



FACULTY OF SCIENCE AND TECHNOLOGY

BACHELOR THESIS

Study programme / specialisation:
Mechanical engineering

The spring semester, 2022

Author: Nauris Svedaruskas, Magnus
Ulsbøl

Open / Confidential

Open access

Magnus Ulsbøl
Nauris Svedaruskas
(signature author)

Course coordinator:

Supervisor(s):
Faculty supervisor: Ove Kjetil Mikkelsen
External supervisor: Jakob Trydal

Thesis title: Design lightweight axis 3 arm

Credits (ECTS): 20

Keywords:

Pages: 41

+ appendix:

Stavanger, May 15th, 2022

Acknowledgment

We would like to express appreciation to our supervisor Ove Kjetil Mikkelsen, who helped us navigate through problems we experienced, and for his time he has offered for us during this last term while writing bachelor thesis.

Jakob Trydal, external supervisor from ABB Bryne. Thank you for your time during the online meetings, answering emails regarding this thesis and providing us with exceptional documents and information regarding IRB5500 robot.

Thanks to Adugna D. Akessa, who gave us the introduction for FEA program called ANSYS in the very beginning of this year, and who also offered help if needed.

Introduction

In the automotive industry, car painting usually involves humans. In the early days there were no painting robots, and everything was done by hand. However, with advancing technology throughout the years painting robots was introduced for automotive industries at around 1985. Industrial robots in general together with painting robots were created to keep people away from dangerous jobs. As the years went by, the increasing demand for car kept increasing heavily, and thus to increase productivity it was beneficial for those who had painting robots. Painting robots did not only increase productivity but also with the time, as robots was constantly evolving – the quality increased as well. The quality came from the precision of the robots, which is very needed while spraying macro layers, which contains paints on the vehicle's bodies.

Robots did not only increase productivity and quality, but it also allowed people to stay away from the painting rooms, which can represent a considerable danger because of VOCs released from paint. VOCs are emitted as gases, by certain solids or liquids, this includes a variety of chemicals, some of which may have adverse effects on health in the short- or long-term [1]

As there is always a push to increase in productivity, there is always a room for improvements. The most concerning thing in production is how much time it takes, and with that a problem occurs, which we as mechanical engineers will try to solve. Our task is to optimize the design of the axis 3 arm of IRB5500 robot, to reduce the weight of the design. Reducing the weight would allow the robot to move faster thus saving second in the painting process.

Together with the help of Jakob Trydal from ABB Bryne and Ove Kjetil Mikkelsen who is our external supervisor and faculty supervisor respectively, we will search for a way to improve on the current design.

Table of Contents

Acknowledgment	3
Introduction	4
Table of Contents	5
List of Figures	5
List of Tables.....	6
Acronyms	7
Summary	7
1. Main part of thesis	8
Task Description	8
Task Limitations.....	9
Early work	10
2. Manufacturing Processes	11
Metal casting processes	11
Sand casting.....	11
IP Protection Rating	13
3. Product Development Process	13
Planning.....	13
Concept Development	14
Concept Screening.....	15
System Level Design.....	16
Back housing	17
Gearbox	18
The arm	20
4. Results.....	22
Von Mises Stresses.....	24
Original Design “Von Mises Stresses”	24
“Concept A” “Von Mises Stresses”	26
Safety Factor	Feil! Bokmerke er ikke definert.
Original Design Safety Factors	28
“Concept A” Design Safety Factors	29
Original Design Displacement	31
“Concept A” Displacement	32
5. Discussion	32
Further Research	33
Arguments	35
Conclusion.....	36
References	37
6. Attachments	39

List of Figures

Figure 1.1 Example of IRB5500 robot.....	8
Figure 2.2 Sand Casting Process	12

Figure 3.1 Three main subsystems of the 3 axis robot arm.....	17
Figure 3.2 Original Design, internal surface.	18
Figure 3.3 Concept A, change in internal surface.	18
Figure 3.4 Gearbox housing before modification	19
Figure 3.5 Gearbox housing after modification	19
Figure 3.6 Top of the arm original design.....	20
Figure 3.7 Bottom of the arm original design	20
Figure 3.8 Top of the arm “Concept A”	21
Figure 3.9 Bottom of the arm “Concept A”	21
Figure 4. 1 Von Mises Stress for Original IRB5500 axis 3 arm design, top right.	24
Figure 4. 2 Von Mises Stress for Original IRB5500 axis 3 arm design, bottom right.	25
Figure 4. 3 Von Mises Stress for Original IRB5500 axis 3 arm design, top left.....	25
Figure 4. 4 “Concept A” of an IRB5500 axis 3 robot arm Von Mises Stress, top right.	26
Figure 4. 5 “Concept A” of an IRB5500 axis 3 robot arm Von Mises Stress, bottom right.....	26
Figure 4. 6 “Concept A” of an IRB5500 axis 3 robot arm Von Mises Stress, top left.	27
Figure 4. 7 Original design of an IRB5500 axis 3 robot arm safety factor, top right.	28
Figure 4. 8 Bottom of the original design IRB5500 axis 3 robot arm safety factor, bottom right.	29
Figure 4. 9 Other side of the original design IRB5500 axis 3 robot arm safety factor, top-left.	29
Figure 4. 10 “Concept A” design of an IRB5500 axis 3 robot arm safety factor, top right.	30
Figure 4. 11 “Concept A” design of an IRB5500 axis 3 robot arm safety factor, bottom right.	30
Figure 4. 12 “Concept A” design of an IRB5500 axis 3 robot arm safety factor, top left.	31
Figure 4. 13 Original design of IRB5500 axis 3 robot arm, displacement.	31
Figure 4. 14 “Concept A” design of IRB5500 axis 3 robot arm, displacement.	32
Figure 6.1 “Rubber Sealing” proposed design, top view.	39
Figure 6.2 “Rubber Sealing” proposed design, side view.....	39

List of Tables

Table 1. Rating scale	15
Table 2 Selection Matrix of Concepts	16

Acronyms

CAD Computer Aided Design

CNC Computer Numerical Control

FAE Finite Element Analysis

IP Ingress Protection Code

VOC Volatile Organic compounds

Summary

The goal of this thesis was to optimize the design of the IRB5500 axis 3 robot arm from ABB, to decrease weight of the robot. By decreasing the weight of the robot, the hope is to make it more productive as it could move faster. The CAD program Inventor Autodesk was used for modeling, and the inbuilt FEA tool in Autodesk Inventor was used to do stress analysis on both the original design and the concept designs that were made in the process of doing the thesis. After making multiple concept designs, two were settled on referred to as concept A and B, and they were compared using “Pugh concept selection”. Concept A showed greater promise and was taken for further comparison with the original robot arm design. Concept A experienced similar or less stress than the original design, while weighting somewhat less, about 3% less. It did however experience a greater maximum displacement, in the analysis concept A experienced about 2,6 millimeters of displacement at the maximum, while the unchanged design experienced about 2 millimeters of displacement at the maximum. As concept A included a hole through the bottom of the arm, it is necessary to do further research on how to stop potential pollutants like paint from entering the inside of the arm, for example by covering the hole with a rubber stopper. It is also necessary to do fatigue analysis on the concept to see if it is able to withstand the fatigue caused under the normal operation of the robot.

1. Main part of thesis

Task Description

The task is to optimize the design of the axis 3 arm of IRB5500 to reduce the weight of the robot arm, while remaining within certain limitations, that will be covered under Task limitations. The current design is made from sand casted aluminum. IRB5500 robot is used in painting various vehicle parts. To improve productivity, we were given the task to reduce the weight which would allow the robot arm to move faster, therefore saving time in the painting process. To change the weight of the arm, we decided that our approach is to make geometrical changes to lower the weight of the axis 3 arm, without decreasing the durability significantly. We also considered using a new material which could help decreasing the weight of the arm. With the help of today's technologies, we will be using CAD to make geometrical changes, and FEA simulation to find relevant information such as Von Mises stresses, displacement and strains.



Figure 1.1 Example of IRB5500 robot.[2]

Task Limitations

- The new design must fit the existing robot, wrist, and process equipment.
- Design optimization should be based on actual forces and torques.
- Both geometrical changes and different materials should be considered.
- The cost and manufacturability of the proposed design cannot exceed the costs of the original design.

Given the data from the external supervisor, the new design must withstand the forces and torques it is occurring during normal operations, and also it must tolerate the plastic deformation occurring in an emergency stop. The axis 3 arm must also fit the rest of the robot, its wrist and components which sets some constraints on the new design, as some parts of the current design cannot be changed. Cost and manufacturability are an important factor in today's competitive marketing world, therefore the cost of a possible new design and the manufacturability of the new design will be considered and evaluated while working on the project. We were given a price range for the manufacturing cost of the current design of the axis 3 arm housings, and the manufacturing cost of an alternative design should be similar to the current design. In order to have competitive, reliable and durable product in the market.

The current robot arm is made of sand-casting aluminum. The back end of the axis 3 arm must be under pressure and with an IP54 ingress protection rating, which prevents flammable gasses from entering the back end of the robot arm, which could cause self-ignition inside the body where the electronics and valves are located. It is very important that the new design meets those requirements and standards as the painting robot is operating under dangerous circumstances with gases from paint in a closed room, which can cause a fire or explosion.

Early work

Very important factor before doing anything is allocating resources and plan timing. Pre study report written in the beginning of the year helped us navigate through problems and be within time boundaries. The first thing was to decide how to approach the main thesis problem, to make a design that had a lower weight than the current design. The decision was to make changes on geometrical side of robot axis 3 arm and possibly find alternative material to the one is currently used (Aluminum A356.0-T6, Sand Cast), and

with the advice from our supervisor, the approach was to either start designing a new design for the robot arm, different than original one, or to design an exact copy of the original design that would be native to inventor, and thus potentially easier to make changes to, and thereafter make changes. Our first approach was to design exactly an exact copy of the axis 3 robot arm in the CAD program Inventor. To make the designing process faster, we asked our external supervisor Jakob from ABB Bryne, to provide us with detailed 2D drawings of the parts. Because we thought it would be easier to make changes later on if the part was made from scratch. Later on, run stress analysis of the assembled part, with the forces and torques applied on it in the ANSYS FEA program to identify the weak points on the robot axis 3 arm. While still in design process of robot arm, with uncertainty and lack of experience, we were not sure whether it would be possible to make changes on the surfaces because of constraints created in the process of making the design. Because of that, the decision was made before we finish designing parts, to make some geometrical changes on it and see whether it's an option. Quickly we understood that this approach would not work, since we it would be difficult to make changes to the 3d models because of the constraints from the design process.

The next approach was to run a stress simulation of the original assembly of the robot arm which Jakob from ABB Bryne has provided us with and look at the weak points. Unfortunately, since the student version of ANSYS had a node limit that was exceeded by our assembly. The analysis was done with a FEA program, which made a mesh of the model, by dividing it into triangles, called elements, the points where the elements meet are called nodes. Since the student version of ANSYS had a limit for how many nodes it could take we could not use this program. Since ANSYS could not be used, an alternative had to be found, we decided on using Autodesk Inventors inbuilt stress analysis program to continue the research.

2. Manufacturing Processes

In modern world, most manufacturing processes is done with automated and computer-controlled machinery, like CNC. The word manufacturing can be defined in two ways, technologically and economically. In this thesis we are not going very deep into the manufacturing processes, however a simple introduction might be necessary, to give the reader a functioning understanding of what it is. Technologically, manufacturing is the application of physical and chemical processes to modify the geometry, properties or appearance of starting material. Manufacturing involves various processes such as machinery, tooling, power, and labor. Economically on the other hand, is the transformation of materials into items of greater value, whether its processing or assembly operations [3].

Metal casting processes

Current IRB5500 robot axis 3 arm is made through a metal casting process, sand casting to be exact. Metal casting processes is divided into two categories based on what type of mold is used in the process. It can either be an expendable mold or a permanent mold. The difference between the two is that with the expendable molds, after the casting is complete, the mold is destroyed in order to remove the cast part. Since the molds are destroyed after every cast, a new mold must be made in order to perform another casting, hence production rates with expendable molds are often limited. In permanent mold casting processes, the mold is made from a durable material and can be used for casting repeatedly before it degrades [3] .

Sand casting

Sand casting is a metal casting process, which is the most widely used, and is one of the few processes that is used to cast metal that requires high melting temperatures, such as steels, nickels and titaniums. The molds are made from sand mixture, which typically is 90% sand, 7% clay and 3% water [book ref.], therefore the name Sand Casting. Molds made from sand is relatively cheap and sufficiently refractory. In order to be able to sand-cast a desired part, first a full-sized pattern of the part is created, usually from wood or metal. The pattern is usually slightly bigger, because of uneven cooling, which means that materials contract while they cool

down. There are various scaled rules used for different materials in order to achieve a casting that has a desired geometry. However, patterns only define the external shape of the cast part. If the desired part is with the internal surface, a core is necessary in order to achieve it. A core is a full scaled model of the interior surfaces and is inserted into the mold before pouring molten metal, so that it flows and solidifies between the mold cavity and the core to form the casting's both external and internal desired surfaces [3] .

In picture below, it is a simplified explanation of how a sand-casting process undergoes, starting from the top and following it to the bottom along arrows.

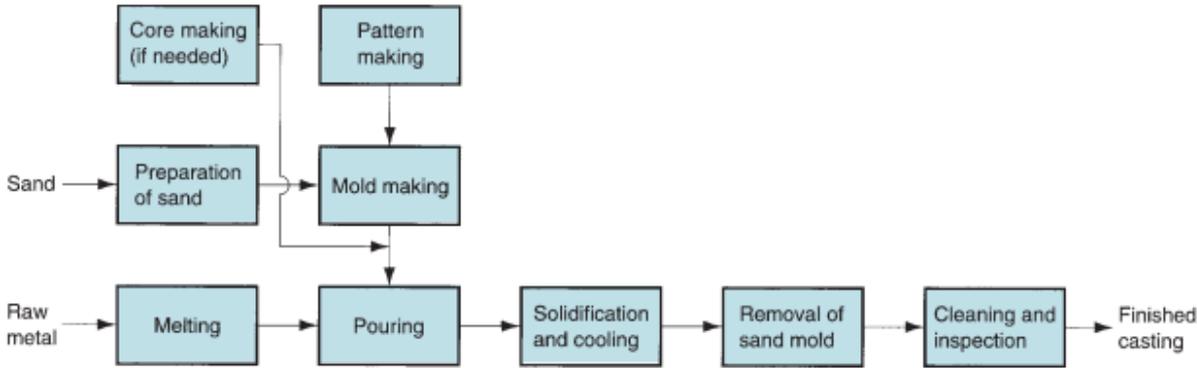


Figure 2.2 Sand Casting Process

IP Protection Rating

IP code or Ingress Protection Code is defined in IEC (International Electrotechnical Commission) 60529 which classifies and provides a guideline to the degree of protection provided by mechanical casings and electrical enclosures against intrusion, dust, accidental contact, and water. First digit stands for intrusion protection, whose rating scale goes from 0-6 and the second digit stands for moisture protection, with same rating 0-6. The higher the digit number is the better protection against intrusion and moisture it offers. IP54 would mean that a part or the object is protected against dust limited ingress, no harmful deposits, and is protected against water splashed from all directions, limited ingress permitted. In order to have such a rating, some of the surfaces have to be fine finished with gaskets in order to prevent intrusion and moisture as well as keep in under pressurized [4] [5] .

3. Product Development Process

Planning

This thesis bases on an incremental improvement to existing product, which means that it may only involve adding or modifying some features of the existing IRB5500 robot design in order to keep product line current and competitive [6]. Because this thesis is about modifying an existing product, there is a set of constraints which is already listed above. Will working to find a new potential design for the robot arm, which would have a lower weight than the current design. Some assumptions are made as considering these would be outside the scope of this thesis, those assumptions are as follows:

- Gears and shafts can withstand higher torques and forces
- The rest of the robot which is not a part of this thesis is able to withstand greater forces and torques.

Concept Development

In the concept development phase, a set of alternative IRB5500 design concepts will be presented and evaluated. Since the connection between the axis 3 arm and the rest of the robot, and the axis 3 arm wrist must remain the same in order to fit the existing robot, wrist and process equipment, alternative designs should be easier to visualize. New design concept will still be made of the same 3 main components:

- Back housing
- Gearbox housing
- The arm

Stress analysis has shown that the current design of robot axis 3 arm can withstand a much greater amounts of forces and torques than it is experiencing under normal operations before it experiences plastic deformation, which gives a little more space in terms of reducing weight. In the concept screening process, we will compare different alternatives for the new design, and evaluate the compared to each other and the original design to find the most promising one.

Concepts and changes

The original design is shown in figures 3-6 to 3-7

In concept A making a hole on the underside of the arm was attempted, the thought was that something, like a rubber stopper, would be used to stop paint and other pollutants would enter the arm, which could cause potential problems. Other changes were also made, including minor changes to the inside of Back housing, small parts of the outside of the gearbox were also cut out. And an additional hole was made on the top of the arm. Concept A is shown in figure 3-8 to 3-9

In concept B no holes were made through the walls of the arm. Instead, the walls have cuts made into them, making them thinner at point, at the thinnest the wall is 4 mm thick. Other wise the same changes are made to the gearbox and back housing, and a hole is also made at the top of the arm, but smaller than in concept A.

Concept Screening

Concept screening is based on a method developed by the late Stuart Pugh in the 1980s and is often called “Pugh concept selection”. As mentioned earlier, evaluation must be completed for alternative concepts to proceed further. To make evaluation easier, a selection matrix will be presented under this section in order to ease this process and see which of the concepts are the most promising ones and are worth investing time into. In the concept screening the current design of IRB5500 will be used for the reference, which will help to find a design concept that is better than the current one. To rate concepts, a scale from 1 to 5 will be used, and later combined with the items weight which will give a total weighted sum at the end of the evaluation. The concept which has the highest weighted sum at the end of the evaluation will be taken further for examination in this project.

The weight of an item refers to how important it is in considering the evaluation of the concept, a total of 5 criteria were chosen, which will help make the concept screening process easier. As this thesis is based on reducing the weight of the designs, the criteria “Design weight” was considered the most important and was thus weighted most. However other criteria than “Design Weight” were also used these were: manufacturability, durability, ease of maintainability and safety plays an important role as well.

Relative Performance	Rating
Much worse than reference	1
Worse than reference	2
Same as reference	3
Better than reference	4
Much better than reference	5

Table 1. Rating scale

Criteria	Concepts						
	Weight	Concept R (reference)		Concept A		Concept B	
		Rating	Weighted total	Rating	Weighted total	Rating	Weighted total
Manufacturability	15%	3	0.45	3	0.45	2	0.3
Durability	15%	3	0.45	4	0.6	3	0.45
Ease of maintainability	20%	3	0.6	4	0.8	3	0.6
Ease of weight	30%	3	0.9	5	1.5	4	1.2
Safety	20%	3	0.6	3	0.6	2	0.4
	Total Score		3		3.95		2.95
	Rank				1		2
	Continue?				Yes		No

Table 2 Selection Matrix of Concepts

By using concept screening method, from the Table 2, we came with a conclusion that Concept A is worth continuing putting work to, as it scored the most, and is showing promise. Concept B was evaluated to be worse than Concept A and will there for not be looked farther into. Further discussion and review of the design and evaluation will be found in the chapters Results and Discussion.

System Level Design

This section is dedicated to the components and subsystems that complete the whole axis 3 robot arm. Decomposition of the system into subsystems and components makes it easier to keep on track, as well as understanding and focusing onto specific areas of the robot. As mentioned earlier, the axis 3 robot arm can be thought of as a system, which can be divided into 3 subsystems, for all the components belonging to the three subsystems, see Figure 3.1

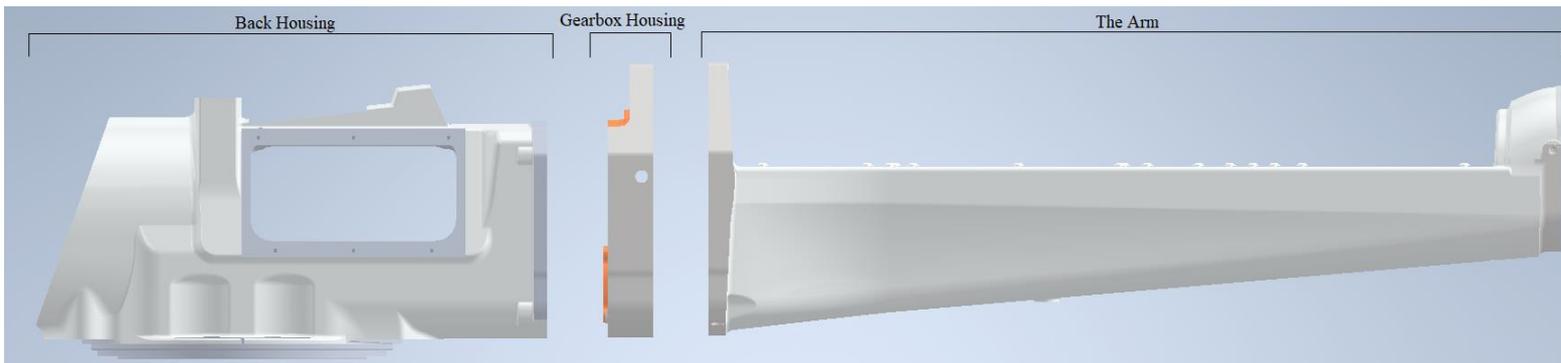


Figure 3.1 Three main subsystems of the 3 axis robot arm

Back housing

The back housing of the arm is a subsystem that contains components in it, which is fitted with various valves and control units. The back housing is a special subsystem because it has constraints that other the subsystems don't. Because of measuring signals with electrical pulses, it is possible for a fire or explosion to happen if gasses enter the back housing. A painting robot work in closed working areas, which contain explosive gasses, which are released from the paint. To ensure that the components are protected from a possible spark, which can cause an accident, it is set under pressure, and is at the same time isolated from the environment with gaskets. Isolation from environment is measured with an IP rating, and specifically for the back housing it must be a rating of at least IP54, which was explained above.

The changes on the back housing are minimal, and the only thing changed was on the internal surface of it, see the Figure 3.1 and Figure 3.2 for comparison below.

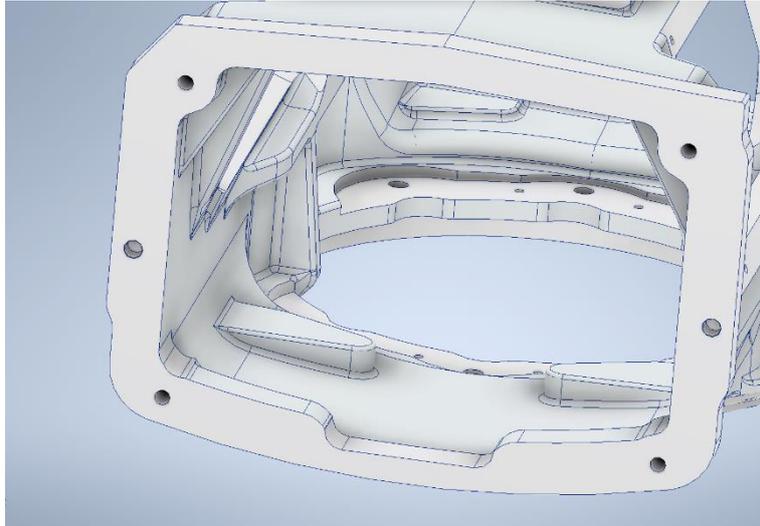


Figure 3.2 Original Design, internal surface.

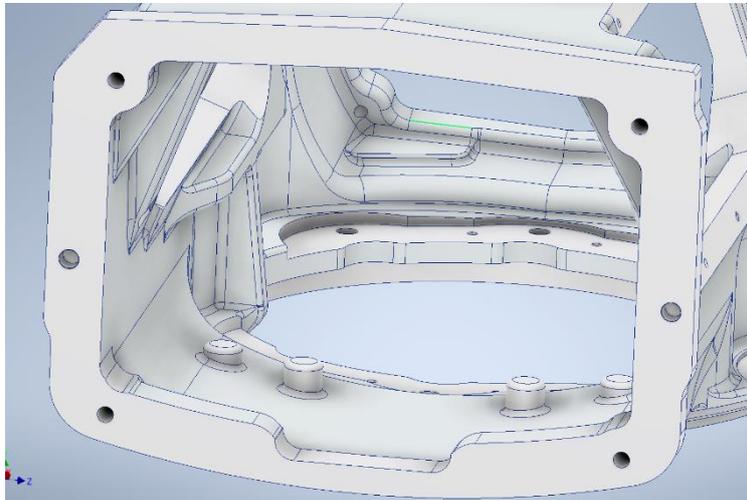


Figure 3.3 Concept A, change in internal surface.

Gearbox

Gearbox housing is the second subsystem that goes after the back-housing and is screwed together with each other. The main components that this subsystem consists of are the gears, and gear motors which rotate them. The gearbox housing is placed between back-housing and the arm itself. Because of how small the gearbox housing is, we have only slightly modified external surface. To notice a difference in design, take a look at the Figure 3.4 and Figure 3.5 top right corners.

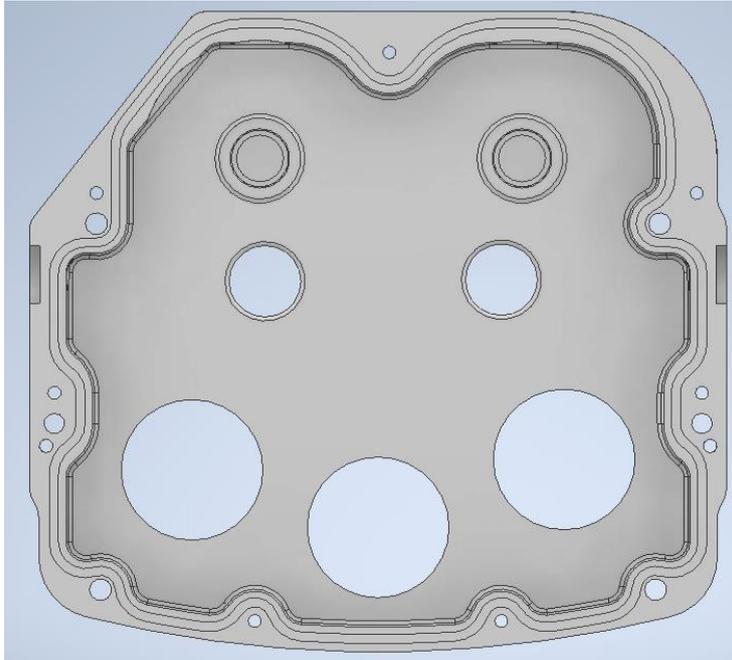


Figure 3.4 Gearbox housing before modification

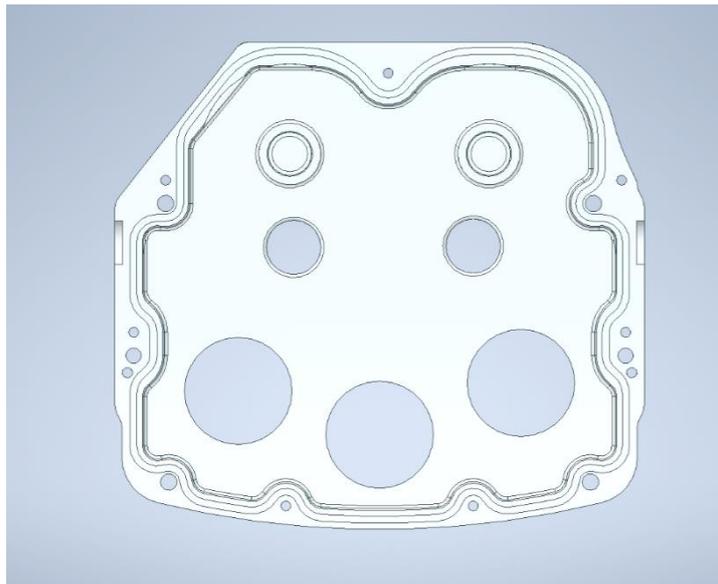


Figure 3.5 Gearbox housing after modification

The arm

Continuing, the last subsystem the arm. The arm consists of various pipelines through which paint is flowing in order to reach paint nozzles. Since the arm is hollow three shafts can go through it, these shafts are connected to the gearbox and goes along the arm reaching the wrist, which the shafts rotate. Because the arm has the greatest length of all three subsystems, it also absorbs most of the stress which appears during normal operations or if an emergency stop occurs. This subsystem allowed for the most reduction of weight. The changes in the arm saved more weight than the changes in the gearbox and the back housing combined, it also increases the safety factor in parts of the robot arm. In the following figure the changes can be seen. Figure 3.6, Figure 3.7 and Figure 3.8 and Figure 3.9. It also includes the same change as the gearbox housing has because they are screwed together, like show above in Figure 3.5

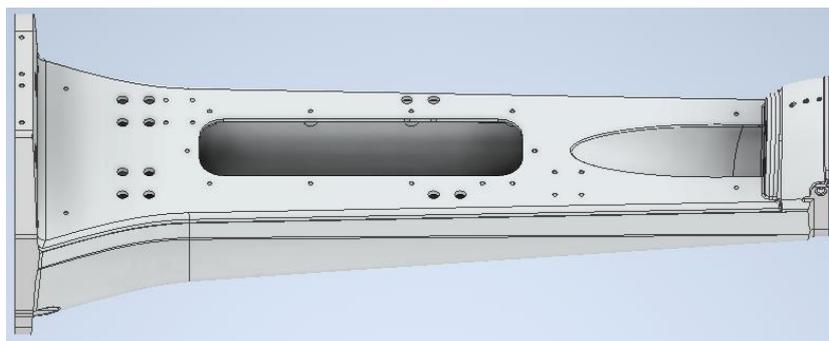


Figure 3.6 Top of the arm original design

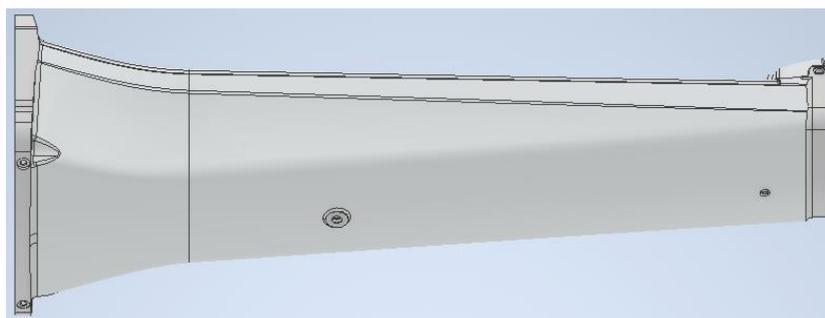


Figure 3.7 Bottom of the arm original design

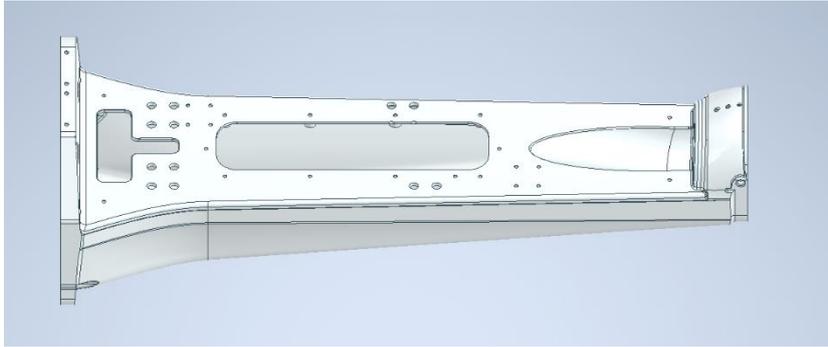


Figure 3.8 Top of the arm "Concept A"

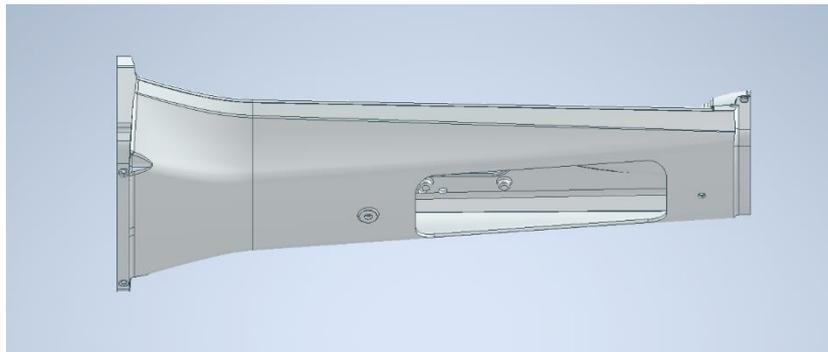


Figure 3.9 Bottom of the arm "Concept A"

4. Results

The thesis task was to optimize the design of the axis 3 arm of IRB5500 to reduce the weight of the robot arm. The approach was to make a new design of IRB5500 axis 3 arm which could withstand the actual forces, torques and at the same time reducing its weight. There were two concepts initially, and with the help of a concept screening process one of the designs was identified as being superior. Since Concept A had a greater weighted rating than Concept B, Concept A was deemed to be better. In the concept screening relevant criteria that seemed like they would help finding the superior concept were used. Because thesis main task is to reduce weight, the criteria “Design weight” had the most weight.

With the “Concept A” we managed to reduce weight by 2.9% or 1.35kg, from the original design of IRB5500 axis 3 arm, and at the same time reduce stresses in some of the areas of the robot, which is seen at the Von Mises Stress comparison in figures 4.1, between original design and the “Concept A”.

Our external supervisor provided sheet of data, which included forces and torques that robot is experiencing during normal operations and during emergency stops. In the simulation we used the ones that occurs at emergency stop, to be sure that “Concept A” can withstand those.

The cutouts that were made on “Concept A”, not only allowed for a lower weight for the robot, but it also caused less stress in the robot arm. In the Figure 4.1 for the original design, and Figure 4.3 for Concept A, the Von Mises Stresses of the two designs can be compared, and how they are distributed along the whole robot arm.

The total displacement at the tip of the arm where the wrist is connecting were slightly bigger in Concept A design. At the original design the total displacement was 2.079mm and in the Concept A it was 2.639mm, which is an increasement of 21.2%.

The safety factor of Concept A was also generally lower than in the original design, as seen in figures 4.7 to 4.10[7].

The safety factor shows the relationship between the stress a material experiences compared to the stress it can tolerate, since plastic deformation in aluminum, a ductile material, is being consider, the tolerable stress is the yield strength. So, in this case the safety factor is the yield strength divided by the experienced stress. The yield strength of the sand casted aluminum alloy used in this thesis is 165 MPa, thus a stress greater than 165 MPa would cause failure in form of plastic deformation.

Von Mises Stresses

Original Design “Von Mises Stresses”

Under this section, Von Mises Stresses will be presented for the original design of IRB5500 axis 3 robot arm from various angles.

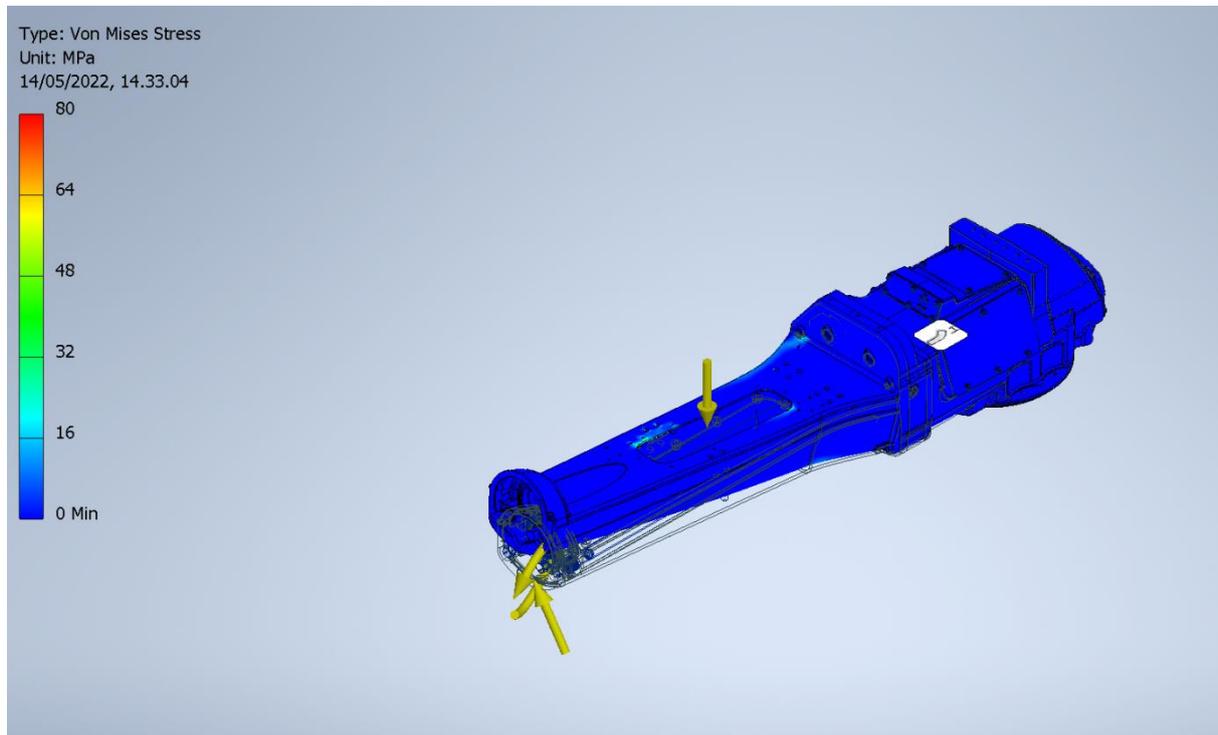


Figure 4. 1 Von Mises Stress for Original IRB5500 axis 3 arm design, top right.

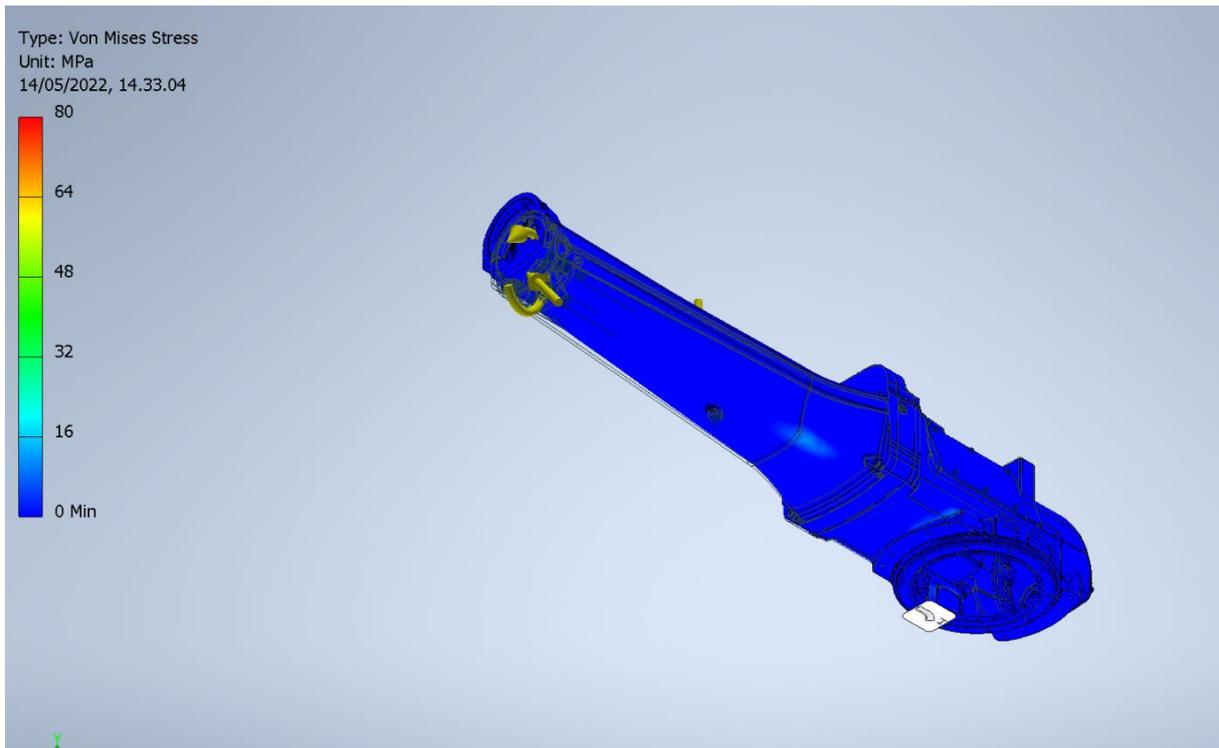


Figure 4. 2 Von Mises Stress for Original IRB5500 axis 3 arm design, bottom right.

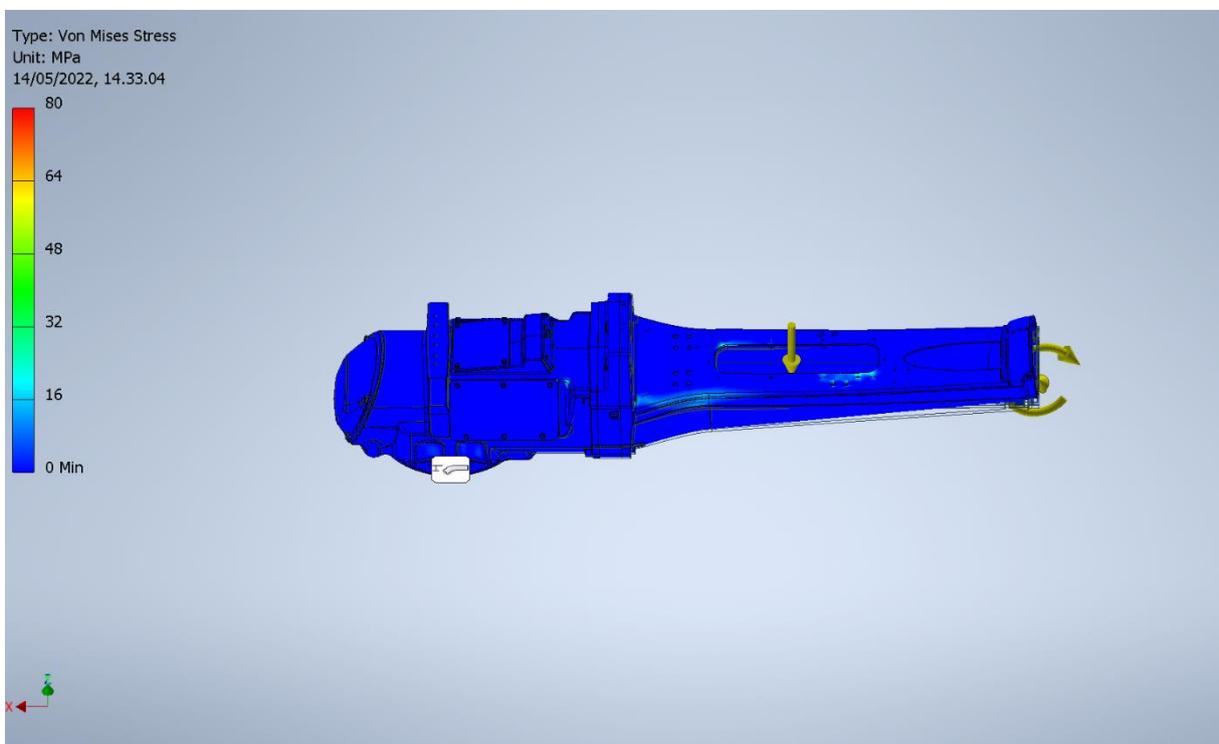


Figure 4. 3 Von Mises Stress for Original IRB5500 axis 3 arm design, top left.

“Concept A” “Von Mises Stresses”

Under this section, Von Mises Stresses will be presented for the “Concept A” design of IRB5500 axis 3 robot arm from various angles.

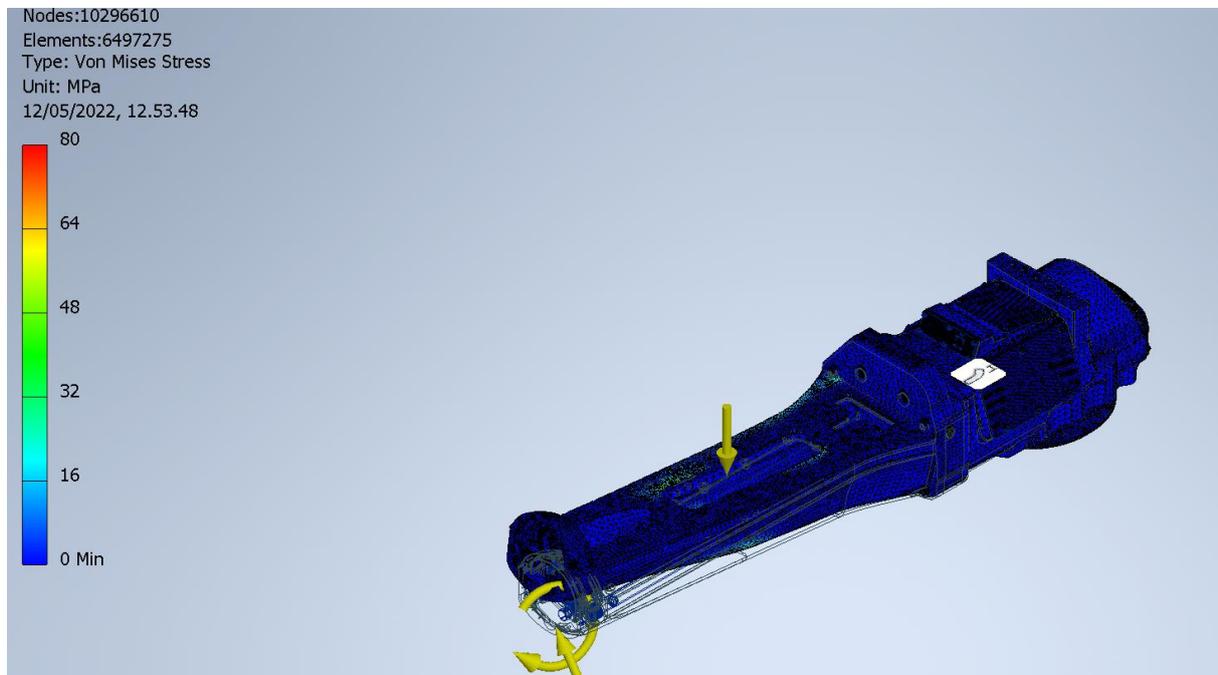


Figure 4. 4 “Concept A” of an IRB5500 axis 3 robot arm Von Mises Stress, top right.

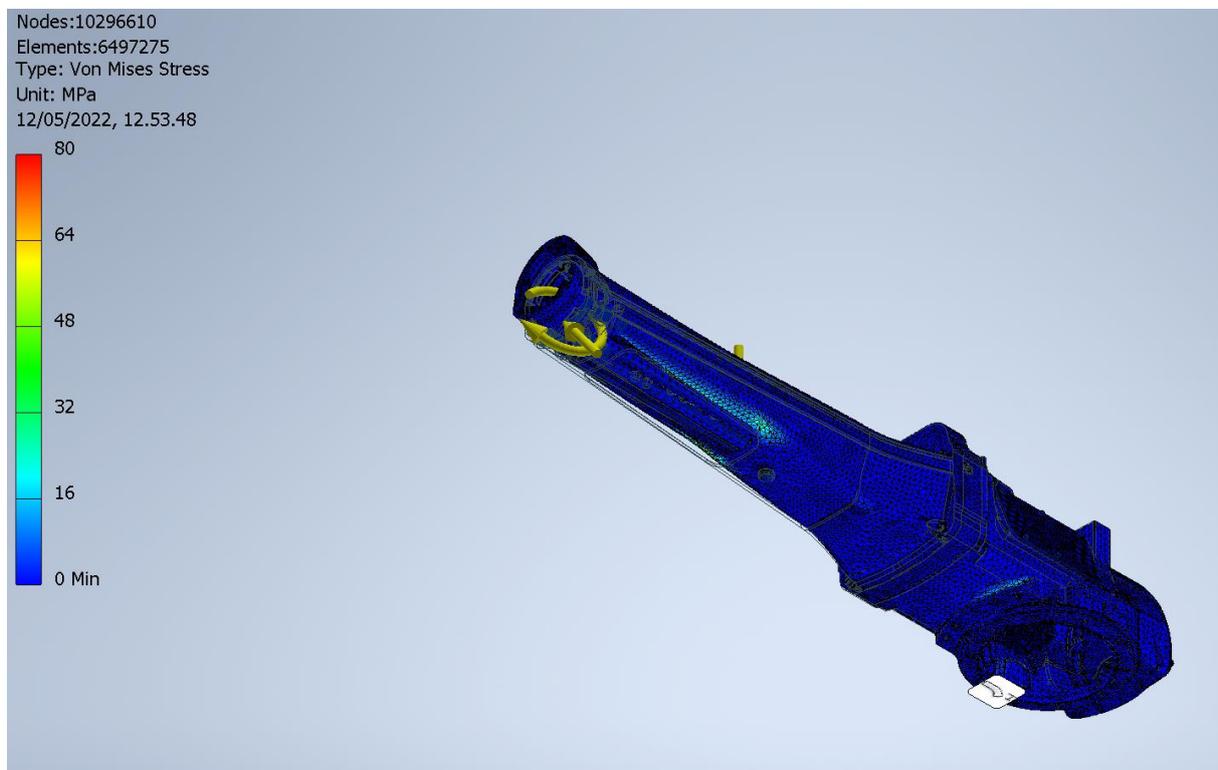


Figure 4. 5 “Concept A” of an IRB5500 axis 3 robot arm Von Mises Stress, bottom right.

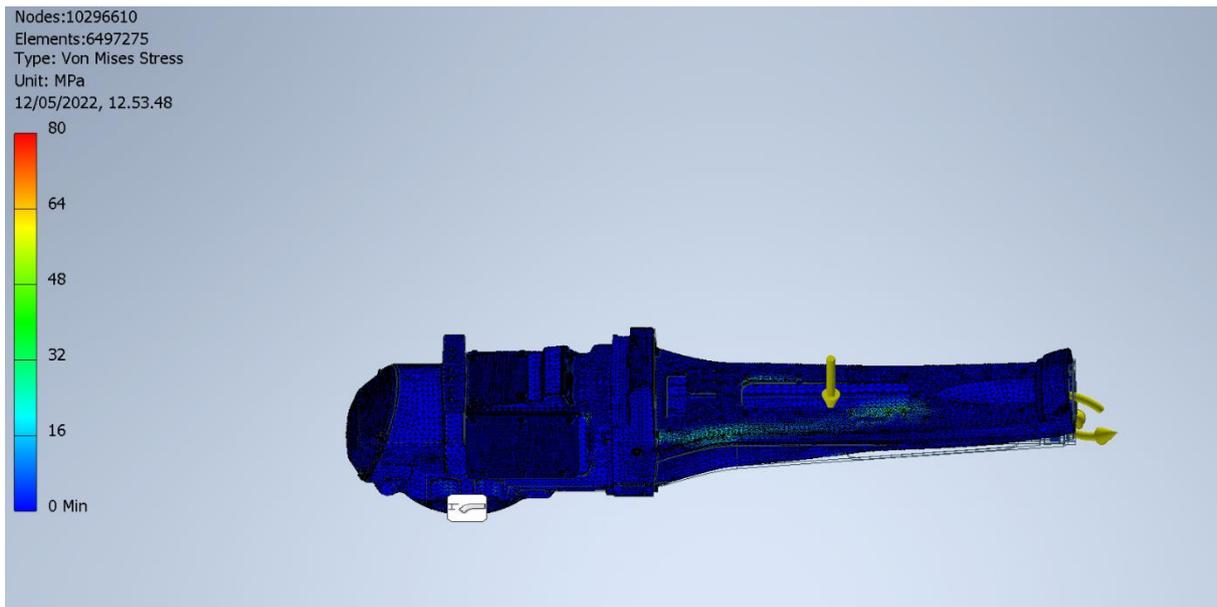


Figure 4. 6 "Concept A" of an IRB5500 axis 3 robot arm Von Mises Stress, top left.

Original Design Safety Factors

Under this section a graphical presentation of safety factor will be found for the whole arm, in its original design.

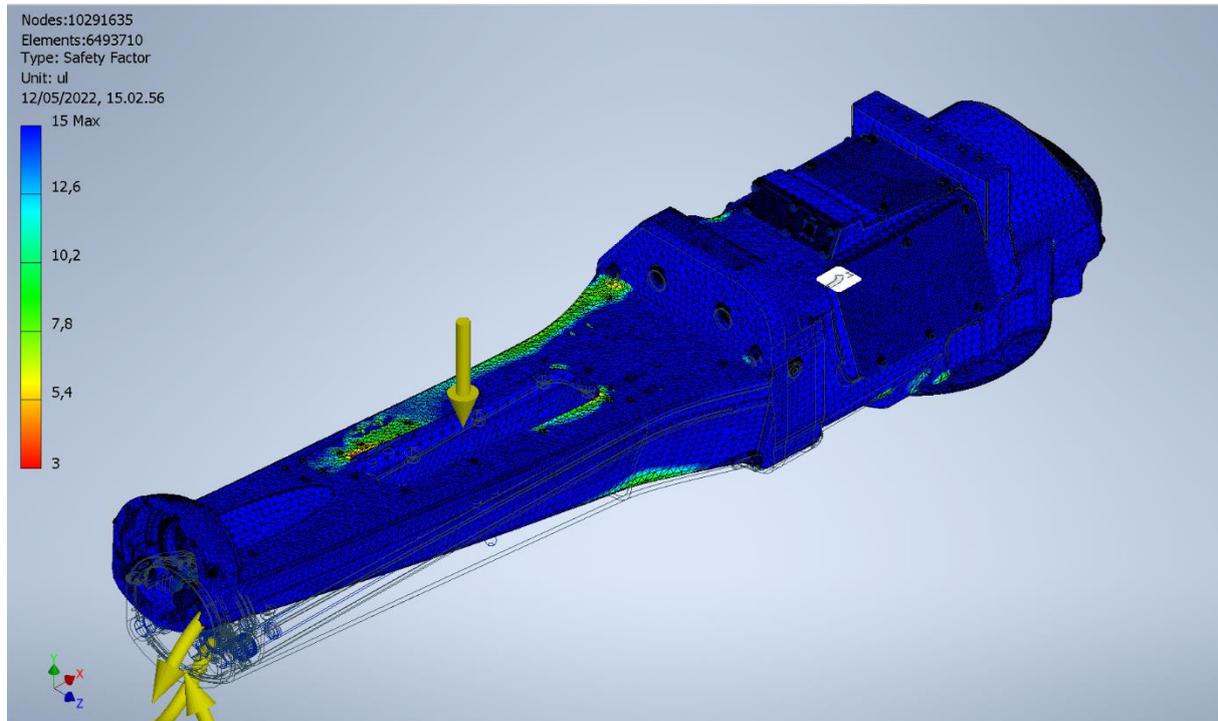


Figure 4. 7 Original design of an IRB5500 axis 3 robot arm safety factor, top right.

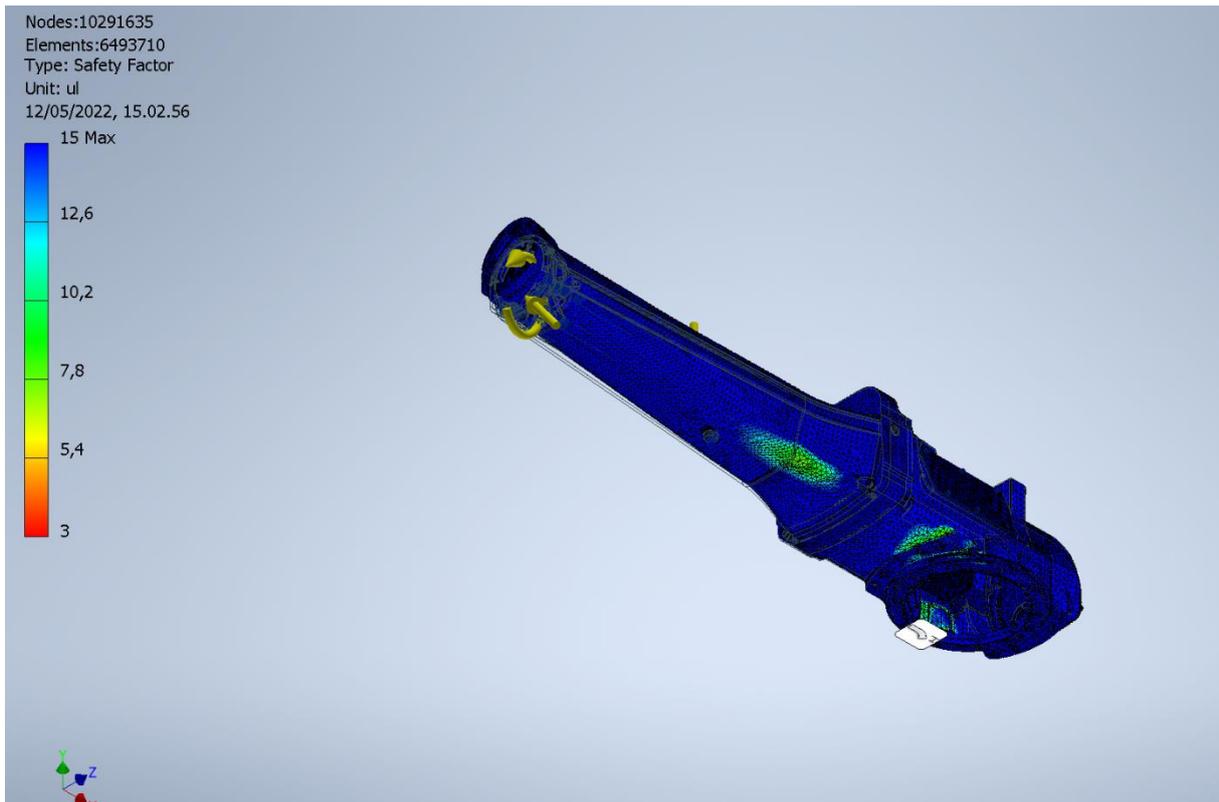


Figure 4. 8 Bottom of the original design IRB5500 axis 3 robot arm safety factor, bottom right.

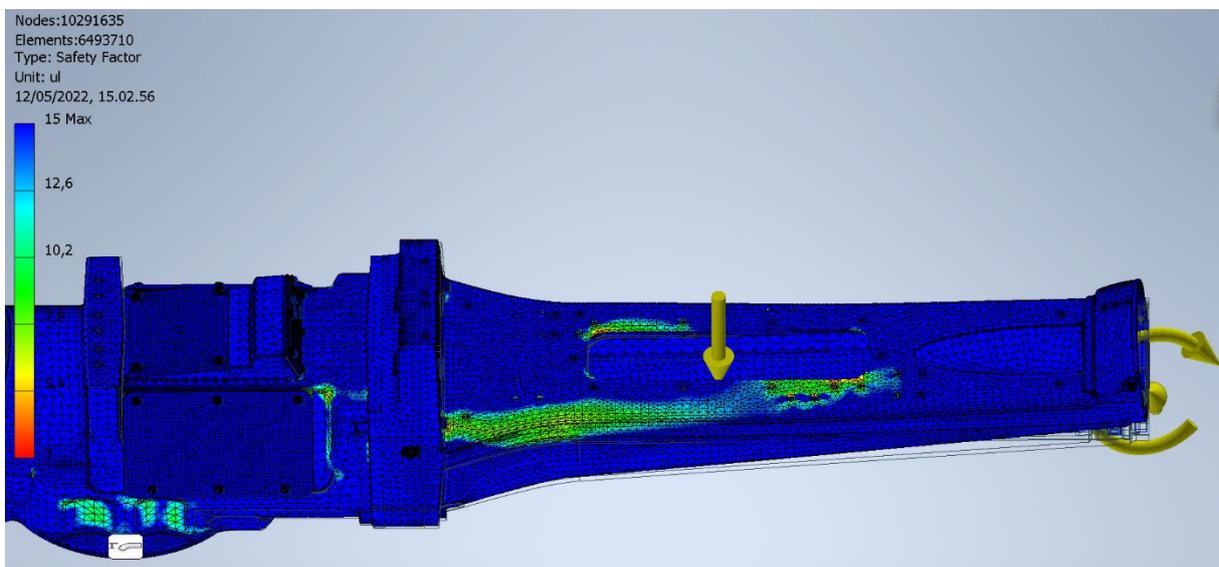


Figure 4. 9 Other side of the original design IRB5500 axis 3 robot arm safety factor, top-left.

“Concept A” Design Safety Factors

Under this section a graphical presentation of safety factor will be found for the whole arm for “Concept A” design.

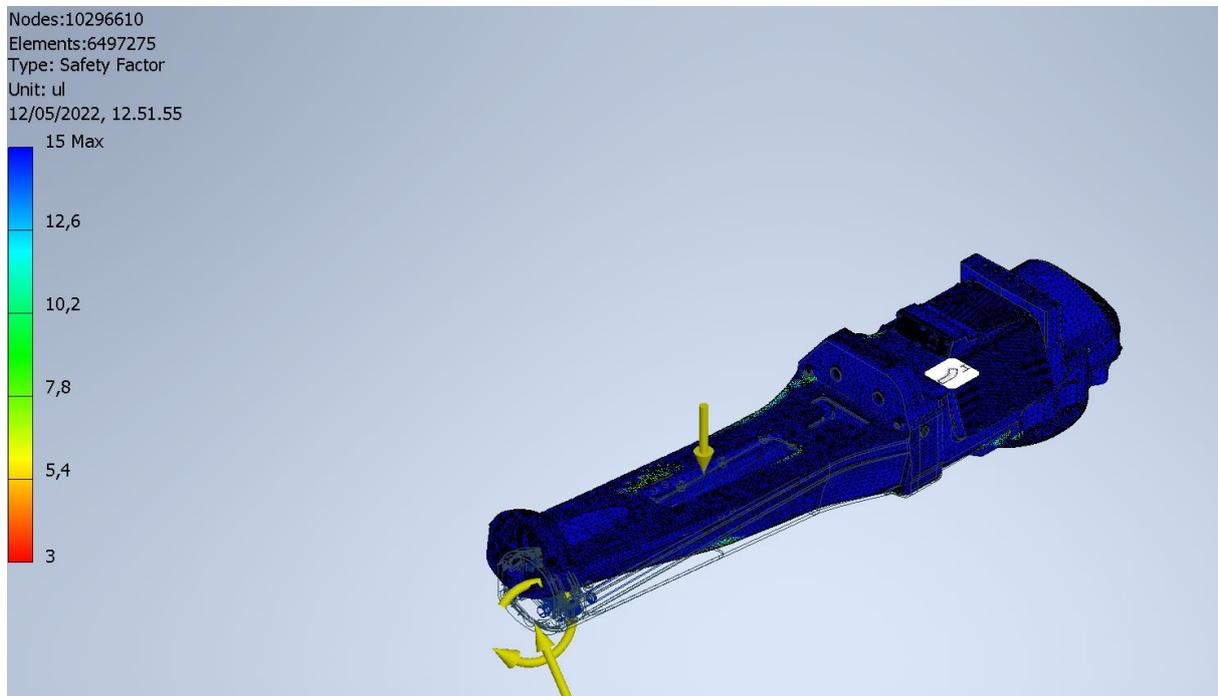


Figure 4. 10 “Concept A” design of an IRB5500 axis 3 robot arm safety factor, top right.

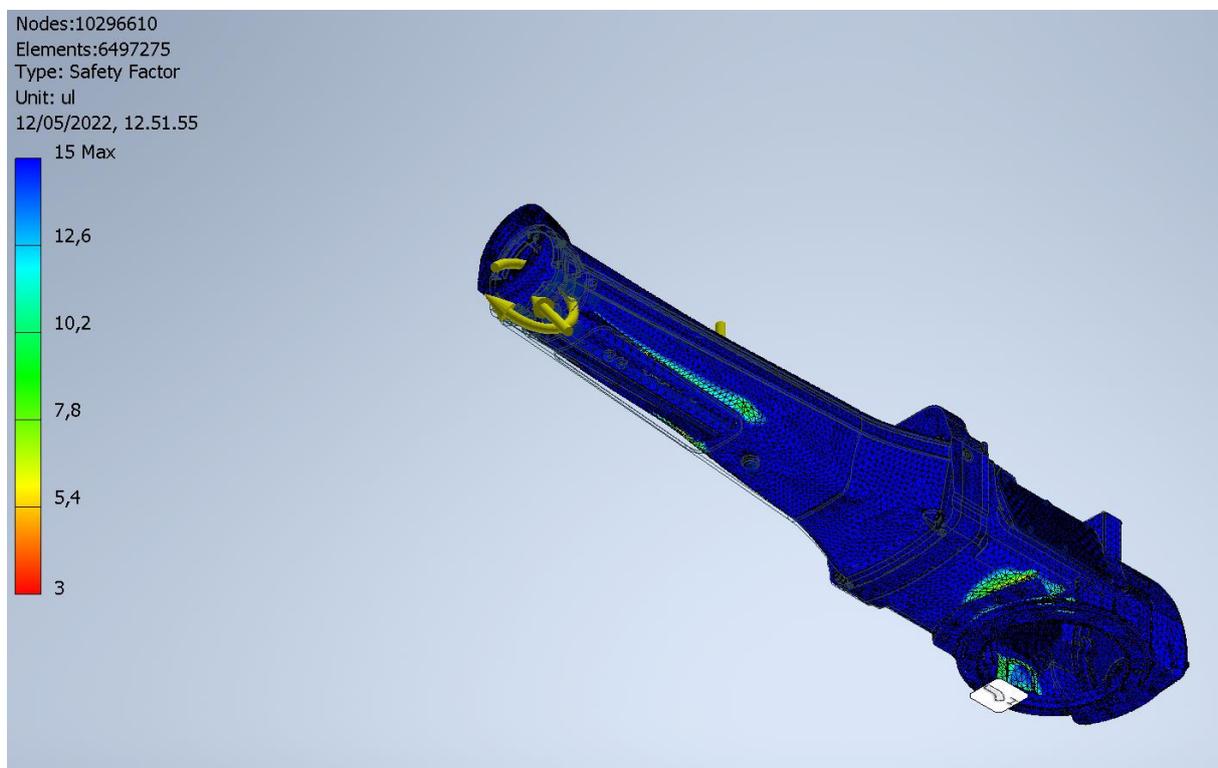


Figure 4. 11 “Concept A” design of an IRB5500 axis 3 robot arm safety factor, bottom right.

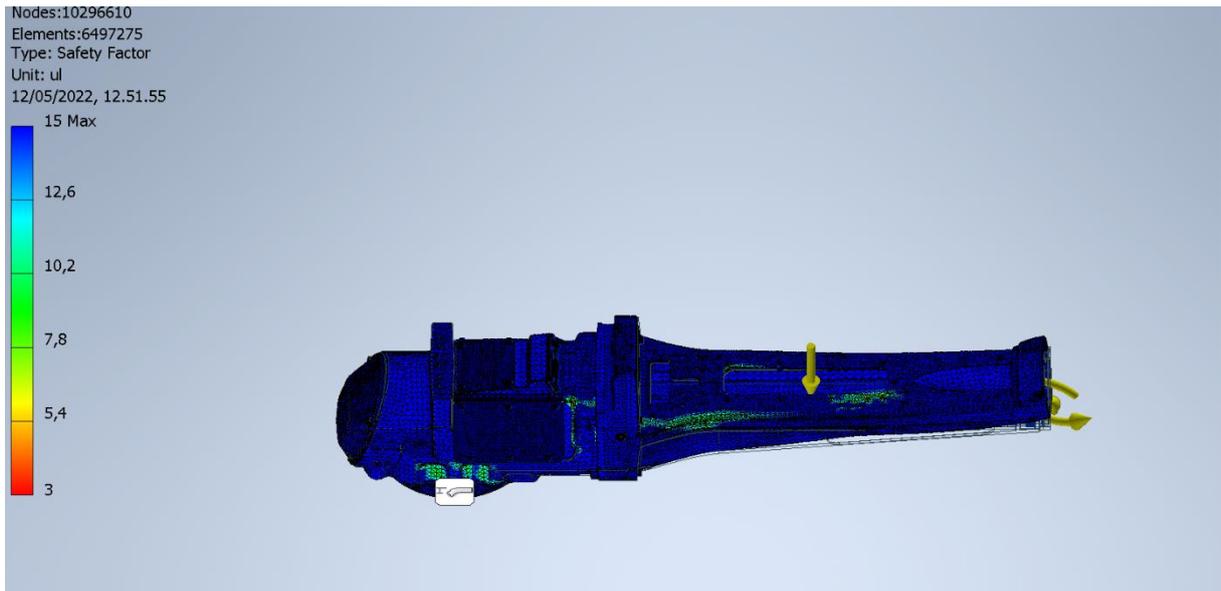


Figure 4. 12 "Concept A" design of an IRB5500 axis 3 robot arm safety factor, top left.

Original Design Displacement

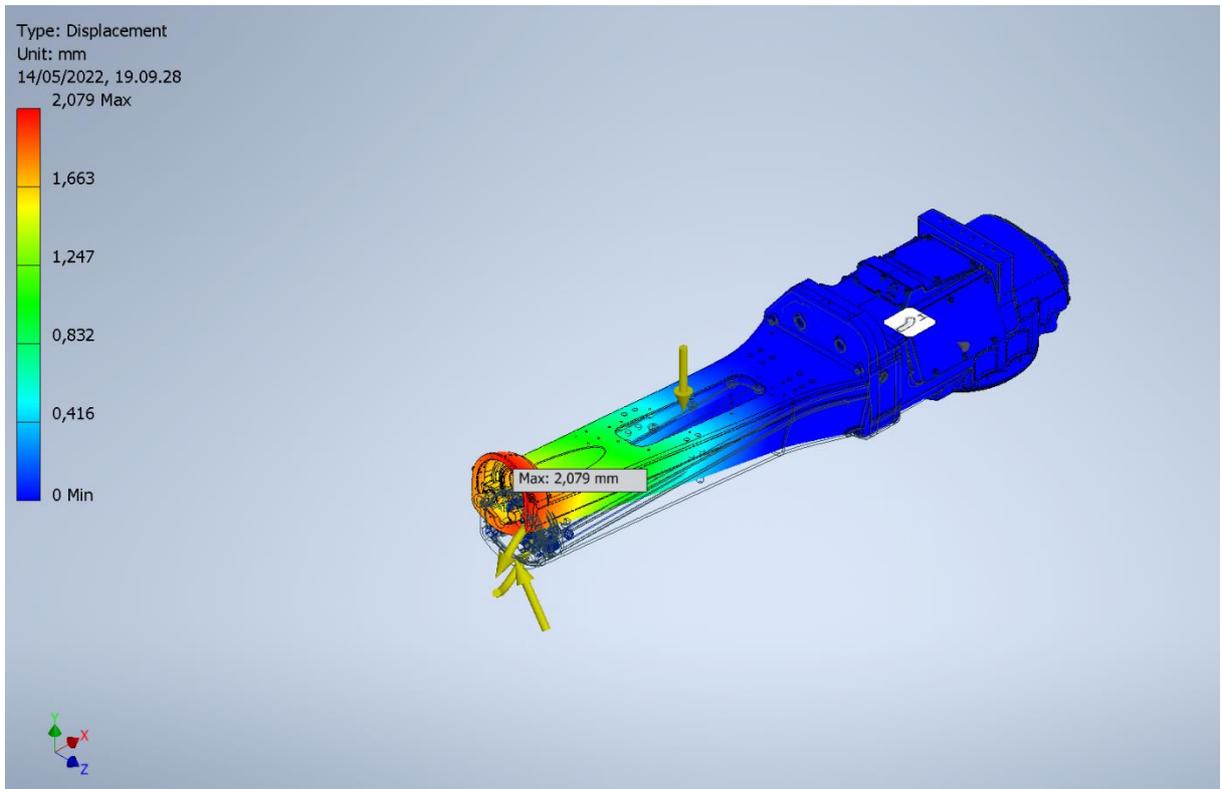


Figure 4. 13 Original design of IRB5500 axis 3 robot arm, displacement.

“Concept A” Displacement

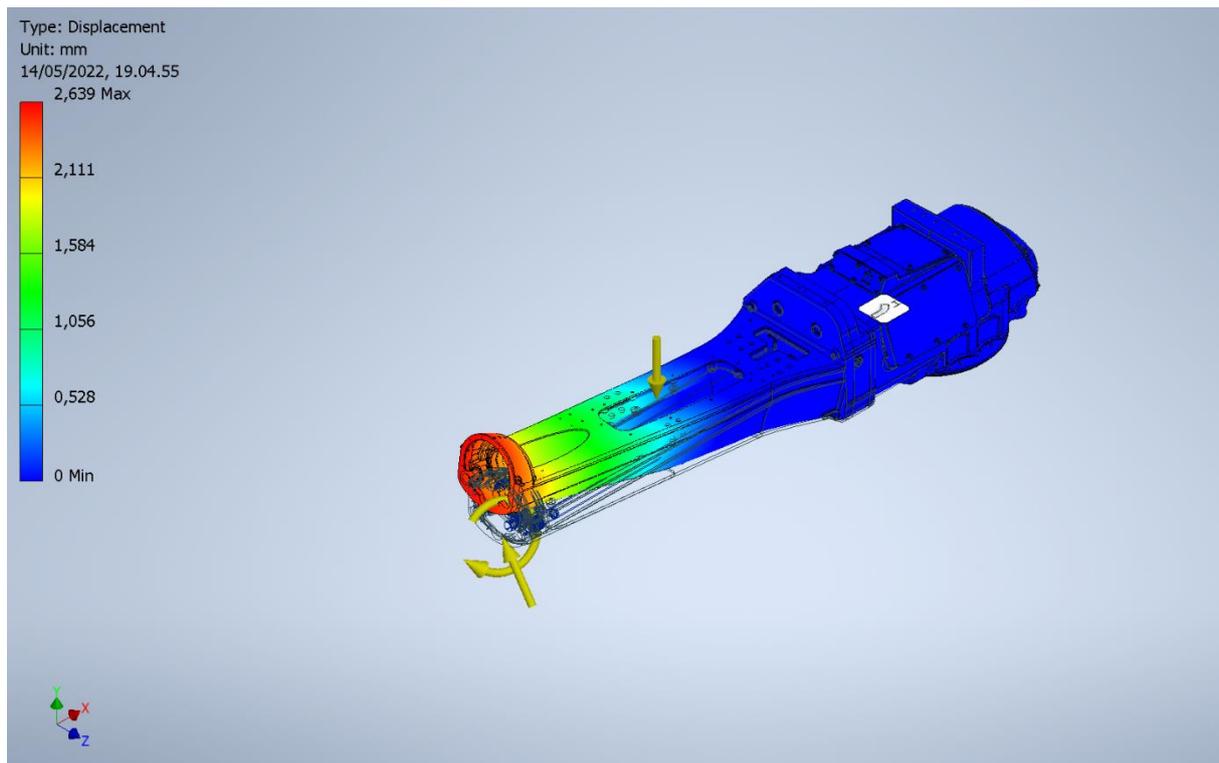


Figure 4. 14 “Concept A” design of IRB5500 axis 3 robot arm, displacement.

5. Discussion

The goal of this thesis was to reduce the weight of the robot IRB5500 axis 3 arm. Initially issues were had with recreating the original models, and an alternative method to make changes to the models had to be found, this was caused by inexperience. When a more practical approach to make changes was found the research could progress smoothly. A method for selecting between potential designs were written about in the book called “Product Design and Development”. This is a method that suits new engineers to get an idea of how new products are made. It’s a process that helps create new concepts for designs and also choose which of them is worth continuing research on. To choose between the concepts, the concept screening process is used to rate the concepts based on certain criteria and the importance of the criteria and thus by finding the weighted total rating of different concepts, the one with the highest rating proceeds into further development.

Using this method, a concept that had a reduce weight of 2.9% was found. And with the help of FEA analysis, it was showed that there was room for improvement, without designing a completely new design or changing material the robot was made of. The changes in the

geometry of the concept did not cause major increases in Von Mises Stress, the stress actually decreased in some places. Since the weight of the arm was decreased from removing part of the underside of the arm, this would in turn lower the strain caused by gravity, this could be an explanation for the lowering of stress in certain places. The maximum displacement however increased, with 0,56 mm when comparing the new concept with the original, Figure 4.13 and Figure 4.14 for comparison.

The distribution of both Von Mises Stress and Safety factor were more even in Concept A than in the original design. In the original design the safety factors was the lowest on the top on the subsystem 3, the arm, as seen in the Figure 4.7. Whereas in Concept A some places even have a higher safety factor than the original design, see Figure 4.10

When it comes to simulations, ANSYS could not be used because of limitations in the student version of the program, and had to work with the inbuilt stress analyzer in Autodesk Inventor. Autodesk inventors inbuilt stress analysis is limited and can for example not do fatigue analyses.

To avoid creating too large of a change in the production cost of the IRB 5500 axis 3 arm robot, the decision was made to not make too many major changes in the geometry of the original design. Any change in geometry is going to require the production of new molds, which require monetary investments before the production of the new design can start. One challenge with Concept A is the hole on the underside, since a hole could allow paint and dirt to enter the arm, it is necessary to have a countermeasure against this, this will be covered more in “Further Research” [8].

Further Research

Autocad Inventor program does not offer many options when it comes to simulations. Originally we were supposed to use ANSYS FEA, but because of student license restrictions as mentioned above, we weren't able to run fatigue analysis to the original design, nor the “Concept A”.

There are 3 methods that are used in fatigue analysis for calculating it. Strain life, stress life and linear elastic fracture mechanics. The tests are performed on the specimen by repeated cyclic loading like tension-tension, compression-tension or other various combinations. The outcome of these methods is by measuring reduction in stiffness and strength of material under repeated loading, the FEA program determines the total number of load cycles to failure [9], [10]. It is

important to run simulations like fatigue analysis, in order to design a product that is viable, robust and reliable.

The cutout that was made on “Concept A” design, bottom of the arm to be exact, must be covered. This opening leads directly inside the hollow arm where the shafts, bearings and other components are, which is a direct danger to the components, as well as for the environment and safety reasons in general. To ensure that no dirt, paint or potentially human fingers can reach it, we’ve made a rubber sealing which would close the opening into the hollow arm, and thus prevent from the things getting inside. This rubber sealing, see Figure 6.1 and Figure 6.2 in the attachments section, would be inserted so that the walls of the arm would sit between the sealings lips. Now, the other possible danger would be that the sealing could come loose and fell off, and thus this need further research whether it is actually a problem-solving technique to use the rubber sealing for the hole.

Arguments

Under section „Arguments“, pros and cons will be discussed briefly mostly about the cutout opening in the bottom of the hollow arm for “Concept A” design. Firstly, about cons:

- Intrusion of dirt, paint and other unwanted materials
- Safety reasons for the robot itself and environment.
- Shortened life

Intrusion of dirt, paint and other unwanted materials is unwanted inside the hollow arm among the components. Eventually it can lead to a shortened life of the product, and at the same time maintaining it more frequently. It can also form cracks, which can lead to major deformation of the robot itself, and it can damage the environment it is operating in, in other words make material damages together with economical. If the rubber sealing would in any way come loose and fall off, this can set a danger to people, for example if they for any reason would stick a finger inside, which is a health harm.

Pros on the other hand:

- Ease of maintenance
- Ease of weight

Having a sealed opening which can be removed easily could make maintenance of the robot easier. If for any reason a malfunction occurs in the hollow arm, it would be a lot easier to remove the rubber sealing for examination and inspection than dismantling the robot. It can also be easier to maintain the robot, in other words lubricating the bearings if that’s necessary, and inspecting that all the components and parts are without any signs of wear. The last thing is that the axis 3 arm would be lighter by 2.9%, which potentially could increase the productivity.

Conclusion

The goal of this thesis was to optimize the design of the IRB5500 3-axis robot arm to reduce the weight of the arm. We created two alternative concepts for the optimization of the design, called Concept A and B. through a concept screening process we found Concept A to show the greatest promise. Since we were not able to do fatigue analyses, there is a possibility that Concept A is not able to tolerate to fatigue stress caused by normal operations of the arm. It would also be necessary to make a design for a rubber stopper or another solution to stop paint buildup inside the arm since the new design is open.

Since the introduction of a new design would require the creation of new mold, it is questionable whether the new design is a worthwhile change, as it only represents a decrease of about 3% weight wise.

References

- [1] “What are volatile organic compounds (VOCs)?” <https://www.epa.gov/indoor-air-quality-iaq/what-are-volatile-organic-compounds-vocs> (accessed May 10, 2022).
- [2] ABB, “Detailed information for: IRB 5500.” <https://new.abb.com/products/3HNA016200-001?printPreview> (accessed Mar. 25, 2022).
- [3] M. P. Groover, *Fundamentals of Modern Manufacturing*, 4th ed.
- [4] “What is an IP Rating? Ingress Protection.” <https://rainfordsolutions.com/products/ingress-protection-ip-rated-enclosures/ip-enclosure-ratings-standards-explained/> (accessed May 08, 2022).
- [5] “IP Code.” https://en.wikipedia.org/wiki/IP_Code (accessed May 01, 2022).
- [6] K. T. Ulrich and S. D. Eppinger, *Product Design and Development*, Fifth Edition.
- [7] “Organizing Academic Research Papers: 7. The Results.” <https://library.sacredheart.edu/c.php?g=29803&p=185931> (accessed Apr. 26, 2022).
- [8] “Organizing Academic Research Papers: 8. The Discussion.” <https://library.sacredheart.edu/c.php?g=29803&p=185933> (accessed May 10, 2022).
- [9] R. G. Budynas and J. Keith Nisbett, *Shigley’s Mechanical Engineering Design*, 11th Edition.
- [10] “Mechanical Fatigue Test.” <https://www.sciencedirect.com/topics/engineering/mechanical-fatigue-test> (accessed May 09, 2022).

1. <https://rainfordsolutions.com/products/ingress-protection-ip-rated-enclosures/ip-enclosure-ratings-standards-explained/> (IP explanation)
2. https://en.wikipedia.org/wiki/IP_Code (IP explanation)
3. https://en.wikipedia.org/wiki/Sand_casting (sand casting process, picture)
4. Product Design and Development 5th edition
5. <https://www.fcusd.org/cms/lib/CA01001934/Centricity/Domain/4529/Fundamentals%20of%20Modern%20Manufacturing%20Materials%20Processes%20and%20Systems%204th%20Edition.pdf>
6. <https://www.epa.gov/indoor-air-quality-iaq/what-are-volatile-organic-compounds-vocs>
7. https://en.wikipedia.org/wiki/Paint_robot
8. <https://new.abb.com/products/3HNA016200-001?printPreview> picture of irb5500
9. <https://www.fcusd.org/cms/lib/CA01001934/Centricity/Domain/4529/Fundamentals%20of%20Modern%20Manufacturing%20Materials%20Processes%20and%20Systems%204th%20Edition.pdf> fundamentals of modern manufacturing book
10. <https://library.sacredheart.edu/c.php?g=29803&p=185931>
11. <https://library.sacredheart.edu/c.php?g=29803&p=185933>
12. <https://www.sciencedirect.com/topics/engineering/mechanical-fatigue-test> further research.

6. Attachments

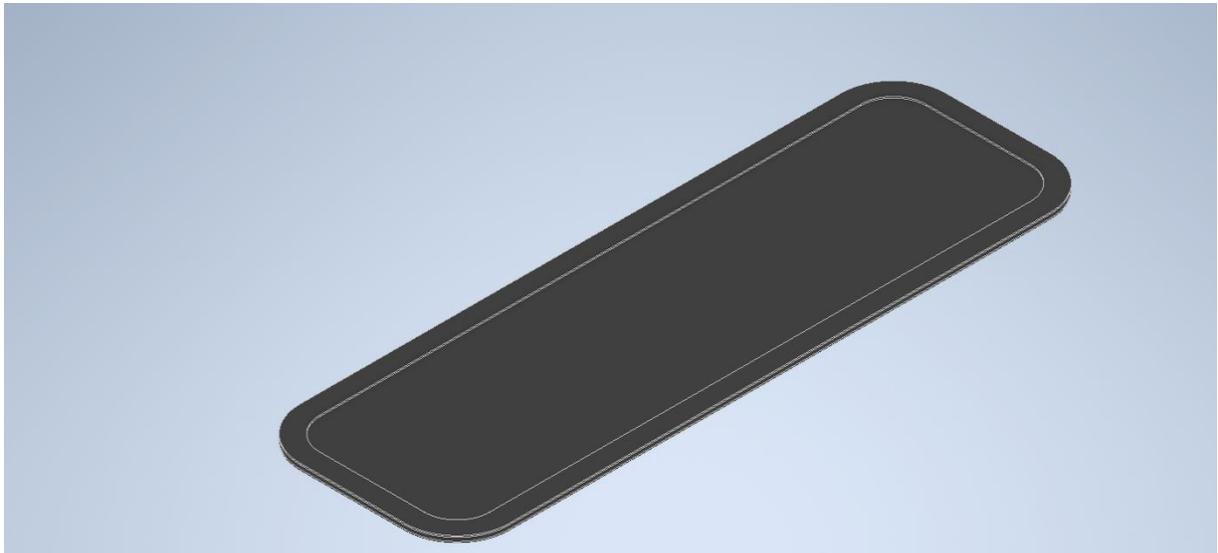


Figure 6.1 "Rubber Sealing" proposed design, top view.

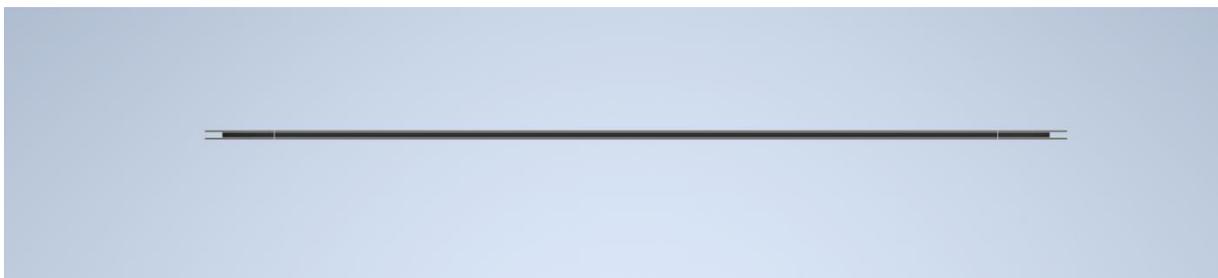


Figure 6.2 "Rubber Sealing" proposed design, side view.

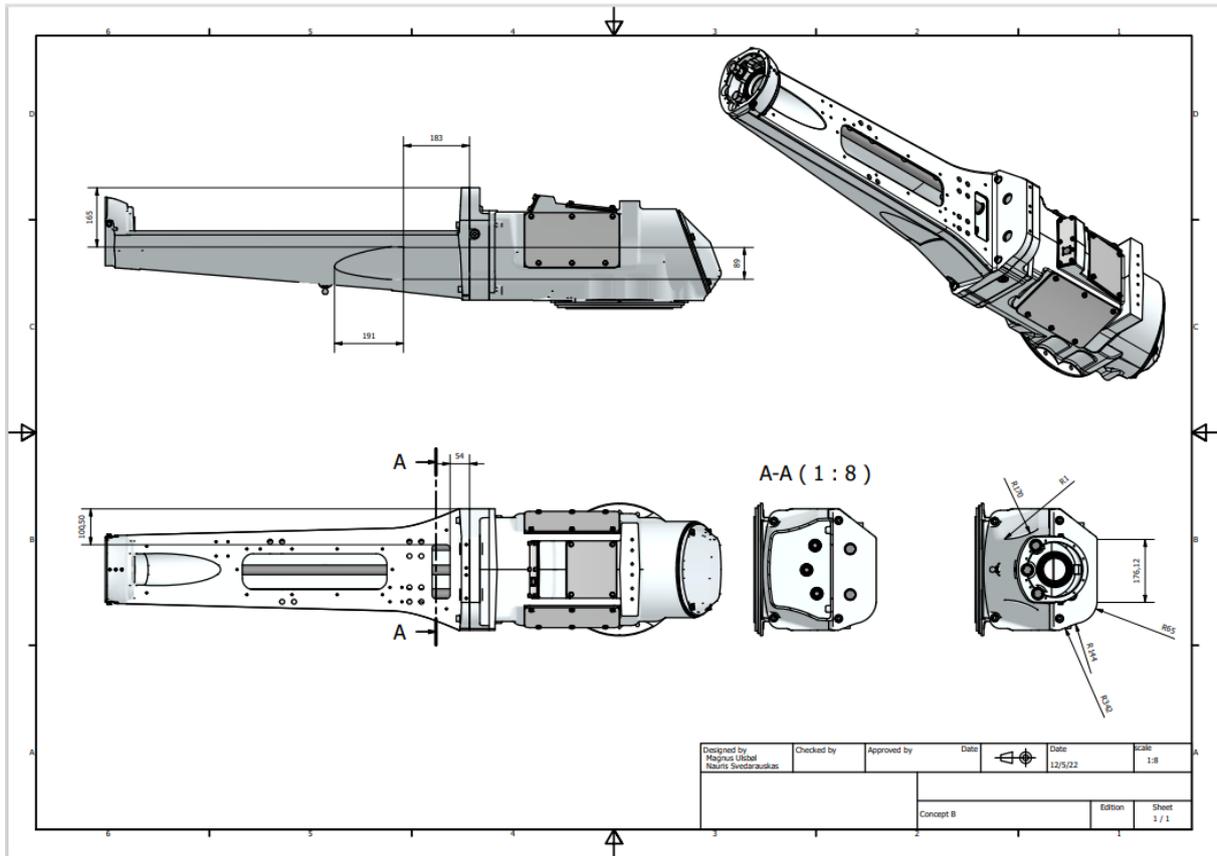


Figure 6.3 2D Concept B design drawings.

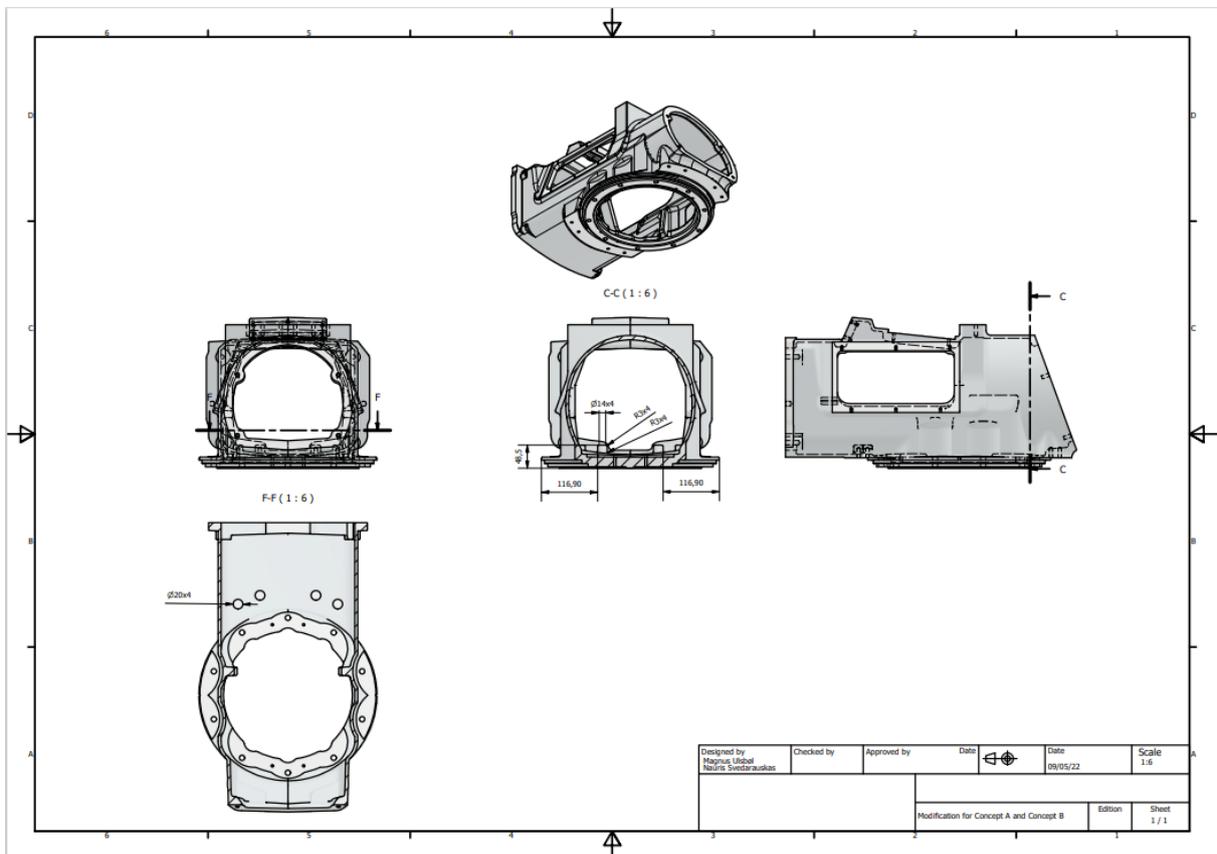


Figure 6.4 2D Concept A and B design drawing.

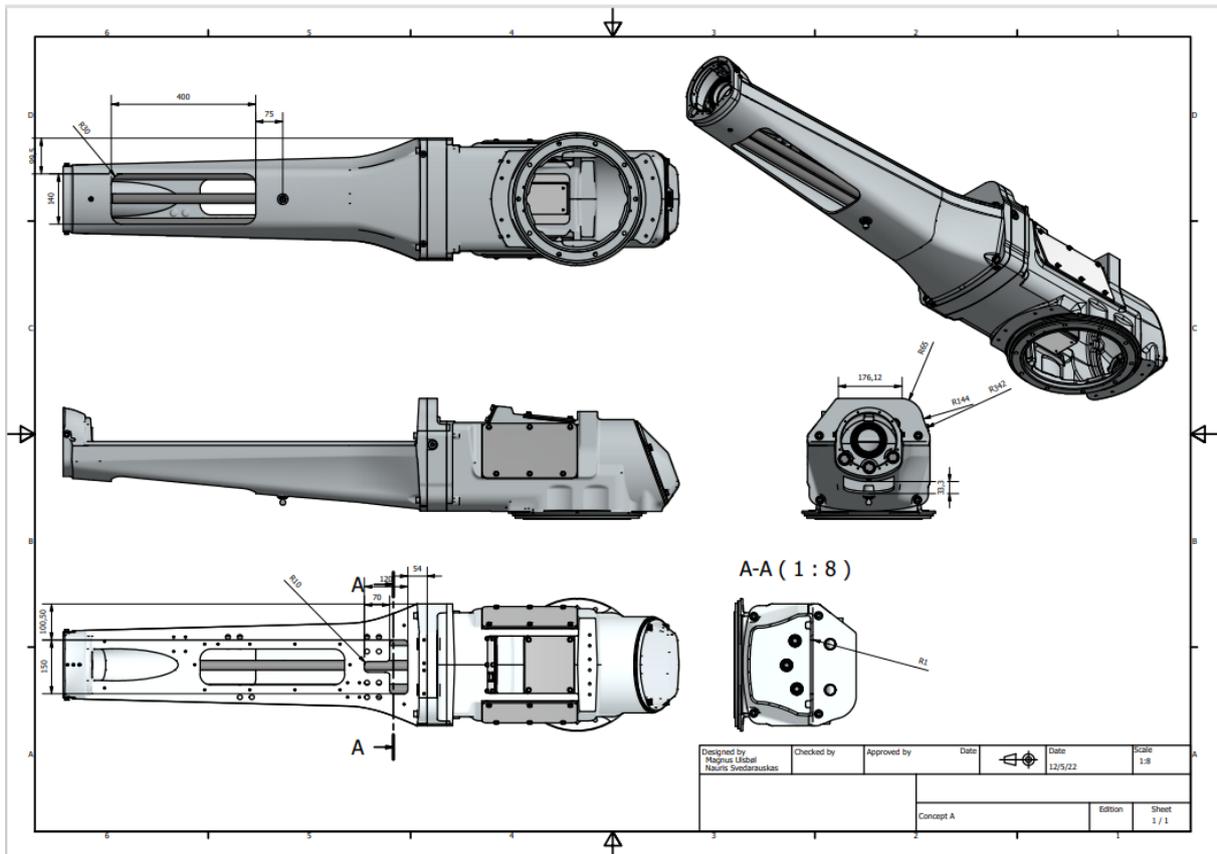


Figure 6.5 2D Concept A design drawing.