new product. [7]

In addition, a further advantage of using a structured systematic development process is that the work is well documented, which provides traceability. Changes at late stages of a product development process are expensive and should be avoided, by using a predefined process this can be prevented. [5]

2.3 DfX

Design for X, is a method or a mindset that can be applied when developing a new product. In DfX, the X is changed to some other letter that is applicable, commonly used is M for manufacturing, A for assembly or S for serviceability. In this thesis Design for Manufacturing (DfM) will be the main focus. As the name suggests it is to make the design easier to manufacture and in that way lower the cost for the design. For example, if the product has simpler geometries to manufacture, consider what tools are available and can be used, and has features that simplify manufacturing, it will be cheaper to produce. Figuring out the manufacturing method to be used and the steps to be taken to manufacture the product during the product development process can have a significant impact on cost. For example, features that are not related to the function of the product may be worth designing in to facilitate e.g. clamping in machines or to facilitate casting. Other ways to lower the cost of the parts that is to be manufactured is to design it in such way that the need for small tolerances and fine surfaces is reduced. [5,8]

Embracing DFM early in a product development process and spend the time making it simpler to manufacture will be rewarded in the end of the process.

2.4 Environment in the tissue machine

The breast roll retraction system and the breast roll is located in the wet end of the machine. The breast roll is located in close relation to the headbox in the former section and has the task of ensuring that the fibers stay in the forming section and to help remove water. Some important property of the breast roll and its suspension is to resist deflection, to avoid variations in the thickness of the sheet of fibers, and to handle the corrosive environment.[9]

The wet end of the tissue machine, have a corrosive environment. There is water, fibers and chemicals. The reason of this is that in pulp production the wood needs to be broken down into fibers, this can be done in three ways, mechanically and chemically or a combination of these [10]. The most common process today is a chemical process where the kraft pulping process is dominant and replaces a previously common method, the sulphite process [10][11]. The chemical substances used in the production of pulp contribute to a harsh environment that are demanding on the materials that are in close proximity to the pulp.

Mechanically produced pulp has higher wood yield compared to chemically produced pulp. The quality of the paper produced with pulp from chemical methods is higher compared to pulp from mechanical methods. However, the development of the mechanical process is moving rapidly as the sustainability of forestry is becoming more important [10]. The advantage of mechanical pulping is that fewer trees are needed for the same amount of paper compared to chemical processes.

2.5 Materials

The forming section is in the wet end of the paper machine and the components located here need to be corrosion resistant both to weak acids and weak alkalis. In the wet end of the machine there is both water and chemicals that expose the component to a harsh environment. In many applications the materials are welded together hence the materials should also have good weldability. In addition to weldability, the materials need to be machinable by cutting, and to make the machining as cheap as possible, the materials need to have good machinability. The material used here consists mainly of a stainless acid-resistant alloy, EN 1.4432 (SS 2353, AISI 316L). Materials such as EN 1.4436 (SS2343, AISI316) and bronze alloys are also used on some components[1].

Stainless steels have long been used in tissue machines, EN 1.4432 and 1.4436 are among the most common materials used in exposed areas of the machine, EN 1.4307 (AISI 304L) is also a common alloy. The latter alloy has a lower corrosion resistance to chloride environments. [12]

EN 1.4432 is an austenitic stainless steel, austenitic steels have good formability and corrosion resistance over a wide temperature range. Machinability is relatively good, however, deformation hardening is high and thermal conductivity is low [13]. These properties lead to higher cutting forces and higher temperatures during machining and results in poor surface finish. [15].

EN 1.4436 is also an austenitic stainless steel like EN 1.4432 and share the properties with the latter, with the difference that the carbon content is allowed to be slightly higher in EN 1.4436. Because the carbon content is slightly higher, EN 1.4436 has slightly better strength compared to EN 1.4432. However, in welded structures, EN 1.4436 may exhibit slightly lower corrosion resistance in areas near the weld compared to EN 1.4432. [14]

Both materials EN 1.4432 and EN 1.4436 are recyclable, the materials can be reprocessed to return to the primary supply chain. The materials can also be downcycled to lower quality materials. [13]

The materials have good weldability with all conventional welding methods such as e.g., MIG, TIG and Plasma [13]. This makes the material suitable for sheet metal constructions.

EN 1.4432 (AISI 316L) tops the list of stainless steels when comparing the cutting speed of stainless steels that can withstand weak acids in an excellent way. The cutting speed according to Granta EduPack is 73 m/min, however this is only for comparison as the cutting speed is affected by a number of factors such as the machining operation being performed, the cutting tool, depth of cut among others. The cutting speed for AISI 304L, according to the same database is only 25 m/min.

The resistance to weak alkalis is good for the stainless steels, both AISI 316L and AISI 304L have excellent resistance to these (see figure 2.2). Materials that have a high machining speed and can withstand weak alkalis in an excellent way is placed close to the upper right corner in figure 2.2. However, all materials that is right of the acceptable line withstand weak alkalis in an excellent way.

[1] Conversation with Jenny Nilman at Valmet Karlstad (2022-02)

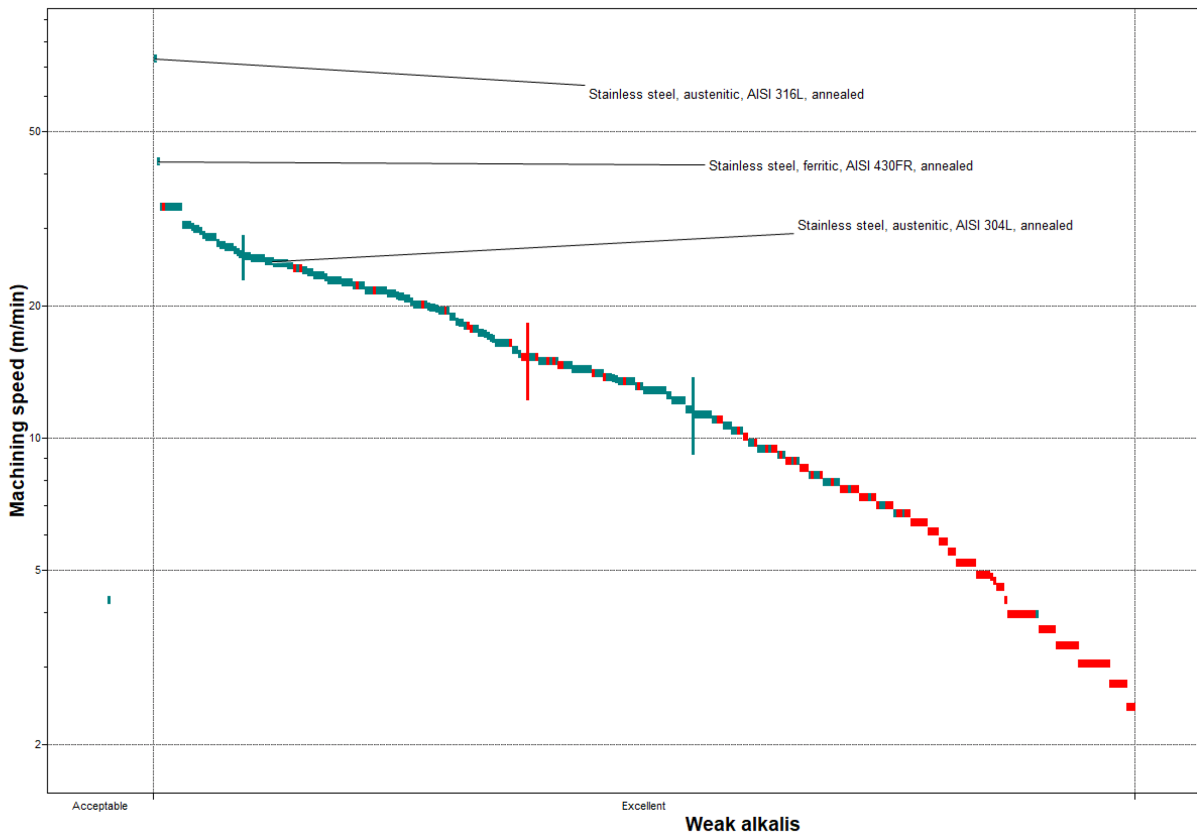

Figure 2.2 Comparison of materials from Granta EduPack 2021 R2 [13], machining speed - resistance to alkalis

Aluminium is a group of materials that has a high resistance to corrosive environments just like stainless steels. Resistance to weak alkalis is however low for most aluminium grades with the exception of 6156, which however has a low cutting speed for aluminium (79 m/min). The cutting speed is normally higher for aluminium than for stainless steels, which makes machining faster. By comparison, the cutting speed for aluminium is 183 m/min, which is considerably higher than for AISI 316L. A problem with using aluminium together with stainless steel is that it could cause galvanic corrosion.

When comparing price per kilo, AISI 304L and AISI 316L are close to each other, which can be seen in figure 2.3 which compares price per kilo with cutting speed. Kilo price is a good comparison for materials of similar density, figure 2.3 also includes an aluminium alloy which has relatively similar price per kilo and cutting speed as AISI 316L, however the aluminium would be lighter if the same volume of material is used. Table 2.1 compares different materials that can withstand both weak acids and weak alkalis. In the lower right corner of figure 2.3 the price is low and the machining speed is high which is optimal, the best material according to price and machining speed is close to that corner of the figure.

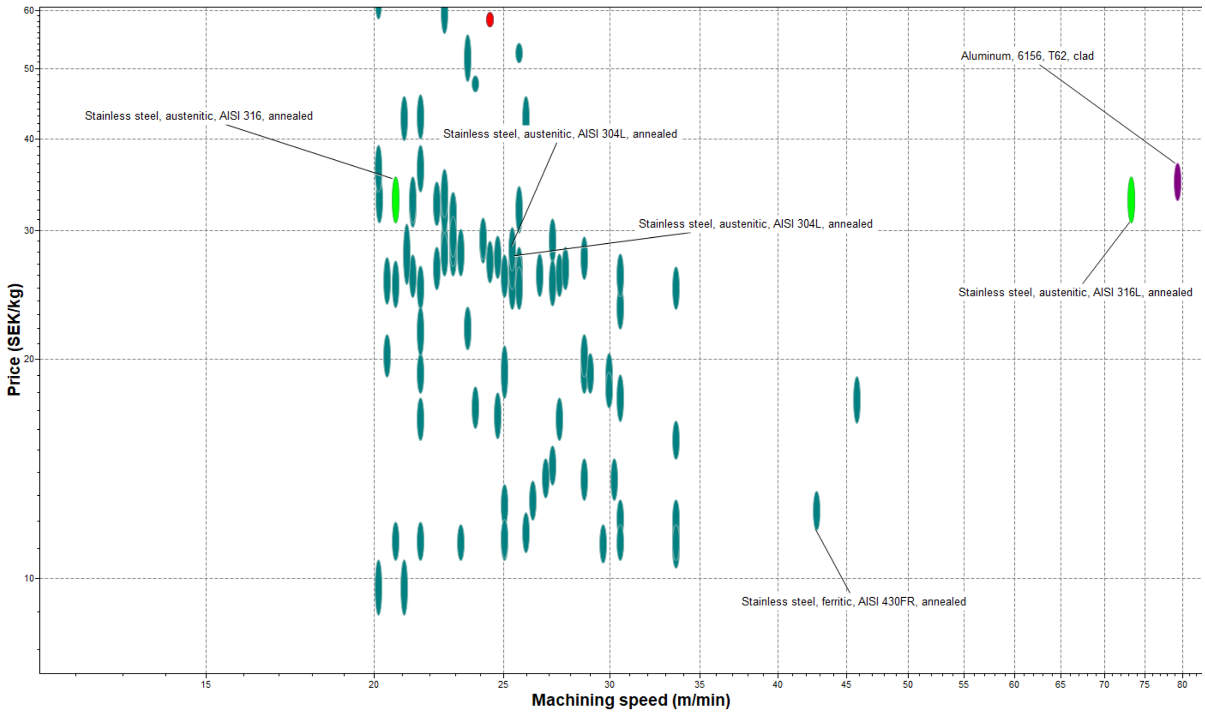

Figure 2.3 Comparison of materials from EDU pack [13], price per kilo – machining speed

Table 2.1. Comparison of materials

Material\property	Withstands weak acids	Withstands weak alkalis	Cutting speed
AISI 316 (1.4436)	Yes	Yes	20,7* (154)m/min
AISI 316L (1.4432)	Yes	Yes	73,2* (160)m/min
AISI 304L (1.4307)	Yes	Yes	25,3* (142)m/min
AISI 430FR	Yes	Yes	42,7* (135)m/min
Alu 6156T62	Yes	Yes	79,2* (n/a)m/min

*Cutting speed from EDU Pack [13]

Cutting speeds in parenthesis () are collected from Walter-tools.com [16]. These cutting speeds are calculated with the optimal tools and other cutting conditions.

Figure 2.4 shows the environmental impact of the materials, the y-axis shows energy consumption in megajoules per kilogram, the x-axis shows CO2 emissions in kilogram per kilogram virgin material produced. Embodied energy in the graph refers to the energy required to produce virgin material in megajoules per kilogram. This includes mining, production and transportation. The best material when it comes to energy consumption and CO2 emissions during production is placed in the lower left corner of figure 2.4. By studying CO2 footprint and embodied energy environmental sustainability can be weighted in when choosing material.

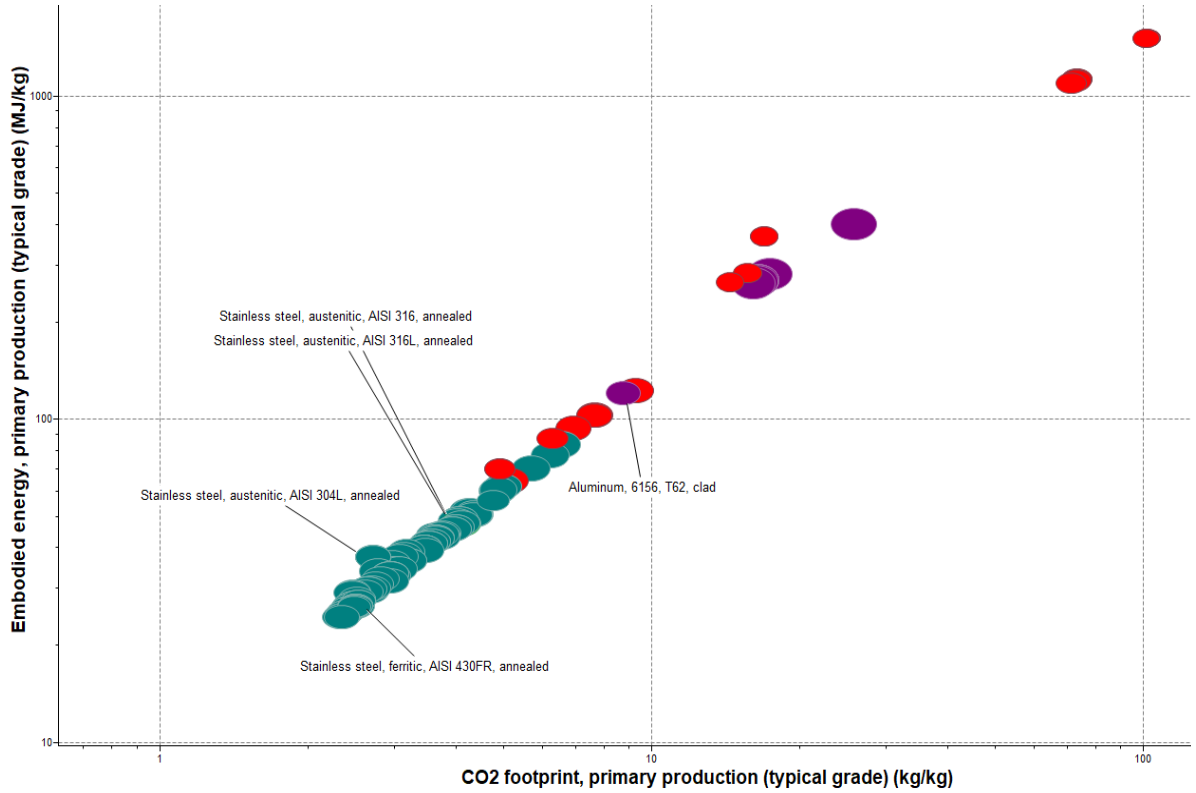

Figure 2.4 Comparison of materials from Granta EduPack 2021 R2 [13], embodied energy - CO2 footprint

Resistance to acids is shown on the x-axis in figure 2.5 and 2.6 with cutting speed on the y-axis.

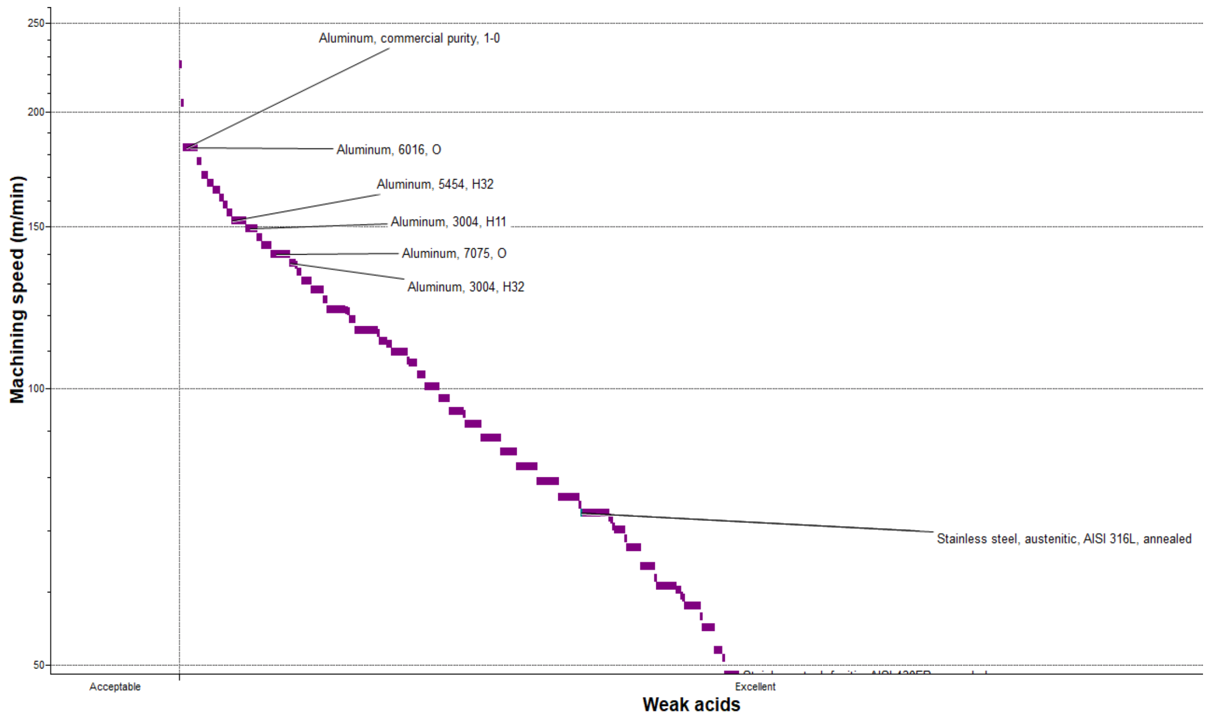

Figure 2.5 Comparison of materials from Granta EduPack 2021 R2 [13], machining speed – resistance to weak acids

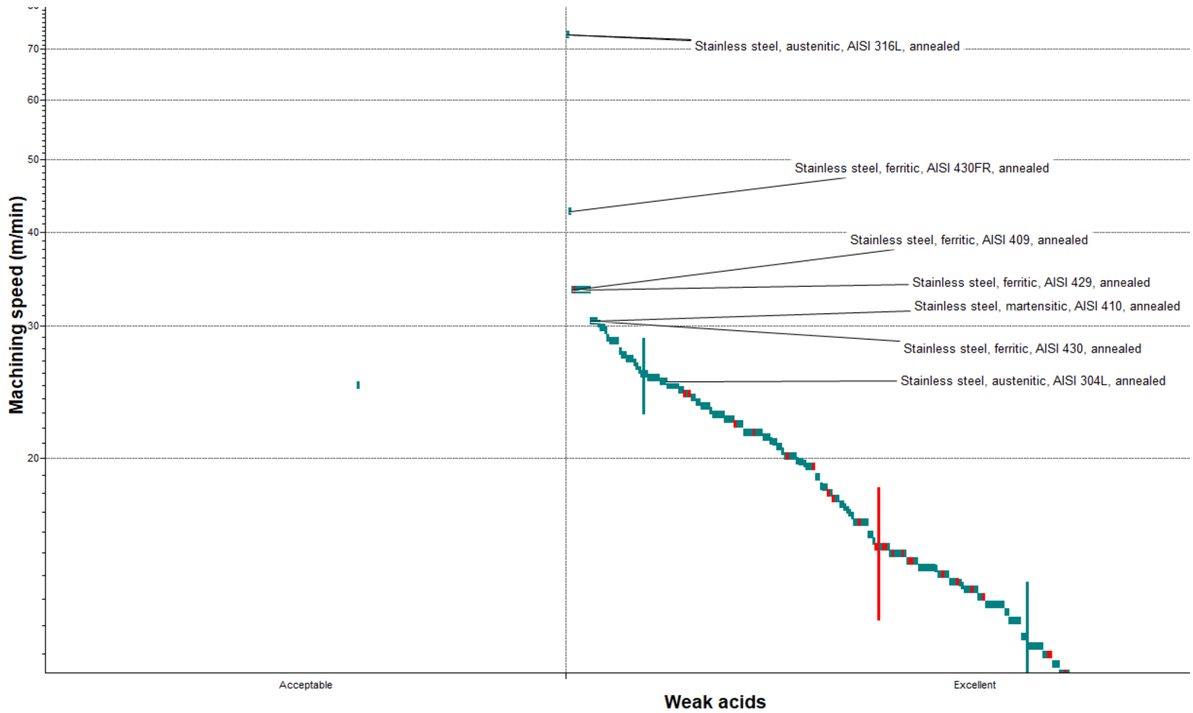

Figure 2.6 Comparison of materials from Granta EduPack 2021 R2 [13], machining speed – resistance to weak acids

2.6 Manufacturing methods

Machining in which material is removed from a workpiece in the form of chips to produce different shapes on the workpiece is called cutting processing [3]. In this chapter, two different types of cutting processing are described, milling and turning, but generally grinding and drilling are also considered as cutting processing. Cutting machining is the most common machining method used in the workshop context, and also the most accurate method for shaping metals [3].

Turning

In turning, the workpiece rotates while the tool is fed relative to the workpiece. The tool can generally move in two axial directions, along the axis of the workpiece and perpendicular to the axis of the workpiece. The latter reduces length, and the former reduces the diameter of the workpiece [3].

Turning is a fundamental method in cutting processing that is both efficient and flexible. When turning along the workpiece axis, thus reducing the diameter, it is called longitudal turning and is the most common turning operation. An operation where the tool is fed perpendicular to the workpiece axis, usually from the larger diameter towards the center, is referred to as face turning. Shape turning is another operation where the tool is guided in both axes at the same time, allowing shapes to be formed with greater freedom. A simpler variant of form turning is taper turning. [3]

Milling

In milling, the rotary motion is performed by the tool instead of the workpiece as in turning. Milling is a universal method that allows production of surfaces with a wide variety of shapes. The machining method provides high surface smoothness, accuracy and is flexible. Typically, the milling tool has several cutting edges that operate intermittently, meaning that the edges cut briefly into the workpiece. An advantage of intermittent machining is that the chips are usually short and therefore easy to handle. The disadvantage on the other hand is that the temperature of the tool varies considerably during a revolution. [3]

Milling operations are divided into three main groups, these are face milling, long edge milling and end milling. In face milling, the cutting edge are mainly used on the periphery of the tool, where the axis of rotation of the tool is perpendicular to the feed direction. Long edge milling refers to an operation where, as in face milling the cutting edges on the periphery of the tool are used, the difference being that the edges of the workpiece is machined. In end milling, grooves or flats are machined, allowing two or three surfaces to be machined simultaneously. [3]

2.7 Fastening elements

A fastening element is used to prevent movement between the parts connected in the element, which is the main function. Furthermore, there are several ancillary functions to the fastening element, the main one is to transfer loads. Other common secondary functions are to fix the position and to allow disassembly. A common classification of fastening elements is whether they are permanent or demountable. Movement in an element can be restrained by a force, shape, or material related function. [17] In this report, only demountable force and shape related fastening elements are considered.

Bolted joints

A bolted joint is clamped together by means of a screw and a retaining nut or threaded hole. The bolted joint is demountable and can be either force or form controlled. The bolted joint can withstand normal forces (tensile forces in the screws) or shear forces perpendicular to the screw. However, the bolted joint is best suited for the transmission of normal forces, which provide a form-conditional function. To transmit shear forces in a bolted joint, the joint is sometimes combined with a form-controlled element, such as a wedge key or a bushing. [17]

Wedge key joint

Wedge key joints are mainly used for transmitting torque between an axle and a hub. There are several different type of wedge keys, the most common of which are the flat key and the woodruff key, which are standardized (see figure 2.7). It is also possible to use key wedges between two flat surfaces to transfer shear forces together with a bolted joint. [17]

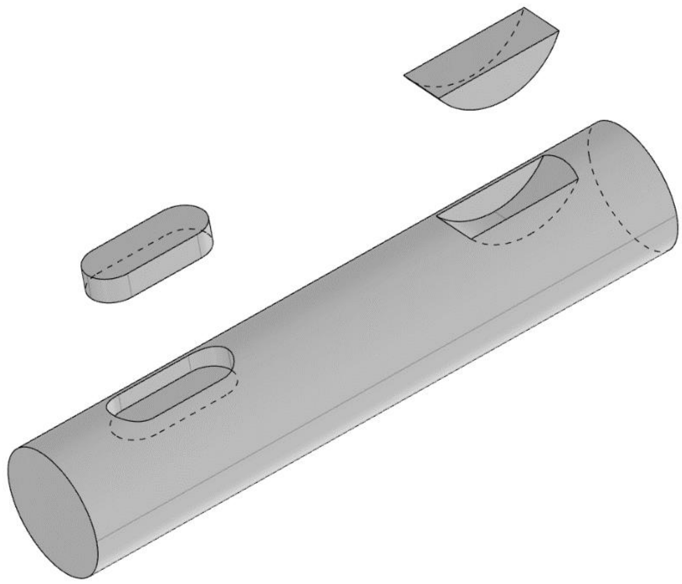

Figure 2.7 Example of the shape of a flat key to the left and a woodruff key to the right

Conical joints

A demountable joint used for torque with a force-conditional function is a conical joint (see figure 2.8). Optionally, this joint can also absorb axial forces. When the cone angle is small, this joint can become self-locking. The self-locking properties are achieved when $\mu > \tan(\alpha)$ (1), where μ is the coefficient of friction and α is the cone angle [17]. The equation is derived from:

$$F_{ax,loss} = \pi p(1 - \mu cot\alpha)(r_2^2 - r_1^2) \qquad (2)$$

Equation (2) is obtained from Mägi [15]. $F_{ax,loss}$ is the force needed to release the joint, p is the contact pressure, μ is the coefficient of friction and α is the cone angle and r_1 and. r_2 is the minimum and maximum radii, respectively, in which the joint is clamped.

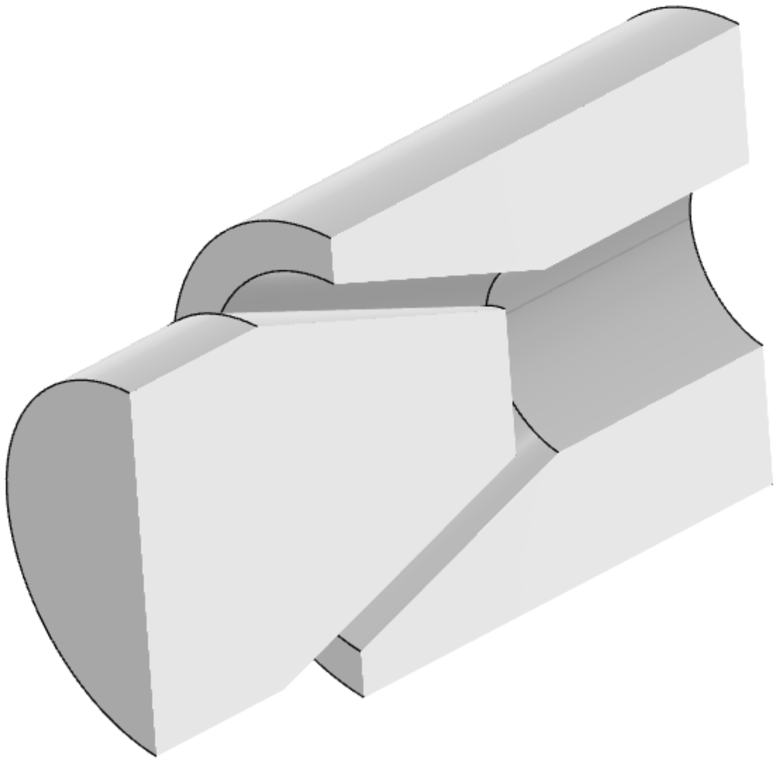

Figure 2.8 Two conical parts about to connect to a conical joint

2.8 Equations

To analyze the final concept ability to withstand the forces exerted on it equations from Björk [18] are used. Equation (3) describes the pressure exerted a hole wall.

$$p = \frac{F}{d \cdot t} \qquad (3)$$

Equation (4) calculates shear stress with known force and area, equation (5) describes the maximum allowed shear stress as a ratio of allowed normal stress.

$$\tau_{max} = \frac{F}{A} \qquad (4)$$

$$\tau_{max} = \frac{\sigma_{max}}{\sqrt{3}} \qquad (5)$$

2.9 Finite element analysis

The finite element method is numerical method used to analyze stress in structures. This is done by dividing the components to be analyzed into several elements which are connected to each other in nodes. Physical laws are applied to each element. Displacements is calculated in the nodes, which leads to a large set of partial differential equations to be solved. This gives an approximative solution for e.g., stress and strain. [19]

To analyze how the geometrical elements interact with each other contacts must be defined. The contact definitions used in the analysis of this thesis is bonded, frictionless, and frictional. If bonded contact is used no separation or sliding between parts or faces can occur, just like they were glued together. This type of contact allows for a linear solution. Frictionless contact allows free sliding in the contact region as the frictional coefficient is set to zero. The solution is nonlinear since the contact area can change as the load is applied. Frictional connection uses a nonzero coefficient. The connected parts or faces stick to each other unless the frictional force is exceeded, the solution is nonlinear for this contact type. [20]

There is several software available to analyze structures with finite element method and for this thesis Ansys 2020 R1 is used as simulation software.

2.10 Sustainability

Triple bottom line, or the three P:s is a good way to analyze the sustainability of a product. The three P:s are **p**lanet, **p**eople and **p**rofit and all these three aspects play a role in sustainable development. [21]

Planet - In figure 2.1 in chapter 2.5 the embodied energy and carbon footprint is illustrated for some materials that can withstand both weak acids and weak alkalis. The embodied energy is all the energy that is required to produce the material, in the figure 2.1 the embodied energy is for virgin material. Less material used give a lower environmental impact, both for the energy used to produce the material and the carbon footprint. To lower the energy used when manufacturing a product, it is important to design the product so the need for high energy demanding manufacturing are kept to a minimum. It is also important that the materials withstands the corrosive environment. If the material can survive the environment for a long time the need for new material and new manufacturing is kept to a minimum. This leads to a higher grade of sustainability. There is a way to lower the carbon footprint for the material which leads to a lower impact on the planet. That is to use steel from a manufacturer that have a sustainable source of energy, and which is located close to where the material is used.

HYBRIT is a project to produce fossil free steel and is a collaboration between three Swedish companies, SSAB, LKAB and Vattenfall AB [22]. The purpose of the HYBRIT project is to eliminate carbon dioxide when making steel. The steel industry stands for about 7% of the global annual CO2 emissions [23].

People – The manufacturing of the product should not be harmful for the people making it. The material used in the design should not be poisonous or release poisonous gases when manufactured by cutting or when welded. The use of the product should not cause any injuries to the people working with it. The design needs to consider how it is used to design out risks that can cause harm. For example every edge or corner on a machined part should be broken with a small radius or a small chamfer. Hence the choice of material is important as well as the shape and function to cause as little harm to the people that comes in contact with the product. To make sure that these aspects is taken in consideration in the product development Olssons matrix [5] is an excellent tool when the products requirements is developed.

Profit – One of the biggest factor when developing a product is that the company should benefit economically from the outcome of the product developing process. To ensure that the product development is not too expensive and so the product is profitable a structured product development process is needed. An extensive work of the requirements of the new product needs to be performed, in order to keep late changes to a minimum. To ensure this the Olsson matrix [5] is used as a tool to ensure that all life cycle phases and aspects are taken in consideration.

3. Method

In this chapter, the methods used during the thesis is described. The project follows the product development process described by Johannesson et al [5]. The concept generation methods used are 6-3-5 and morphological matrix. The concept selection is done with the help of Harris profile and relative decision matrix.

3.1 Product development process

During the **feasibility** study, a problem analysis is carried out before development of a product. The pre-study should derive the functional requirements for the product and what it is intended to do. The next step, the requirement specification, aims to establish a specification of what is to be achieved through the product development process. The specification is formulated so that it can be used during concept generation and to evaluate the final concept. The requirement specification is a dynamic document that evolves as the process progresses and new knowledge emerges. A requirement specification should be formulated in such way that the criteria are measurable, unique, unambiguous and that the stakeholders and life cycles are considered. [5]

The starting point in the **concept generation** phase is the criteria in the requirement specification. Systematic concept generation focuses on the functional requirements for the new product, with the aim of creating several different solutions to meet them. As a first step general somewhat abstract solutions should be found. The next step is a functional analysis, which should show that all the functions to be achieved by the new product. The aim is to break down the problem into smaller sub-problems and then find solutions to these. These sub-solutions are then combined into solutions that solve the whole complex problem. [5]

A concept should roughly describe the product in terms of both appearance and function. Concepts are often described with a simple sketch accompanied by explanatory text or a simple approximate model created in a three-dimensional environment. Concept generation does not require very large resources and is relatively quick compared to the whole product development process. Therefore, there is no reason not to do this part of the development process thoroughly with well-developed methods.[6]

In the **concept selection** phase, the different solutions from the concept generation phase should be evaluated and compared with the requirement specification. Then each solution is analyzed against each other to select the highest value option that can best meet the requirement specification. [5]

Using a method that selects product concepts in a structured way makes it easier to carry out the process objectively. At the same time, it contributes to efficient decision-making. [6] The evaluation process is illustrated as shown in figure 3.1.

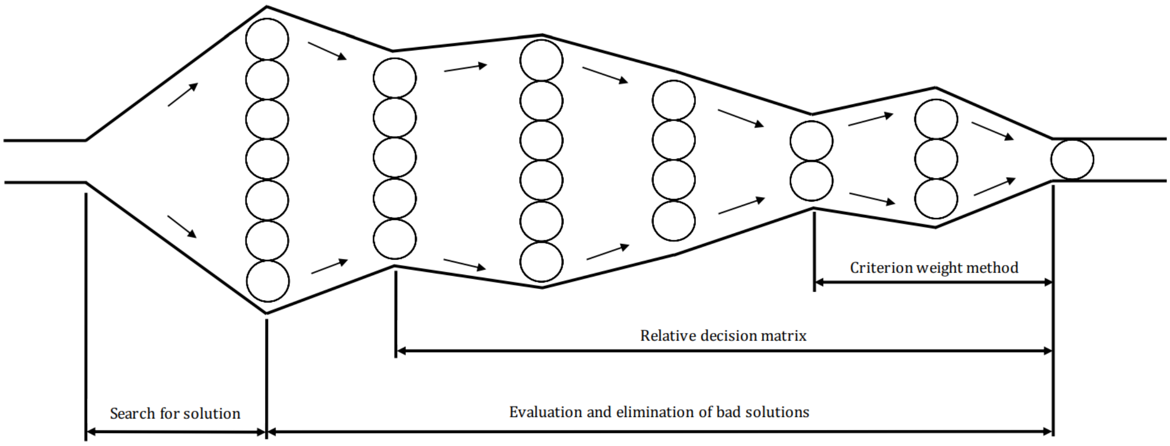

Figure 3.1 evaluation process, according to Ulrich and Eppinger [F.3]

The selected concept should now be further developed into a working product that best meet the criteria in the requirement specification. This is done in the phase described as **detailed design**. This phase includes dimensioning and, as far as possible, adapting to standard components. In this phase a redesign of details and the choice of material for them is done. The aim is to be able to produce the solution in the form of a prototype for further analysis. [5]

There are various reasons for developing **prototypes**. It can be to demonstrate shape and surface properties or to test function [5]. Prototypes can be of different types, for example a small-scale model, or a prototype that lacks certain features that should not be tested.

The bases used for the solution and prototype may need further development, both if new information emerges after the prototype testing, and to adapt the product for manufacturing, this is done through a **manufacturing adaption phase**. In this final phase of the product development process, the product is adapted to be manufactured and assembled using conventional methods and adapted to be economically sustainable. [5]

3.2 Planning

A **project plan** for the work was developed at an early stage and was broadly based on Eriksson et al [24]. The project plan describes, among other things, the background, problem formulation, objectives and time schedule. A project plan can be seen as a contract between the student and the client, describing how the task is to be solved and within what time frame. [24]

A **Gantt chart** of the work was also generated in conjunction with the project plan, to show how different activities are related and how long they are expected to take and when they should be completed. The Gantt chart provides a good overview of the activities of the work and constitutes the main planning for the thesis. If necessary, the planning will be adjusted as the work progresses.

WBS – work breakdown structure is a systematic way of breaking down a project into smaller manageable parts. The results are a tree diagram that gives a picture of the whole project at a detailed level. [24]

3.3 Software

In this chapter the software used for CAD, material selection and FEM, during the thesis is described.

CAD

Computer aided design (CAD) are used to model and create parts and assemble these in a 3d-environment. The CAD model is used to make drawings for manufacturing, the model can also be exported to other software's for example to make an FEM analysis. The CAD program used during this thesis is Catia V6.

Granta EduPack

Granta EduPack 2021 R2 is a program for making material choices and material analyses. The database contains over 4000 materials, and these can be sorted and screened by different properties e.g., mechanical properties or Co2 footprint. The results of the screening can be presented in graphs to give a good overview of all materials.

FEM (Finite Element Method)

The final concept was analyzed in Ansys in an iterative way in order for the design to withstand all forces in a good way. To shorten the computation time, when many analyses are to be run, displacement of the parts is tested until it gives a reaction force corresponding to the force the components are subjected to. This is done because the program calculates faster this way when frictional contacts are used.

3.4 Study visits

To gather information about how the machines are assembled and works in order to get a better understanding about the machine parts and the size of the machine, a visit at the machine assembly, R&D department and, to the pilot machine was made.

3.5 Current design analysis

In order to get a picture of how the current solution works, a current situation analysis has been carried out. By examining CAD models and drawings, the current solution has been examined. The same method has been used to investigate the function of the fastening element and how it relates to other components of the tissue machine. In addition to the investigation via CAD and drawings, meetings and discussions with supervisors and other employees at Valmet have been held where questions about form and function have been raised.

3.6 Function analysis

Before the idea generation a functional analysis is done. This is done by dividing the product into main functions, subfunctions and support functions. The aim is to express the product in functions abstractly in order to have as broad approach to the idea generation as possible.

3.7 Requirement specification

A requirement specification identifies the criteria that should apply to the product and lists the requirements and wishes of the product's stakeholders. By starting from Olsson's matrix [5] where life cycle phases are lined up and stakeholders/aspects are listed for each life cycle, (see table 3.1), all requirements are captured. By using a systematic approach with the help of Olsson's matrix all three P:s of sustainability are covered. The matrix is used to systematically decide which criteria are needed for the product in question. Each cell in the matrix represents a product aspect during the considered life cycle phase.

Table 3.1, Olssons criteria matrix

Life cycle phases	Aspects			
	Process	**Environment**	**Human**	**Financial**
Development	1,1	1,2	1,3	1,4
Manufacturing	2,1	2,2	2,3	2,4
Sales	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

When writing the requirements specification, the main function of the product is first described. For each cell in the Olsson matrix, criteria for the product are formulated, if the cell is relevant. When all criteria are identified, they are categorized according to requirements or wishes. All wishes are then ranked from 1-5 to determine priority. All criteria are then categorized as function or constraint. [5]

The requirements specification is seen as a dynamic document throughout the thesis, and thus can be modified if new information becomes available. The requirement specification is developed in consultation with supervisor at Valmet. During concept generation and evaluation, the specification will serve as a basis and the concepts will be evaluated using the criteria listed.

A well thought-out and executed requirement specification leads to, shorter development time, better quality, lower development cost, and an effective way of transferring knowledge.[5]

3.8 Concept generation

In order to generate concepts on a new design two methods of concept generation was used. In this chapter the methods brainwriting 6-3-5 and morphological matrix are described.

Morphological matrix

A morphological matrix or idea matrix is a method for generating partial solutions to the various sub-functions of which the total function is composed. The method starts with a function analysis where the main function is broken down into smaller sub-functions. After the problem has been broken down into sub-functions, several solutions are generated for each sub-function. These sub-solutions are then combined with each other to generate overall solutions. If any of the overall solutions are not feasible or are not geometrically and physically compatible, they are discarded. A morphological matrix is a structured method for generating many different solutions in a short time [25]. Figure 3.2 shows an example when a morphological matrix is used to solve the problem of transporting cargo.

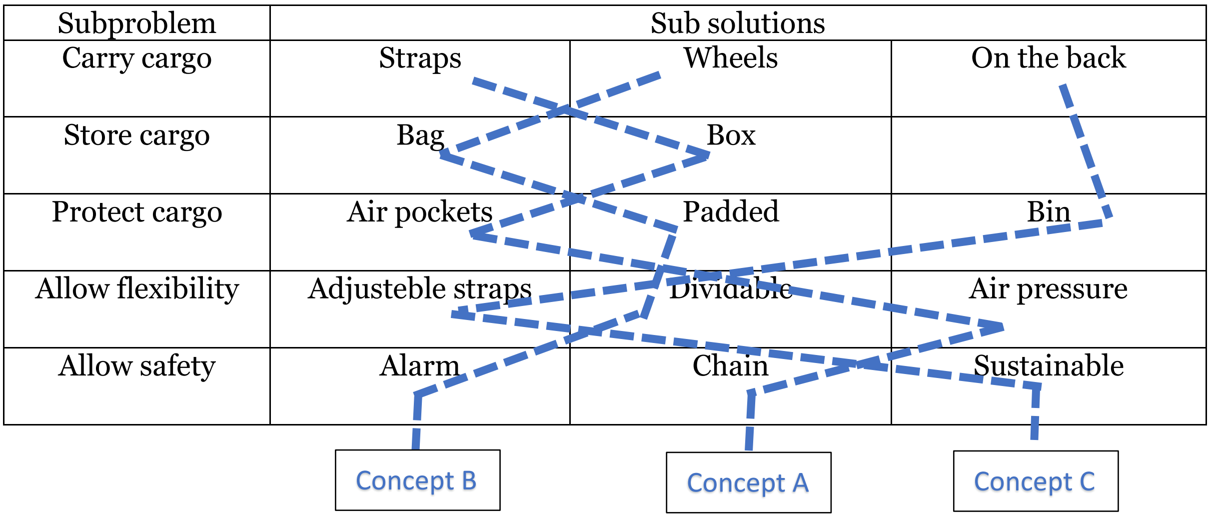

Figure 3.2 an example of morphologic matrix. Inspirated from Wikberg [25]

Brainwriting 6-3-5

The 6-3-5 method is a pure creative group method that starts with a problem formulation. The exercise starts with everyone in the group individually sketching and describing three different ideas on three different papers, one idea per paper. After five minutes, the three ideas are passed to the next person counterclockwise. The three ideas from the previous person are now further developed, after five minutes the now further developed ideas are passed again for the same procedure. This procedure is repeated until all concepts have been shared and developed by all participants. The whole method is carried out without communication between the participants. During the execution of the method, criticism is not allowed, the goal is quantity over quality. [5]

3.9 Concept selection

In order to select concepts on a new design two methods of concept evaluation was used. In this chapter the methods Harris profile and relative decision matrix are described.

Harris profile

Harris profile is a method for systematically selecting concepts by scoring. All concepts are listed in separate columns and criteria are listed in separate rows to form a matrix. Concepts are scored on how well they can meet each criterion by giving red or green blocks, a maximum of two green or two red for each criterion and concept. Once all concepts have been scored, count all green blocks, and subtract the red ones. The concept with the highest score can be considered as the best option.

Relative decision matrix

Relative decision matrix is a method for selecting a concept. The selection criteria used are based on the requirement specification, for the method to work well a maximum of 15-20 criteria should be used. A reference solution should be selected, which can be an existing solution. Each generated concept is then compared with the reference solution for all criteria. Concepts that meet the criterion better than the reference solution are marked with a plus (+) in the table (See table 3.2), if the concept is equally good or less good than the reference solution it is marked with a zero (0) or a minus sign (-) respectively. When all concepts have been scored, the assessments are summed up and a net value can be calculated. Decisions on further development of the concept can now be made using the net value. The process can then be repeated, but with the difference that the highest ranked concept is chosen as the reference. It is also possible to assign weights to the criterions in the final evaluation, the weights are then multiplied with the plus and minus assessments (see table 3.3) [5]

Table 3.2, relative decision matrix according to Pugh

Criteria	Concept				
	1 (ref)	2	3	4	5
Requirement A	D	0	+	0	-
Wish B	A	+	+	+	+
Requirement C	T	0	0	-	-
Requirement D	U	0	-	0	0
Wish E	M	-	+	-	-
Sum +		1	3	1	1
Sum 0		3	1	2	1
Sum -		1	1	2	3
Net value	0	0	2	-1	-2
Rank	2	2	1	4	5
Further development	yes	yes	yes	no	no

Table 3.3, relative decision matrix with weights according to Pugh

Criteria	Concept				
	3(ref)	2	1	new	
Requirement A (w=5)	D	-	-	0	
Wish B (w=4)	A	0	-	+	
Requirement C (w=3)	T	-	0	+	
Requirement D (w=5)	U	-	+	0	
Wish E (w=3)	M	-	-	-	
Sum +		0	5	7	
Sum 0		4	3	10	
Sum -		16	12	3	
Net value	0	-16	-7	+4	
Rank	2	4	3	1	
Further development	yes	no	no	yes	

4. Results

In this chapter the results from the methods that have been presented in the previous chapter are presented. First the results from the planning, current design analysis and function analysis. After that the requirement specification, concept generation and selection together with refined concepts are presented.

4.1 Planning results

The planning phase resulted in a project plan that includes a Gantt chart for scheduling which can be seen in full in Appendix A. The Gantt chart is divided into three sections, planning phase, methodology phase and final phase. The planning phase includes the project plan and other key milestones. The methodology phase involves a literature review and investigations of the current solution, the results of which are presented in chapter 2, and in chapter 4.2. The final phase involves concept generation, concept selection and the production of 3D models and drawings. The planning phase also resulted in a WBS chart which can be seen in Appendix B.

4.2 Results of the current design analysis

The current solution for positioning and locking the breast roll consists of two keyways with associated wedge keys together with eye bolts see figure 4.1 and 4.2. Seen from above, these keyways form the shape of the letter T in order to lock the position in both directions. The arm which holds the breast roll is fastened on this locking device. The top of the keys is shaped like the letter V in cross section which makes it centered in the upper groove with the same shape.

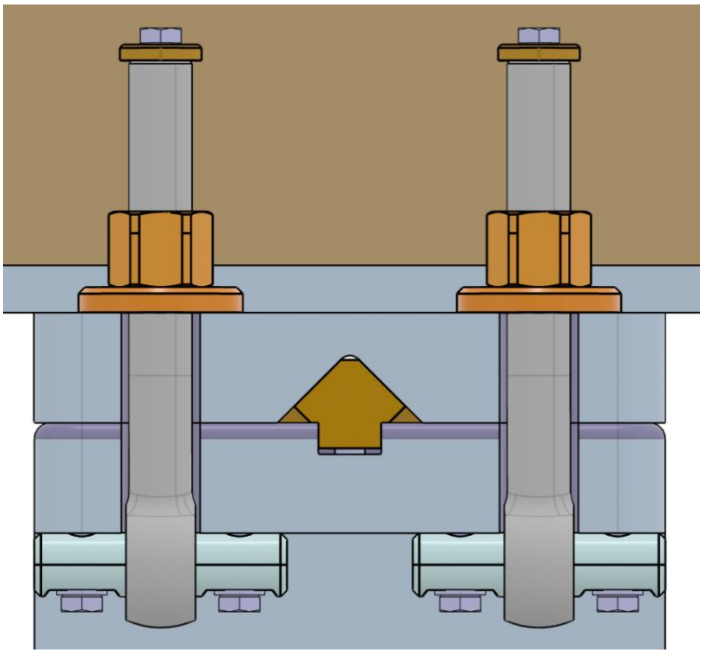

Figure 4.1 Current locking of the breast roll with eye bolts.

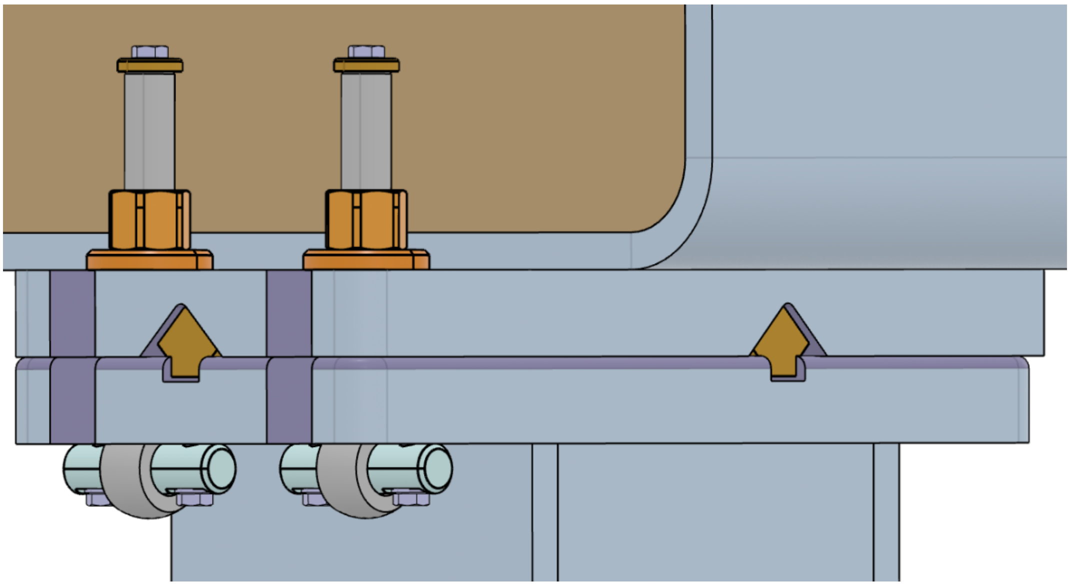

Figure 4.2 Current locking of the breast roll with eye bolts

The keys used in the current solution are not of standardized shape (see figure 4.3) as for example the flat wedge key. These keys are milled from a square bar with dimensions 200x30x30mm in the material EN 1.4436 (AISI 316). These dimensions give a volume of purchased material for to wedge keys of 0.00036m3 which gives an approximate weight of 2.8 kg. The volume and weight of material purchased will affect the price as well as the amount and how complex manufacturing is required. A cheaper solution may be one that provides easier manufacturing and/or uses less material.

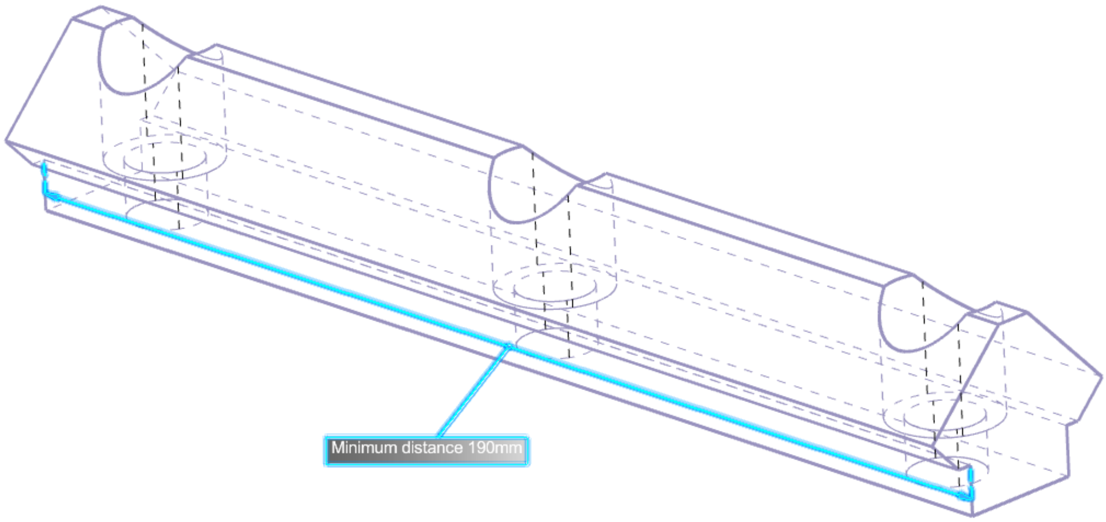

Figure 4.3 current wedge key, the length is 190mm

The keys are fixed in position with three M10 screws each in a bottom plate, the bottom plate has two conventional wedge key grooves which are positioned in relation to each other like the capital letter T. These keyways need to be milled out. To reduce the cost of this part, the manufacturing need to be made easier or faster for the keyways. The same is true for the top plate which the keys 45° faces rests against. These keyways are not of standard type as they are shaped like the letter V in profile. The manufacturing of these keyways is relatively more difficult than a standard shaped keyway, as they are milled with walls that are inclined 45°

from the vertical plane. The bottom that connects the two 45° faces is a 4mm radius. The machining of this type of keyway is difficult as both the angle and the bottom radius have to be taken into account. Also, the arm itself that the keyways are positioned on, is in the way when machining this keyway. In order to reduce the cost of this part, it is of utmost interest to obtain a design that can be more easily machined.

Figure 4.4 below shows the breast roll retraction system, the breast roll suspension is shown as number 2 in the figure and the breast roll is positioned to the right. The thesis focuses on the positioning and locking mechanism shown as number 1 in the figure. When the retraction system opens the arm is rotated around the hinge marked as number 3 in the figure. The radii of rotation to the current keyways are 1190 mm with a tolerance of ±0,1 mm. When the breast roll is lowered back to the operating position it is important that the roll returns to its previous position with great accuracy. This is to minimize the need for re-alignment of the breast roll against the opposing forming roll and the headbox, in order for the paper sheet to maintain uniformity and correct thickness.

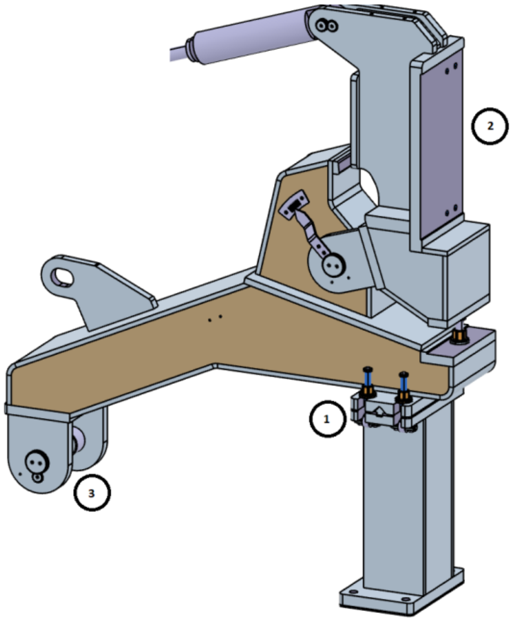

Figure 4.4 Explanatory picture of the function, distance between the hinge 3 and middle of the keys at 1 is 1190mm

The hinge holes have a H7 tolerance and the pin that goes through have an e7 tolerance (number 3 in figure 4.4). If the hole is at its maximum diameter and the pin at its minimum diameter the gap between them is 0,12mm (diameter). The outside width between the hinge ears is 280mm which leads to a maximum calculated angle error of 0,025° (see figure 4.5) according to equation (6). However, it is hard to verify this value on the real machine, but the design needs to take the error in account. From the hinge to the middle of the keyway that means a positioning error of 0,51mm from the angle (see figure 4.6 and equation (7)).

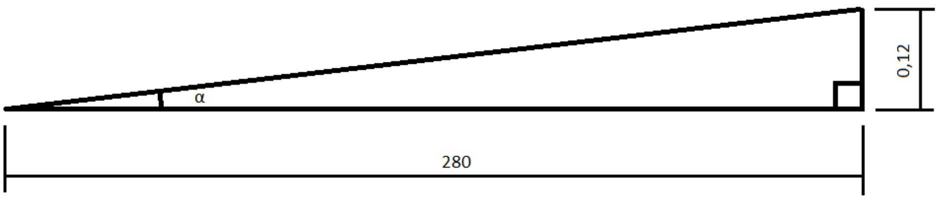

Figure 4.5 Triangle to calculate the angle error in the hinge

$$\alpha = \tan^{-1}\left(\frac{0{,}12}{280}\right) = 0{,}0246° \qquad (6)$$

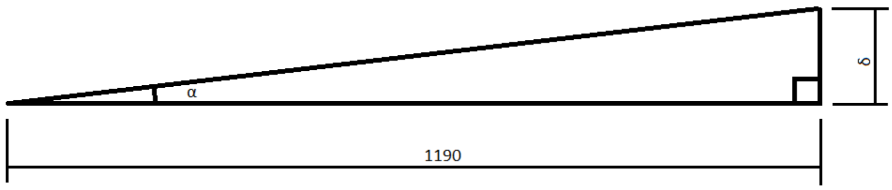

Figure 4.6 Triangle to calculate the position error of the arm

$$\delta = 1190 \cdot \tan(\alpha) = 1190 \cdot \tan(0{,}0246°) = 0{,}51 \qquad (7)$$

In the final assembly of the breast roll retraction system, there is between the hinge ears, a pipe. The distance between the ears, on the inside, is 220 mm. The tube that fits between the ears have a length of 215 mm. That means that the positioning error is 5 mm from the gap between the ears and the pipe. There is also tolerances between ears and on the pipe between plus positioning tolerances on the parts and to the existing keyway. All by all this adds up to an error as large as 6,7mm which the new design must be able to correct.

The locking and positioning system needs to withstand forces to fulfill the function. The force to which the locking device is subjected is here divided into components in the x,y and z directions as shown in figure 4.7. The x component force is about 30 000 N, the y component is about 3 700N, in the z direction the component force is close to 17 000N[2]. The total force that the locking and positioning system needs to withstand is about 35 000N.

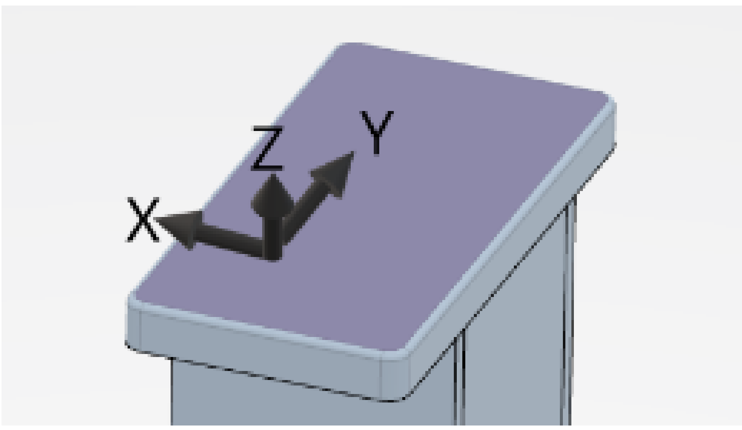

Figure 4.7 direction of forces

[2] From internal document (2022-02-16)

Designs of breast roll retraction system in other tissue machines

In another machine variant there is only one rotation point of the breast roll retraction, and the keyway is only fixating the position in one way. As shown in fig. 4.8 and 4.9, the keyway is as in previous explanation of the same shape with 45-degree inclined walls, however the bottom keyway and the key is different as well as that there is only one keyway. The key is here made of a round bar, which is welded to a plate, the round bar is welded after assembly to make sure that it is positioned at the right place. Under the plate which the bar is welded to, there is shims to adjust the height of the breast roll. The eye bolts are the same for this retraction system as for the previously described one.

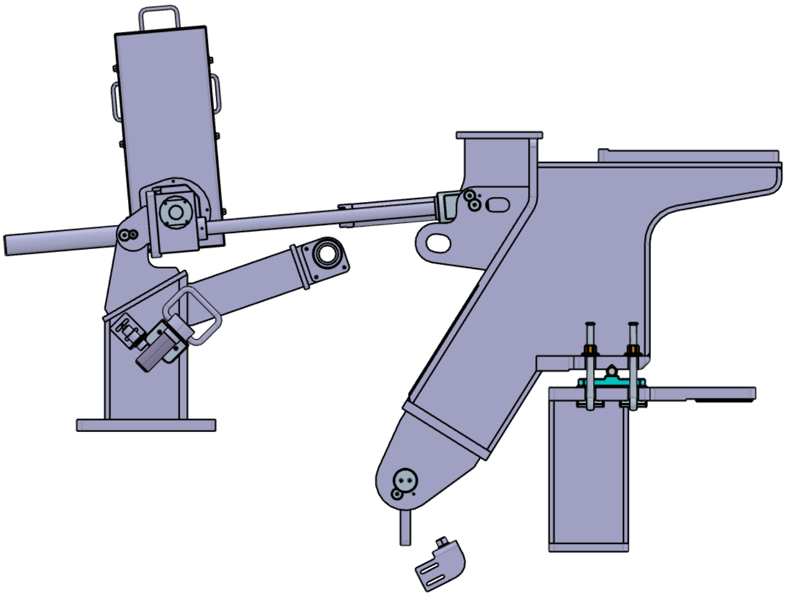

Figure 4.8 Design of breast roll retraction system in another machine, the total with, in the figure is around 2000mm

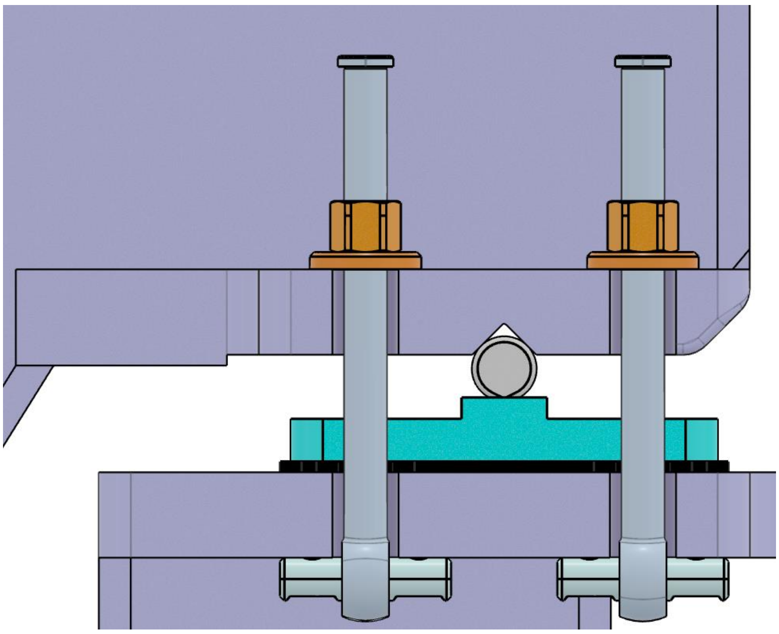

Figure 4.9 Closer view of the positioning and locking mechanism

4.2.1 Function analysis

The positioning and locking of the breast roll are only released during maintenance of the machine and is locked during operation. Maintenance may include lead roll replacement, forming wire replacement or felt replacement.

The main functions of the breast roll retraction are to fix the position and to maintain that position when the machine is operating these functions is a necessity. One subfunction is to allow the element to open during maintenance. Another subfunction is to correct the position when closing the element, it must correct a position error up to 6,7mm. Figure 4.10 below illustrate the result from the function analysis.

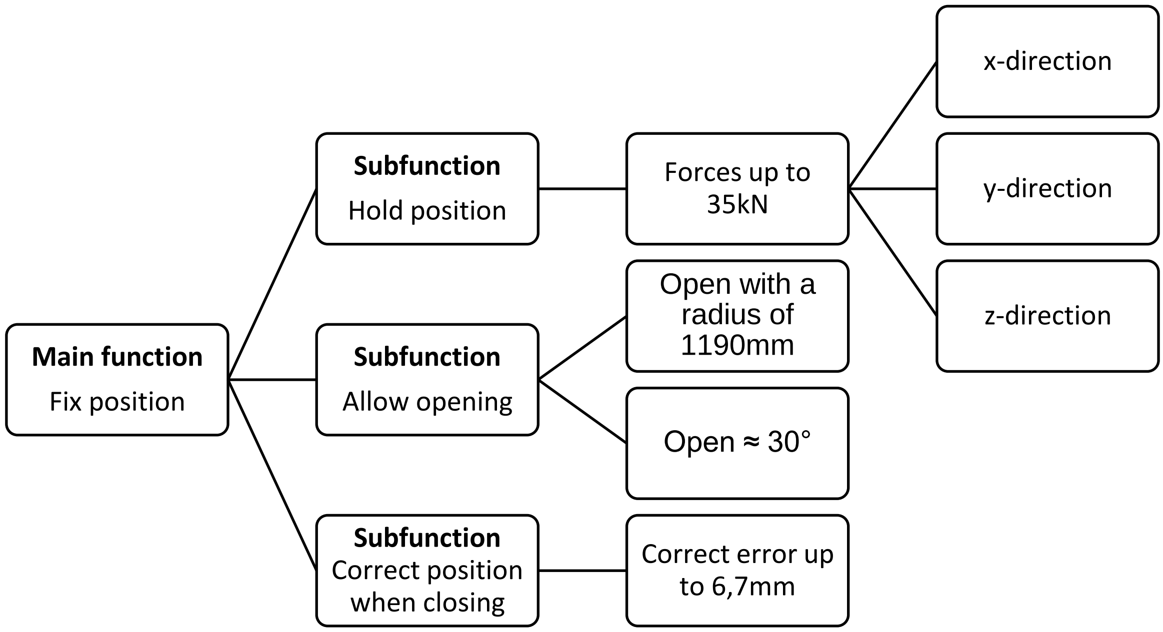

Figure 4.10 Hierarchy of the functions

4.3 Requirement specification

Main function: positioning and locking of the breast roll retraction system. Table 4.1 shows the product specification for the product.

Table 4.1, requirement specification with Olssons matrix as reference

Number	**Cell**	**Criteria**	**Requirement= R Wish = W**	**Function =F Limitation = L**	**Weight**
1	1,1	Comply with ISO standards and EU materials	R	L	-
#	1,2	N/A			
#	1,3	N/A			
#	1,4	N/A			
2	2,1	Manufacturing should preferably be possible by conventional methods	W	L	5
3	2,2	Manufacturing should have low impact on internal and external environment	W	L	3
#	2,3	N/A			
4	2,4	Total cost less than the current design (materials and manufacturing)	R	L	-
5	4,1	Withstand forces Fx=29720N Fy=3680N, Fz=16920N	R	L	-
6	4,1	Size not to exceed 400x200x70mm	W	L	3
7	4,1	Repeatable position in the range 0.1 mm	R	F	-
8	4,1	Allow movement of breast roll retraction system	R	F	-
9	4,1	Possibility to fit more clamps/brackets in the machine	W	F	3
10	4,1	The locking device must withstand forces of 12680N	R	L	-
11	4,2	Withstand vibrations	R	L	-
12	4,2	Corrosion resistant material, chemicals and water	R	L	-
13	4,3	Low forces for loosening and tightening	W	F	4
14	4,4	Long life	W	L	4
15	4,4	Maintenance free	W	L	4
16	5,1	Possible to replace parts	W	L	2
17	5,2	Recyclable material	W	L	3
#	5,3	N/A			
#	5,4	N/A			

Explanation of criteria's

1. The use of EU materials and compliance with ISO standards ensures that the materials are of the right quality and are well documented and available.
2. To keep cost down the final concept should be able to be produced by conventional methods. Geometries that can be produced by conventional methods allow more suppliers to produce the product.
3. Production should not have a negative impact on the environment, neither internally nor externally to the manufacturing company.
4. The total cost of producing the solution should be cheaper than the current solution.
5. In order for the product to fulfill its function, it should be able to withstand the forces to which it is subjected, in total this force is about 30 000N in the x-y plane see figure 4.5. Vertically this is a force of about 17 000 N in the z-direction, see figure 4.7.
6. The solution should stay size-wise within a rectangular block of 400x200x70mm, which is the size of the present solution.
7. The product should have a repeatable positioning of 0.1 mm to reduce the need for adjustment when re-folding the breast roll.
8. The fastening element must be lockable and allow rotational movement of the breast roll suspension during maintenance.
9. It is desired that the new solution can be adapted to accommodate more locking/unlocking devices in the machine.
10. The locking system should be able to withstand a pull apart force of approx.: 12700N.
11. During operation there are vibrations, the new solution must be able to cope with these.
12. In the forming section of the paper machine there are various chemicals as well as water and fibers, the material used must be resistant to all of these.
13. It is desirable that the locking device is easy to open and does not require much force to open.
14. The fastener should have the same lifetime as the other components of the former section.
15. The new solution should be designed to be maintenance free.
16. It is desirable to have the possibility of replacing components in the new solution.
17. The product should be made of a material that can be recycled to reduce the climate impact.

4.4 Concept generation

The results from the concept generation sessions are presented in this chapter. First the results from the morphologic matrix is presented then the results from 6-3-5 method. After that the refined concepts is shown as a result from the idea generations. Both concept generation sessions were carried out with people at Valmet with different experiences.

4.4.1 Morphologic matrix

The morphologic matrix solved the problems, fix position in x,y and z. The session resulted in 15 sub solutions, which were combined into three solutions. The result of the method can be seen in table 4.2 below. The input to the matrix is the function analysis, the x direction is parallel to the hinge axis and y direction is perpendicular to the hinge axis. In the y-axis the positioning element needs to allow that the arm opens with a radius.

Table 4.2. Results from the morphologic matrix

Subproblem	Sub solutions					
Fix position in x	¾ key (original)	Cylindrical cone	Flat key	Walls on the arm that goes on the outside of the bracket.	Inclined plates. The contact area is shaped like a V	Woodruff key
Fix position in y	¾ key (original)	Cylindrical cone	Half cylinder		Inclined plates. The contact area is shaped like a V	
Fix position in z	eye bolts (original)	Strong magnet	"Click lock" like skiing boots	Cam lever, like on bikes	Quick release like in welding fixtures	

4.4.2 6-3-5 method

The brainwriting method resulted in 14 concepts which can be seen in appendix C, after categorizing of similar ideas resulted in 10 different concepts. Some of the concepts are variants of the same idea and is combined to 5 concepts. Just like in the morphologic matrix, the input is the function analysis and the sub solutions from the morphologic matrix.

4.4.3 Refined concepts

After the concept generation sessions, concepts with similar main idea were categorized and merged. After this, a sifting of ideas was done, and the remaining ones were refined. This was carried out with the function analysis in mind, so that all functions are fulfilled. The outcome of this is presented in this chapter.

Concept 1

In concept one the idea is to have the positioning elements separated from the bracket and arm and fasten it with some fastening element, such as a screw. In the arm and bracket a simpler geometry is considered, for example a cylindric hole. The idea is to manufacture a rotational symmetric geometry which is conical in the contact area. The concept is shown in figures 4.11, 4.12, 4.13 bellow.

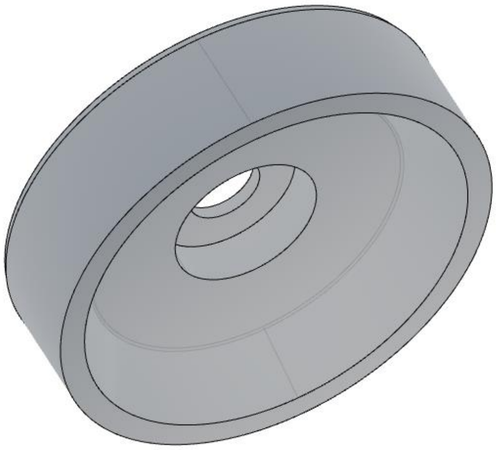

Figure 4.11 One half of the positioning solution of concept one

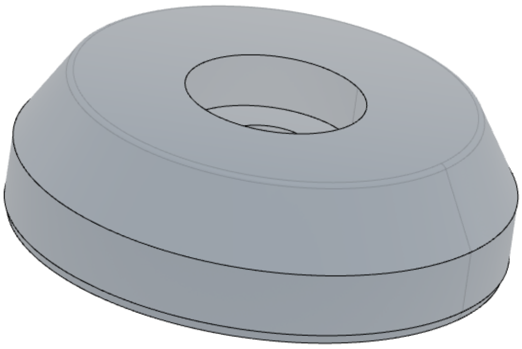

Figure 4.12 The other half of the positioning solution of concept one

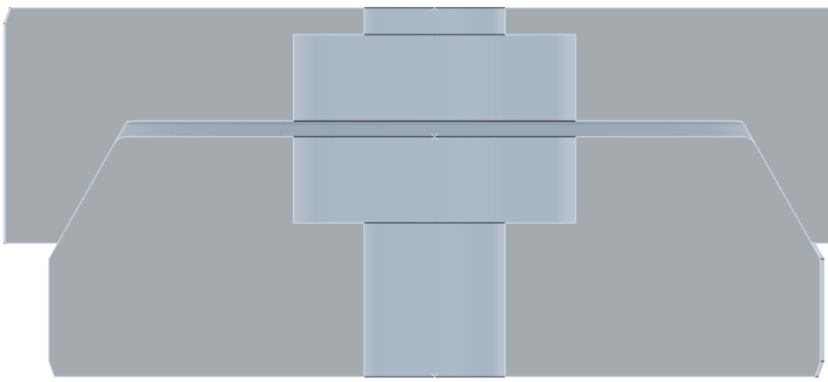

Figure 4.13 The two parts of concept one in contact with each other, in the "run position" the largest diameter is around 100mm

Concept 2

The idea of concept two is to alter the shape of the arm and bracket so the plates are angled, see figure 4.14 and 4.15. The arm (upper part) has two plates welded together with an angle to each other of 90 degrees and two parts on the side.

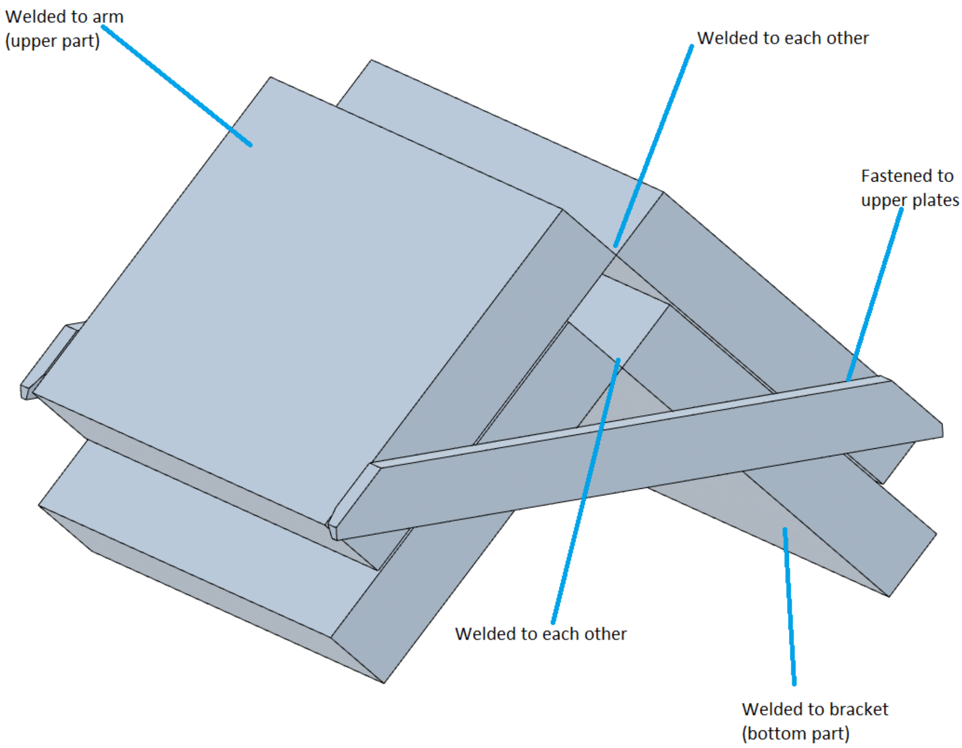

Figure 4.14 The inclined plates of concept 2

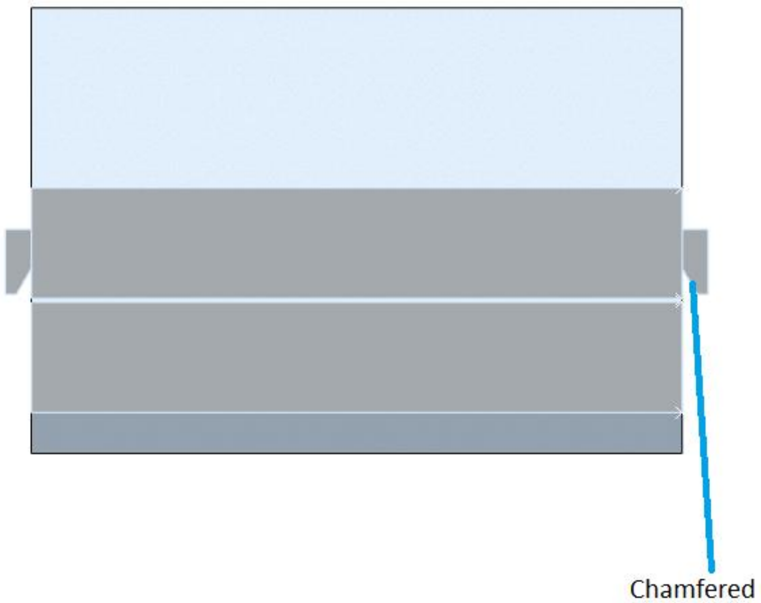

Figure 4.15 Cross section of concept 2

Concept 3

In concept three the main idea is to have a loose plate that holds the keyways or other fastening elements. The plate is fastened on the arm with screws and guide pins or with fitted screws. The keys could be the same as in the current design. One of the keyways, the one perpendicular to the rotational axis of the arm, could be a key of standard shape. The concept is illustrated in figure 4.16. In figure 4.17 a variant of the loose plate is illustrated, with the difference that one of the keyways, the one perpendicular to the rotation axis, is of standard type.

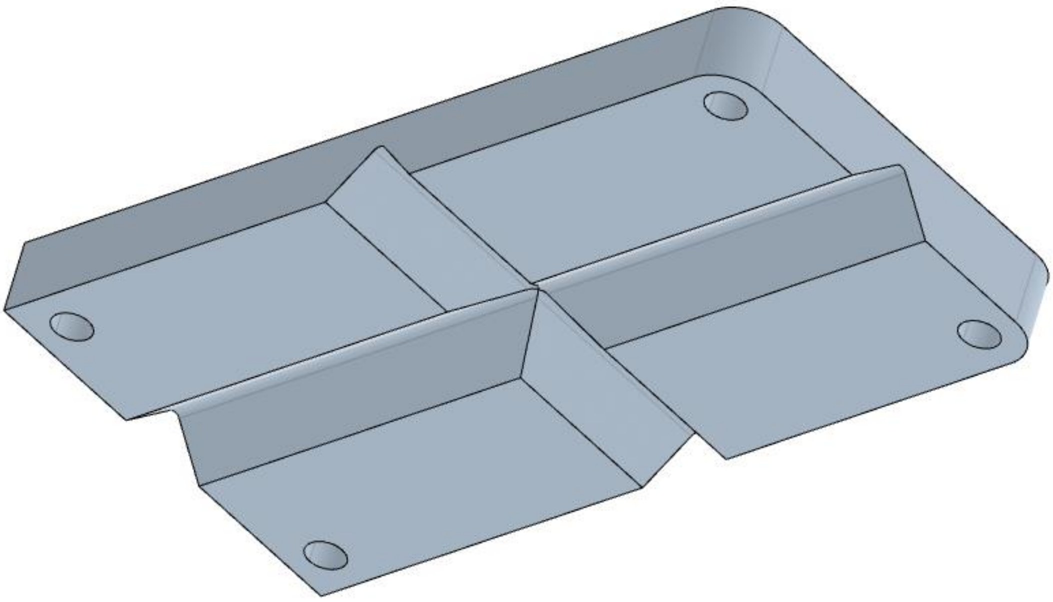

Figure 4.16 the loose plate of concept 3 with holes for fitted screws. The plate have the dimensions 400x200x35mm

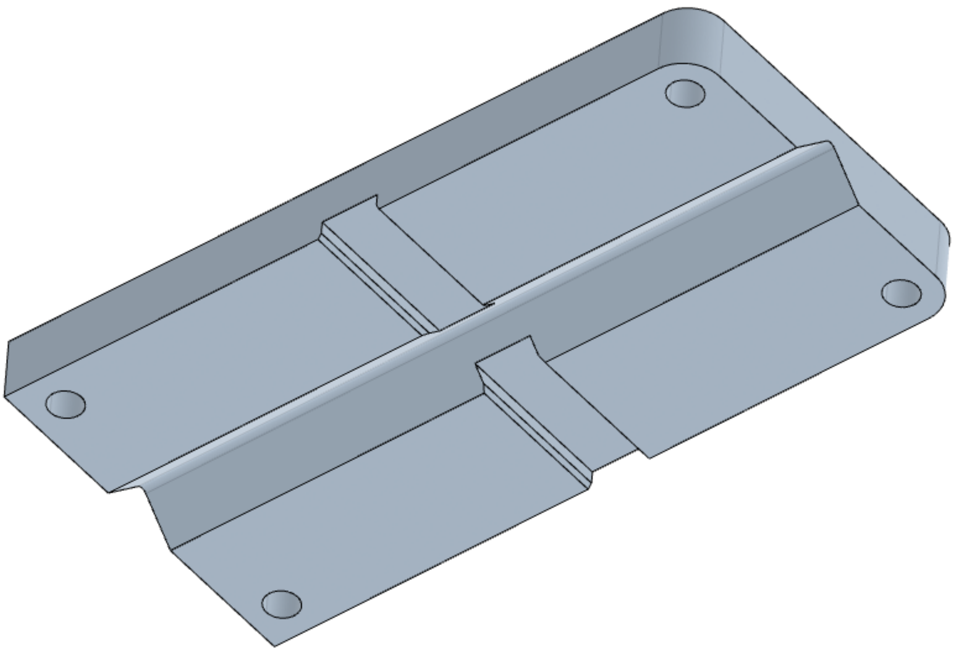

Figure 4.17 Concept 3 with a standard keyway in one direction. The plate have the dimensions 400x200x35mm

Concept 4

Concept four consists of two cylindrical holes with a smaller threaded hole in the bottom. To fixate the position a round bar with corresponding diameter and a hole for a screw to fasten it to one of the plates. The upper plate in figure 4.18 is welded to the arm and the bottom plate is welded to the bracket. The figure 4.19 shows the round bar and plates in cross section.

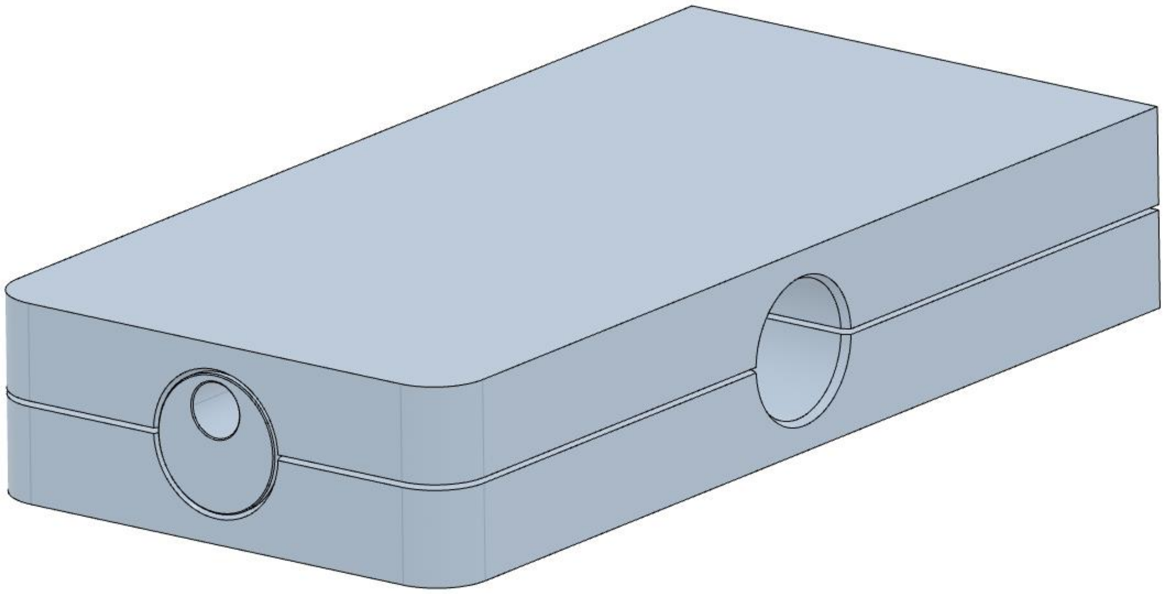

Figure 4.18 Concept 4 with cylindric "key" in one hole. The plates have the dimensions 400x200x35mm

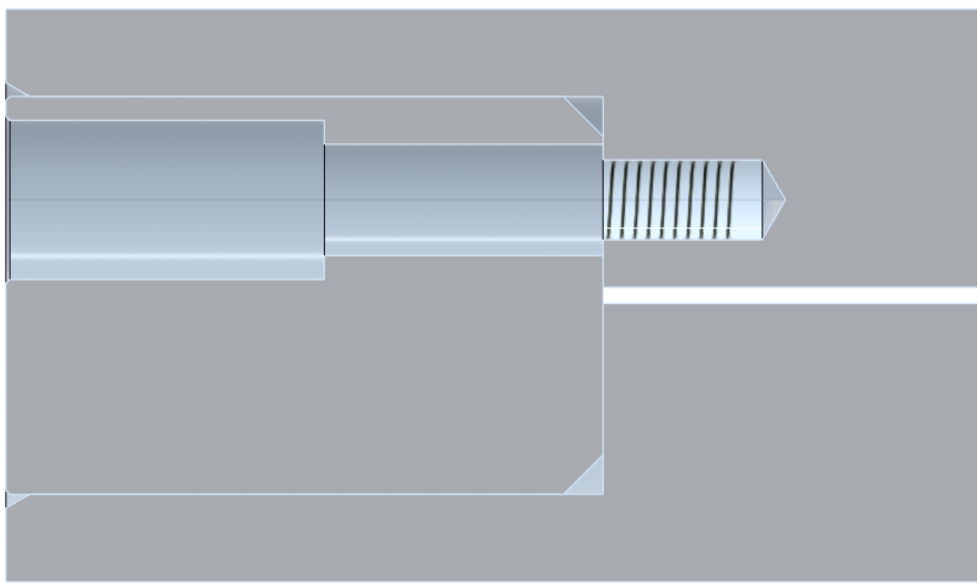

Figure 4.19 Cross section of concept 4 that shows how to fasten the cylindric key

Concept 5

Concept five contains of a standard key with corresponding keyway in the direction perpendicular to the rotation axis. In the other direction, there is a standard key that is spring loaded. In this way the key can be forced down when the arm closes, and due to the springs is forced into the keyway on the arm after the movement of the arm. Figure 4.20 and 4.21 below shows the concept.

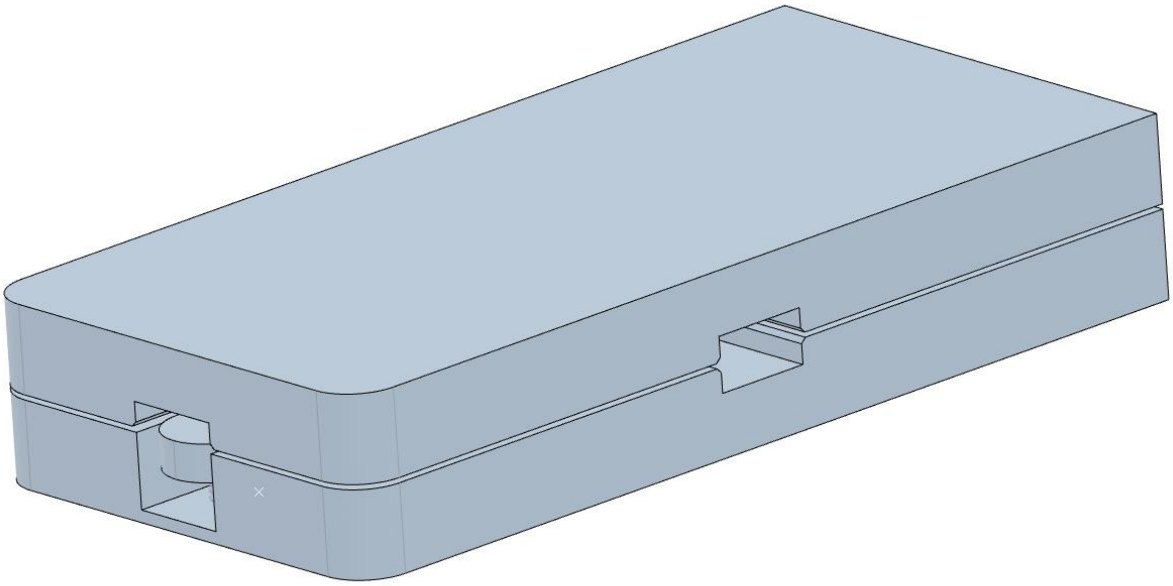

Figure 4.20 Concept five illustrated with standard keys. The plates have the dimensions 400x200x35mm

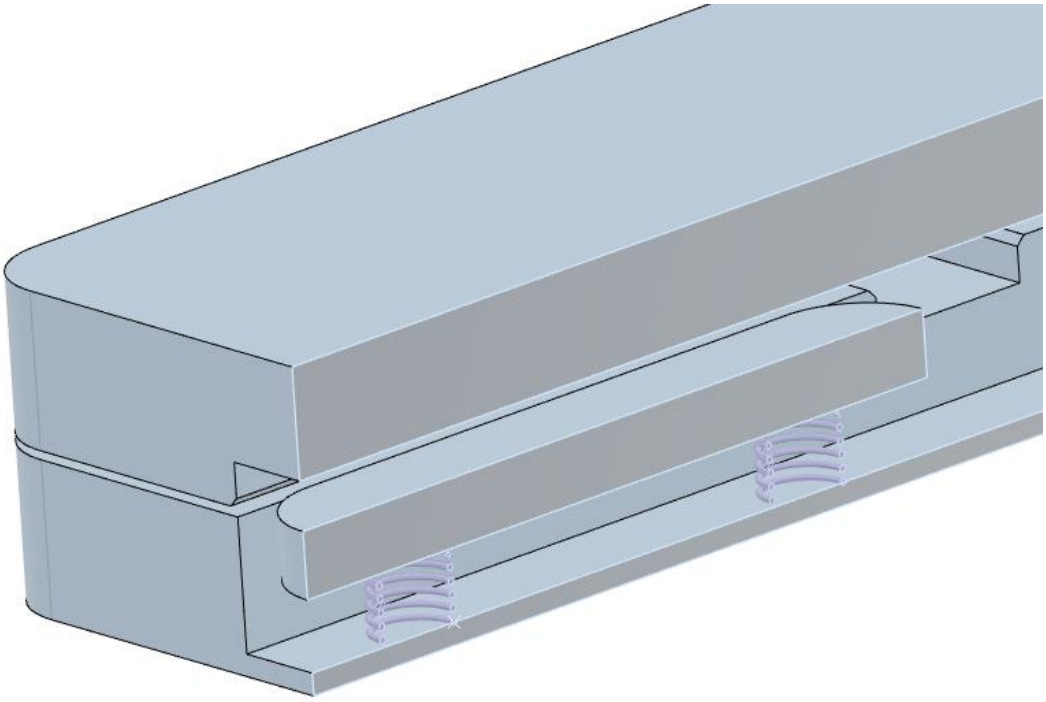

Figure 4.21 cross section to show the springs that force the key in the upper keyway. The plate have the dimensions 400x200x35mm.

4.5 Concept selection

This section shows the results from the concept selection using Harris profile and Relative decision matrix.

Harris profile

Table 4.3 shows the results from the Harris profile. The scoring is based on an estimate on how easy it is to implement the criteria on the concept. The highest scoring concept is concept one, which scores a total of 28. Some criteria are hard to evaluate like the total cost, the scoring on total cost is estimated. No scoring is done on the locking for the opening of the retraction system, the concepts in the table are only focusing on the positioning.

Table 4.3 Harris profile

Harris profile	Concept 1				Concept 2				Concept 3				Concept 4				Concept 5			
Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Comply with ISO standards and EU materials																				
Manufacturing should preferably be possible by																				
Manufacturing should have low impact on internal and																				
Total cost (materials and manufacturing) less than																				
Withstand forces Fx=29720N Fy=3680N, Fz=16920N																				
Size not to exceed 400x200x70mm																				
Repeatable position in the range 0.1 mm																				
Allow movement of breast roll retraction system																				
Possibility to fit more clamps/brackets in the																				
The locking device must withstand forces of 12680N																				
Withstand vibrations																				
Corrosion resistant material, chemicals and water																				
Low forces for loosening and tightening																				
Long life (define in years)																				
Maintenance free																				
Possible to replace parts																				
Recyclable material																				
Total:	28				23				27				27				20			

Relative decision matrix

In table 4.4 the results of the relative decision matrix are shown, concept 0 (ref) is the current design. Concept one got the highest net value and are therefore the highest ranked concept. Concept three and four ended up in tied second place. Concept **one**, **three** and **four** is chosen to further development.

Table 4.4 Relative decision matrix

Criteria	Concept					
	0 (ref)	1	2	3	4	5
Comply with ISO standards and EU materials	Datum	0	0	0	0	0
Manufacturing should preferably be possible by conventional		0	0	0	0	0
Manufacturing should have low impact on internal and external		0	0	0	0	0
Total cost (materials and manufacturing) less than current		+	+	+	+	+
Withstand forces Fx=29720N Fy=3680N, Fz=16920N		0	0	0	0	0
Size not to exceed 400x200x70mm		0	0	0	0	0
Repeatable position in the range 0.1 mm		+	0	0	0	0
Allow movement of the roller suspension during maintenance		0	0	0	0	0
Possibility to fit more clamps/brackets in the machine		0	0	0	0	0
The locking device must withstand forces of 12680N		0	0	0	0	0
Withstand vibrations		0	0	0	0	0
Corrosion resistant material, chemicals and water		0	0	0	0	0
Low forces for loosening and tightening		0	0	0	0	0
Long life (define in years)		0	0	0	0	-
Maintenance free		0	0	0	0	0
Possible to replace parts		0	-	0	0	0
Recyclable material		0	0	0	0	0
Sum +		2	1	1	1	1
Sum 0		15	15	16	16	15
Sum -		0	1	0	0	1
Net value	0	2	0	1	1	0
Rank	3	1	3	2	2	3
Further development	No	Yes	No	Yes	Yes	No

4.6 further development of concepts

Concept one, three and four is further developed to get more precise estimations of how well they fulfill the criteria. The further developed concepts are shown below.

Concept 1

The two parts of the concept is fitted to the arm and bracket trough cylindrical pockets in the arm and bracket. The parts are then fastened with screws. The pocket needs to withstand the pressure executed from the force. The smallest diameter the hole can have to withstand 183 MPa is 17 mm according to equation (3). The smallest area the parts can have is calculated with the equation (4). The maximal allowed shear stress is calculated with the equation (5).

With a depth of 15 mm, the smallest diameter the pocket can have is according to equation (2) 17 mm. The smallest cross section area the parts can have is according to equation (3) 0.00044 m^2. The conical contact surfaces should not self-locking hence μ should be smaller than tan(α) according the equation (1). μ is estimated to be 0,18 [26] if the surfaces are dry, that means that the contact angle α needs to be larger than 10.2°. in the figures 4.22 and 4.23 it is shown how the concept is applied to the existing parts of the machine.

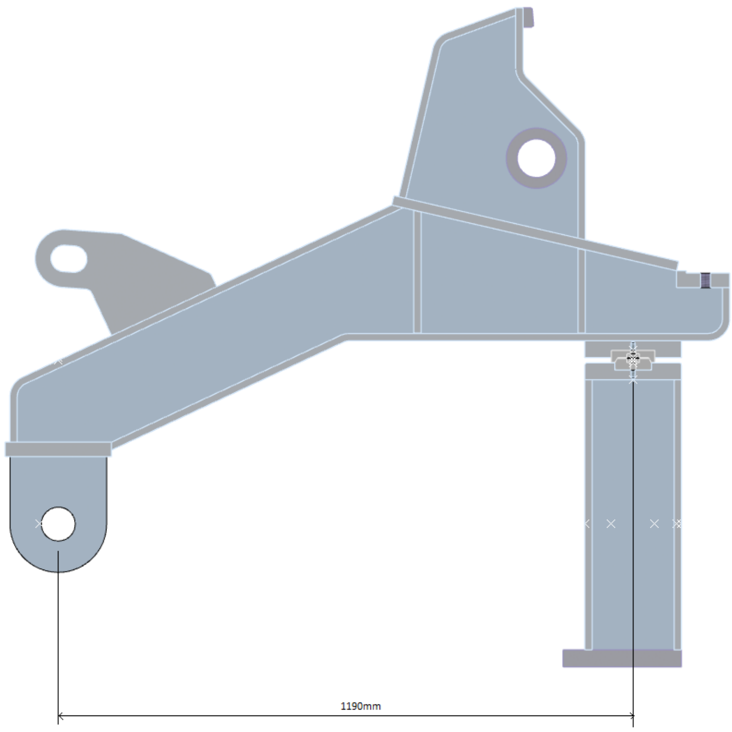

Figure 4. 22 Concept one inserted in the existing parts

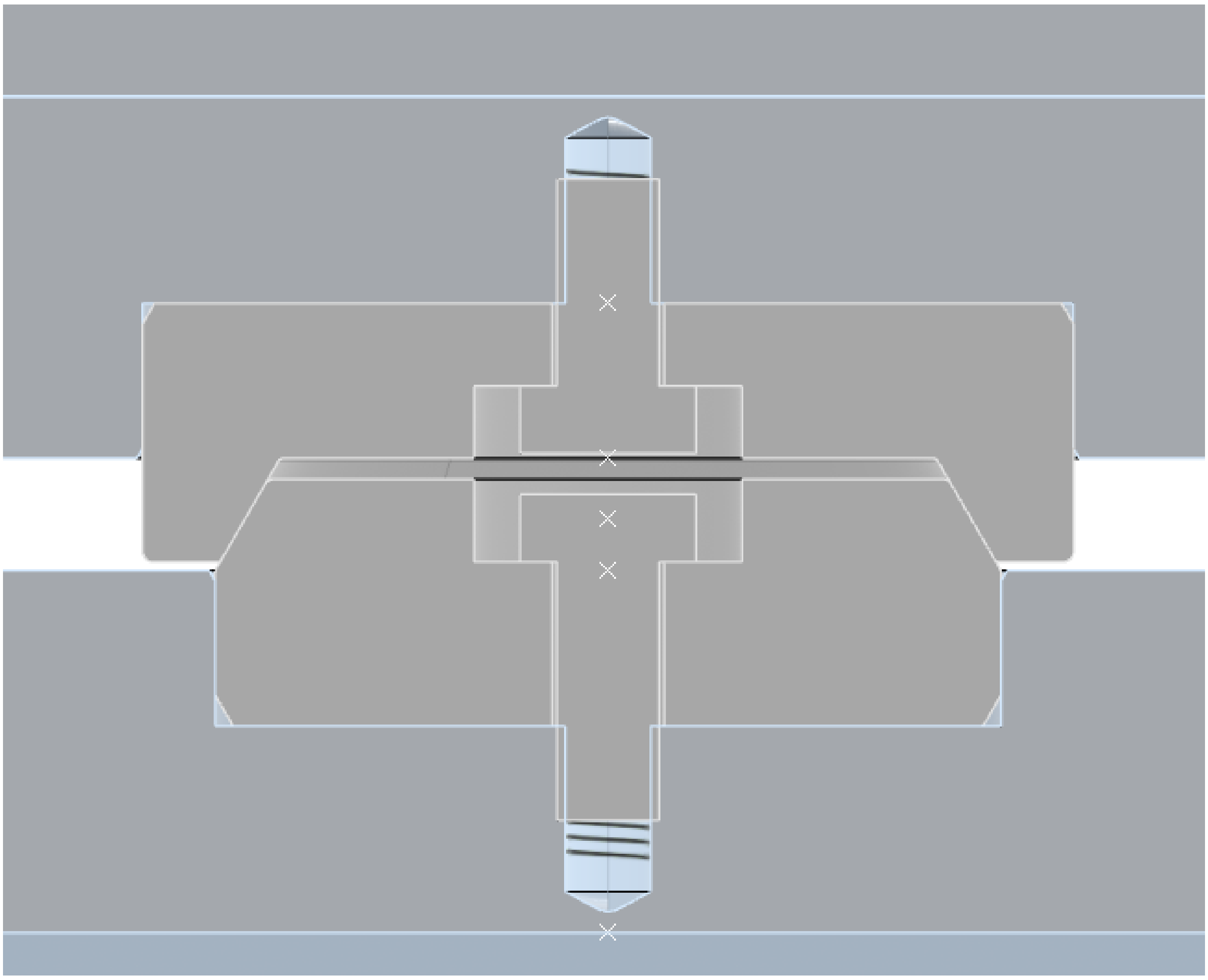

Figure 4.23 Cross section of concept 1 with screws to attach the conical parts. The angle of the cone is 30° and the upper cone is 100mm in diameter.

Concept 3

Concept three uses the same principle as the original design, but with a detachable plate which the keyways are milled on. One of the keys and keyways is in this concept of a standard shape and the other one is the same as the original. The plate is attached to the arm with four screws and four cylindrical pins to assure the correct position. The locking mechanism is the same eye bolts and the plate is designed to make sure the screws have enough room. Figure 4.24, 4.25 and 4.26 illustrates the plate and how it is attached to the arm.

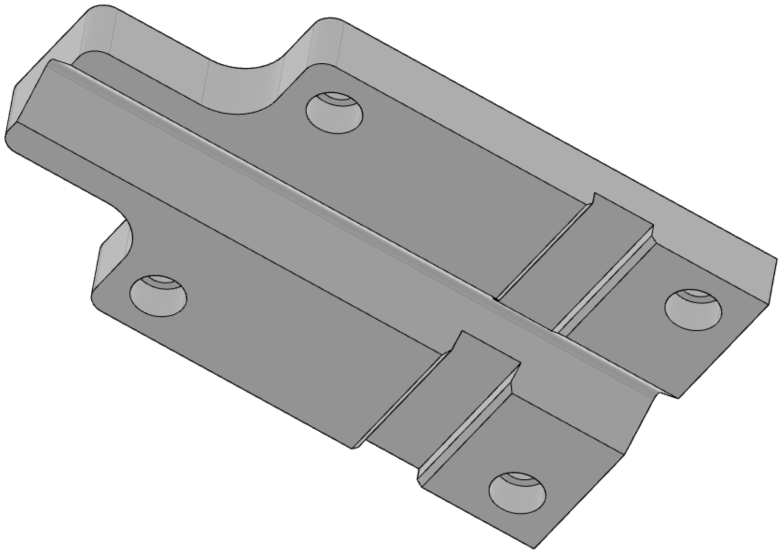

Figure 4.24 Concept 3 further developed. The plate have the dimensions 400x200x35mm

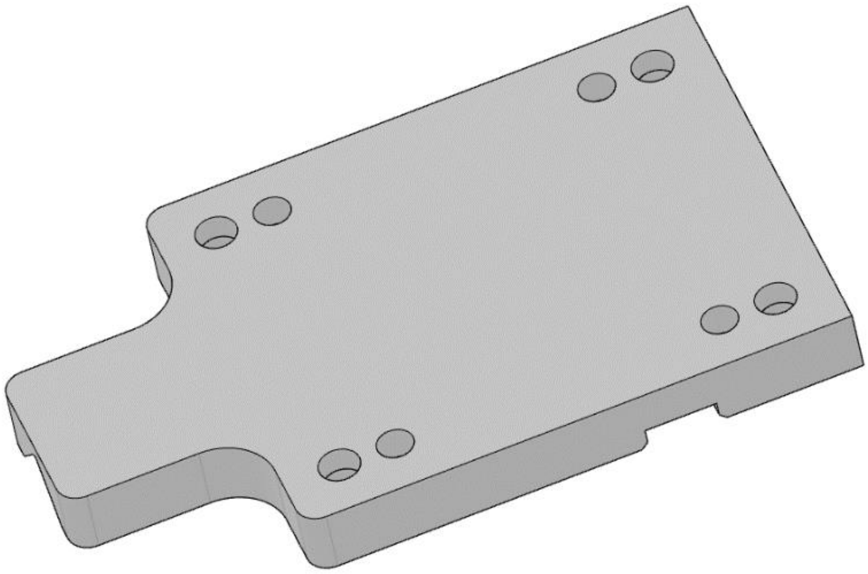

Figure 4.25 Concept 3 with visible holes for the cylindrical pins. The plate have the dimensions 400x200x35mm

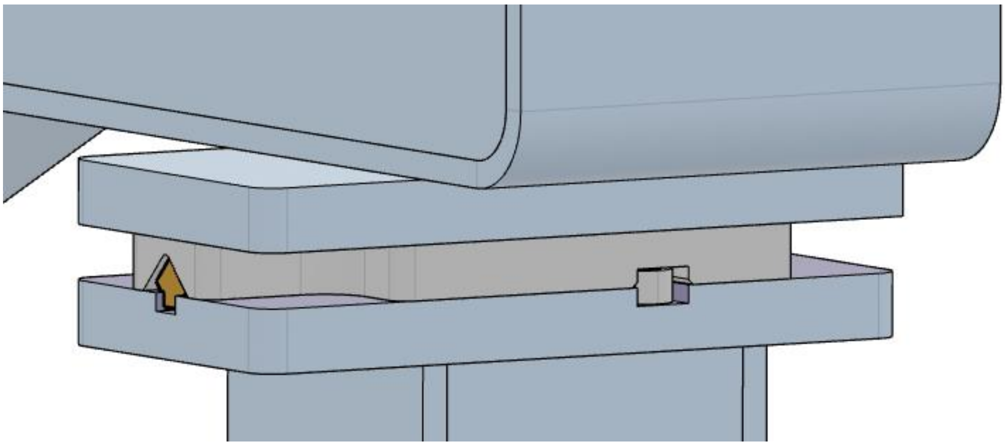

Figure 4.26 The detachable plate and keys assembled with arm and bracket

Concept 4

Concept four with the cylindrical key with chamfered edges on the keyway (see figure 4.27 and 4.28). The design of the keyway with flat bottom and chamfered corners so the manufacturing can be done from one side. In the bottom of the keyways threaded holes is manufactured and on the cylindrical "key" holes to fit the screws are made.

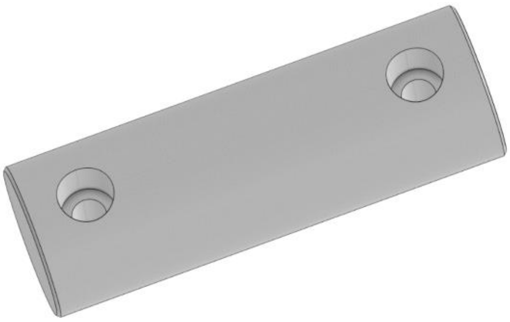

Figure 4.27 The cylindrical "key" with holes to fasten it with screws the overall length of the cylinder is 150mm and the outer diameter is 50

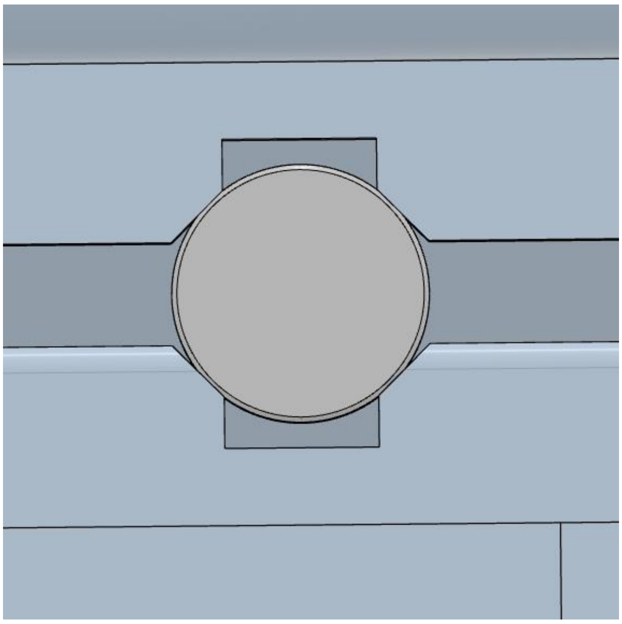

Figure 4.28 Concept 4 with a cylindrical "key" and chamfered edges that the key rest against

Concept 6 (new idea)

Concept six is a new idea derived from concept one, instead of a conical contact surface like in concept one, this concept has a spherical surface. In addition, a thread is applied on the outer surface to one of the parts making it possible to adjust the height of the arm. The other parts are bolted with a screw. Figure 4.29 shows the concept and the spherical contact surfaces.

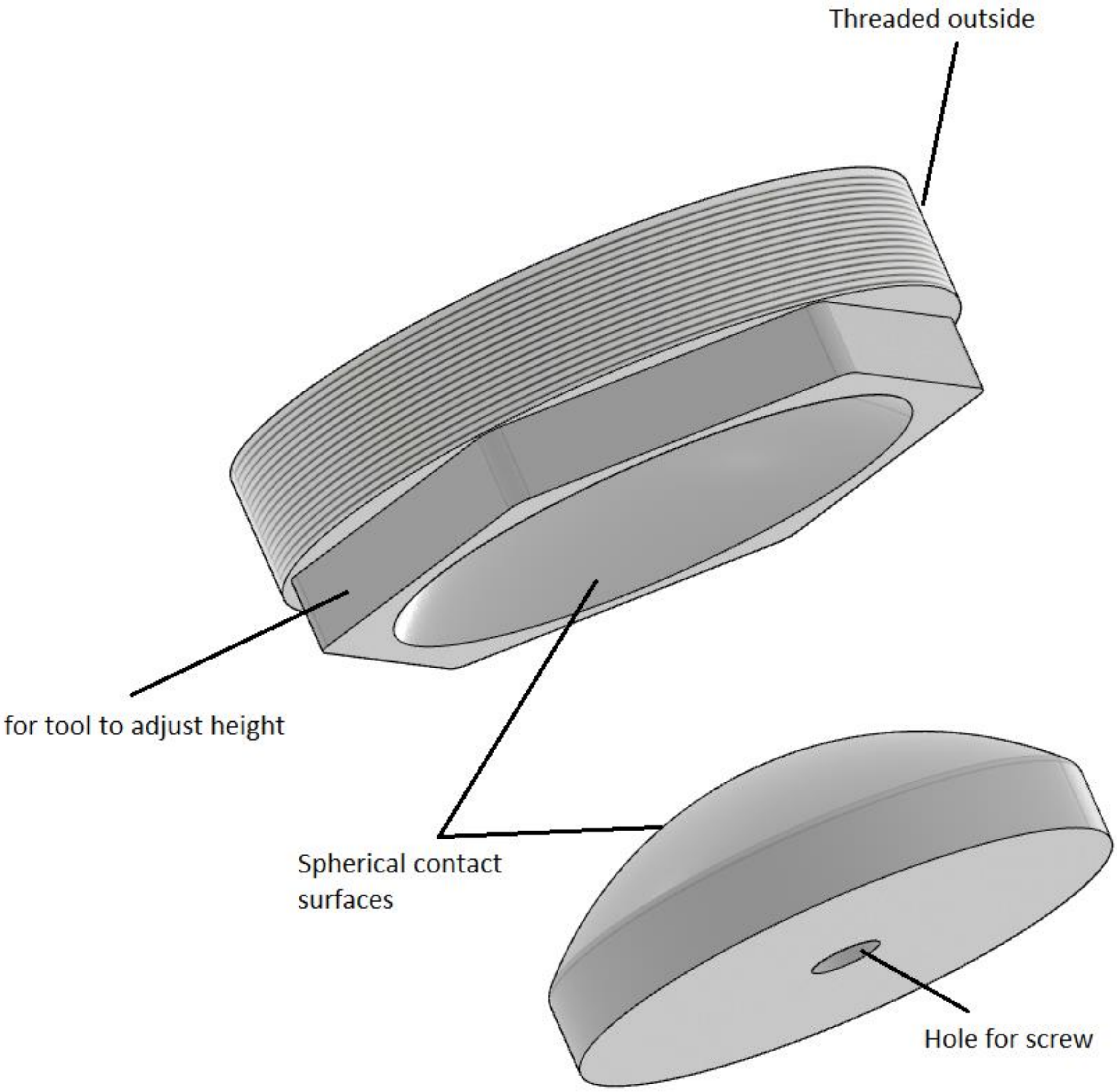

Figure 4.29 Concept 6 with descriptions

4.7 Concept selection final evaluation

Another round of the relative decision matrix was made with weighed criterions on the further developed concepts plus the new idea (concept 6). The results are presented in table 4.5 below. Concept 1 is the winner in the weighted decision matrix concept 3 and 4 is considered to have a more expensive manufacturing[3]. Concept 3 still have one of the keyways that is considered to be expensive to manufacture. In concept 3 there is a large plate that needs to be milled on all sides and it needs to have holes on the opposite side from the keyways to ensure the correct position. Since it is a lose plate, one more step is added on the tolerance chain which makes the precision less good in the positioning system. Concept 4 still has walls with an angle, but with a slightly simpler geometry in the bottom of the keyways to mill. The key is a round bar which can be turned in a lathe. Concept 1 have the simplest geometry in the arm and bracket, a cylindrical pocket with a threaded hole in the bottom. This is easy to manufacture in a mill, and easy to measure the tolerance of the diameter and depth. The keys are here turned in a lathe which can cut a conical geometry with ease. The male and female parts could be measured together to make it easier to measure the cone. The new concept (concept 6) has a lower ability to withstand forces in x- and y directions.

Table 4.5 Relative decision matrix with weights

Criteria	Concept			
	1 (ref)	3	4	new
Comply with ISO standards and EU materials (w=1)	Datum	0	0	0
Manufacturing should preferably be possible by conventional methods (w=3)		0	0	0
Manufacturing should have low impact on internal and external environment (w=1)		0	0	0
Total cost (materials and manufacturing) less than current design (w=5)		-	-	0
Withstand forces Fx=29720N Fy=3680N, Fz=16920N (w=5)		0	0	-
Size not to exceed 400x200x70mm (w=3)		0	0	0
Repeatable position in the range 0.1 mm (w=5)		0	0	0
Allow movement of the roller suspension during maintenance (w=5)		0	0	0
Possibility to fit more clamps/brackets in the machine (w=3)		0	0	0
The locking device must withstand forces of 12680N (w=5)		0	0	0
Withstand vibrations (w=5)		0	0	0
Corrosion resistant material, chemicals and water (w=5)		0	0	0
Low forces for loosening and tightening (w=2)		0	0	0
Long life (define in years) (w=3)		0	0	0
Maintenance free (w=3)		0	0	0
Possible to replace parts (w=3)		0	0	0
Recyclable material (w=3)		0	0	0
Sum +		0	0	0
Sum 0		55	55	55
Sum -		-5	-5	-5
Net value	0	-5	-5	0
Rank	1	2	2	2
Further development	Yes	No	No	No

[3] Interview with purchase, production and quality departments at Valmet.

4.8 The final concept

Multiple variants of the concept are considered, there is possible to alter the angle of the cone, the height of the cone and the diameter. It is also possible to have two or more conical parts in the arm and bracket. The arm and brackets plates could be designed to have a gap between each other or to have contact.

In figure 4.30 one cone is used and there is a gap between the plates, the arrows in the figure is representing the force from the screws.

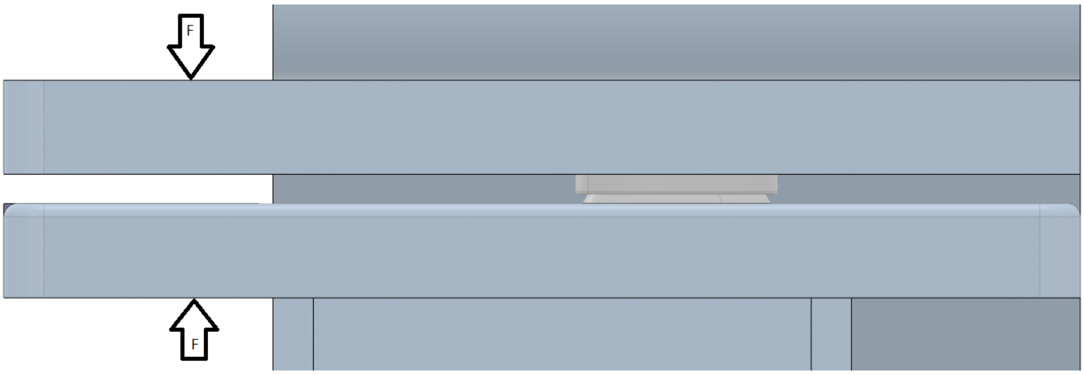

Figure 4.30 One conical connection and gap between the plates. The plates are 400mm from left to right.

Another variant of the concept is to have gap between the plates and use two conical contacts like in the picture 4.31.

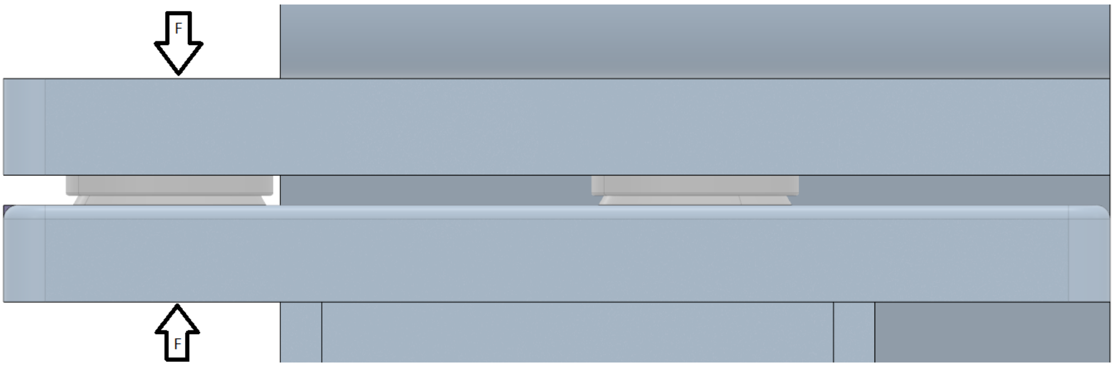

Figure 4.31 Two conical connections and gap between the plates. The plates are 400mm from left to right.

A third variant is to use one conical connection and have no gap between the plates like figure 4.32 illustrates.

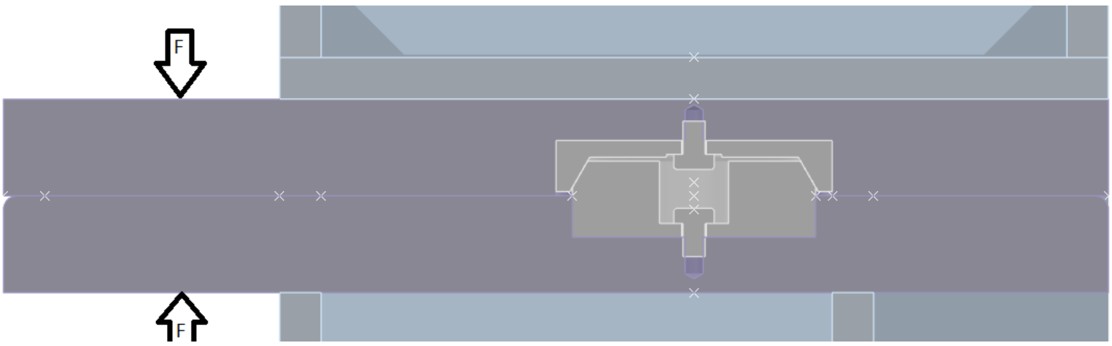

Figure 4.32 One conical connection with no gap between the plates. The plates are 400mm from left to right.

A new relative decision matrix was carried out to chose one of the different variants of concept 1. The new round of the decision matrix has fewer criteria. The variant with one cone and no gap between the plates is chosen as reference. The result is shown in table 4.6. The results from the relative decision matrix with the variants of concept 1 shows that the variant with one cone and no gap should be further developed. The fact that the plates are in contact makes it better to handle vibrations. The variant with two cones is less good since it has more parts to manufacture.

Table 4.6. Relative decision matrix of the three variants of concept 1.

Criteria	Concept		
	One cone, no gap (ref)	One cone, gap	Two cones, gap
handle clamping force (w=5)	Datum	-	-
Withstand vibrations, with respect to eigenfrequencies (w=5)		-	-
Total cost (materials and manufacturing) less than current design (w=5)		0	-
Sum +		0	0
Sum 0		5	0
Sum -		-10	-15
Net value		-10	-15
Rank	1	2	3
Further development	Yes	No	No

4.9 FE-analysis of the final concept

The FE-analysis shows that one conical contact with the dimensions of a diameter 90mm for the cup and 88mm of the cone with an angel of 30° and a height of the contact of about 9,5mm withstands the forces. The alternative where there is a gap between the plates will press the plates towards each other where the screws is and will also make the gap larger on the opposite side. In figure 4.33 the results from the FE – analyze of the concept with one conical contact and no gap between the plates is shown. The stress is lower than the maximum allowable (183 MPa) everywhere in the model. In the FEM the forces are in, x- direction 3700N, y-direction 30400N and z-direction 19500N which is slightly higher than the expected. Hence the conical design is accepted to withstand the forces. The highest stress is in the inner corner of the cup.

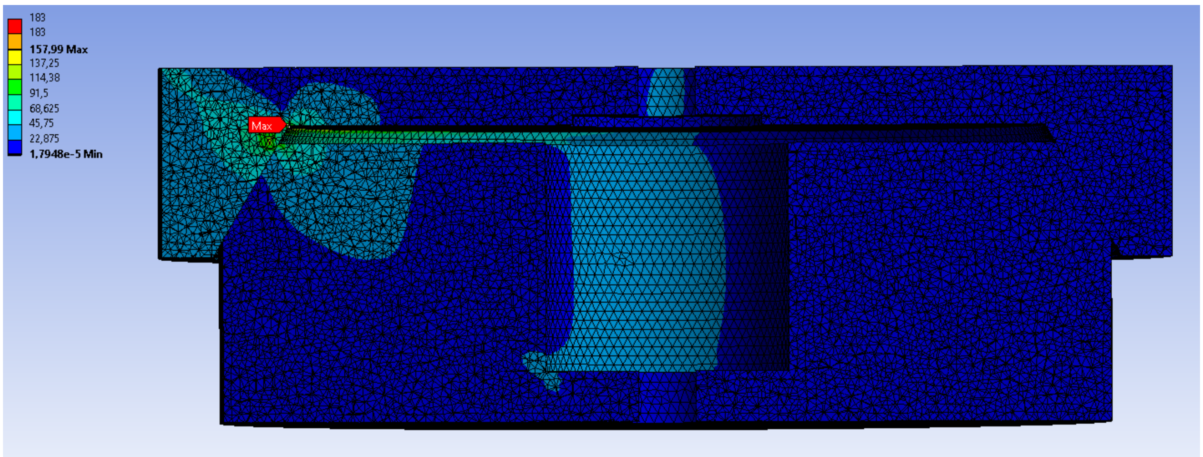

Figure 4.33 Results from FEM of the conical design with no gap between the plates, excessive deformation visible.

An analysis of the same parts but with an angle of 45° shows similar results with a maximum stress of 180MPa. The forces in the analysis are in, x-direction 4000N, y-direction 31000N and in z-direction 24000N. Figure 4.34 shows the FEM results.

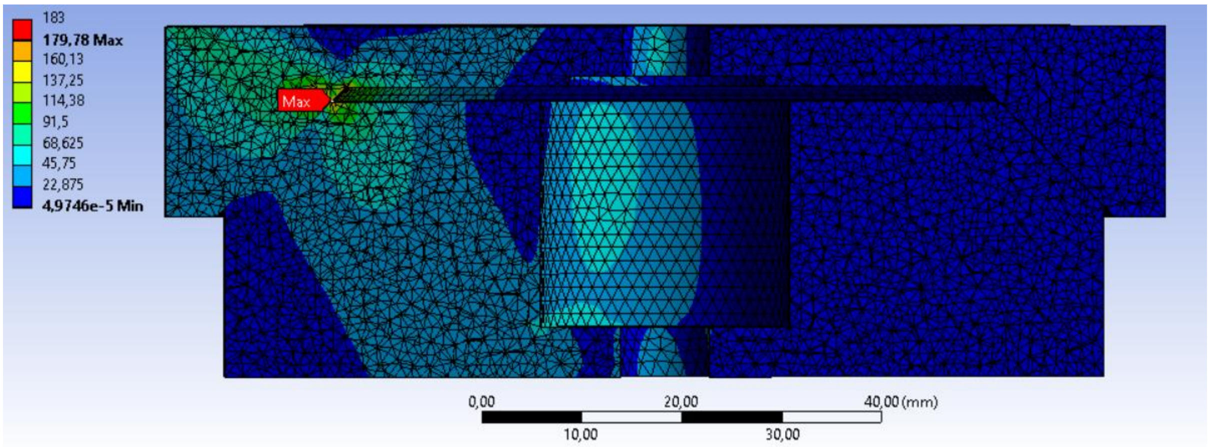

Figure 4.34 Results from FEM of the conical design with 45 degrees walls

4.10 Cost estimation

Since the price of manufacturing and materials varies with time, it was decided that drawings would be sent out to the supplier to determine the price. Drawings of both the design proposed by the project and the current design were sent to the same supplier at the same time. This was done to get a comparable price.

The design on which the positioning system is located is a relatively large and many of the components on the associated parts is not covered by the thesis. Since large parts of the arm and bracket remain the same, it was decided to compare prices only on the machining related to the positioning. That is the current keyways on both the arm and bracket and the keys that is currently used. This were compared to the new design which replaces the keyways with cylindrical pockets and the keys is replaced by the conical parts.

According to the manufacturer the new positioning design have about 40% less manufacturing cost compared to the current one.

5. Analysis and discussion

In this chapter the results of the thesis is analyzed and discussed. First the methods and process of the thesis project is analyzed and discussed and later the final concept is analyzed and discussed.

5.1 The method and process

Overall the thesis followed the product development process described by Johannesson [4]. all steps were followed up to and including detailed design, subsequent steps were omitted due to time constrains. Following a predetermined process made the work easier. In concept generation and evaluation, this was evident as the concepts developed met the requirements and functionality relatively well. After a final concept was selected and refined, no major changes were needed. This is supported by Johanesson [4] as well as Bergman [6] who explains that a systematic approach leads to few late changes and a high-quality product.

The time schedule made at the start of the project turned out to be almost accurate, only minor changes was needed. The time schedule and the Gantt was made to be a dynamic document throughout the project and have been a great tool during the project. The Gantt was not that detailed, but the major activities were identified. The WBS was made in the beginning and a good tool when making the time schedule. The WBS was not used after the planning were made. A more detailed two-week planning was made with the help of the Gantt, which have been a very good way to keep track on what has to be done in the coming days and weeks. The planning of the nearest two weeks has been done continuously through the project. This planning have been the most helpful to achieve the time target set.

The study visits were made later than wanted due to Covid-19 restrictions so the outcome of them was not that helpful as planned. The study visits were interesting and gave some perspective of the size of the machine and how the machines are assembled. However, it did not help the thesis project as much due to the late date. The tissue machine that was shown during the visit in the assembly department was not the same as the one the thesis focuses on. That is another reason that the study visit was not that helpful.

The analysis of the current design was mostly made in a 3D environment (Catia v6). This was a great tool to use and gave the ability to disassemble and zoom in on details which would have been difficult on a real machine. Details of the current design was also made by examine drawings which led to a better understanding of how the parts are manufactured. Together with the 3D and drawings the function and design were discussed with employees at Valmet. This gave a good understanding of what function that the new design needs to fulfill and what the limitations are.

The outcome from the current design analysis was a requirement specification which was a necessary document to have when developing concepts for the new design. Experienced employees at Valmet have been involved from an early stage in the development of the requirement specification. This led to a good document that needed few changes and was a great tool to make sure that the new design actually fulfilled what it was supposed to do.

The two concept generation sessions resulted in many similar ideas. The outcome from the morphological matrix was 15 sub solutions which were combined in to three different solutions. The input to this session was the functional analysis. The results from both the functional analysis and the morphological matrix was an input to the 6-3-5 method. The outcome of the 6-3-5 method was good, the participants were mostly of experienced employees but also some with less experience. This mix of experiences seemed to create both completely new ideas and ideas similar to the current, or other machine designs. It was clear that the more experienced participants were more conservative since they considered forces and needed tolerances to fulfill the function. The less experienced participants were more able to think outside the box. The different inputs on the ideas from both unexperienced and experienced led to good ideas on what the opportunities and pitfalls on the different ideas were. The inputs were great to have when trying to develop concepts from the ideas.

During the concept selection estimates were made on how well the concepts met the criteria. This was made partly by own experience but also with experienced employees at Valmet. The first round removed concepts that could not be developed to something that was better than the other concepts, both the Harris profile and relative decision matrix was used. The second round considered the concepts when they were a little more developed to get a better picture of how they would fit the current design and which details that was needed to do so. The final round led to the winning concept. The second and final round of concept selection was made with relative selection matrix. The winning concept was developed further and analyzed with FEM, this development and analysis led to three variants of the concept. That is why one more round of the relative decision matrix was done, this time with less criteria to get a faster evaluation.

The Harris profile was not an optimal tool to evaluate how well the concepts met the criteria in this project. This is because it is hard to evaluate for example requirement 6 “Size not to exceed 400x200x70mm” on a -2 to +2 scale. The evaluation was done in such way that a judgement on how easy it is for the design to for example withstand forces, if the design could be rather small and still withstand the forces a high grade was given. On the other hand, if the design needed to be quite large and have big modifications to withstand the forces a low grade was given. Other concept selection tools would maybe be better to use such as Kesselring for example.

The relative decision matrix is a better tool to evaluate and compare the concepts with these kinds of criteria compered to Harris profile, however, the evaluation is still subjective. Although the assessments were made with input from experienced employees at Valmet some factors could have been misjudged. If the assessments were made by several parties and the average result was used instead, this could have been avoided. If this was done it would result in a more objective judgement.

5.2 The final concept

There were three different ideas of setup for the final concept, one cone contact and a gap between the plates, two cone contacts and a gap between the plates then there was a suggestion of one cone contact and no gap between the plates. The two first ideas were there was a gap between the plates, was chosen not to continue with after a relative decision matrix. This is, for the first option with one cone contact, because when the screws that is clamping the element together is tightened the plates will be pressed down and on the opposite side the plates will rise. For the second option the side where there is an overhang of the plates need to be stiffer to not deflect. Yet another reason is that the variants with a gap between the plate withstands vibrations less good. Hence, the third option with no gap between the plates is considered the best choice. Since there will only be a need for one conical contact, that is two parts, less parts are considered better. A second reason is that the plates can be kept as they are and don’t need any changes such as, stiffening, plus the friction between the plates helps holding the element together. However, in the analysis this friction is ignored to make sure that the conical parts will hold for the full force. The conical parts will be little smaller than in the 3D model due to tolerances, so the conical parts in firsthand only position the breast roll retraction system.

The FEM analysis of the alternative with 30° walls shows that the highest stress is in the inner corner of the cup (the upper conical part), on the real part there will be a radius here. This radius will lower the stress concentrations, hence the parts will handle the stress applied to them. The analysis of the alternative with 45° walls shows that the highest stress concentrations is in the upper corner of the cone (lower part), the same applies here that the corner will have a radius that lowers the stress. So when it comes to solid mechanics both variants works well.

The variant with 45° walls can correct a larger error in positioning with the same dimensions that the variant with 30° can. In the chapter about sustainability, it is clarified that a design with less material is better to use if the quality of the material is the same. There is no major difference between manufacturing the different variants, therefore it is better to proceed with the one that corrects the largest error.

The upper cone (the cup) have a starting diameter for the cone of 90mm and an end diameter of 64mm with an angle of 45°. The lower cone have a starting diameter for the cone of about 67mm and an end diameter of 88mm with an angle of 45°. The dimensions are chosen so they can withstand the forces and give the impression to hold, but in the same time be as small as possible so the material use are kept to a minimum. With less material needed to be removed less machining time is needed, hence less energy needed when machining is done. Less machining time also leads to less tool use, since the tool wears down with time. These factors makes the environmental impact lower for a smaller design than for a larger. Also, the weight is a factor that impacts on the environmental footprint, heavier parts leads to more energy needed to transport the items. Therefore, a smaller part also make the energy need for transportation lower.

The current design analysis shows that the arm can have an error in positioning of about 6,7 mm that the positioning element needs to be able to adjust. The new design can tolerate an error of around 11,5 mm and still correct the position of the arm. This design corrects the calculated error of the arm with a margin of 4,8 mm. In a worst case scenario, the arm itself can deflect like a bending beam. The design take that into account, but it is difficult to calculate how much the arm can deflect. With a larger angle for instance 60° the design could correct an error of almost 20 mm instead. Smaller angles center the position easier than a larger angle, that's why a smaller angle is preferable. With a 45° wall angle the conical parts can be made in a suitable size so it fits in the breast roll retraction system without any larger changes. At the same time the 45° angle is proven to work since the current angle of the keys is 45°. Furthermore, the chosen angle gives a good margin to correct the position even in the worst-case scenario. The wall angle also admits to open the arm to an angle of around 30° with a radius of 1190mm which is the length from the middle of the cone to the rotation center at the hinge.

The material needs to withstand a corrosive environment and at the same time be as easy as possible to machine. The material should also have as low impact on the environment as possible and use as little conflict materials as possible. The requirement specification states that the material should be a standard material which makes it easier to obtain material from different suppliers. From the material theory chapter, two materials are top ranked when it comes to resistant to both weak acids and alkalis, and have a good machinability (data from Walter.com), the materials are AISI316 and AISI316L. These materials are also compatible with the other materials that will be in contact with the parts. Aluminium could make a galvanic cell with the other materials and corrode, and is therefore a bad choice. Another important factor is that the materials used must be approved by Valmet, which both AISI316 and AISI316L is. The two stainless steel alloys are very similar. Price per kilo is almost the same and the CO_2 footprint and the embodied energy is almost identical for both AISI316 and

AISI316L. However, to do a proper sustainability analysis of materials, more data is needed. This would include energy consumption and CO2 emissions from transport from manufacturing to where it is machined and transportation to assembly as an example. However, this analysis is not within the scope of this thesis.

The current design with two keyways with a wall angle of 45° in the arm is identified, in the current design analyze, to be the most expensive to be machined. The main cause of this is that the both keyways is hard to reach in the same machine setup, if it is not machined in a large 5-axis machine. Then there are the tolerances both on the keyway in the arm and the keys. The design proposed from this thesis have a simpler geometry on the arm consisting of a cylindric pocket and a threaded hole which is easy to machine in a single setup. The new positioning elements is rotational symmetric and can be machined in a lathe, they still have a wall angle of 45° but this is simpler to manufacture. This is because instead of tilting the tool in a mill which needs a machine with 4-axis, in a lathe the toolpath is programed in the correct angle and uses only 2-axis. The current design and the design proposed from the thesis was compared with respect to manufacturing price with the help of a supplier. The supplier suggested a 40% lower price for the new design. This confirms that the geometry of the new design is cheaper to produce and that it is possible to significantly influence the price by designing using DFM early in a product development process.

A wide search at a large amount of suppliers of different clamping and fixturing parts was done. Most parts that might be able to solve the problem does not allow the positioning error needed. Neither is the material of the right quality, some parts can be ordered in stainless steel, but none that is acid resistance. Some suppliers might be able to produce the part with a material that will withstand the environment. The problem with the correct geometry is still there. If this solution should work it will still be a special order with compromises on the function. Hence, the recommended action is to order the parts that solves the problem without compromises.

The locking system which today consists of two eye bolts with corresponding nuts is already a cheap solution. The thesis did not focus on developing a new solution for this, as the positioning system was considered to be the most expensive in this context. However, a search at suppliers of standard parts was done, and resulted in that the material seldom was acid resistant. Furthermore, the locking devices at suppliers seldom managed the forces needed. Clamping parts that was of interest to investigate where for example cam levers, cam clamps and toggle clamps as they are easy to use and does not require any tools to use. The thesis leaves this area to be investigated for future work.

The final concept provides opportunities to fulfill all demands and all wishes but one in the requirement specification (see table 5.1). The wish that is not fulfilled is number nine “Fit more clamps in the machine”. The other clamps in the machine have a different function, it might be possible to fit the solution from the thesis, but it would most likely be a less good solution than the existing.

Table 5.1, requirement specification with Olssons matrix as reference

Number	Criteria	Req.= R Wish = W	Weight	Fulfilled
1	Comply with ISO standards and EU materials	R	-	Yes
2	Manufacturing should preferably be possible by conventional methods	W	5	Yes
3	Manufacturing should have low impact on internal and external environment	W	3	Yes
4	Total cost less than the current design (materials and manufacturing)	R	-	Yes
5	Withstand forces Fx=29720N Fy=3680N, Fz=16920N	R	-	Yes
6	Size not to exceed 400x200x70mm	W	3	Yes
7	Repeatable position in the range 0.1 mm	R	-	Yes
8	Allow movement of breast roll retraction system	R	-	Yes
9	Possibility to fit more clamps/brackets in the machine	W	3	No
10	The locking device must withstand forces of 12680N	R	-	Yes
11	Withstand vibrations	R	-	Yes
12	Corrosion resistant material, chemicals and water	R	-	Yes
13	Low forces for loosening and tightening	W	4	Yes
14	Long life	W	4	Yes
15	Maintenance free	W	4	Yes
16	Possible to replace parts	W	2	Yes
17	Recyclable material	W	3	Yes

6. Conclusions

The new concept with a cylindrical position device fulfills the requirement specification and meet the aims of the project. The concept is easy implemented in the machine and eliminates the expensive manufacturing of the previous keys and keyways. The main purpose of the thesis was to find a more cost-effective design. The new design has a manufacturing cost that is 40% lower than the current design, so the purpose is considered well met.

The variant with no gap between the plates that holds to positioning elements is recommended since it withstands vibrations better. The variant with 45° walls on the cones is considered best because it can correct a bigger error than needed, so even additional errors that are difficult to predict can be corrected.

The suggested material for the parts is AISI 316 or AISI 316L. These materials are similar and work equally well. The availability and price of the supplier can be used to decide which material to use.

The Aims and purpose of the thesis was to propose a design with lower cost than the current design, that have the same function. Provide 3D models and drawings for the new design and suggest manufacturing methods for the new design. The thesis should also compare the current design with the design proposed from the thesis with respect to function and cost. The thesis have found a design that have around 40% lower manufacturing cost compared with the current keys and keyways. The thesis have also provided complete drawings and 3D models for the new design and suggests turning of the conical parts and milling of the pockets in the arm and bracket. The new design have been compared to the current design during the thesis in the relative decision matrix. Hence, the theses has met all the objectives from the project description.

6.1 Future work

The retraction system is made up of two arms, one arm, the upper one have an adjustment screw. If the location of this screw is changed, so that the same surface on which the positioning system sits is used, the tolerances on the positioning system could be made less tight without adversely affecting the repeatability of the position.

In order to lower the cost even more for the arm it is suggested to find a design that eliminates the upper arm that is attached to the arm in the thesis. If this arm is eliminated the design could be cheaper and the tolerance of the breast roll positioning do not need to be as tight as it is today.

The brackets which holds the lower cone is not symmetrical today. If this bracket is redesigned in order to make it symmetrical, the same bracket can be used on both sides of the machine.

To make the system even cheaper the locking system that is used today, the eye bolts, could be replaced by standard parts. For example a heavy duty toggle clamp could be used, if it is possible to order this in the correct material. During this thesis a search of these kind of toggle clamps have been made without finding one both with the correct material and that can handle the forces.

The positioning of the breast roll retraction system could be replaced by standard parts if a suitable part is found in the correct material and with the ability to correct the position error.

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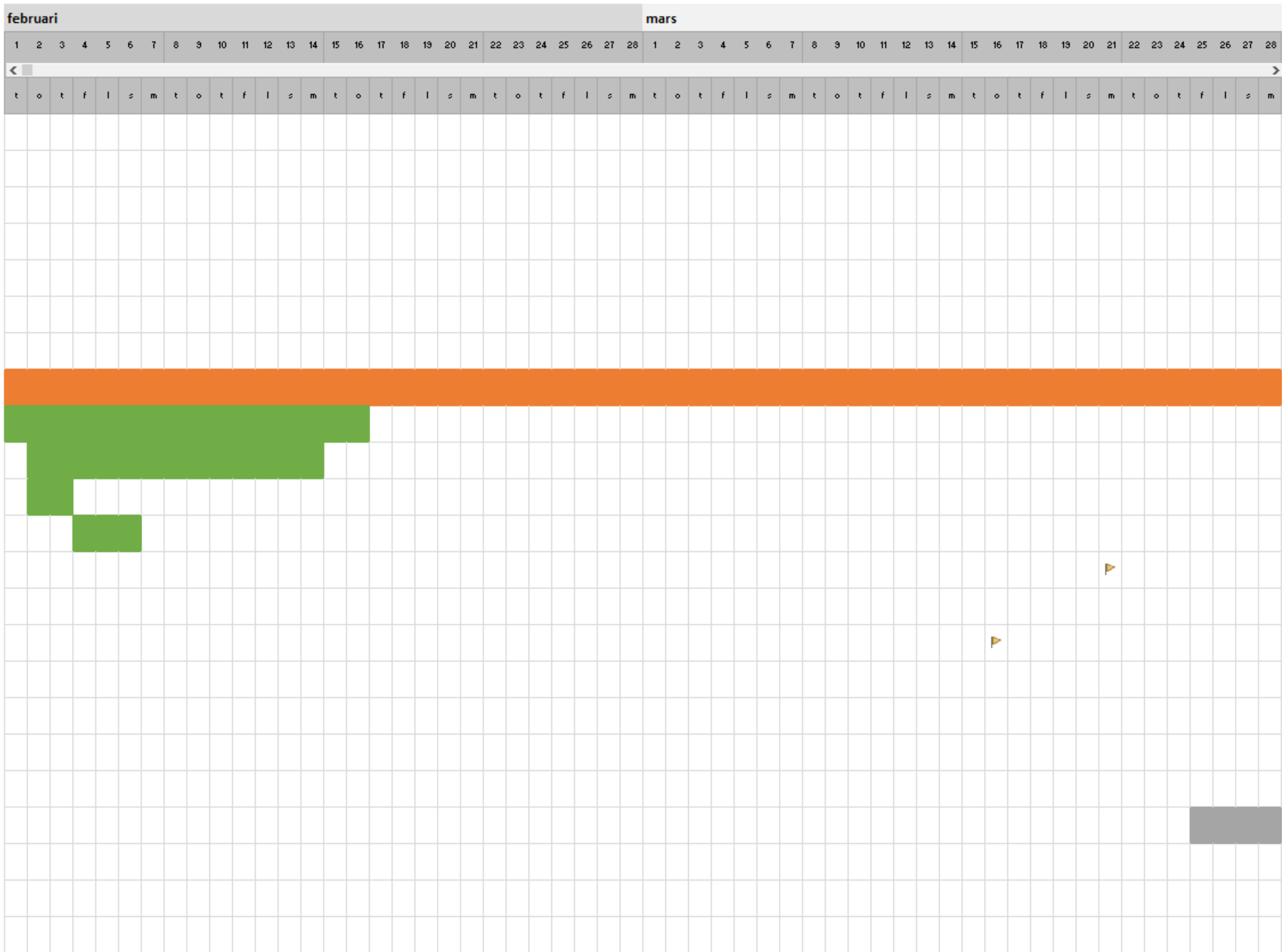
Appendix A - Gantt

Företag	Valmet AB	, Karlstads Universitet	
Student	Tobias Sjöberg		
Dagensdatum:	2022-01-31	Startdatum:	2022-01-17
Rullningsteg:	1	Slutdatum:	2022-06-05

Förklaring: Enligt plan | Låg risk | Medelstor risk | Hög risk | Ej tilldelad

Milstolpebeskrivning	Kategori	Tilldelad till	Framsteg	Start	Dagar
Planeringsfas					
Projektplan	Låg risk		100%	2022-01-17	10
Gantt schema	Låg risk		100%	2022-01-19	1
Uppstartsmöte med Valmet	Mål		100%	2022-01-25	1
Veckoplanering	Låg risk		100%	2022-01-19	1
Inlämning projektplan	Milstolpe		100%	2022-01-28	1
Metodfas					
Metodkapitel	Medelstor risk		100%	2022-01-28	60
Undersökning av nuvarande lösning	Låg risk		100%	2022-01-28	20
Litteraturundersökning	Låg risk		100%	2022-02-02	13
Konkurent analys	Låg risk		100%	2022-02-02	2
Undersökning av förband i andra brancher	Låg risk		100%	2022-02-04	3
Inlämning av metodkapitel	Milstolpe		100%	2022-03-21	1
Presentation Metodkapitel KAU	Milstolpe		100%	2022-03-29	1
Presentation Mid-term Valmet	Milstolpe		100%	2022-03-16	1
Slutfas					
Rapportskrivning	Medelstor risk		100%	2022-03-30	47
Slutpresentation KAU	Milstolpe		100%	2022-05-24	1
Final Presentation Valmet	Milstolpe		0%	2022-06-20	1
Konceptgenerering	Enligt plan		100%	2022-03-25	12
Koncep- utvärdering /-val	Enligt plan		100%	2022-04-06	5
Cad och ritningar	Enligt plan		100%	2022-04-11	20
Inlämning slutrapport	Mål		0%	2022-06-03	1



Företag	Valmet AB	, Karlstads Universitet	
Student	Tobias Sjöberg		
Dagensdatum:	2022-01-31	Startdatum:	2022-01-17
Rullningsteg:	57	Slutdatum:	2022-06-05

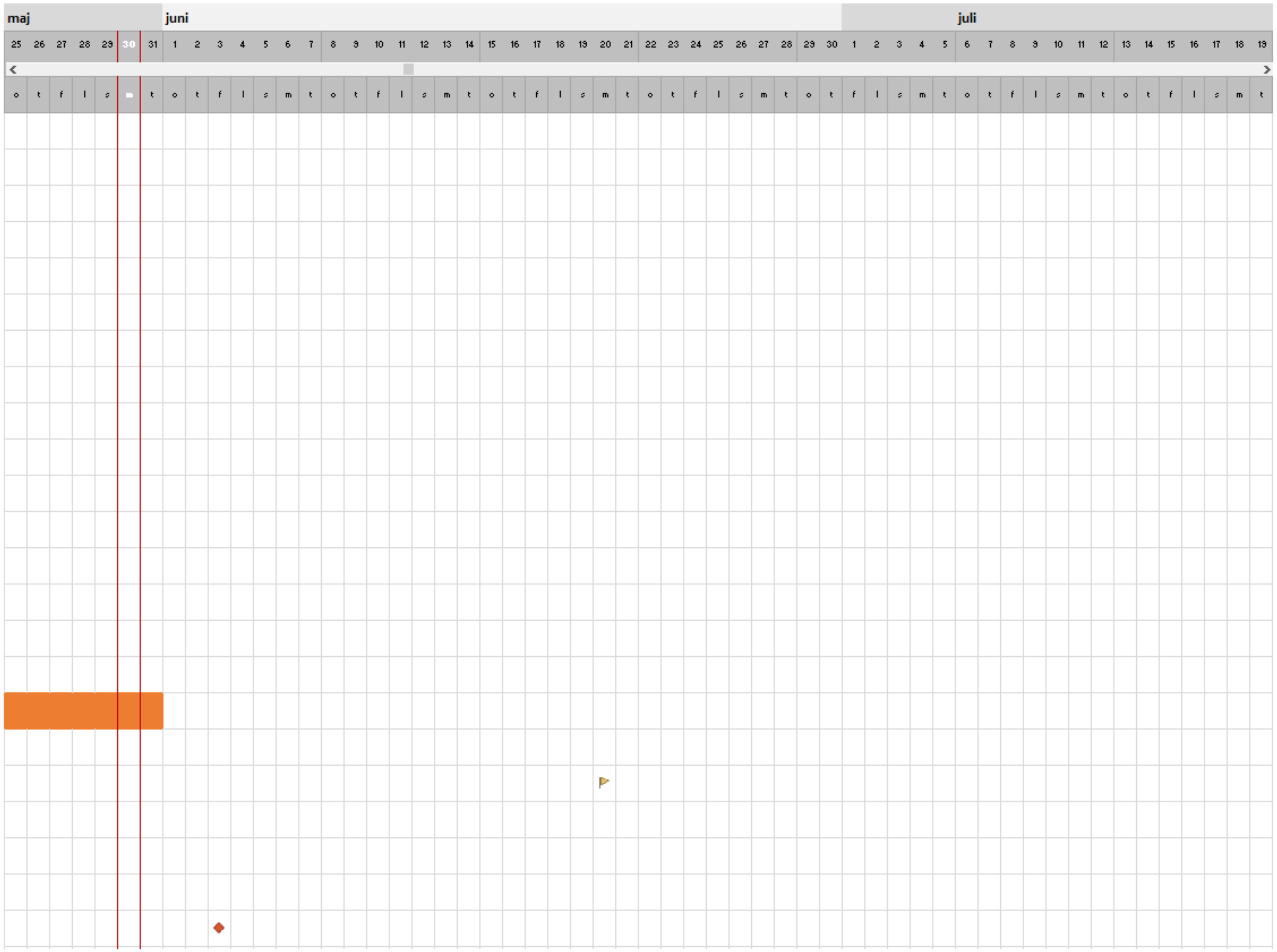
Förklaring: Enligt plan | Låg risk | Medelstor risk | Hög risk | Ej tilldelad

Milstolpebeskrivning	Kategori	Tilldelad till	Framsteg	Start	Dagar
Planeringsfas					
Projektplan	Låg risk		100%	2022-01-17	10
Gantt schema	Låg risk		100%	2022-01-19	1
Uppstartsmöte med Valmet	Mål		100%	2022-01-25	1
Veckoplanering	Låg risk		100%	2022-01-19	1
Inlämning projektplan	Milstolpe		100%	2022-01-28	1
Metodfas					
Metodkapitel	Medelstor risk		100%	2022-01-28	60
Undersökning av nuvarande lösning	Låg risk		100%	2022-01-28	20
Litteraturundersökning	Låg risk		100%	2022-02-02	13
Konkurent analys	Låg risk		100%	2022-02-02	2
Undersökning av förband i andra brancher	Låg risk		100%	2022-02-04	3
Inlämning av metodkapitel	Milstolpe		100%	2022-03-21	1
Presentation Metodkapitel KAU	Milstolpe		100%	2022-03-29	1
Presentation Mid-term Valmet	Milstolpe		100%	2022-03-16	1
Slutfas					
Rapportskrivning	Medelstor risk		100%	2022-03-30	63
Slutpresentation KAU	Milstolpe		100%	2022-05-24	1
Final Presentation Valmet	Milstolpe		0%	2022-06-20	1
Konceptgenerering	Enligt plan		100%	2022-03-25	12
Koncep- utvärdering /-val	Enligt plan		100%	2022-04-06	5
Cad och ritningar	Enligt plan		100%	2022-04-11	30
Inlämning slutrapport	Mål		0%	2022-06-03	1

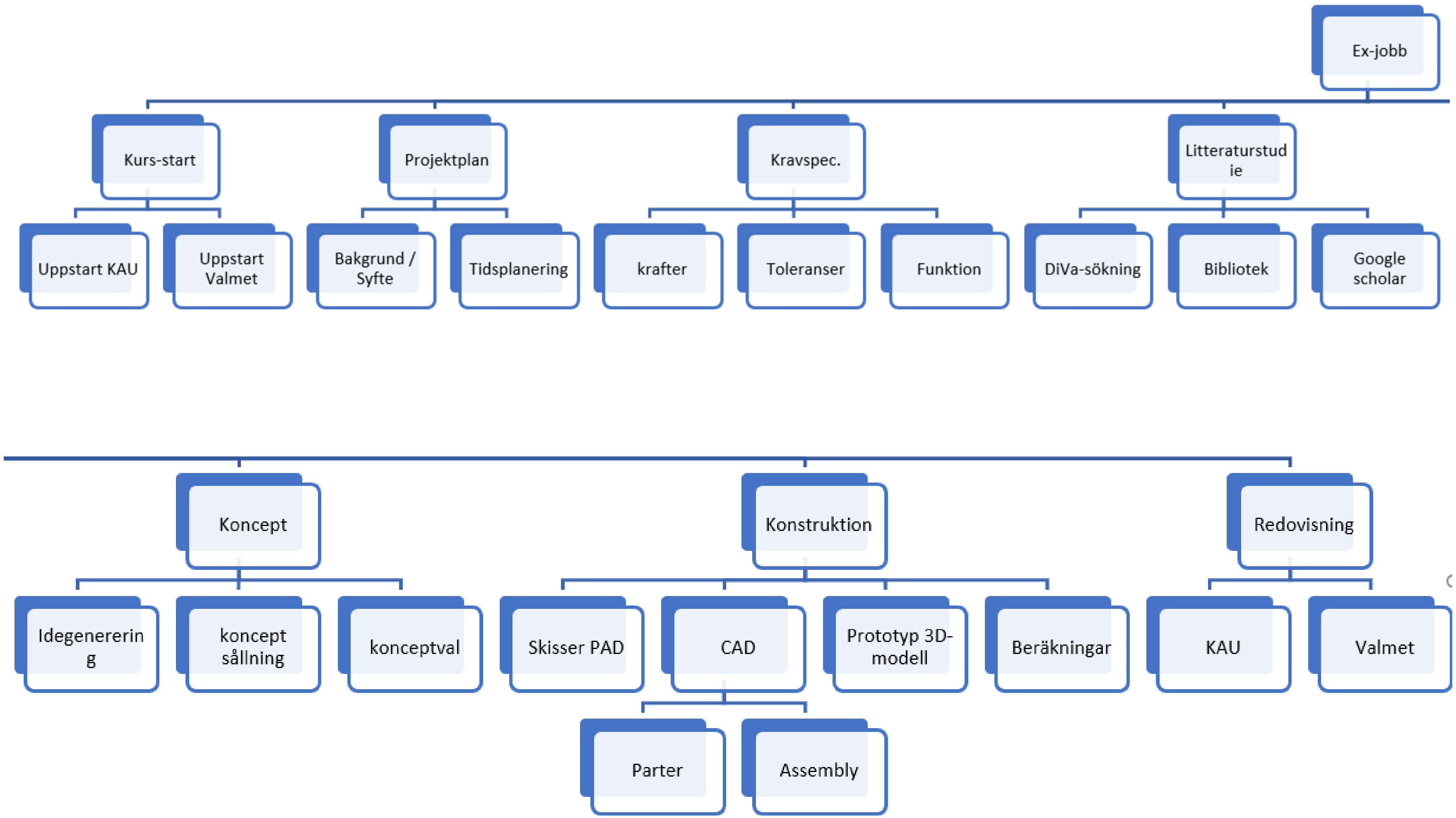
Företag	Valmet AB	, Karlstads Universitet	
Student	Tobias Sjöberg		
Dagensdatum:	2022-01-31	Startdatum:	2022-01-17
Rullningsteg:	114	Slutdatum:	2022-06-05

Förklaring: Enligt plan | Låg risk | Medelstor risk | Hög risk | Ej tilldelad

Milstolpebeskrivning	Kategori	Tilldelad till	Framsteg	Start	Dagar
Planeringsfas					
Projektplan	Låg risk		100%	2022-01-17	10
Gantt schema	Låg risk		100%	2022-01-19	1
Uppstartsmöte med Valmet	Mål		100%	2022-01-25	1
Veckoplanering	Låg risk		100%	2022-01-19	1
Inlämning projektplan	Milstolpe		100%	2022-01-28	1
Metodfas					
Metodkapitel	Medelstor risk		100%	2022-01-28	60
Undersökning av nuvarande lösning	Låg risk		100%	2022-01-28	20
Litteraturundersökning	Låg risk		100%	2022-02-02	13
Konkurent analys	Låg risk		100%	2022-02-02	2
Undersökning av förband i andra brancher	Låg risk		100%	2022-02-04	3
Inlämning av metodkapitel	Milstolpe		100%	2022-03-21	1
Presentation Metodkapitel KAU	Milstolpe		100%	2022-03-29	1
Presentation Mid-term Valmet	Milstolpe		100%	2022-03-16	1
Slutfas					
Rapportskrivning	Medelstor risk		100%	2022-03-30	63
Slutpresentation KAU	Milstolpe		100%	2022-05-24	1
Final Presentation Valmet	Milstolpe		0%	2022-06-20	1
Konceptgenerering	Enligt plan		100%	2022-03-25	12
Koncep- utvärdering /-val	Enligt plan		100%	2022-04-06	5
Cad och ritningar	Enligt plan		100%	2022-04-11	30
Inlämning slutrapport	Mål		0%	2022-06-03	1

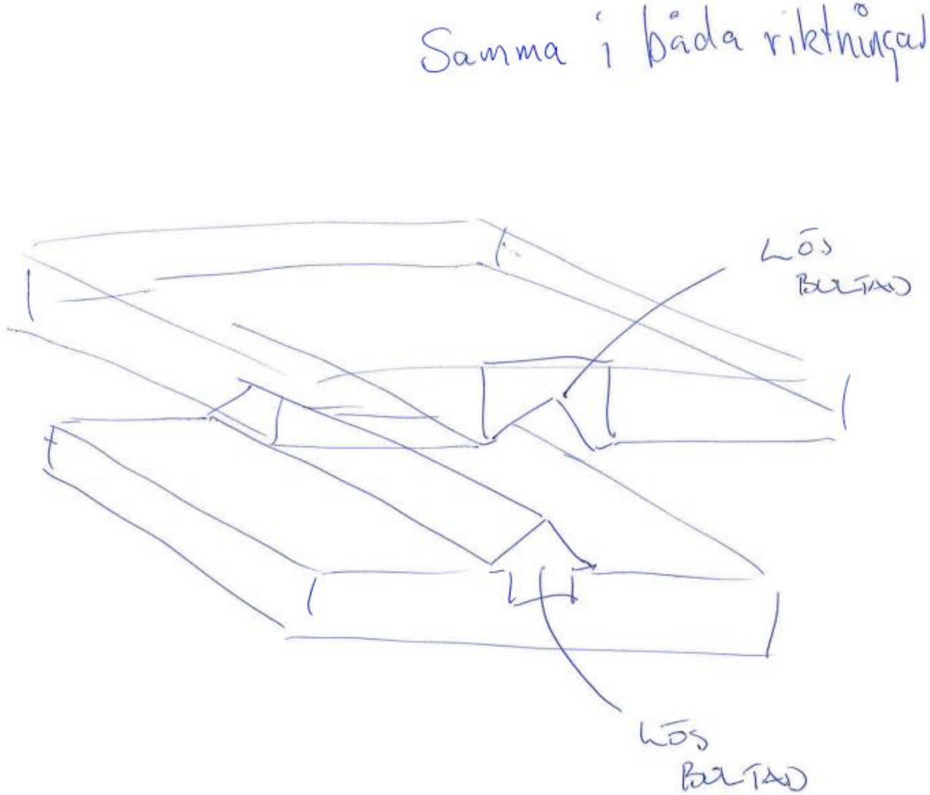


Appendix B - WBS

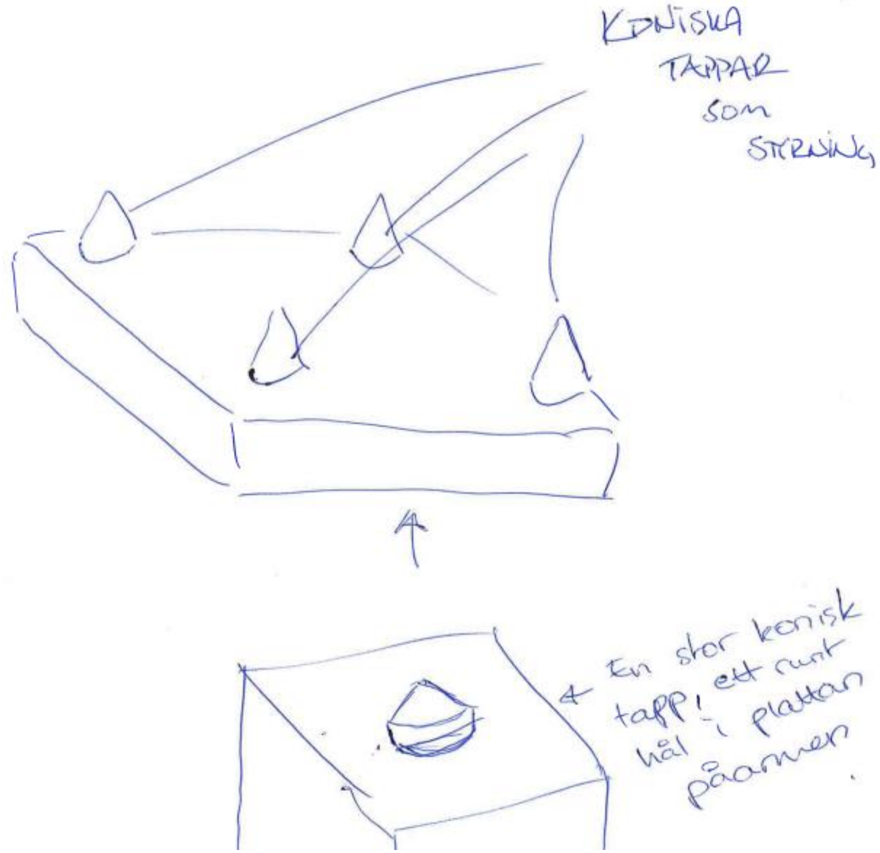


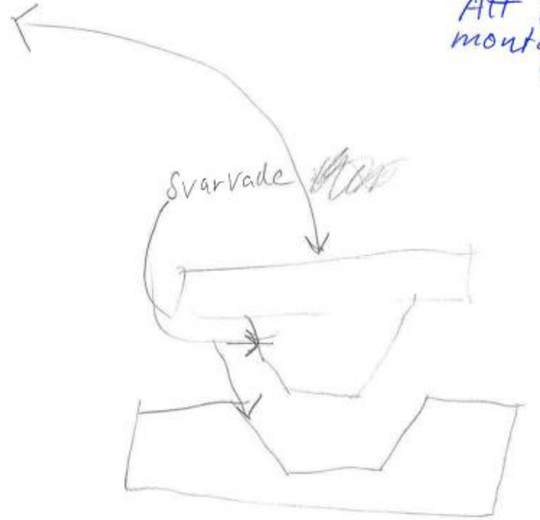
Appendix C – Outcome from the 6-3-5 method

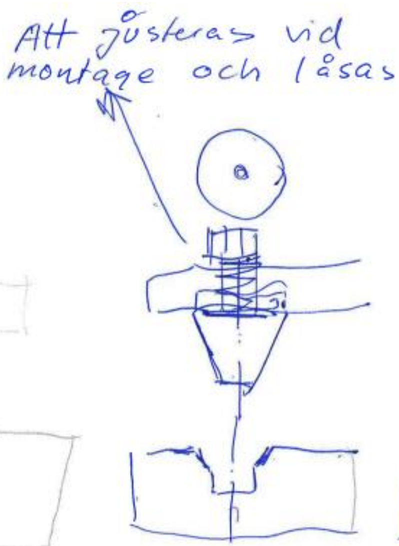
IDE 3

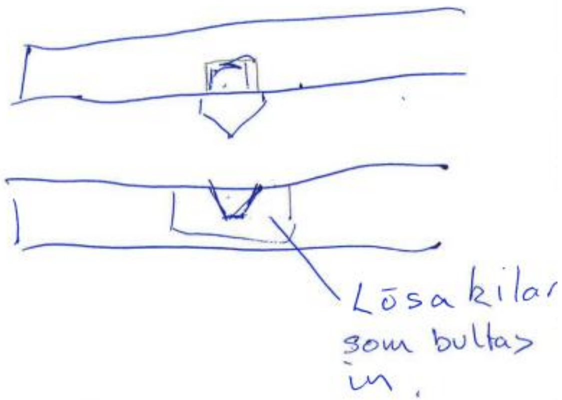


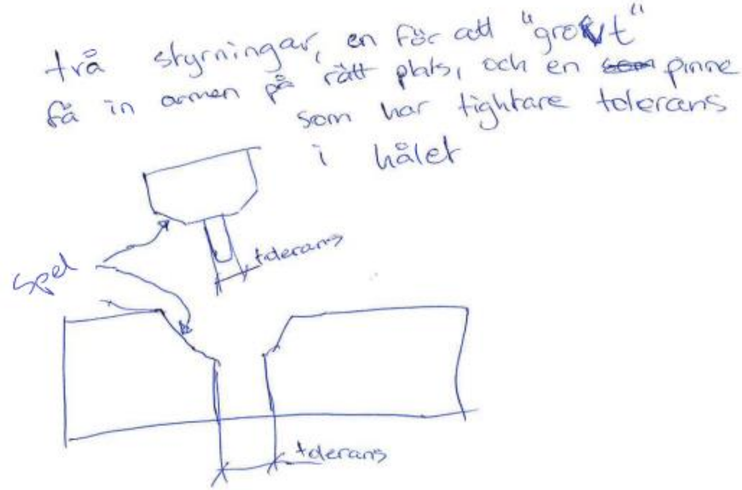
IDE 2

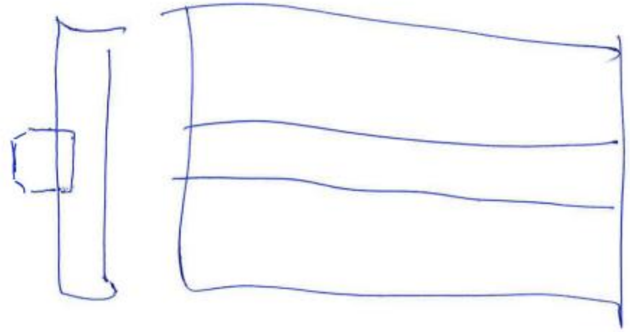

KONISKA TAPPAR SOM STYRNING
En stor konisk tapp, ett runt hål i plattan på armen

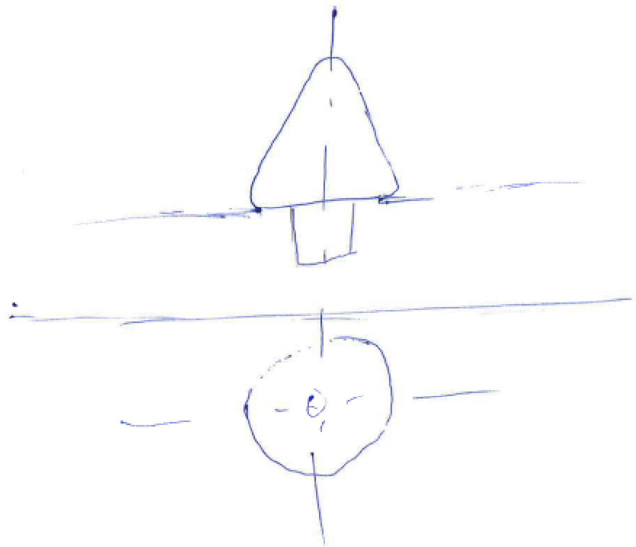

Svarvade

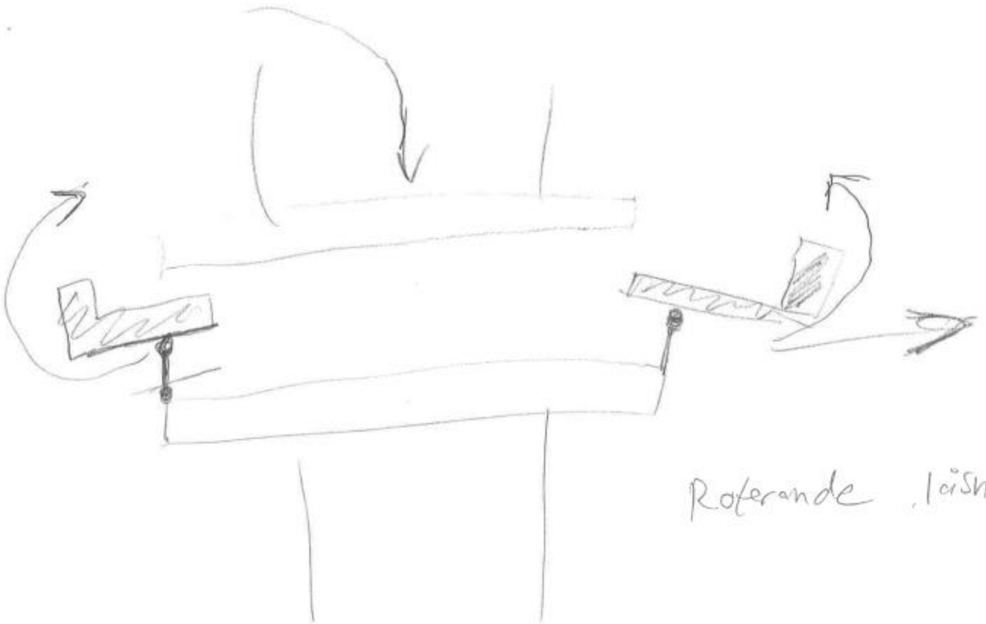

Att justeras vid montage och låsas

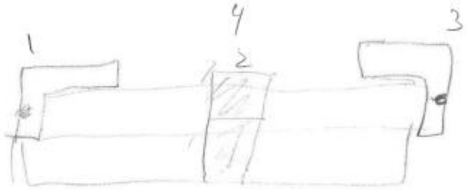

Lösa kilar som bultas in.


två styrningar, en för att "grovt" få in armen på rätt plats, och en pinne som har tightare tolerans i hålet
spel
tolerans
tolerans

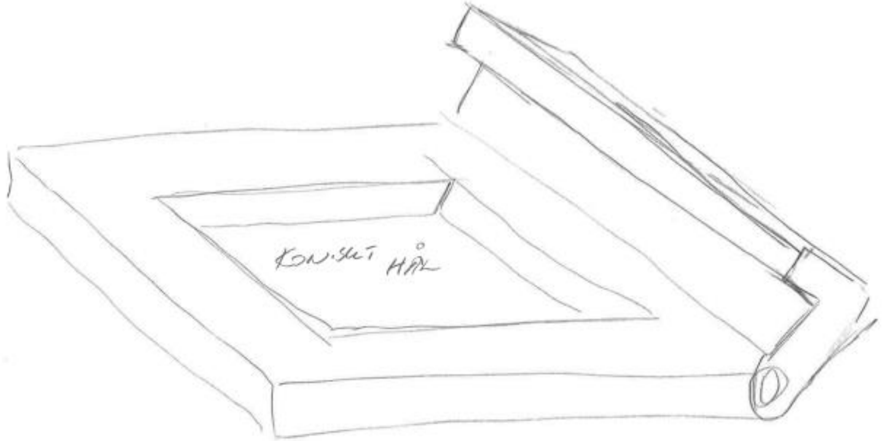


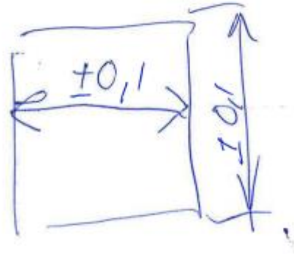


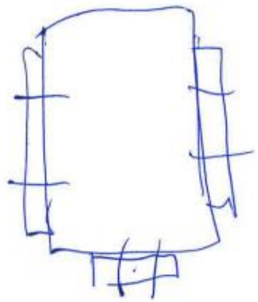


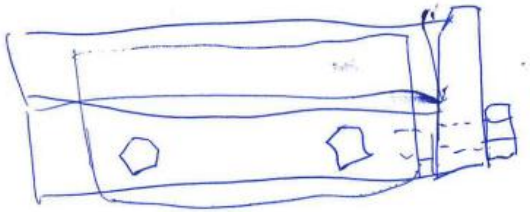


Roterande låsningar X4

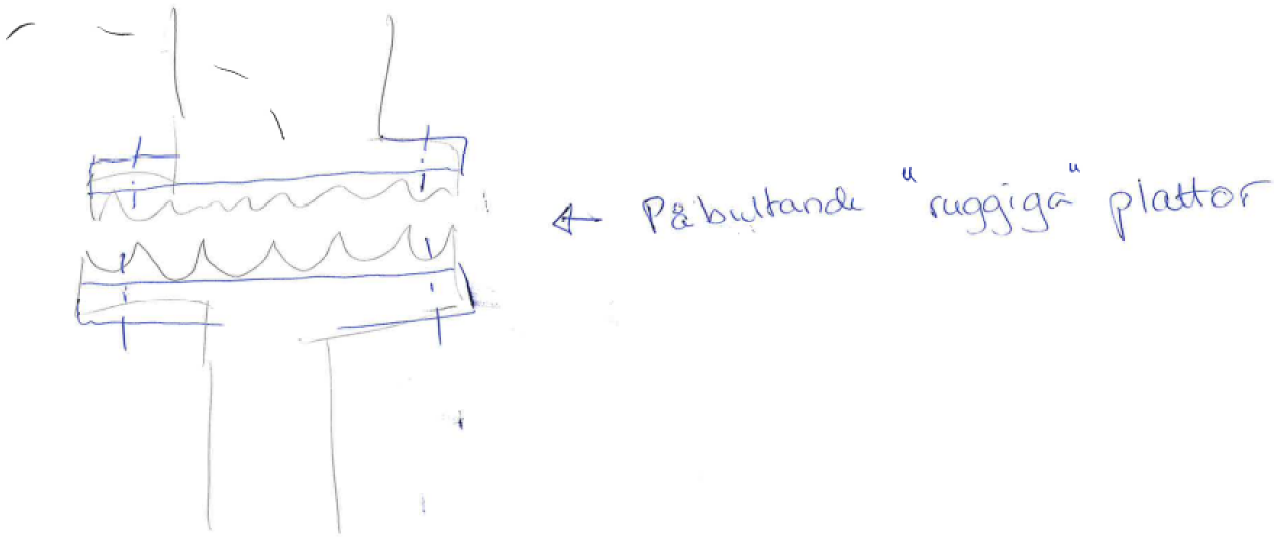



±0,1
±0,1

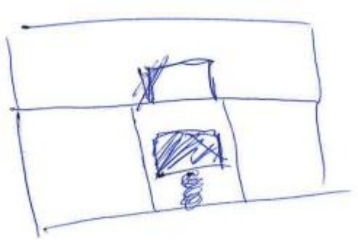




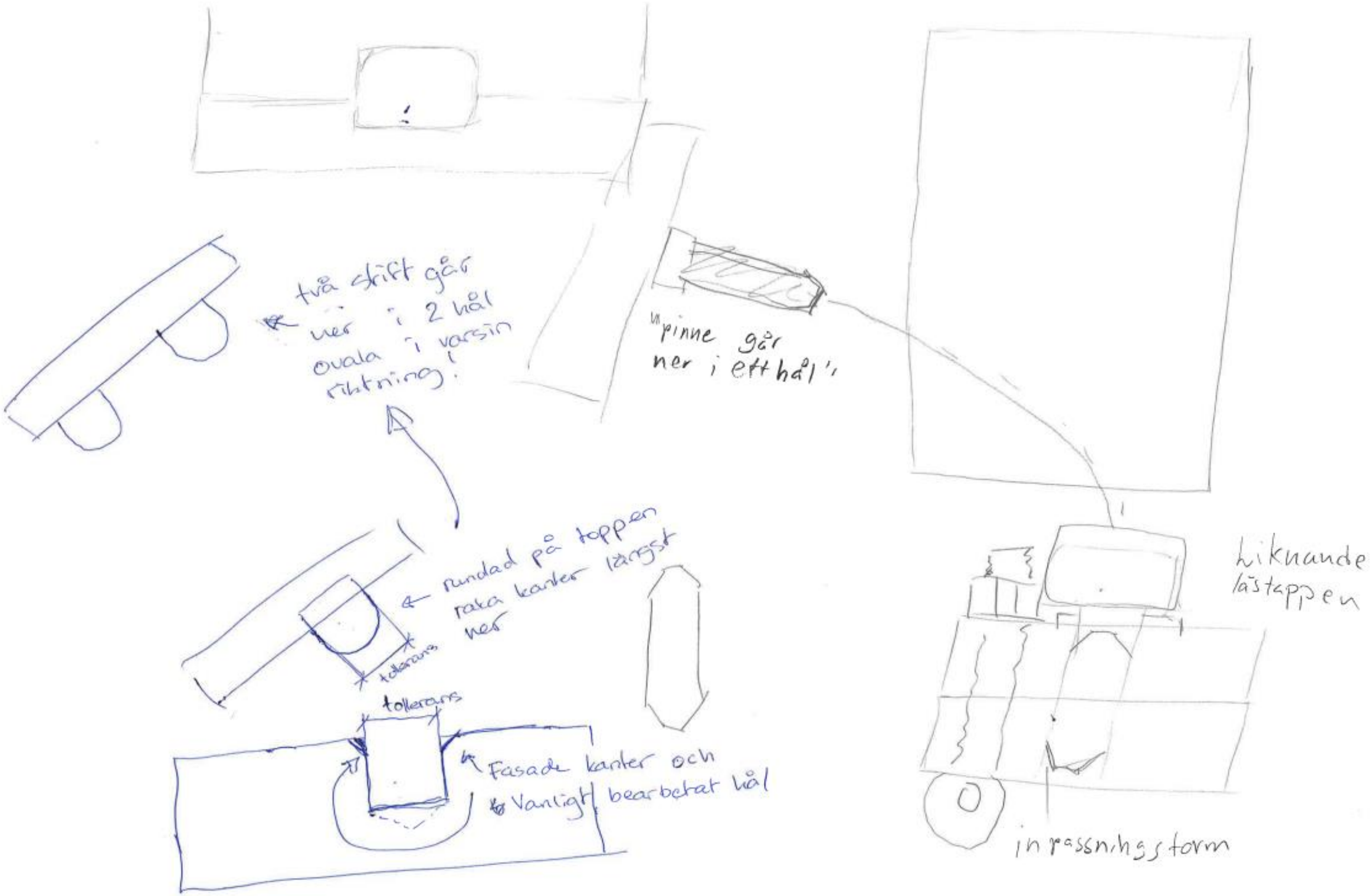
V-formade plattor
Löser bara en riktning

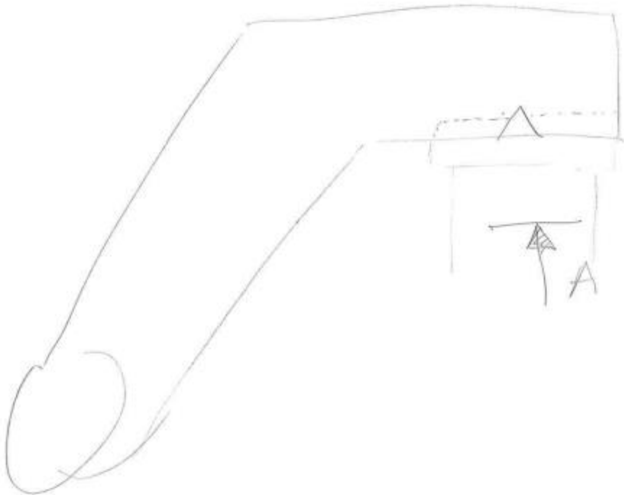


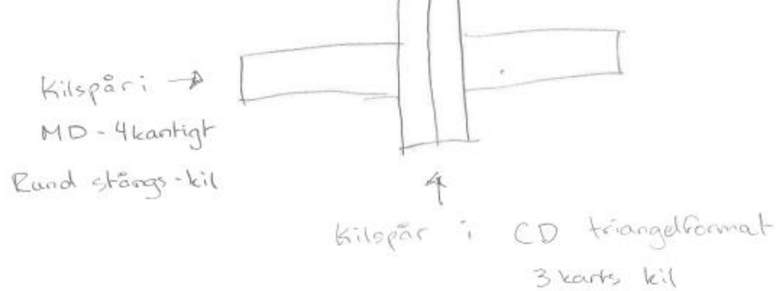
Bakkig överallt

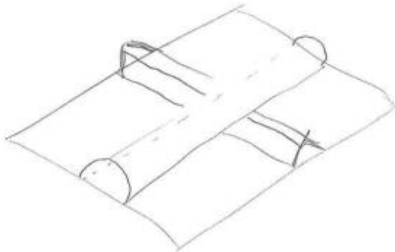


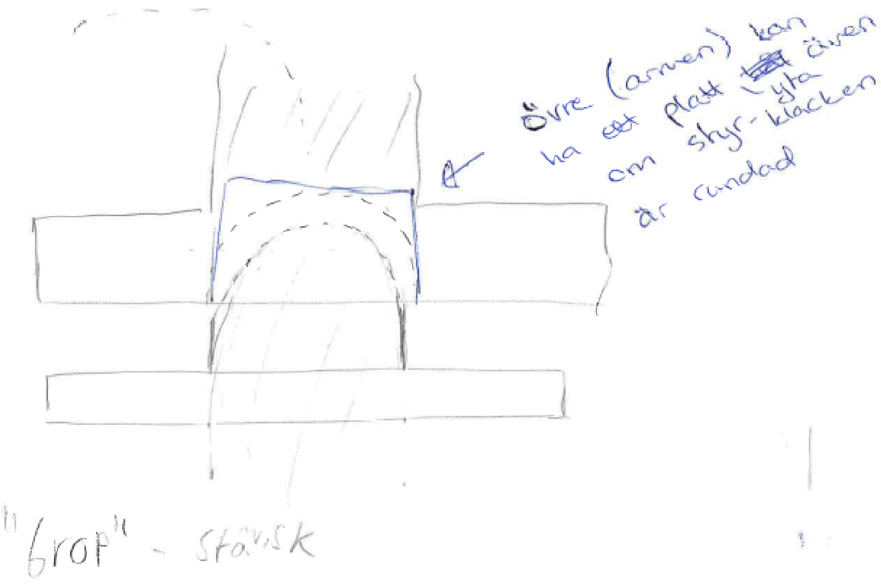
- Armen går ner först
kil "skuts upp" när ytorna redan
är ihop, i en linjär rörelse


två stift går ner i 2 hål ovala i varsin riktning!
"pinne går ner i ett hål"
rundad på toppen raka kanter längst ner
tollerans
tollerans
Fasade kanter och
Vanligt bearbetat hål
Liknande låstappen
inpassningsform


A

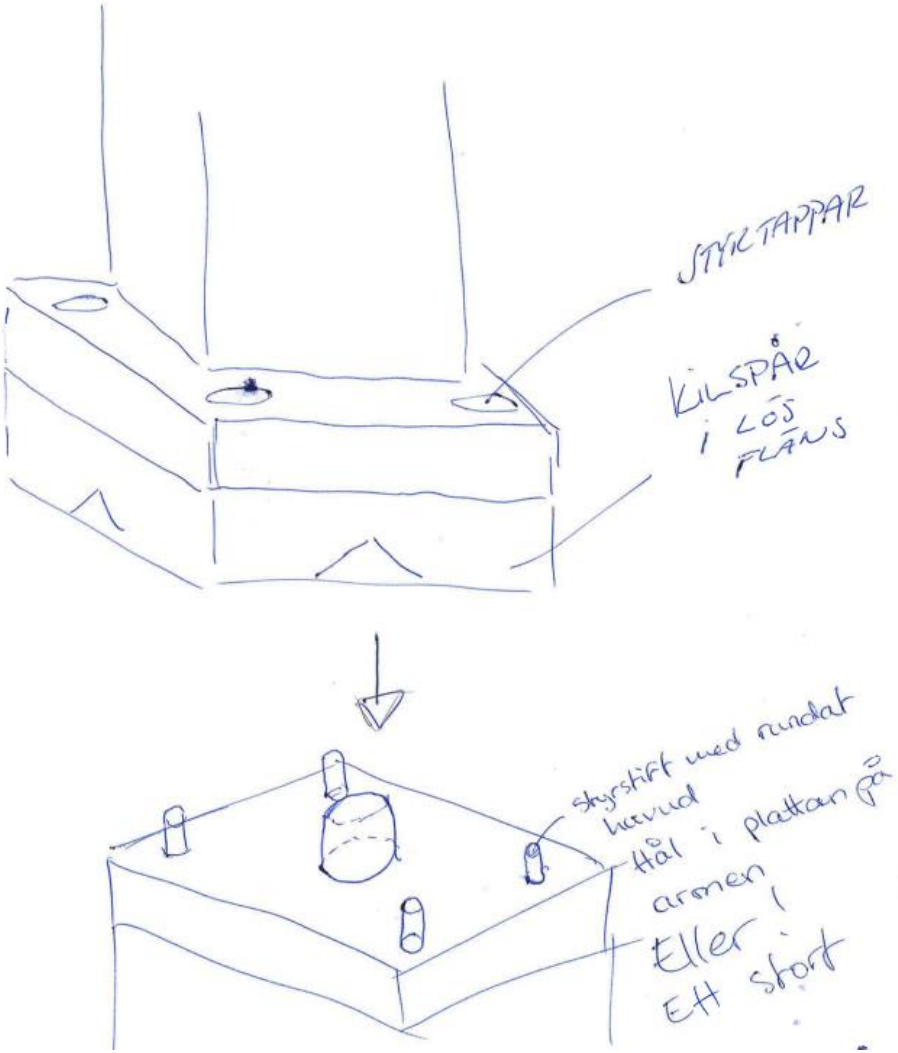

Kilspår i →
MD - 4kantigt
Rund stångs-kil
Kilspår i CD triangelformat
3 kants kil




Övre (armen) kan
ha platt yta även
om styr-klacken
är rundad
"Grop" - stävisk


4-kantigt kilspår, 4-kantig kil med
fasade kanter. (Symbeltlåsning på NTT)
dock behövs ± 0,5 mm i tolerans
problem med inpassning ?

IDE 1


STYRTAPPAR
KILSPÅR
i LÖS FLÄNS
Styrstift med rundat huvud
Hål i plattan på armen
Eller:
Ett stort