Subsea Secondary Release Tool

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Preface

The bachelor thesis is written for the Department of Mechanical Engineering and Maritime Studies at Western Norway University of Applied Sciences (HVL). The project is the final part of the study program for the bachelor's degree in General Mechanical Engineering at Bergen campus.

The topic is given by OneSubsea, the department of subsea stations. The thesis was selected for its scope and relevance, requiring 3D modeling, the Finite Element Method (FEM), and theory from our course of study. The bachelor group has learned about designing an innovative product, focusing on different tools to achieve an open and curious mindset for finding good solutions.

We would like to express our gratitude to our internal supervisor, Dr. Saeed Bikaas, for asking critical questions and providing continuous feedback. Additionally, we would like to thank our external supervisor from OneSubsea, Marius Nordøen, who has given us the necessary information to carry out such a project. Thanks to Torgeir Hasaas and Eivind Halhjem, who created the thesis and have been supportive during the semester. We would also like to thank the team at the HVL lab, Frode Wessel Jansen, Harald Moen, and Nafez Ardestani, for their help with manufacturing and guidance.

slb One Subsea

Abstract

This thesis addresses a real problem faced by OneSubsea on the seabed, where they have large pump modules requiring power supply. The power supply is known as a Medium Voltage-head (MV-head). After a certain number of years, the MV-heads need to be removed due to maintenance on the pump modules. However, the cables are often stuck, likely due to a combination the design, and other factors like marine growth and corrosion. OneSubsea wanted a Subsea Secondary Release Tool to be developed that could effectively remove these MV-heads.

After a long and careful ideation process, a suitable tool could be designed with the help of a 3D modeling program. Hand calculations and the use of the Finite Element Method (FEM) have verified the tool's capacity for the operation. Production- and assembly drawings are made according to industry standards, and the tool can be manufactured with traditional methods. A user manual with specifications and user instructions is provided.

The tool uses four hydraulic cylinders to de-mate the MV-head, and one open/close cylinder to enable the Remote Operated Vehicle (ROV) pilot to position the tool correctly. The tool can be operated by any standard work class ROV and is made of stainless steel due to the corrosive environment.

Two "proofs of concept" have been made to assess the tool's fit with the MV-head: one in wood early in the project and one in steel for the final design. Due to expenses and delivery time, none of these include cylinders.

At the end of the semester, the bachelor group manufactured a prototype intended for use for a project in Angola. New information about the MV-head led to a design update, and suppliers with the required materials and components were contacted to complete the prototype.

Sammendrag

Denne bacheloroppgaven tar for seg et reelt problem som OneSubsea står overfor på havbunnen, der de har store pumpemoduler som krever strømforsyning. Strømforsyningen er kjent som en «Medium Voltage-head» (MV-head). Etter et visst antall år må disse kobles fra grunnet vedlikehold på pumpemodulene. Imidlertid sitter strømforsyningen ofte fast, sannsynligvis på grunn av en kombinasjon av designet og andre faktorer som marin groe og korrosjon. OneSubsea ønsket å utvikle et undervanns nødverktøy som effektivt kan koble fra strømkablene.

Etter en lang og grundig idéprosess kunne et egnet verktøy utformes med hjelp av et 3D-modelleringsprogram. Håndberegninger og bruk av «Finite Element Method» (FEM) har verifisert verktøyets kapasitet for operasjonen. Produksjons- og monteringstegninger er laget i henhold til industrielle standarder, og verktøyet kan produseres med tradisjonelle bearbeidingsmetoder. En brukerhåndbok med spesifikasjoner og brukerveiledning følger med.

Verktøyet bruker fire hydrauliske sylindere for å koble fra strømforsyningen, og en åpne/lukke sylinder for å muliggjøre at undervannsfartøyet (ROV) kan posisjonere verktøyet riktig. Nød verktøyet kan betjenes av hvilken som helst standard arbeidsklasse ROV, og er laget av rustfritt stål grunnet det korrosive miljøet.

To konseptmodeller er laget for å vurdere passformen til verktøyet mot en «MV-head». Den første ble laget tidlig i prosjektet av trevirke, mens den andre ble laget i stål etter at det endelige designet var bestemt. Ingen av disse har påmonterte sylindere grunnet kost og leveringstid.

Ved semesterets slutt produserte bachelorgruppen en prototype ment for bruk i et prosjekt i Angola. Ny informasjon om «MV-head» førte til en designoppdatering, og leverandører med nødvendige materialer og komponenter ble kontaktet for ferdigstilling.

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Abbreviations

WROV – Work class Remotely Operated Vehicle

MV-Head – Medium Voltage head. See Figure 2.

SSRT – Secondary Subsea Release Tool

SUTA – Subsea Umbilical Termination Assembly

FPSO – Floating Production Storage and Offloading

WDM – Weighted Decision Matrix

FEED – Front-End Engineering Design

HSEQ – Health, Safety, Environment and Quality

DFMEA – Design Failure Mode and Effect Analysis

FEM – Finite Element Method

HAZ – Heat Affected Zone

CAD – Computer Aided Design

List of Symbols

Q – Flow [$\frac{L}{min}$]

P – Power [kW]

p – Pressure [bar]

A – Areal [mm^2]

F – Force [N]

ρ – rho [kg/m^3]

h – Height [mm]

g – Gravity [$\frac{m}{s^2}$]

w – width [mm]

M_b – Bending moment [Nm]

I_x – Moment of inertia [mm^4]

σ_b – Normal stress [$\frac{N}{mm^2}$]

σ_{jf} – Combined stress [$\frac{N}{mm^2}$]

$\sigma_\perp$ – Normal stress perpendicular [$\frac{N}{mm^2}$]

τ_b – Shear stress [$\frac{N}{mm^2}$]

SF – Safety factor

1. Introduction

Have you ever tried to un-plug your power cable and experienced that it is stuck? Maybe you need to use more force than expected to get it out. OneSubsea has the same problem, but hundreds of meters below sea level. Our solution will be that extra force.

OneSubsea is a worldwide subsea service company founded in 2013 by the companies Cameron and Schlumberger. They have a big product portfolio and deliver *world-leading subsea technology and solutions* [1]. With over 11,000 employees and 94 nationalities, they specialize in compression technologies used for oil and gas production. Such products can be subsea pump modules, as seen in Figure 1. These are placed on the seabed and driven by high voltage power cables, controlled from topside [2].

Figure 1 - OneSubsea pump module

The pump modules may need service during their design lifetime. If needed, the pump module will need to be retrieved from subsea to topside. In this case, the power cables must be disconnected. This disconnection has proven to be challenging, likely caused by a combination of the design and other factors such as marine growth and corrosion.

So far, the issue has been solved by either abandoning the cable, or using improvised ROV tools which can cause damage to the pump module and the cable. The assembly of the connector, seen in Figure 1, consists of both OneSubsea and Siemens parts. The design is uniquely made for their subsea pump modules. For this reason, there are no existing solutions to the challenge.

1.1 Statement of the Problem

With this project, we are going to engineer an ROV tool that can safely and efficiently disconnect the power cable assembly. The tool will be called a Subsea Secondary Releasing

Tool and will be used as a contingency tool if the ROV manipulator fails to disconnect the power cable. The power cable is shown in Figure 1, and the MV-head at the ends of the power cable is shown in Figure 2.

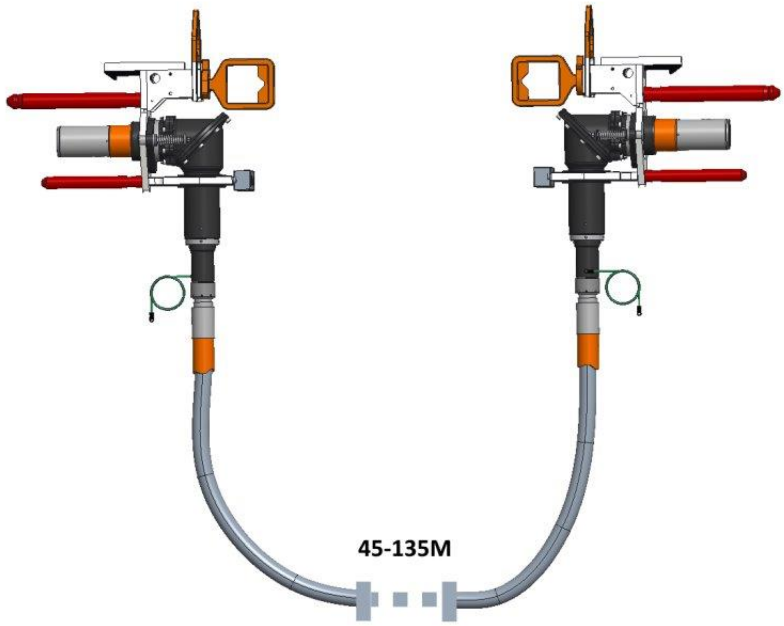


Figure 1 - Power cable assembly

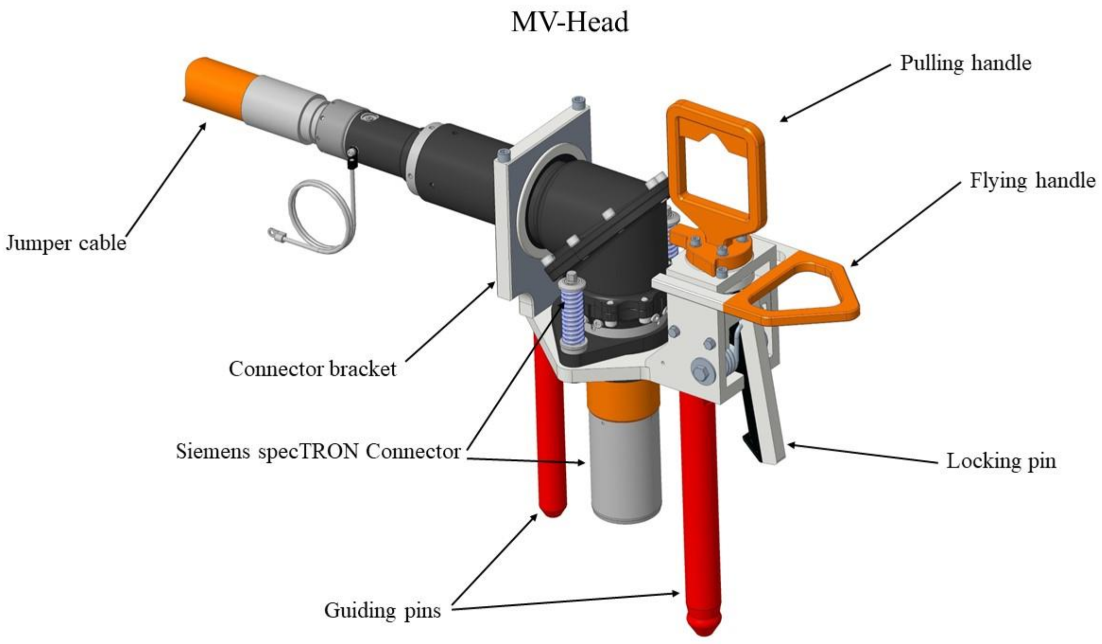


Figure 2 - MV-Head

1.2 Product Design Specification

At the start of the project, we had a kickoff meeting with OneSubsea where all project parameters were discussed. These parameters are shown in Table 1.

Table 1 - Product Design Specification

Time	- Start bachelor project: 10.01.2024 - Kickoff meeting with OneSubsea: 11.01.2024 - Underway presentation: week 11 - Submit bachelor project: 21.05.2024 - Presentation bachelor project: 3.-11.06.2024
Function	- Disconnect Siemens SpecTRON connector from pump module - Protect power cable and pump module during operation - Handled by any WROV, ref. API Recommended Practice 17H – Remotely Operated Tools and Interfaces on Subsea Production Systems
Construction	- Easy handled by any work class ROV - Protect any components on pump module and power cable during operation - Free to decide size of tool - Interface plate on pump modules can vary – tool must fit any interface plate - Design of tool should adhere to industry standards
Material	- Free of choice - Material will be exposed for corrosion (subsea) - Coating/surface treatment if needed - Anodes can be considered - Weight must be taken into consideration (possible buoyancy)
Economics	- Design of tool should adhere to industry standards - No budget is required
Documentation	- Necessary CAD files given by Company at project start - 3D design in Creo - Simulation report from Ansys - Production drawings, GA drawing, P&ID and specifications
Working conditions	- Weekly meetings with Project Supervisor - Monthly meetings with Company - All ideas should be considered and discussed - Constructive criticism should be given and received in a respectful manner - Rules and laws by HVL are applicable, ref Regler_og_retningslinjer_per_13_september_2023.pdf
Resources	- Creo, Ansys, Matlab, Microsoft - Supervisor and OneSubsea - Lab at HVL (3D printer and workshop)

1.3 Objective

The project objective is created as a guide for the project group to deliver a product with the specifications and expectations of the customer. OneSubsea needs a Subsea Secondary Release Tool used as a contingency to disconnect power cables from subsea pump modules.

Our project objective from OneSubsea is as follows:

"The objective of the project is to engineer a Subsea Secondary Releasing Tool for disconnecting power cables from subsea pump modules. The project shall be done by 21th of May 2024."

Sub-objectives

Sub-objectives are created to break down the objective, where functionality and use of the subsea tool shall be highlighted.

- *"The tool will be handled by any work class ROV, in accordance with API Recommended Practice 17H – Remotely Operated Tools and Interfaces on Subsea Production Systems"*

- *"The tool must protect the cable and pump module during operation from damages. Force applied must be calculated and analyzed for material stress calculations."*

- *"Marine growth, corrosion and chalk shall be removed by injecting citron acid to connector head and guiding pins, either by the tool or as a step in the operation."*

- *"The tool must fit all the interfaces between connector and pump module, and between the connectors."*

- *"The tool must be able to connect for power from ROV if this is needed, either by electric power or hydraulic power."*

2. Theory

In this chapter, the necessary theory to complete the project is explained.

2.1 Subsea Module

This sub-chapter will explain the theory behind the Company's subsea module. Each major component of this subsea module will be discussed.

2.1.1 Subsea Pump Station

A subsea pump station is a structure placed on the seabed, consisting of components such as a pump unit, a control module, and a flow meter. The pump station is designed to be placed permanently on the seabed, while its components can be replaced by lifting them out of the structure. After years of operation when the oil or gas field is empty, the pump station will be abandoned on the seabed. Figure 3 shows a pump station and its components. The yellow parts are permanently installed, and the white parts are replaceable [3].

2.1.2 Jumper Cable

A jumper cable is a cable going from a subsea umbilical termination assembly, SUTA, and to the pump module. This is often a 10kV system that supplies the pump or compressor with power from the surface. This power comes either from a platform, FPSO, or land facility with a cable and is connected to the SUTA [3].

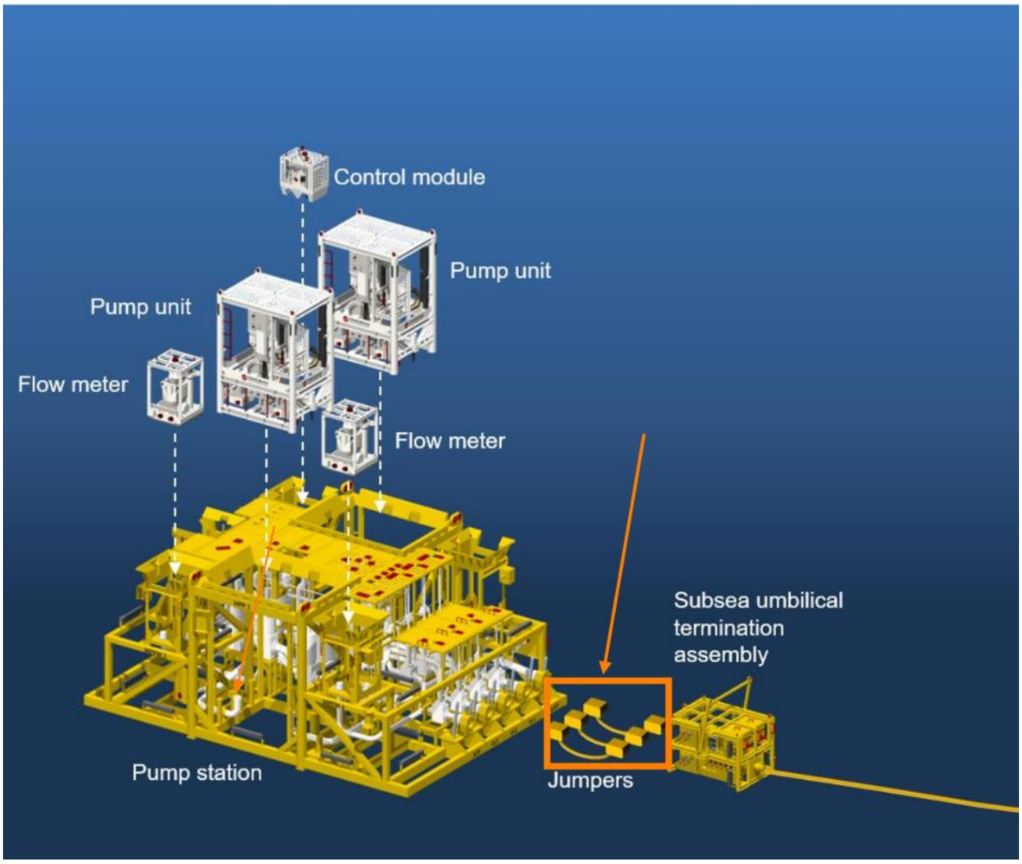


Figure 3 - Pump station and components [3]

A MV-head is attached to both ends of the jumper cable.

2.1.3 MV-head

The MV-head is a proprietary design from the Company and Siemens Energy. The electrical connector and the cable are Siemens Energy products, named Siemens SpecTRON. In this project, the Siemens SpecTRON 8 and 10 are in focus, which are two versions of the jumper cable. The remaining design is from the Company, painted in white and orange. These are components such as the guiding pins, flying handle, pulling handle, and locking pin. These parts are visualized in Figure 2 in the Abbreviations chapter. Figure 4 shows the assembly of the MV-head and jumper cable.

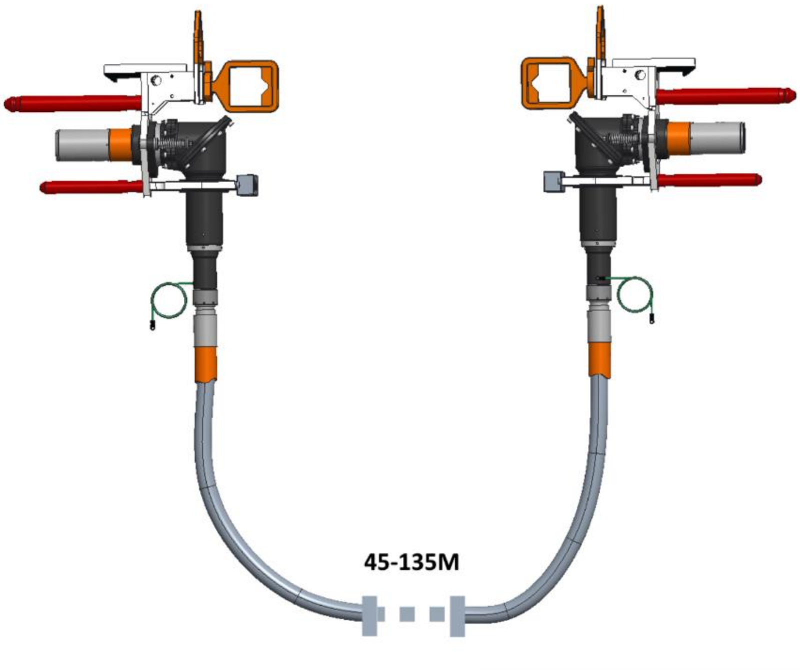


Figure 4 - MV Jumper [3]

2.2 Remotely Operated Vehicle (ROV)

An ROV, Remote Operated Vehicle, is an underwater vehicle used instead of divers, especially in deep water. It is used mainly in the oil and gas industry [4]. The ROV uses various equipment, depending on its operations. The type of ROV this project requires is shown in Figure 5, and is called a Work Class Remotely Operated Vehicle, WROV. In this project, the Group will call it an ROV.

Figure 5 - Working Class ROV [5]

A standard ROV will at least have two manipulator arms, thrusters, cameras, lights, hydraulic pumps, and valves for hydraulic flow control. It is supplied with power from topside, through an umbilical and tedder [5].

2.2.1 Manipulator Arms

One manipulator arm is used as a “grabber” to hold onto subsea modules and installations. The arm can be locked, and with the help of the thrusters, the ROV can hold still with a minimum of movement. The grabber arm is robust, but often only a 5-function arm. A 5-function manipulator arm has five different movements, using cylinders and/or motors.

The other manipulator is a 7-function, used as the “working” arm, as seen in Figure 6. The arm is very precise and an experienced ROV operator can do complex operations. While the ROV pilot flies the ROV and controls the grabber arm, another operator controls the working manipulator.

Figure 6 - Schilling T4 7-functions manipulator (left) [6], and controller (right) [7]

For instance, the 7-function Shilling Titan 4 has a reach of 1922 mm and a payload capacity of 122 kg at full length [6].

2.2.2 Electric Interface

External equipment that requires communication from topside or power from the ROV, can connect to 24 V or 110 V output from the ROV. This requires a watertight or oil-compensated cable to prevent ground fault and possible equipment failure. The connectors are often molded to the cable with the correct pinout for the ROV and external equipment, as seen in Figure 7 [8].

Figure 7 - Molded ROV cable with connectors (private photo)

2.2.3 ROV Skid

The ROV can be equipped with a skid, as shown in Figure 8. The skids can be built for different uses and equipped with tools required for the operation. This includes hydraulic pumps, valve packs, extra compensators for fluid storage, drawers for storing tools, etc. [9].

Figure 8 - ROV skid [9]

2.3 Hydraulics

Hydraulic is a collective term for fluid under pressure. It is used all over the world and the invention of Pascal's principle back in 1650, Figure 9, has contributed to the world we know it today [10].

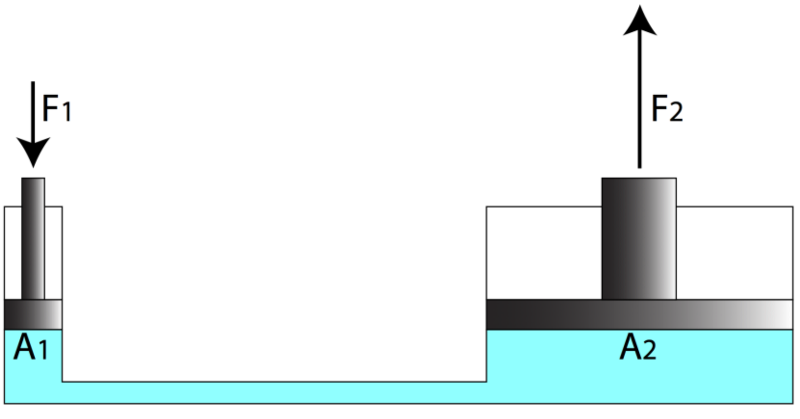


Figure 9 - Pascal's principle [11]

Where F_1 is the force applied to the system [N] and A_1 is the area of that piston [mm], and this makes the pressure P_1 $[bar]$. At the same time P_2 will be F_2 divided by the area of piston 2, A_2 [mm] [11].

$$P = \frac{F}{A} \tag{1}$$

2.3.1 Hydraulic Pump

The hydraulic pump converts mechanical energy to hydraulic energy which makes the fluid flow. The pressure is created from the resistance in the circuit, and increased resistance gives increased pressure. Pumps are designed differently depending on the use of the circuit. Some of the most common pumps are axial variable piston pumps, centrifugal pumps, and gear pumps. [12]

On closed hydraulic circuits with variable flow and pressure, a variable piston pump as seen in Figure 10 is often used. Piston pumps are regularly used in ROV due to their reliability. The maximum pressure is adjusted to 207 bar (3000 psi) using a regulator and/or pressure relief valves. The flow capacity depends on the size and power supplied to the pump. Typical ROVs have a flow between 80-150 l/min [8], [13], [14]

The power delivered from a hydraulic pump is given in equation (2).

$$P = \frac{p \cdot Q}{600} \qquad (2)$$

Where P is the power [kW], p is pressure [bar] and Q is flow [l/min].

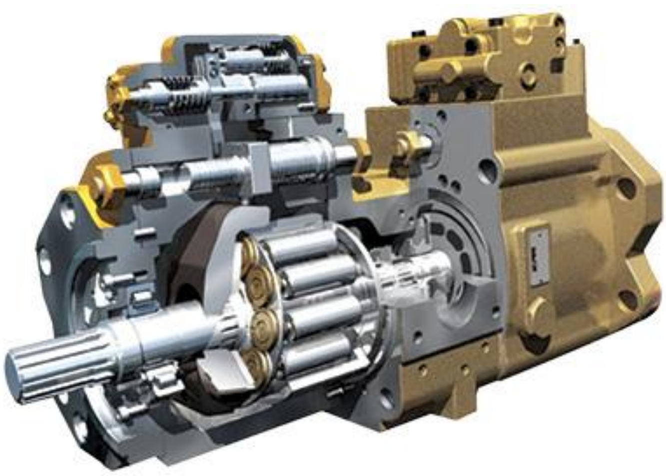


Figure 10 - Variable piston pump hydraulic cylinder [15]

2.3.2 Valve Pack

A valve pack, shown in Figure 11, is used to control the hydraulic flow from the hydraulic pump on the ROV. The valves are operated from the topside by the ROV pilot. Types of valve packs depend on the use, flow, and pressure needed for the operation. The ROV is equipped with numerous valve packs that control the ROV. External equipment, such as cylinders and motors, can be connected and operated [16].

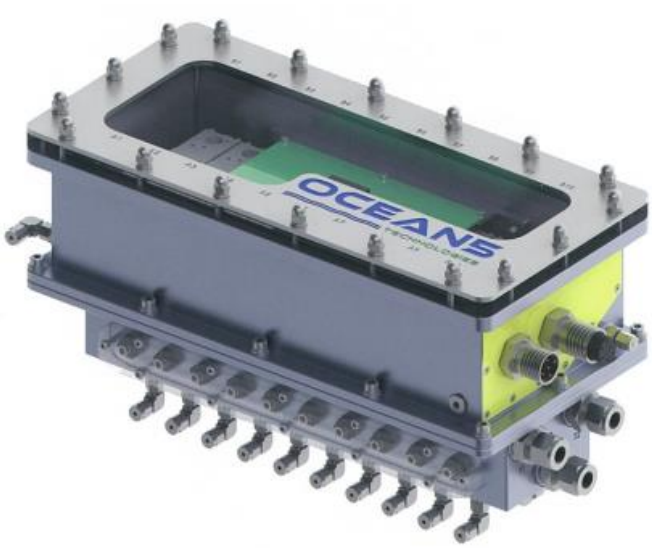


Figure 11 - ROV valve pack [16]

The valve packs can either have spools that are on/off, or proportional to control the flow from the valve. An on/off valve is either on or off with constant flow. A proportional valve can adjust the flow.

2.3.3 Hydraulic Cylinder

Hydraulic cylinders convert the hydraulic energy created by the pump to mechanical energy. The use and design vary in size, the force needed, and function. The cylinder's main components, as shown in Figure 12, are a piston connected to a rod, a cap, and sealings to prevent leakages.

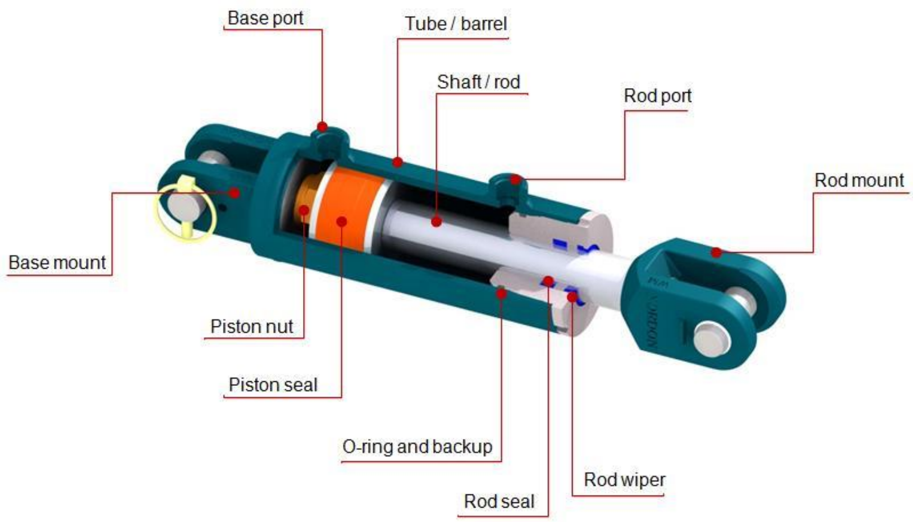


Figure 12 - Hydraulic cylinder [17]

The forces created by a cylinder is:

$$F = \Delta p \cdot A \tag{3}$$

2.3.4 Hydraulic Oil

Every hydraulic system needs a medium to transfer the hydraulic forces. Hydraulic oil is mostly used, because of its lubrication ability. An ideal hydraulic medium shall, at least, have these demands [18]:

- Good lubrication ability
- Long lifetime
- Not poisonous
- Small viscosity changes due to temperature and time

Due to these demands, mineral oil is mostly used in modern hydraulic systems. However, better technology and knowledge have presented the options of water-based hydraulic oil and synthetic oil, which is also fire-resistant compared to mineral oil. Before switching the oil type on a hydraulic system, components like gaskets, filters, hoses, etc. must be checked if it's compatible with the new medium [18].

Hydraulic components have certain viscosity areas limits on where they can be operated. These limits are given by the supplier and can vary from component to component. Therefore, in a hydraulic system, there must be taken measures on which type of hydraulic oil to be used. The lubrication ability is the most important, and by using a viscosity diagram based on different temperatures, one can find out which oil viscosity to use for the operation [18].

Figure 13 shows an example of how a viscosity diagram for hydraulic oils can be presented.

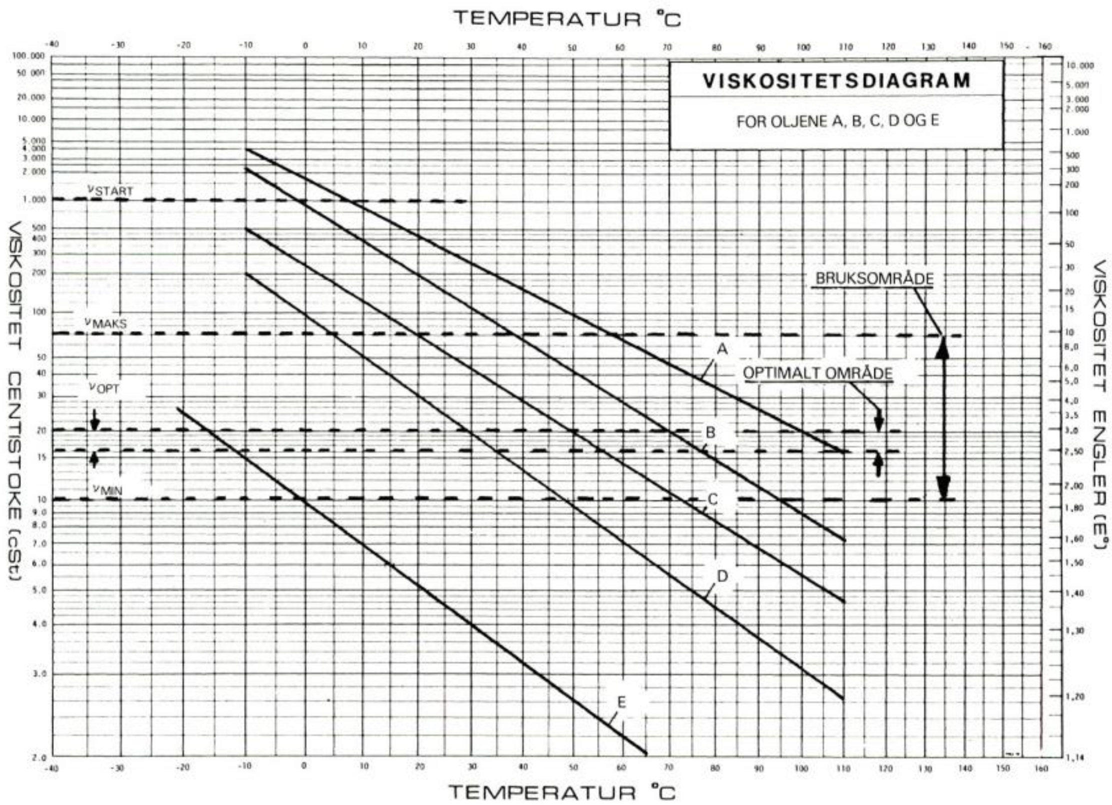


Figure 13 - Viscosity diagram for hydraulic oil [18]

2.4 Basic Concepts in Mechanical Engineering

In this chapter, essential basic concepts from mechanical engineering will be presented.

2.4.1 Material

Steel Types

The main components of steel are iron and carbon. There are many different steel types, and the carbon quantity has a big impact on the characteristics of the material. One also separates between alloy and non-alloy steel. Non-alloy consists of iron, carbon, and small amounts of other elements, while alloy steel has a bigger amount of mixture. The carbon separates steel between [19]:

- Construction steel: up to 0,3% C
- Tool steel: More than 2% C
- Cast iron: 2,5% - 4,5% C

The different steel types are made after different requirements:

- Weldability and machinability
- Yield strength (can vary from 150 MPa to 3000 MPa, depending on the alloys)
- Resistance from corrosion
- Hardness (Brinell, Rockwell etc.)
- Toughness
- Temperatures
- Price

Construction steels

Construction steels are used everywhere. The wide variety of alloys gives a lot of opportunities to use correctly steel for the structures and tools. Construction steels are standardized in for example NS-EN 10025. Table 2 shows some of the used steels.

Table 2 - NS-EN 10025 material standards [19]

Betegnelse	Sammensetning, maks. %						Mek. egenskaper, min.					C_e maks %
	C	Mn	Si	P	S	N	R_m N/mm²	R_e N/mm²	A %	Slagseighet J	Slagseighet °C	
S 185	Ingen krav						310	135	8	Ingen krav		
S235JR	0.20	1.40	-	0.045	0.045	0.009	360	235	17	27	+20	0.35
S235JO	0.17	1.40	-	0.040	0.040	0.009	360	235	-	27	0	0.35
S235J2G3	0.20	1.40	-	0.045	0.045	0.007	360	235	-	27	+20	0.35
S235J2G4	0.17	1.40	-	0.035	0.035	-	360	235	16	27	-20	0.35
S275JR	0.22	1.50	-	0.045	0.045	0.009	430	275	15	27	+20	0.40
S275JO	0.18	1.50	-	0.045	0.045	0.009	430	275	-	27	0	0.40
S275J2G3	0.18	1.50	-	0.035	0.035	-	430	275	-	27	-20	0.40
S275J2G4	0.18	1.50	-	0.035	0.035	-	430	275	13	27	-20	0.40
S355JR	0.24	1.60	0.55	0.045	0.045	0.009	510	355	15	27	+20	0.45
S355JO	0.22	1.60	0.55	0.040	0.040	0.009	510	355	-	27	0	0.45
S355J2G3	0.22	1.60	0.55	0.035	0.035	-	510	355	-	27	-20	0.45
S355J2G4	0.22	1.60	0.55	0.035	0.035	-	510	355	13	27	-20	0.45

Chrome

Chrome makes steel corrosion resistant when over 12% is mixed in the alloy because it creates a chromium oxide layer [19].

Chrome-nickel alloys

Nickel, together with chrome, gives higher hardenability, improved fatigue properties, and higher impact toughness [20]. The mixture can often be 18% chrome and 8% nickel, called 18/8 steel [19]. These steel alloys are called stainless steel, but they can still corrode in harsh environments.

Chrome-nickel alloys with molybdenum

If molybdenum is mixed into a chrome-nickel steel alloy, it gets a high resistance from corrosion and the strength is proven. It can have a yield strength up to 550 N/mm^2 and is often used in the marine- and oil industry. Typical stainless steel is duplex, super-duplex and AISI 316(L) steel. These are all weldable and machinable. Table 3 shows the components in AISI 316 steel [19], [20], [22].

Table 3 - Components in AISI 316 steel [21]

Element	**316 (%)**
Carbon	0,07 max
Manganese	2,00 max
Phosphorus	0,05 max
Sulfur	1,0 max
Silicone	0,02 max
Chromium	16,50-18,50
Nickel	10,00-13,00
Molybdenum	2,00-2,50
Iron	Balance*

*The rest of the alloy is iron

Corrosion

Corrosion is defined as the destructive attack of a metal and ordinarily begins at the surface. This is an electrochemical reaction, meaning electrons are transferred from one chemical substance to another [23].

Figure 14 - Corrosion at the surface of a car with a plain carbon-steel body [24]

Metals lose electrons in an oxidation process, and this occurs in an anode:

$$Fe \rightarrow Fe^{2+} + 2e^{-}$$

The electrons coming from each atom that is oxidized must be taken up by another chemical substance in what is called a reduction reaction. The reduction reaction occurs in a cathode:

$$2H^{+} + 2e^{-} \rightarrow H_2$$

Here are some forms of corrosion:

- **Uniform Attack:** An electrochemical corrosion that occurs over the entire exposed surface and often leaves behind a scale or deposit.
- **Galvanic corrosion:** When two metals or alloys with different compositions are electrically coupled while exposed to an electrolyte.
- **Pitting:** A form of very localized corrosion attack which forms small holes or pits.
- **Erosion-Corrosion:** Arises from the combined action of chemical attack and mechanical abrasion or wear due to fluid motion.

In the scenario given in Figure 15, an electrochemical cell consisting of iron and zinc electrodes, each immersed in a 1 M solution of its ion, is shown. The iron represents a reduction process, where iron ions (Fe^{2+}) from the solution gain electrons and are reduced to solid iron. The zinc electrode corrodes and represents an oxidation process, losing electrons and going into solution as zinc ions (Zn^{2+}) [23].

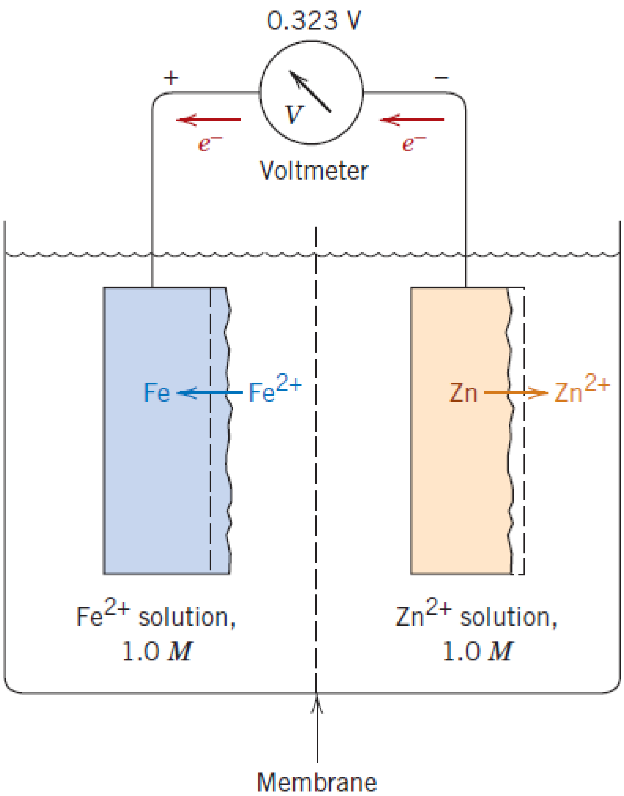


Figure 15 - An electrochemical cell consisting of iron and zinc electrodes [23]

The challenge with metallic corrosion is significant, and corrosion prevention is therefore crucial. In economic terms, it has been estimated that approximately 5% of an industrial nation's income is spent on corrosion maintenance, replacement, and prevention due to metallic corrosion. General techniques for corrosion prevention include material selection, coating, cathodic protection, and environmental alteration [23].

Other Materials

A material that is often used in the marine- and oil industry is nylon. Nylon is a polymer that includes the familiar plastic and rubber material, and they often have low density. Polymers have different mechanical characteristics than metallic and ceramic materials as they are not as stiff or strong. Some benefits of nylon include relatively good mechanical strength, durability, high toughness, as well as a low coefficient of friction. Nylon is often used in bearings, gears, and cams [23].

Materials on MV-head

The MV-head is made of super duplex steel. Super duplex is a part of the duplex family which is a term for a special group of steel that is corrosive resistant. It has better mechanical properties and is more corrosive resistant than 316 and 304 stainless steel, and therefore Duplex steel fits well in corrosive environments [25].

Technical details on the MV-head are seen in Table 4.

Table 4 - Material specifications for MV-head [3]

Operational Design Depth	3000 meters (3050 MSW)
Design Life	30 years
Ambient Medium	Seawater
Maximum operational service temperature in seawater	<20°C
Ambient transport/storage temperature for all equipment	-25 °C < T< +60 °C
Material seawater exposed parts	Super Duplex, Norsok std. M-630 Norsok MDS D55/D57 As documented in Siemens TMDS-0001, TMDS- 0016, TMDS-0123 (TMDS's covers Norsok MDS's without PT testing post final machining)
Test jumpers:	Minimum AISI 316, TMDS/0002
Material M16 bolts for fixed mount flange and compliant mount flange	ASTM B446 / ASTM B564, UNS 06625 MDS N01
Connector/penetrator type	SpecTRON 10 mk II series
Min. number of WM operations	100

2.4.2 Material Processing

A material can be processed in many ways, and it is important to know what happens with a material when processing it.

Welding

Welding is when two or more metal parts are joined to form a single part. This is done when you can't make one part from fabrication, casting, or similar. There are different types of welding depending on what type of material the part is made of and the purpose of the part. This is such as gas and arc welding. Regardless of the welding method used, a Heat Affected Zone (HAZ) will form, leading to changes in microstructure and properties. Upon cooling, stresses may occur and will weaken the joint [23].

Fabrication

Plasma cutting is a method used to split and cut parts. A plasma is an extremely hot and ionized gas. This gas can be 10 000 – 20 000 K and the light bow is forced through a narrow nozzle, which is a water-cooled brass nozzle. This technique is used for cast iron, stainless steel, and other high-alloy steel [26].

2.4.3 Elastic and Plastic Deformation

Every material has some kind of ability to resist external forces without big changes in the shape of the product, or a fracture occurring [27]. How much a material can be strained, varies based on the material's ductility. Ductility is a measure of the degree to which a material plastically deforms, by the time fracture occurs [23].

Whenever a material is loaded within the elastic region, it will always return to its original form and shape. If the material is loaded above the elastic region and into the plastic region, the material will no longer return to the state it was at the beginning. The point where the plastic region starts are called the yield point and the symbol is σ_{yield} or σ_y, as shown in Figure 16 [23].

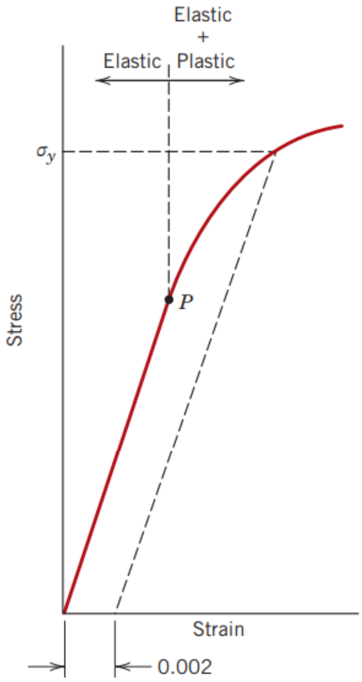


Figure 16 - Elastic- and plastic deformation [23]

2.4.4 Pressure

When operating on the seabed, an object will be exposed to hydrostatic pressure from the water:

$$P_{abs} = P_{gauge} + P_{atm} \tag{4}$$

Where P_{abs} is the absolute pressure [bar], P_{gauge} can be both positive and negative and is the difference between the absolute pressure and the local atmospheric pressure [bar]. P_{atm} is the pressure from the atmosphere, which can vary some due to high pressure and low pressure, but is often set to be 1 bar [28].

The formula for P_{gauge} is:

$$P_{gauge} = \rho g h \tag{5}$$

Where ρ (rho) is the density of the fluid $[\frac{kg}{m^3}]$, g is the gravity force $[\frac{m}{s^2}]$, and h is the height from the object to the reference point [m].

2.4.5 Von-Mises Stress

Engineered parts will experience a variety of loads, from tension and compression to torsion, bending, and shear stress. All these loadings result in a complex stress state which comes from six different values. The values are now combined into one single equivalent stress value. Von-Mises stress is an equivalent stress value which is used to determine whether the material will yield or not, when comparing to the yield strength of the material [29].

2.4.6 Design Failure Mode and Effects Analysis (DFMEA)

DFMEA is a tool that helps engineers to understand the impact of a failure in a design. This will answer questions such as what will happen if the design fails, the consequence of such a failure, and how the engineer can prevent this failure [30].

All the potential risks are listed and numbered in a table. From this table, they are brought forward to a risk assessment table. Here, the potential hazards are evaluated relative to probability (P) and consequence (C). They are both scaled from one to five, where the lower the number the better the result. (P) and (C) are then multiplied with each other which gives the risk score (R). Green is the best, orange is not good but may be acceptable, and red is a no-go.

The hazards are first scored ahead of any measures taken. The meaning of this is to lower the risk score when measures are eventually taken. All hazards are then brought forward to a table which shows the danger of each hazard, both before and after measure are taken.

2.4.7 Basic Formulas

Bending moment, M_b:

$$M_b = F \cdot l \tag{6}$$

Moment of inertia of rectangular geometry, I_x:

$$I_x = \frac{wh^3}{12} \tag{7}$$

Normal stress, σ_b:

$$\sigma_b = \frac{M_b}{I_x} \cdot \frac{h}{2} \tag{8}$$

Normal stress in outer weld, σ_{bA}:

$$\sigma_{bA} = \frac{M_b}{I_x} \cdot \left(\frac{h}{2} + a\right) \tag{9}$$

Moment of inertia for fillet weld, I_x

$$I_x = \frac{1}{12}(WH^3 - wh^3) = \frac{1}{12}((w + 2a)(h + 2a)^3 - wh^3) \tag{10}$$

Combined stress, σ_{jf}:

$$\sigma_{jf} = \sqrt{\sigma_\perp^2 + 3 \cdot \tau_\perp^2 + 3 \cdot \tau_\parallel^2} \tag{11}$$

Normal stress perpendicular to the throat of a weld, $\sigma_\perp$:

$$\sigma_\perp = \tau_\perp = \frac{\sigma_b}{\sqrt{2}} \tag{12}$$

Shear stress, τ_b:

$$\tau_b = \frac{F}{2 \cdot a \cdot h} \tag{13}$$

Safety factor, SF:

$$SF = \frac{\sigma_{yield}}{\sigma_{load}} \tag{14}$$

Forces on a cylinder

$$F = p \cdot A \tag{15}$$

3. Method

This chapter contains the various methods and approaches used to complete the objective. These techniques include idea generation, CAD software, theoretical and experimental approaches.

3.1 Information Collection

At the start of a project, all parties must have a complete understanding of the objective. A kickoff meeting between participants is an effective way of communicating the expectation, as well as sharing all the information that is relevant to solving the problem. This form of information collection is qualitative and is valuable for further steps in a project.

3.2 Design Methods

To make a design that meets the criteria in the statement of the problem, different techniques are used to reach the final product in an innovative way. These techniques will be explained in the next sub-chapters.

3.2.1 First Five

The “First Five” technique is a good way to start an innovative project where the objective is to make a new design. Each member of a group will come up with five ideas without communicating with each other. This ensures that the design does not go down a narrow path without exploring other options. One should not be critical considering feasibility at this stage. Going in with a broad and open mind gives room for more creativity.

The first five ideas from each member are then shared with another member of the group, and the goal is to take inspiration from these ideas to make five new ones. After this stage, there will be around 10 ideas per group member.

3.2.2 Brainstorming

The brainstorming stage is entered after the initial ideas. Here, the team discusses all the ideas that have come up. When generating many ideas, brainstorming can identify the most promising concepts for further development, as well as introduce new ones.

3.2.3 Three Random Words

Another technique is the “Three Random Words” technique. These words should not be technical, and can for example come from a friend, a random word generator, or a non-technical book. One should not “cheat” if one does not fancy one of the words that are given, but rather force the mind to create an idea from that word.

3.2.4 Existing Solutions

Using existing solutions can be done both intentionally and unintentionally. It is done unintentionally by using principles from experience. Knowing about hydraulics or how to loosen a bearing are principles that occur in the thinking process. However, the main point in this stage is to intentionally search the internet or in literature, to adapt the idea into new ideas.

3.2.5 SCAMPER

Another method that can be used to find new ideas is the SCAMPER method. In this method the point is to go through the letters step by step, (S) substitute, (C) combine, (A) adapt, (M) modify, (P) put to another use, (E) eliminate, and (R) reverse. This method makes it easier to develop new ideas, and the different steps are explained in Table 5 [31].

Table 5 - Scamper table [31]

S	C	A	M	P	E	R
Substitute	**Combine**	**Adapt**	**Modify**	**Purpose**	**Eliminate**	**Reverse**
Replace one part with another that works better	Put different components together to improve	Update the product to new preferences	Change the appearance and presentation	Use the product for a purpose that wasn't intended	Eliminate the useless parts that are not valued	De-construct or re-think some of the main pillars

3.2.6 Weighted Decision Matrix

The Weighted Decision Matrix is a model used to decide between several ideas. If the objective of a project requires some essential criteria for the final product, these can be included in the matrix with a given weighting of the importance. The ideas get a score, and the highest score "wins".

Each criterion is weighted by numbers (1-3, 1-5, etc.) or by percentage of importance. The ideas are compared and given a value for each criterion. The score is multiplied by the weighting and summed up. However, the ideation process is not finished. The matrix can be used to combine the different alternatives for an even better product.

There should be at least three alternatives in the matrix. It is often that the project members will have an opinion on which solution is the best before the matrix is used, but the results can tell you otherwise due to the weighting of the criteria. Table 6 shows an example of a WDM, where Option 3 is the winner.

Table 6 - Example of a WDM

Criteria	Weightening	Option 1	Option 2	Option 3
#1	5	3	3	5
#2	2	5	1	2
#3	4	1	2	3
#4	3	5	1	4
#5	1	2	3	2
#6	2	2	5	3
Total		50	41	61

3.3 Software

There are many softwares to use for mechanical engineering and it is important to know which program to use when, and how it works.

3.3.1 Creo Parametric

Creo Parametric is a 3D Computer-Aided Design (CAD) solution that helps an engineer to accelerate product innovation to build faster and better products [32]. This program is a crucial tool for visualizing the Front-End Engineering Design (FEED) and for the final design. It enables the user to create a 3D model of their design and generate engineering drawings that showcase all the details. This makes it possible to manufacture the tool accurately [33].

3.3.2 Ansys

Ansys is a calculations program that uses numerical procedures and offers software that includes the range of physics, which will make any field of engineering simulations possible [34]. This software is essential in ensuring that all components of the operation can withstand the involved forces. These aspects include preventing any damage and creating a product that is strong enough to handle the forces. The software also enables the user to optimize the design based on the size, material, and weight.

Singularity fault

During a meshing, the software splits a body into many elements. These elements are very small, and sometimes one element can obtain more force than what is realistic. This leads to a high force on a very small area, which leads to a high local stress. This is called a singularity fault or artificially high stress. Therefore, it is important to look at the result from a critical point of view. Probes can be used around the singularity fault area to display realistic results [35].

3.4 Experimental Method

It is often a good idea to make a prototype of the design to ensure that the measurements for instance are correct. This can be done in several ways. You can make the product in a cheap material, like cardboard, wood, or similar. If the product is very big, you can scale it in a proper dimension, and even make it from 3D-printing. This helps you to easily visualize the final product. You can make a full-scale version of the right material of the product if you have the possibility and knowledge to do so. This is called proof of concept.

4. Solution Development

In this chapter, all ideas are presented, and a screening process is implemented to select the best ideas. These ideas are further evaluated in a weighted decision matrix, and the highest scoring ones are modeled.

4.1 Idea Generation

As described in the Method chapter, the idea generation begins with the "First Five" technique. All members produce their initial five ideas and exchange them with another group member. Each member elaborates on the first five ideas from their partner and expands them to create five new concepts. These ideas are evaluated in a brainstorming process.

With around 30 ideas from the first phase, the next step is to use three random words to create three new ideas per group member. The important thing is what concepts, mechanisms, and opportunities that are seen in the idea. These aspects will be used later in the SCAMPER method.

Due to the unique design of the MV-head, there are no existing solutions, but the Group is looking at similar concepts in the industry.

4.2 Ideation

Most ideas that have been accumulated will be shown and shortly explained in this subchapter. Ideas similar to each other has been combined in one explanation. Since the members of the Group are Norwegian, there are some texts in Norwegian in the pictures.

4.2.1 Ideas

This tool will be placed from the top by the ROV. The flying handle will act as a counterforce. The tool, shown in Figure 17, will have two cylinders in blue that will push the MV-head out.

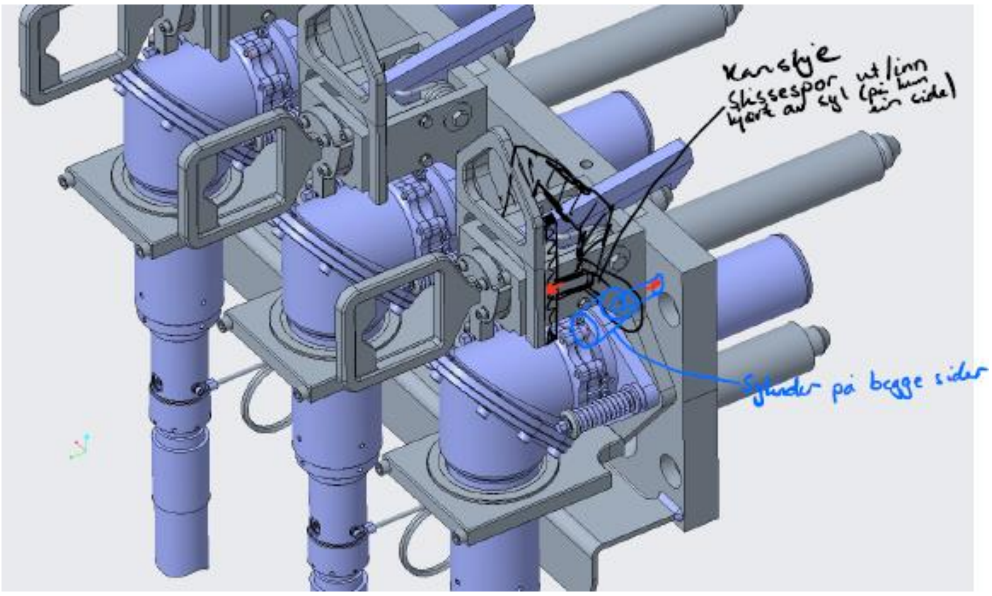


Figure 17 - Idea 1, from First Five

Idea 2 will also have two cylinders. This tool uses the ROV pulling handle as a counterforce by utilizing a locking pin. The locking pin can be moved in and out, which makes it easy to mount the tool, as shown in Figure 18.

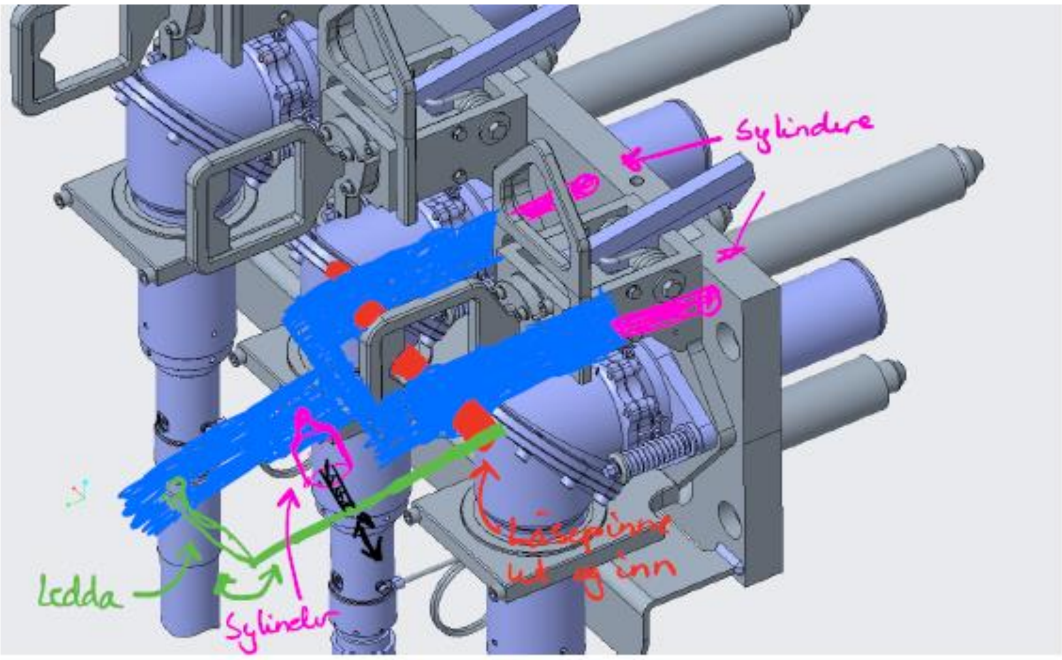


Figure 18 - Idea 2, from First Five

The idea shown in Figure 19 is to connect the jumper cable to a small ROV or submarine and use their force to pull it out.

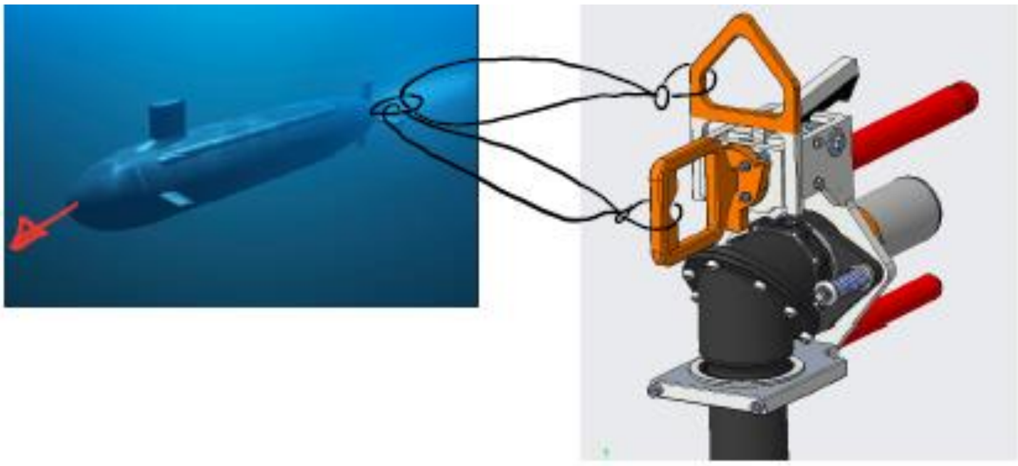


Figure 19 - Idea 3, from First Five

The fourth idea is fully mechanical, and it needs the ROV arm during the whole operation, as shown in Figure 20. The tool will push against the slot plate and de-mate the MV-head.

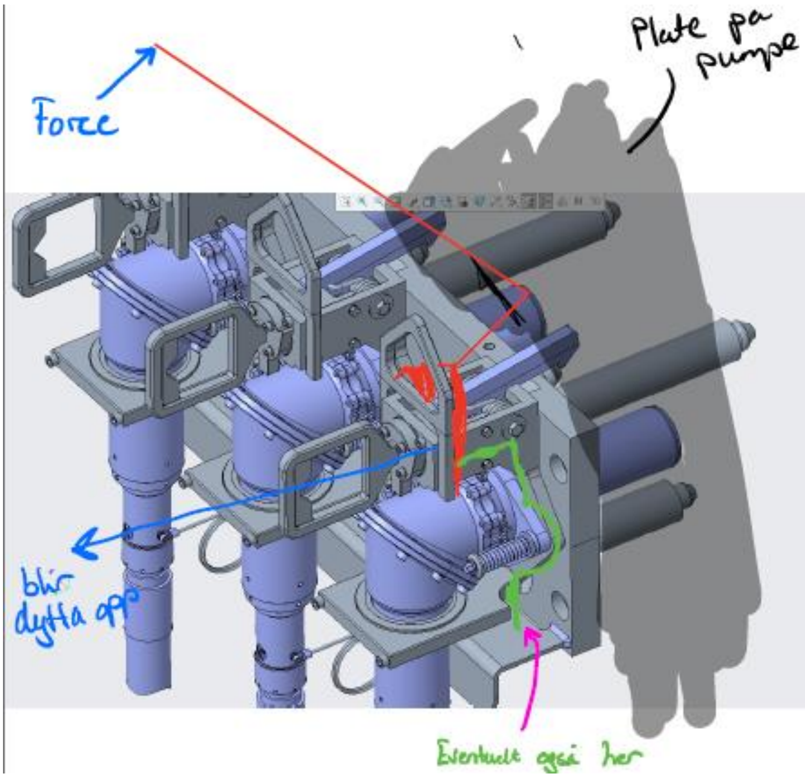


Figure 20 - Idea 4, from First Five

Idea 5 in Figure 21 will have a groove in the blue plate to be threaded on the pulling plate. The tool will have three bolts that will be screwed into the plate on the module and then push the MV-head out.

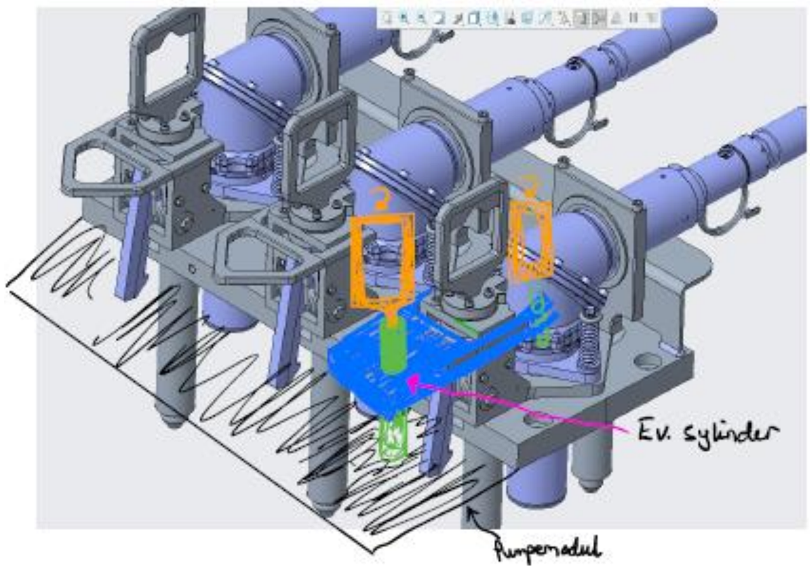


Figure 21 - Idea 5, from First Five

The idea in Figure 22 will have four cylinders mounted on a plate that has joints to easily mount the tool on the MV-head. The tool will be mounted around the cable.

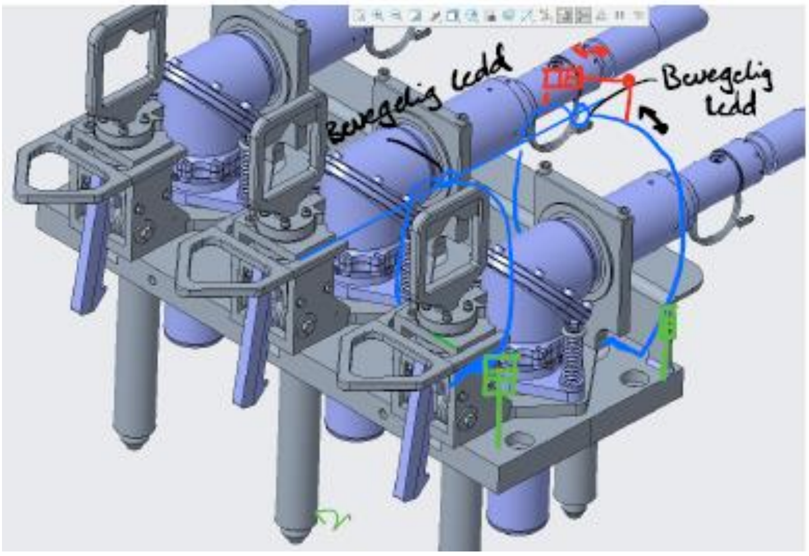


Figure 22 - Idea 6, from Brainstorming

Idea 7 will use a shock cylinder to knock the cable out. This knocking will repeat continuously until the cable comes loose. This is shown in Figure 23.

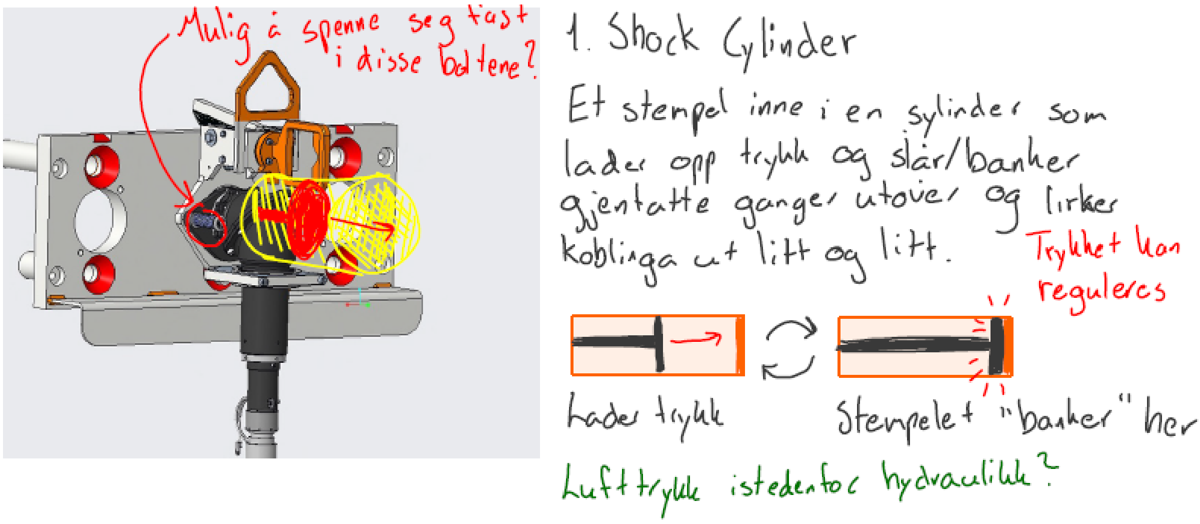


Figure 23 - Idea 7, from First Five

Idea 8 is fully mechanical where the ROV needs to push the tool downwards for de-mating. The tool will grip around the cable to get fastened, as shown in Figure 24.

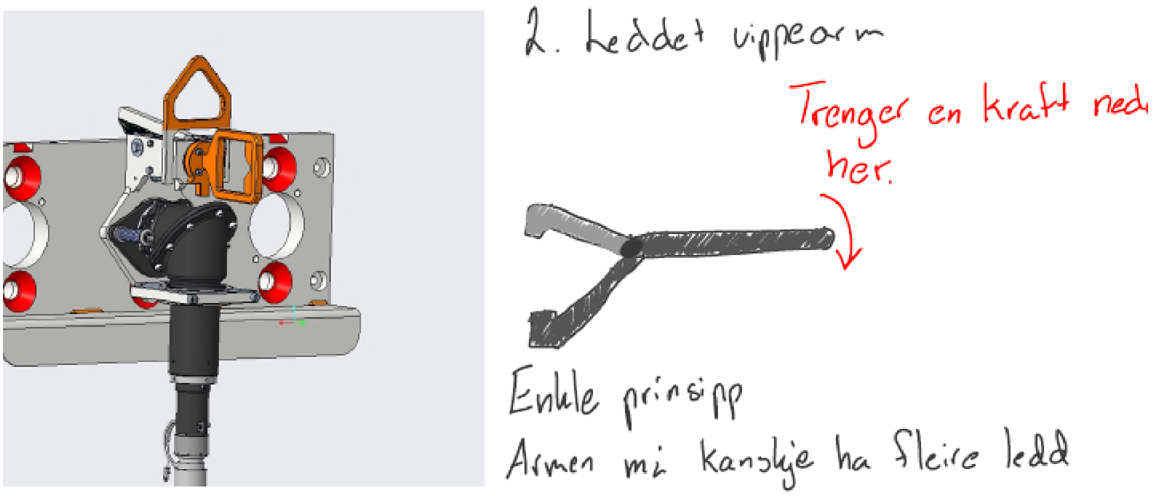


Figure 24 - Idea 8, from First Five

The idea in Figure 25 is a combination of acid injection and a vacuum technique. The tool will be sealed around the MV-head and then acid will be injected. After a while, the MV-head should be easy to pull out.

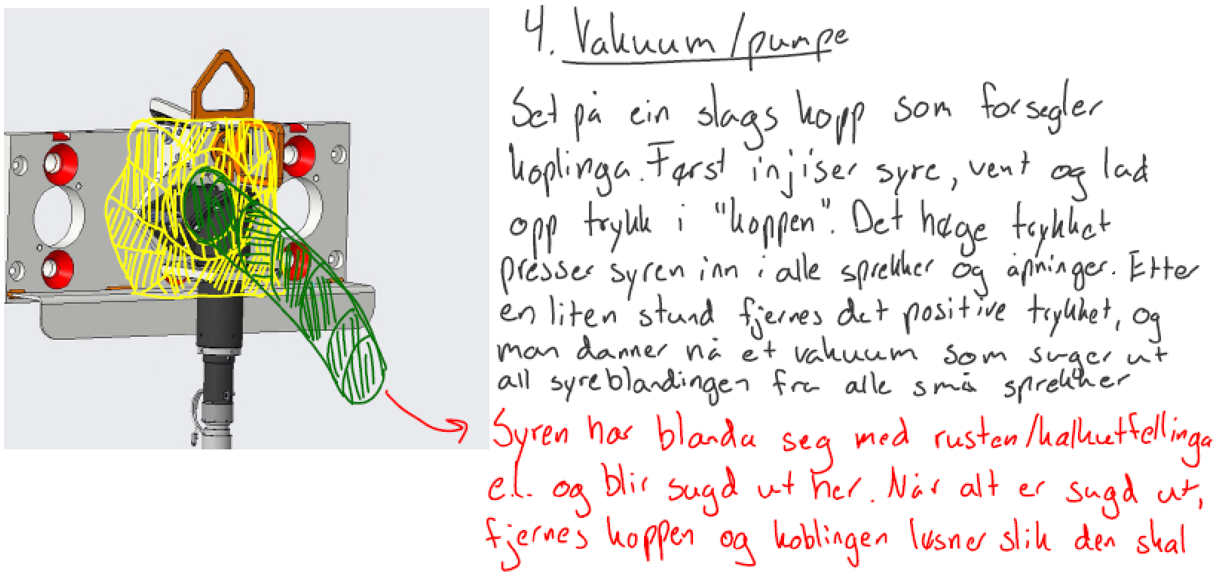


Figure 25 - Idea 9, from First Five

Idea 10 in Figure 26 is a tool that will use a combination of cylinders and springs for de-mating. The concept behind using springs is to evenly distribute the load.

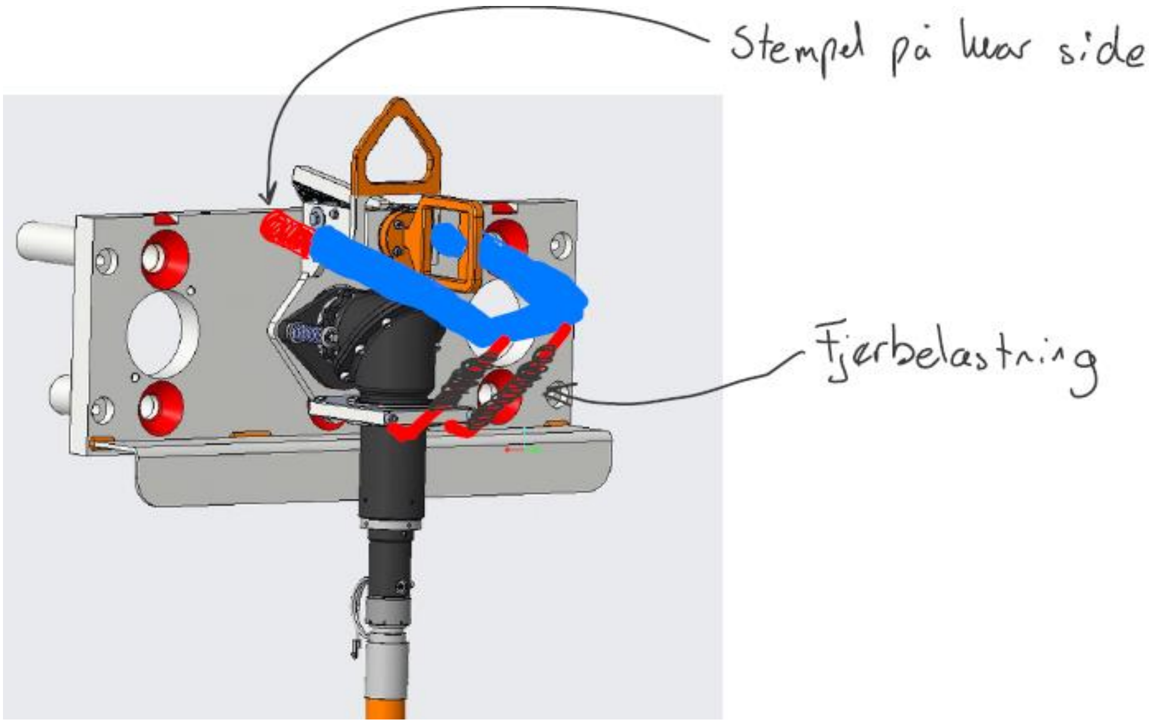


Figure 26 - Idea 10, from First Five

The idea in Figure 27 will use sprockets and grip around the tool like a claw. As the two sides rotate, they will make contact with the MV-head and push it out.

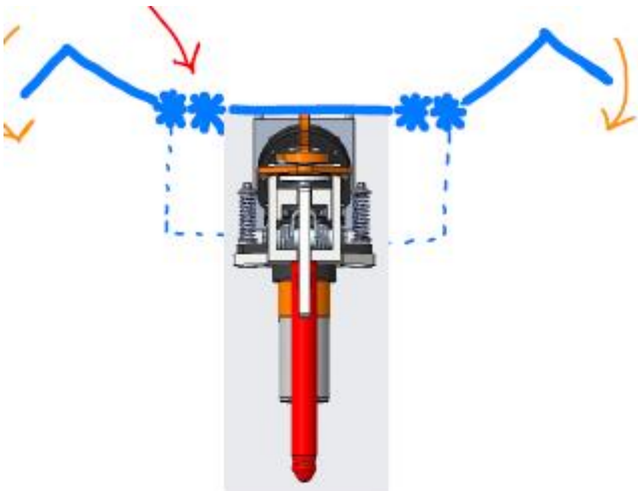


Figure 27 - Idea 11, from Brainstorming

Idea 12 will use magnets to hold on to the connector and then use cylinders to push against the plate. Figure 28 shows the magnet placement in red, as well as the inspiration for the idea.

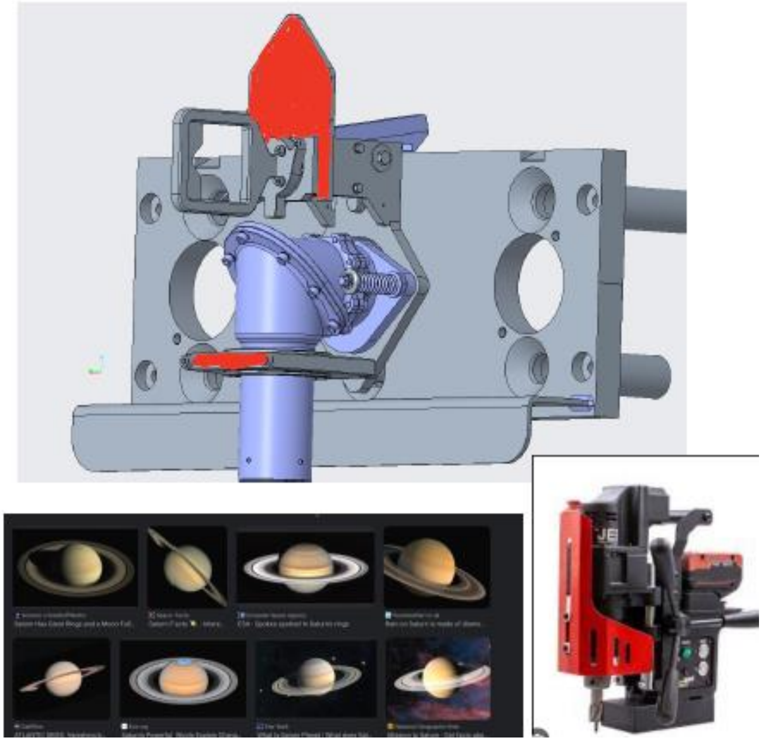


Figure 28 - Idea 12, “Astronomy” from Three Random Words [36], [37]

Figure 29 shows a simple mechanical idea. The tool will use the plate to push out the MV-head as the ROV pushes the blue handles.

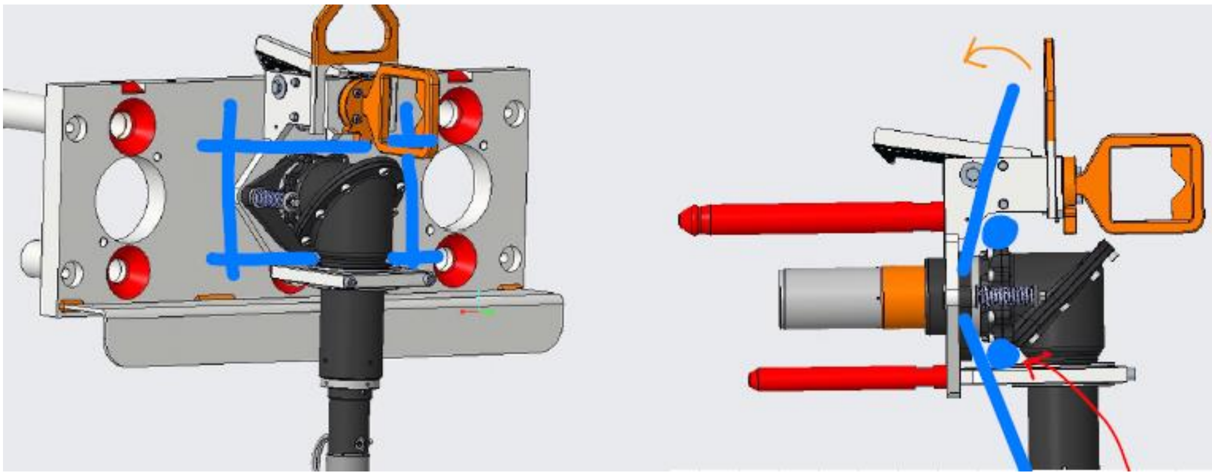


Figure 29 - Idea 13, “Contemporary” in Three Random Words

Idea 14, shown in Figure 30, uses a bellow/air cushion as a force. The bellow will be pressurized and push the blue plate against the MV-head.

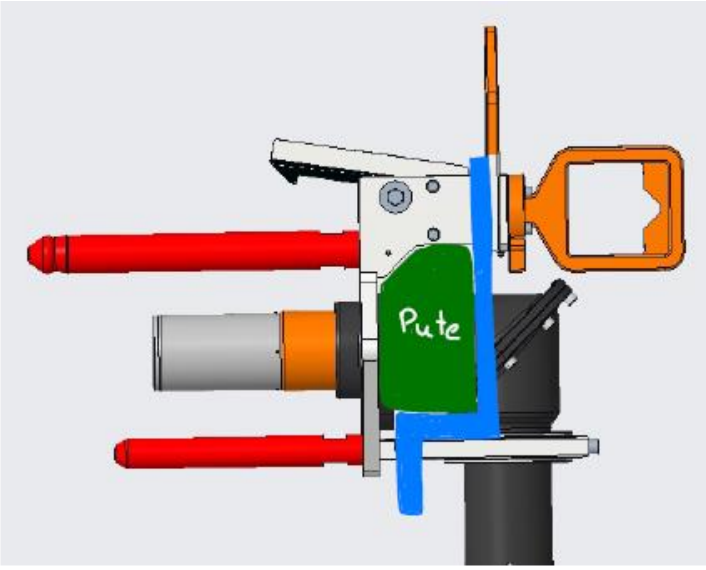


Figure 30 - Idea 14, “Chop”, from Three Random Words

Idea 15 will be mounted on the cable and use a combination of cylinders and springs to make a shock motion. The cylinders will compress the spring and when the cylinders release the pressure, a shock will occur to loosen the MV-head. See Figure 31.

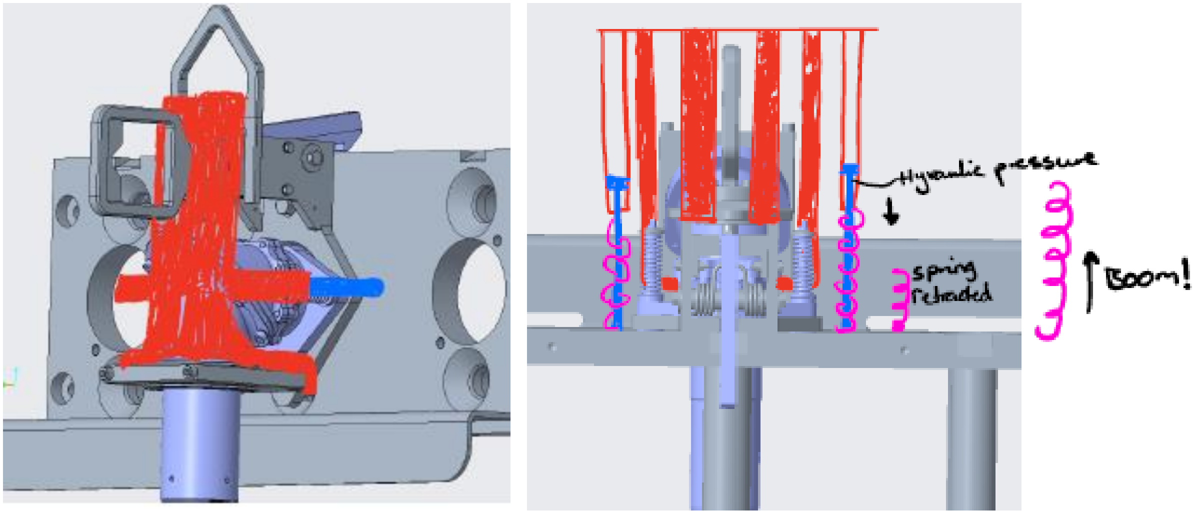


Figure 31 - Idea 15, from “Bicycle” in Three Random Words

The tool in Figure 32 is for acid injection in areas where there could be marine growth. This could be a second tool that the ROV can bring to site for acid injection.

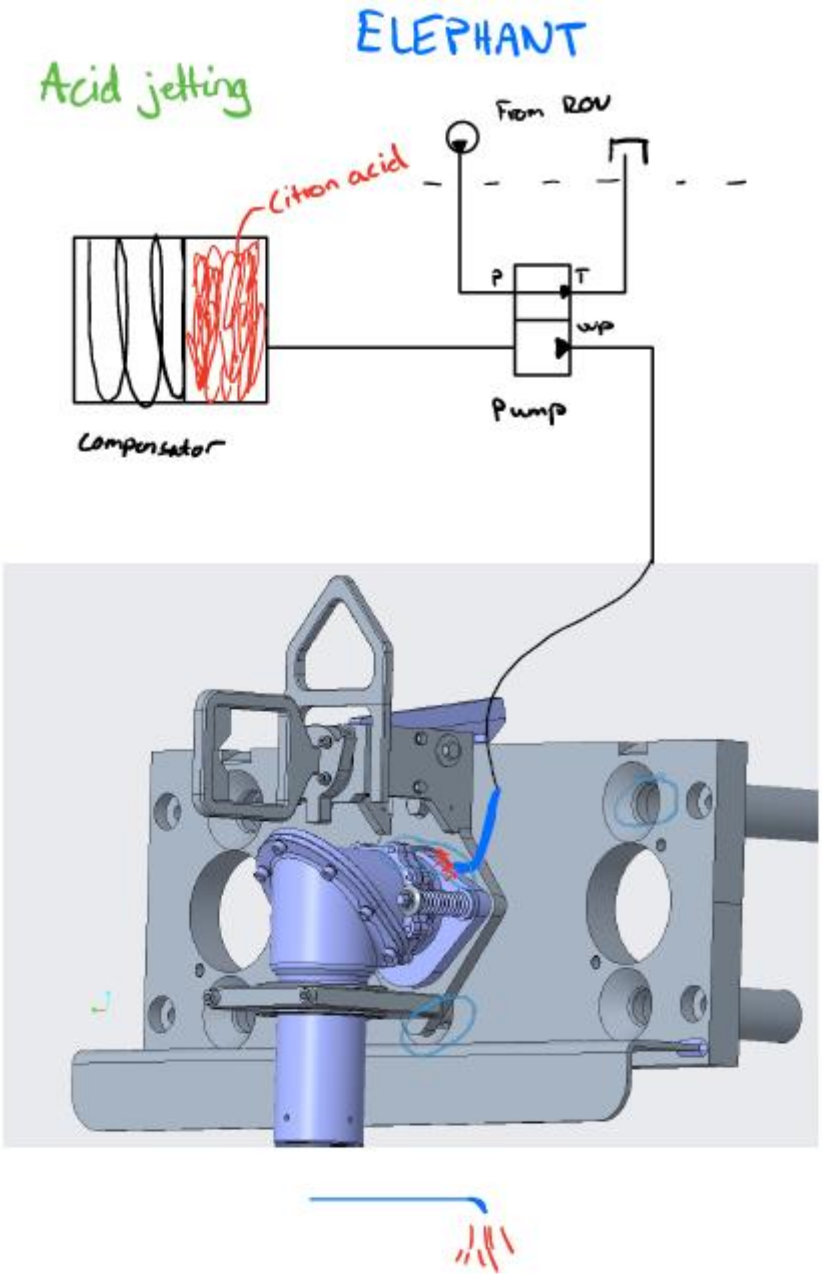


Figure 32 - Idea 16, from “Elephant” in Three Random Words

Idea 17 is a hydraulic press between the MV-head and the slot plate. The red box, shown in Figure 33, is the jack, and the blue circles are the cylinders. The box is fastened around the MV-head.

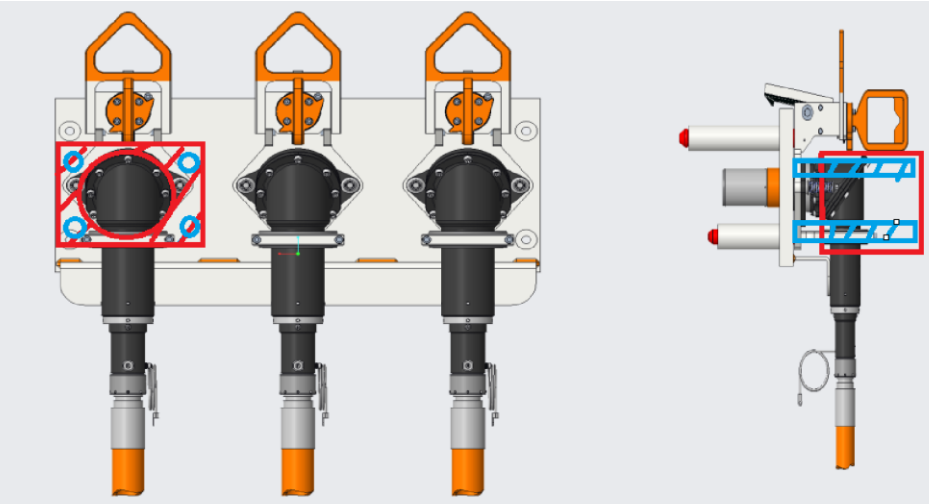


Figure 33 - Idea 17, from First Five

Figure 34 shows a jack. It uses an extractor with an extendable handle and springs, with two separate plates that can be connected with a hook. The blue springs are fastened in the purple plate and uses the plate where the connector is connected as a counterforce. To fasten the tool the ROV needs to mate two plates around the MV-head.

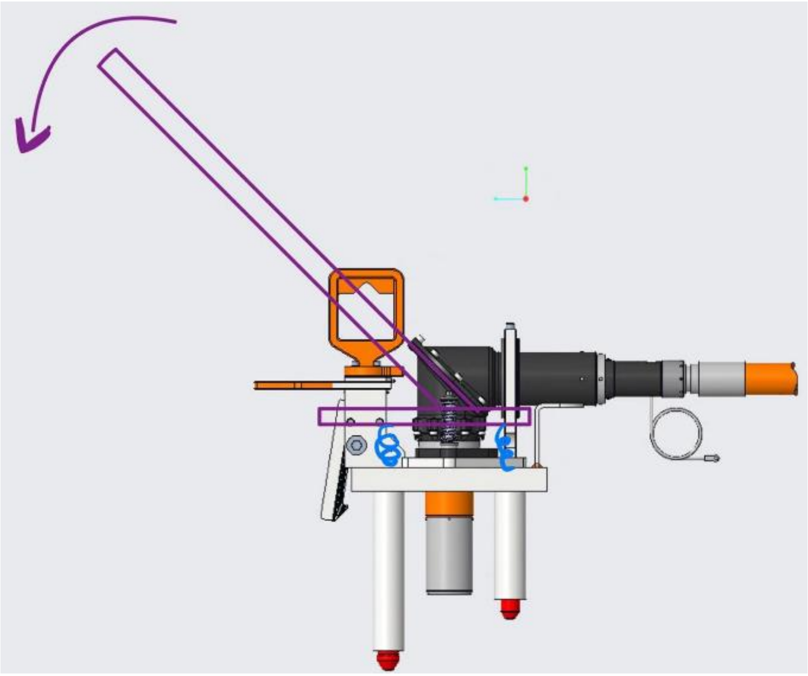


Figure 34 - Idea 18, from Brainstorming

The concept presented below takes the form of an extractor that employs threaded bolts to dislodge the MV-head. The tool will feature a movable skid, as illustrated in Figure 35, so that it can be mounted on the jumper cable. In the small gap between the cable and the plate, four hooks will be fitted to grip the cable, and as the bolts are turned, they will exert pressure to push the cable out.

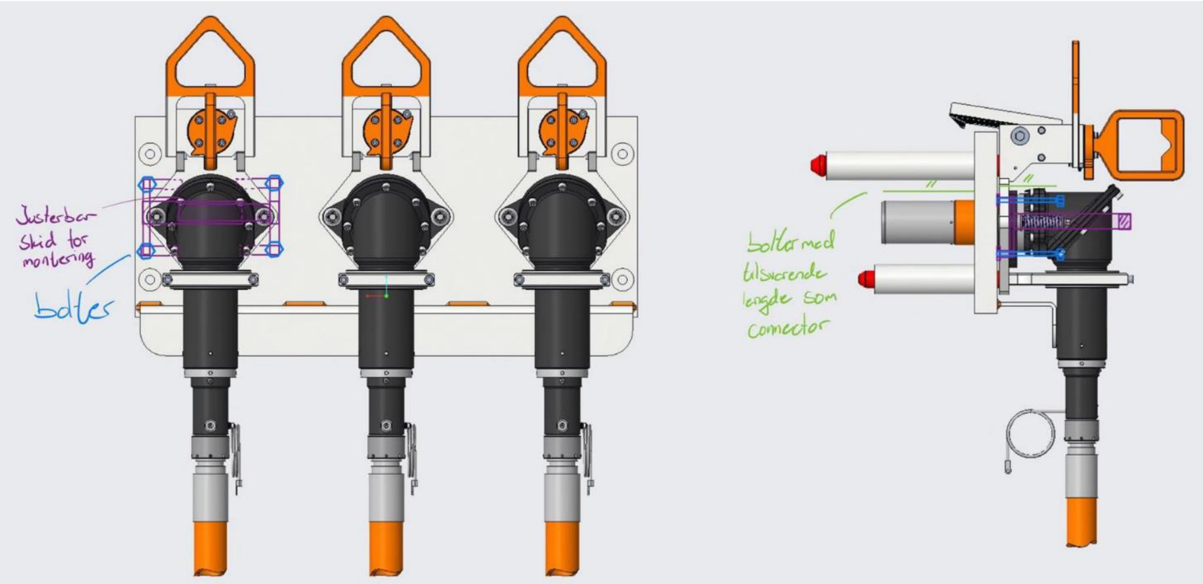


Figure 35 - Idea 19, from First Five

Idea 20 in Figure 36 is another extractor that uses bolts. The green plate will be mounted from the top and will use the edge of the flying handle as a counterforce. The blue bolts will then be unscrewed simultaneously, and the cable will come loose.

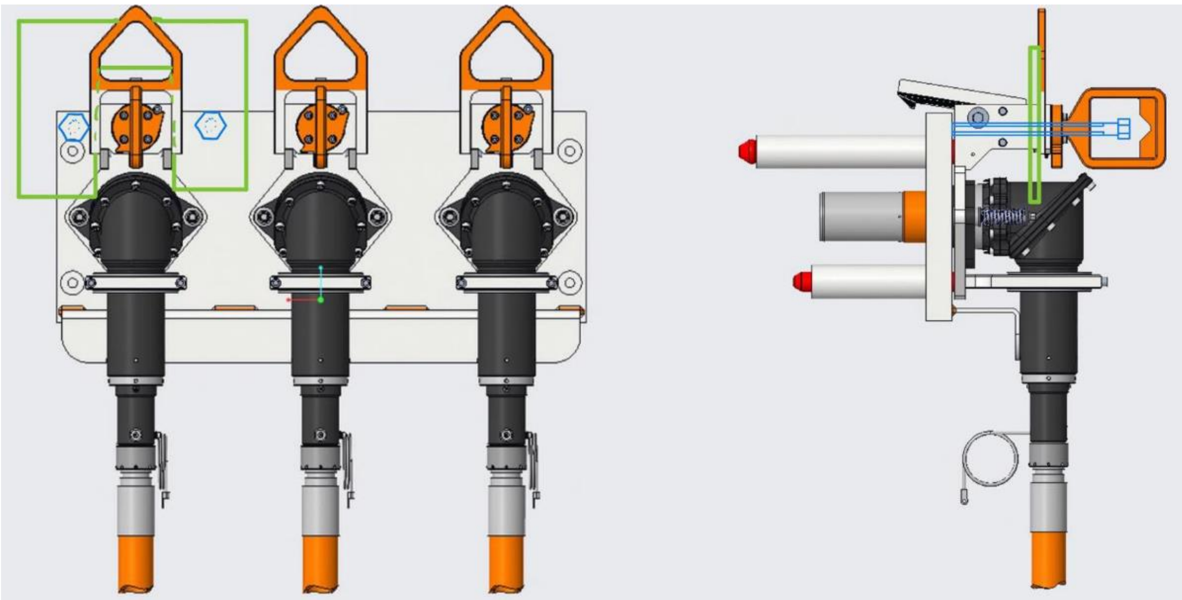


Figure 36 - Idea 20, from Brainstorming

The idea in Figure 37 uses an inflatable air cushion. The cushion will be placed in the tiny gap between the jumper cable and the plate, expand and then force the MV-head out.

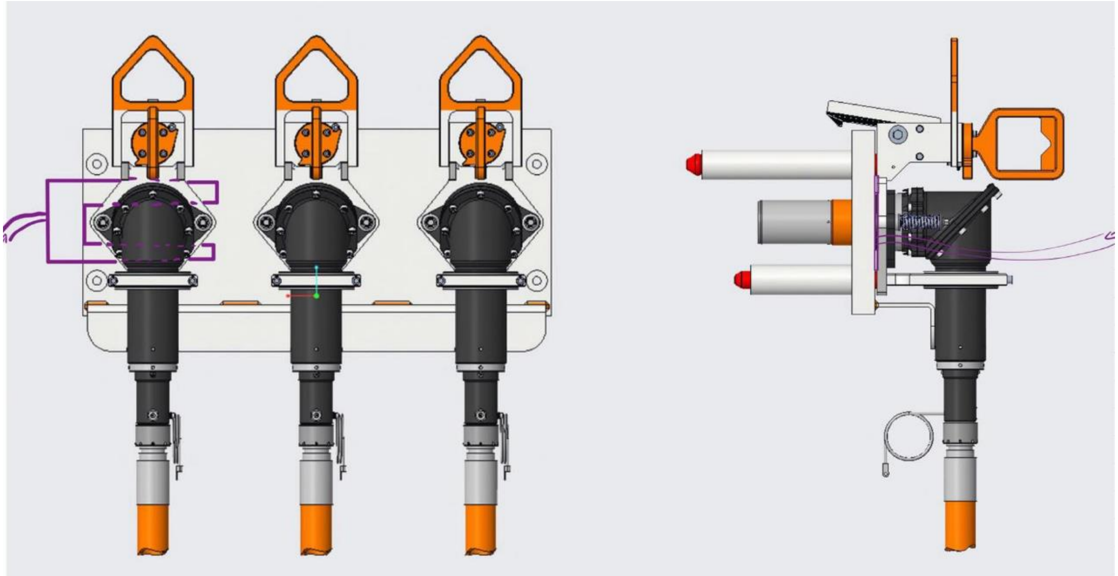


Figure 37 - Idea 21, from First Five

This next idea works like a telescopic jack. A plate is slid behind the flying handle and uses the edge on the handle as a counterforce. The ROV will pull down the handle on the tool and the cable will eventually come out. This is done little by little, and for each jack, the handle will extend to maintain the equal force distribution. This is shown in Figure 38.

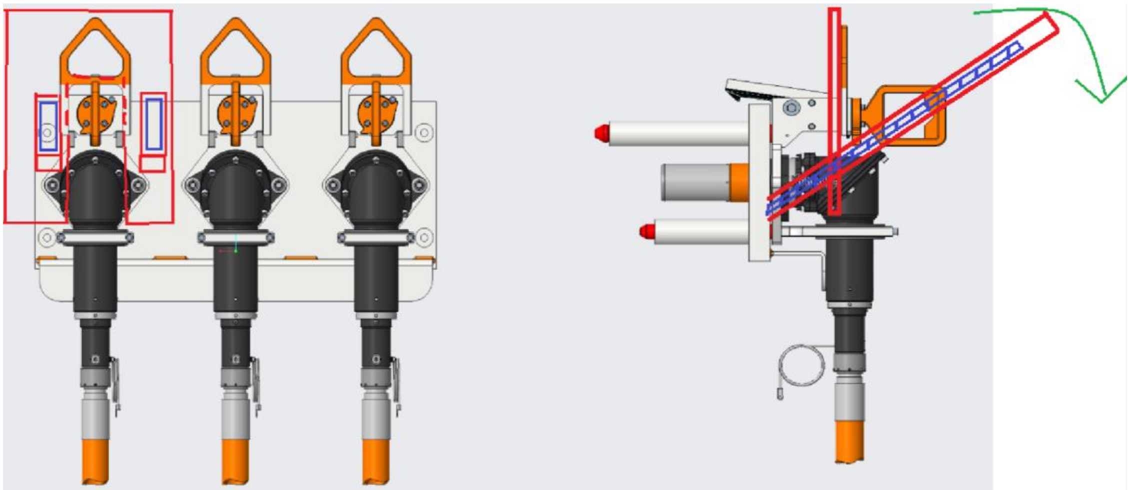


Figure 38 - Idea 22, from Brainstorming

The idea below is a line with a motor. The line is fastened in the jumper cable at one end, and a mini ROV in the other end, as shown in Figure 39. The ROV uses thrust in a repeated motion and thereby nudges the MV-head until it comes loose.

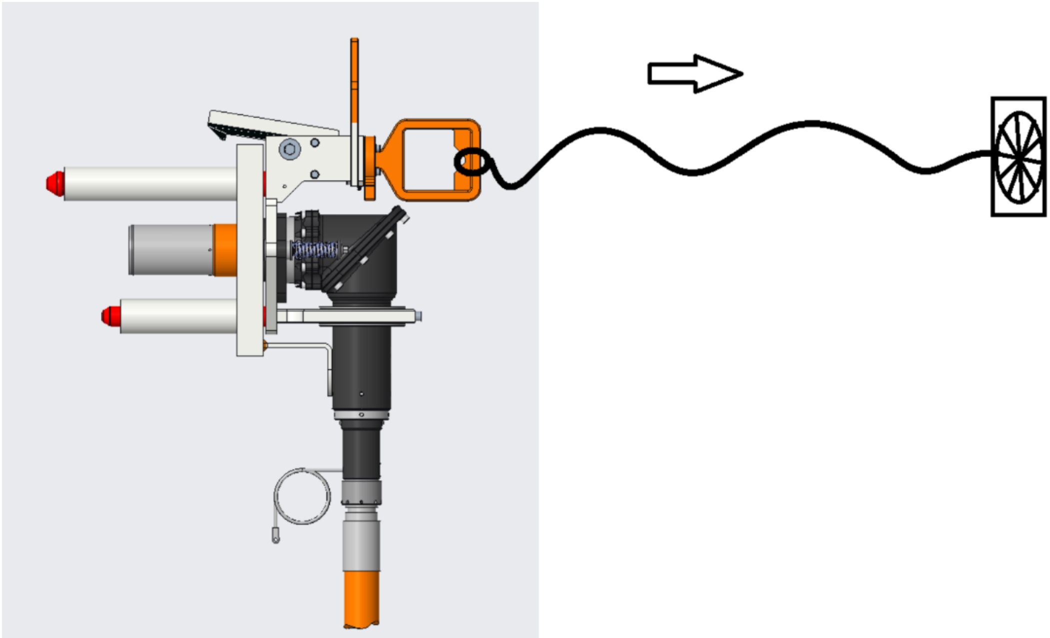


Figure 39 - Idea 23, from First Five

This idea can be called a thruster plate. Four small thrusters assist the ROV to pull the MV-head. This requires that the ROV also will pull the MV-head, as illustrated in Figure 40.

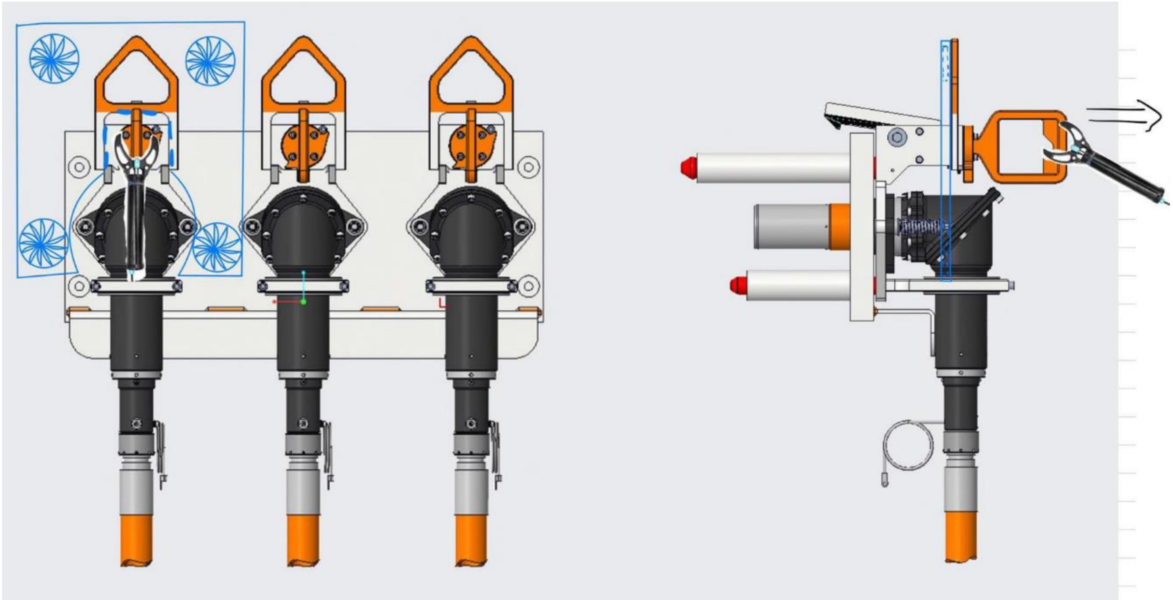


Figure 40 - Idea 24, from First Five

Idea 25 in Figure 41 is a cup that will be mounted on the MV-head. It has a hole for the flying handle so the handle can be used as a counterforce. The tool has four cylinders to push out the jumper cable. In addition to this, the tool has a tank containing acid, and this acid can be injected through small nozzles.

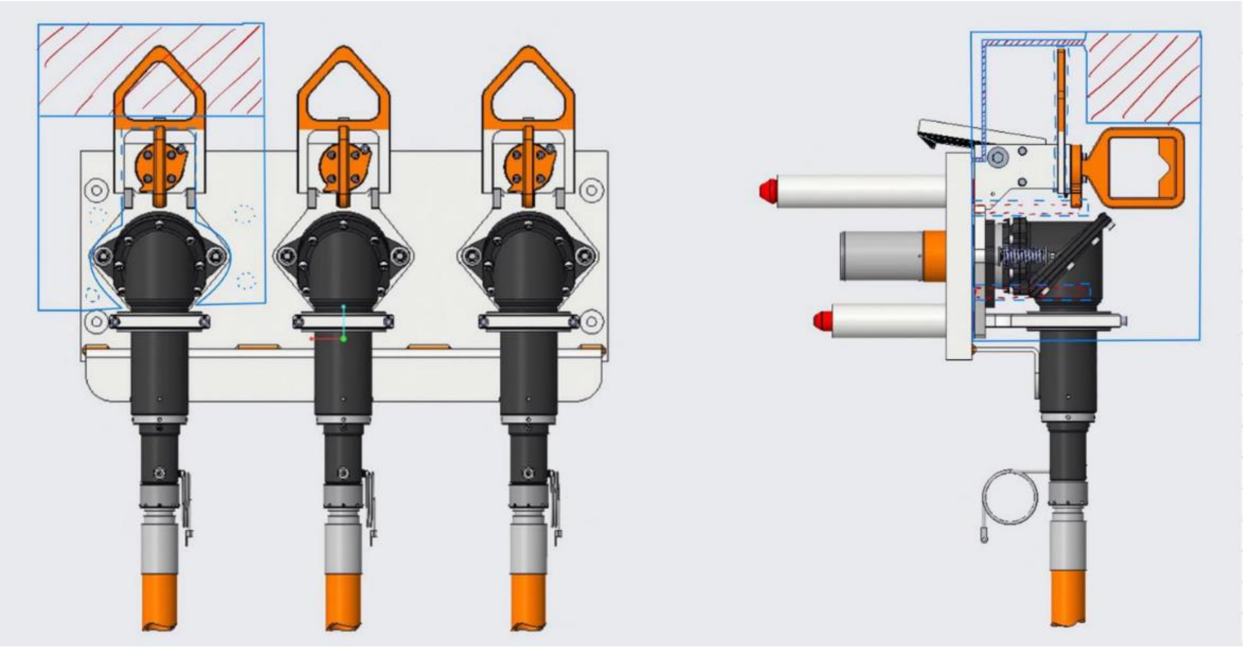


Figure 41 - Idea 25, from Brainstorming

The tool in Figure 42, will use both the handle and the bracket holding the cable as a counterforce and will use two cylinders to push the MV-head out.

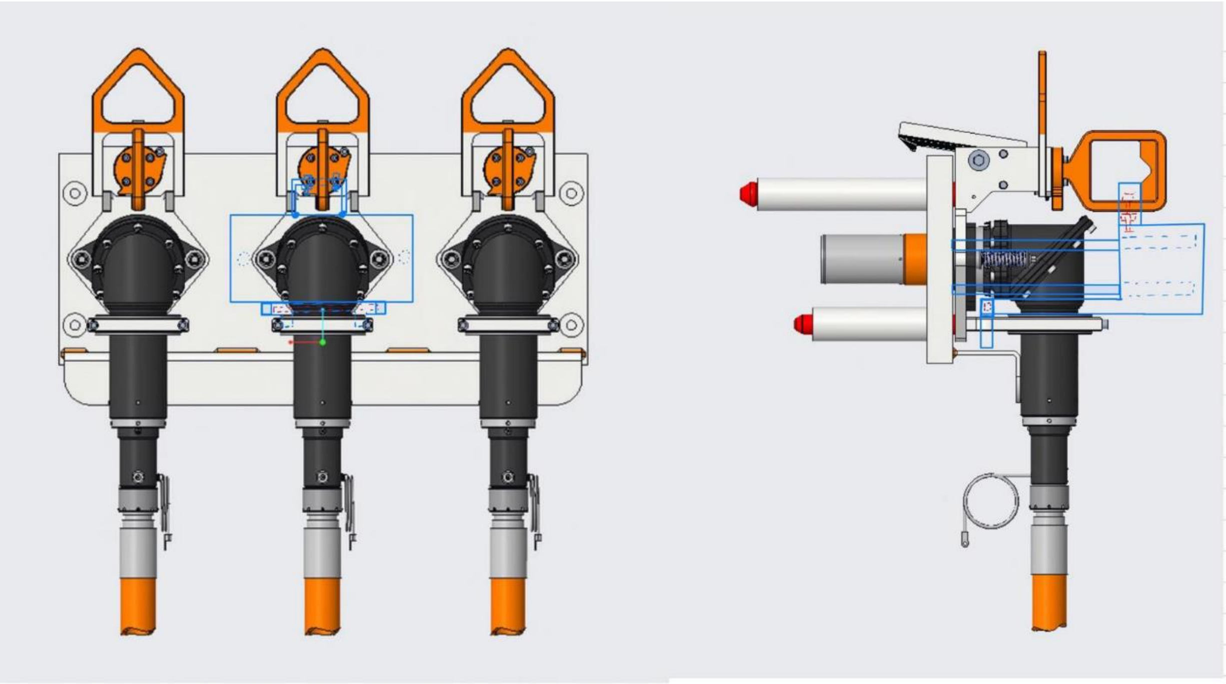


Figure 42 - Idea 26, from Brainstorming

In Idea 27, as shown in Figure 43, a small gap exists between the tool and the flying handle. This gap restricts the moment when the tool's two cylinders are used to push against the plate.

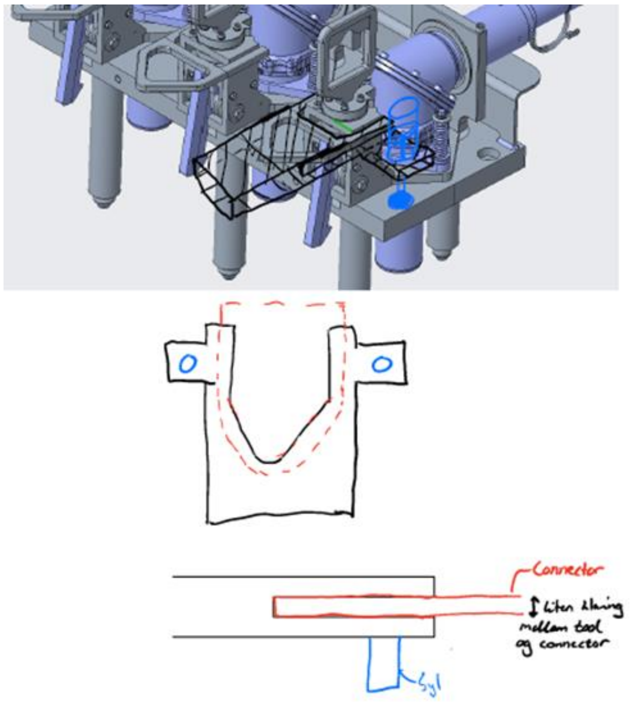


Figure 43 - Idea 27, from Brainstorming

Idea 28 shown in Figure 44 is a plate with four cylinders and an open/close function. The open/close function is operated by a fifth cylinder. The idea is that the tool can be mounted in an open position, and then closed once it is placed.

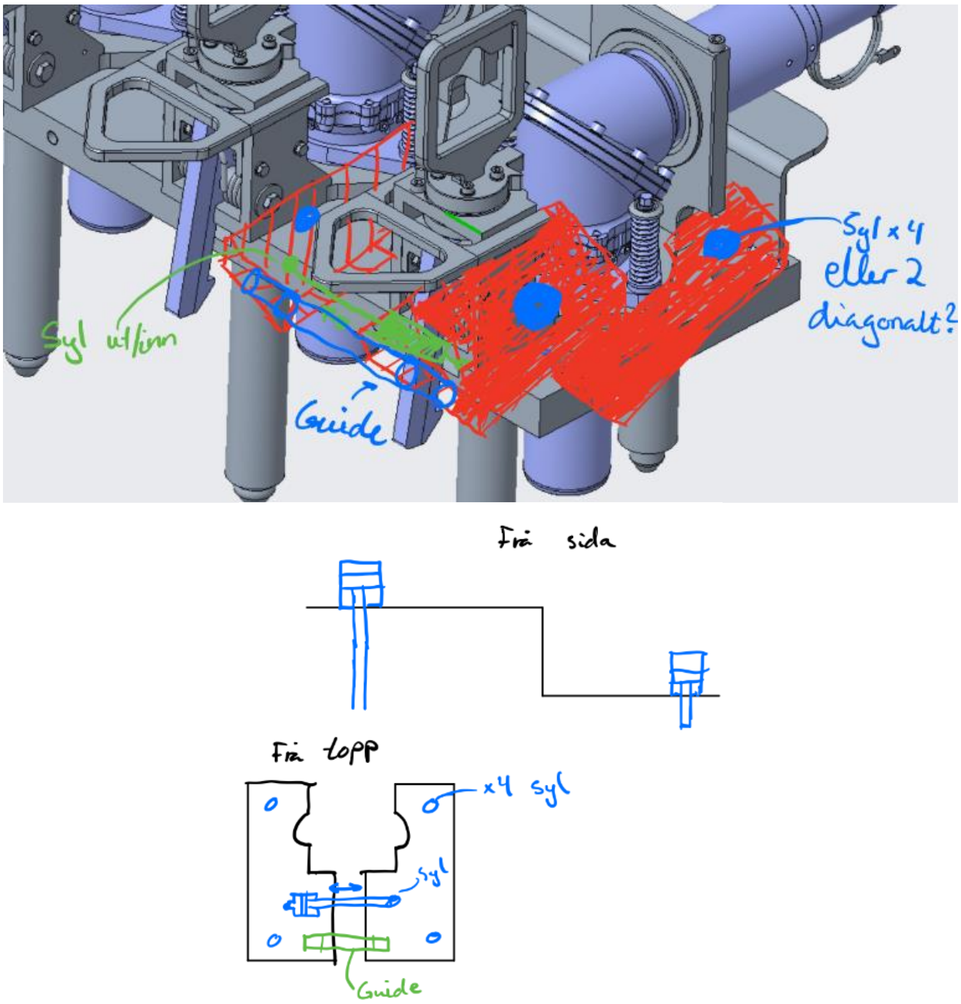


Figure 44 - Idea 28, from First Five

4.2.2 Criteria for a Customer

To create an effective tool, it is important to consider the “buyer's” perspective. A list of specs and functions is developed to ensure the tool meets their needs.

Specs:

- Protect power cable and pump module during operation (momentum, internal- and external damages)
- Handled by any WROV, ref. API Recommended Practice 17H – Remotely Operated Tools and Interfaces on Subsea Production Systems.
- Interface plate on pump modules can vary – tool must fit any interface plate.
- Field proven.
- Environmentally friendly.

Function:

- Easy to handle and operate for ROV crew.
- Safe and controlled pulling operation.
- Easy maintenance and good availability on spares.

4.3 Screening the Ideas

The Group is keeping a total of eight different ideas from the screening process. The ideas are selected based on their feasibility and functionality. The ideas are numbered from 1 to 8 and given a describing name.

4.3.1 Idea 1 – Telescope

Idea 1 is divided in two. They are very similar but have two different ways to be mounted on the MV-head. The first one, shown in Figure 45, will have magnets that will be connected to the back of the flying handle as a counterforce. The red handle is extended to ensure that the force always will be distributed in the middle of the connector. The ROV will pull down the handle and force the connector out. It is important to not pull the handle too much, because this will create a moment on the connector which can cause damage. This process will continue until the connector is loose and the ROV can easily take it out.

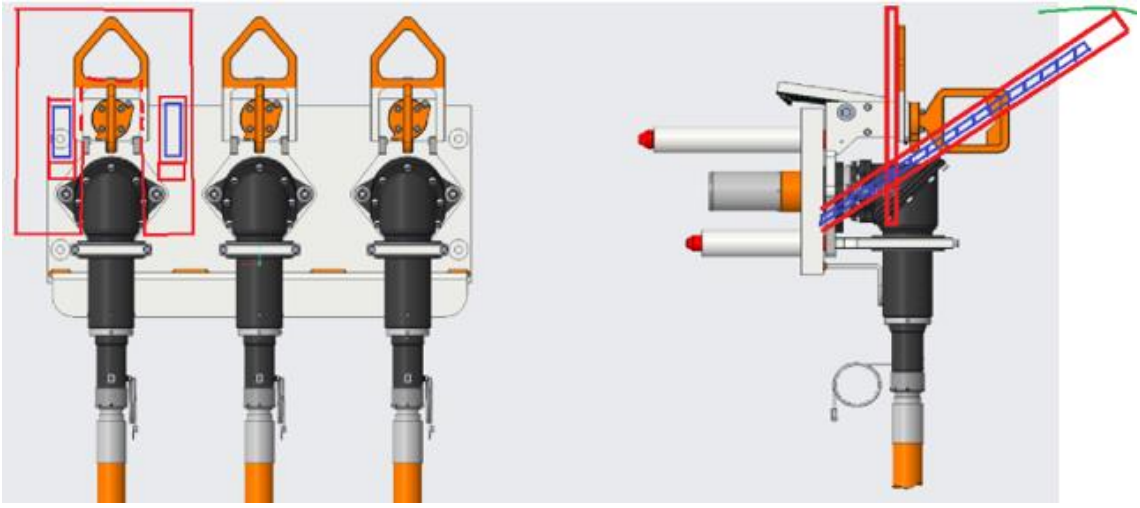


Figure 45 - Idea 1.0, from Brainstorming

When working with Idea 1, a new idea came up. The two ideas are very similar and therefore they are categorized as the same idea. The new idea, shown in Figure 46, uses the same principle, but is further developed by using the SCAMPER method. This tool will have a hole that fits over the flying handle with a small tolerance to have as much area as possible for counterforce.

This concept was discovered by using the C (combine) in the SCAMPER method where the idea in Figure 45 and the idea in Figure 43 were combined, to make the new design. There is also a small wheel at the end of the extender arm. This ensures that the force will enter at the right place and improves the friction. Except from the small changes in the design, the working principle is the same. The new idea is shown in Figure 46.

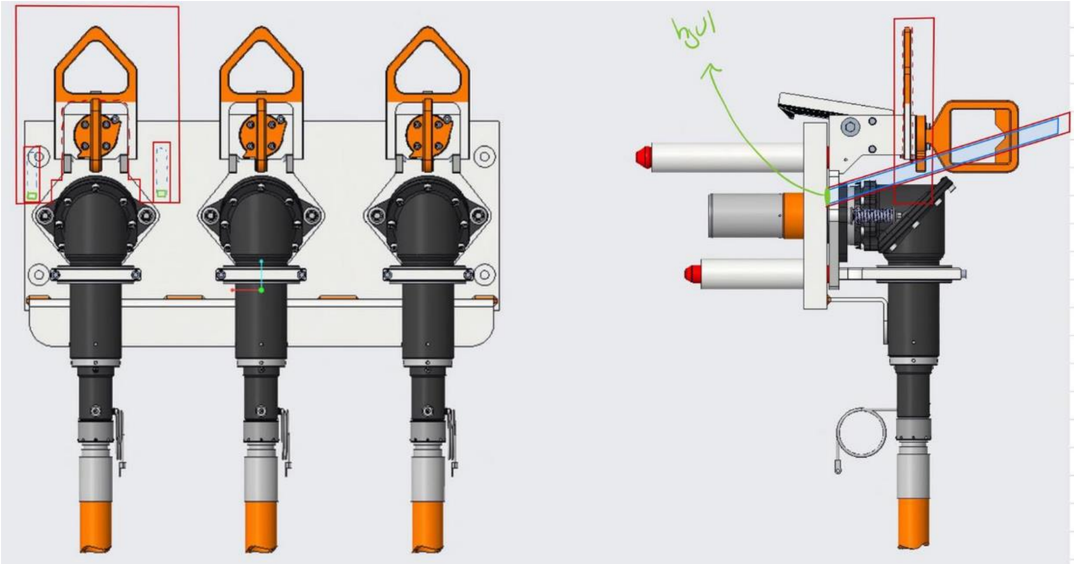


Figure 46 - Idea 1.1, from SCAMPER

4.3.2 Idea 2 – Pulling and Injection

This idea came up by using the three random words technique. The word was *octant*, which gave the design the shape shown in Figure 47. The idea is to have both a pushing force and an injection of an acid. The tool would have a tank with acid and tubes with a small pump to inject the acid into the locking pins and MV-head. It will act like a cup around the MV-head for sealing. After a while, the four cylinders will push out the MV-head.

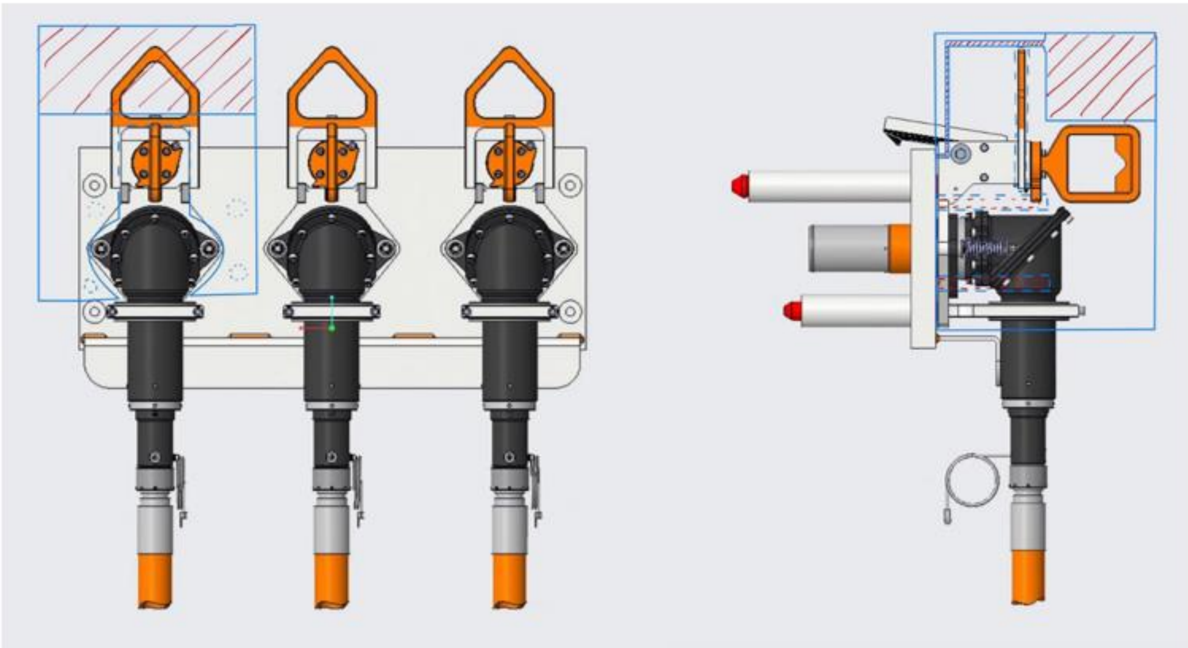


Figure 47 - Idea 2 from Three Random Words: Octant

4.3.3 Idea 3 – Hook Tool

In Figure 48, Idea 3 is shown. The idea is that it should be easy for the ROV pilot to mount the tool. The ROV can attach the tool from a space where it is no obstruction. The four hooks, used as a counterforce, should be mounted around the bracket and the flying handle. This could be done either by the ROV moving the hooks, or by additional cylinders. When the hooks are in the right position, the four pushing cylinders will be operated until the tool is under tension. The ROV let go of the tool, and the cylinders are operated again. This allows the ROV to keep a safe distance during the operation.

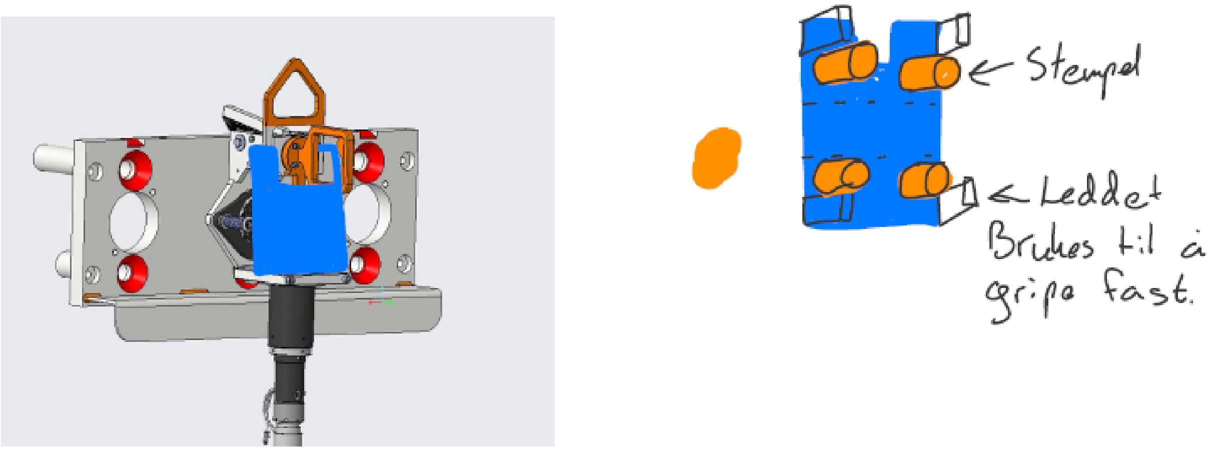


Figure 48 - Idea 3, from Brainstorming

4.3.4 Idea 4 – Shocking Tool

Idea 4 is a result from the SCAMPER method. As shown in Figure 49, the design is very similar to the shock cylinder shown in Figure 23. The difference is how the tool is mounted on the MV-head. In this idea, the tool will use the bracket and the flying handle as the counterforce. This punching method creates a vibration in the connector which breaks the bond between the MV-head and marine growth. The ROV can de-mate it easily afterwards.

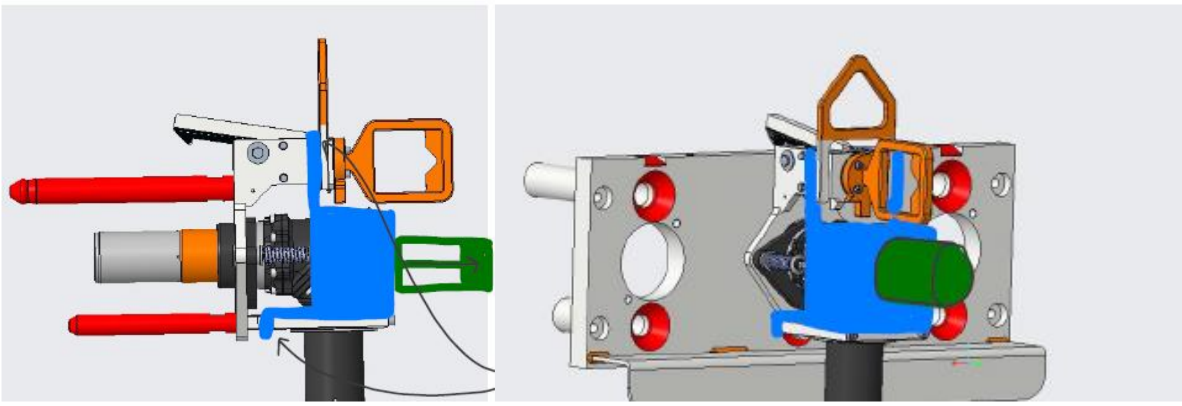


Figure 49 - Idea 4, from SCAMPER

4.3.5 Idea 5 – Plate with Cylinders

Idea 5, shown in Figure 50, enters from the front of the MV-head. It will be locked to the flying handle and bracket. Four cylinders will push against the slot plate and loosen the MV-head.

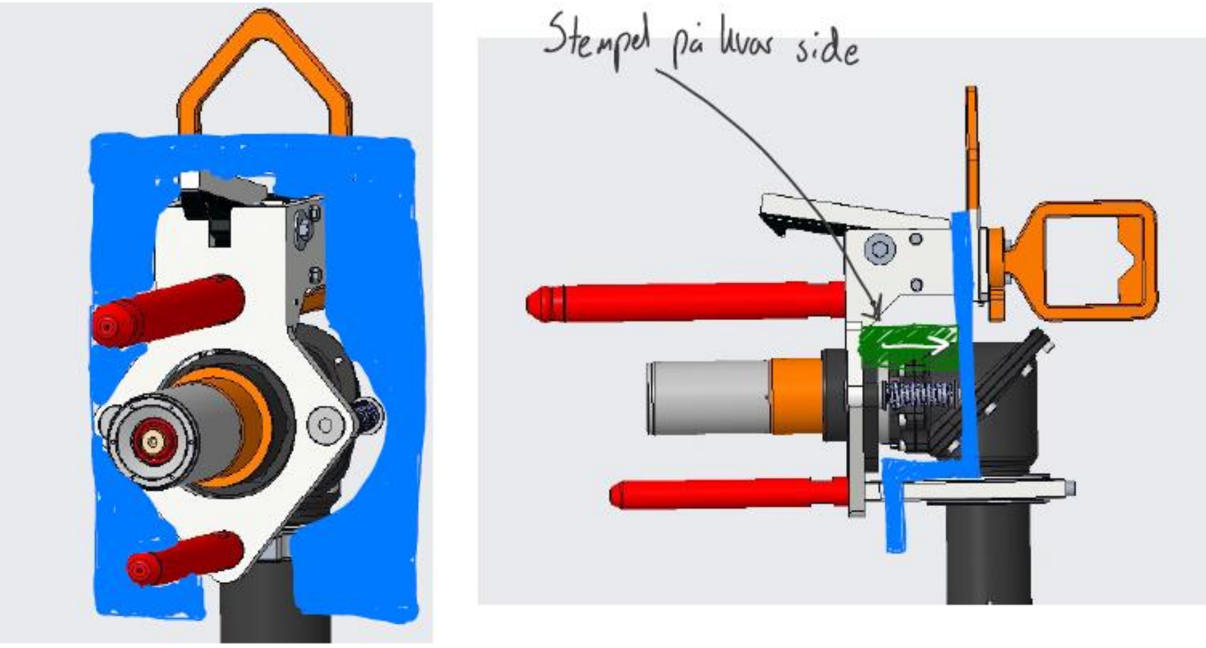


Figure 50 - Idea 5, from Brainstorming

Figure 51 shows a detailed view of the principle of Idea 5. There will be two separate plates held together with a cylinder. This cylinder will separate the plates during mounting and retract once the tool is in place. In addition, there is a guiding pin that makes sure the plates are aligned.

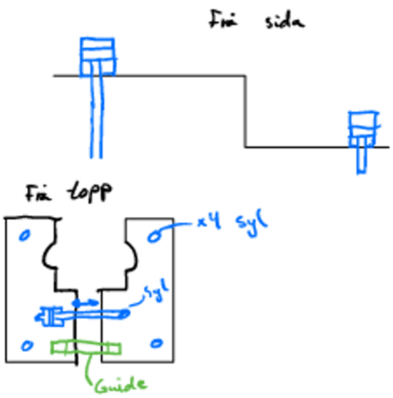


Figure 51 - Idea 5, detailed- and side view

4.3.6 Idea 6 – Groove Plate

Idea 6, shown in Figure 52, requires a steady ROV pilot since the tool needs to be guided into the flying handle with a small tolerance. This tolerance will make the counterforce more equal, and there will be less moment on the MV-head. There are two cylinders, on each side, which push the jumper cable out.

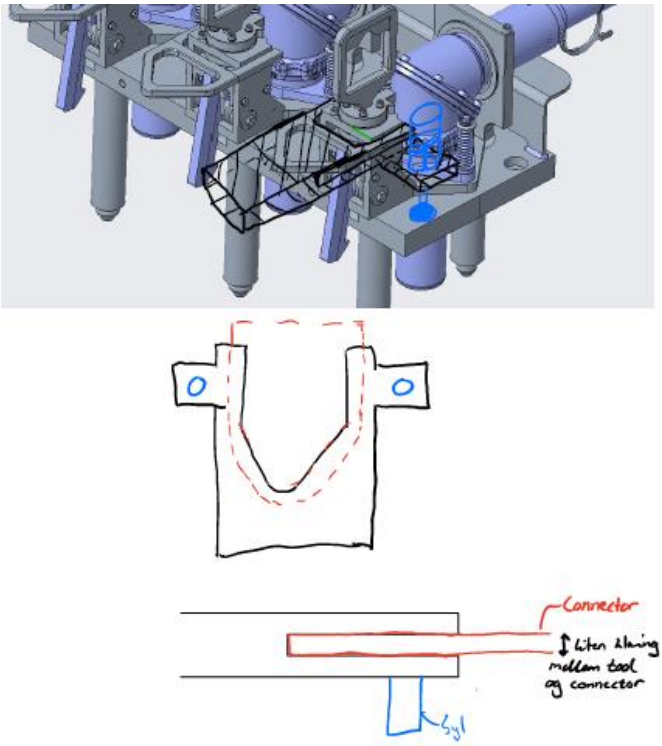


Figure 52 - Idea 6, from Brainstorming

In addition to this, there is room for extending the plate and adding two extra cylinders.

4.3.7 Idea 7 – Pushplate with Cylinders

Figure 53 shows Idea 7, where the point is to use the plate as a counterforce and the MV-head as the target force. There will be four cylinders that has the cylinder house partly inside the counterforce plate, and partly out in the free. The cylinders are connected in pairs and connected to a press-plate. The press-plate pushes against the flying handle and bracket. In this idea there could also be various extra functions, as magnets on the counterforce plate, to make it easy for the ROV to place the tool.

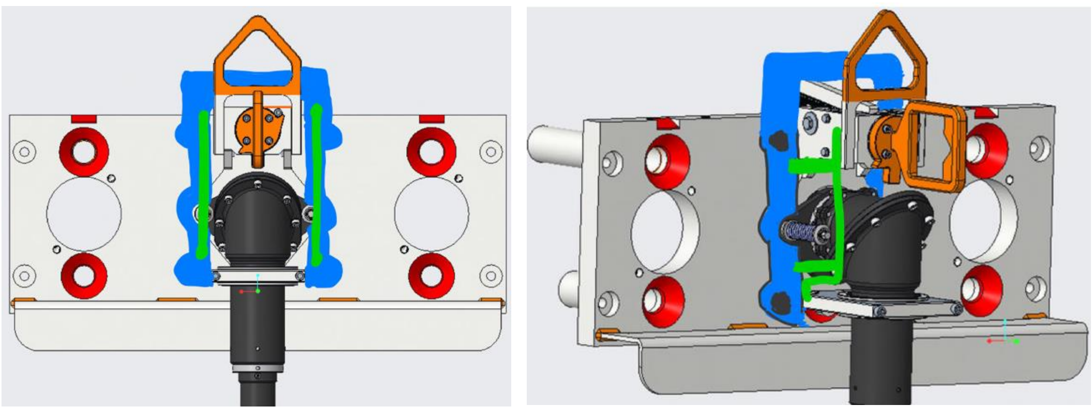


Figure 53 - Idea 7, from SCAMPER

4.3.8 Idea 8 – Magnet Plate

This idea is from a combination of the Three Random Words technique and SCAMPER. It uses magnets to attach to the MV-head as counterforce. There are two magnets, one on the front of the flying handle and one at the front of the bracket. There can also be two additional attachments, shown in green in Figure 54. This will make the tool more robust. To get the MV-head out, there will be two or four cylinders to push against the slot plate.

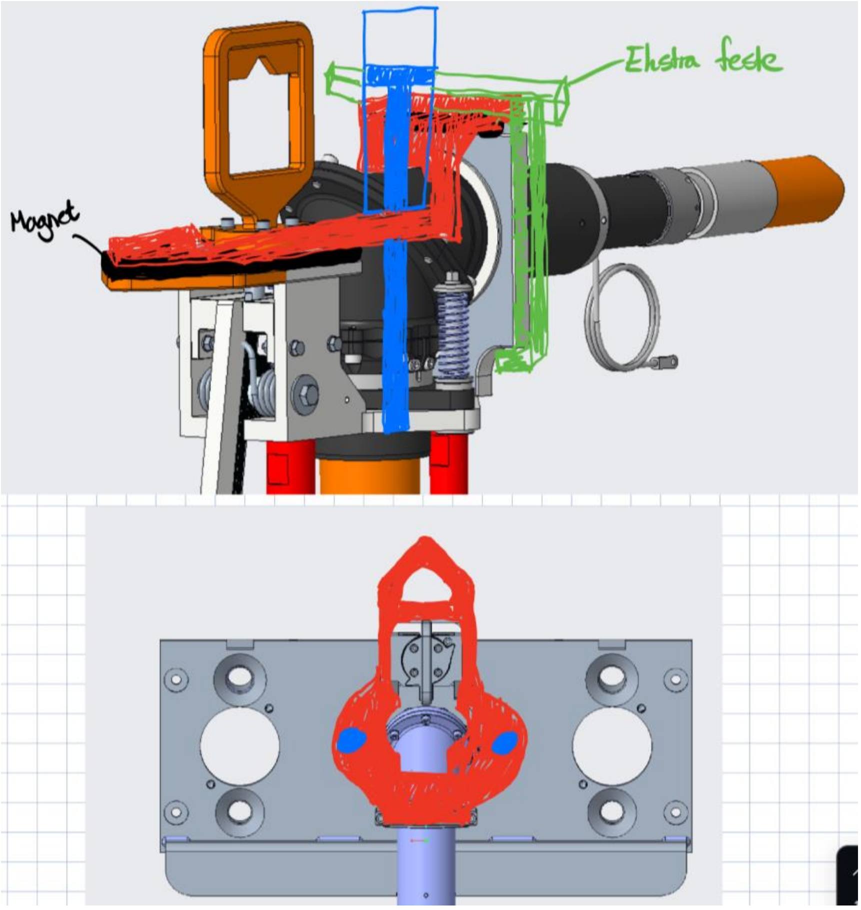


Figure 54 - Idea 8, from three random words and SCAMPER

All these eight ideas will be brought forward to the weighted decision matrix in the next chapter.

4.4 Weighting Decision Matrix

The criteria in the matrix are vital to achieve the objective of the project. The Group picked out six different criteria, based on the Company's requirements and the Group's decisions.

The criteria are weighted from 1-5:

- 1: Insignificant
- 2: Not so important
- 3: Average
- 4: Important
- 5: Crucial

Every idea is given a value between 1-5 for each criterion.

The valuing is:

- 1: Useless
- 2: Bad
- 3: OK
- 4: Good
- 5: Very good

The value is multiplied by the weighting of the criteria and summed up to a total score.

4.4.1 Criterion 1 - Force Distribution

The force distribution during the pulling operation is the root behind the initiation of this project. The pulling handle on the MV head (Figure 2) creates a moment on the connector during the pulling with the ROV manipulator and can therefore destroy the MV head. It is crucial that the SSRT delivers an equal force distribution to the MV head.

Force Distribution weighting: 5

4.4.2 Criterion 2 - Efficiency

The efficiency values how effective the disconnecting operation will be. From the time the ROV grabs to the subsea module, until the MV head is disconnected and the SSRT job is done. Since the operation is not an "everyday" task, efficiency is not so important as long as the operation is successful.

Efficiency weighting: 2

4.4.3 Criterion 3 - ROV Handling

During the operation, the SSRT must be easy to handle by the ROV pilot. Only one manipulator arm (7-function) is available because the other manipulator arm must be used as a grabber to the subsea module. Parameters like weight, complexity of the SSRT, number of movements on the manipulator, and the visibility for the ROV pilot are important.

ROV Handling weighting: 4

4.4.4 Criterion 4 - Pollution

UN-17's (United Nations) sustainability goals are made to achieve a better and more sustainable future. The SSRT can have an impact on goals like nr. 13, "Climate Action" and nr. 14, "Life Under Water". Even though it is the Company that is going to do the operation, the Group, as a supplier, must facilitate the SSRT to be a sustainable ROV tool. [38].

Possible emissions for the SSRT can be hydraulic leakage, paint, corrosive medium and material disposal. Since the Company have the possibility to use water based hydraulic oil and paint, the most crucial parts disappear. The SSRT will be made robust to handle the operation, so the risk for material disposal is small.

Pollution weighting: 3

4.4.5 Criterion 5 - Acid Injection

The Company has a wish, not a requirement, that the SSRT can also inject acid to the MV-head before the disconnecting operation starts. The acid will help to dissolve the corrosion and marine growth to make an easier de-mating. The Group concluded during the ideation that this will require a very advanced ROV tool.

Acid Injection whitening: 1

4.4.6 Criterion 6 - Possibility Factor

The possibility factor tells how likely it is that the tool will work. This is not a fixed parameter, but unique for every idea. One example can be Idea 8 in Figure 54, where electromagnets are used to mount the SSRT on the MV-head - is the area of the magnets big enough to hold the force during the pulling operation?

Possibility factor weighting: 2

4.4.7 Weighted Decision Matrix

Idea 5, 7 and 8 are the three designs that stands out, shown in Table 7. The similarities are the use of hydraulic cylinders to produce force, and brackets that do not create momentum on the MV-head.

Even though the Group has finished the Weighting Decision Matrix, the ideation part is still not completely closed. During 3D modeling, new ideas on how to solve the objective can occur.

The next step is to make simple 3D models of the three ideas and look for errors and adjustments to see if the designs are feasible. There will also be a design review with the Company, where the ideas and 3D models will be presented and discussed.

Table 7 -Weighted Decision Matrix results

Weighted Decision Matrix

Criteria	Weightening	Idea 1 Telescopi	Idea 2 Pulling and injection	Idea 3 Hook tool	Idea 4 Shocking tool	Idea 5 Plate with cylinders	Idea 6 Groove plate	Idea 7 Pushplate with cylinders	Idea 8 Magnetplate
Force distribution	5	3	5	5	5	5	3	5	5
Effieciency	2	2	1	2	2	4	4	4	5
ROV handling	4	2	1	3	3	4	4	4	5
Pollution	3	5	1	4	4	4	4	4	4
Acid injection	1	1	1	1	1	1	1	1	1
Possibility factor	2	2	1	3	2	4	2	4	2
Total		47	37	60	58	70	56	70	72

Weightening: 1-5
5: Crucial
4: Important
3: Average
2: Not so important
1: Insignificant

Valuing: 1-5
5: Very good
4: Good
3: OK
2: Bad
1: Useless

4.5 Preliminary Designs

After the ideation process where the goal is to find different solutions, the Group ends up with three different designs which will go through the Front-End Engineering Design (FEED) phase. During this phase, the objective is to focus on getting a preliminary design. Project parameters must also be in mind, but all the details will come during the Engineering chapter.

A drawing of the MV-head is made to get an overview of the measurements, Figure 55. One of the biggest challenges is the space between the MV-heads when connected, Figure 56.

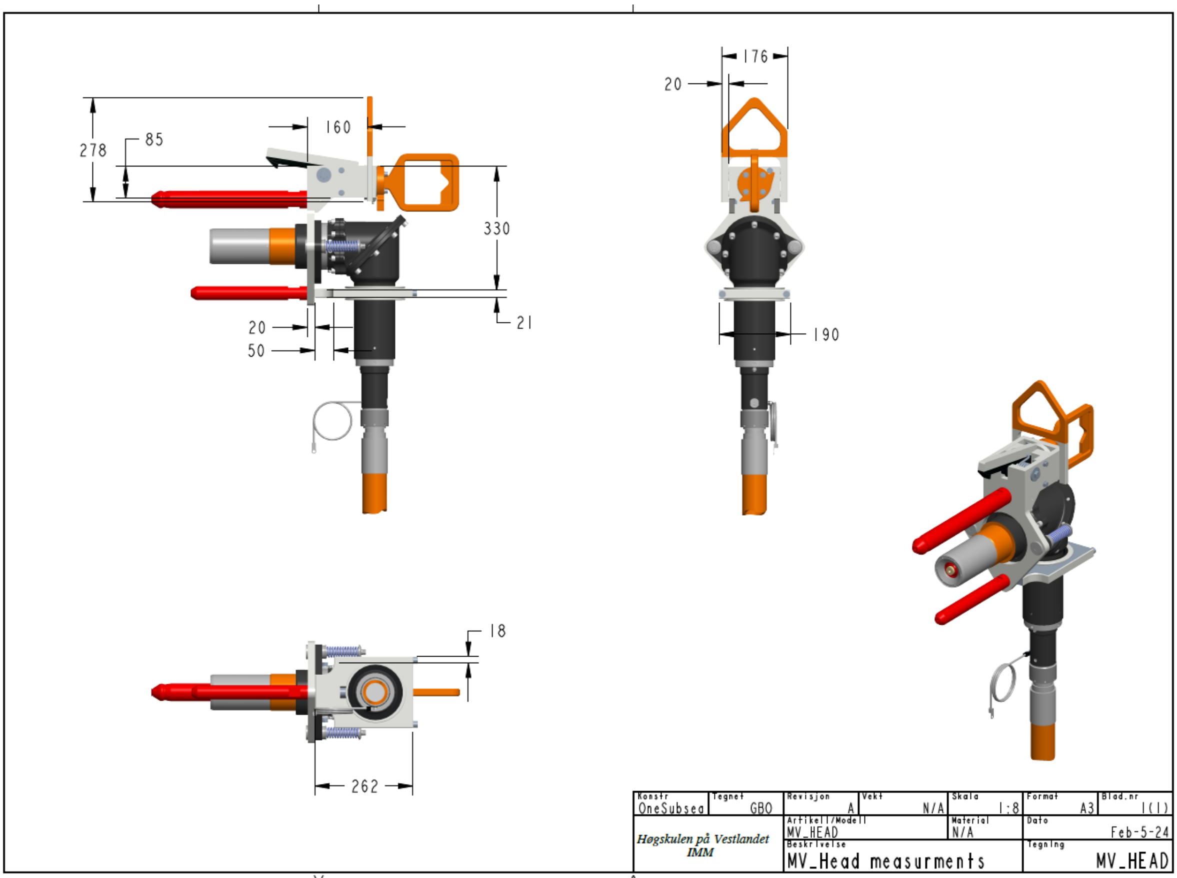


Figure 55 - MV-Head measurements

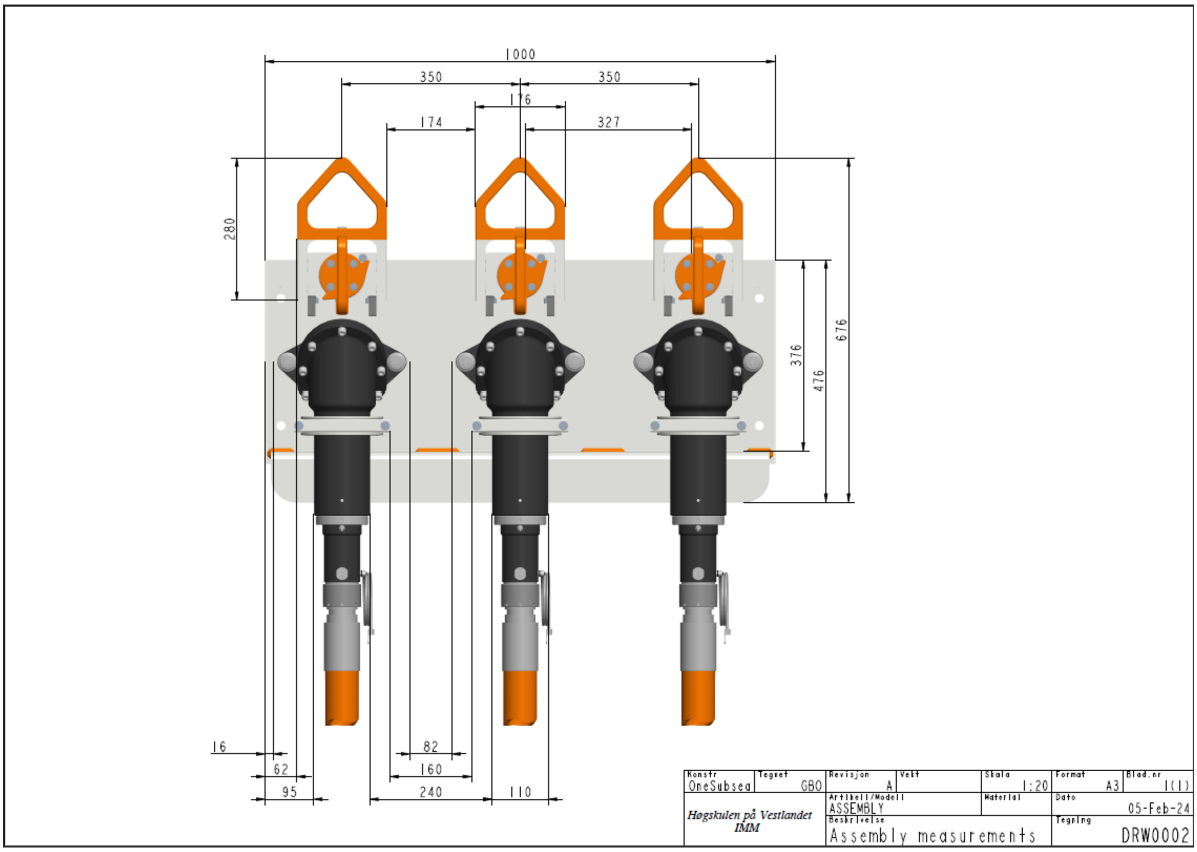


Figure 56 - Interface plate measurements

All three ideas that are brought forward to FEED have in common to interface with the flying handle and the MV-head. The Siemens specTRON connector is not designed to be interfered with other forces. It is possible to enter the SSRT from above the MV-head or directly from the front. The first objective is to find out if it is space enough to interface with both the flying handle and the connector head.

The members of the Group will make a preliminary design on each idea. Details like material width, correct equipment, forces, design details, etc. are not accounted for. The ideas will be taken to the Company for design review.

4.5.1 Idea 5 – Plate with Cylinders

Idea 5 original plan was to slide the tool from top of the MV head, and be locked in place by a cylinder, shown in Figure 57, Figure 58 and Figure 59.

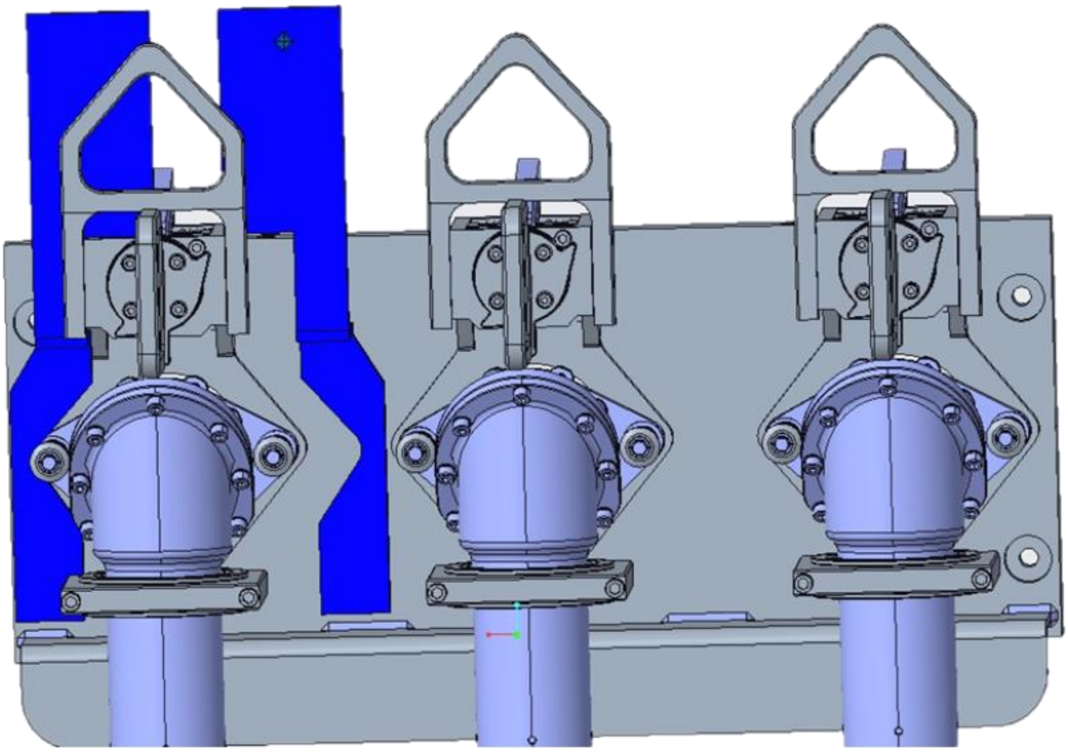


Figure 57 - Idea 5 Mounting Position (front view)

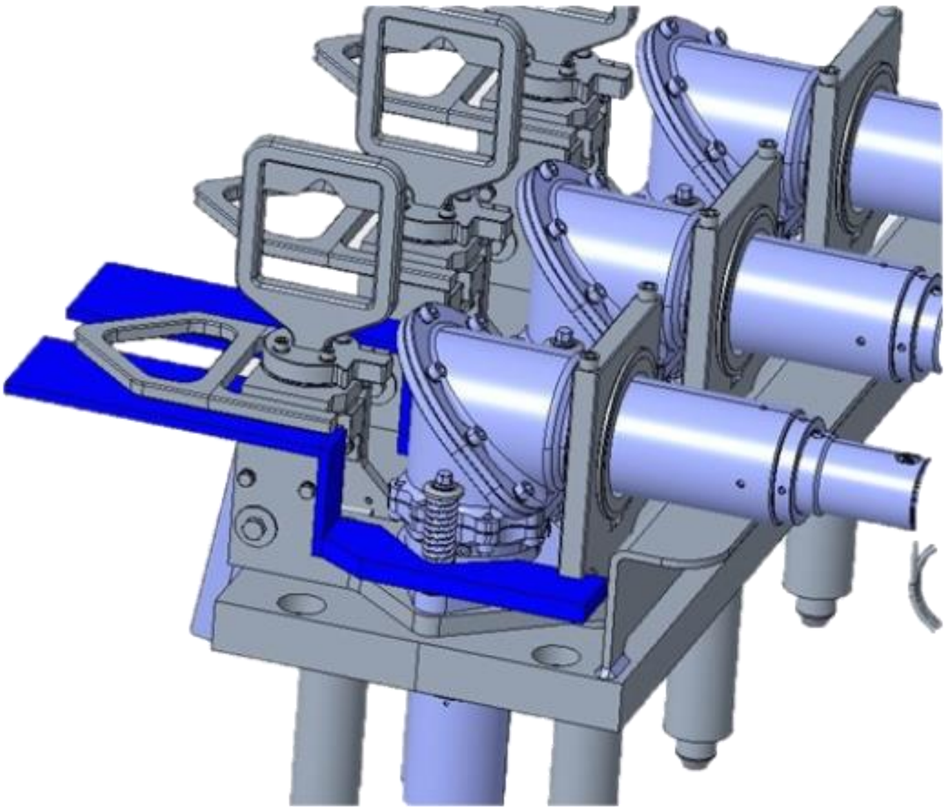


Figure 58 - Idea 5 seen from the side

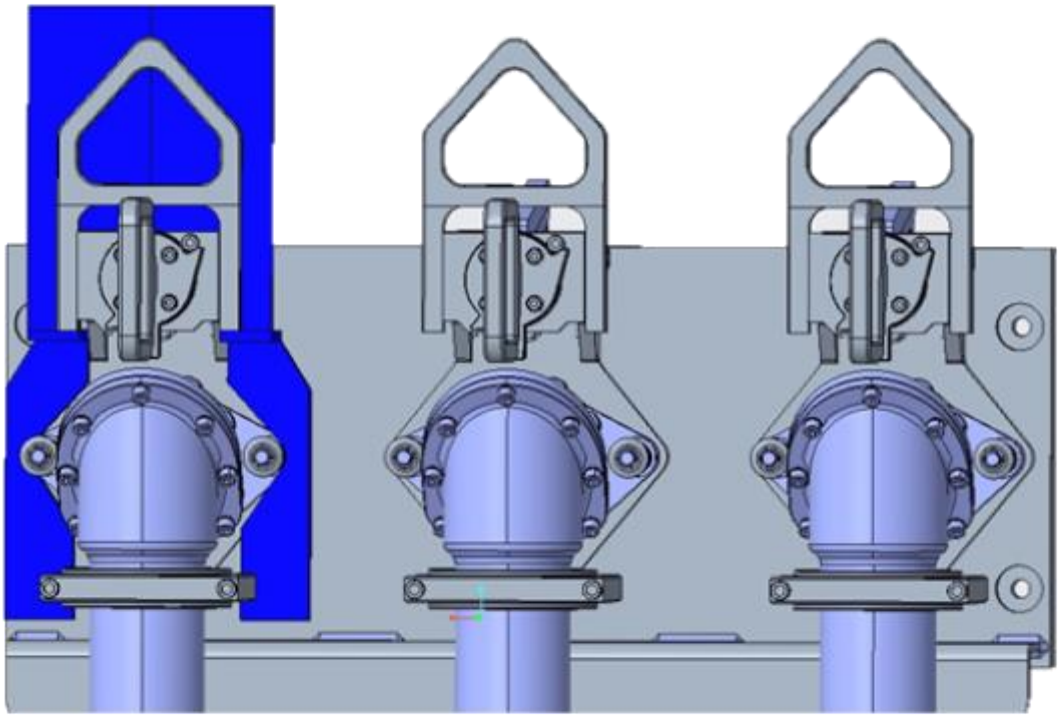


Figure 59 - Idea 5 in locked position (front view)

The springs on MV-head makes the width of the bracket very tiny due to the mounting, which can cause a problem. Changes to the mounting method is made and Idea 5 will now be entered from the front.

Figure 60 and Figure 61 shows the new preliminary design where the SSRT is installed directly to the MV-head. The width on the cylinder bracket is much better, and the cylinders has enough space. The size of the cylinders (Ø25/16) are checked for availability on the market, and there are several suppliers who delivers these types of cylinders.

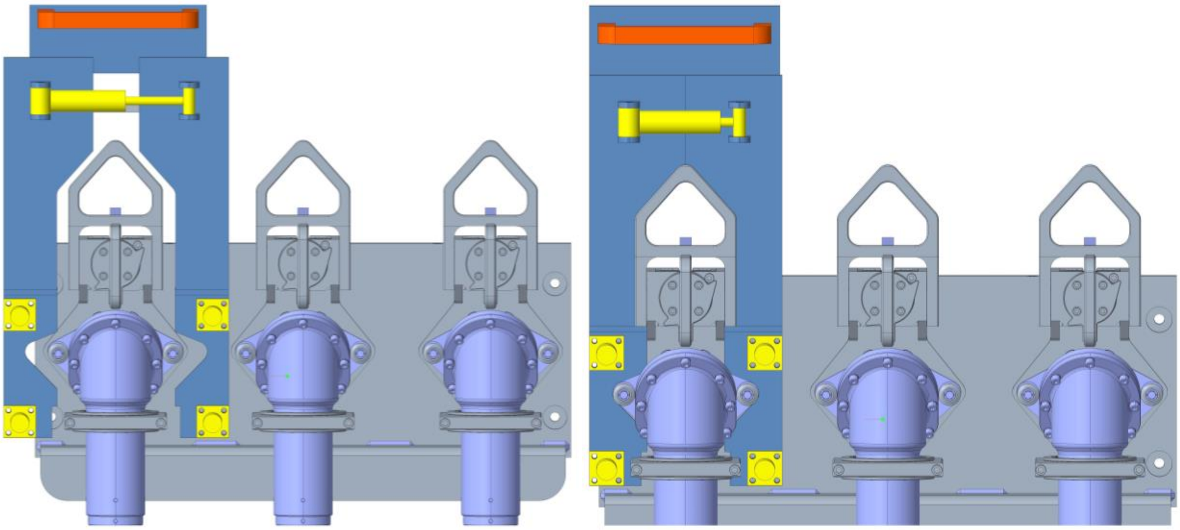


Figure 60 - Idea 5 in open and closed position (front view)

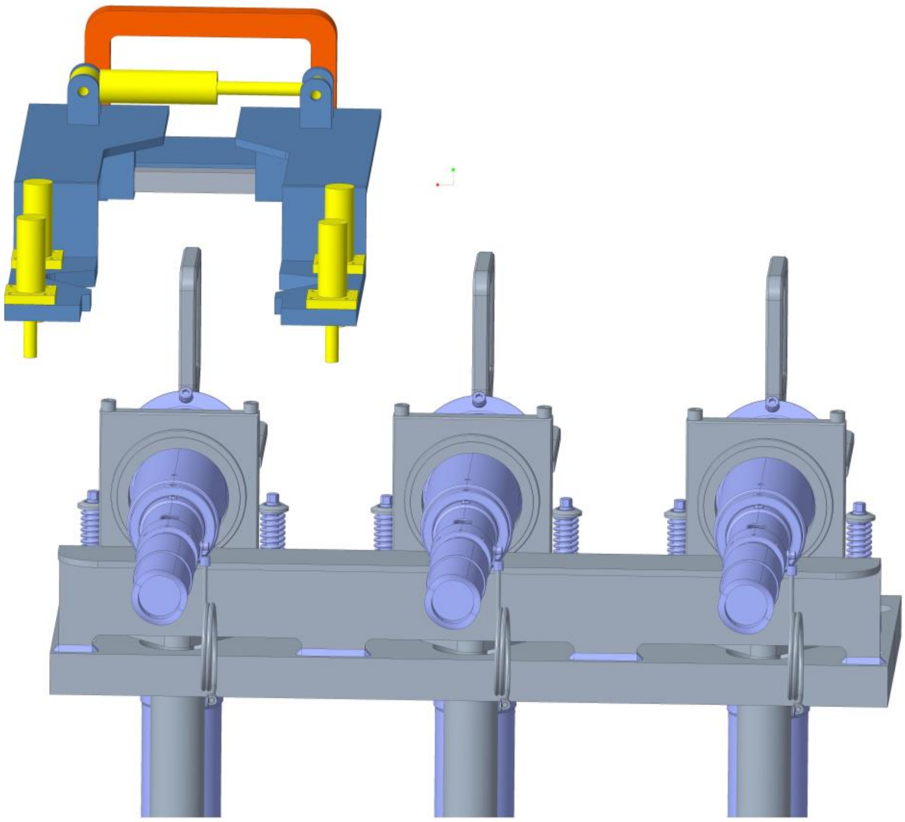


Figure 61 - Idea 5 during mounting

4.5.2 Idea 7 – Pushplate with Cylinders

Idea 7 has similarities with Idea 5, but instead of having cylinders pressing against the slot plate, the cylinders are pushing the MV-head outwards. Two cylinders on each side are fixed to a plate, using the same contact points as the plate in Idea 5. Figure 62 shows the idea behind this design. During the design process, two issues must be solved. Firstly, the length of the cylinders is limited, and getting the tool into position is not possible with such a design.

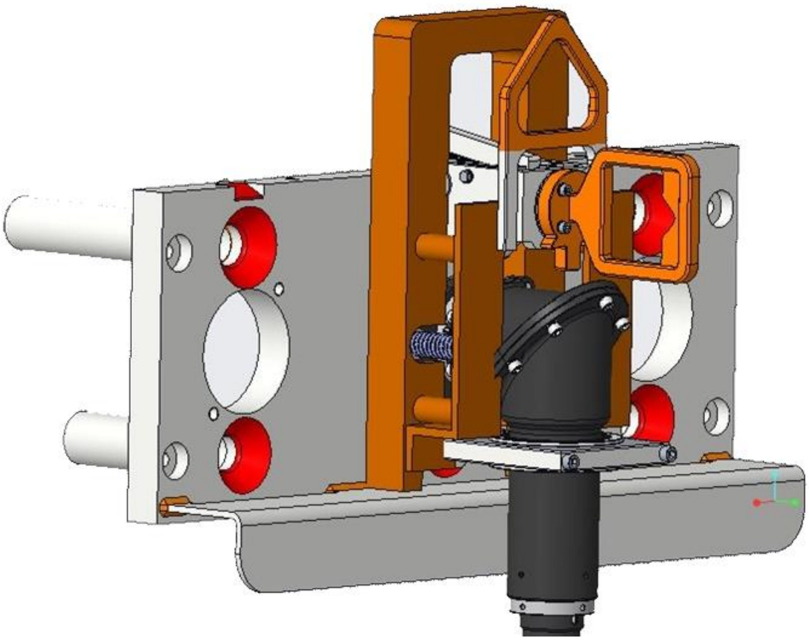


Figure 62 - First 3D-model of Idea 7

Figure 63 shows the new design of Idea 7. Getting the tool into position will now be possible using a cylinder (illustrated in yellow), with an open/close function. The tool enters from the front in open position, and then mates the two sides of the tool. The new design also features two orange ROV flying handles. These handles must slide along with the tool as it opens and closes.

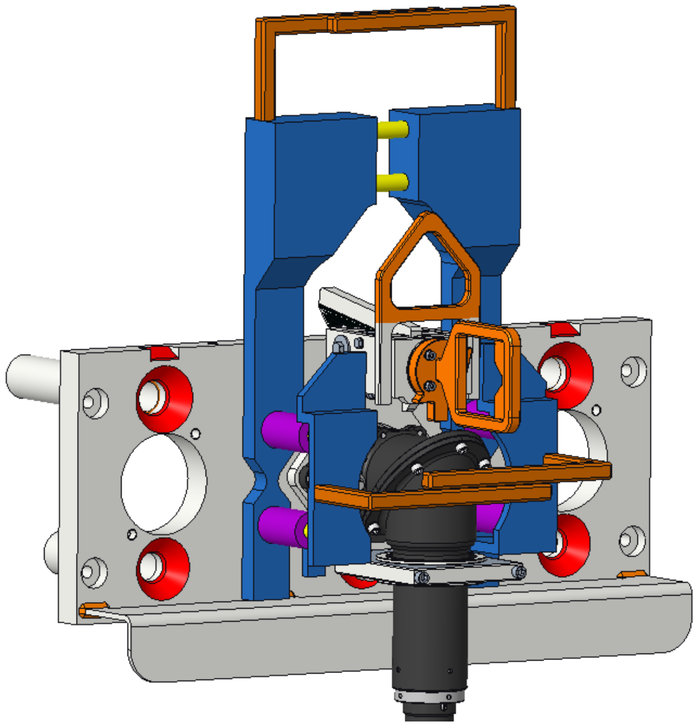


Figure 63 - Idea 7 in open position

The issue with the limited length of the cylinders is solved by extending the press plate outwards. The plate can be extended further if required, essentially erasing the issue with the cylinder length. Figure 64, Figure 65 and Figure 66 visualizes the preliminary design of Idea 7.

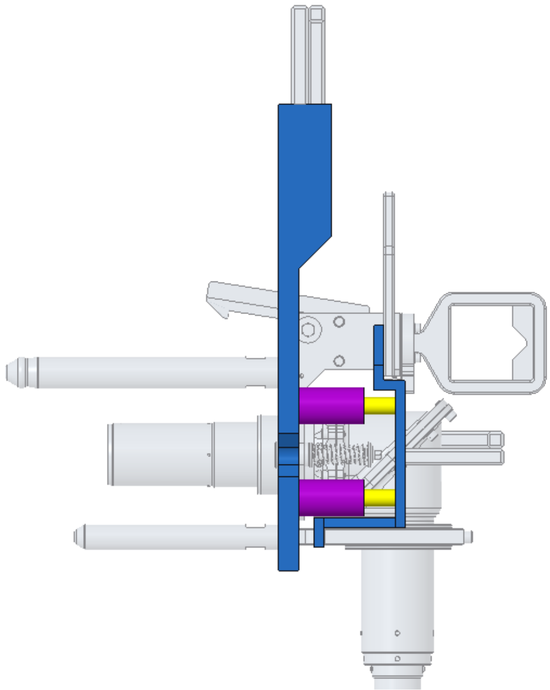


Figure 64 - New plate design (side view)

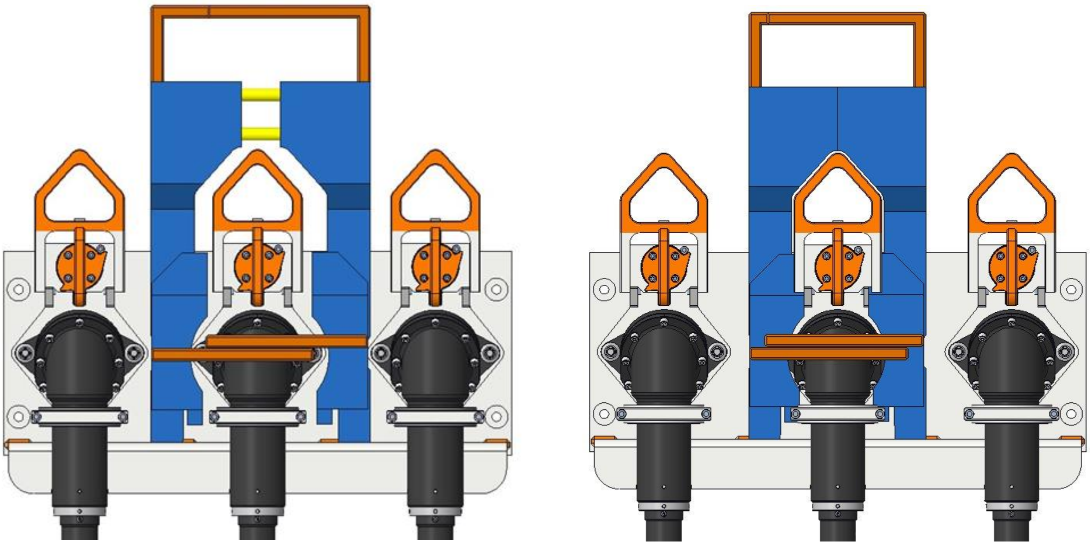


Figure 65 - Idea 7 in open and closed position (Front view)

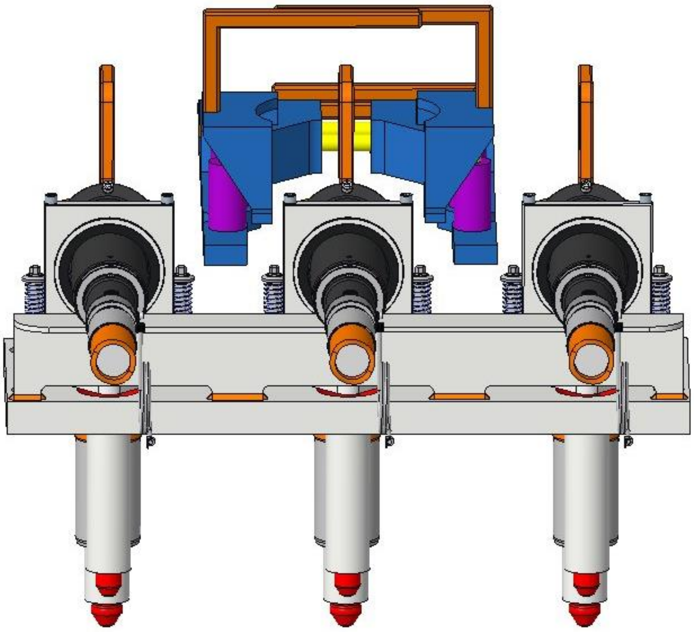


Figure 66 - Idea 7 during mounting

4.5.3 Idea 8 – Magnet Plate

In this idea, the main issue will be the strength of the electromagnet. It must be done a lot of research and testing if this design will be the final product. The WDM (Weighted Decision Matrix) shows a high uncertainty factor. In Figure 67, it is shown how the tool will look like when it is mounted on the MV-head.

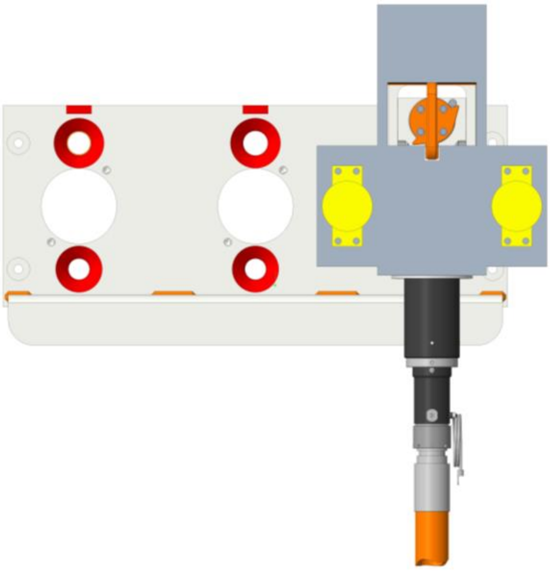


Figure 67 - Mounted magnet tool (front view)

As shown in Figure 68, the cylinders will push against the slot plate, after the tool is fastened with electromagnets (shown in black).

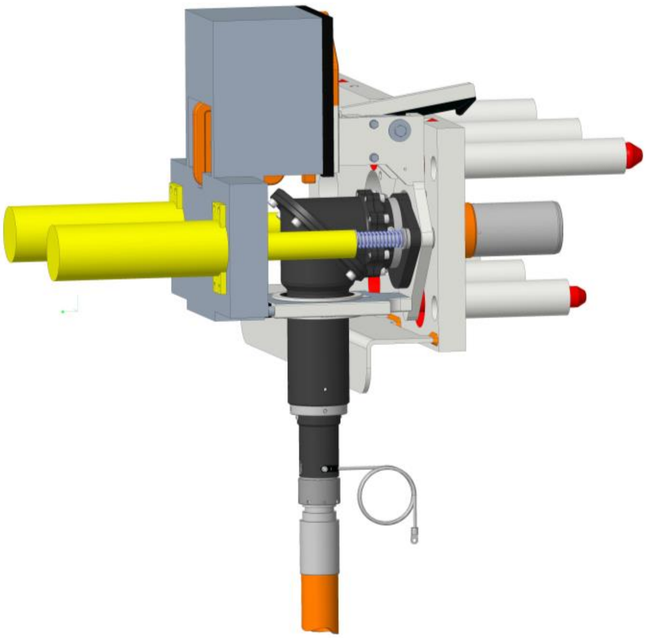


Figure 68 - Idea 8 in mounted position

The mounting of the tool will be done from the front of the MV-head, shown in Figure 69. The ROV pilot will fly with the tool in a handle, and when the tool is on the right place, the pilot activates the electromagnet. The ROV lets go of the tool and it will maintain the position during the operation. The cylinders will then push out the MV-head.

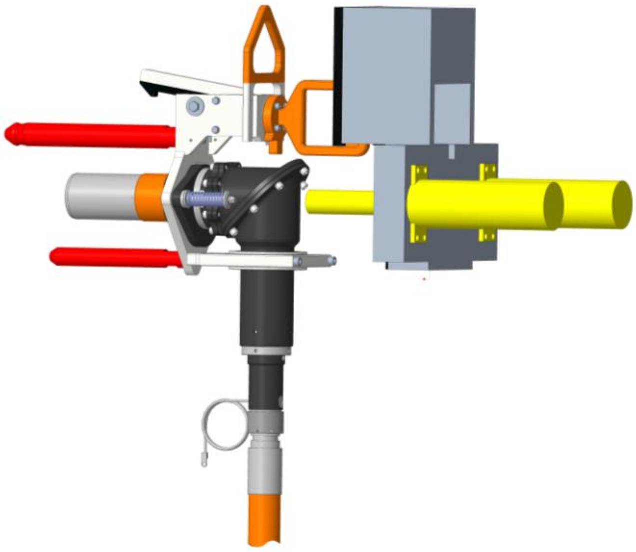


Figure 69 - Idea 8 during mounting

4.5.4 Design Review nr. 1

On February 14th, 2024, the Group had a meeting with the Company for design review nr. 1. The agenda was:

- Progress
- Present different ideas from Ideation progress
- Weighted Decision Matrix
- Presentations of preliminary designs (Idea 5, Idea 7 and Idea 8)
- Discussions about preliminary design
- Way forward

The objective of the meeting was to present the different concepts to identify if there were any errors/no-go with the solutions. The most important questions asked to the Company was:

- Agreed using connector bracket and flying handle, shown in Figure 2 - MV-Head, as fixing point for equal force distribution over MV-Head. *Yes, the Company agreed.*
- Agreed that the connector bracket and flying handle are the best items to apply force to? *Yes, the Company agreed.*
- Agreed to use hydraulic (or similar) to do the disconnecting operation. This will free one manipulator arm to hold and store the MV-Head when it’s disconnected. *Yes, the Company agreed, in addition, the SSRT must be able to hold itself on the interface plate or MV-Head after the disconnecting of MV-Head, otherwise it will fall to the seabed. The Group will investigate options to solve this in the detailed design phase.*
- The Group needs measurements on available space above, and on the sides of the slot plate, see Figure 70.

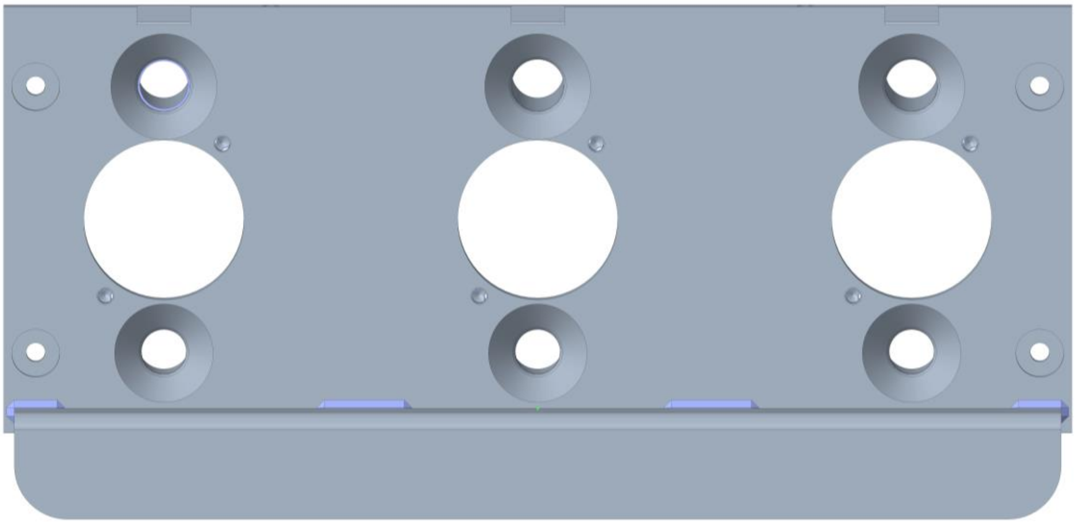


Figure 70 - Slot plate

The company will send measurements but emphasizes that there may be different spaces on various modules. The most used modules should be sent measurements forward.

- Comments on design? *Company agreed on the criteria and weighting in the Weighted Decision Matrix*, Table 7. *By the preliminary designs, Idea 5 was the preferred design at this stage, followed by* Idea 7. *Company agreed that the use of magnets like* Idea 8 *has unknown factors. The Group will continue with detailed design on Idea 5 and 7 and use previous ideas for solving upcoming challenges. It is also preferable to have as few moving parts as possible.*

The Group is asked to check if it’s possible to develop the ideas without the use of cylinder for the opening/closing function, Figure 71. This will be investigated in the detailed design.

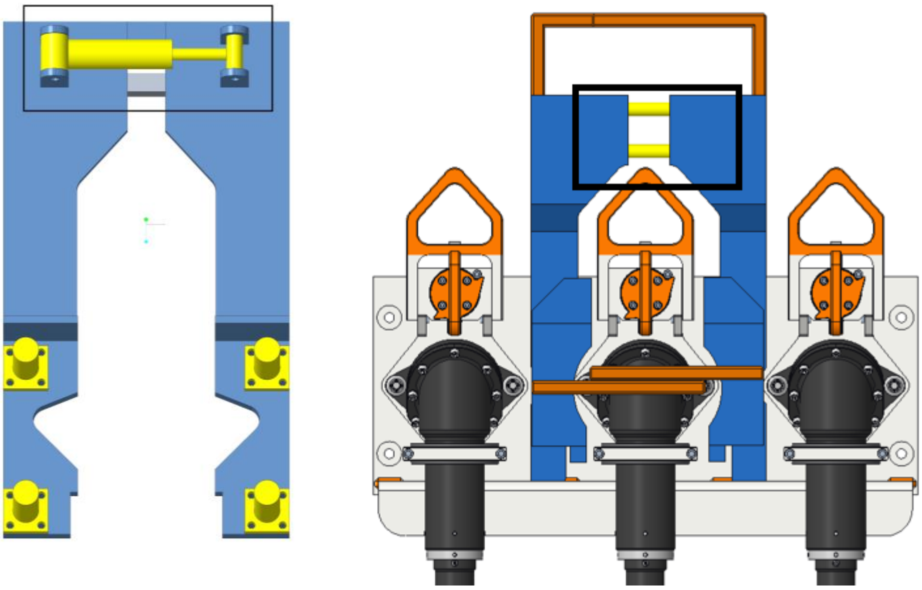


Figure 71 - Open/close cylinder

It is agreed that the solution development stage is finished, and the Group will move on to engineering.

5. Engineering

Engineering plays an important role in a product development to ensure that the product withstands the requirements. This chapter will demonstrate this process.

5.1 Simple Testing of Designs

Ahead of Design Review nr.2, Idea 5 was modified into three different designs. These designs use the same contact points on the MV-head and the same force. Simplified stress analyzes and hand calculations will be performed to see what stress occur to the MV-head and the SSRT. This is to evaluate if we can proceed with the current designs.

5.1.1 Idea 5 – Plate with Cylinders

The original idea with open/close function is shown in Figure 72.

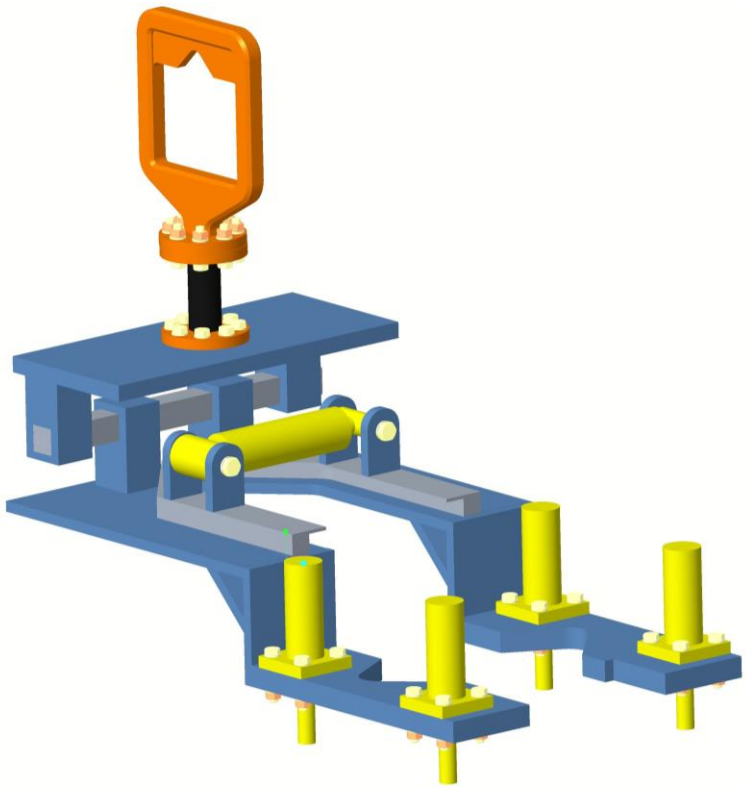


Figure 72 - Idea 5 with open/close function

5.1.2 Idea 5 – Without open/close Function

One of the agreements with the Company was to check the possibilities to make a tool without an open/close function. The Group have redesigned Idea 5 that will be placed directly without having any movable parts.

Before making a detailed design, a simplified Finite Element Method (FEM) analysis is carried out in Ansys to determine the thickness of the brackets due to the limited space. A force of 5000 N per cylinder and a thickness of 20 mm is assumed. The contact interfaces will be on the flying handle and on the connector bracket, showed in Figure 73.

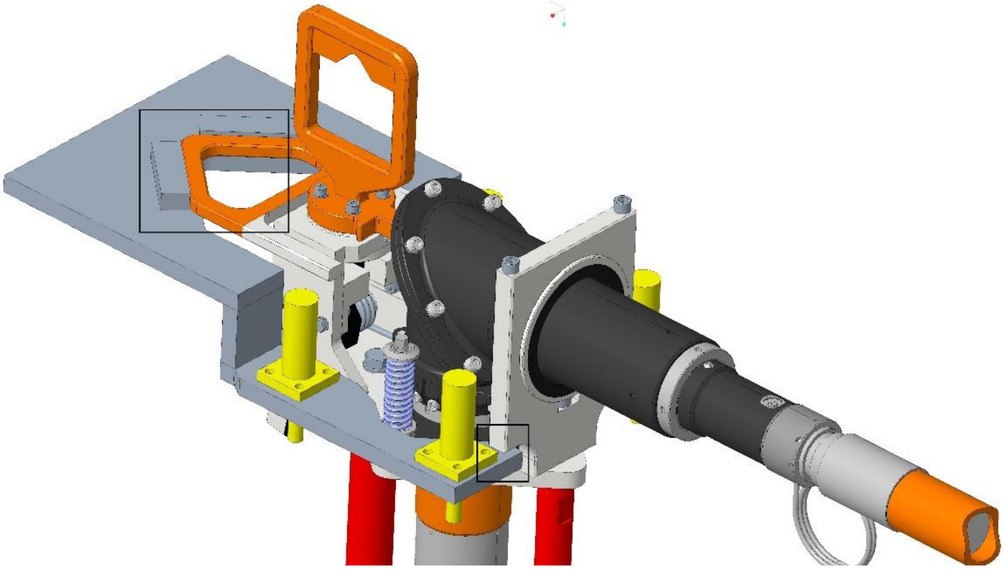


Figure 73 - Contact points on the MV-head

In Ansys Design Modeler, the contact interfaces and the cylinder bolts faces are split. It is also simplified with symmetry and standard structural steel, as seen in Figure 74.

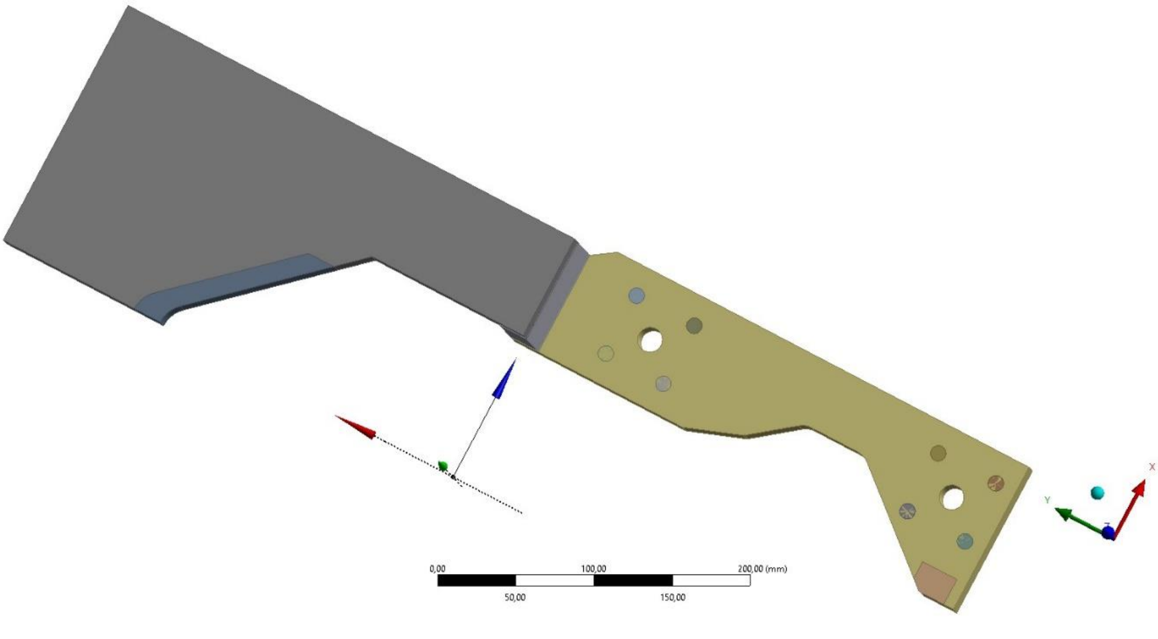


Figure 74 - Geometry in Design Modeler

For this simulation, the mesh settings are simplified, as seen in Table 8 and Figure 75.

Table 8 - Mesh size for bracket

Element size	4mm
Element order	Quadratic
Nodes	51298
Elements	23406

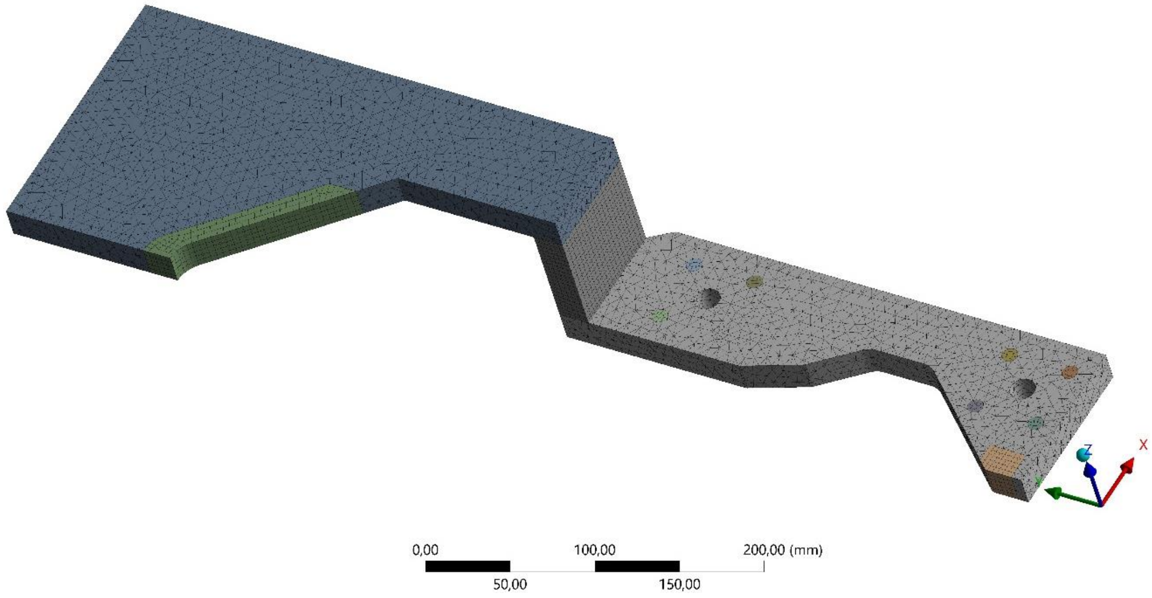


Figure 75 - Simplified mesh settings

Figure 76 shows the boundary conditions. Stress and deformation are shown in Figure 77.

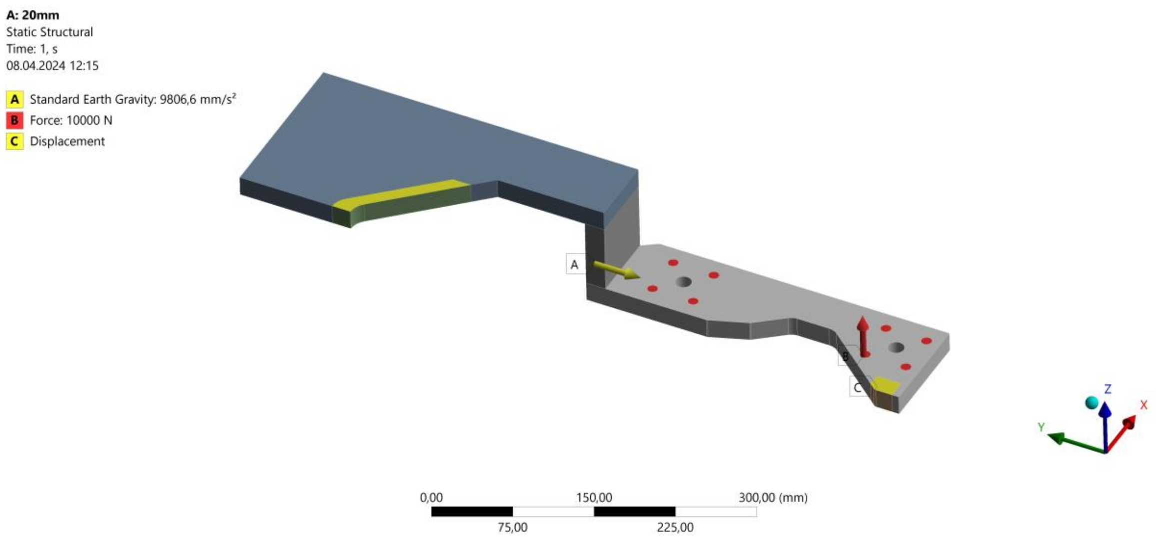


Figure 76 - Boundary conditions for 20 mm thickness

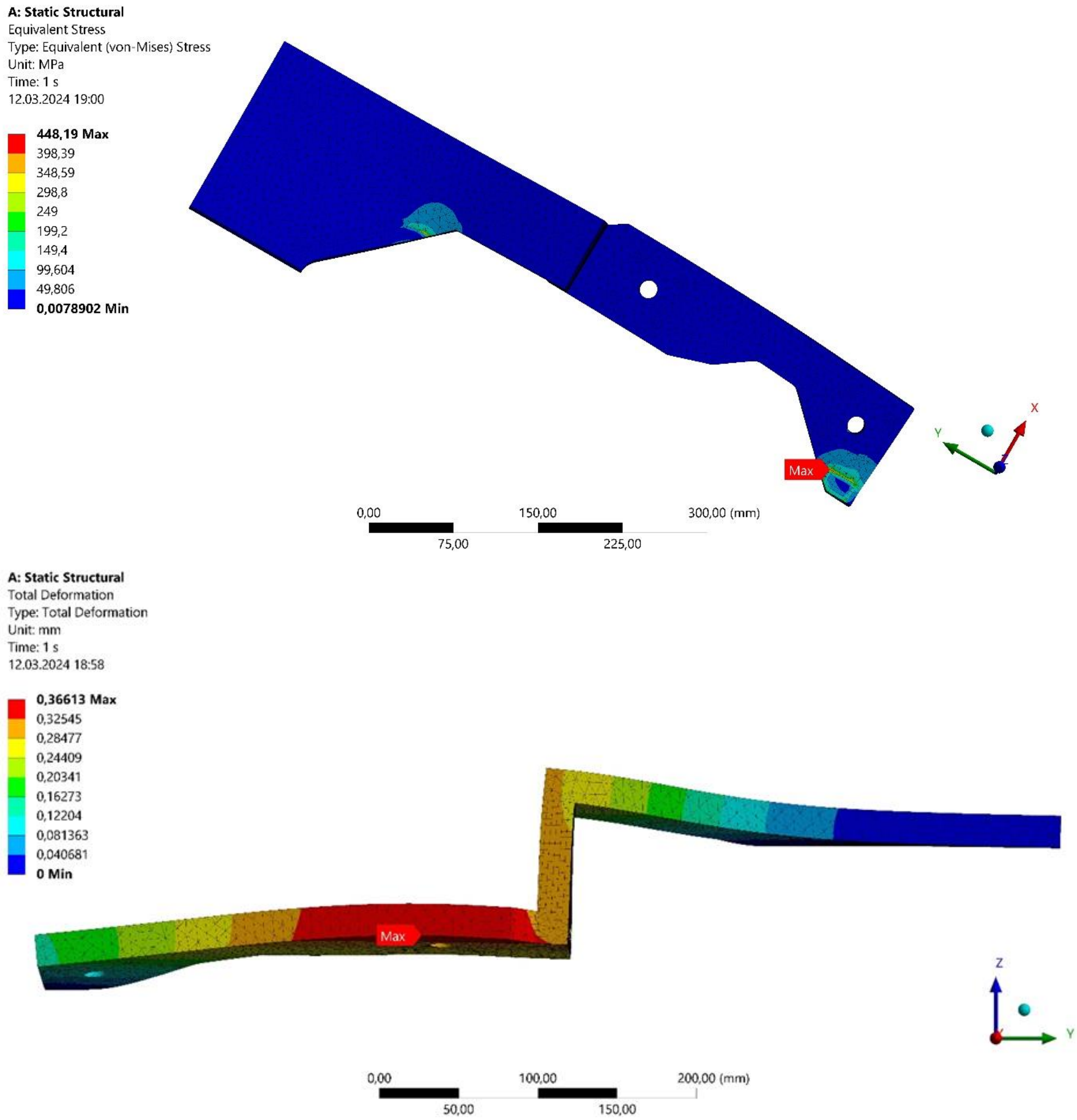
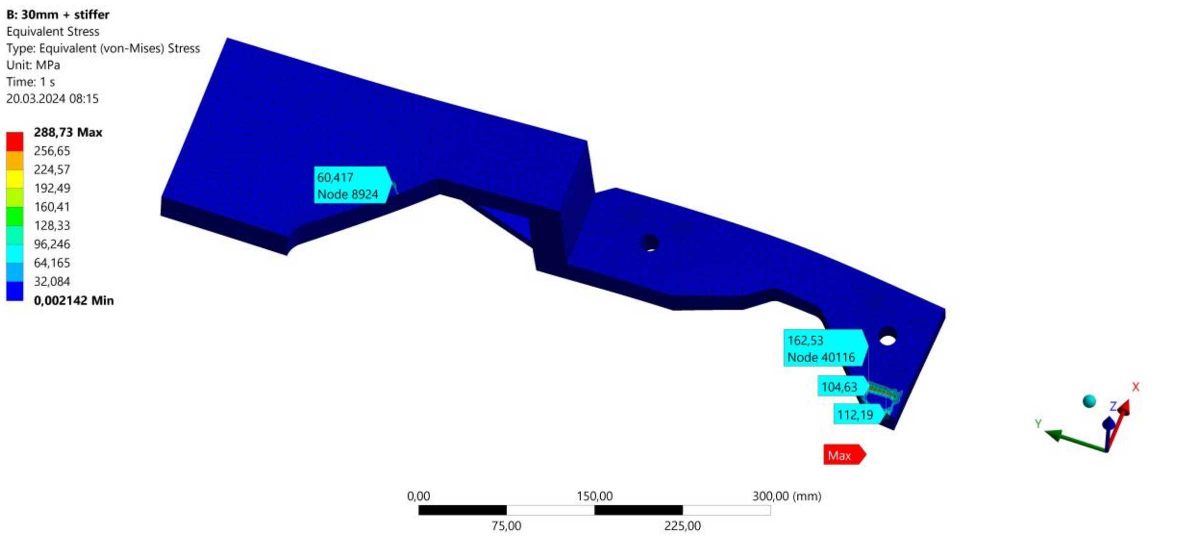


Figure 77 - Stress and deformation results on modified idea 5 with 20 mm thickness

The stress is high, and this is a singularity fault. The bracket is modified to 30 mm thickness, and a stiffer is mounted to see the difference. This is the maximum thickness the bracket can have due to the limited space between MV-head and the slot plate. The new stress and deformation results are shown in Figure 78.



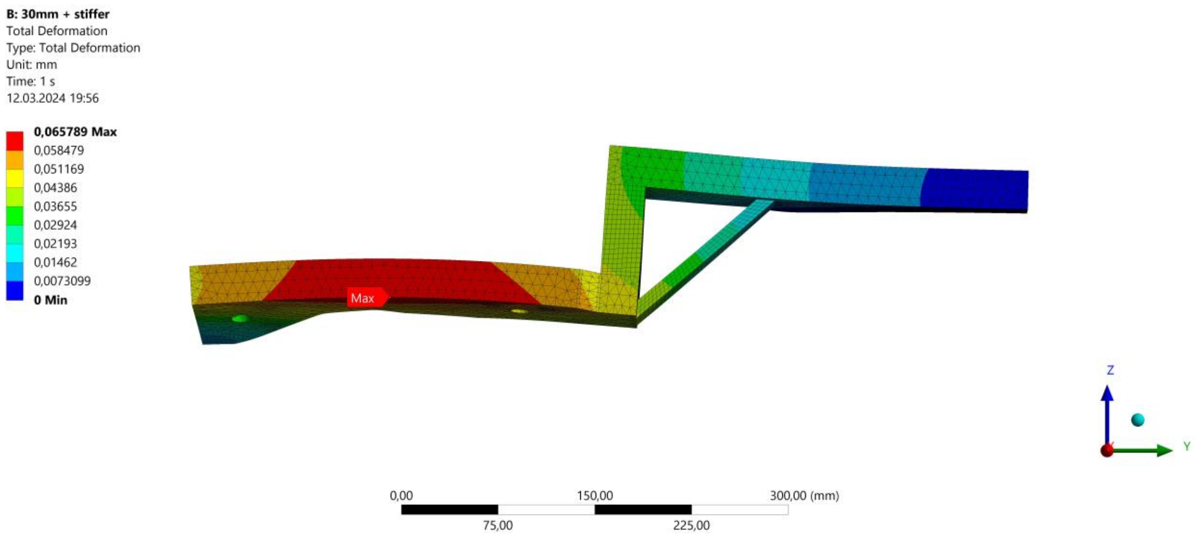


Figure 78 - Results of modified idea 5 with stiffer and 30 mm thickness

The figure shows an approved test on the brackets. The highest actual stress found are 163 MPa. These results shows that the bracket can handle the forces it will face with a load on 5000 N on each cylinder. There are metal alloys which will handle the stress and the design can also be optimized further.

Another modified design of Idea 5 is made. This design has an extra contact point to the MV-head, as well as more guiding for the tool. See Figure 79.

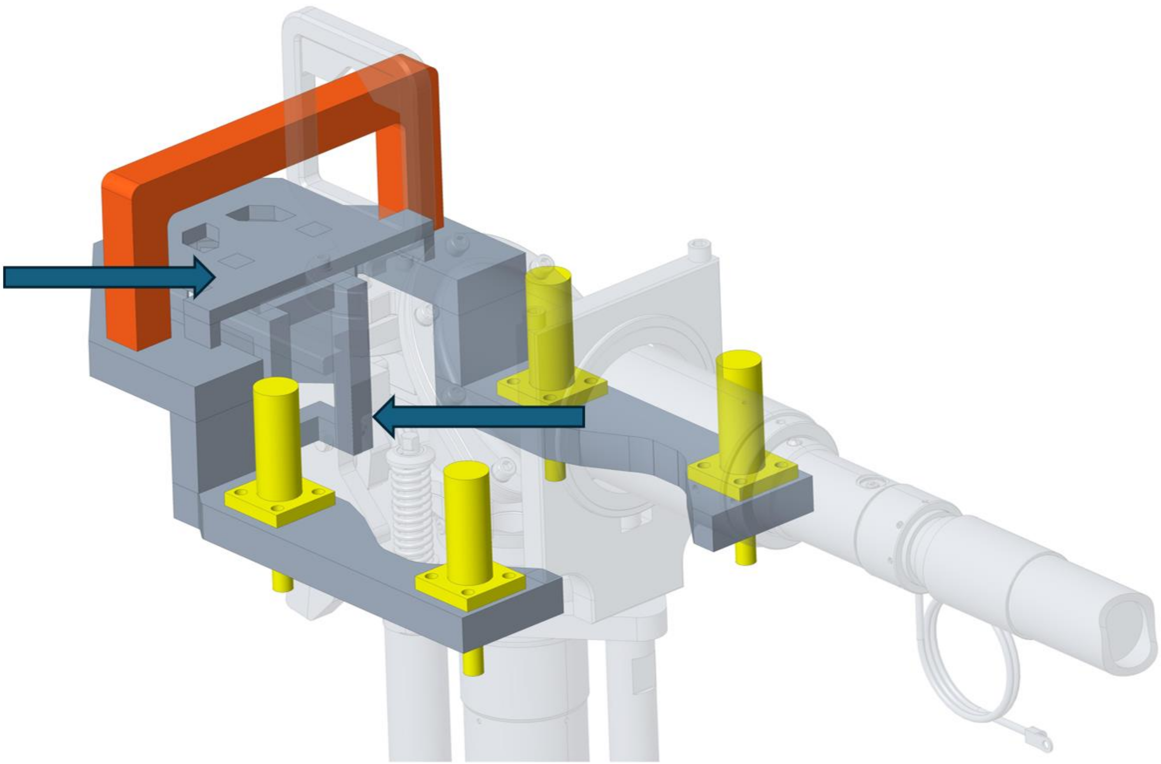


Figure 79 - Modified idea 5 with guiding

The Group ran a simplified simulation on this design as well, with the same inputs as the previous simulation, shown in Figure 80.

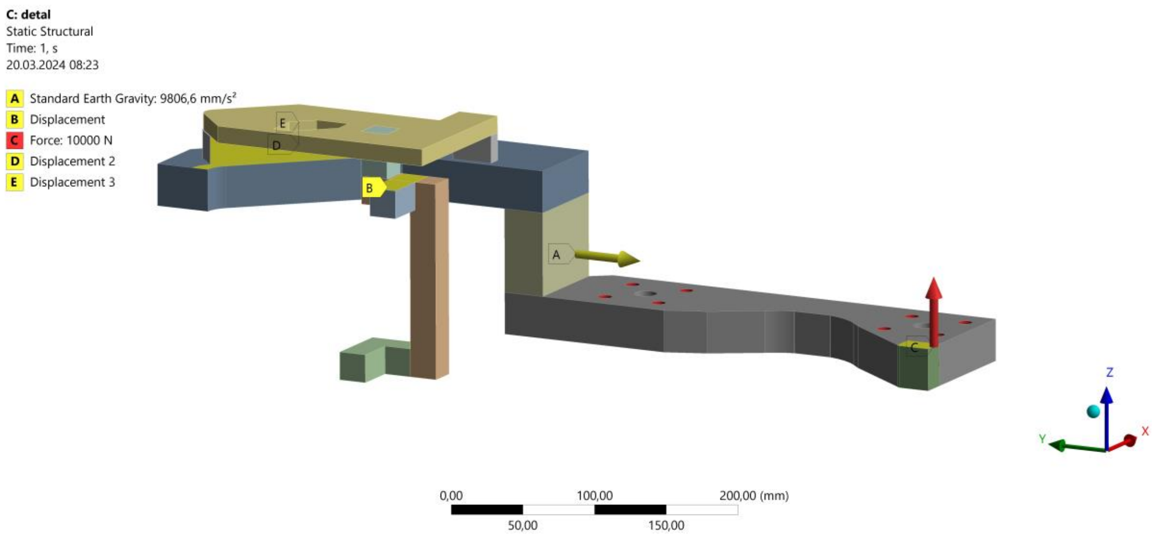


Figure 80 - Inputs on modified idea 5 with guiding

The results are very similar, see Figure 81.

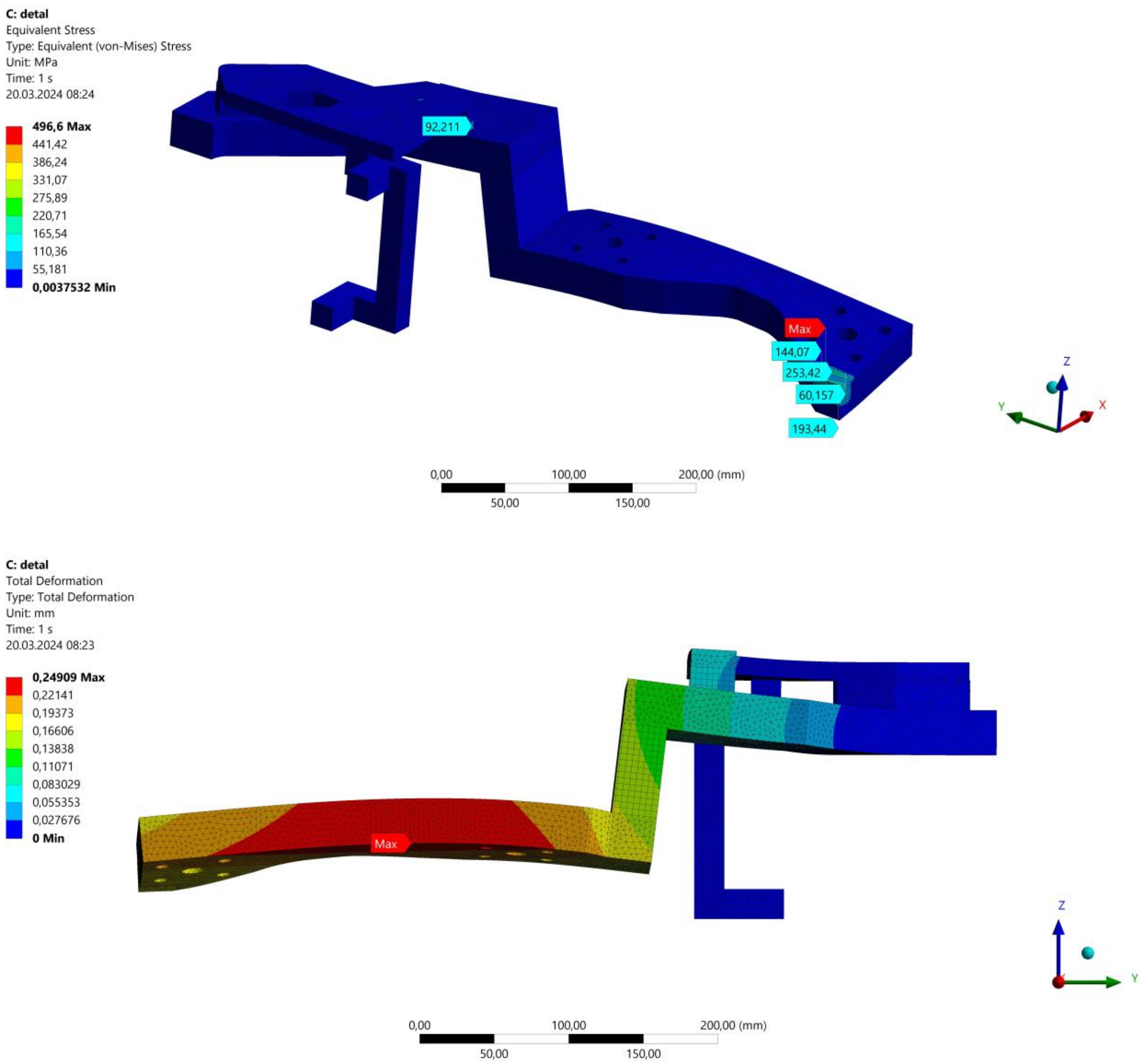


Figure 81 - Results of modified Idea 5 with guiding

The Group is confident that the bracket on these designs is strong enough to move forward to detailed design. For the final, detailed design there will be a better meshing and a more realistic load.

5.1.3 Idea 5 – Doorlatch

Another idea that came up after the first design review was to use a mechanism similar to a door latch. This tool can be guided into position and lock itself automatically. The flat side of the door latch, pointing inwards in Figure 82, will be the contact point for extracting the MV-head. This is to satisfy the wish of the Company to have a tool without an open/close function.

Figure 82 - Door latch mechanism [39]

The design is shown in Figure 83. The red boxes mark the contact points, or the "door latches". These components require a FEM analyze to make sure they can handle the stress.

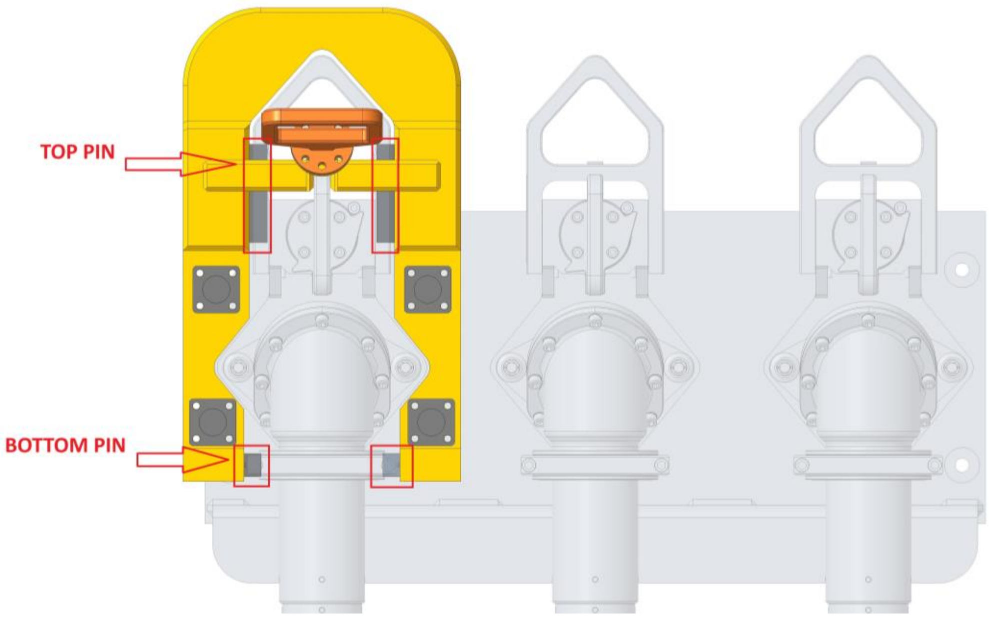


Figure 83 - SSRT doorlatch design

The force is defined at 5000 N, and acts normal to the contact surface. Boundary conditions are defined as fixed supports. See Figure 84.

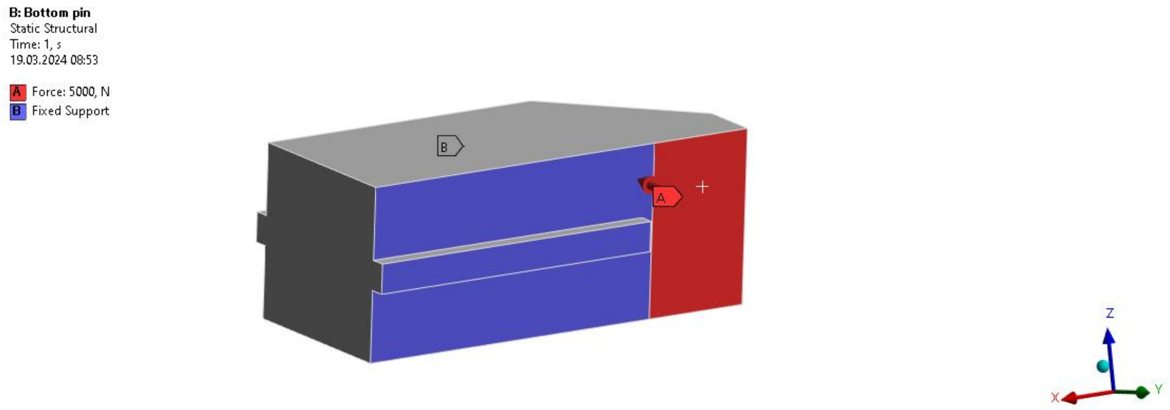
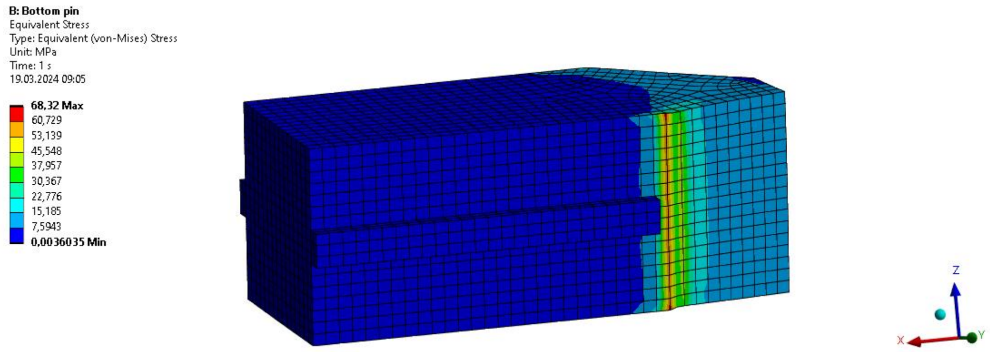


Figure 84 - Static Structural

The bottom pin stress is 68 MPa and the total deformation is negligible, seen in Figure 85.



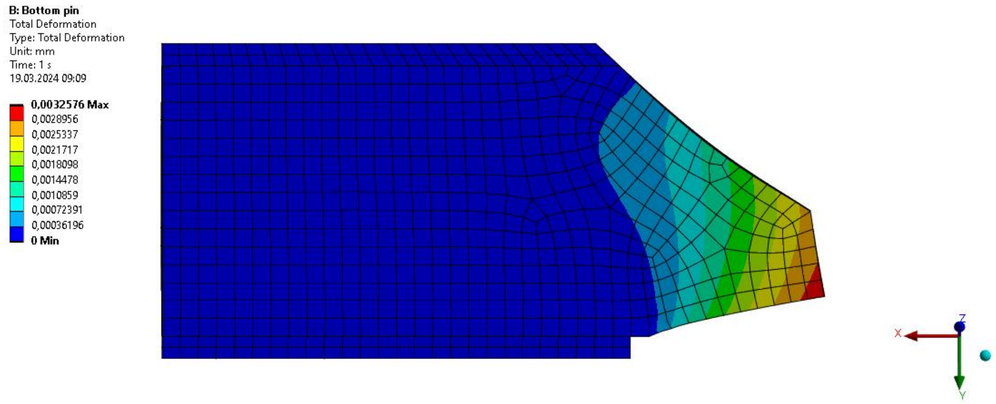


Figure 85 – Results on bottom pin from Ansys

The top pin has the same inputs as the bottom pin and the results are shown in Figure 86. This pin has a larger contact surface, and therefore the stress is much lower, 17 MPa. The deformation is negligible.

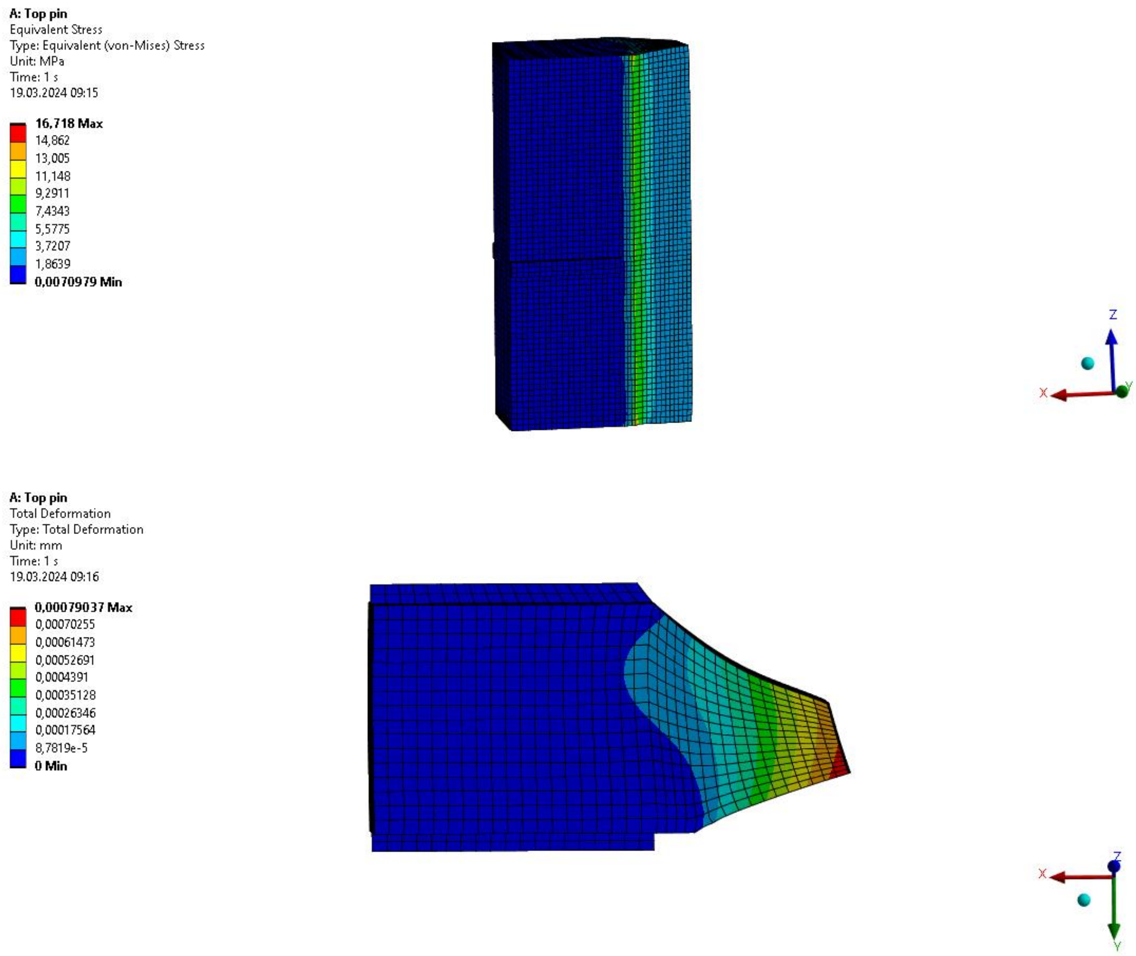


Figure 86 - Top pin Total Deformation

5.1.4 Design Review nr. 2

On March 22nd, 2024, the Group had a second design review meeting with the Company. The agenda for this meeting was to

- Present three modifications from Idea 5
- Select one of these designs
- Discuss the datasheet regarding the de-mating force
- Way forward

Two main criteria from the first design review meeting were considered for the new designs:

- *The SSRT should hold itself in place after disconnecting the MV-head.*
- *There should be as few moving parts as possible.*

The presented designs are shown in Figure 87.

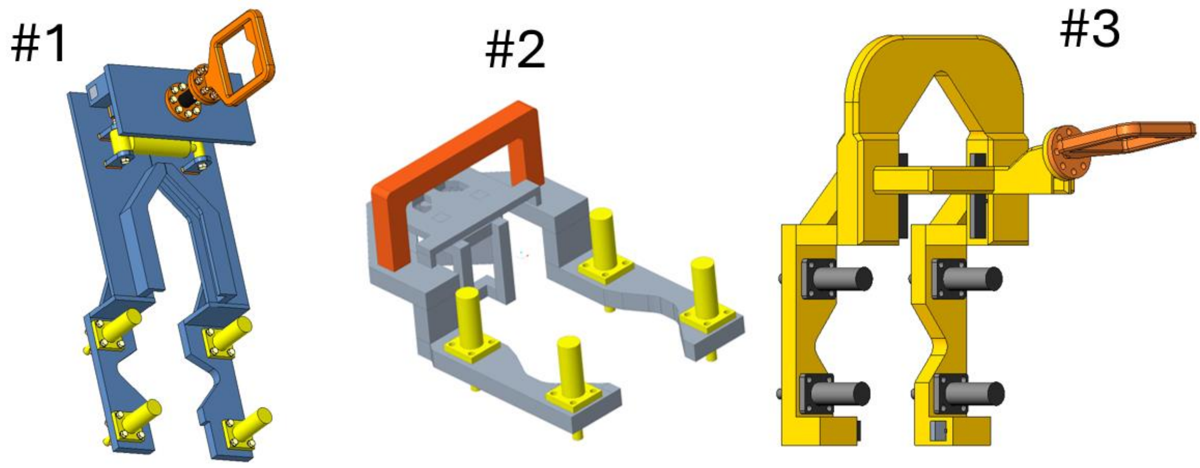


Figure 87 - Designs presented in Design Review nr.2

Comments from the meeting:

- The Company believed all three ideas would work.
- #1 and #3 stood out, but a realization of #3 could be difficult as the spring-loaded latches will need a secondary open function if the tool gets stuck.
- Participants agreed on #1.
- Discussion of datasheet regarding hydraulic pressure for each cylinder. Figure 88 shows the maximum force on the D-handle. The Company decided that the SSRT shall withstand the maximum forces applied by the cylinders. The datasheet should not be any limitation.

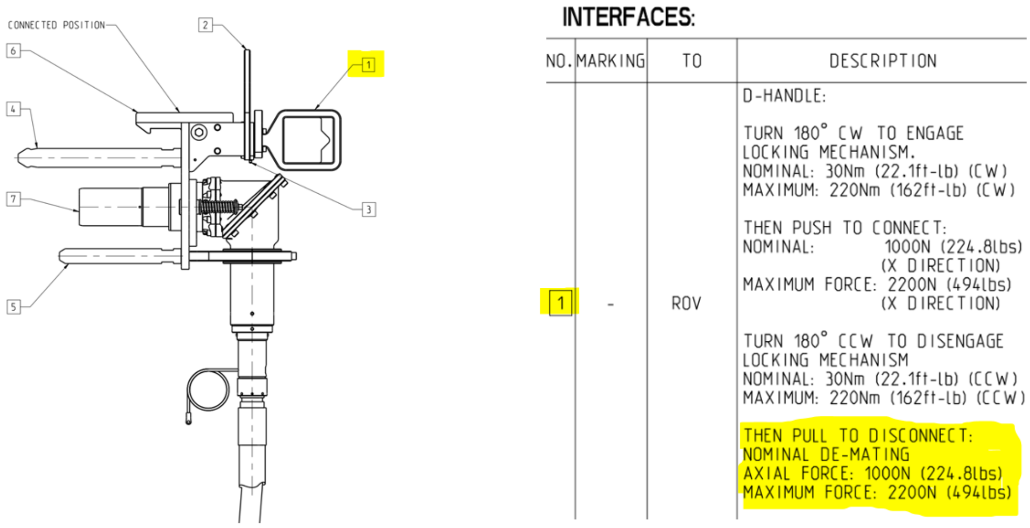


Figure 88 - Datasheet showing nominal de-mating force [3]

- The Group will create a proof of concept to validate the 3D drawings given from the Company.

5.2 Proof of Concept

To ensure that the tool will fit the MV-head, a 1:1 scaled wooden SSRT is made. The plan is to try this tool on-site at Horsøy at the Company's test facilities when an MV-head is available. This proof of concept is from Idea 5, but without the open/close function at the top, and this is shown in Figure 89.

Figure 89 - Idea 5 without open/close function in wood

In addition to the wooden proof of concept, there is also made one in steel. The parts will be cut out with a CNC plasma cutter and welded together. Due to limitations in the material stock at the HVL lab, the steel model will be 10 mm thick, and the material will be structural steel. There will not be actual cylinders on this model, as the delivery time is too long. However, 3D printed cylinders will be added for illustrating what the tool will look like. The proof of concept is shown in Figure 90.

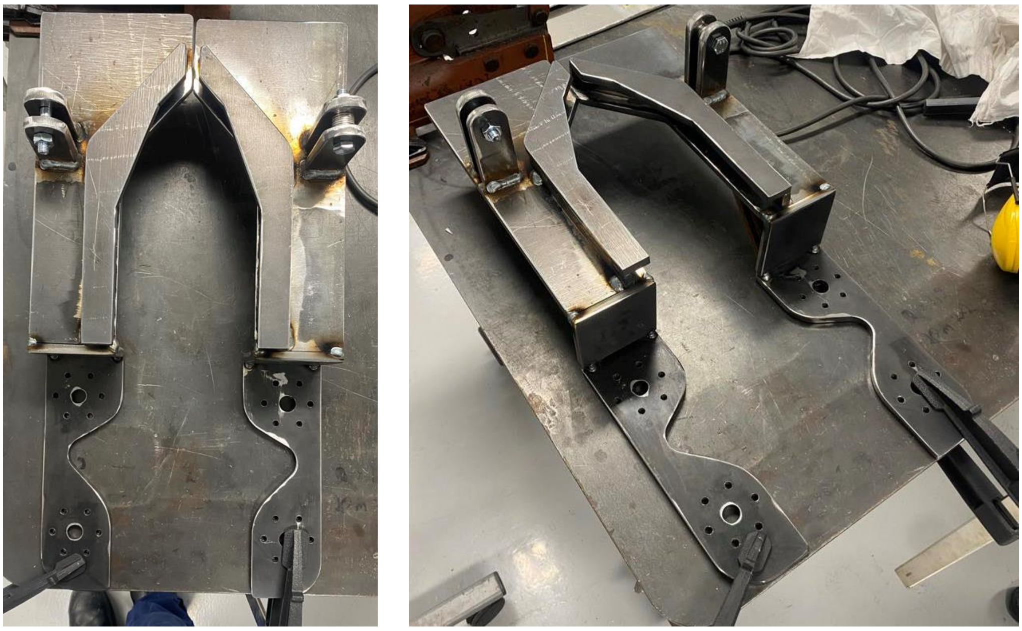


Figure 90 - Proof of concept

Due to a small selection of available materials, the sliding function had to be improvised. The sliding function and ROV plate is seen in Figure 91.

Figure 91 - Sliding function

The complete tool with pushing cylinders in both open and closed position is shown in Figure 92. The cylinders are from another project that will be explained in chapter 7.

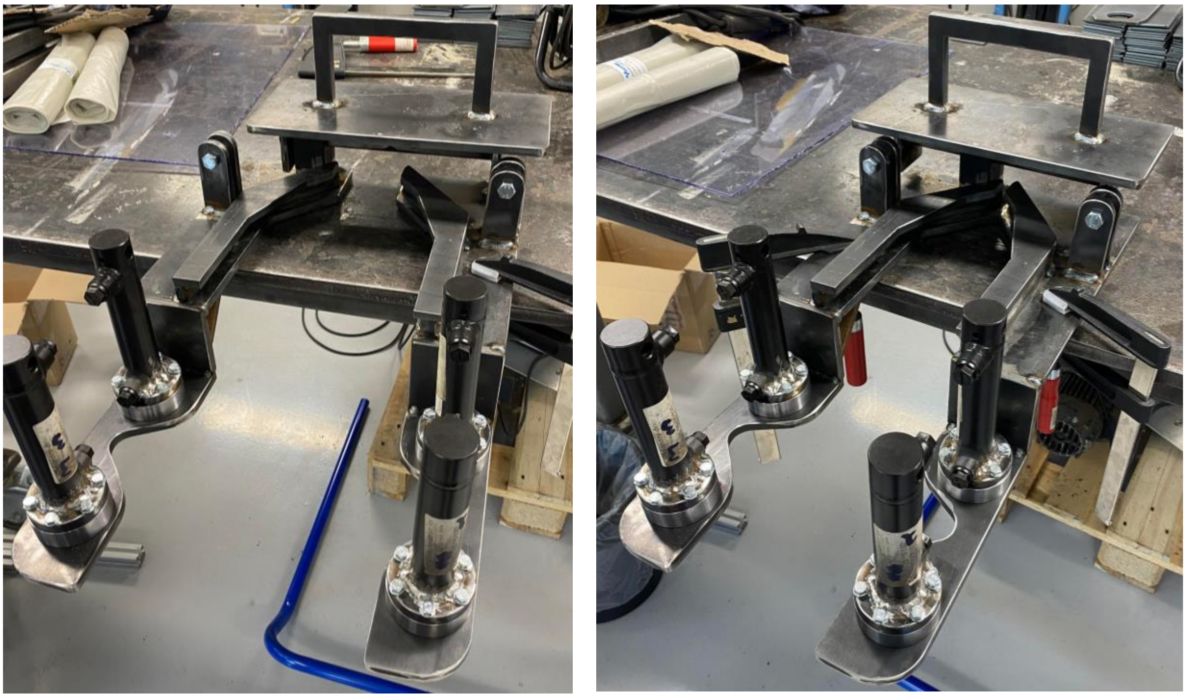


Figure 92 - Proof of concept in open and closed position

5.3 Components Design

This chapter will explain the different elements of the final design and give a reason for the tool's appearance.

The bracket's shape allows contact points with both the connector bracket and the MV-head. These points are offset from each other, which is the reason why the bracket has an "S-shape". Figure 93 shows how the shape was sketched in Idea 28 in Figure 44, and how it has evolved. The bracket is also fitted with welded stiffeners. The contact points are marked in red.

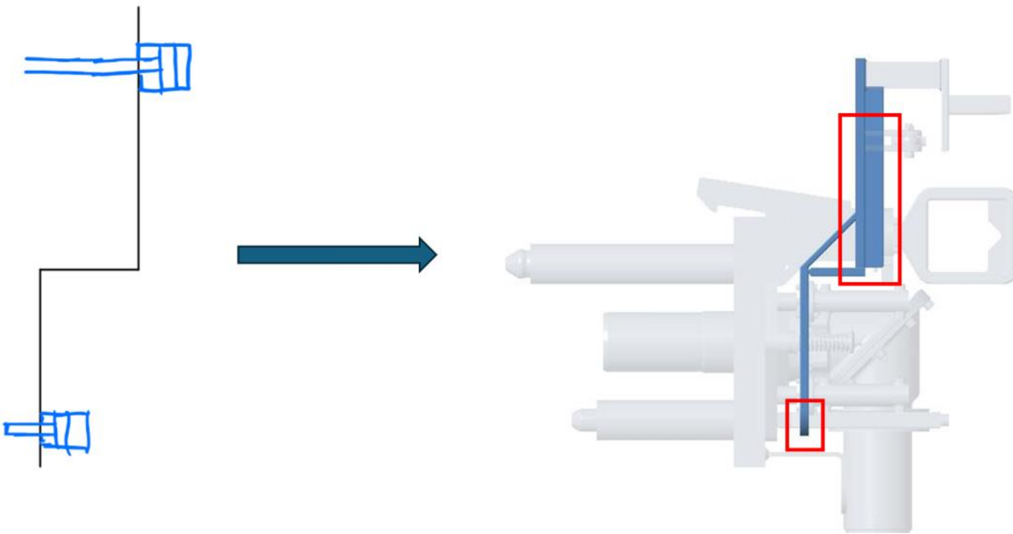


Figure 93 – Bracket profile

The bracket uses the geometry of the MV-head to be as area-efficient as possible. The cylinders are placed towards the middle to minimize the width of the tool. Due to the moment of inertia, the thickness of the cylinder brackets is the deciding factor. The width of the tool can therefore be reduced to minimize space.

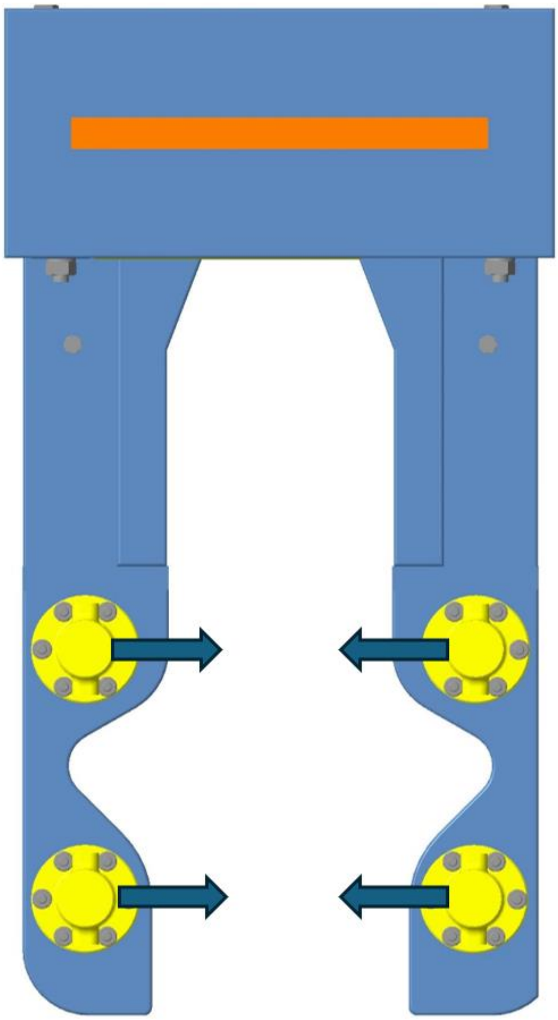


Figure 94 - Bracket shape and cylinder placement

The rods on each cylinder are fitted with threaded aluminum bushers, shown in Figure 95. Aluminum has a lower hardness than the S355 steel on the slot plate and therefore avoids damage to this plate during operation [40].

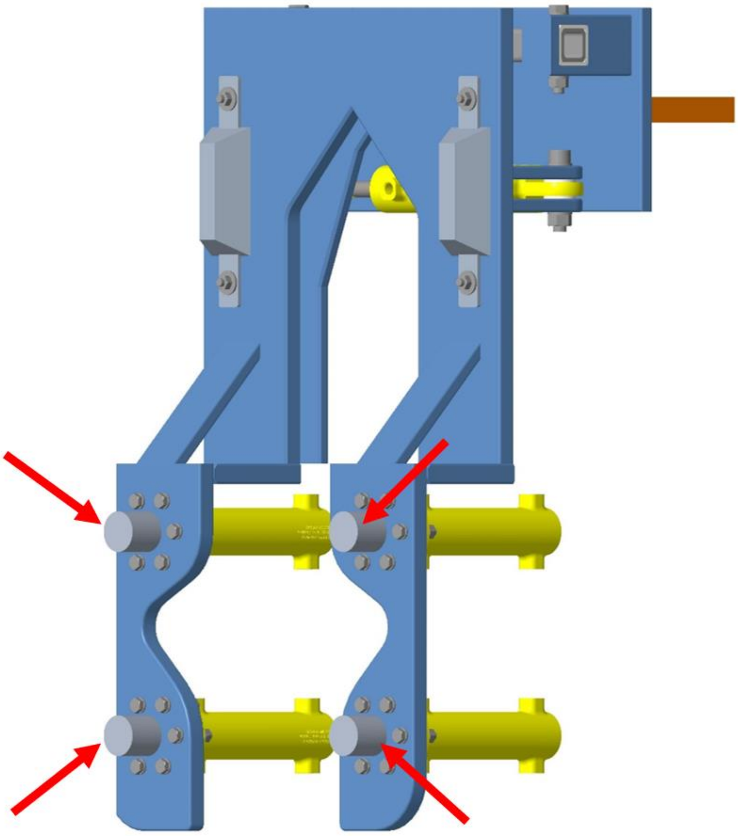


Figure 95 - Aluminum bushing

Due to the electrochemical potential in the aluminum bushings, the tool is fitted with cathodic protection in the form of zinc anodes [41]. These are shown in Figure 96.

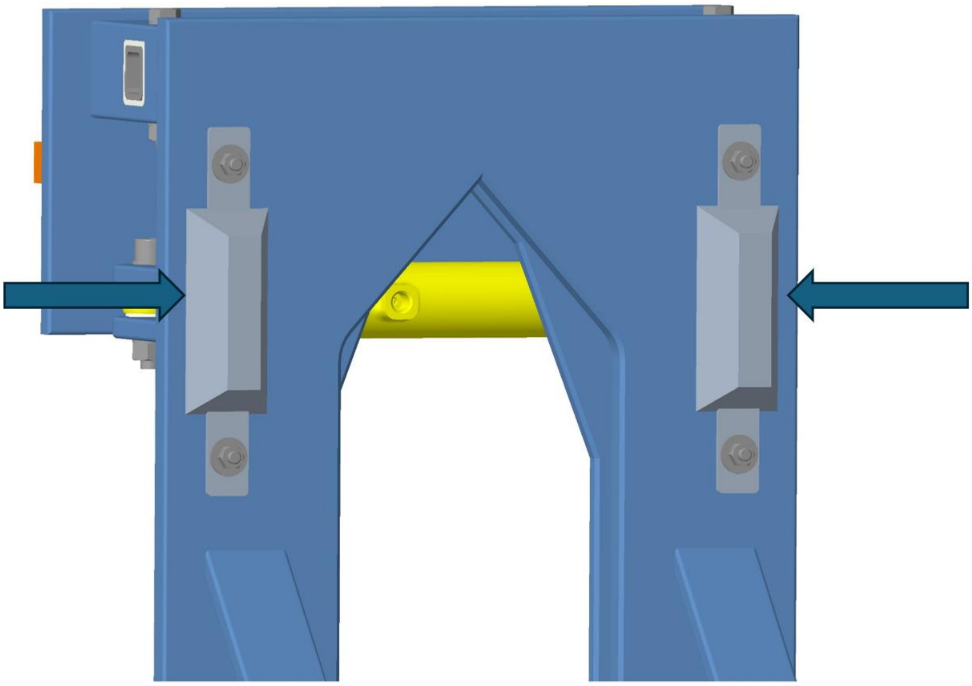


Figure 96 - Zinc anodes

The open/close cylinder is fitted with white nylon bushings between the cylinder head and the cylinder bracket. These bushings can easily be replaced if they are subject to excessive wear. See Figure 97.

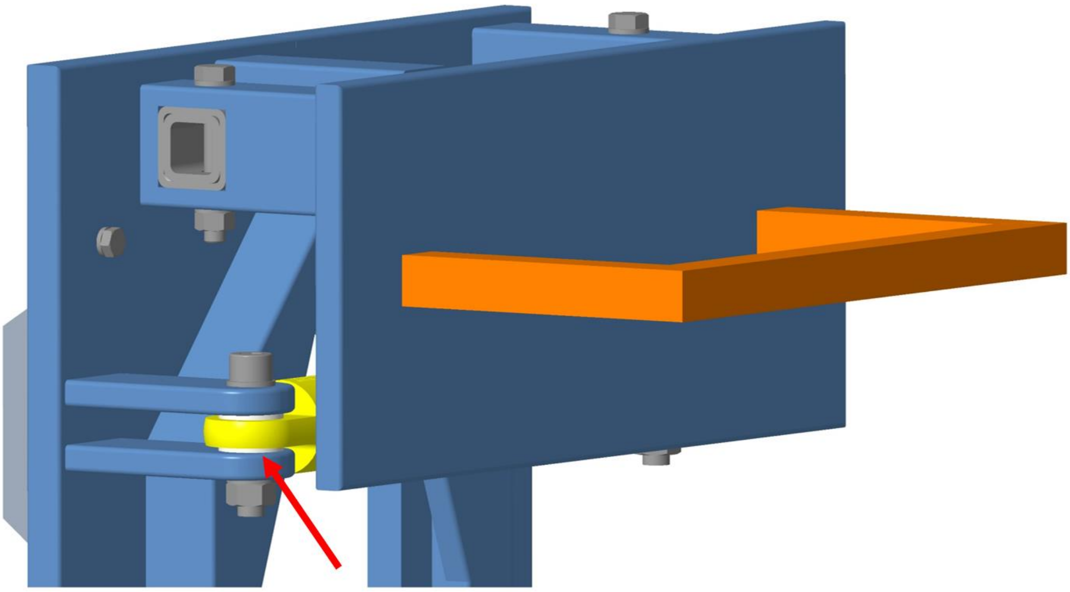


Figure 97 – Bushings

The tool comes with a guiding/locking profile on both sides, as shown in Figure 98. This functions as a guide, helping to position the tool using the flying handle on the MV-head, and locks it securely in place. When the MV-head is de-mated, the SSRT will remain locked until the MV-head is safely parked subsea. The ROV pilot will then grab the SSRT and open the cylinder for removal of the SSRT.

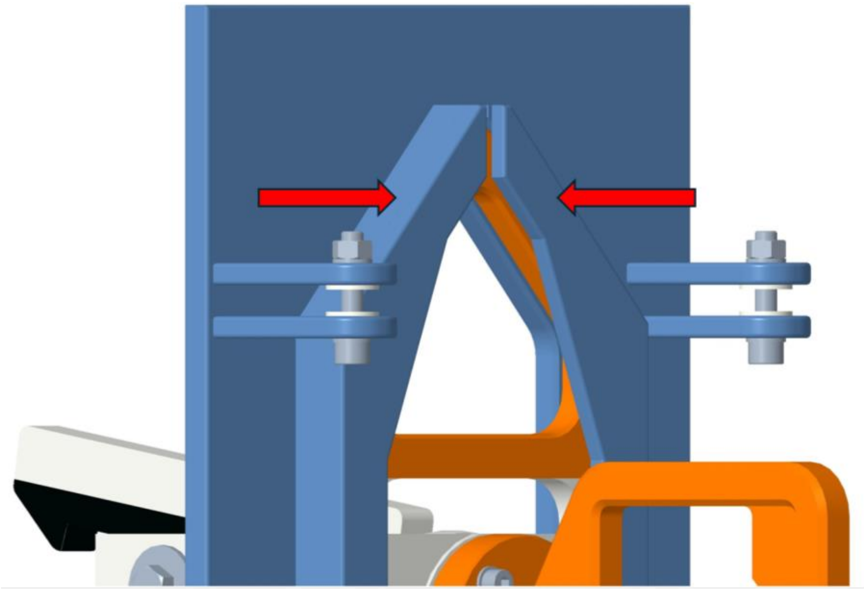


Figure 98 - Guiding and locking profile

The four Ø25/16 push-cylinders use M6 fasteners, and the open/close Ø25/16 cylinder uses size M10, shown in Figure 99. The measurements are given by the proposed supplier.

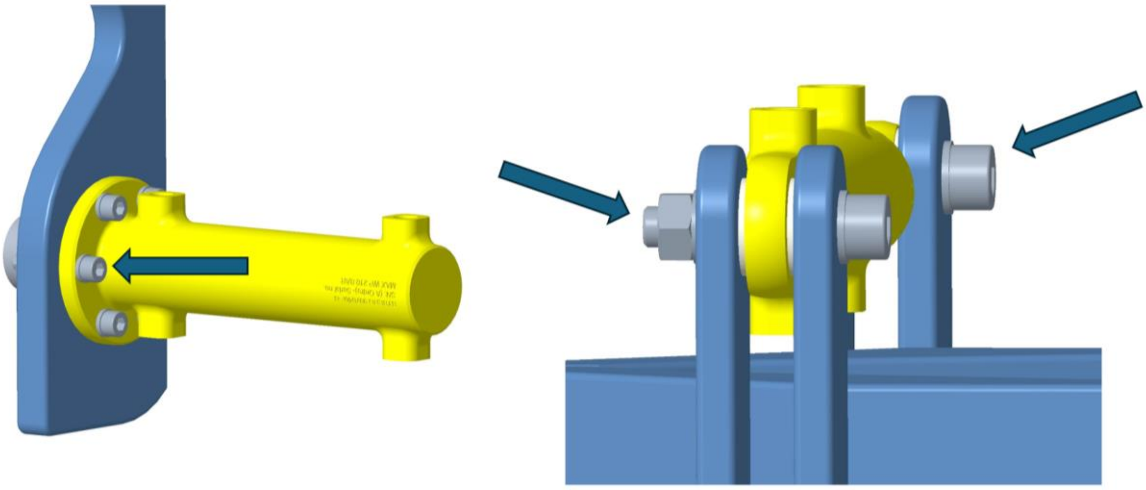


Figure 99 - Cylinder fasteners

The slide function shown in Figure 100, uses a square tube with AISI 316 bushings. The square shape of the slider avoids any twisting that could occur if it were circular. The fastener on each side locks the slider (red arrow), and the only sliding movement happens in the middle part (blue arrow).

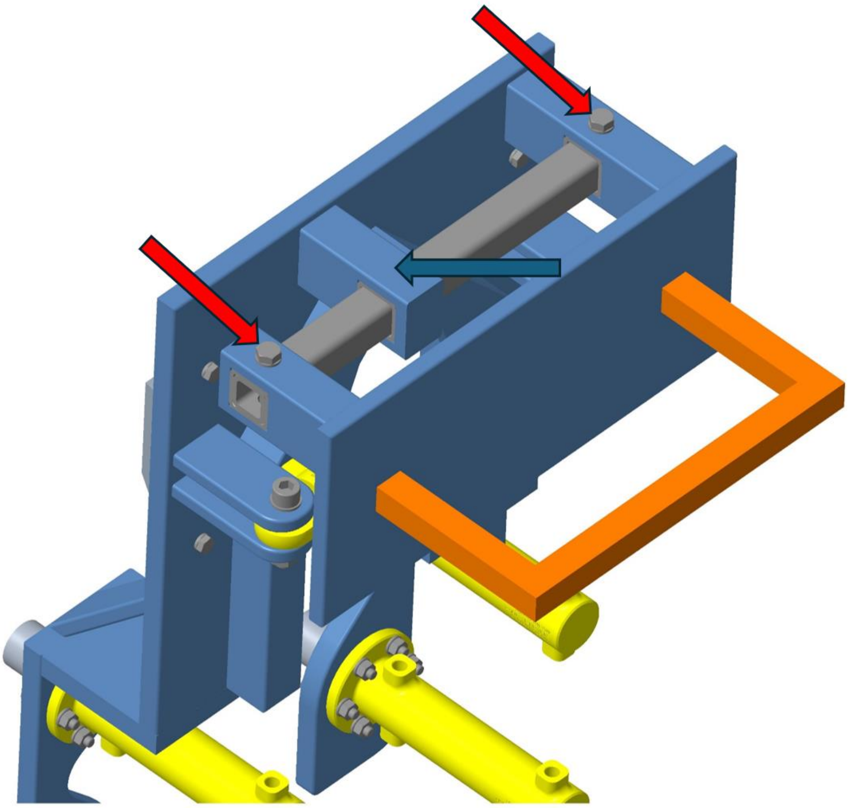


Figure 100 - Slide function

The flying handle is made from 19x19 mm square bars, according to API 17H [42]. See Figure 101.

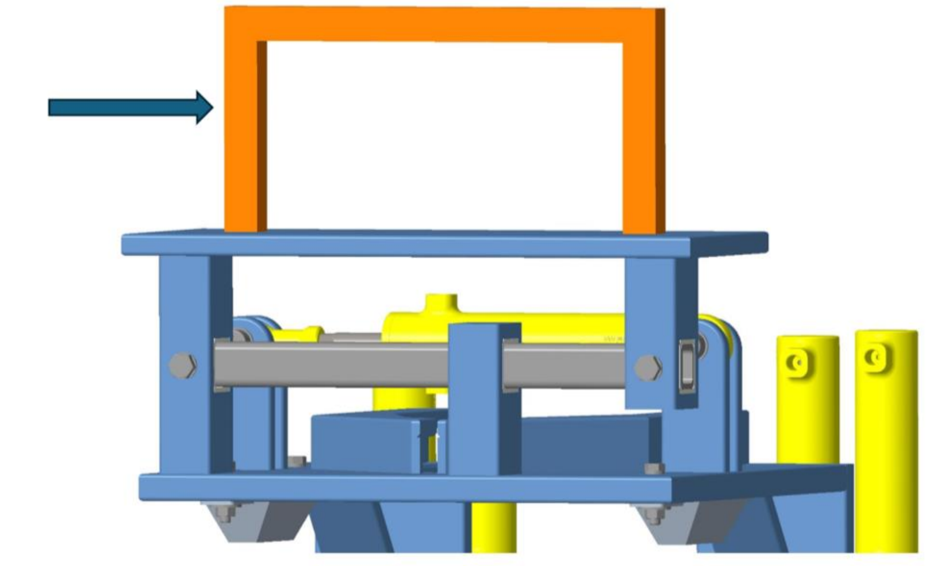


Figure 101 - Flying handle design

The tool is fitted with tubes, hoses, and fittings. The tubing is according to the hydraulic schematic in Figure 104. The final design of the tool is shown in Figure 102. The figure shows the Group's proposal of the design for the hydraulics. The recommendation is to do the pipework at site when the SSRT is produced, instead of prefabricating. The hoses going out of the picture will go to the ROV. The reason for the hoses inside the SSRT is that the line must be flexible when operating the open/close function.

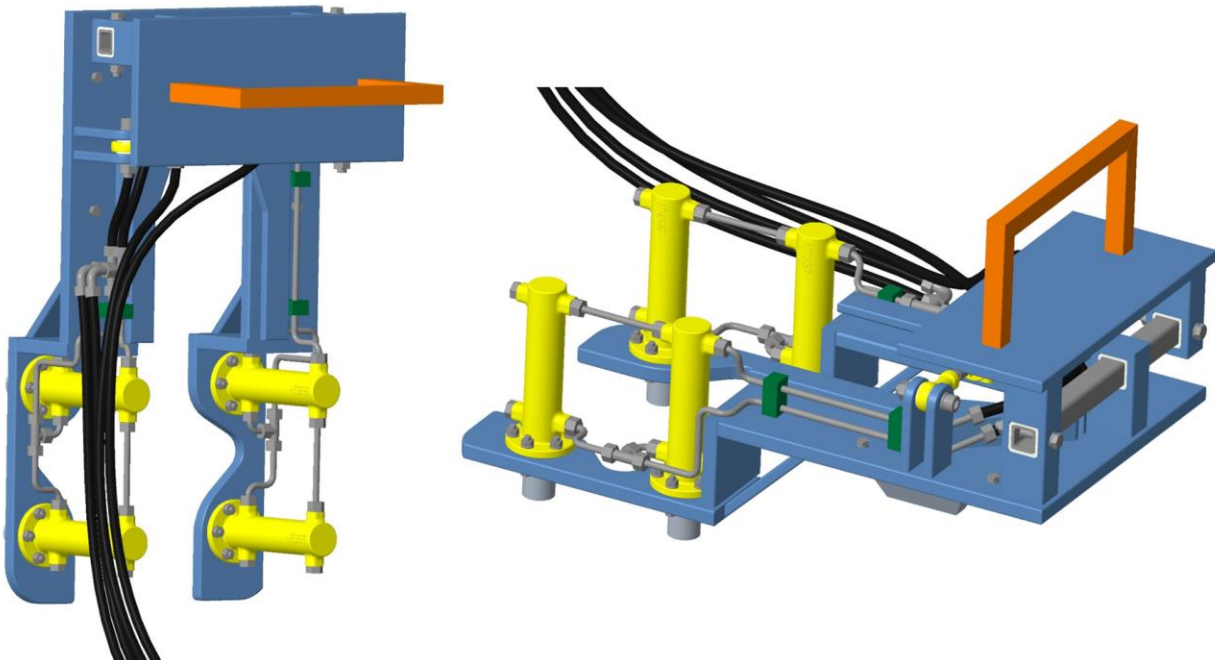


Figure 102 - Final design with tubes, hoses, and fittings

5.4 Material Selection

The material selection is affected by the safety factor given from the Company. This is displayed in Table 9.

Table 9 - Safety Factors from the Company

Description	Safety factor
Forces	1.30
Material	1.15

Forces from cylinders will have a safety factor of 1.30. All materials will have a safety factor of 1.15.

Super Duplex

Due to the corrosive environment on the seabed, the MV-head is made from super duplex. The material properties of the super duplex used on the MV-head are shown in Table 10, given by the Company.

Table 10 - Super duplex material properties given by the Company

Material Density	7800 kg /m³
Young’s Modulus	200 GPa
Poission’s ratio	0.3
Tensile Strength	800 MPa
Yield Strength	550 MPa
Brinell Hardness	270

S355J2

The slot plate where the MV-head is placed is made of 355J2 according to the Company. The material properties of the S355J2 used on the slot plate is shown in Table 11.

Table 11 - S355J2 material properties [43]

Material Density	7800 kg /m³
Young’s Modulus	210 GPa
Poission’s ratio	0.3
Tensile Strength	630 MPa
Yield Strength	355 MPa
Brinell Hardness	190

AISI 316

Since this tool will not stay on the seabed for a long time, and therefore not be as exposed to the corrosive environment as the MV-head, super duplex is not necessary to prevent corrosion. The SSRT will be made of AISI 316 because of its availability and properties. It is typically used in an industry with harsh environments, as it has great corrosion resistance and a high tensile strength in various temperatures [44]. The material properties of AISI 316 are shown in Table 12.

Table 12 - AISI 316 material properties [44]

Material Density	8000 kg /m³
Young's Modulus	193 GPa
Poission's ratio	0.29
Tensile Strength	580 MPa
Yield Strength	290 MPa
Brinell Hardness	219

Aluminum

The slot plate is made of S355J2 steel, and to protect the plate an aluminum busher is mounted on the pushing cylinders. The aluminum has lower Brinell hardness, and therefore the slot plate will not get any damage. If the aluminum bushers are damaged, they can easily be replaced with a minimum cost compared to replacing the slot plate or the cylinders.

Table 13 – Aluminum material properties [40]

Material Density	2780 kg /m³
Young's Modulus	72 GPa
Poission's ratio	0,34
Tensile Strength	345 MPa
Yield Strength	205 MPa
Brinell Hardness	93

5.5 Welds

The SSRT will have several welds. When the material is welded, some standards say that the yield strength of the parent material is weakened. The Eurocode 3: Design of steel structures, part 4.5 Stresses on the throat section of a fillet weld for the correlation factor β_w, will be followed. The SSRT will have both fillet welds and partial penetration butt welds. Partial penetration butt welds have the same properties as the fillet welds, so Equation (16) will be valid for both welds.

The different stresses on the weld are shown in Figure 103.

$\sigma_{\perp}$ - is the normal stress perpendicular to the throat

$\sigma_{\parallel}$ - is the normal stress parallel to the axis of the weld

$\tau_{\perp}$ - is the shear stress perpendicular to the axis of the weld

$\tau_{\parallel}$ - is the shear stress parallel to the axis of the weld

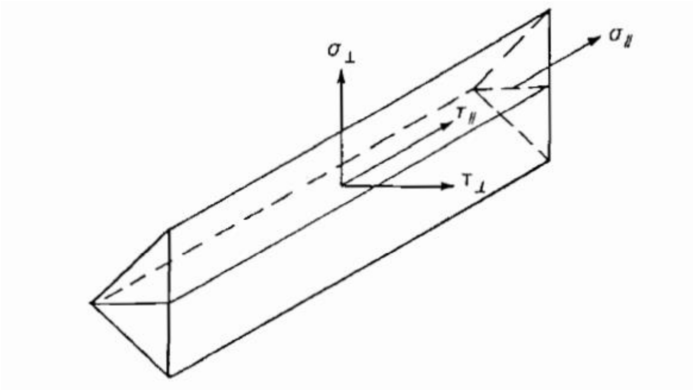


Figure 103 - Normal stress and shear stress, both perpendicular and parallel [45]

Both requirements must be satisfied for the design resistance of the fillet weld to be sufficient:

$$[\sigma_{\perp}^2 + 3(\tau_{\perp}^2 + \tau_{\parallel}^2)]^{0.5} \leq f_u/(\beta_w \gamma_{M2})] \quad \text{and} \quad \sigma_{\perp} \leq 0{,}9 f_u/\gamma_{M2} \qquad (16)$$

where:

f_u is the nominal ultimate tensile strength of the weaker part joined, 290 MPa.

β_w is the appropriate correlation factor, which in this case is 0,92 [46].

γ_{M2} is the partial safety factor for joints, including resistance of bolts, rivets, pins, welds, and plates in bearings and the recommended value is 1,25.

$[\sigma_{\perp}^2 + 3(\tau_{\perp}^2 + \tau_{\parallel}^2)]^{0.5}$ is the von Mises stress, and $\sigma_{\perp}$ is the normal stress to the throat of the weld [45].

The von Mises stress must be lower than $f_u/(\beta_w \gamma_{M2})$:

von Mises $\leq \frac{290\ MPa}{0{,}92 \cdot 1{,}25} = 252\ MPa$

The normal stress perpendicular to the throat must be lower than $0{,}9 f_u/\gamma_{M2}$:

Normal stress $\leq 0{,}9 \cdot \frac{290\ MPa}{1{,}25} = 208{,}8\ MPa$

5.6 Hydraulic

The SSRT will have five cylinders that are hydraulically supplied by the ROV. A proposal will be provided for how these cylinders should be operated and a hydraulic schematic will be made.

5.6.1 Hydraulic Schematic

The hydraulic schematic, seen in Figure 104, covers the lines from the ROV valve pack to the SSRT. The suppliers and setup of ROV hydraulics are many, and therefore this is a proposal on how to connect the tool to the ROV.

1- Ø35 4P, 690 bar hot stab and receptacle placed in ROV skid drawer
2- Push cylinders on SSRT
3- Open/close cylinder on SSRT

The "ROV" stapled line is the bulkhead between the ROV and the SSRT, where the receptacle (1) is mounted in the skid drawer, seen in Figure 8. A receptacle and hot stab are a quick connector for hydraulics, which allows the ROV to disconnect from the SSRT using the manipulator. Due to this, the SSRT can be deployed in a subsea basket to save storage space on the ROV. The Group's proposal is to use a Ø35, 4-port Blue Logic system, seen in Figure 105. They have max pressure 690 bar and gives a typical pressure drop 10 bar @ 20 l/min [47].

The receptacle is connected to two low-flow proportional valves (1A/B and 2A/B) with pressure adjustment valves internally in the ROV valve pack. Valve 1 operates the push cylinder, while valve 2 operates the open/close cylinder. The ROV pilot operates the valves and adjusts the pressure.

The push cylinders are extracted when Valve 1A is operated and retracted when Valve 1B is operated. The open/close cylinder opens when valve 2A is operated and closes by 2B. The maximum pressure for the open/close cylinder is set to 150 bar (see 5.8.6 for calculations).

Due to the low flow requirement and space, the Group suggests using ¼'' hoses and tubes. The Company must use fittings, hoses, and tubes rated for SSRT design pressure, which is 207 Bar, in addition to the surrounding pressure given by equation (4) and (5). It is recommended that SSRT is tested according to ISO 13628-6-2006 for hydrostatic leak tests. The hoses will be the connection between the ROV and SSRT, while the tubes are mounted between the push cylinders on the SSRT.

The Company must be sure that the ROV use compatible oil to the hydraulic components on the SSRT.

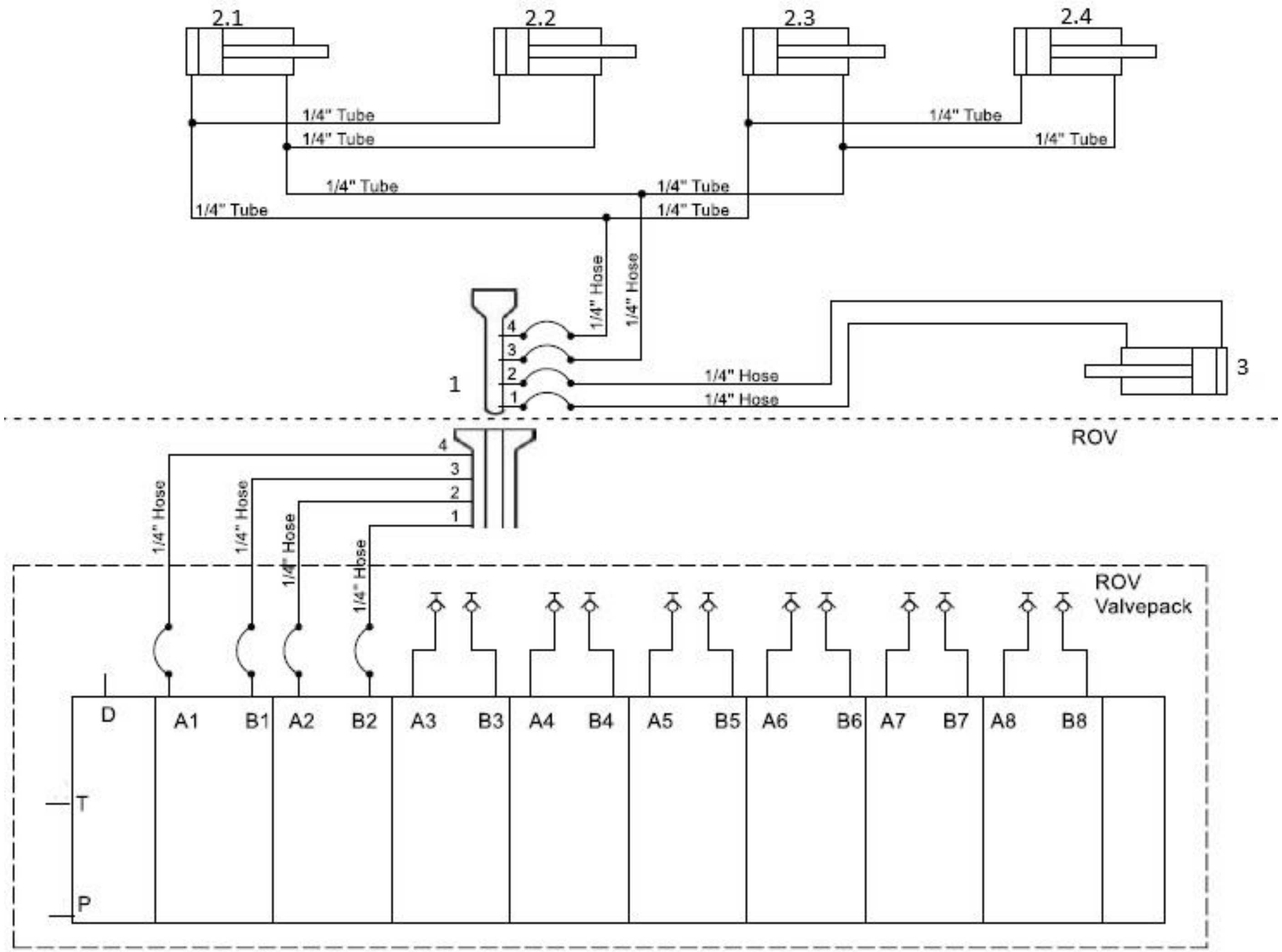


Figure 104 - Proposal for SSRT and ROV hydraulic schematic

Figure 105 - Ø35 hot stabs and receptacle. 4-port to the right [47]

5.6.2 Forces from Hydraulic Cylinders

Maximum pressure supply from ROV to cylinders is 207 bar [8]. The cylinders have a piston diameter at 25 mm.

Theoretical force from one cylinder will be (mechanical losses are not accounted for):

$$F = 20{,}7\ MPa \cdot \frac{(25\ mm)^2 \cdot \pi}{4} = 10156\ N \tag{15}$$

Force from four cylinders will be:

$$F_{tot} = 4 \cdot 10156\ \text{N} = 40624\ \text{N}$$

Force on each cylinder with safety factor 1,3:

$$F_{SF} = 10156\ N \cdot 1{,}3 = 13200\ N \tag{16}$$

5.7 Calculations by Hand

To ensure that the MV-head can handle the force that it is exposed to, both hand calculations and simulations are done. In this chapter, the calculations done by hand are presented.

5.7.1 Boundary Conditions and Forces

To find forces acting on the MV-head, theory from static calculations will be used. In Figure 106, the calculations are shown. The forces from the cylinder are called F1 and F2 and are 13200 N, shown in equation (15). Both the moment diagram and shear force diagram are shown.

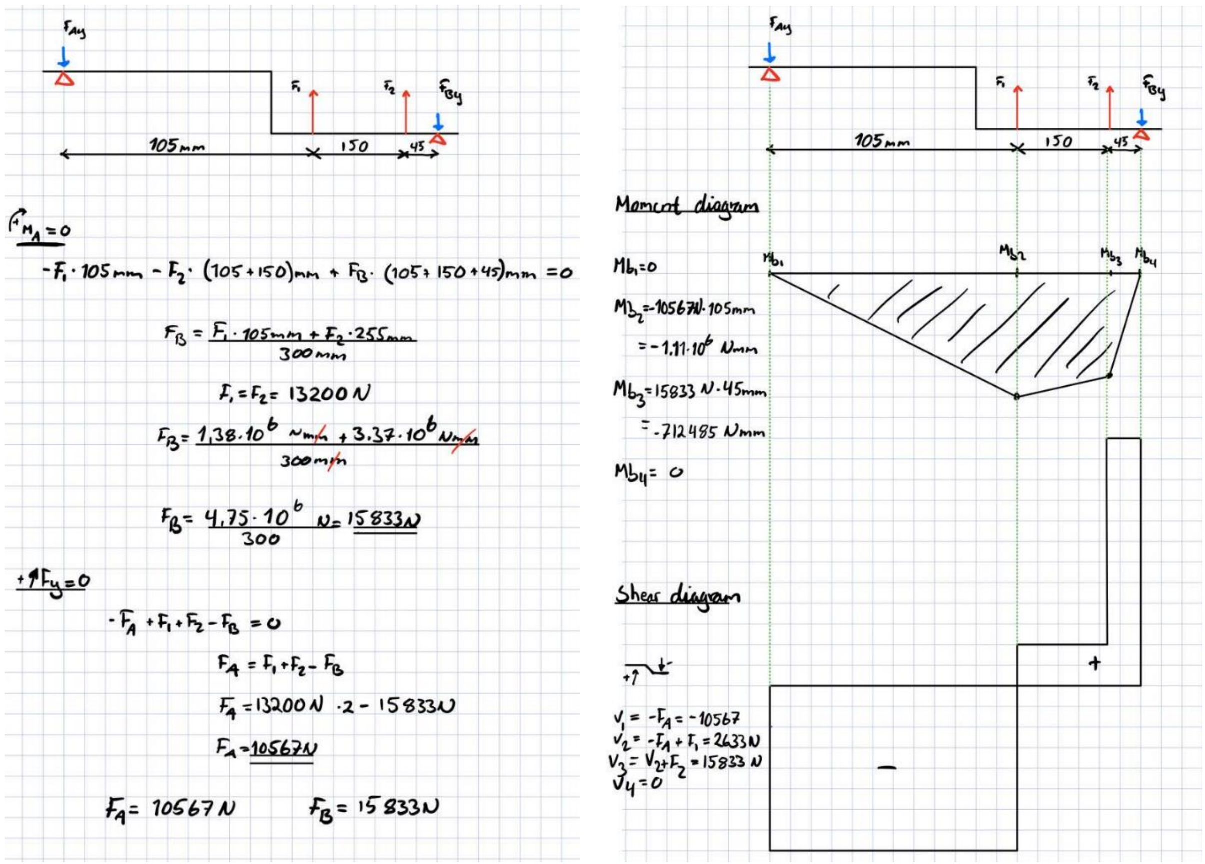


Figure 106 - Hand calculations for force distribution

From the calculations, we see that the force acting on the flying handle and the bracket on the connector is respectively 10567 N and 15833 N.

5.7.2 Flying Handle Weld

The flying handle is welded to the MV-head, and since the tool will use the flying handle as a counterforce, the weld will be checked. The Company has already said that the SSRT should be designed after the maximum forces given by the push cylinder. If these results shows that the flying handle will yield, the force from the push cylinders will still be designing factor for the SSRT.

Load, F = 10567 N

Weld, $a = 5\ mm$

Yield strength material, $\sigma_{All} \leq 550\ MPa$

Moment acting on the weld:

$$\underset{+}{\rightarrow} \sum F_x = 0 => R_x = 0$$

$$\uparrow + \sum F_y = 0 => R_y = F = 10560\ N$$

$$\downarrow + \sum M_o = 0 => M - R_y \cdot 20\ mm = 0 => M = 10560\ N \cdot 20\ mm = 211200\ Nmm$$

Material

Moment of inertia of rectangular geometry, I_x:

$$I_x = \frac{85\ mm \cdot (15 mm)^3}{12} = 23906\ \ mm^4 \tag{7}$$

Normal stress, σ_b:

$$\sigma_b = \frac{211200\ Nmm}{23906\ mm^4} \cdot \frac{85\ mm}{2} = 375\ MPa \leq 550\ MPa \tag{8}$$

Weld

Moment of inertia for fillet weld, I_x

$$I_x = \frac{1}{12}\left((85\ mm + 2 \cdot 5\ mm)(15\ mm + 2 \cdot 5\ mm)^3 - 85\ mm \cdot (15\ mm)^3\ \right) \tag{10}$$

$$I_x = 99792\ mm^4$$

Weld in A

Normal stress in outer weld, σ_{b_A}:

$$\sigma_{b_A} = \frac{211200\ Nmm}{99792\ mm^4} \cdot \left(\frac{85}{2}\ mm + 5\ mm\right) = 100{,}5 \text{ MPa} \tag{9}$$

Combined stress, σ_{jfA}:

$$\sigma_{jfA} = \sqrt{2} \cdot \sigma_{bA} = 142 MPa \tag{11}$$

Weld in B

Normal stress, σ_{b_B}:

$$\sigma_{b_B} = \frac{211200\ Nmm}{99792\ \ mm^4} \cdot \frac{15\ mm}{2} = 15{,}9\ MPa \tag{8}$$

Shear stress, τ_b:

$$\tau_b = \frac{10560\ N}{2 \cdot 5\ mm \cdot 15\ mm} = 70{,}4\ MPa \tag{13}$$

Combined stress, σ_{jfB}:

$$\sigma_{jfB} =\ \sqrt{2 \cdot {\sigma_{bB}}^2 + 3{\tau_b}^2} = \sqrt{2 \cdot 15{,}9^2 + 3 \cdot 70{,}4^2}\ MPa = 124\ MPa \tag{11}$$

Compared results:

$$\sigma_{jfB} < \sigma_{jfA} \leq 550\ MPa$$

As shown in the calculations, the biggest shear stresses will occur in weld A and will be 142 MPa. This calculation supports the Company's wish to design the after maximum force given by the cylinders.

5.8 Ansys

In this chapter, the FEM analyzes from Ansys will be presented.

5.8.1 Flying Handle

As mentioned in Chapter 5.7, one of the counterforces is the flying handle. It is therefore important to check if the handle can withstand the forces. As shown in Figure 107, the force shown in red, will be continuous on the flying handle. The weld makes the part fixed in all six degrees of freedom, but to prevent singularity fault, displacement is used instead of fixed support.

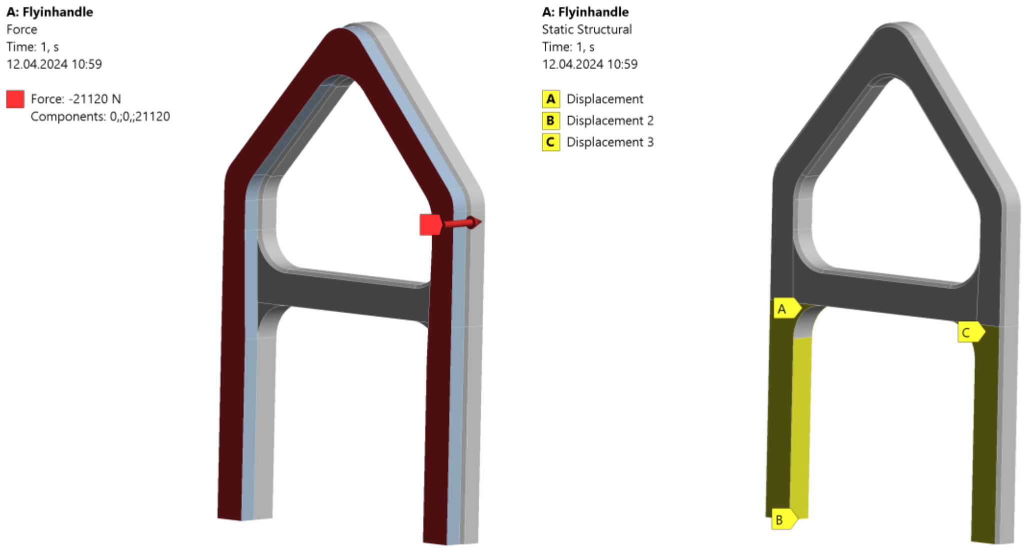


Figure 107 - Force and support on flying handle

Mesh settings for flying handle is shown in Table 14 and Figure 108.

Table 14 - Mesh settings for flying handle

Element size	2 mm
Element order	Quadratic
Nodes	65692
Elements	36270

Figure 108 - Mesh on flying handle

The stresses are shown in Figure 109, and as shown the max stress on the flying handle is 470MPa.

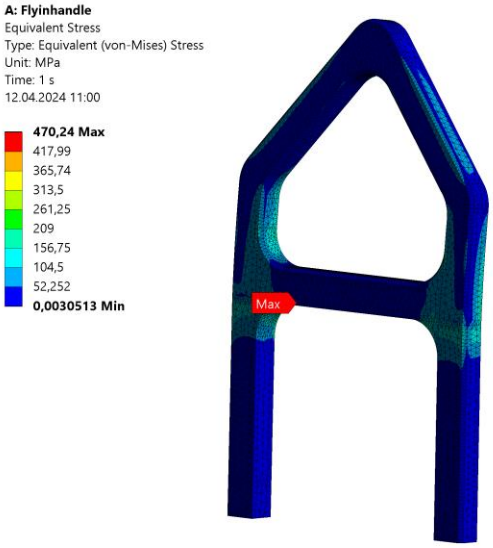


Figure 109 - Stress on flying handle

As shown in Figure 110, the realistic max stress is around 257 MPa, which is good because the yield stress of the material is 550 MPa.

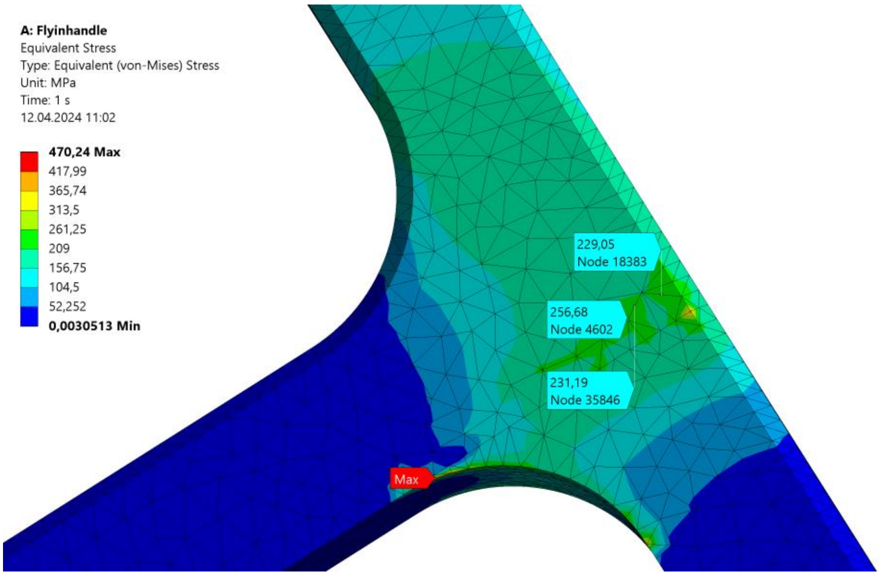


Figure 110 - Stress results on flying handle

5.8.2 Connector Bracket

The second counterforce on the MV-head is the bracket that the cable is fastened in. The forces will be on the two small surfaces shown as B and C in Figure 111. The blue section A is where the bracket is fastened in the MV-head, as fixed support.

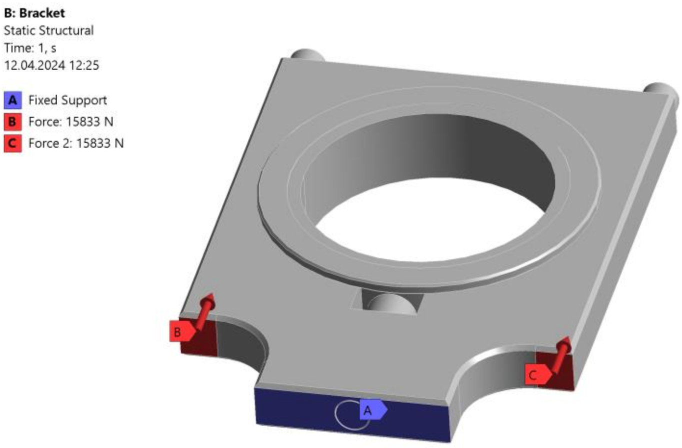


Figure 111 - Force and displacement on connector bracket

Mesh settings on the bracket are shown in Table 15 and Figure 112.

Table 15 - Mesh settings for connector bracket

Element size	5 mm
Element order	Quadratic
Nodes	88758
Elements	51167
Body sizing	3 mm

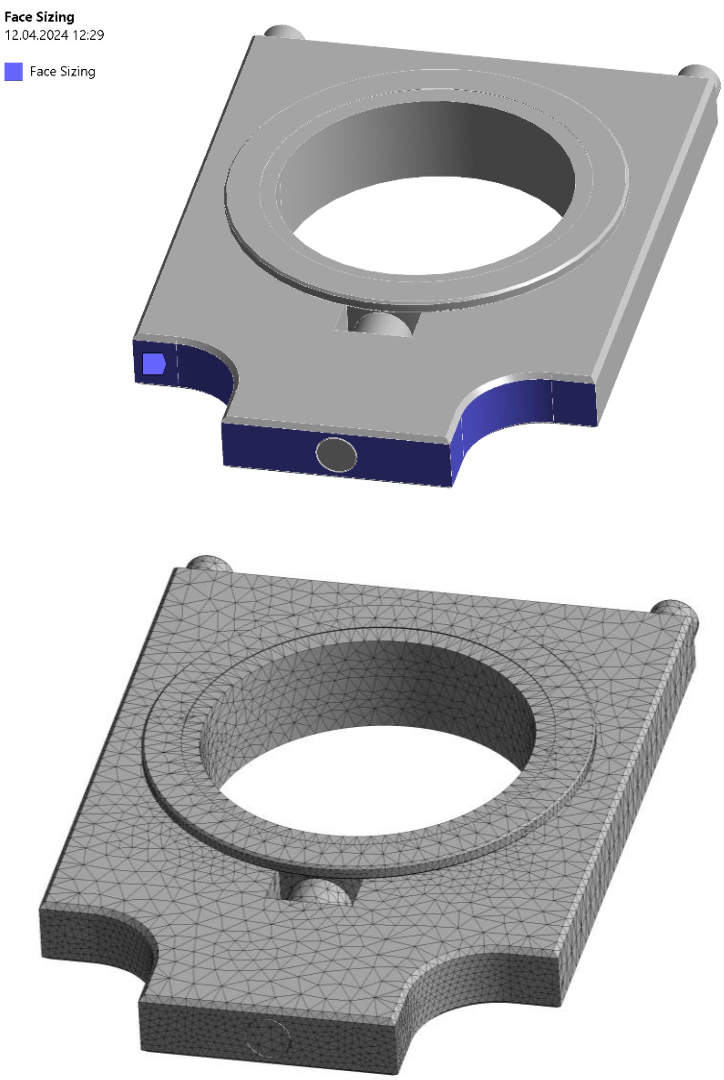


Figure 112 - Mesh on connector bracket

The stress results from the analysis are shown in Figure 113. The max stress is 15 MPa, which is low compared with the yield strength of the material, which is 550 MPa.

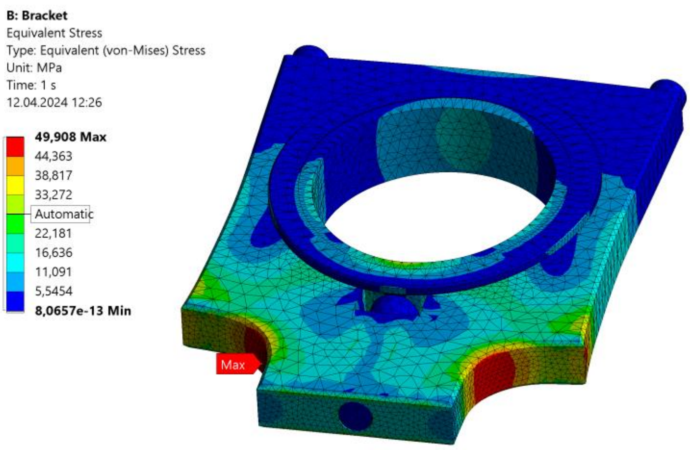


Figure 113 - Stress on connector bracket

5.8.3 Cylinder Bracket

To find the thickness of the cylinder bracket seen in Figure 114, an optimization in Ansys will be performed.

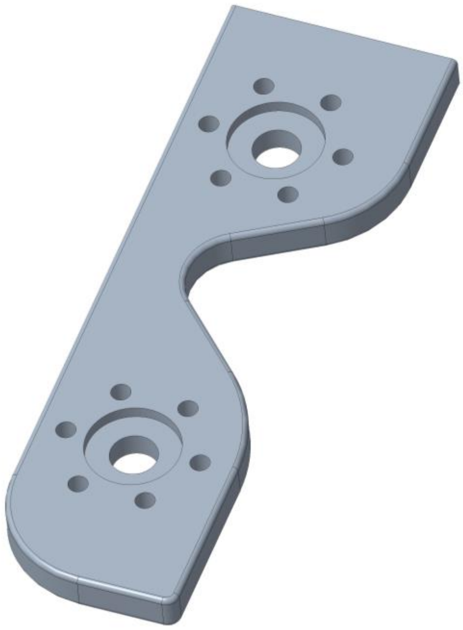


Figure 114 - Cylinder bracket

In Ansys Design Modeler, the cylinder bracket is split to several bodies for boundary conditions and to remove typical points where singularity faults can appear. The contact face between the MV-head bracket and cylinder bracket is built up 7 mm with 5 mm fillet to limit the singularity fault. See Figure 115 from Ansys.

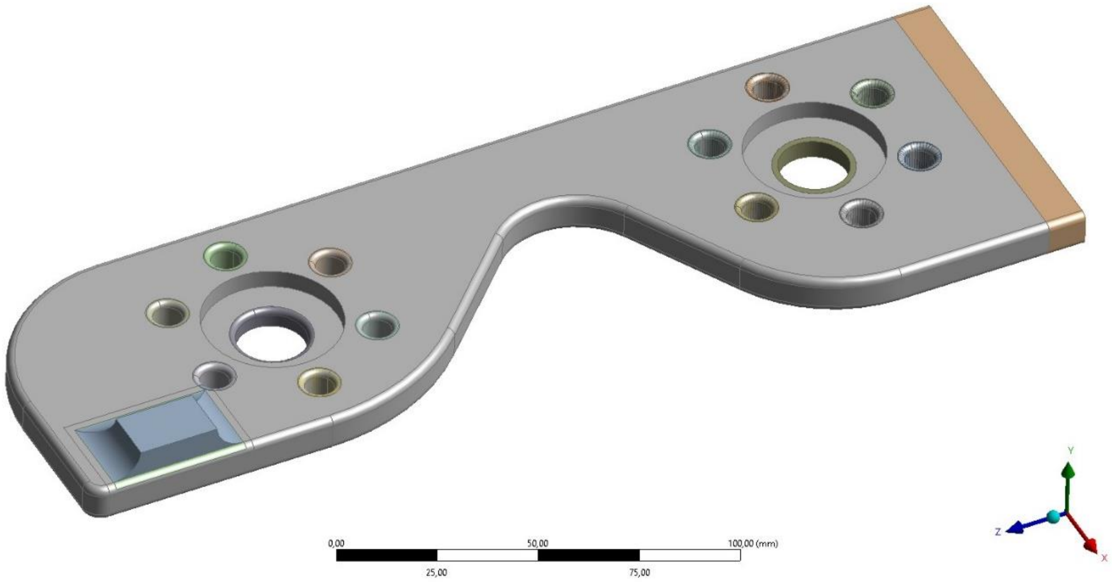


Figure 115 - Cylinder bracket in design modeler

The mesh settings are shown in

Table 16 and Figure 116.

Table 16 - Mesh settings cylinder bracket

Element size	1,2 mm
Element order	Quadratic
Nodes	308897
Elements	174893

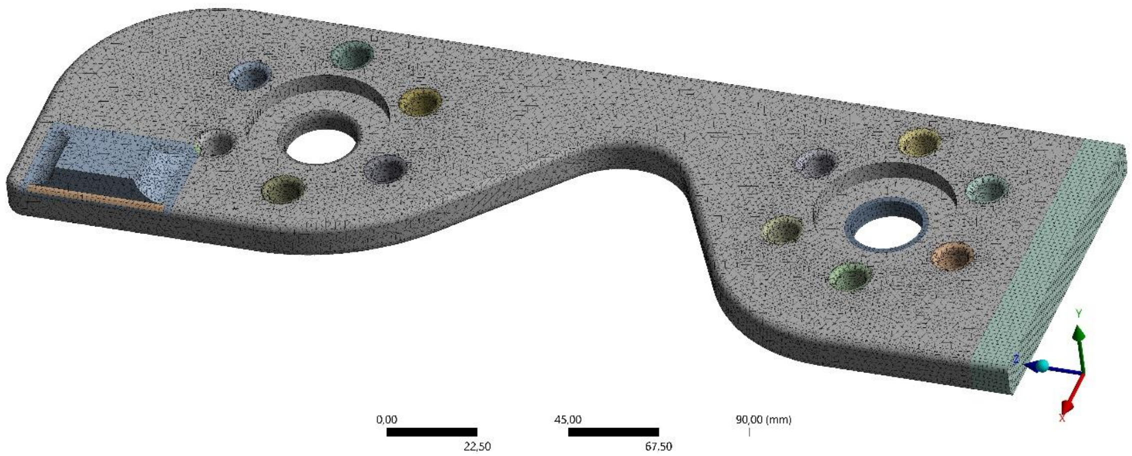


Figure 116 - Meshing on cylinder bracket

The boundary conditions and forces are displayed in Table 17 and Figure 117. Gravity is set to 9,81 m/s^2 due to topside testing. The gravity will be different subsea due to buoyancy.

Table 17 - Boundary conditions on cylinder bracket

Displacement, C	Y - constant
Displacement, E	Z, Y - constant
Displacement, F	X - constant

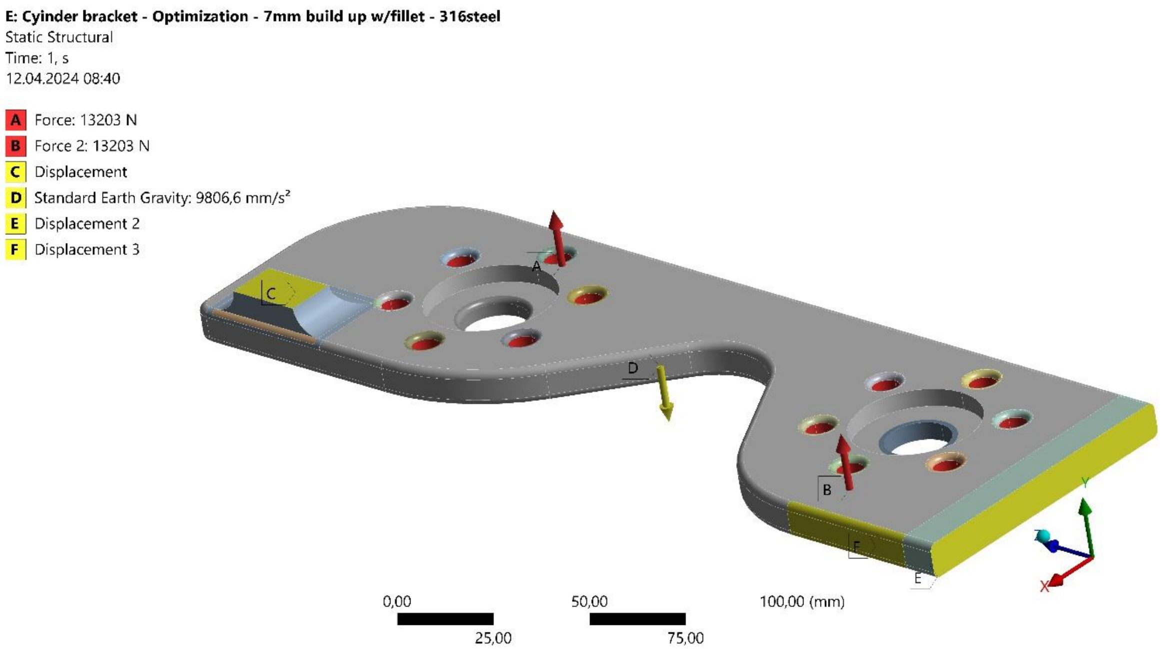


Figure 117 - Boundary conditions and forces on cylinder bracket

The parameters to be found in Table 18 and Figure 118.

Table 18 - Parameters for cylinder bracket

ID	Parameter	Type	Parameter Name
P3	Input	Thickness of bracket	P336@ds
P1	Output	Safety factor	Safety Factor Minimum
P2	Output	Maximum stress for bodies without singularity faults	Equivalent Stress 3 Maximum
P4	Output	Deformation	Total Deformation Maximum

2:Engineering Data | Parameter Set | F2,G2:Design of Experiments | G4:Optimization

Outline of All Parameters

	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	Input Parameters			
3	Cyinder bracket - Optimization - 7mm build up w/fillet - 316steel (E1)			
4	P3	P336@ds	10	
*	New input parameter			
6	Output Parameters			
7	Cyinder bracket - Optimization - 7mm build up w/fillet - 316steel (E1)			
8	P1	Safety Factor Minimum	0,68698	
9	P2	Equivalent Stress 3 Maximum	422,14	MPa
10	P4	Total Deformation Maximum	1,1573	mm
*	New output parameter			
12	Charts			

Figure 118 - Parameters for cylinder bracket

From Table 9, Table 12 and equation (14) we get the maximum stress allowed, with a safety factor of 1,15:

$$\sigma_{allowed} = \frac{290\ MPa}{1,15} = 252\ MPa \tag{14}$$

A simulation is done first with parameter P3 = 10mm. The material used is AISI 316 steel, see Table 12 for material properties. Total deformation is 1,2 mm, as seen in Figure 119.

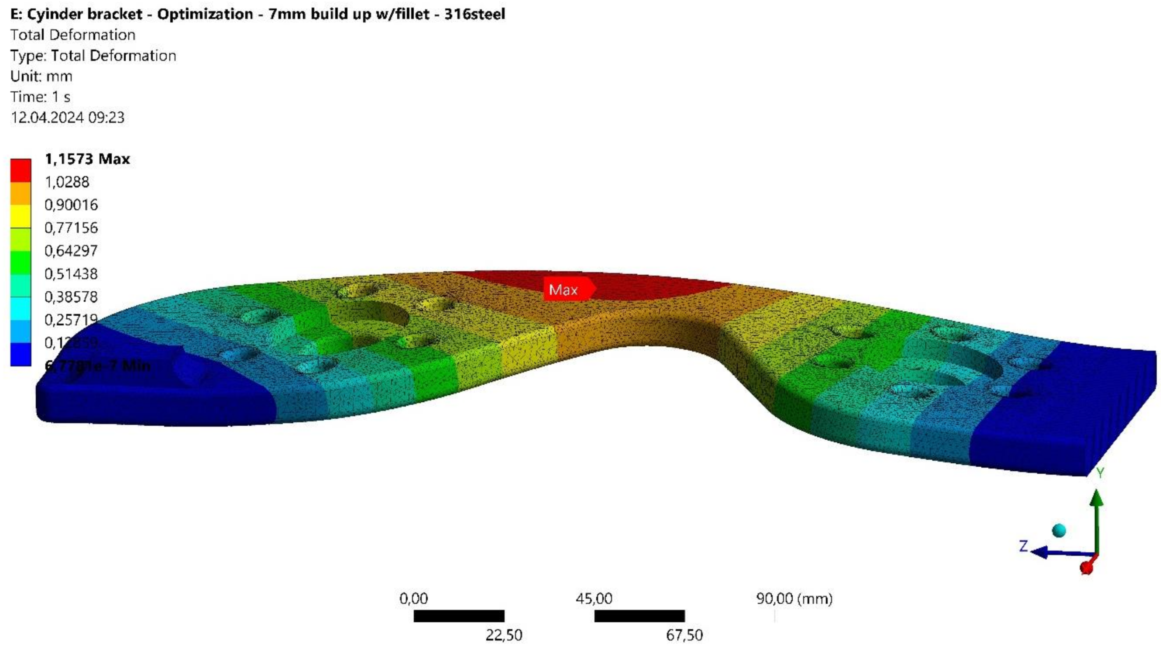


Figure 119 - Cylinder bracket total deformation with 10 mm plate

Singularity faults are shown in Figure 120 and Figure 121. These faults are removed and Figure 122 shows the results. This result display will be used for the rest of the optimization.

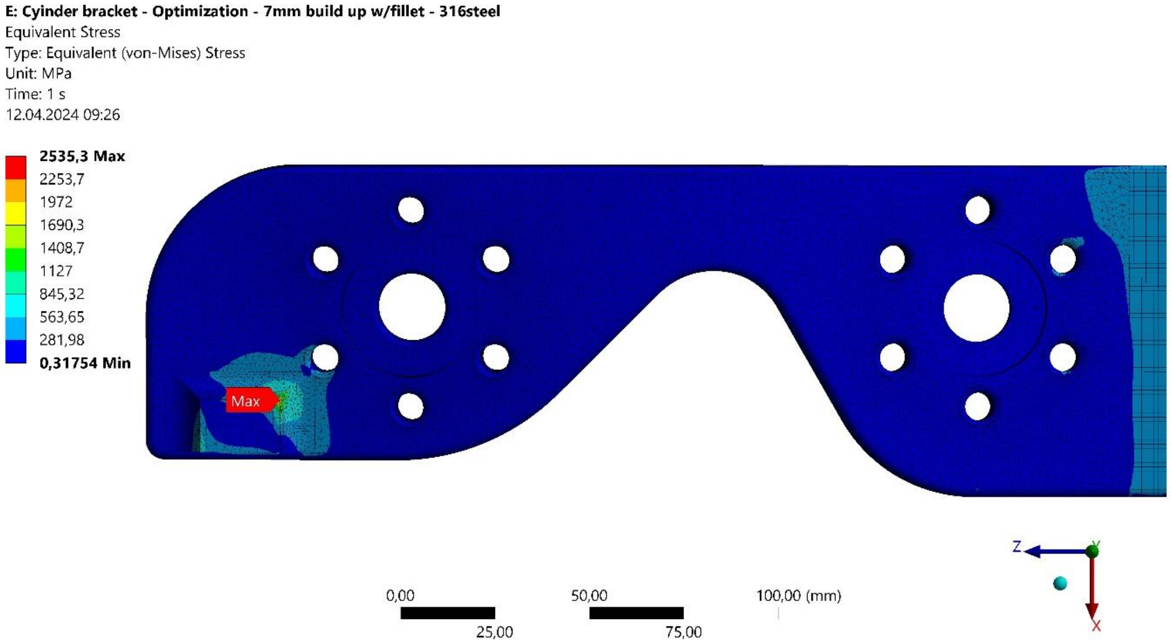


Figure 120 - Singularity fault on cylinder bracket with fillet and build up

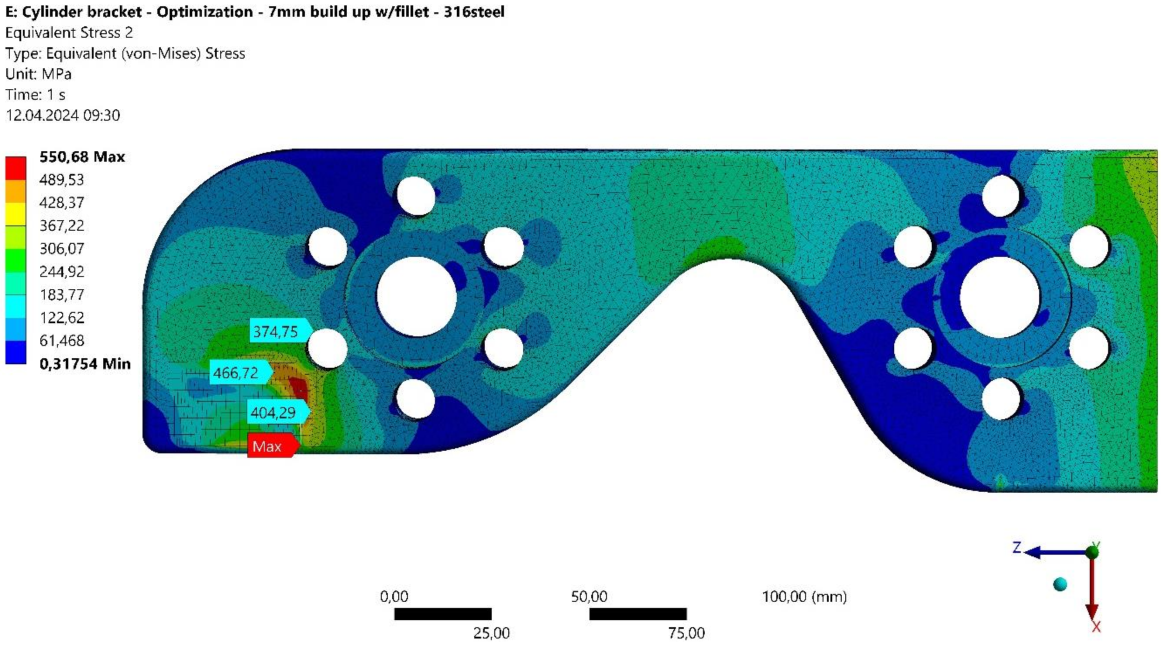


Figure 121 - Singularity fault on cylinder bracket with removed fillet and build up

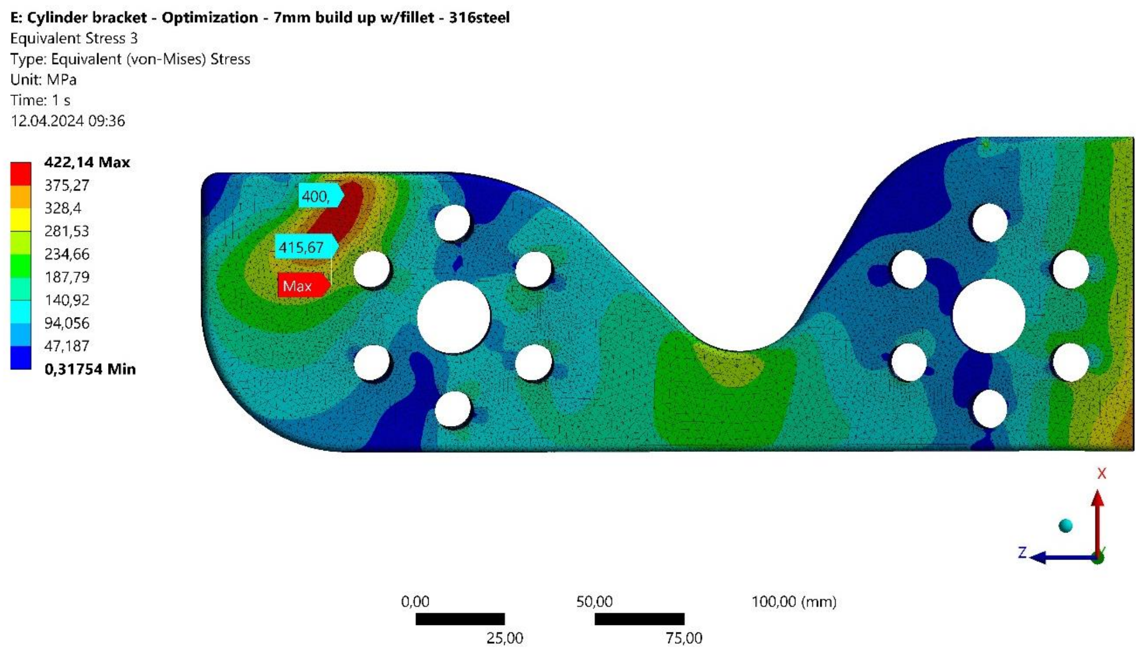


Figure 122 - Stress results without singularity faults on cylinder bracket

The maximum stress is 422 MPa, which is greater than $\sigma_{allowed}$. 10 mm is therefore not sufficient, and an optimization is required.

In Ansys Parameter Set, some Design Points on P3 (bracket thickness) are tested, see Figure 123.

Table of Design Points

	A	B	C	D	E	F	G	H
1	Name	P3 - P336…	P1 - Safety Factor Minimum	P2 - Equivalent Stress 3 Maximum	P4 - Total Deformation Maximum	Retain	Retained Data	Note
2	Units			MPa	mm			
3	DP 0 (Current)	10	0,68698	422,14	1,1573	☑	✓	
4	DP 1	15	1,2975	223,51	0,45207	☑	✓	
5	DP 2	20	1,5086	192,24	0,25889	☑	✓	
6	DP 3	25	2,1239	136,54	0,1739	☑	✓	
7	DP 4	30	2,5028	115,87	0,1255	☑	✓	
*						☐		

Figure 123 - Design points on thickness of cylinder bracket

Figure 123 shows that 15 mm width on the cylinder bracket is nearest the safety factor of 1,15 with a maximum stress on 224 MPa. Still, a new simulation is performed with Design of Experiments with lower- and upper boundaries on P3, seen in Figure 124:

- Lower bound: 12 mm
- Upper bound: 18 mm
- Any allowed values

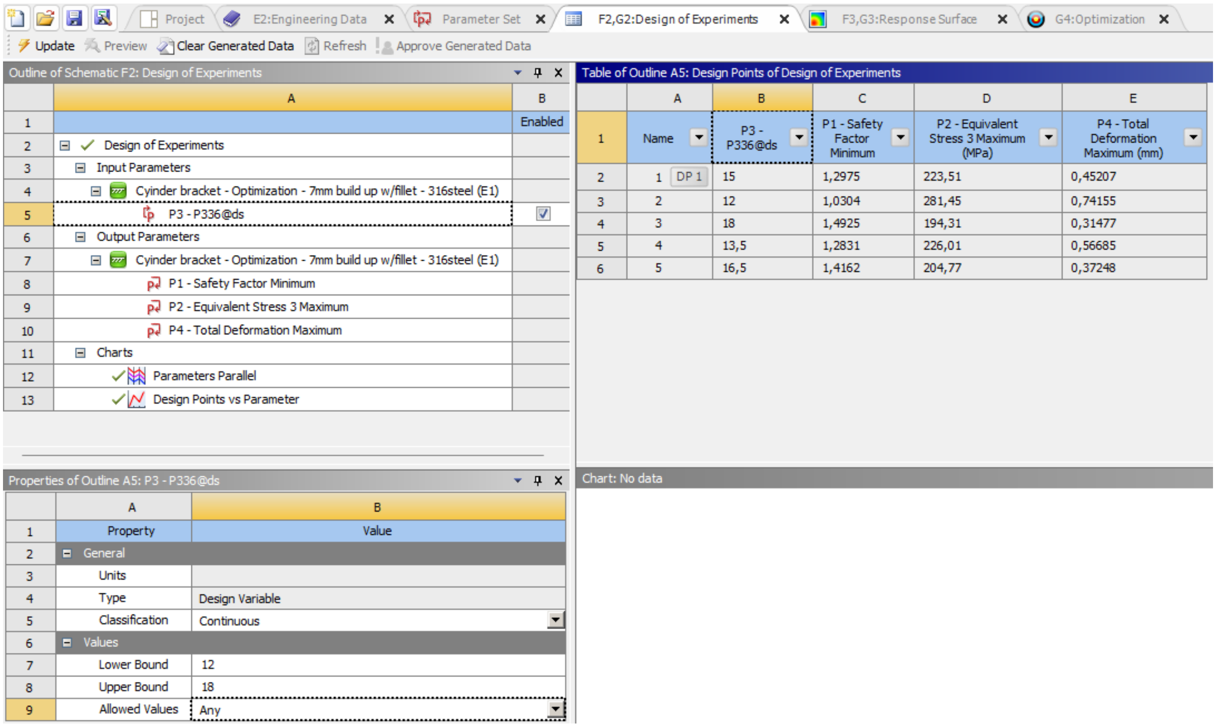


Figure 124 - Design of Experiments off P3 on cylinder bracket

Figure 125 shows the results from the Design of Experiments with P1- Safety factor on Y-axis and P3 - Bracket thickness on X-axis.

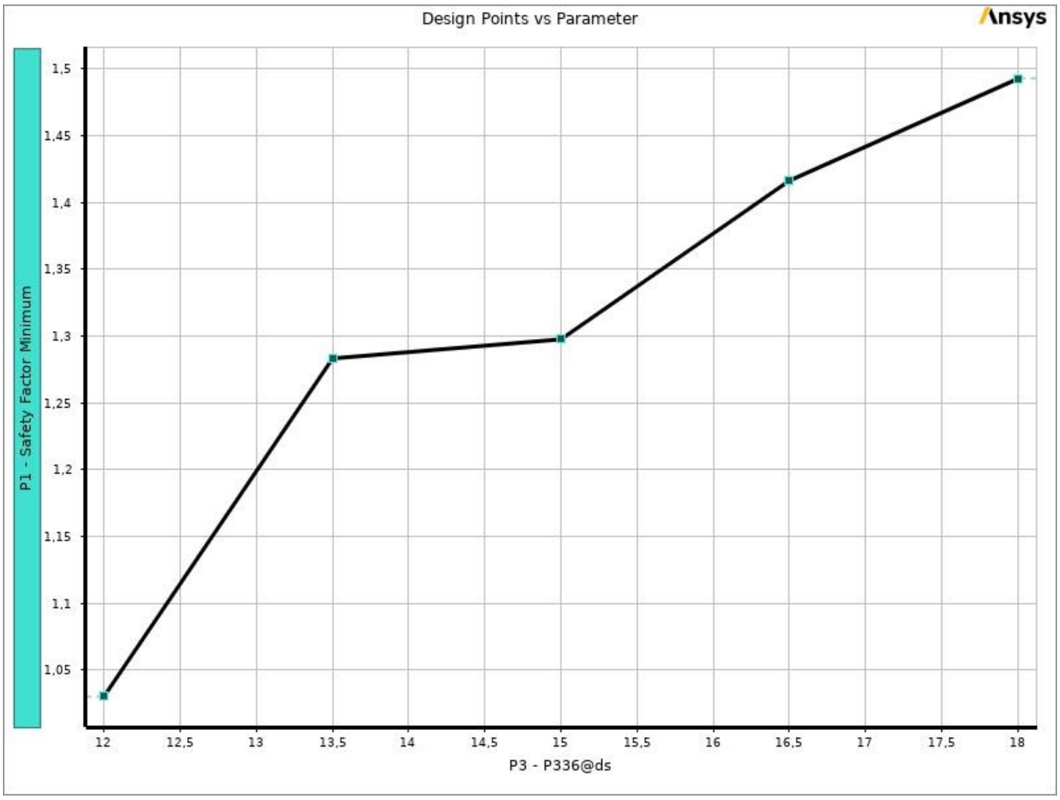


Figure 125 - Results of Design of Experiments

The results show that a width between 13 mm and 15 mm is above the safety factor of 1,15.

Min/max on outputs are shown in Figure 126. 12 mm width is too small and 18mm gives a safety factor ~1,5 which is greater than 1,15.

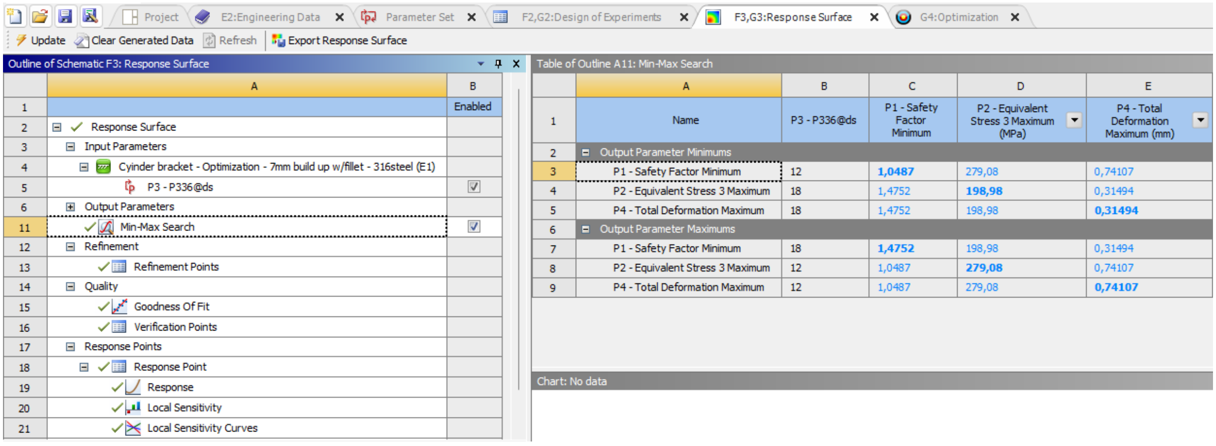


Figure 126 - Min/max outputs on cylinder bracket

Figure 127 shows the Response Chart for the cylinder bracket. Equivalent stress in Y-axis and width of the bracket in X-axis.

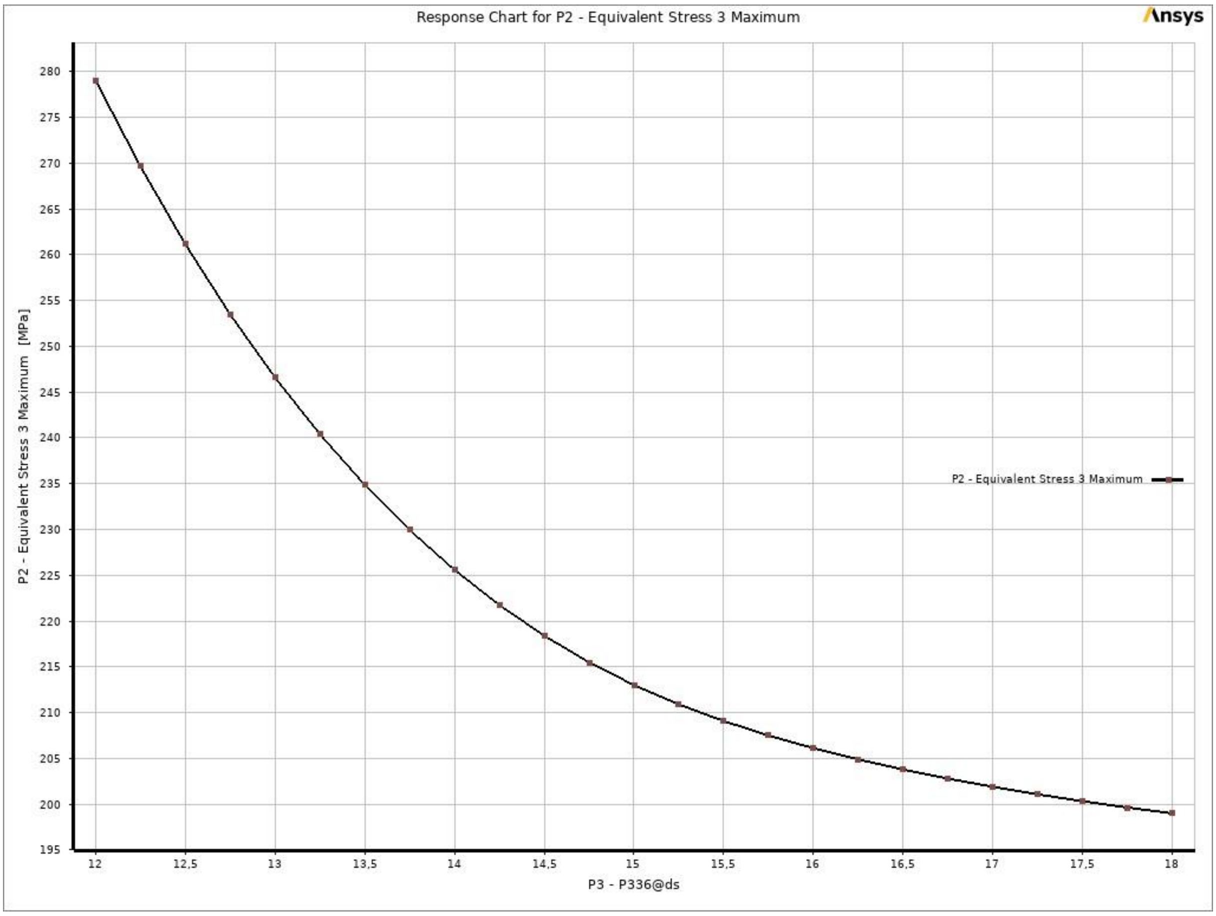


Figure 127 - Response chart for cylinder bracket

For the optimization, the objective is to seek P1- Safety Factor = 1,15. The results are displayed in Figure 128 and Figure 129. There is also added a custom candidate point on P3 = 15mm due to the material availability in the market.

Table of Schematic G4: Optimization , Candidate Points

	A	B	C	D	E	F	G
1	Reference	Name	P3 - P336@ds	P1 - Safety Factor Minimum		P2 - Equivalent Stress 3 Maximum (MPa)	P4 - Total Deformation Maximum (mm)
2				Parameter Value	Variation from Reference		
3	◉	Candidate Point 1	12,786	★★★ 1,15	0,00 %	252,46	0,64182
4	○	Candidate Point 2	12,787	★★★ 1,1501	0,01 %	252,43	0,64171
5	○	Candidate Point 3	12,788	★★★ 1,1502	0,02 %	252,4	0,64156
6	○	Custom Candidate Point	15	– 1,3476	17,18 %	212,99	0,45141
7	○	Custom Candidate Point (verified) DP 1		★ 1,2975	12,83 %	223,51	0,45207
*		New Custom Candidate Point	15				

Figure 128 - Results of optimization of cylinder bracket

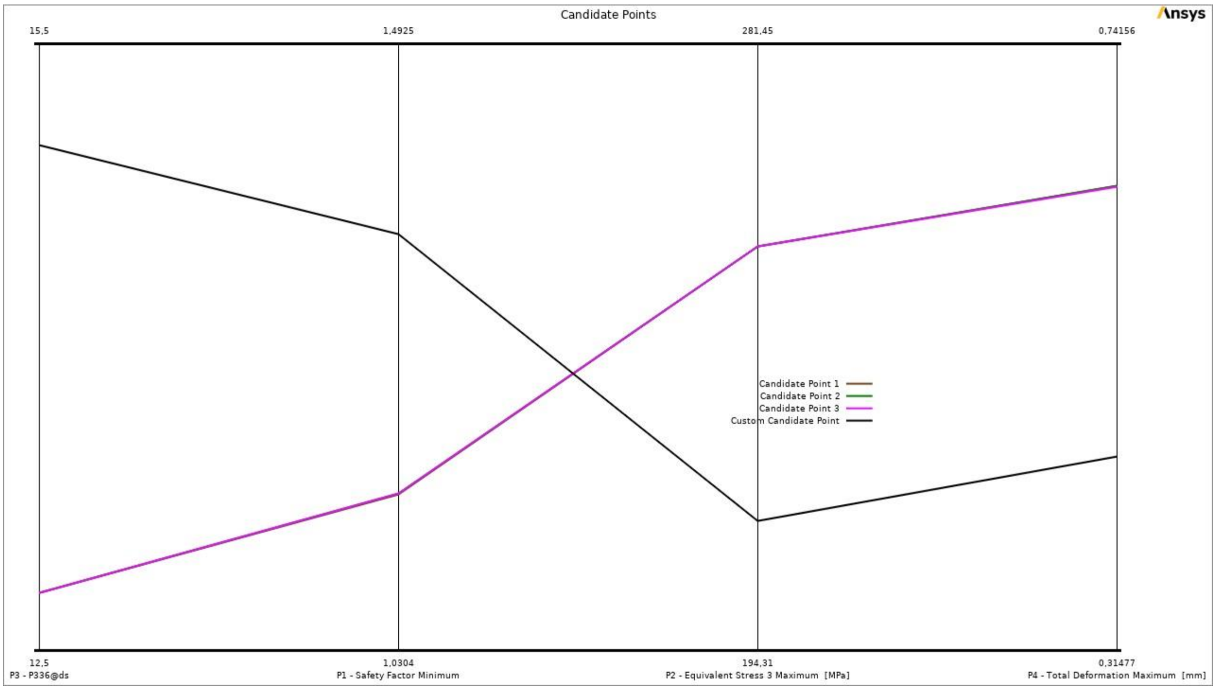


Figure 129 - Candidate points for cylinder bracket after optimization

Results Cylinder Bracket

The results after optimization for the cylinder bracket tells that a width ~ 13 mm gives a safety factor of 1,15. However, the Group must consider the availability of AISI 316 plates, and therefore 15 mm is the best option.

Figure 130 displays the result with 15 mm bracket and removed bodies where singularity faults occurred. The max stress is 223 MPa.

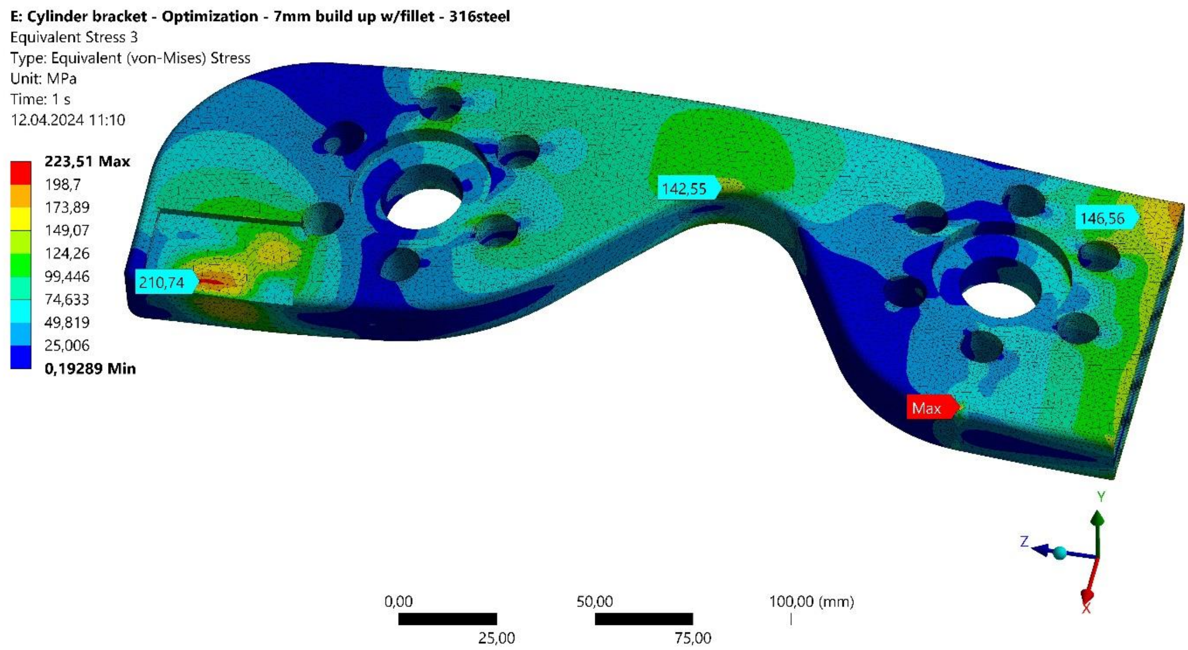


Figure 130 - Result of cylinder bracket after optimization

Figure 131 shows the result after optimization with all bodies. The maximum stresses are similar to Figure 130.

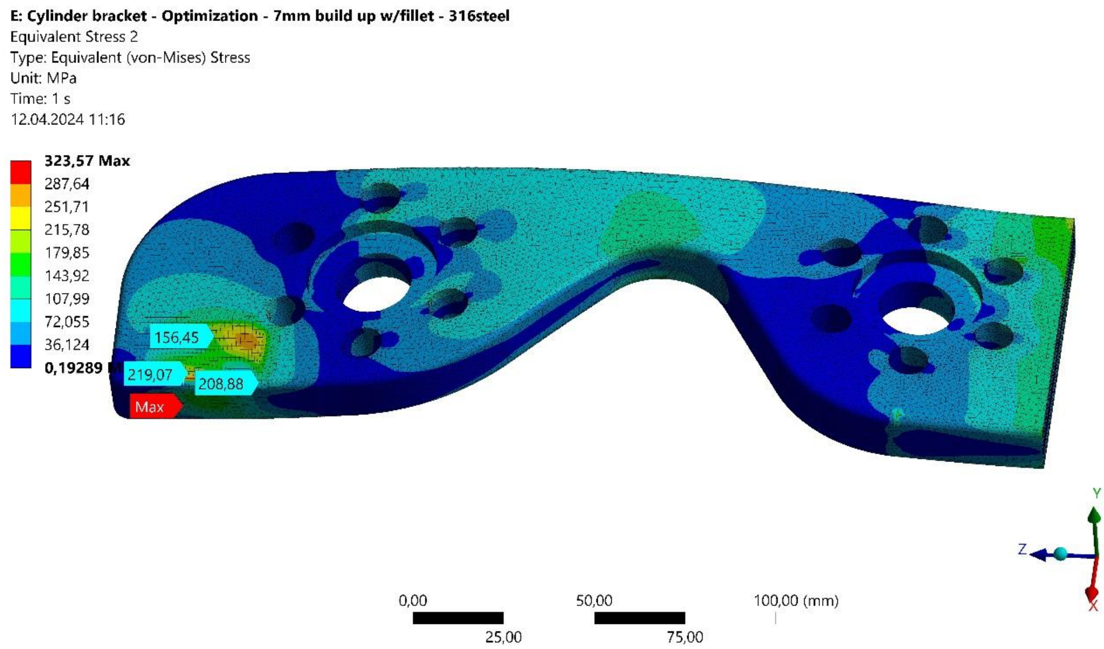
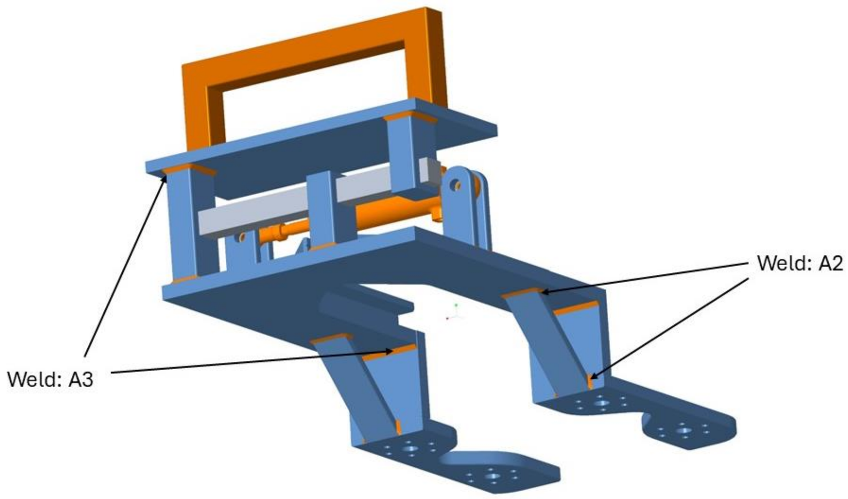


Figure 131 - Result of cylinder bracket after optimization with singularity faults

5.8.4 Gravity Check of Design

The Group performs a gravity check in Ansys on the assembly to see the stresses and deflection appearing. Welds will also be checked, and the parts exposed for the significant stress has A3 weld, while all other has A2 weld. Figure 132 is a picture of the welds.



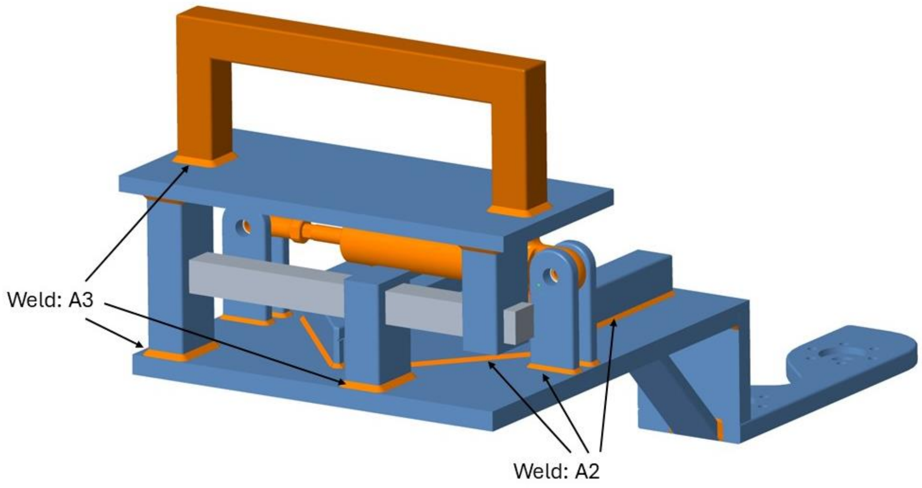


Figure 132 - Weld size on SSRT

The two brackets, shown in Figure 133, will have a K-slot weld filled to the surface. In Ansys, these K-slots are split to bodies for better stress results in the welds.

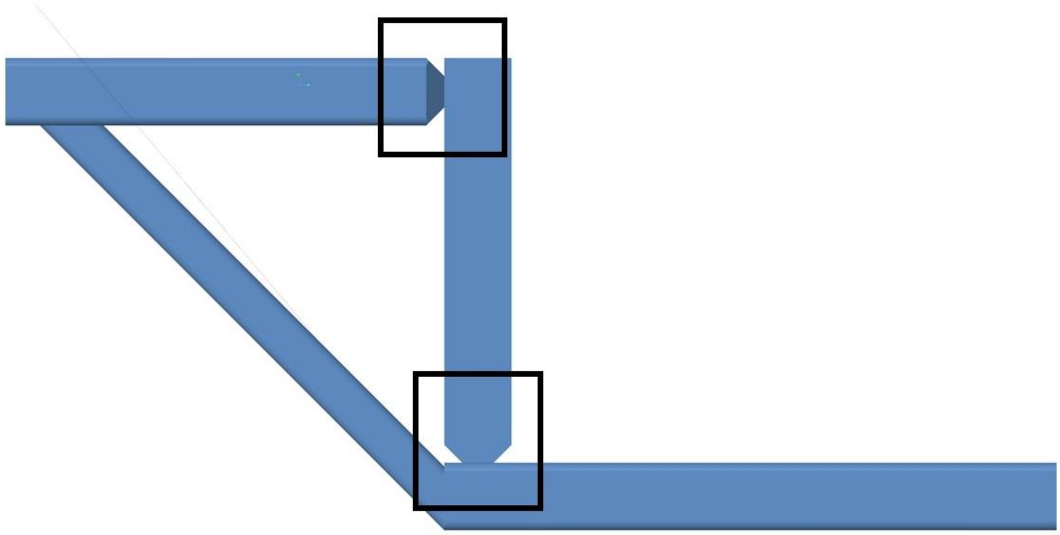


Figure 133 - Chamfers on SSRT

The split bodies are shown in Figure 134, from Design Modeler in Ansys. For simplicity, the cylinders are removed and replaced with a force to represent their weight.

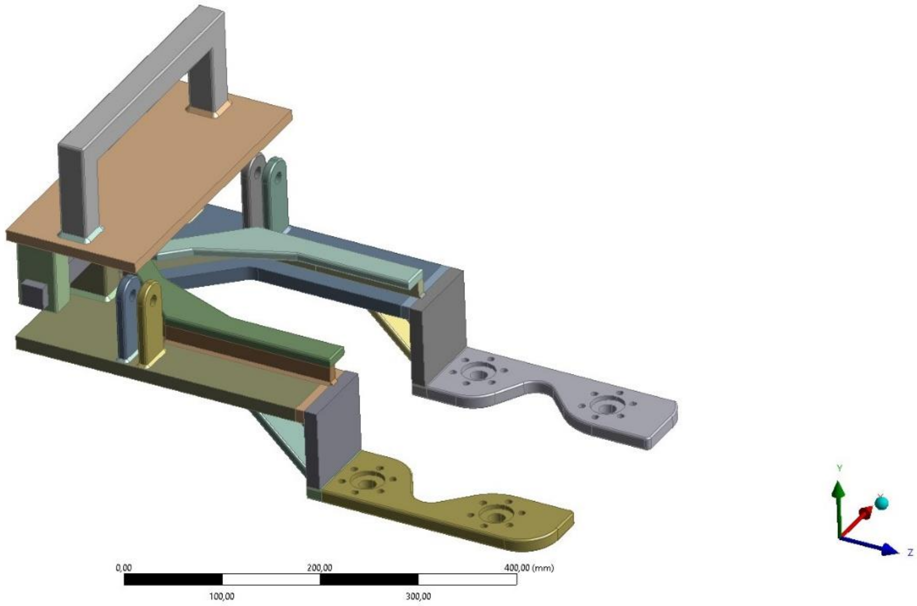


Figure 134 - SSRT in Design Modeler

The material used is AISI 316. All contact surfaces are bonded, except the frictionless gliding tube, seen in Figure 135.

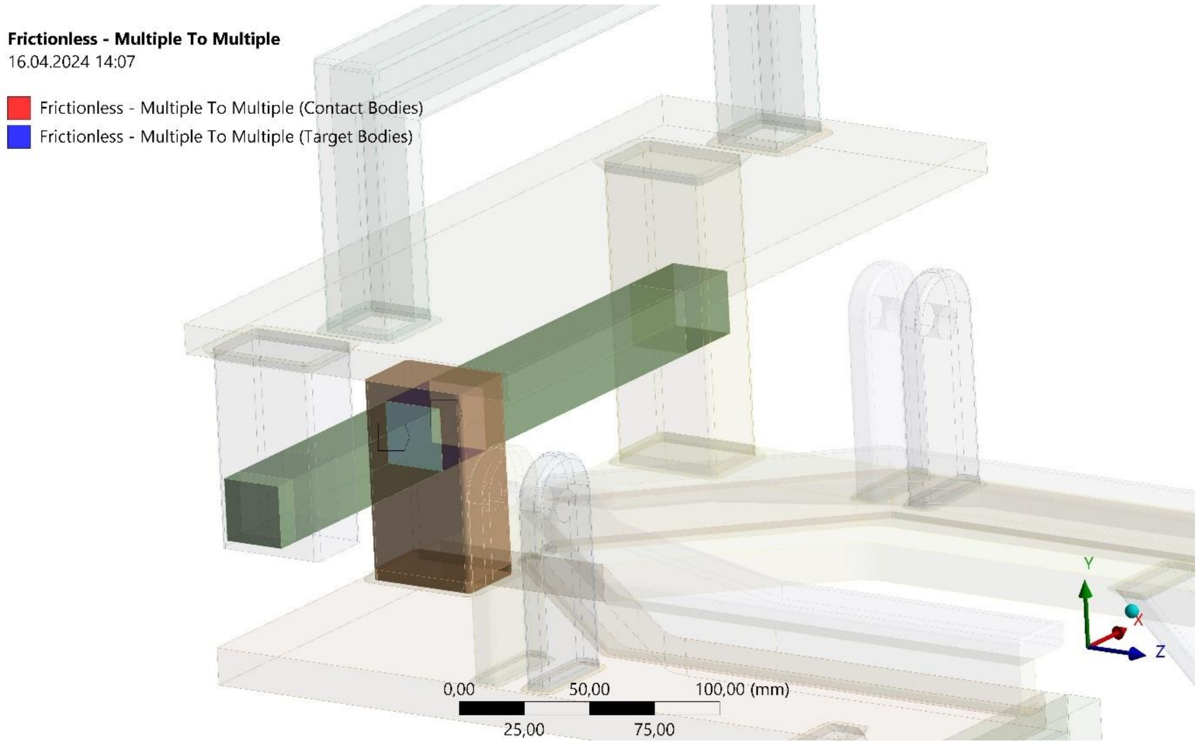


Figure 135 - Frictionless contact in SSRT

The mesh settings are seen in Table 19 and Figure 136. The loaded welds has body sizing for a more precise result.

Table 19 - SSRT mesh settings

Element size	5 mm
Element order	Quadratic
Nodes	532891
Elements	315388
Element size, A2 welds	1,5 mm
Element size, A3 welds	1,5 mm

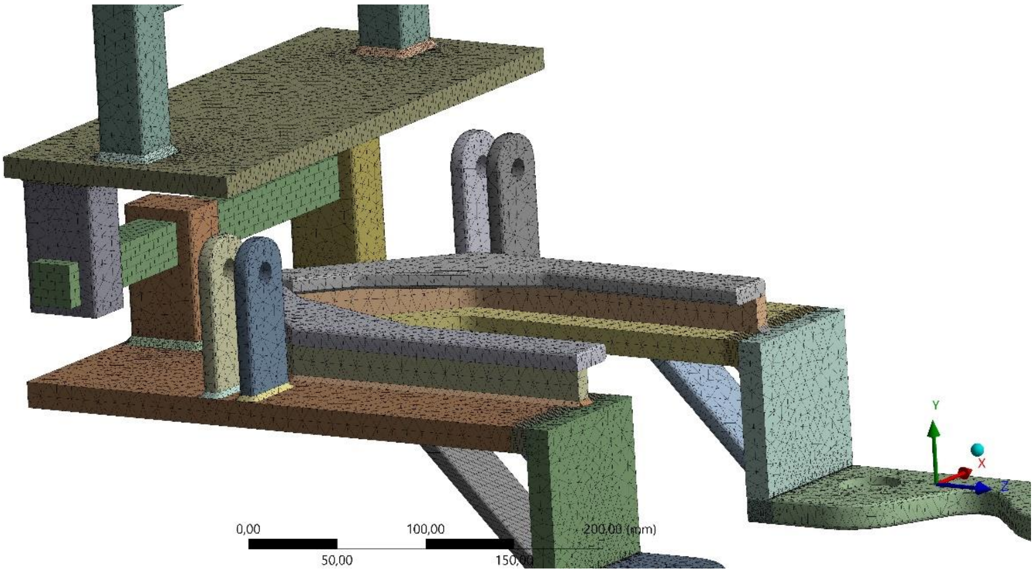


Figure 136 - SSRT mesh settings

The given loads and boundary conditions are seen in Table 20 and Figure 137. Force of 30 N displays the open/close cylinder and the bearing load, 100N, replaces the four push cylinders. Both including hydraulic oil and components.

Load scenario 1

Table 20 - Boundary conditions and loads for load scenario 1

Fixed Support, A	N/A
Standard Earth Gravity	Z
Force, 30 N (open/close function)	Z
Bearing load, 100N (Push cylinders)	Z

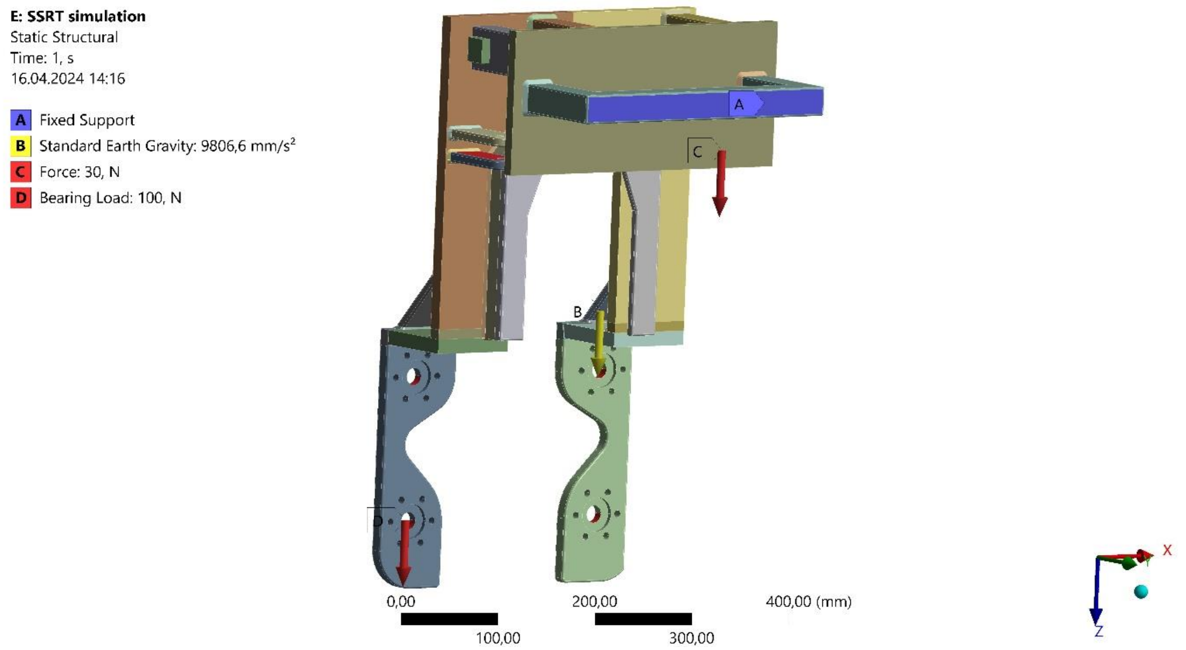


Figure 137 - Boundary conditions and loads for scenario 1

The total deformation is 0,5mm, which is negligible, seen in Figure 138.

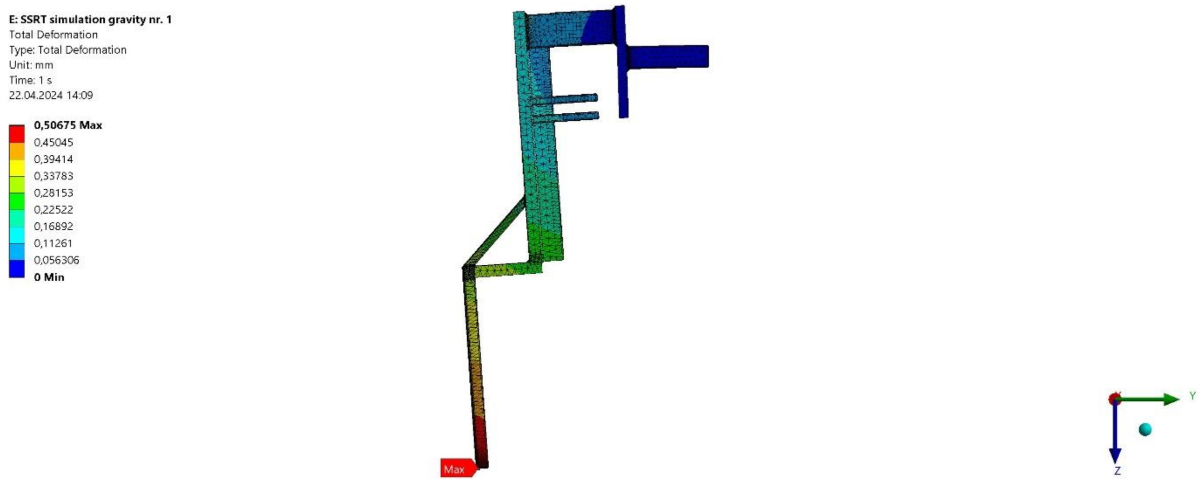


Figure 138 - Total deformation on SSRT with gravity loads scenario 1

The stress given by gravity is seen in Figure 139, Figure 140 and Figure 141. Maximum equivalent stress is 39 MPa. For the welds, a user defined result and a new coordinate system is made to get $\sigma_{\perp}$, the normal stress perpendicular to the throat. $\sigma_{\perp}$ on welds in Z direction is ~ 45 MPa.

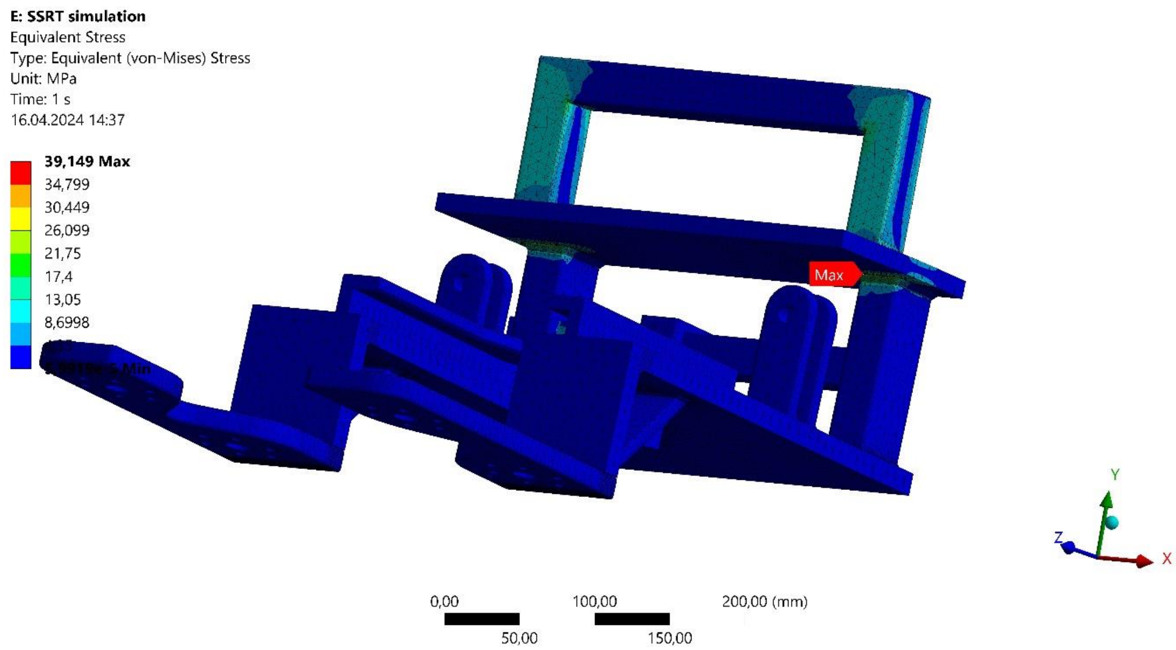


Figure 139 - Maximum equivalent stress on SSRT scenario 1

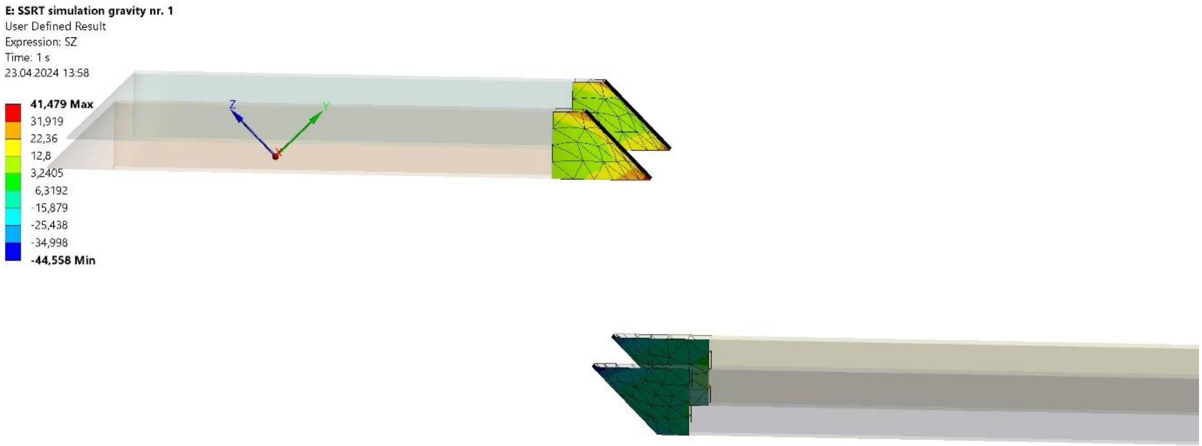


Figure 140 - $\sigma_{\perp}$ stress in welds load scenario 1, Z direction

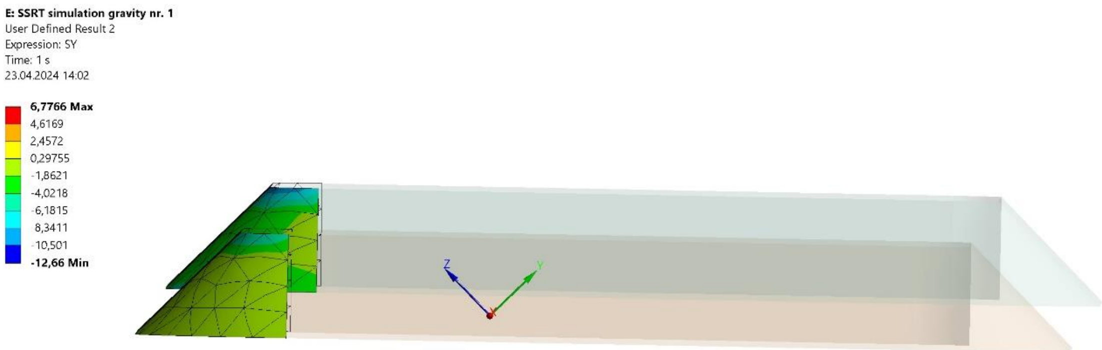


Figure 141 - $\sigma_{\perp}$ stress in load scenario 1, Y direction

Results to be discussed in Results of gravity check.

Load scenario 2

Another load scenario will be performed. This is shown in Table 21 and Figure 142.

Table 21 - Boundary conditions and loads for load scenario 2

Fixed Support, A	N/A
Standard Earth Gravity	-Y
Force, 30 N (open/close function)	-Y
Bearing load, 100N (Push cylinders)	-Y

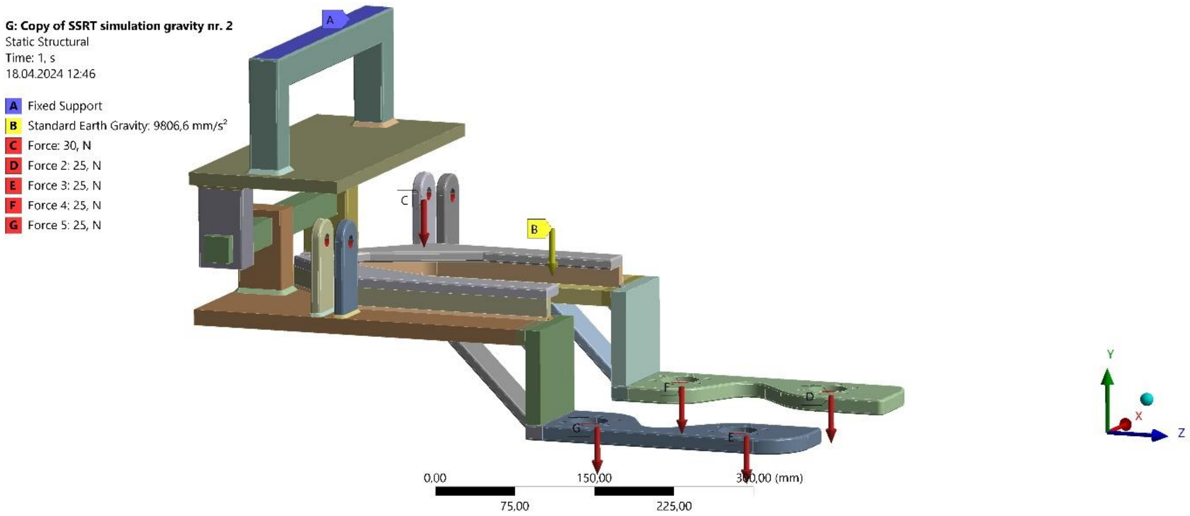


Figure 142 - Boundary conditions and load for scenario 2

Figure 143 shows the max deflection of 0,9 mm for load scenario 2. This is more than load scenario 1, but still negligible.

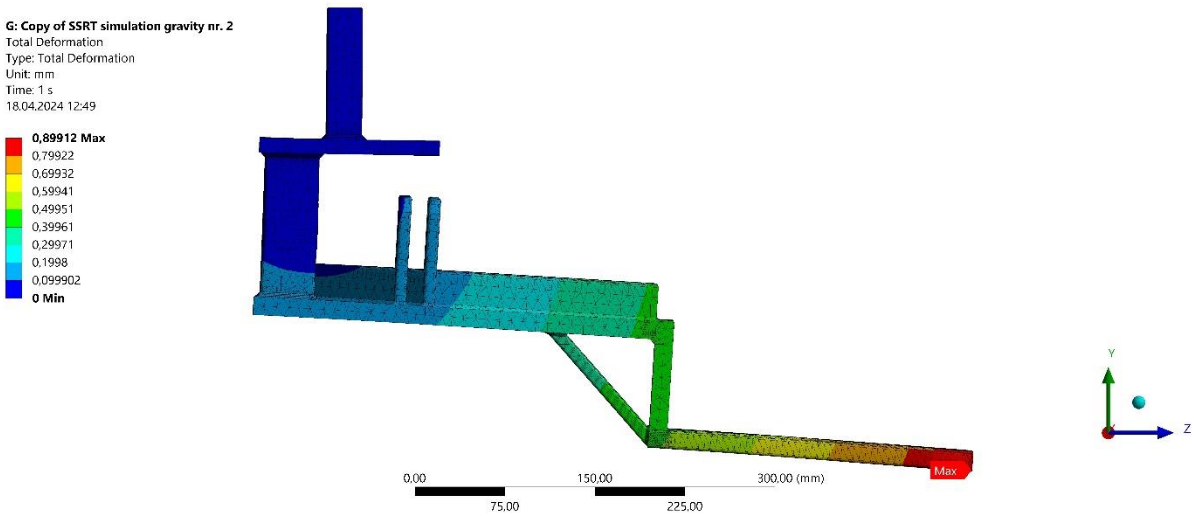


Figure 143 - Max deflection for SSRT in load scenario 2

The maximum equivalent stress in this load scenario is ~ 60 MPa in the A3 weld shown in Figure 144. $\sigma_{\perp}$ stress on welds is seen in Figure 145 and Figure 146, with the value ~ 67 MPa in Z direction and ~ 42 MPa in Y direction.

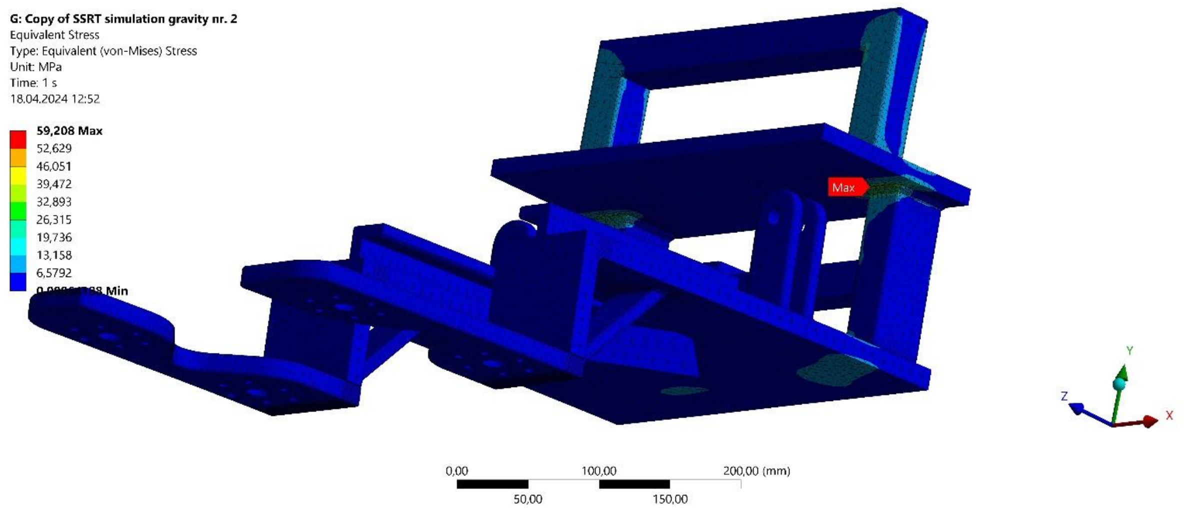


Figure 144 - Maximum equivalent stress on SSRT in load scenario 2

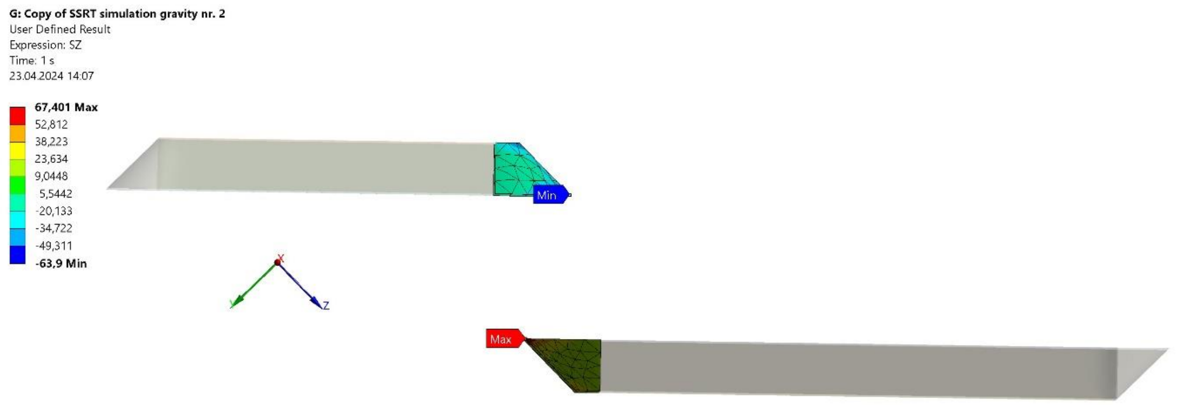


Figure 145 - $\sigma_{\perp}$ stress on welds in load scenario 2, Z direction

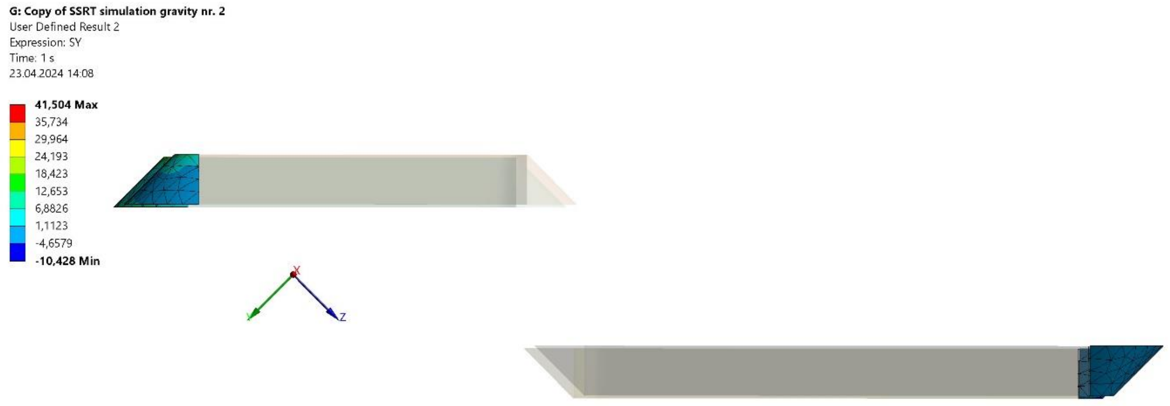


Figure 146 - $\sigma_{\perp}$ stress on welds in load scenario 2, Y direction

Results of gravity check

The results of the gravity check on the SSRT are shown in Table 22. The maximum stresses appear in A3 welds.

Table 22 - Results of gravity check on SSRT

	Load scenario 1	Load scenario 2	Maximum value allowed	Approval
Deflection (mm)	0,5	0,9	N/A	Yes
Maximum equivalent stress (MPa)	40	60	252	Yes
Maximum $\sigma_{\perp}$ stress (MPa)	45	67	209	Yes

Load scenario 2 gives the highest stresses and is approved according to Eurocode 3: Design of steel structures, part 4.5.

5.8.5 SSRT Simulation

A full-scale simulation of the SSRT will be performed to find possible faults, testing of welds, and see how the design moves when force is applied.

Cylinders and the ROV plate are suppressed for simplification of geometry, as they are not important in this simulation. To remove most of the singularity faults and get the correct stress results, the design is split into several bodies, seen in Figure 147.

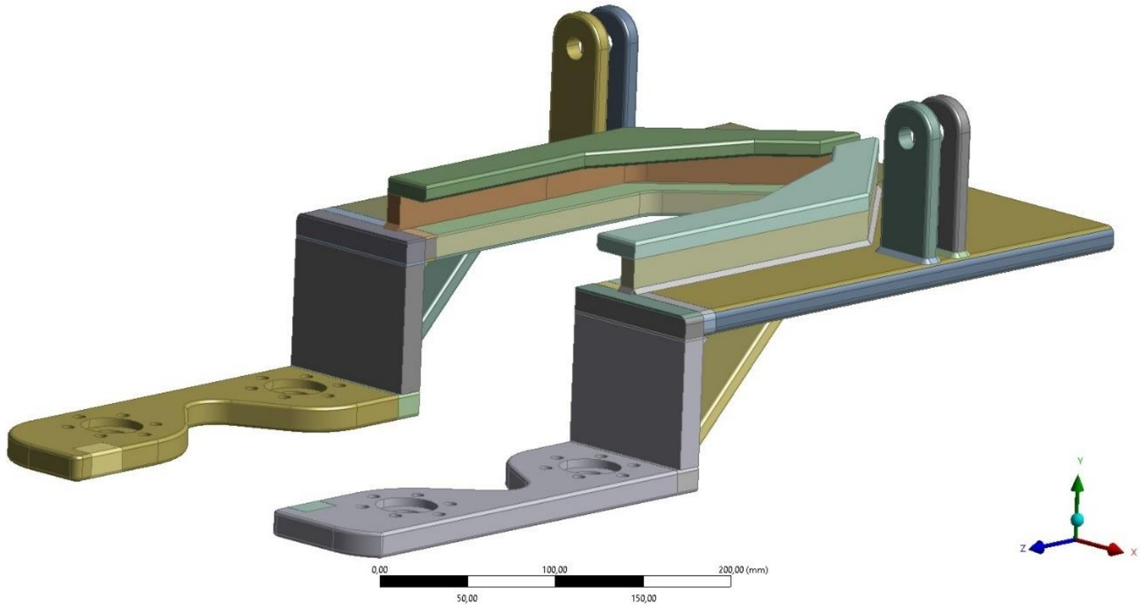


Figure 147 - SSRT in design modeler before full-scale test

All bodies are bonded, and the material used is AISI 316. Mesh settings are seen in Table 23 and Figure 148. Due to an already fine mesh around the welds and small differences in results, there is no body sizing used in this simulation.

Table 23 - SSRT mesh settings for full scale-test

Element size	3mm
Element order	Quadratic
Nodes	540033
Elements	219928

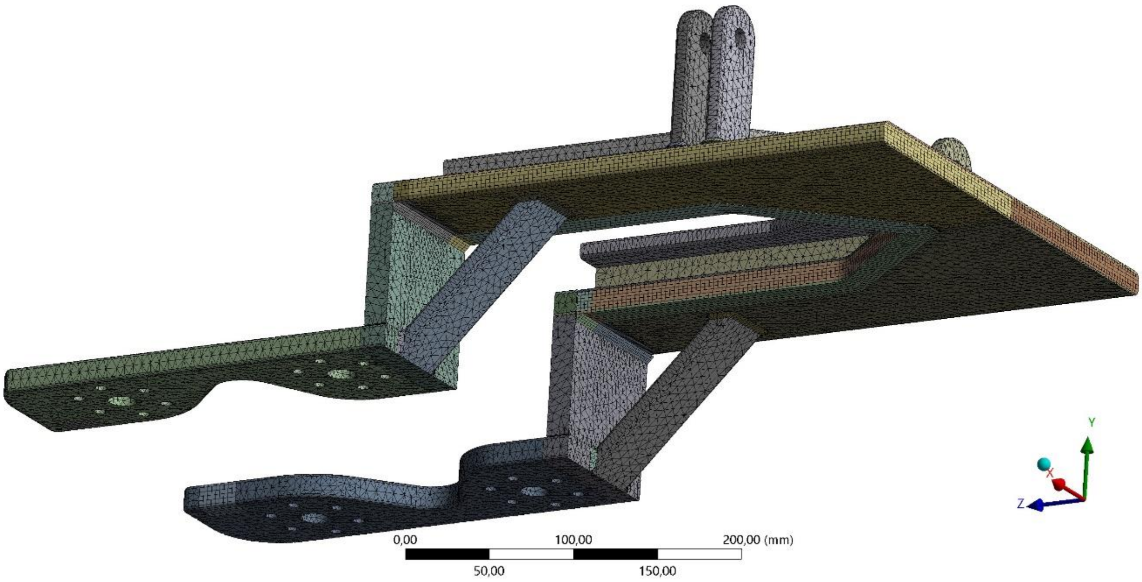


Figure 148 - SSRT mesh for full-scale test

Boundary conditions and forces are seen in Table 24 and Figure 149.

Table 24 - Boundary conditions and loads for full-scale SSRT test

Displacement, F (contact points on MV-head)	Y - Constant
Displacement, G	X,Z - Constant
Standard Earth Gravity	Z
4x Force, 13200 N (represents 4x cylinders)	Y

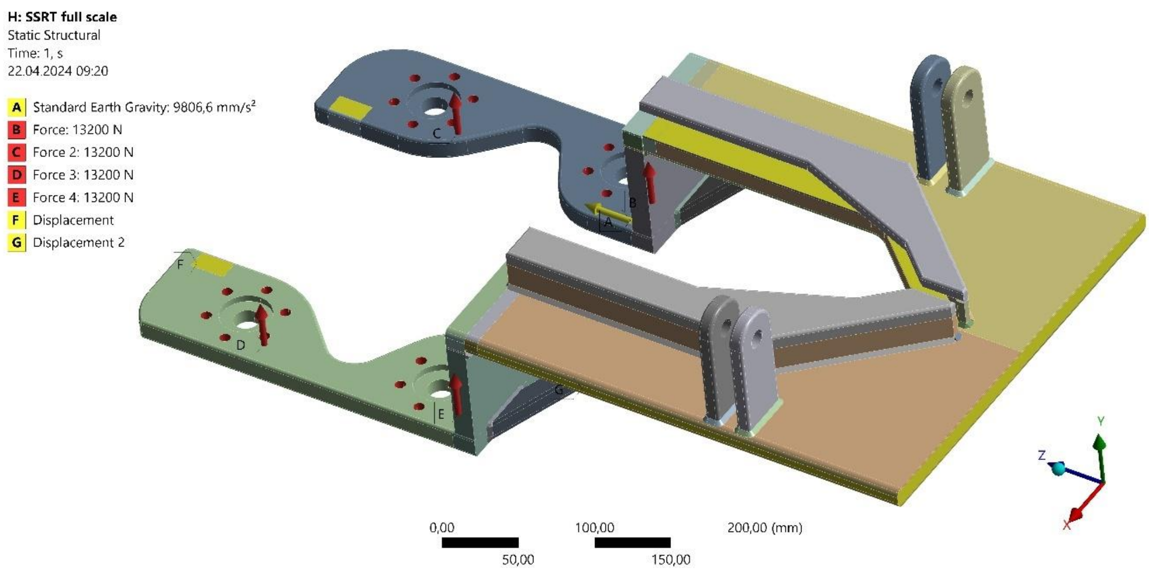


Figure 149 - SSRT full-scale boundary conditions and forces

Deformation is seen in Figure 150. The biggest deflection is ~ 0,5 mm between the cylinders, and the contact point with MV-head bracket ~ 0,2 mm, which is negligible for both.

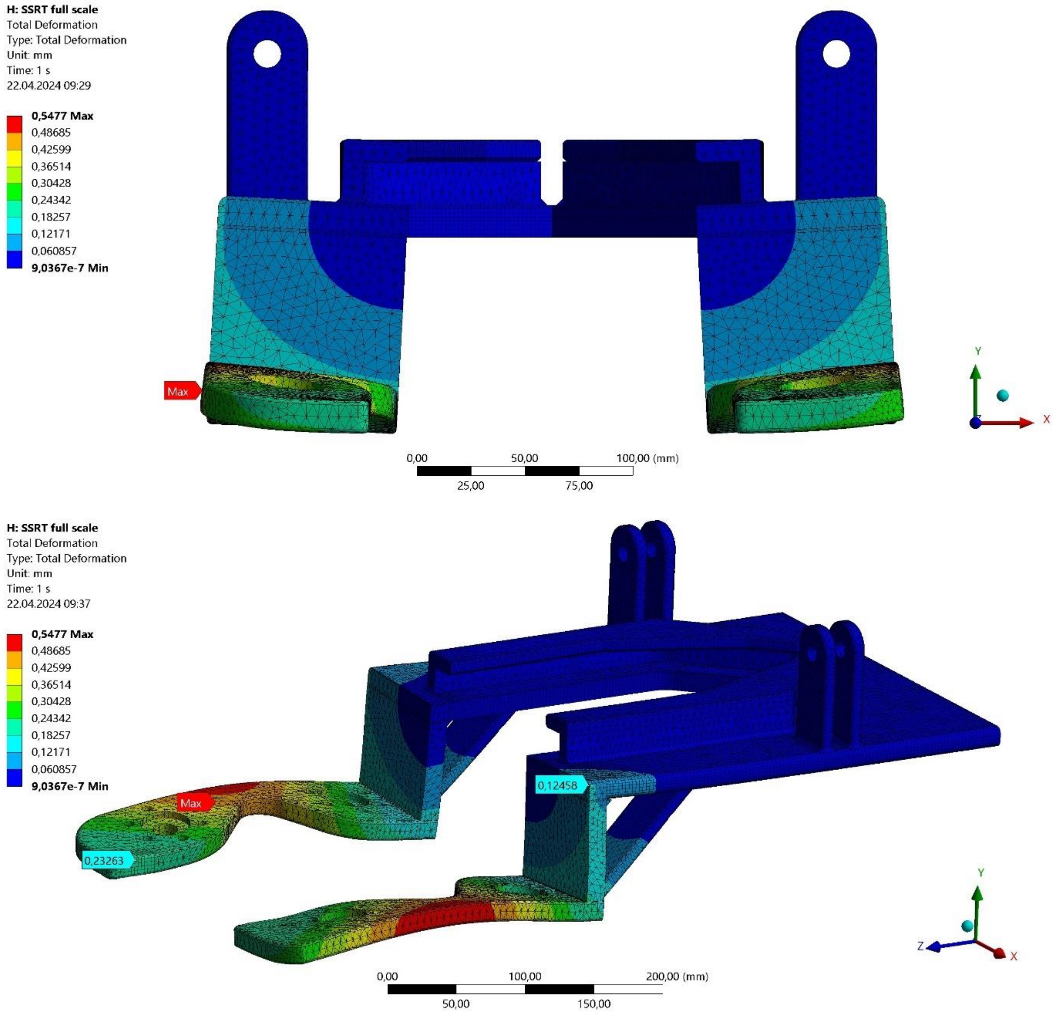


Figure 150 - Deformation on SSRT in full-scale test

Geometry where singularity faults appear, as seen in Figure 151, is removed from the result by not displaying the “fault bodies”. Cylinder bracket has already been simulated and optimized, see 5.8.3, and therefore not displayed.

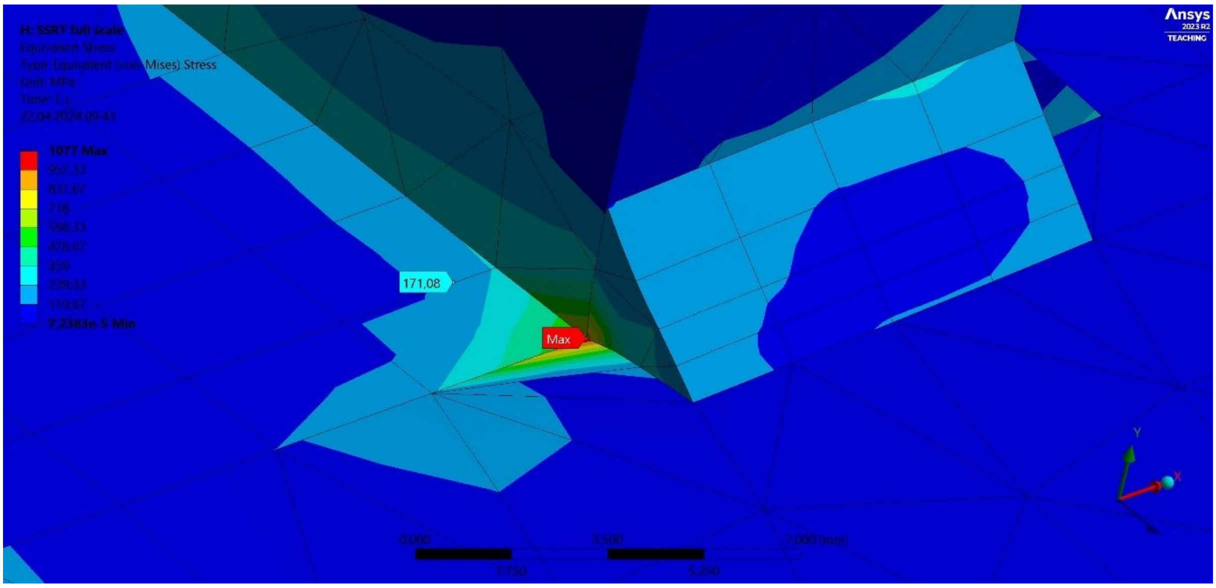


Figure 151 - Singularity faults in SSRT full-scale results

The maximum equivalent stress is seen in Figure 152. There are still some singularity faults, but the probes prove that the realistic maximum stress is ~ 234 MPa.

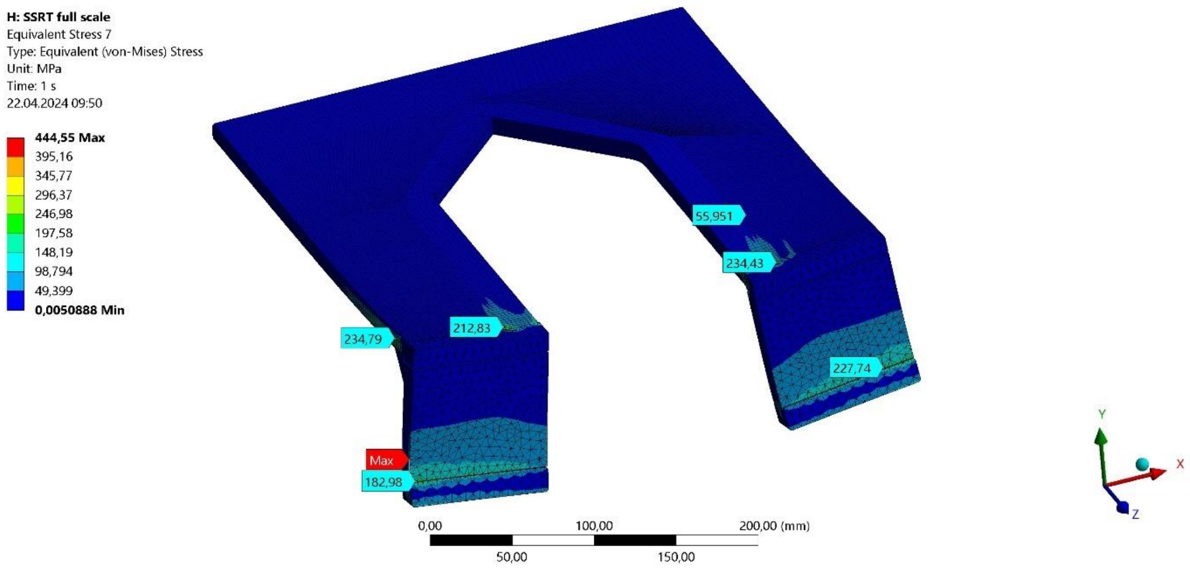


Figure 152 - Maximum equivalent stress on full-scale test

The $\sigma_{\perp}$ stress in welds is shown in Figure 153 and the highest value is ~ 186 MPa in z-direction.

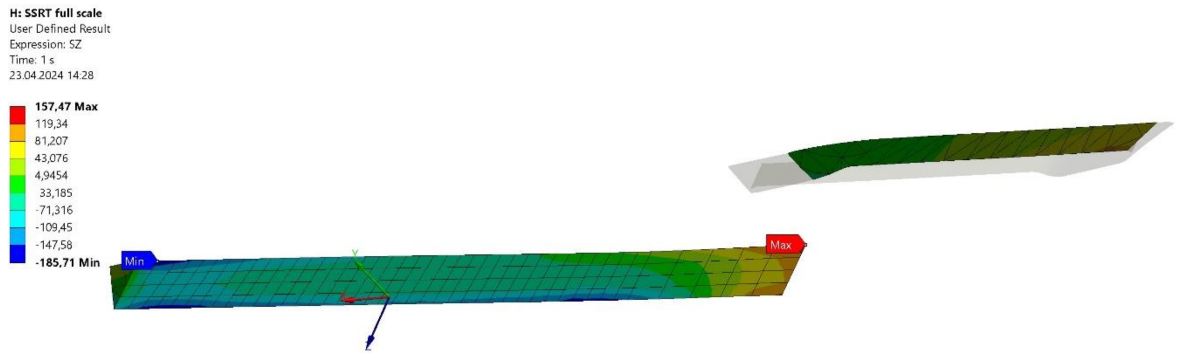


Figure 153 - $\sigma_\perp$ stress in welds on SSRT in full-scale test

Results of SSRT simulation

Results of the SSRT simulations are shown in Table 25.

Table 25 - Results of SSRT simulation

	SSRT simulation	Maximum value allowed	Approval
Deflection (mm)	0,6	N/A	Yes
Maximum equivalent stress (MPa)	234	252	Yes
Maximum $\sigma_\perp$ stress (MPa)	186	209	Yes

The highest stresses are approved according to Eurocode 3: Design of steel structures, part 4.5.

5.8.6 Open/close Brackets

The open/close function, Figure 154, will be simulated in the close movement. When the cylinder is opening, the stroke will be stopped by the piston inside the cylinder. When it's closing, the stroke will be stopped by the brackets, and therefore needs to be checked for stress.

Max pressure on the open/close cylinder is set to 150 bar to protect the SSRT and the MV-head in case the tool is mounted incorrectly. The simulation will be performed at 207 bar (ROV max pressure) in case of wrong operation by ROV pilot.

The force given by 207 bar is:

$$F = 20{,}7\ MPa \cdot (491\ mm^2 - 201\ mm^2) = 6000\ N \quad (15)$$

The force given by 150 bar is:

$$F = 15\ MPa \cdot (491\ mm^2 - 201\ mm^2) = 4350\ N \quad (15)$$

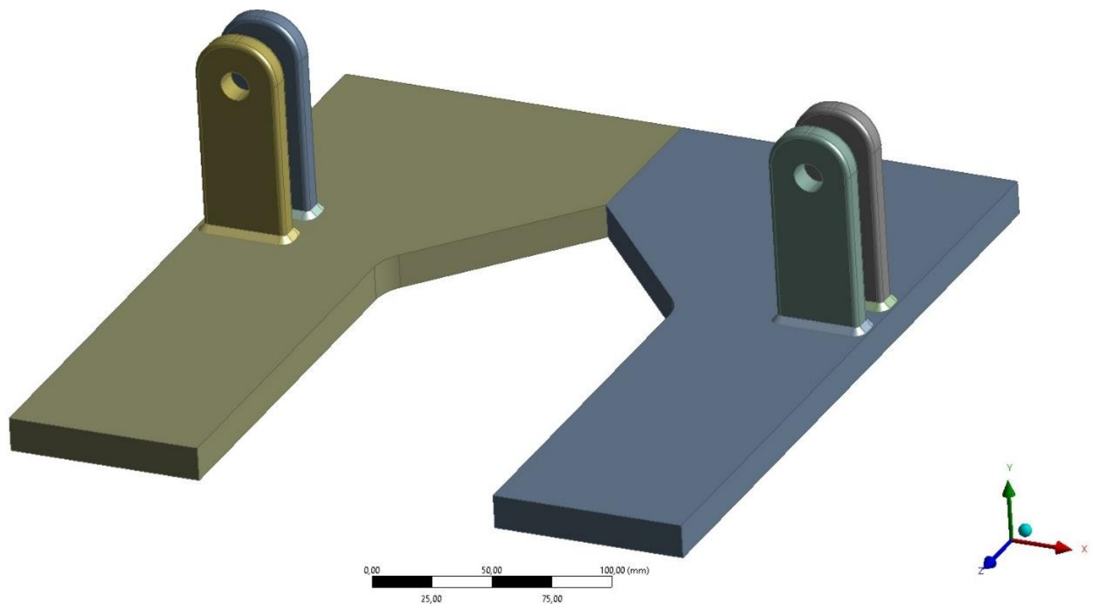


Figure 154 - Open/close function in Design modeler

The mesh is seen in Table 26 and Figure 155.

Table 26 - Open/close mesh settings

Element size	4mm
Element order	Quadratic
Nodes	570985
Elements	342045
Element size, A2 welds	1,2mm
Element size, Cylinder brackets	1,5mm

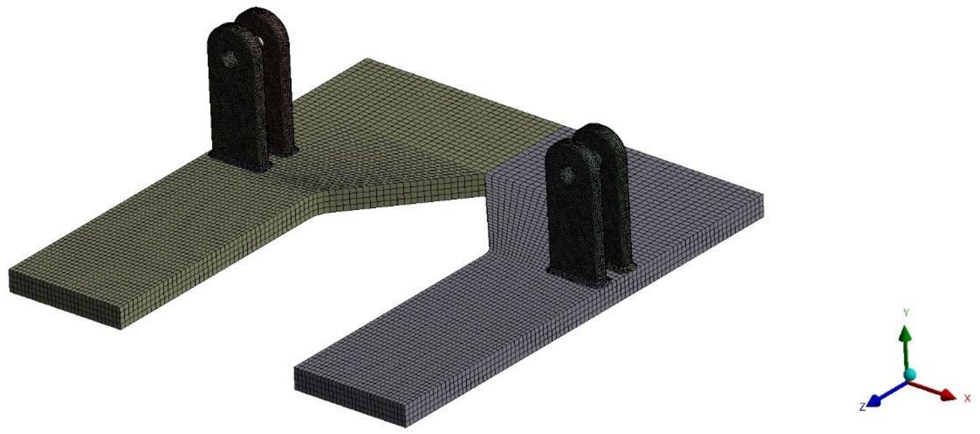


Figure 155 - Meshing of open/close simulation

The boundary conditions and forces are seen in Table 27 and Figure 156. The bearing loads represent cylinder force at 6000 N.

Table 27 - Boundary conditions and loads for open/close simulation

Fixed Support, C	N/A
Bearing load A, 3000N	-X
Bearing load B, 3000N	X

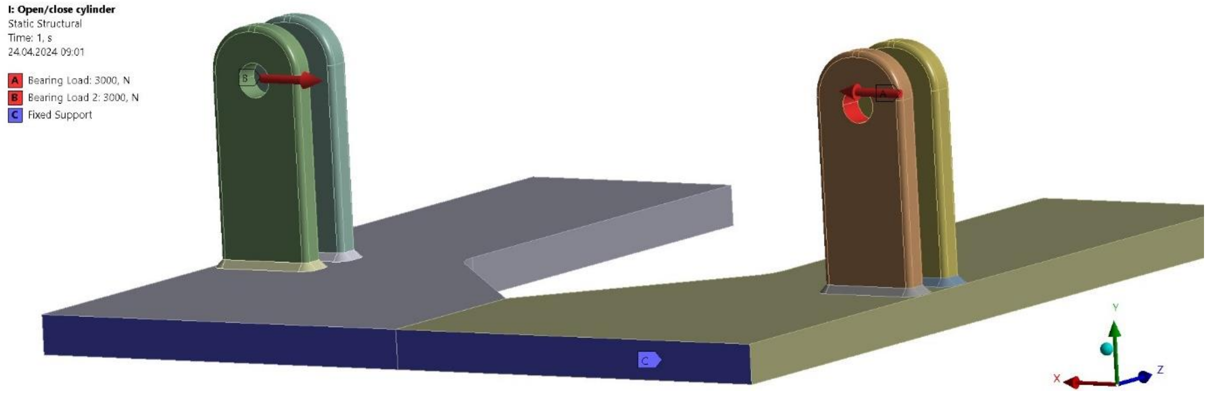


Figure 156 - Boundary conditions and loads for open/close simulation

Max deformation, seen in Figure 157, is ~0,3mm and negligible.

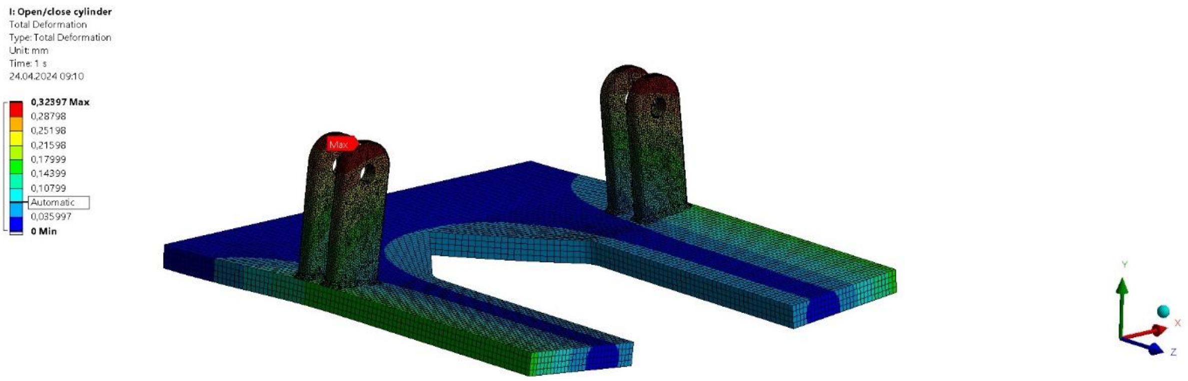


Figure 157 - Max deformation in open/close function

Maximum equivalent stress is 231 MPa and occurs in the welds. This is a singularity fault, but still below the safety factor. Max realistic $\sigma_{\perp}$ stress in welds is in the Y direction ~ 178 MPa. The results are seen in Figure 158 and Figure 159.

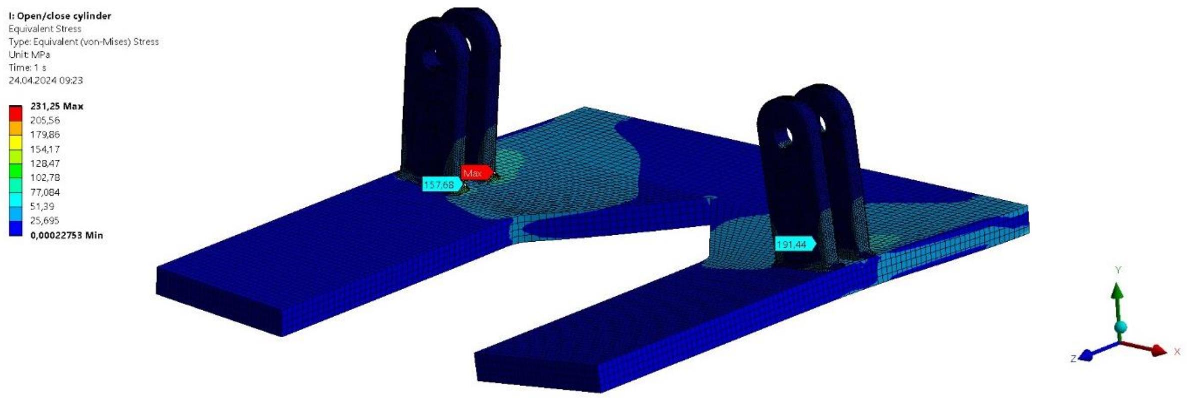


Figure 158 - Maximum equivalent stress in open/close simulation

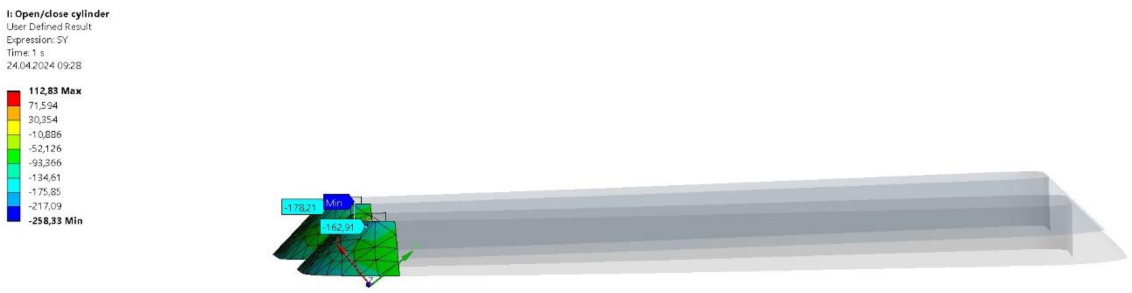


Figure 159 - The $\sigma_{\perp}$ stress in open/close simulation, Y direction

Results open/close simulation

The results of the open/close simulation are seen in Table 28.

Table 28 - Results of open/close simulation

	SSRT simulation	Maximum value allowed	Approval
Deflection (mm)	0,6	N/A	Yes
Maximum equivalent stress (MPa) for material	<231 MPa	252 MPa	Yes
Maximum equivalent stress (MPa) for welds	231	252	Yes
Maximum $\sigma_{\perp}$ stress (MPa)	178	209	Yes

The highest stresses are approved according to Eurocode 3: Design of steel structures, part 4.5.

5.8.7 Verifying of FEM Simulation

To verify the Ansys simulations, the Group will do hand calculations to compare with the results from Ansys. If the results from hand calculations are lower than the simulations, one can conclude that FEM software brings trustworthy results.

The open/close brackets will be used to verify the results from Ansys, see Figure 160.

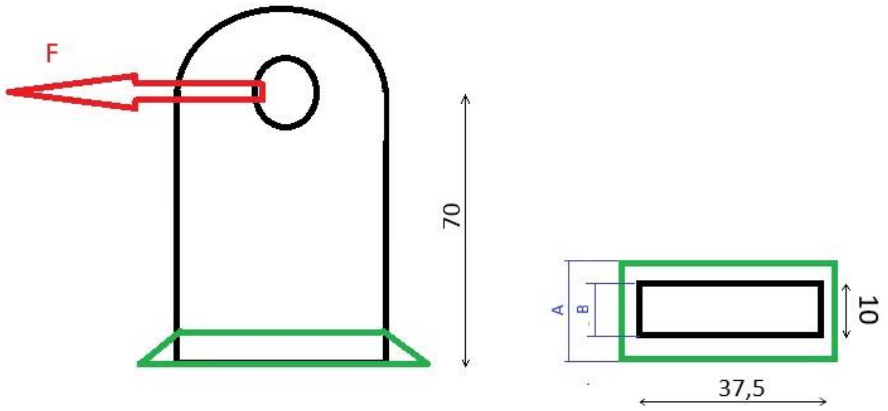


Figure 160 - Open/close brackets for hand calculation of weld

Load, F = 1500 N

Weld, a = 2 mm

Yield strength material, $\sigma_{\mathrm{All}} \leq 252$ MPa

Von mises stress in weld, $\sigma_{\mathrm{jf}} \leq 252$ MPa

Normal stress perpendicular to the throat, $\sigma_{\perp} \leq 209$ MPa

Material

Moment of inertia of rectangular geometry, I_x:

$$I_x = \frac{10\ \mathrm{mm}\cdot(37{,}5\ \mathrm{mm})^3}{12} = 43945\ \mathrm{mm}^4 \tag{7}$$

Normal stress, σ_b:

$$\sigma_b = \frac{1500\ \mathrm{N}\cdot 70\ \mathrm{mm}}{43945\ \mathrm{mm}^4}\cdot\frac{37{,}5\ \mathrm{mm}}{2} = 44{,}8\ \mathrm{MPa} \leq 252\ \mathrm{MPa} \tag{8}$$

Weld

Moment of inertia for fillet weld, I_x

$$I_x = \frac{1}{12}\left((10\ \mathrm{mm} + 2\cdot 2\ \mathrm{mm})(37{,}5\ \mathrm{mm} + 2\cdot 2\ \mathrm{mm})^3 - 10\ \mathrm{mm}\cdot(37{,}5\ \mathrm{mm})^3\right) \tag{10}$$

$$I_x = 39440\ \mathrm{mm}^4$$

Weld in A

Normal stress in outer weld, σ_{b_A}:

$$\sigma_{bA} = \frac{1500\ \mathrm{N}\cdot 70\ \mathrm{mm}}{39440\ \mathrm{m}m^4}\cdot\left(\frac{37{,}5\ \mathrm{mm}}{2} + 2\ \mathrm{mm}\right) = 55{,}2\ \mathrm{MPa} \tag{9}$$

$$\sigma_{\mathrm{jfA}} = \sqrt{2}\cdot\sigma_{bA} = \sqrt{2}\cdot 55{,}2\ MPa = 78\ MPa \tag{11}$$

Weld in B

Normal stress, σ_{b_B}:

$$\sigma_{b_B} = \frac{1500\ N\cdot 70\ mm}{39440\ mm^4}\cdot\frac{37{,}5\ mm}{2} = 49{,}9\ MPa \tag{8}$$

Shear stress, τ_{bB}:

$$\tau_{bB} = \frac{1500\ N}{2\cdot 2\ mm\cdot 37{,}5\ mm} = 10\ MPa \tag{13}$$

Normal stress perpendicular to the throat, $\sigma_{\perp}$:

$$\sigma_{\perp} = \tau_{\perp} = \frac{49{,}9\ MPa}{\sqrt{2}} = 35{,}3\ MPa \tag{12}$$

Combined stress, σ_{jfB}:

$$\sigma_{jfB} = \sqrt{35{,}3^2 + 3 \cdot 35{,}3^2 + 3 \cdot 10^2} = 72{,}7\ MPa \leq 252\ MPa \quad (11)$$

Compared results:

$$\sigma_{jfB} < \sigma_{jfA} \leq 252\ MPa$$

As shown in the calculations, the biggest shear stresses will occur in weld A and will be 78 MPa which is lower than the allowed stress. There is some difference in the results from Ansys to the hand calculations, but this is because the formula is for a perfect rigid body. If the hand calculations are approved, as it is, the welds will be no limitations for the tool.

5.9 DFMEA

The biggest variable for the SSRT is the ROV pilot. The ROV pilot must have proper training and knowledge about the SSRT. Because of the limitations in space close to the MV-head, the ROV pilot must act with caution to prevent damage to both the tool and the connector. If any dents or deformation occur from impacts, the tool could get stuck, or it can be defective.

Another problem that can occur is a hydraulic failure. This failure could for example come from damaged hoses or tubes, which will cause hydraulic pressure loss and oil spill to the sea.

A third problem can be an operational failure. Such failure could be if the pushing cylinders fail during de-mating. In this case, the operator must remove the tool and do required maintenance.

All the potential risks are listed and numbered in Table 29, and brought forward to the risk assessment table, shown in Table 30. Hazards before and after measurements are taken, are shown in Table 31 and Table 32.

Table 29 - Risk assessment, potential hazards

Nr	Potensial Hazards	Type of Hazard	What can cause the impact
1	Damage on tool	Collision with subsea assets	Uncautious ROV-pilot
2	Damage on tool	Misuse	Not good enough training for ROV pilot
3	Damage on the MV-head	Collision with subsea assets	Uncautious ROV-pilot
4	Damage on the MV-head	Misuse	Not good enough training for ROV pilot
5	Hydraulic failure	Damage on hose	Not good enough check before deploying tool
6	Hydraulic failure	Damage on hose	Damage on hose during operation
7	Hydraulic failure	Leakage	Fitting not tightened correctly
8	Operational failure	Tool get stuck during de-mating	Design fail or misuse
9	Operational faliure	Tool get stuck after de-mating is completed	Design fail or misuse

Table 30 - Risk assessment

Unwanted incident	Id.nr	Variant (Reason)	Classification			Justification	Existing measures	Risk	Proposals for measures	Classification			Risk
			P	C	R					P	C	R	
Damage on tool	1	Collision with subsea assets	3	2	6	The ROV-pilot can hit obstacles with the tool, wich can cause damage on the tool.	Proper training		Do not stress when operating the tool.	1	2	2	
	2	Misuse	2	5	10	The ROV pilot can use the tool in a non-proper way which can cause damage to the tool. For instance, place the tool in a not fully locked position	Proper training		Familiarity to the SSRT	1	4	4	
Damage on the MV-head	3	Collision with subsea assets	3	3	9	The ROV-pilot can hit the MV-head with the tool, which can cause damage on the MV-head	Proper training		Do not stress when operating the tool.	1	2	2	
	4	Misuse	1	5	5	The ROV pilot can use the tool in a non-proper way which can cause damage to the Mv-head. For instance, place the tool in a not fully locked position	Proper training		Familiarity to the SSRT	1	4	4	
Hydraulic failure	5	Damage on hose	2	3	6	There can be damages on the from previous operation or from the storage	Routine control of the tool with checklist		Two persons to inspect the tool, to verify the control	1	4	4	
	6	Damage on hose	2	3	6	There can occur damages on the hose during operations, if the tool hit the pump module or the MV-head	None		Do not stress when operating the tool.	1	3	3	
	7	Leakage	1	4	4	The hoses han be hooked or stuck to an obstacle, and the coupling can be broken or the hose can get disconected	None		Do not stress when operating the tool.	1	3	3	
Operational faliure	8	Tool get stuck during de-mating	1	5	5	The tool can get stuck on the MV-head if there is a pressure failiure on the cylinder	None		Insert hot stab and receptacle on ROV. Recover ROV for maintanance on hydraulic system	1	3	3	
	9	Tool get stuck after de-mating is completed	1	4	4	The tool can get stuck to the MV-head after operation if the MV-head or the tool has deformed	None		Recover connector cable to topside or ROV get cutter tool to dismount the SSRT from the MV-head	1	3	3	

Table 31- Risk before measure

Before measure	C1: Safe	C2: Some risk	C3: Dangerous	C4: Critical	C5: Extremely critical
P5: Very possible					
P4: Very likely					
P3: Likely		Nr1	Nr3		
P2: Less likely			Nr5, Nr6		Nr2
P1: Not likely				Nr7, Nr9	Nr4, Nr8

Table 32 - Risk after measure

After measure	C1: Safe	C2: Some risk	C3: Dangerous	C4: Critical	C5: Extremely critical
P5: Very possible					
P4: Very likely					
P3: Likely					
P2: Less likely					
P1: Not likely		Nr1, Nr3	Nr6, Nr7, Nr8, Nr9	Nr2, Nr4, Nr5	

5.10 Sources of Error

During a project that requires external information, one must be critical of the sources that one uses. As engineers, it is crucial to be critical of information on the internet. This can always be a source of error.

There can also be variations on the MV-head. This is something the Group discussed with the Company, but it was decided to be neglected. This can still be a source of error. If an ROV has caused any damage to the MV-head, especially on the flying handle and the bracket on the cable, the SSRT may not fit anymore.

The SSRT is dimensioned from the drawings and 3D model given by the Company. If the drawings differ from the real assembly, this will affect the fit of the SSRT. This can also be a source of error.

6. Final Design of SSRT

In the Engineering chapter, all the necessary calculations, material selections, etc. are shown and explained. The tool was modeled in Creo Parametric. All parts are designed for traditional manufacturing methods, including production drawings with industrial standards and relevant tolerances. A userguide is found in the attachments.

The tool has been checked to ensure that it meets the material properties and criteria set by the Company. This has been done by using manual calculations and FEM analysis in Ansys. The results show that the SSRT will be able to handle the de-mating operation.

The full list of components and materials needed to realize the tool is shown in Table 33. Prices are not given due to supplier's protection.

Table 33 – Part list SSRT

Name	Type	Material	Proposal of Supplier	Price (NOK)
15mm steel	15,0 x 1250 x 2500 mm	AISI 316	Norsk stål	N/A
Pushing cylinder	997646F-T	AISI 316	Byberg	N/A
Open/close cylinder	997646B-B	AISI 316	Byberg	N/A
Cylinder bushing	Ø12 x 2 mm	Nylon	Plastbutikken	N/A
Cylinder socket	Ø30 x 30 mm	Aluminum	Norsk stål	N/A
Hydraulic tubes and fittings	N/A	AISI 316	N/A	N/A
Hex socket cap bolt	M12 x 60 mm	AISI 316	N/A	N/A
Hex socket cap bolt	M6 x 35 mm	AISI 316	N/A	N/A
Hex bolt	M8 x 80 mm	AISI 316	N/A	N/A
Nyloc nut	M12	AISI 316	N/A	N/A
Nyloc nut	M8	AISI 316	N/A	N/A
Nyloc Nut	M6	AISI 316	N/A	N/A
Washer	M12	AISI 316	N/A	N/A
Washer	M8	AISI 316	N/A	N/A
Washer	M6	AISI 316	N/A	N/A

6.1 3D Model

The final 3D-model design of the SSRT is shown in Figure 161, Figure 162, Figure 163, Figure 164 and Figure 165. The hoses connected to the tubing is the hydraulic supply from the ROV.

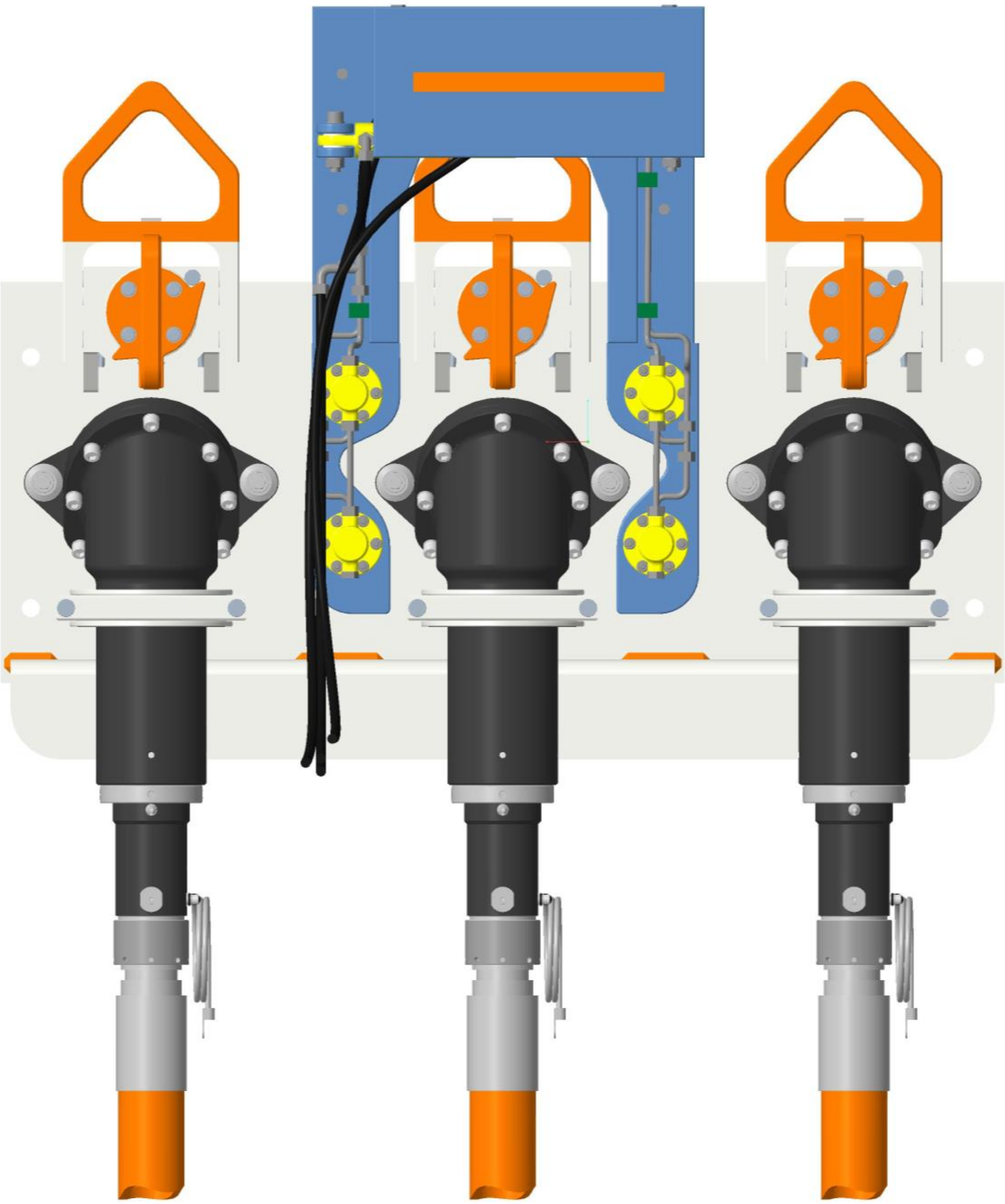


Figure 161 - SSRT during mounting (open position)

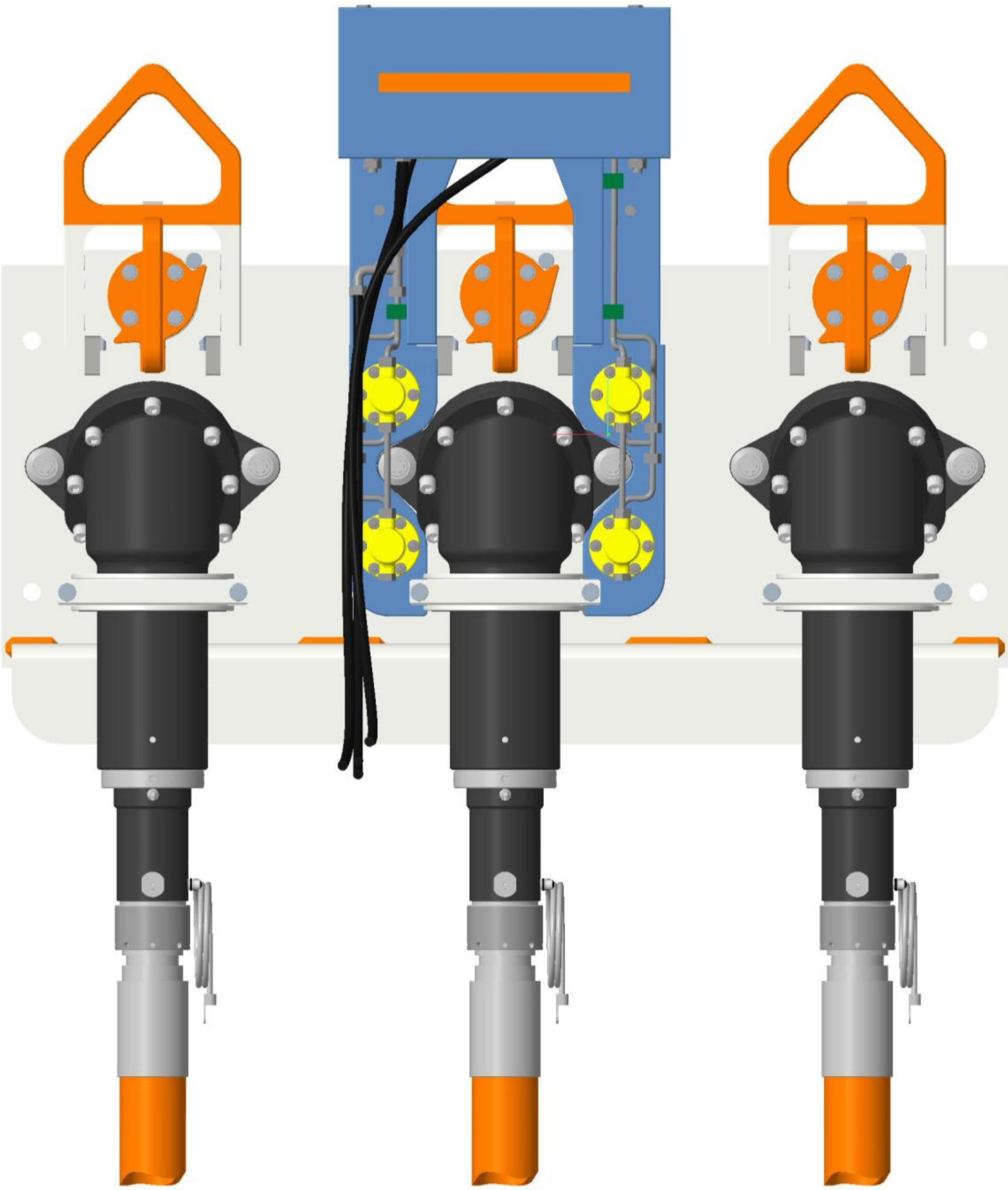


Figure 162 - SSRT while mounted (closed position)

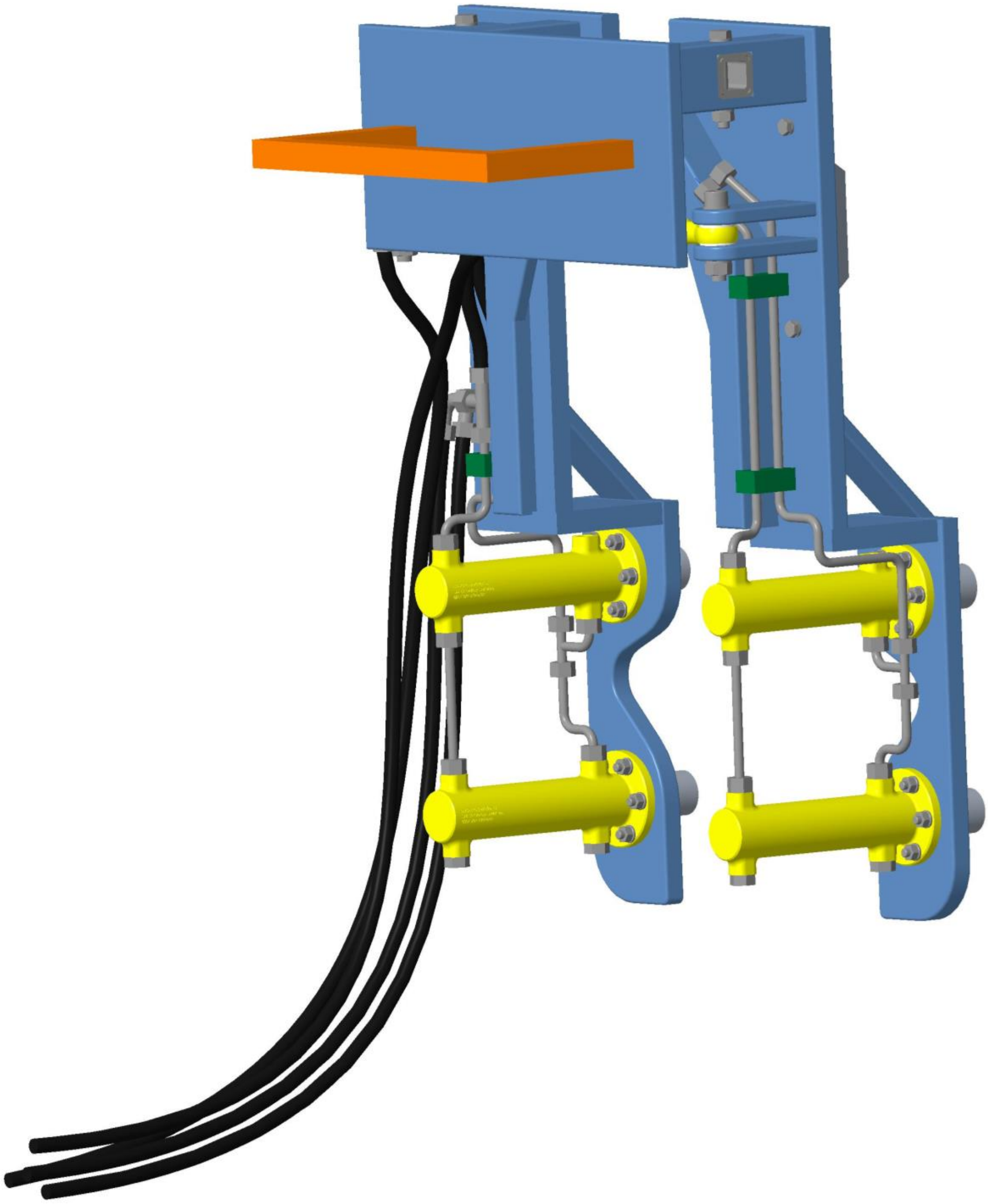


Figure 163 – SSRT detailed view 1

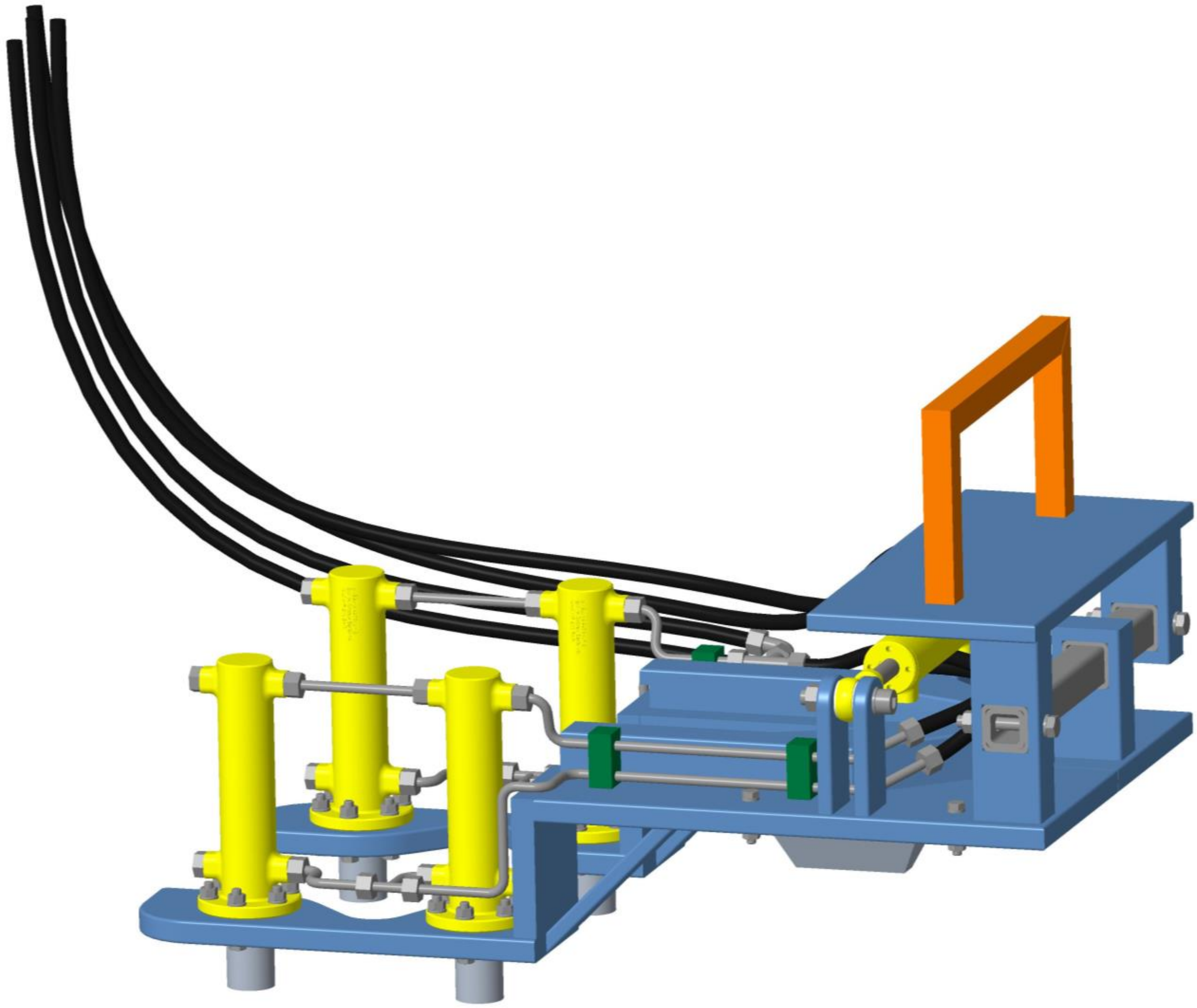


Figure 164 – SSRT detailed view 2

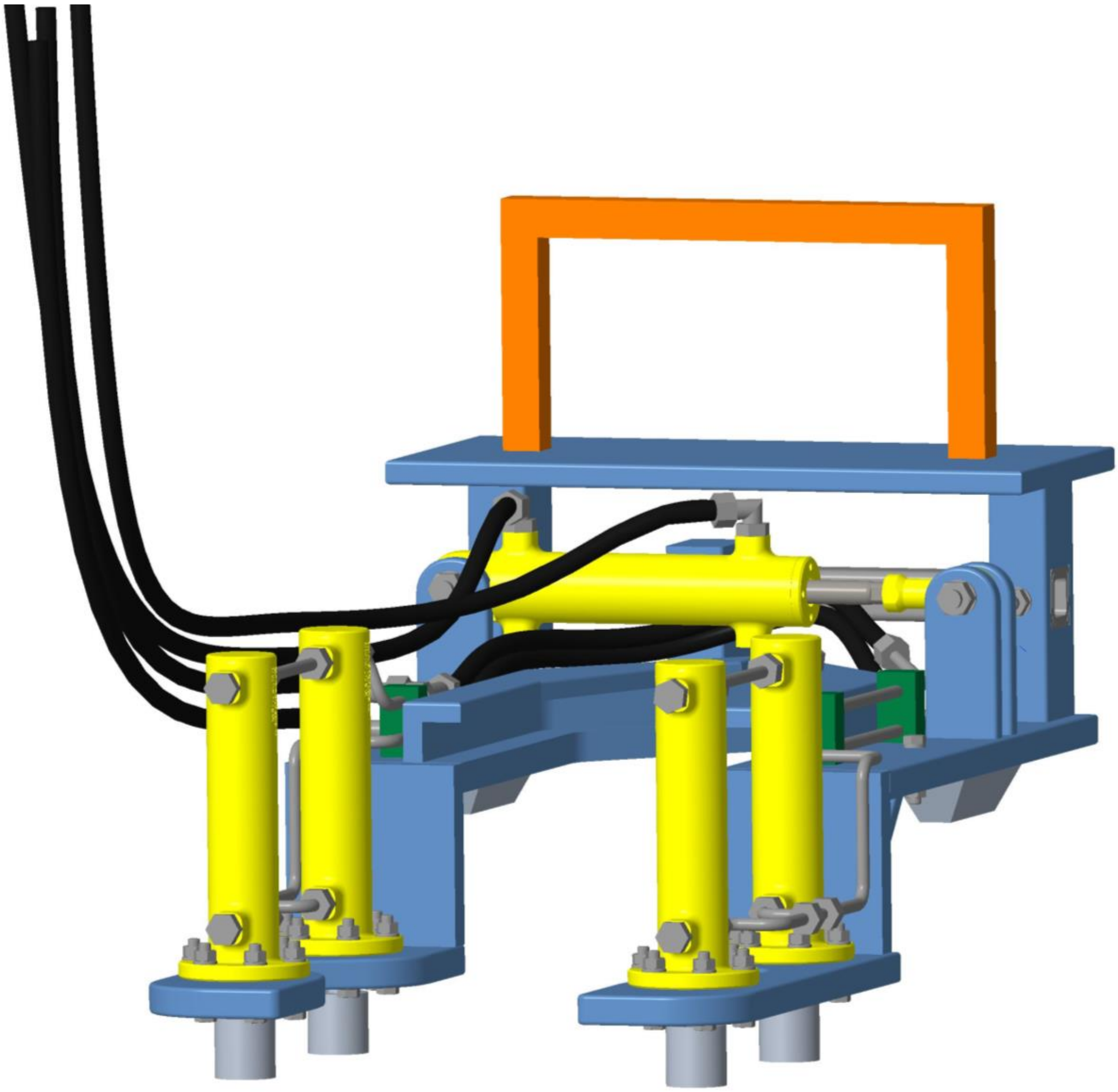
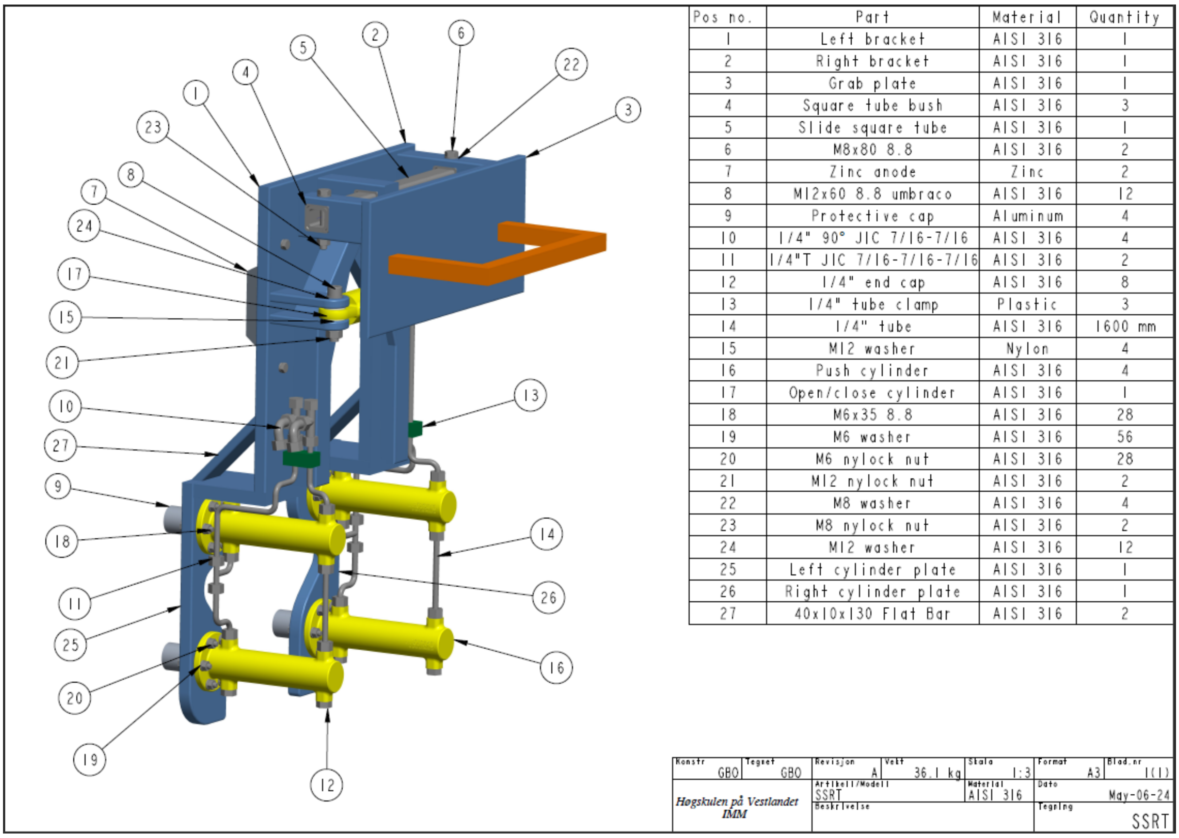


Figure 165 – SSRT detailed view 3

6.2 Final Drawings

Assembly- and production drawings of the SSRT are shown in Figure 166, Figure 167, Figure 168, Figure 169, Figure 170, Figure 171, Figure 172, Figure 173, Figure 174 and Figure 175.



Pos no.	Part	Material	Quantity
1	Left bracket	AISI 316	1
2	Right bracket	AISI 316	1
3	Grab plate	AISI 316	1
4	Square tube bush	AISI 316	3
5	Slide square tube	AISI 316	1
6	M8x80 8.8	AISI 316	2
7	Zinc anode	Zinc	2
8	M12x60 8.8 umbraco	AISI 316	12
9	Protective cap	Aluminum	4
10	1/4" 90° JIC 7/16-7/16	AISI 316	4
11	1/4"T JIC 7/16-7/16-7/16	AISI 316	2
12	1/4" end cap	AISI 316	8
13	1/4" tube clamp	Plastic	3
14	1/4" tube	AISI 316	1600 mm
15	M12 washer	Nylon	4
16	Push cylinder	AISI 316	4
17	Open/close cylinder	AISI 316	1
18	M6x35 8.8	AISI 316	28
19	M6 washer	AISI 316	56
20	M6 nylock nut	AISI 316	28
21	M12 nylock nut	AISI 316	2
22	M8 washer	AISI 316	4
23	M8 nylock nut	AISI 316	2
24	M12 washer	AISI 316	12
25	Left cylinder plate	AISI 316	1
26	Right cylinder plate	AISI 316	1
27	40x10x130 Flat Bar	AISI 316	2

Figure 166 - SSRT assembly drawing

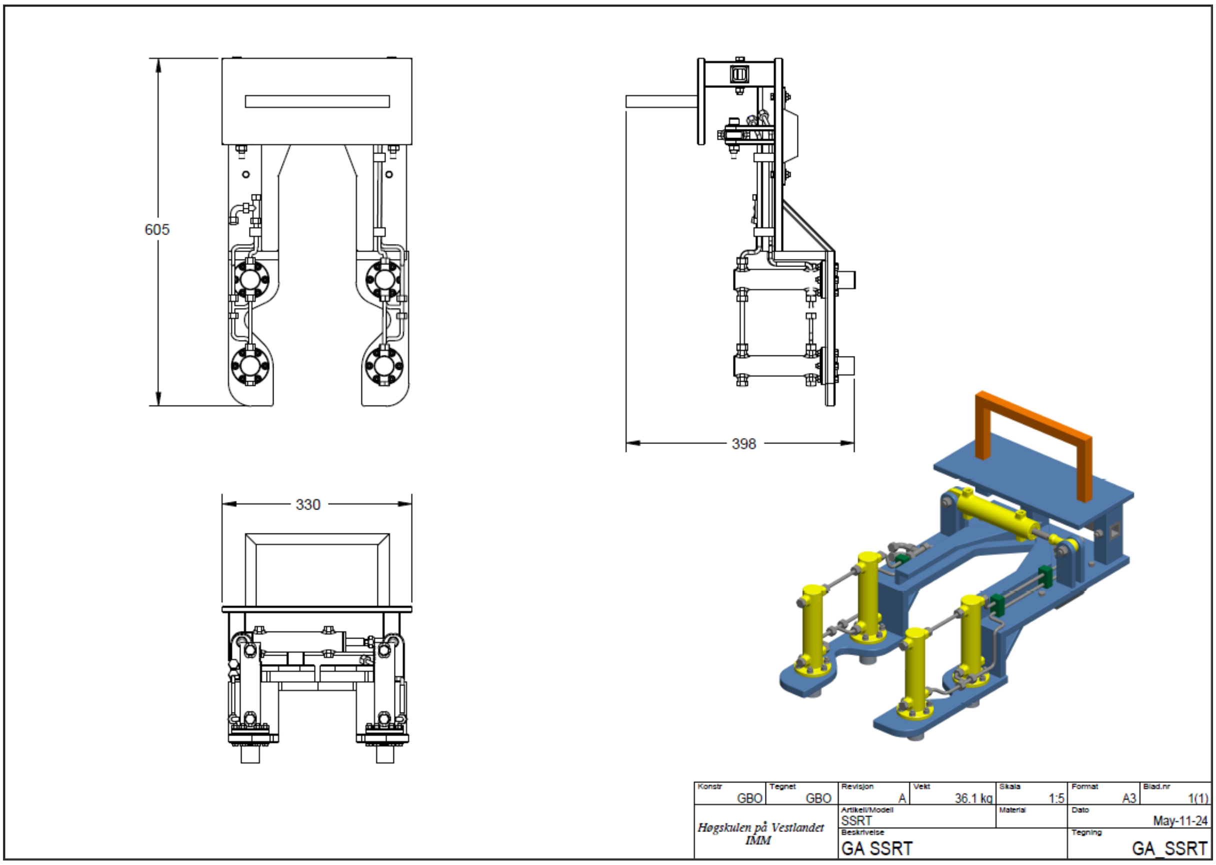


Figure 167 - SSRT General Assembly (GA) drawing

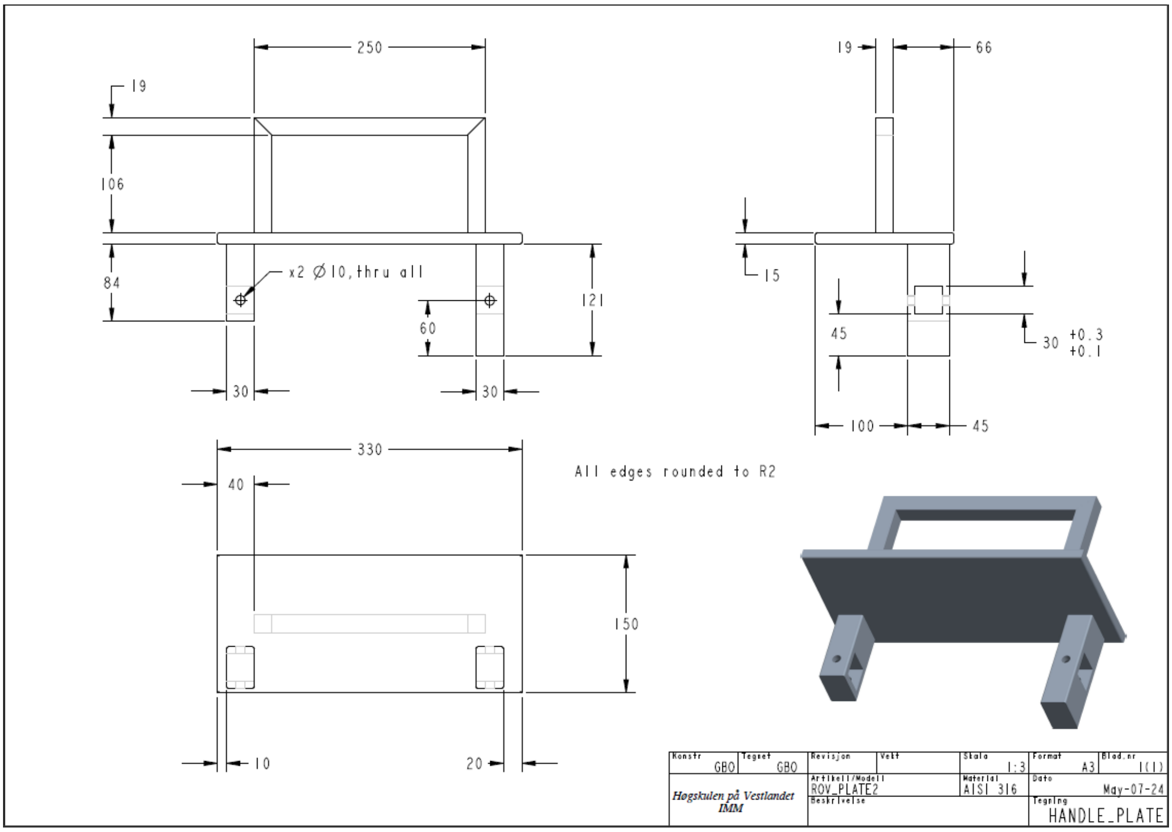


Figure 168 - ROV handle plate drawing

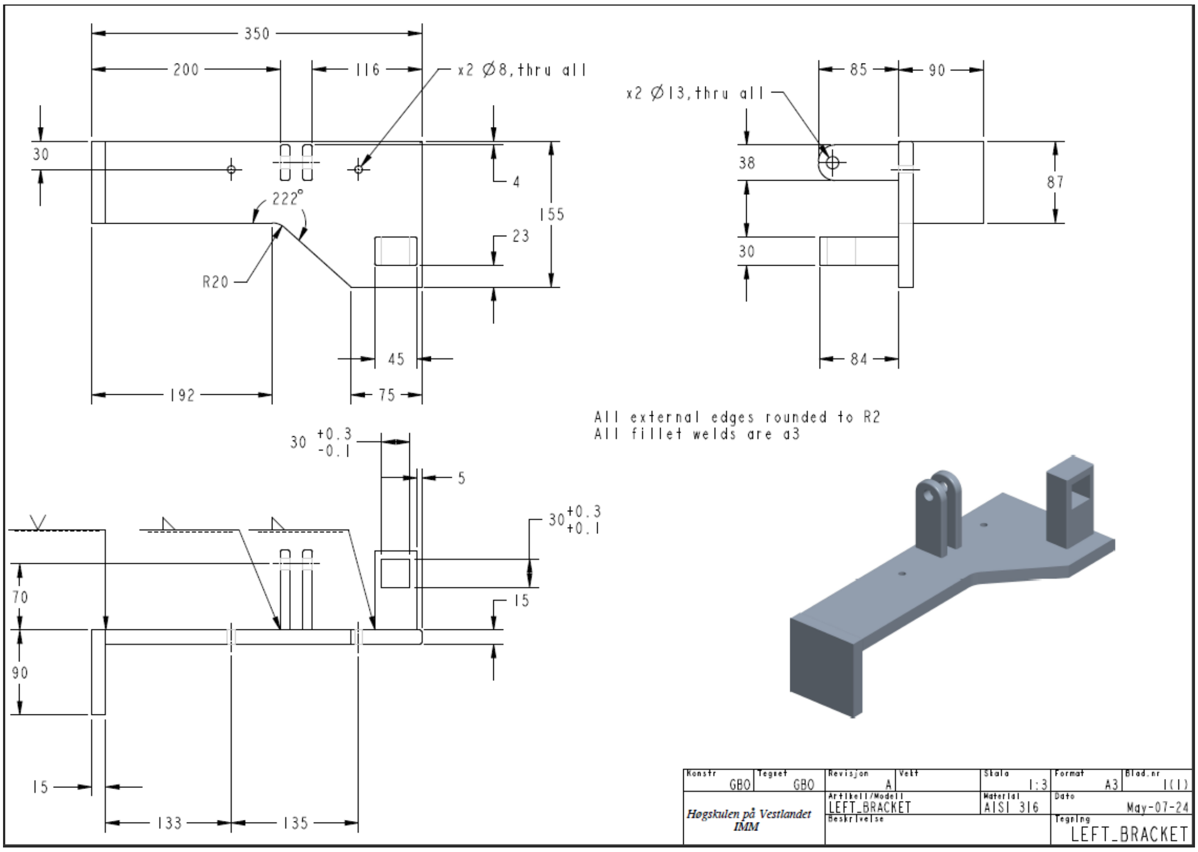


Figure 169 - Left bracket drawing

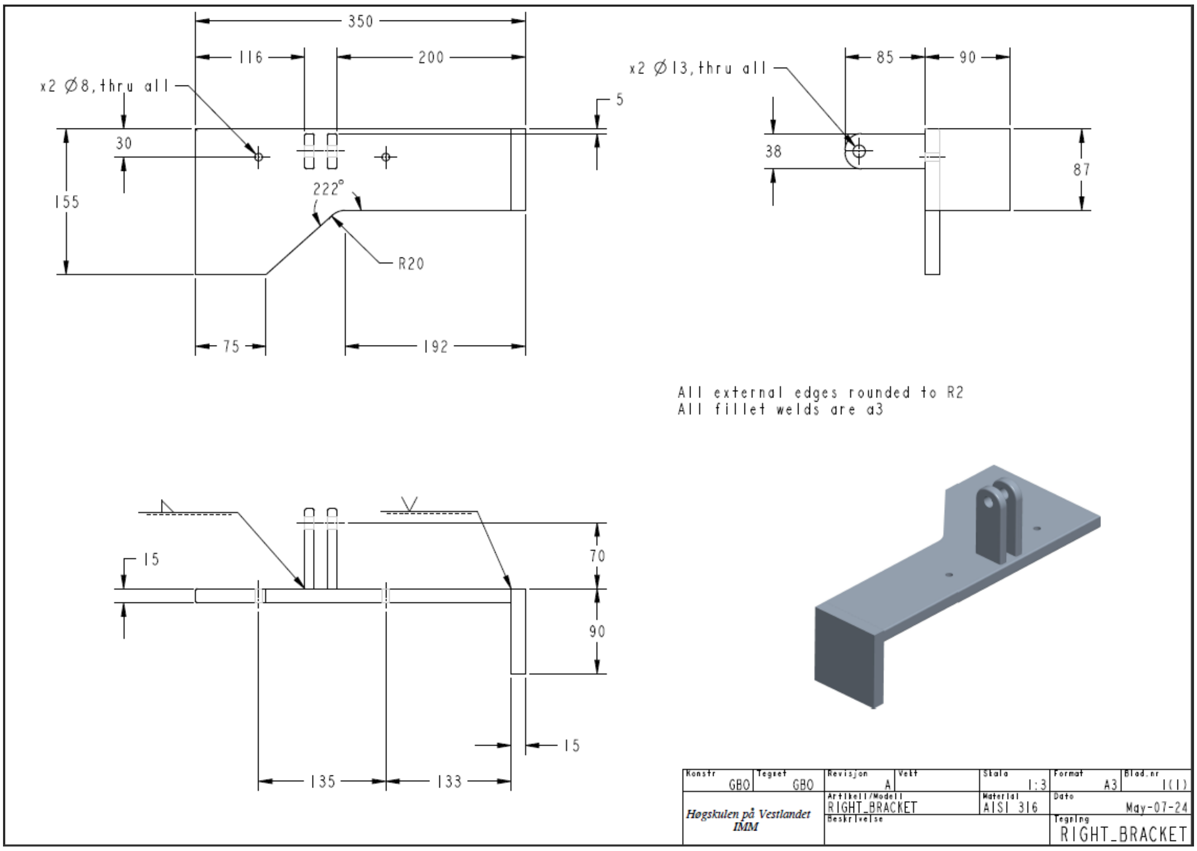


Figure 170 - Right bracket drawing

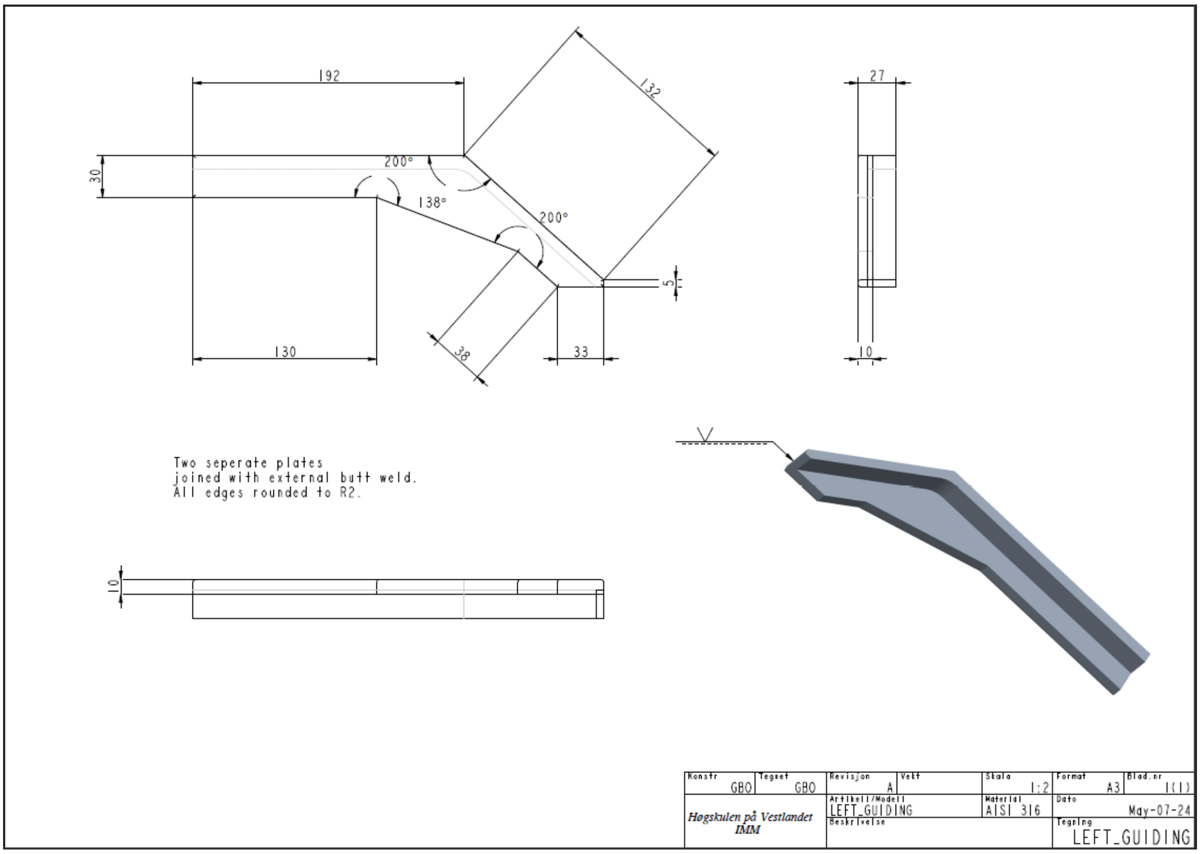


Figure 171 - Left guiding drawing

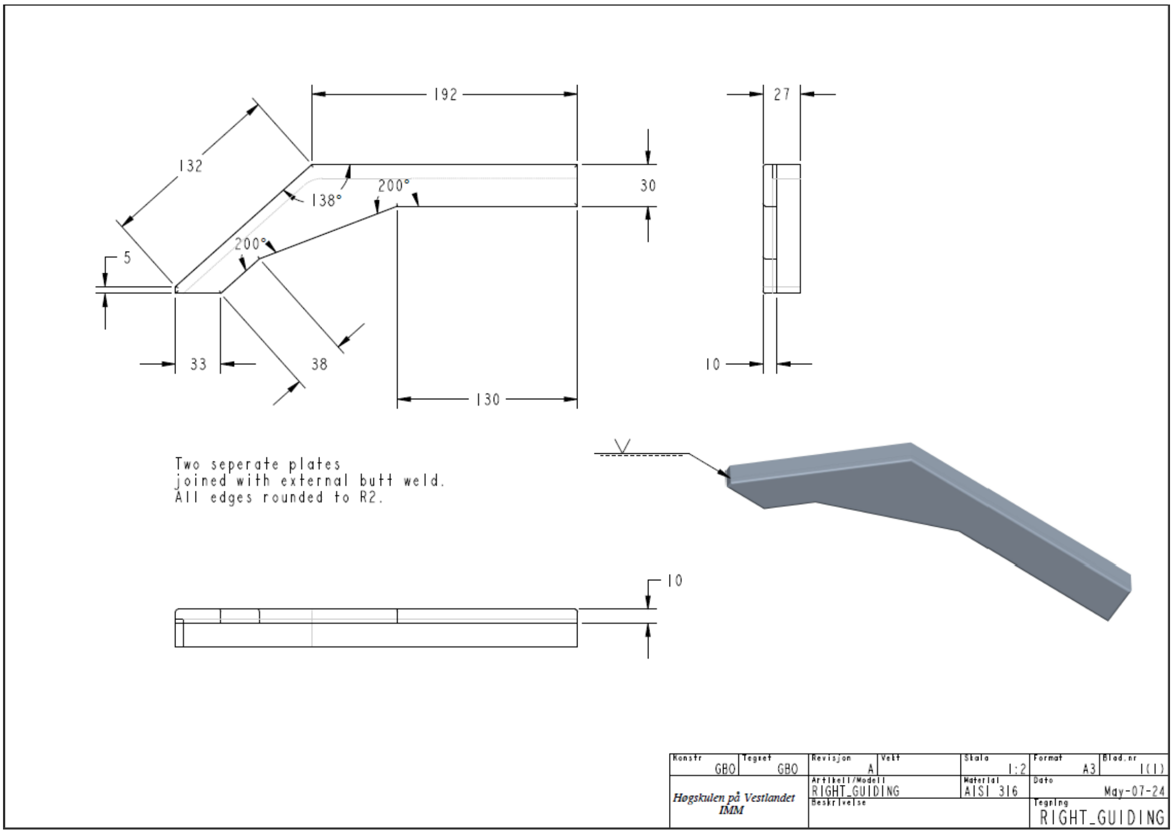


Figure 172 - Right guiding drawing

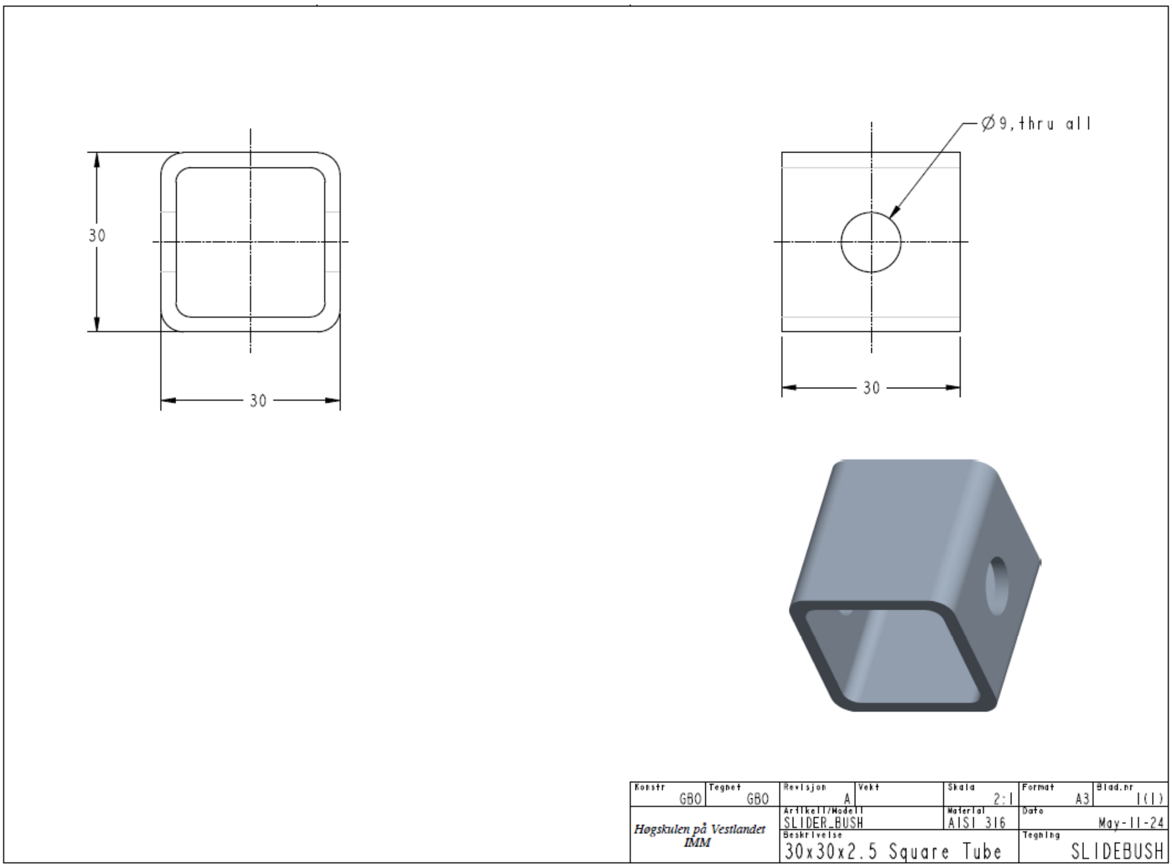


Figure 173 - Bushing for slide function drawing

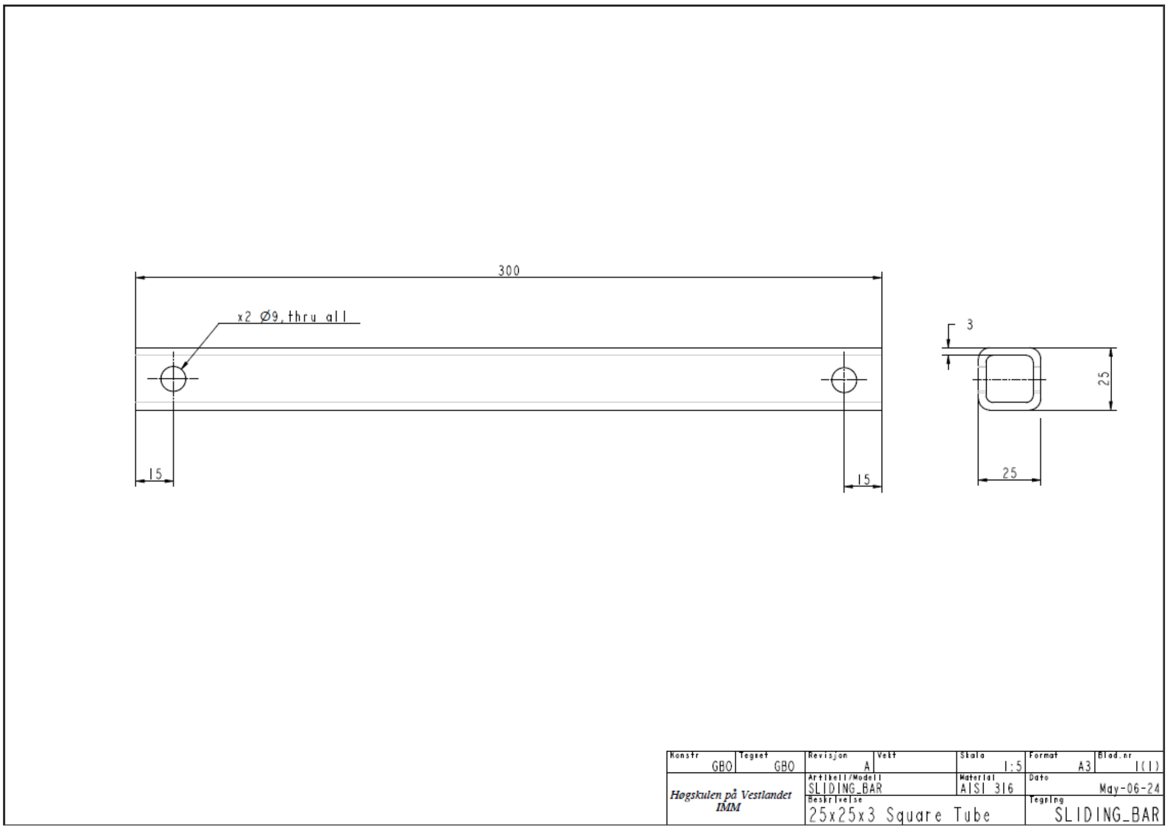


Figure 174 - Sliding bar drawing

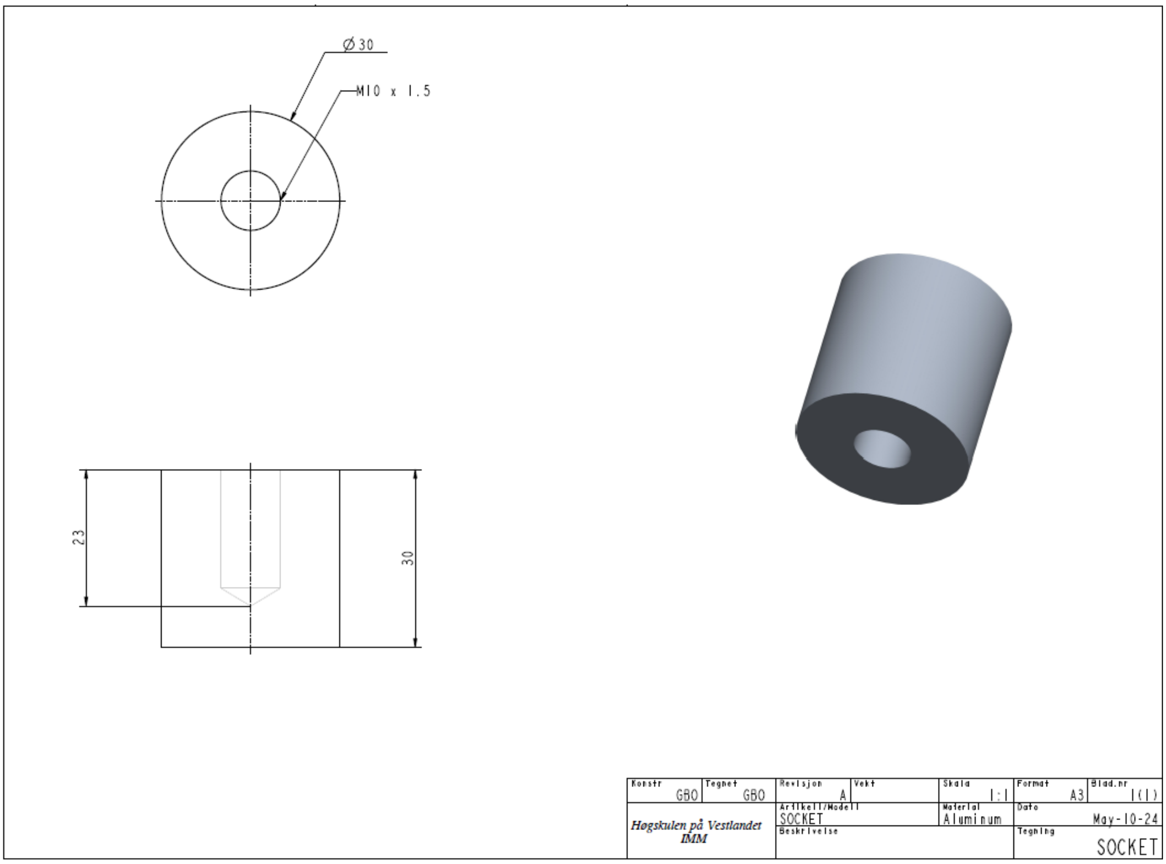


Figure 175 - Protective socket drawing

7. Prototyping

During the bachelor project an opportunity to realize the SSRT came up due to a project the Company has in Angola, called project GirRi. The Company wanted to check the possibilities for the Group to complete this tool within three weeks.

The Group took the opportunity and started working immediately to realize the GirRi project.

7.1 GirRi Project

At the GirRi kickoff meeting, it came apparent that it differed somewhat from the bachelor project. One notable difference is that the MV-head in this project was unlike the MV-head this bachelor thesis is based on. The flying handle and the connector bracket, seen in Figure 2, are not mounted on the MV-heads in Angola. Another difference is a 30mm clearance between the MV head and the slot plate. The pulling handle is also different.

The tool in the bachelor project is based on pushing against the flying handle and the connector bracket, and therefore a change in the design is necessary to deliver a functional tool to GirRi project.

Because of the time limit, it is preferred that the tool is easy to fabricate and assemble. Therefore, the tool is made in a simple but efficient way. The cylinders are from a different supplier due to delivery time.

The tool, with the previous cylinders, is shown in Figure 176.

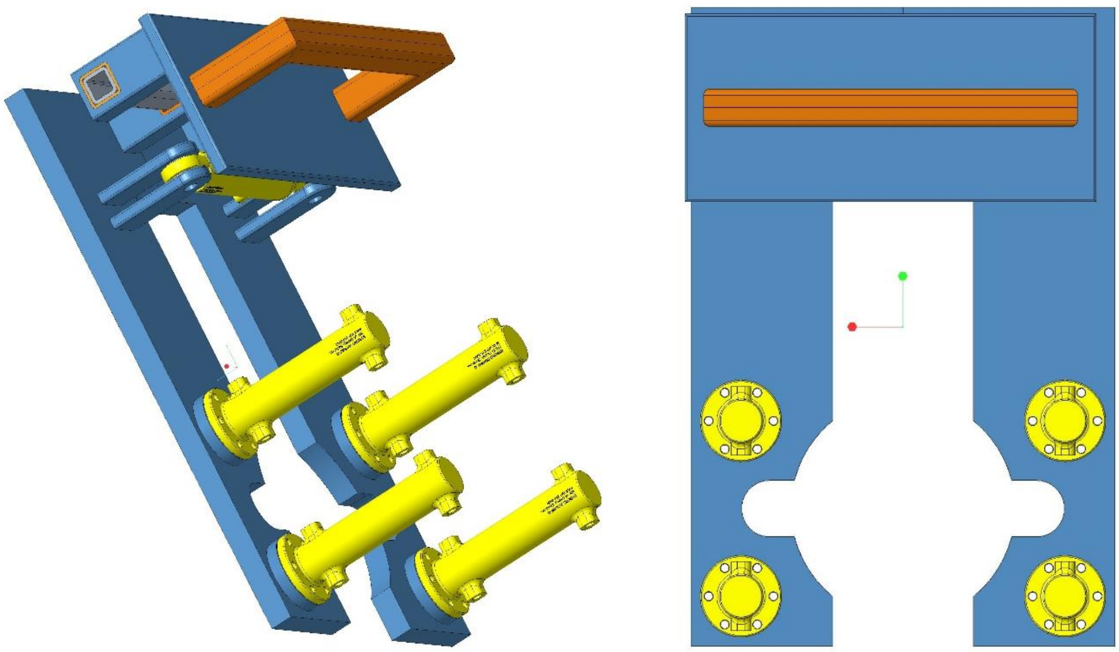


Figure 176 - GirRi tool

As shown in Figure 177, one can see that the MV-head is missing the flying handle at the top. The 3D model of the bracket where the slot plate is fastened was sent by the Company, shown in yellow.

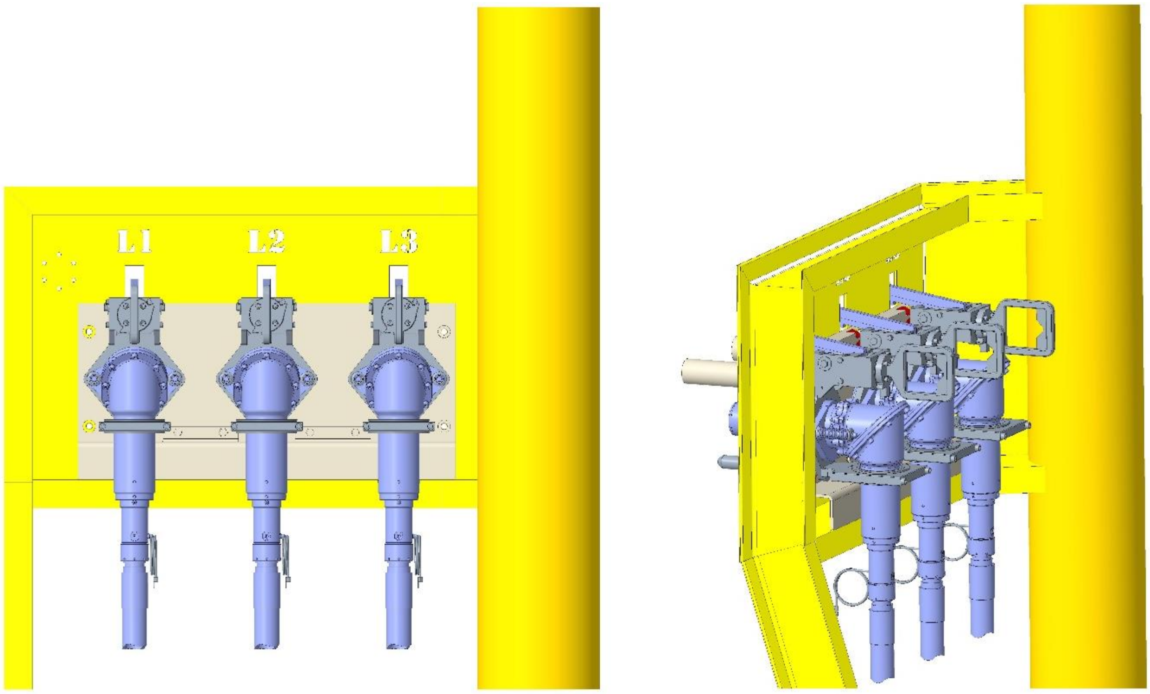


Figure 177 - GirRi project with MV-head

In Figure 178, the SSRT is mounted on the MV-head.

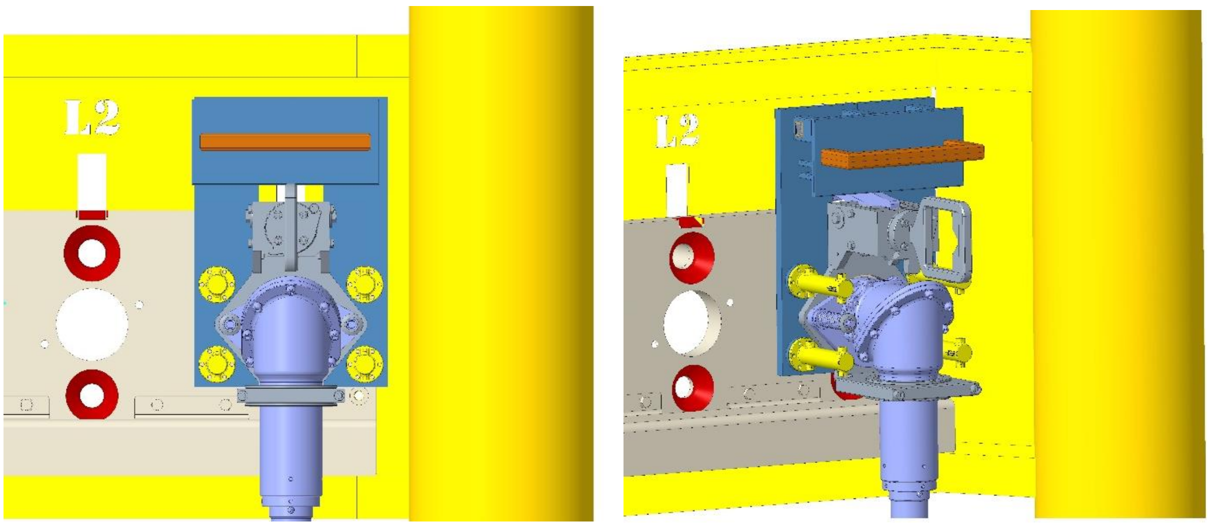


Figure 178 - Tool mounted on MV-head

Between the pushing cylinders, a slot is made for guiding the SSRT during mounting and dismounting. These slots are placed behind the purple spring on both sides of the MV-head. This is shown in Figure 179.

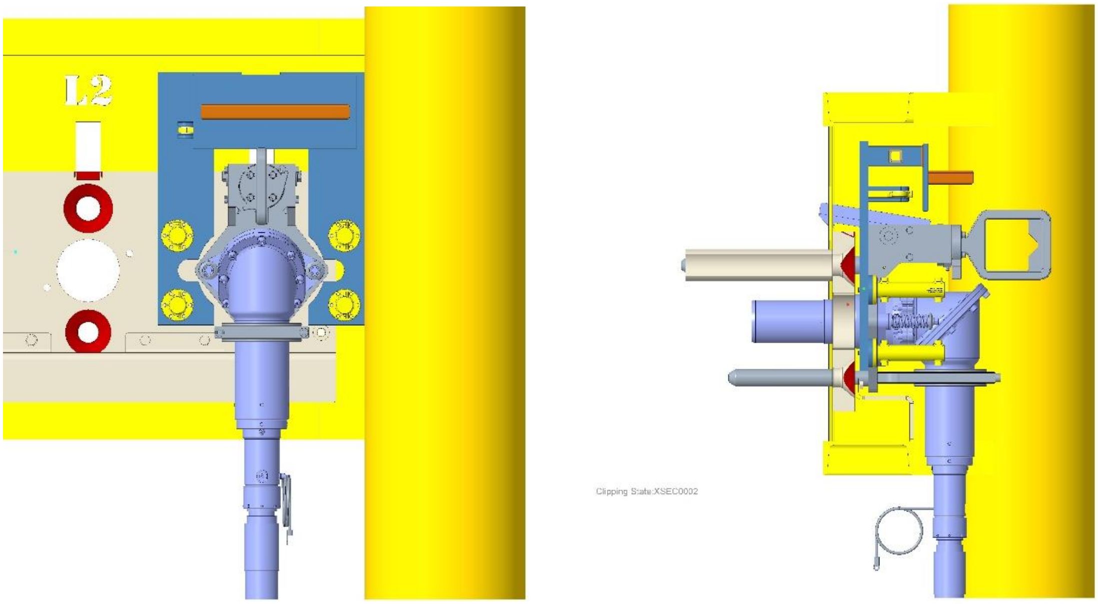


Figure 179 - Tool open in place

Due to the limited completion time of the tool, there will be hoses instead of tubes connected to the cylinders. To make sure the hoses will not be an obstacle for the tool, some clamps may be installed to secure the hoses. These clamps are shown with black arrows in Figure 180. The hoses can be zip-tied to the clamps.

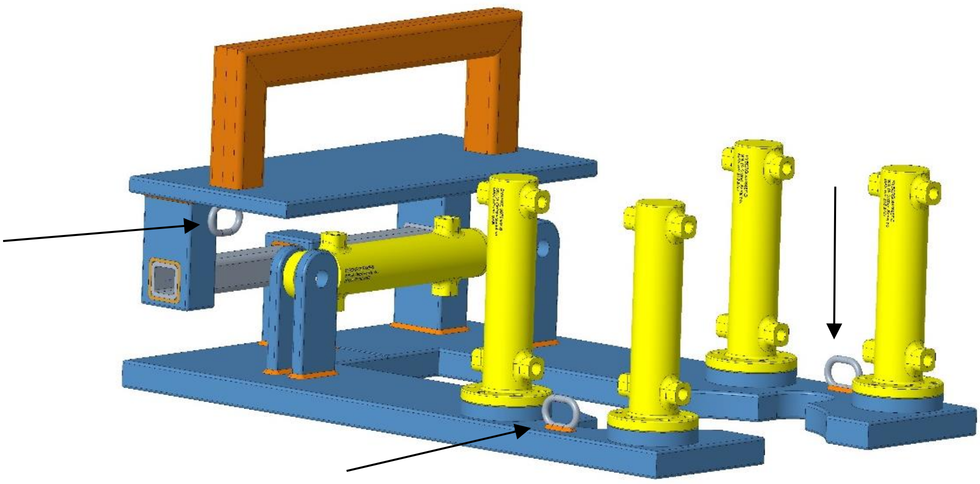


Figure 180 - Clamps for hoses

7.2 Manufacturing

All five cylinders will be the same and of the type “Sylinder 50 slagl 25 innv faste øyer” from a producer in Sarpsborg called “Økonomideler”.

Item number: **HC 505-25-16-050**

Figure 181 - Cylinders in GirRi project [48]

For the four pushing cylinders there must be a small modification. The cylinder eye, shown to the left in Figure 181, must be cut off. A flange is welded to the cylinder to mount it on the cylinder bracket. This is shown in Figure 182.

Figure 182 - Cylinder with flange

7.3 Testing

The tool will be tested at OneSubsea test facilities at Horsøy. Stress calculations have also been performed in Ansys.

In Figure 183, forces and displacement on the tool during de-mating are shown to the left and gravity check for topside is shown to the right.

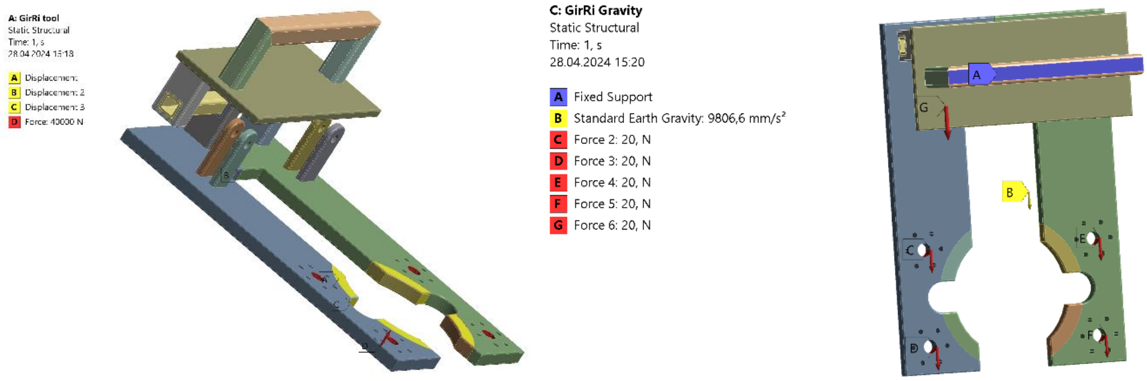


Figure 183 - Force and displacement during operation and topside

The stress on the tool during de-mating is shown in Figure 184. The max stress is around 65 MPa as shown in probes to the right. 206 MPa is a singularity fault from Ansys.

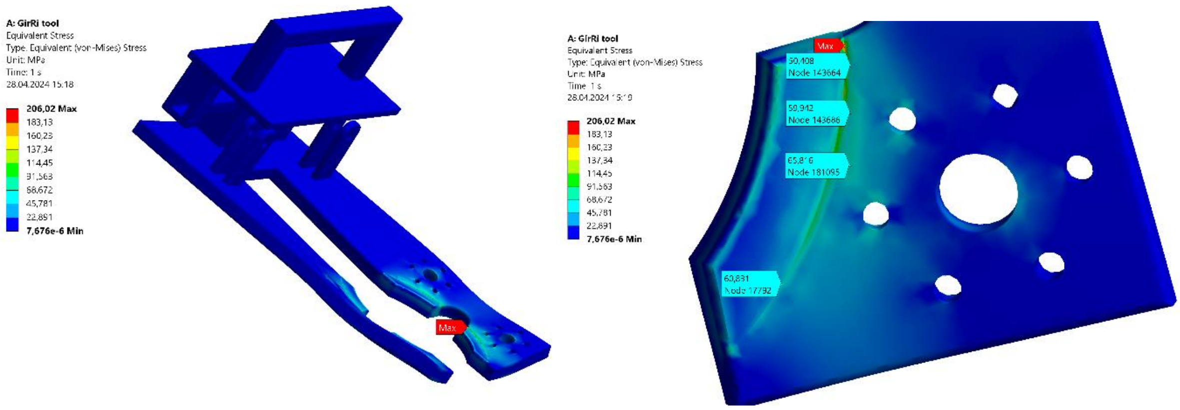


Figure 184 - Stress on tool during de-mating

The max stress when the tool is held topside, is 54 MPa as shown in Figure 185.

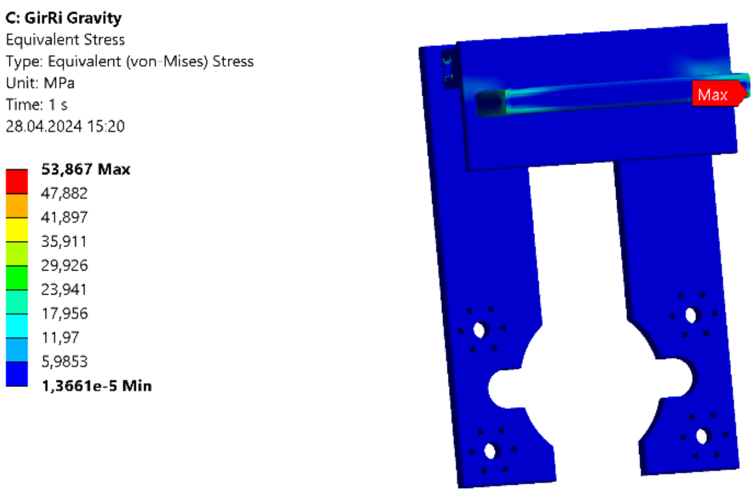


Figure 185 - Stress topside

Both results are approved, due to the AISI 316 yield strength and the given safety factors from the Company.

Because of short delivery time on the tool, and a long delivery time on AISI 316, the Group decided to check the possibilities of using materials that were in the HVL workshop. These are 10 mm S235 steel plates, so new calculations with the new material and a slightly new design of the guiding/sliding function at the top were performed. The sliding function is changed due to material limitations on the workshop. The new sliding design is shown in Figure 186. All the boundary conditions and forces are the same as in Figure 183.

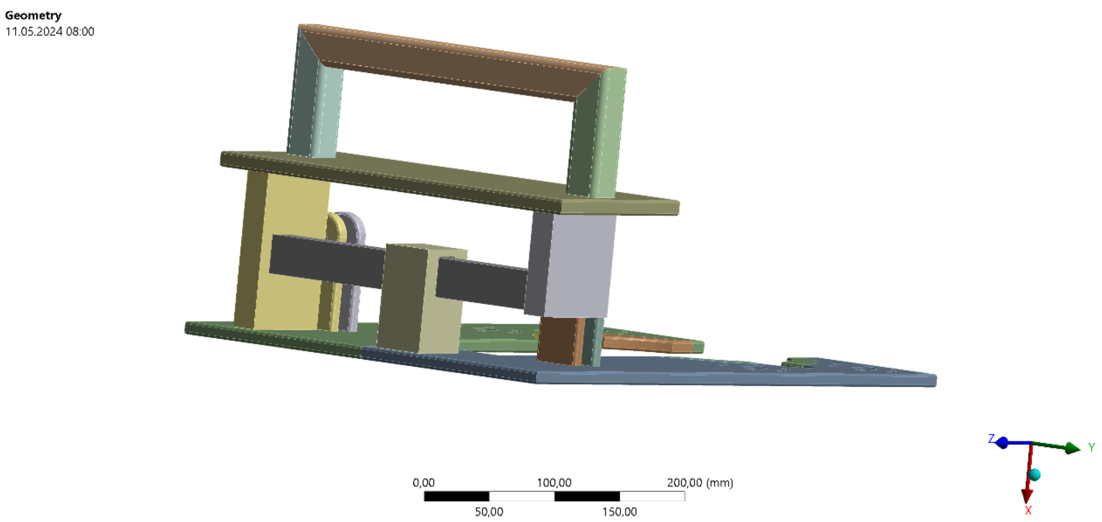


Figure 186 - New guiding design

The results of the analysis is shown in Figure 187. On the left side one can see the singularity fault, so probes are installed to see the actual stress. This is shown in Figure 188.

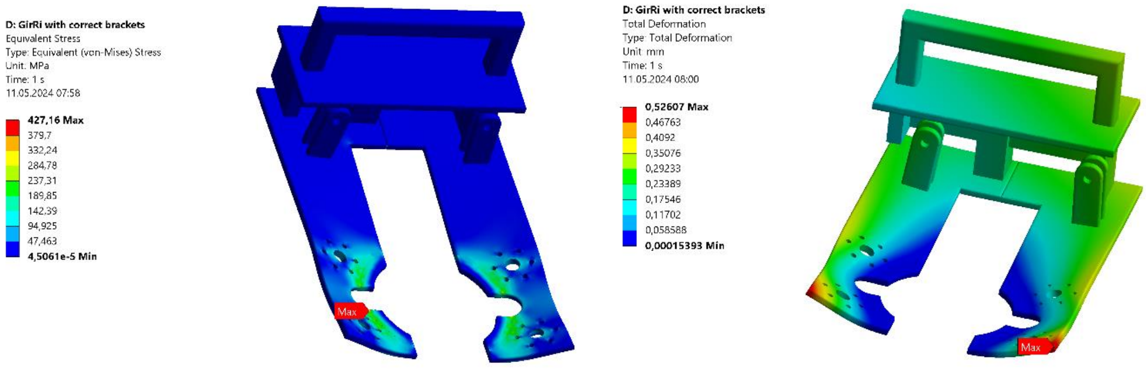


Figure 187 - Stress and deformation on 10 mm GirRi-tool

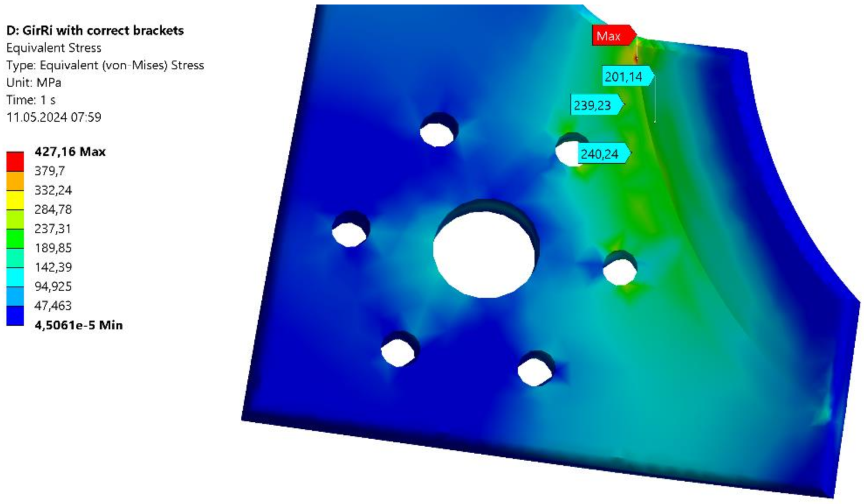


Figure 188 - Actual stress on tool

The stress is around 240 MPa, which is above the yield point of the material (235 MPa). These results were sent to the Company, because during GirRi kick-off meeting, one of the supervisors mentioned that the tool most likely would not operate at full power. The supervisor wanted the Group to check the stress on the tool with a total force of 25000 N. The new results are shown in Figure 189 and Figure 190.

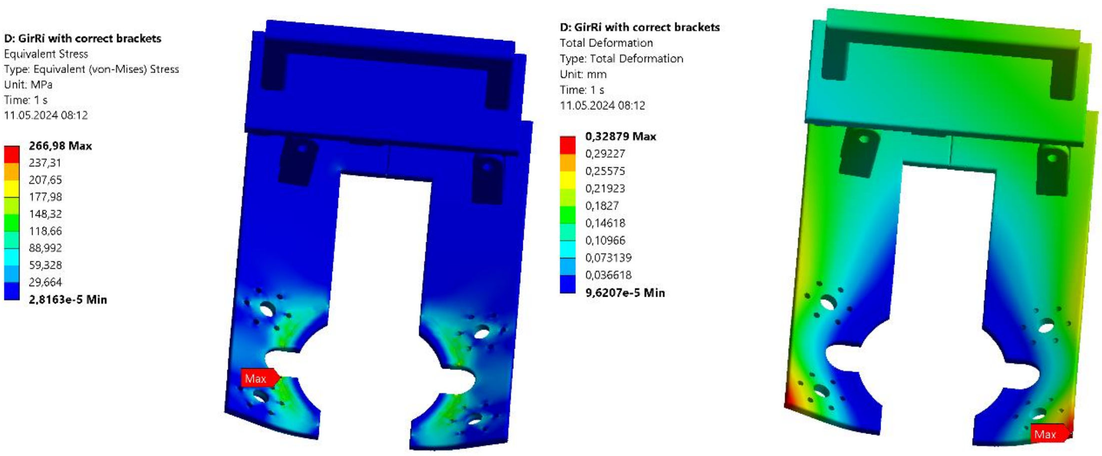


Figure 189 - Stress and deformation with 25000 N

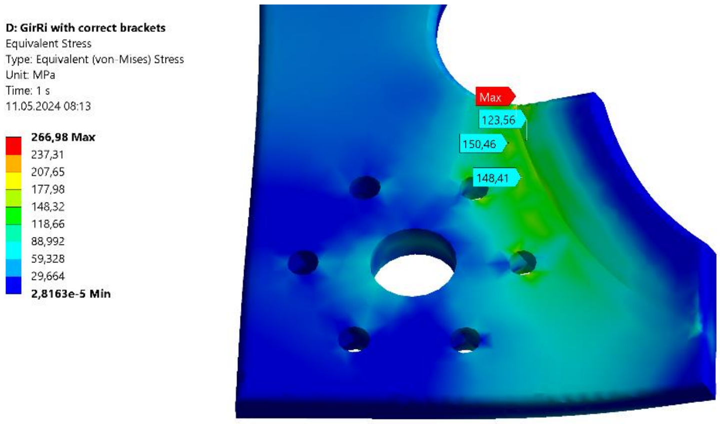


Figure 190 - Actual stress with 25000 N

The results are approved by the Company. Since the material will be thinner and therefore lighter than the original calculations, there is no need for a gravity check.

7.4 Production

The Group, with the help of the employees at the HVL workshop, produced the GirRi tool. Plasma cutter for the parts, drill machine for holes, and welding machine is used. Hydraulic hoses are ordered from a supplier.

Figure 191 - Engineer to be, Adrian, inspects the plasma cut parts

Figure 192 - Mikal welds parts for the GirRi project

Figure 193 - Cylinders demounted for welding of flange

Figure 194 - CNC machining of bracket

7.5 Result

After all the parts were welded together, the SSRT was painted. This is shown in Figure 195, Figure 196 and Figure 197.

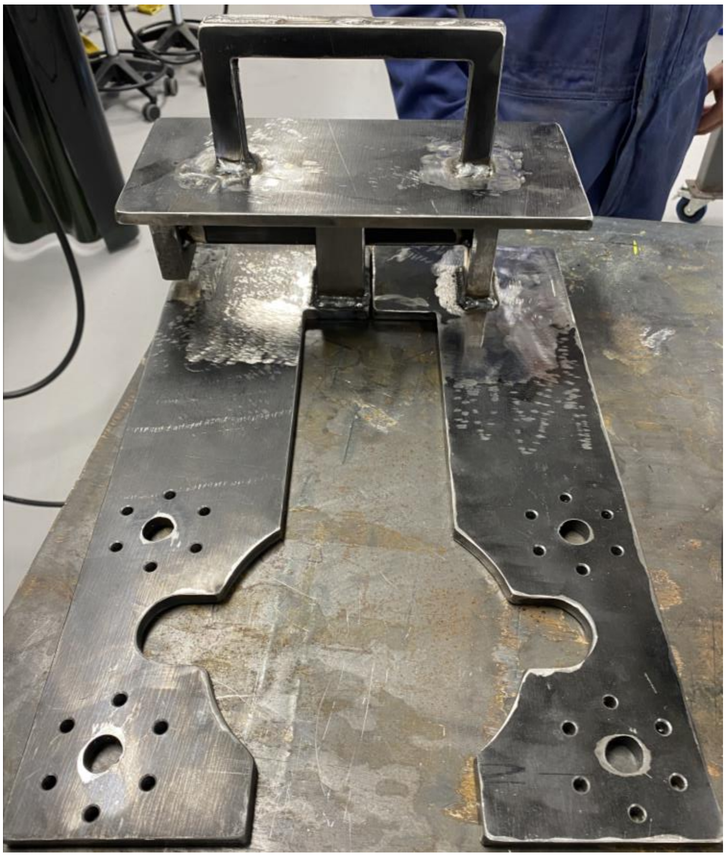


Figure 195 - GirRi SSRT before painting

Figure 196 - GirRi SSRT during painting

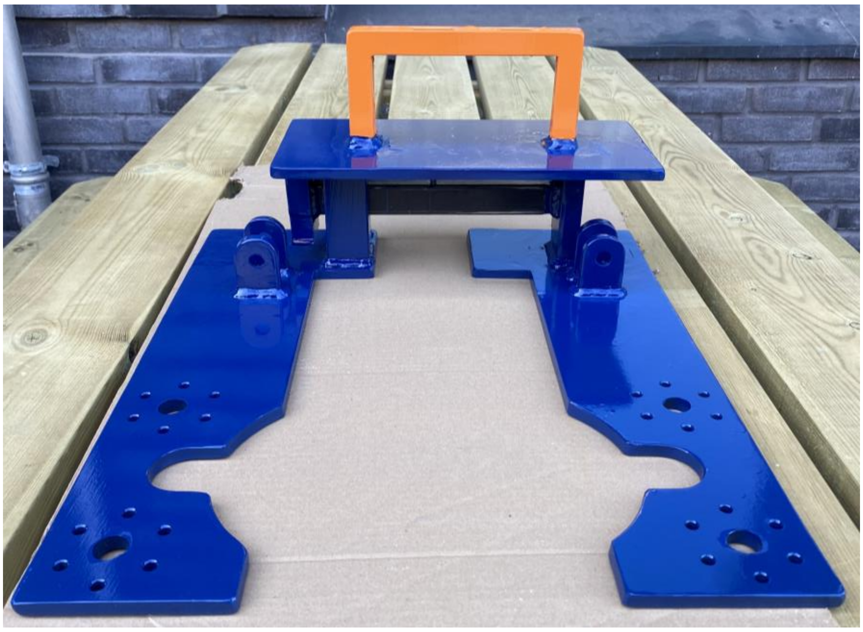


Figure 197 - GirRi SSRT with paint

The full assembly of the GirRi SSRT with hoses and fittings are shown in Figure 198, Figure 199, Figure 200, Figure 201 and Figure 202.

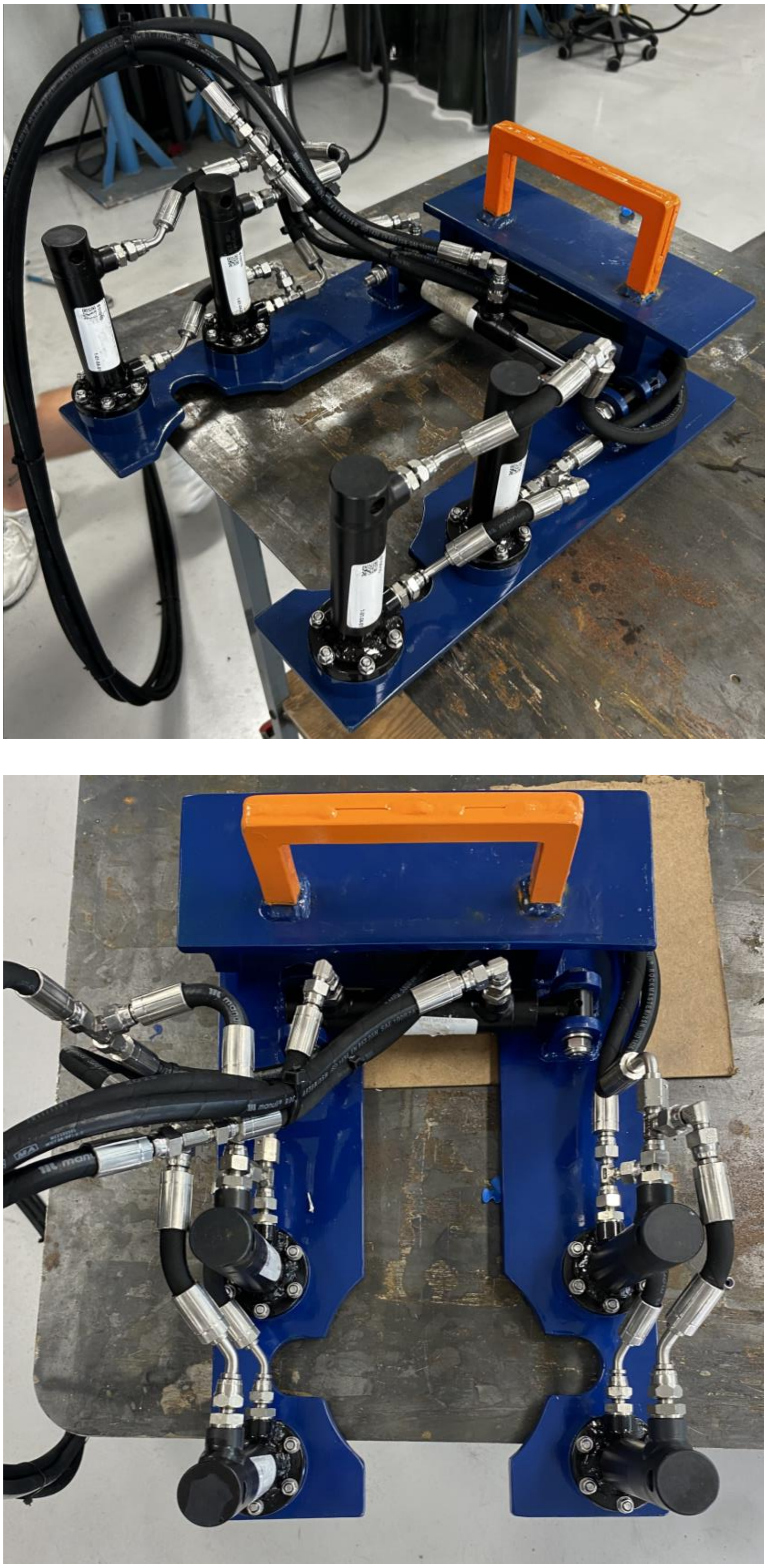


Figure 198 - GirRi SSRT with hoses and fittings

Figure 199 - GirRi SSRT in closed position

Figure 200 - GirRi SSRT in open position

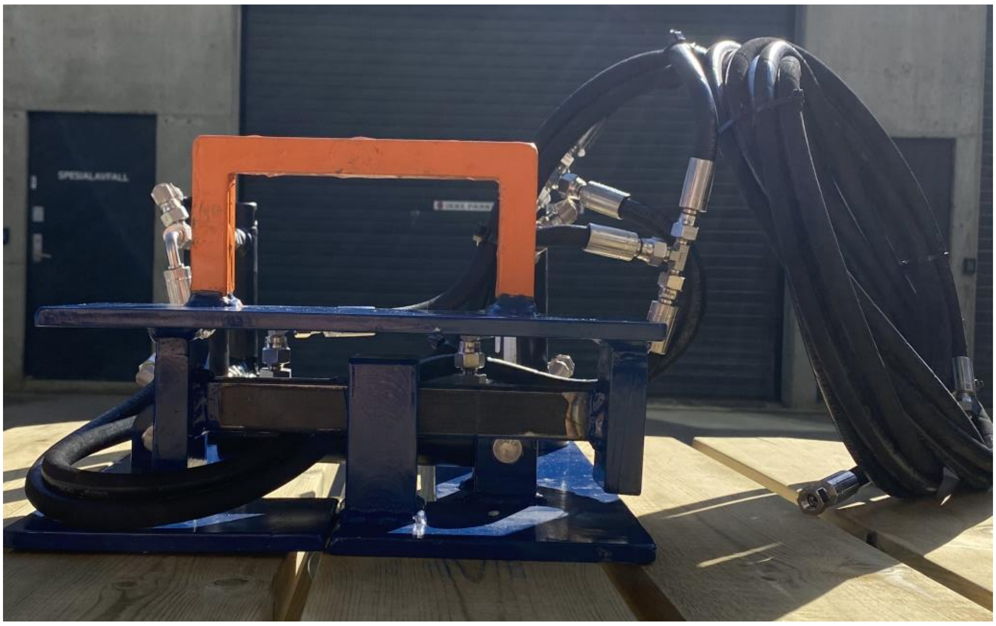


Figure 201 - GirRi SSRT top view

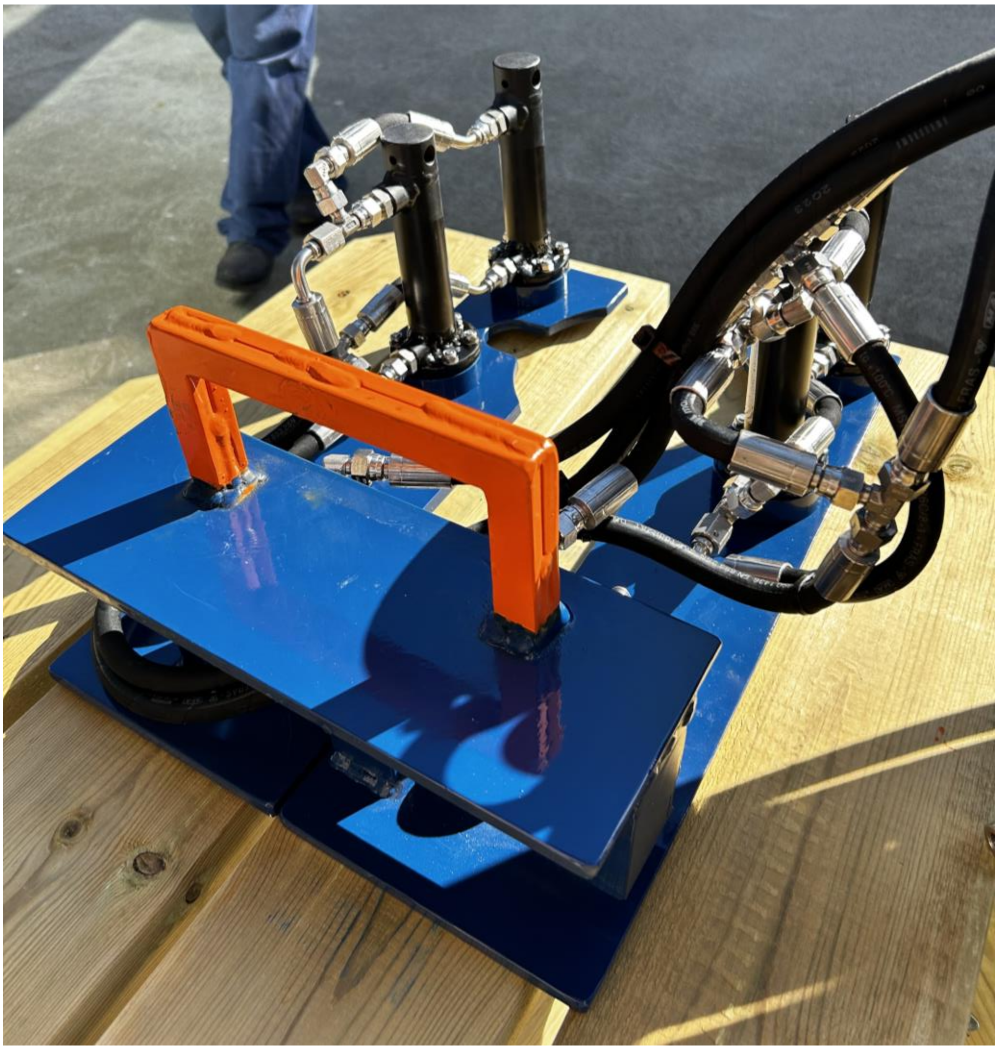


Figure 202 - GirRi SSRT final result

8. Discussion

At the start of the bachelor project, the Group had a kickoff meeting with the Company. All the project parameters and possible challenges were explained and discussed. During the entire project, the communication between the Group, the internal supervisor and the Company has been good. Design reviews meetings, invitation for weekly meetings, Teams- and mail correspondence has been helpful for the pace and quality of the project.

One of the sub-objectives was to look at possibilities for acid injection, either directly from the SSRT or as an additional tool. The Group, with approval from the Company, has disregarded this function due to the SSRT's high and even force distribution on the MV-head.

The Company had a MV-head at their test facilities before the second design review. The final design of the tool was not decided at this point, and therefore no proof of concept was ready. This could have been changed if the Group had decided on the final design at an earlier stage. If the final design was chosen and a design was made, the tool could at least be fit-tested on a real MV-head. When the proof of concepts was finished, there were no available MV-heads at the test facility.

Regarding the GirRi project, the original plan was for the Group to act as engineers and primarily focus on supervising the manufacturing process. However, as time passed, it became apparent that the Group had to undertake most of the manufacturing to meet the delivery deadline. This required a significant amount of time and attention, combined with finalizing the thesis. Despite this challenge, the Group were ultimately able complete both the thesis and the tool, and are pleased with the outcome.

9. Conclusion

"The objective of the project is to engineer a Subsea Secondary Releasing Tool for disconnecting power cables from subsea pump modules. The project shall be done by 21th of May 2024".

The Group carefully concludes that the SSRT is capable to disconnect the power cables from the subsea pump modules using any standard ROV. The tool is designed to protect the MV-head from any potential damages, and thereby makes the MV-head usable after the de-mating. The manufacturing can be done with traditional industrial methods, and all materials are accessible. This fulfills all the sub-objectives except the acid injection functions. The Group, as discussed in Chapter 8, has disregarded this point because the tool can do the operation without any acid injection.

The group has created production drawings, a user manual, hydraulic schematics, and performed FEM analysis for the tool. The next step for this project is to purchase all the necessary materials and components for producing the tool. The company should then manufacture the tool and test it to validate its function in conditions similar to those on the seabed.

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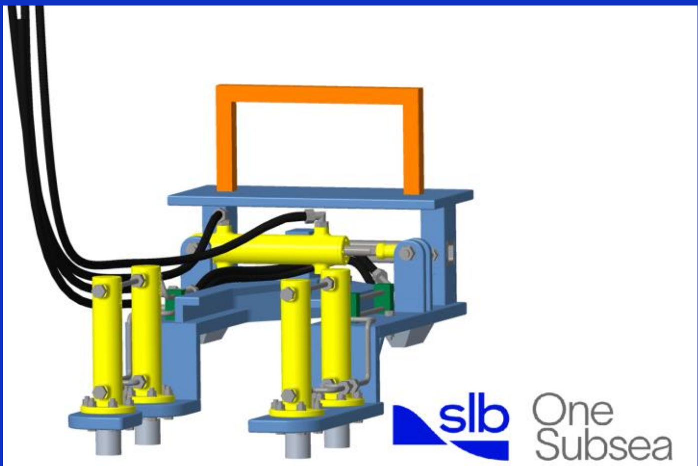
List of Figures

List of Tables

11. Attachment 1



SUBSEA SECONDARY RELEASE TOOL

USER GUIDE

Kristian Gjelstad, Adrian Bjørlykke, Mikal Osmundsvåg

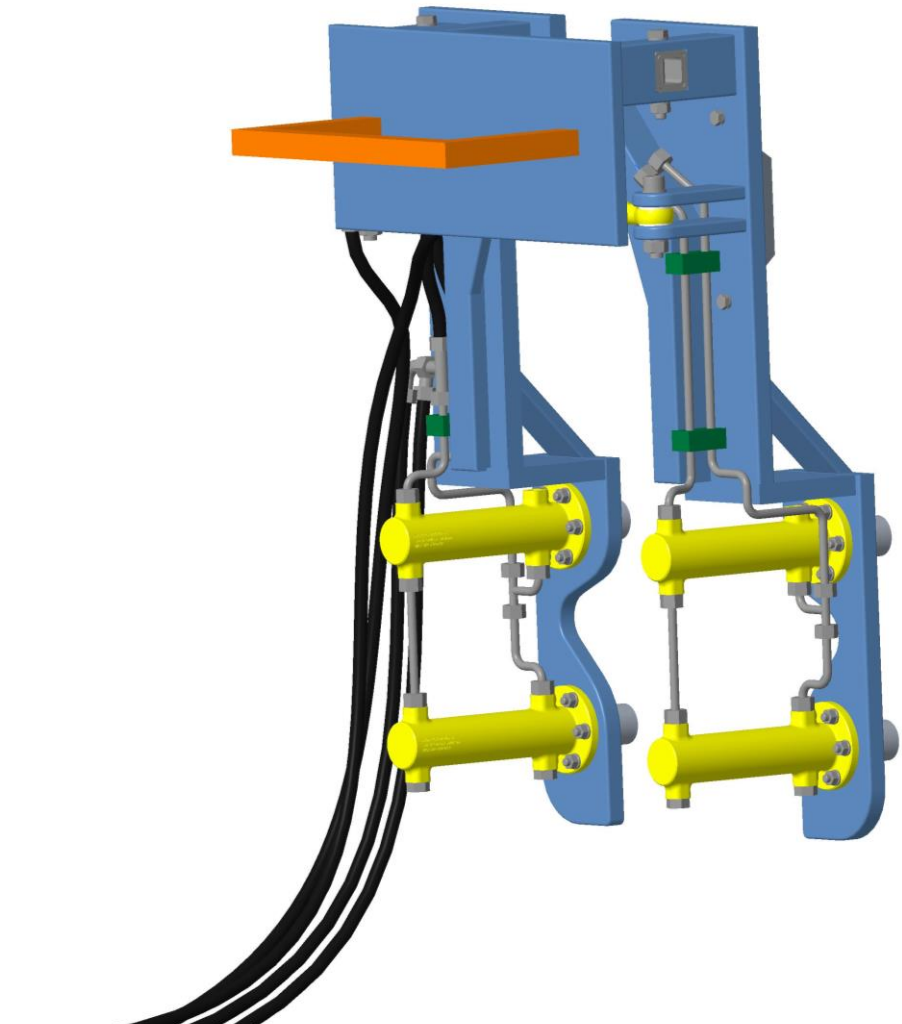
Bachelor thesis

PUBLISHED	REVISION	REVISION NOTE
21.05.2024	0	IFC
PREPARED	CHECKED	APPROVED
ABJ	KLG	MOS

SSRT

The Subsea Secondary Release Tool is an additional tool for de-mating a OneSubsea MV-head. This tool is only to be used when the connector is stuck to the slot plate. It is a secondary ROV tool, and it requires certified personnel for operation. Please read the whole user guide before operations.

The tool is made by students at Western Norway University of Applied Sciences (WNUAS) after a request from OneSubsea. The SSRT is OneSubsea property and shall not be used without approval from OneSubsea.



SSRT

Product Name	SSRT
Materials	Tool – AISI 316 Bolts – AISI 8.8 Cylinder washer – Nylon Cylinder socket – Aluminum Anodes - Zinc
Hydraulic Supply	Pressure: Max 207bar (3,000 psi)
Supply Fluid	Mineral Oil
Force Output	0N - 40 000N (0 Bar - 207 Bar)
Hydraulic Connections	1/8” BSP
Weight in Air	36,1kg (without hoses and oil)
Weight in Water	N/A
Dimension	W330mm, H605mm, D398mm

User manual:

Warning! Always follow general safety rules when using hydraulic tools to avoid line of fire. Read the user manual before use and retain it for later reference.

General Safety Rules:

1. **Keep away from unauthorized personnel.**
   Always keep the tool away from unauthorized personnel to prolong the lifetime of the tool.
2. **Keep the workspace clean.**
   When maintenance on the tool is ongoing, keep the workspace clean. Always keep in mind the line of fire. A messy workspace can cause accidents.
3. **Store the tool in a proper place.**
   To ensure that the tool is ready for use when needed, store the tool in a manner that the tool will not get any damage.
4. **Always wear proper PPE**
   Working with the tool demands proper PPE (Personal Protection Equipment). This includes a minimum of safety goggle, hard hat, coverall, and impact gloves.
   To enhance your list of general safety rules, consider adding the following points:
5. **Use the tool only for its intended purpose**.
   Ensure the tool is used only for its designated tasks as outlined in the operating manual. Avoid using the tool for any other applications to prevent accidents or damage.
6. **Conduct regular inspections and maintenance.**
   Regularly inspect the tool for any signs of wear, damage, or malfunction. Perform routine maintenance as recommended by the manufacturer to keep the tool in safe and optimal working condition.
7. **Be aware of surroundings and potential hazards.**
   Stay alert to your surroundings while using the tool and be mindful of potential hazards such as moving parts, electrical sources, or tripping hazards. Keep others clear of the work area to prevent accidents.
8. **Use proper lifting techniques.**
   When handling heavy or bulky tools, use proper lifting techniques to avoid strain or injury. Lift with your legs, not your back, and ask for assistance if needed.
9. **Report any safety concerns or incidents immediately.**
   If you notice any safety concerns, defects, or accidents related to the tool, report them to your supervisor or safety officer immediately. Prompt reporting can prevent future incidents and ensure a safe work environment for everyone.

Instructions:

Before deploying the SSRT to the sea, it is recommended to grease the sliding bar with marine grease. Function test the SSRT with the dedicated ROV and check for errors. Inspect the tool before deploying.

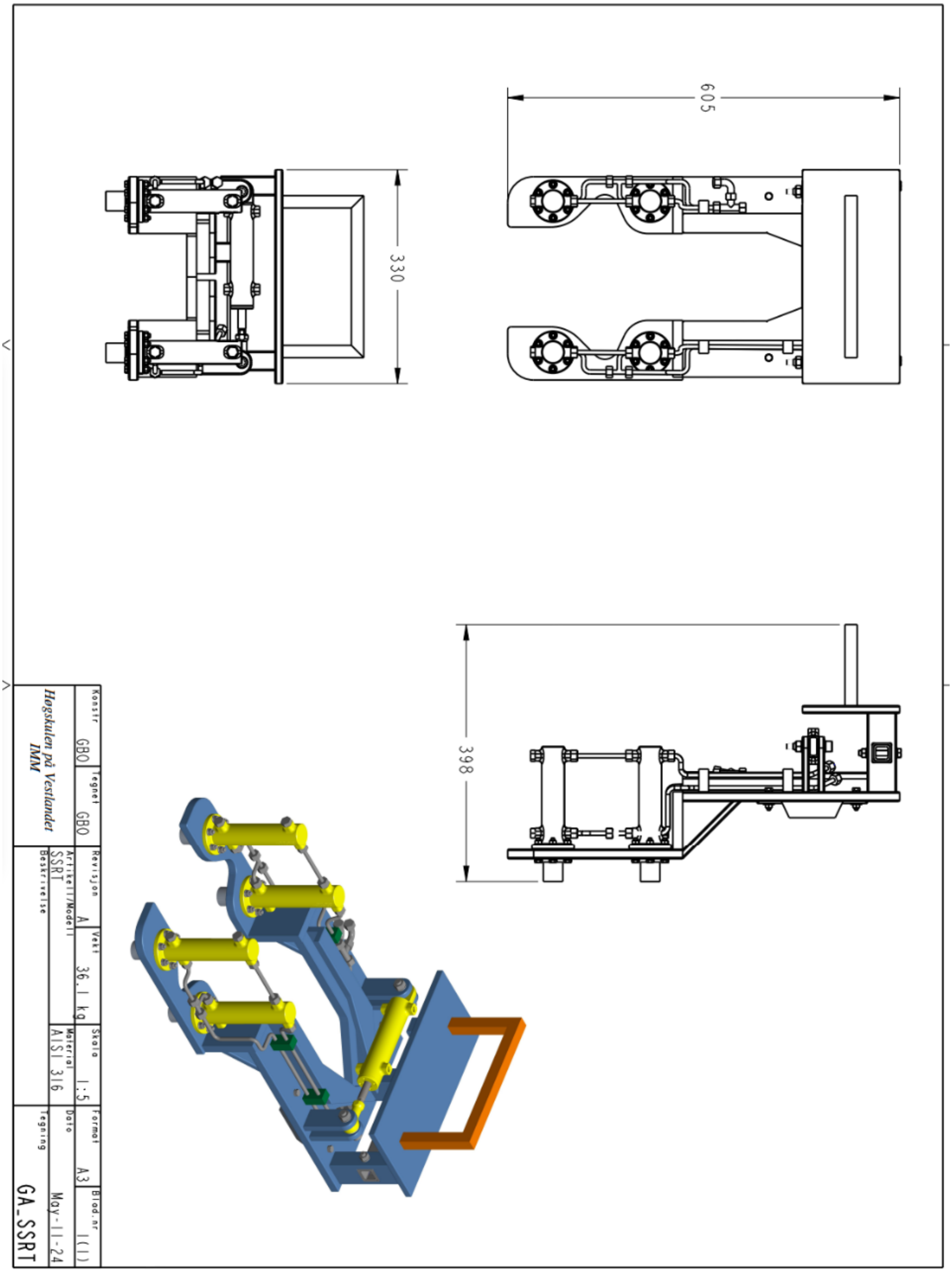
When deploying the tool at sea, make sure that the tool is correctly fastened to either the subsea basket or the ROV skid, in case of buoyancy. Lower the tool in an open position, due to the load that the cylinders are exposed to.

When the ROV and SSRT are placed in the relevant operation place, the ROV must carefully pick up the SSRT and maintain it in a vertical position while holding on to it. If the SSRT is not opened topside, the ROV pilot must operate the open/close cylinder to open the tool.

When the tool is placed in the right place over the MV-head, the ROV pilot must close the tool carefully with low hydraulic pressure. When the guiding for the flying handle is in the right place, the ROV can let go of the tool when fully closed. The tool will not fall off, so the ROV pilot can place its manipulator on the pulling handle. It is important that the ROV does not pull the MV-head but keeps the manipulator ready to take it when the de-mating is finished. The tool will maintain the position after the de-mating and can be retrieved either before placing the MV-head in its parking position, or while the MV-head is free. The operation can then continue.

After the operation, it is important to retrieve the tool topside and flush it with fresh water. When the tool is flushed an inspection of the tool is necessary. This is to detect any errors early. If errors occur, maintenance must be done either on the field or at OneSubsea’s facilities.

SSRT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