Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Design

Markus Frydenlund Ruud

Redesign of a Small Bore Actuator Control Module

Master's thesis in Industrial Design
Supervisor: Jon Herman Rismoen
June 2023

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Institutt for design

Master thesis for student Markus Frydenlund Ruud

Title Redesign of actuator SB ACM Package
Tittel Redesign av aktuator SB ACM Pakke

This thesis aims to redesign an actuator system (SB ACM) for Aker Solutions AS in connection with the operation of a Christmas tree. The present system consists of two canisters, whereas Aker Solutions need a design solution for a single canister, 1-to-4 (1-off electronic canister controlling 4-off valves).

Aker Solutions aims to redesign this equipment and improve the product's locking mechanism, weight, production, and cost. To achieve this, the present system must be simplified to an optimal solution, including the 1-off electronic canister and 4-off valves.

Examples of methods to be used

- Interviews
- Field trip
- Functional analysis
- Modeling
- Simulation
- Prototyping

The expected result is a redesign of the SB ACM actuator, with the concept justified through theory and testing/simulation. Renders will illustrate the product. The final delivery has the goal of complying with Akers's requests.

The assignment is carried out according to the "Guidelines for master's thesis in Industrial Design".

Supervisor: Jon Herman Rismoen
Business contact: Fernando Popia (Aker Solutions)

Project Startup: 9. January 2023 Delivery deadline: 29. May 2023

NTNU, Trondheim, (09.01.2023)

Jon Herman Rismoen
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Jon Herman Rismoen

Sara Brinch

Abstract

This master's thesis deals with the redesign of an actuator control module for Aker Solutions, with the aim of optimizing it for a "flow control module". The report covers several areas within subsea systems, and presents this through visualizations and text. The process followed is a hybrid of recommended practices to achieve a qualified product. This includes establishing requirements for the product from the insight phase, as well as performing threat and risk analysis to uncover potential problems with the product and design. The result is a cost-optimized actuator control module adapted for use on the "flow control module".

Sammendrag

Denne masteroppgaven omhandler redesign av en aktuator kontroll modul for Aker Solutions, med mål om å optimalisere den for en "flow control module". Rapporten dekker flere områder innenfor subsea systemer, og presenterer dette gjennom visualiseringer og tekst. Den fulgte prosessen er en hybrid av anbefalte praksiser for å oppnå et kvalifisert produkt. Dette inkluderer å sette krav til produktet på funn fra innsiktsfasen, samt utføre trussel- og risiko analyse for å avdekke potensielle problemer med produktet og designet. Resultatet er en kostoptimalisert aktuator kontroll modul tilpasset bruk på "flow control modul".

Preface

The presented project is a final master's thesis in Industrial Design with a specialization in product design. This project aims to redesign an actuator control module for operating valves on subsea Xmas trees. The actuator is designed to fit a flow control module and therefore undergoes a change in both function and application.

Subsea is the project's central theme and is a fascinating research topic that demands a deep dive into an environment new to most people. The result is achieved through a thorough literature study leading to a design process where ideas are evaluated, chosen, detailed, and analyzed.

I would like to express my gratitude to Jon Herman Rismoen, my internal supervisor, for guidance, support, insights, and recommendations throughout the course of this thesis.

Since this master's is conducted in collaboration with Aker Solutions, I extend my sincere appreciation to the company for the opportunity and to all employees who have helped with the process, including field trips and interviews. I especially want to acknowledge my supervisors Fernando, Øystein, and Einar at Aker, who have supported me with the necessary materials, engaged in discussions, and approved my work. The collaboration has been a steep learning curve for me as the subsea environment is a new area to my experience, giving me insight into the dimensions of working with extreme conditions.

These experiences have given me valuable insight into this field's challenges and dimensions. I am grateful for the knowledge and growth I gained during this journey, and I hope this project will inspire readers, offering a unique view of subsea exploration and product design.

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2 - Research

3 - Qualification Basis

4 - Ideation

5 - Technology Assessment

6 - Threat Assessment

7 - Result

8 - Discussion

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Appendix 1

Terms

Xmas trees - Complex assembly of components used subsea to control production flow of oil or manage fluid/gas injection.
FCM - Retrievable module installed on Xmas trree to control systems and flow.
ROV - Remotly controlled vehicle
Actuator - Control module
Drive Heads - Creates a spinning motion to adjust the connected valve.
Jumpers - Transfer data and power between modules.
SCM - Control module that communicates with top side control stations.
PCGM - Communication gateway that replaces the SCM
SB ACM - Module that controls drive heads, allowing for precise control of valve operation.

1 Introduction

Background

The Norwegian petroleum business has existed for over 50 years and investigated a total of 12 000 wells, with several fields in the early stages still producing. This has made the petroleum business an essential part of Norwegian history, being the base for the country's welfare society and providing over 200 000 jobs. This is possible because the state secures a significant share of the values through the property rights to the petroleum resources belonging to the community. (Norsk Petroleum, 2023)

Through the years, gas and oil production has contributed over 18 000 billion kroner, while it is estimated that only half of the oil and gas on the Norwegian shelf is extracted (Norsk Petroleum, 2022). The U.S. Energy Information Administration forecasts an increase in oil demand from 99.4 million barrels per day in 2022 to 102.3 million in 2024 (Energy Information Administration, 2023). Today, oil and gas industries supply about 80 percent of the world's energy (EESI, 2021). On the Norwegian shelf are 43 oil companies active, with Aker BP being one of the most prominent (Bryhni, 2022).

Aker BP continuously grows, with more than 500 million barrels of oil in the ground through several wells and 135 licenses across Nordsjøen, Norskehavet, and Barentshavet (Rosvold and Askheim, 2023). Aker ASA owns forty percent of Aker BP, a Norwegian group founded in 1841, which has several interests and owns 40% of the industrial concern Aker Solutions.

Aker Solutions

Aker Solutions is a widespread company stretching over 20 countries, with 50 locations and 15 000 employees. The company delivers integrated solutions, services, and products to the global energy industry, focusing on low-carbon gas and oil production through renewable solutions. Sustainability is, therefore, a significant part of the company's strategy. Aker Solutions are continuously developing sustainable solutions to lower the impact of Co2 emissions. (Aker Solutions, 2023a)

A crucial development within the oil and gas field is to reduce the environmental print when producing oil. In this regard, Aker Solutions are developing and building one of the first full electric Xmas trees for subsea use. These electrical Xmas trees are being produced in Drammen at Tranby and are being completed during 2023 (Dahl, 2021). The Xmas trees contain all-electric subsea control modules, which control power and signal to different actuators on the tree. The benefits of this system are significant, reducing the cost of cables (umbilical) and providing new solutions to high-pressure and high-temperature wells where hydraulic fluid is currently used. Electrifying the Xmas trees decreases economic and environmental issues related to the leakage of hydraulic control fluids and the overall complexity of working with hydraulics. (Bau and Bai, 2012, pp. 200-201) The trees are smaller, lighter, easier to repair, and cheaper due to not needing to accommodate hydraulics. (Murphy, 2000)

AkerSolutions

Research Question

Aker Solutions are currently in a design and concept phase where different solutions for electric Xmas trees are being tested and designed. Aker Solutions wishes to improve one of its systems and is, therefore, a provider of the background intellectual property and provides the problem description for the project.

The project aims to improve and adapt a Small Bore Actuator Control Module operating directly on Xmas trees to a flow control module designed for a new electrical system. Due to changes in this new system and product use, simpler solutions are essential for an optimized and improved product. An optimized solution will reduce the module's cost and production time. To ensure an enhanced product, interim goals are defined.

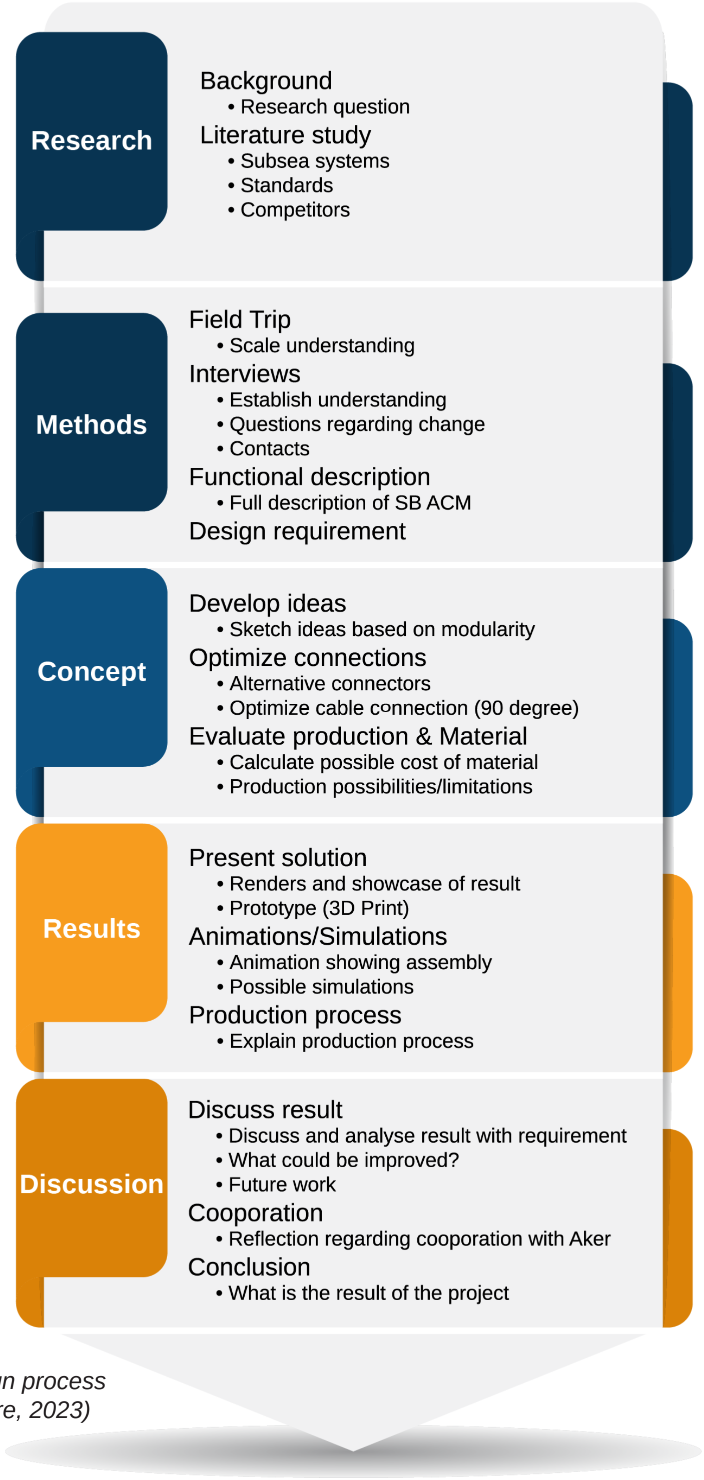
Design a cost-effective control module for control of four valves within a Flow Control Module, leveraging the principles of the Small Bore Control Module

- Design a module to deliver the required functionality based on requirements.
- FCM design considerations.
- Avoid a design that leads to changes in the standardized electronic equipment.
- Technology-approved solutions.
- Risk acceptable result.
- Identification/mapping out cost reduction.

Process

Approach

The project follows a design process to ensure a strategic approach to improving the project results. Different aspects are investigated to understand the product and possible solutions. Literature, interviews, and field trips are examples of methods used to gather insight and set a design requirement for the product.



Research

Background
- Research question

Literature study
- Subsea systems
- Standards
- Competitors

Methods

Field Trip
- Scale understanding

Interviews
- Establish understanding
- Questions regarding change
- Contacts

Functional description
- Full description of SB ACM

Design requirement

Concept

Develop ideas
- Sketch ideas based on modularity

Optimize connections
- Alternative connectors
- Optimize cable connection (90 degree)

Evaluate production & Material
- Calculate possible cost of material
- Production possibilities/limitations

Results

Present solution
- Renders and showcase of result
- Prototype (3D Print)

Animations/Simulations
- Animation showing assembly
- Possible simulations

Production process
- Explain production process

Discussion

Discuss result
- Discuss and analyse result with requirement
- What could be improved?
- Future work

Cooperation
- Reflection regarding cooperation with Aker

Conclusion
- What is the result of the project

Figure 1. Design process (Private picture, 2023)

Recommended Practice

As a method to ensure reliable technology within specified limits, recommended practices are used. These practices give a systematic approach to technology qualification, which is not covered in the design process. DNV RP A203 (DNVGL, 2017) describes how DNV GL can assist with technical qualification and achieving a qualified project. Aker Solutions also use similar tools during projects, which makes the RP A203 an excellent base for process-level guidance to qualify products intended for use in applications, such as subsea.

The practice secures a qualified product using processes that test and optimize the assembly and part levels solutions. In this project, only the first process steps will be included due to the project's scope. Qualification Basis, Technology Assessment, Threat Assessment, and Modifications are the steps that will be combined with the established design process.

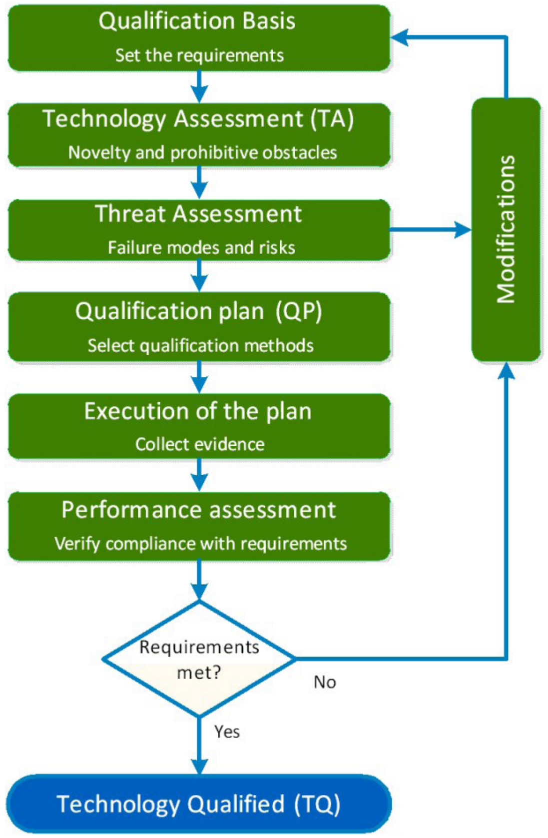
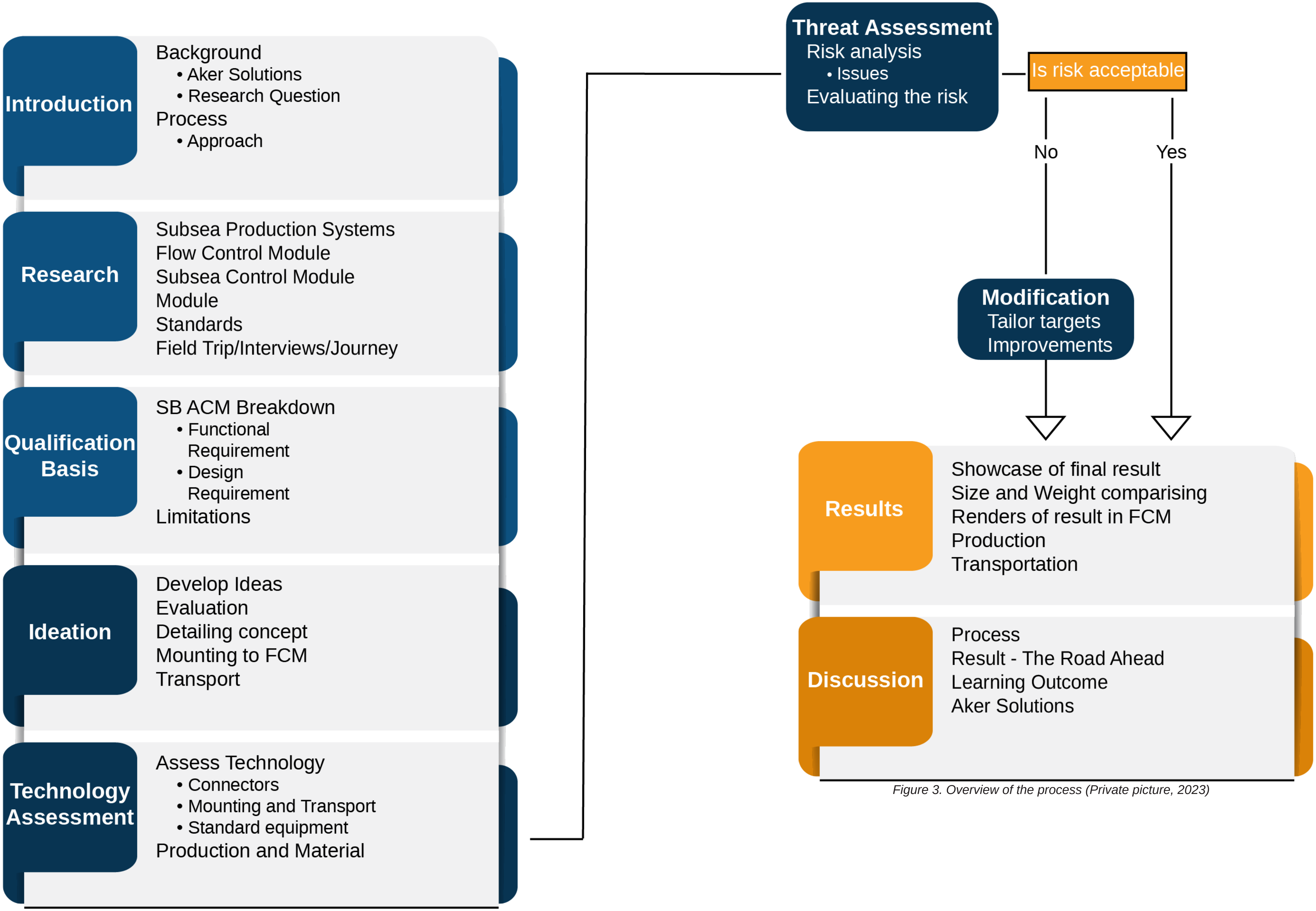


Figure 2. DNV Recommended practice (DNVGL, 2017)

Complete process

This results in a remade combination of the recommended practice and the design process. The process is illustrated below and shows an overview of the steps included in the different chapters while visualizing the engineering approach. The concept is evaluated toward the project's goals through the defined design requirement and cost evaluation. An analysis is then executed to accomplish a risk assessment. If the risk is unacceptable, the concept must be modified and improved. Once the issues enlightened in the risk are solved, the product can be detailed and presented.



Introduction

Background
- Aker Solutions
- Research Question

Process
- Approach

Research

Subsea Production Systems
Flow Control Module
Subsea Control Module
Module
Standards
Field Trip/Interviews/Journey

Qualification Basis

SB ACM Breakdown
- Functional Requirement
- Design Requirement

Limitations

Ideation

Develop Ideas
Evaluation
Detailing concept
Mounting to FCM
Transport

Technology Assessment

Assess Technology
- Connectors
- Mounting and Transport
- Standard equipment

Production and Material

Threat Assessment

Risk analysis
- Issues

Evaluating the risk

Is risk acceptable

No

Yes

Modification

Tailor targets
Improvements

Results

Showcase of final result
Size and Weight comparising
Renders of result in FCM
Production
Transportation

Discussion

Process
Result - The Road Ahead
Learning Outcome
Aker Solutions

Figure 3. Overview of the process (Private picture, 2023)

(Aker Solutions, 2018)

2

Reseach

Subsea Production Systems

Subsea production systems is a complex term ranging from several wells connected in a subsea manifold to a well-linked single satellite connected to an offshore or onshore installation. A subsea production system produces oil from shallow-water or deepwater reservoirs but can inject water or gas to pressure or maintain a reservoir. The elements needed in a subsea production or injection system are adaptive and can be configured in several ways. Subsea production systems can therefore be optimized for a field development strategy. (Compass, 2022) This chapter will explain different parts of subsea systems and their role in this project.

All - Electric Production System

As the introduction states, subsea Xmas trees are evolving into more sustainable and safer products. Electrification of the infrastructure will decrease environmental impact by giving access to low-carbon power, improving efficiency, and reducing the physical size of the production system. (SLB, 2023a) The main difference between a hydraulic production system and an electric system is that a hydraulic system uses electric power for sensors and electronics but hydraulic power to control valves and chokes. In contrast, the electric system utilizes electrical power and batteries throughout the tree. The electric system has a topside electric power unit, subsea electronics, and power cables. A hydraulic system has a topside hydraulic power unit, accumulators, hydraulic lines, and hydraulic actuators. This power supply requires comprehensive and extensive infrastructure compared to the electrical system. The electric system replaces the hydraulic control system with electrical solutions, eliminating the need for a hydraulic control system and power supply, including units such as accumulators and hydraulic lines. (Myhrvold, u.y) Electric actuators, such as the SB ACM, will replace hydraulic actuators. All electric software and hardware will significantly benefit the terms OPEX and CAPEX (Operating expenses and Capital expenditures) and HSE (Health and Safety Executive), improved flexibility, reliability, and increased functionality. (Myhrvold, u.y)

Subsea production systems can be installed as deep as 3 000 meters and 200 kilometers from shore due to the integration of third-party power electronics and electrical systems, leading to more cost-effective solutions for powering transformers, speed drives, and switchgear. (Aker Solutions, 2023b)

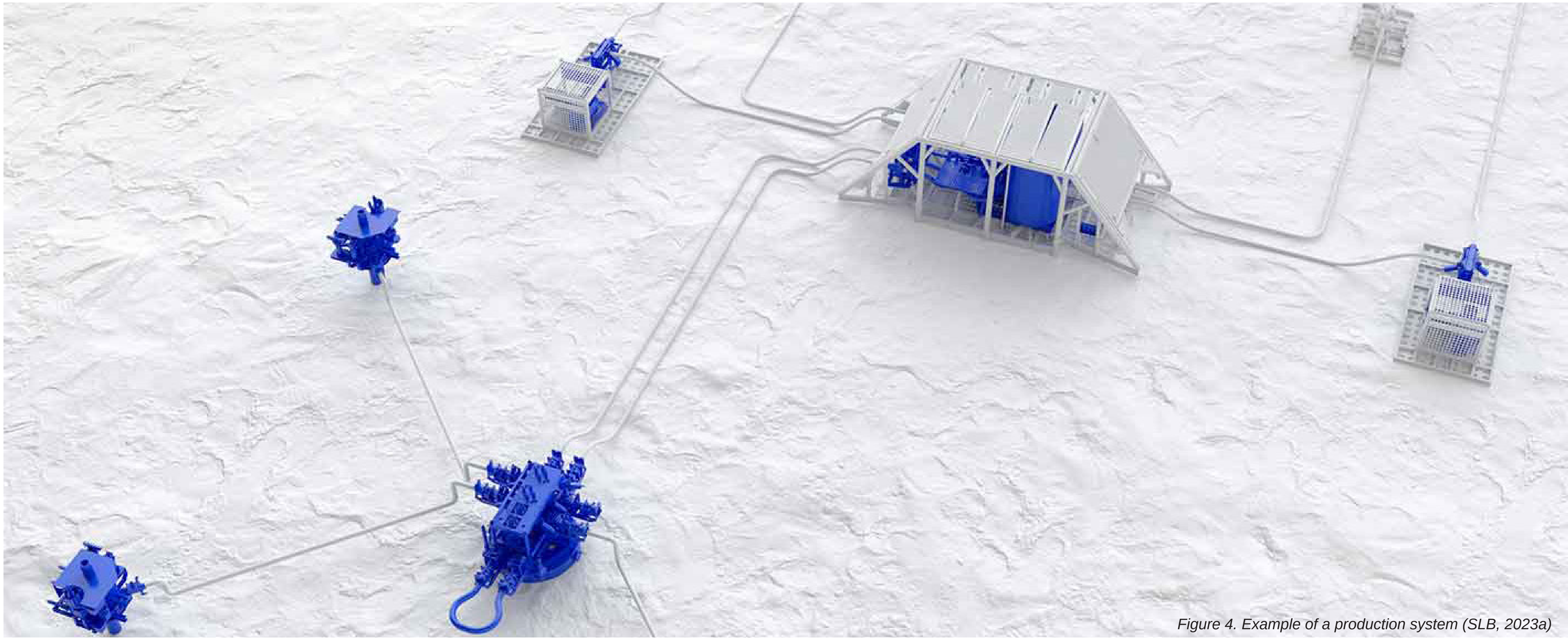


Figure 4. Example of a production system (SLB, 2023a)

Subsea Environment

Deepwater currents and pressure

Ocean or deepwater currents can flow up to thousands of meters beneath the surface. These currents are driven by water density, which is controlled by salinity and temperature. (National Ocean Service, u.y) The currents will not directly impact the functionality of the SB ACM, but it reasons why a reliable fastening method is essential.

Biological fouling

When designing equipment for subsea use, it is vital to understand the factors affecting the lifetime and performance of the product. When subsea equipment is submerged, they are colonized by over 1700 species, consisting of more than 400 organisms. These form a community of barnacles, mollusks, seaweed, algae, zebra mussels, biofilm slime, and more. The development of biological fouling can lead to a decline in the integrity of the equipment, where the property of metallic materials can be undesirably changed due to biofilm. In the United States alone, this results in billions of dollars in damage yearly. The growth of marine life can eventually lead to dents and visible cracks in equipment. (Acteon, 2020)

Biological fouling will also add additional weight load and reduced safety for personnel. Fouling makes it difficult to identify different equipment and challenges divers or ROVs when assessing if a valve is in an "open" or "closed" position. (Aquasign, 2021)

Figure 5. Biological fouling on subsea equipment (Aquasign, 2021)

Subsea Xmas Trees

A subsea tree is complex assemblies of flow pathways, piping, valves, and connectors. The tree is placed between the wellhead and the manifold or flowline to control and monitor production flow (Offshore Technology, u.y). Subsea Christmas trees are the leading equipment in offshore oil and gas production systems. The main functions of a Subsea tree are listed: (Bai and Bai, 2005)

- It is a vital component in the well integrity barrier envelope.
- It attaches to the wellhead and directs flow through several valves to the flowline.
- It is used to isolate flow from the well.
- It provides access to well intervention operations.

In the widespread industry, there are two types of subsea tree systems. Vertical (Conventional) and horizontal (Spool) trees are used in shallow, deep, and ultra-deepwater. There are also hybrid combinations that are used in some rare cases. The SB ACM can be used on both vertical and horizontal trees.

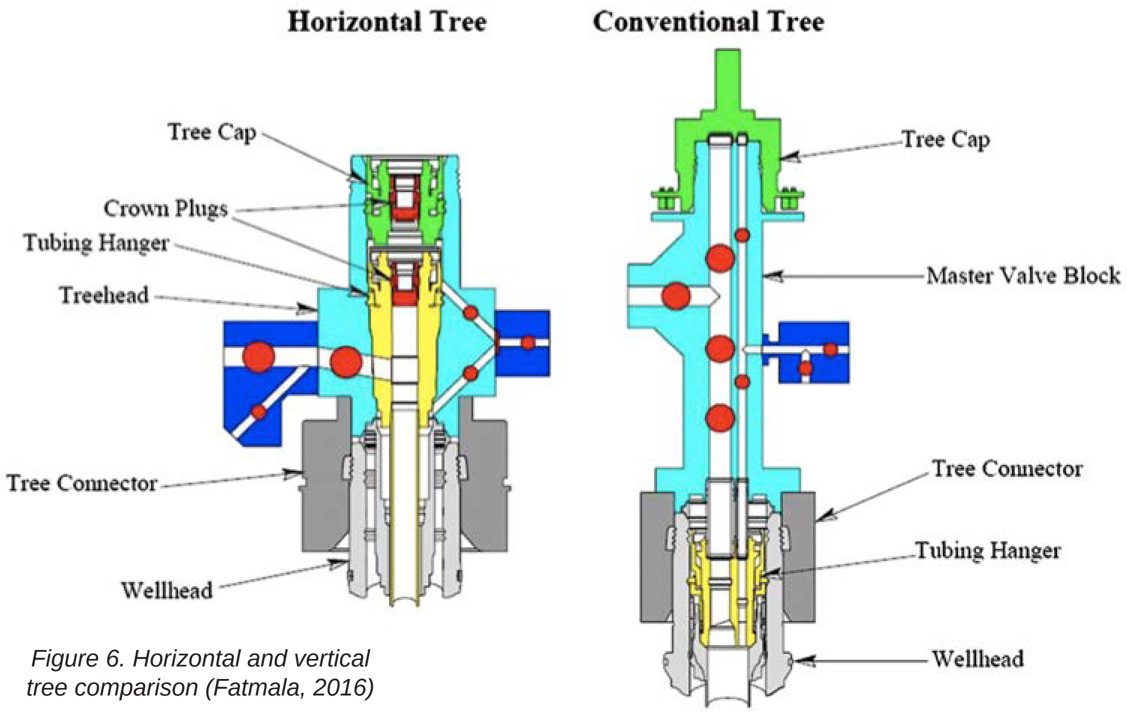


Figure 6. Horizontal and vertical tree comparison (Fatmala, 2016)

A horizontal tree is made with all flow control valves located outside the central part of the wellbore. In this type of tree, the production tubing is suspended, improving tubing retrieval access since the valves are not located at the center. (Offshore Technology, u.y). The name horizontal comes from the primary valves being arranged in a horizontal configuration. (White, 2013)

A vertical tree has its primary valves arranged vertically, hence its name. The valves are configured above the tubing hanger; the well is, for this reason, completed before the tree itself is installed. Vertical Xmas trees are the most used due to their flexibility of operation and installation. (White, 2013)

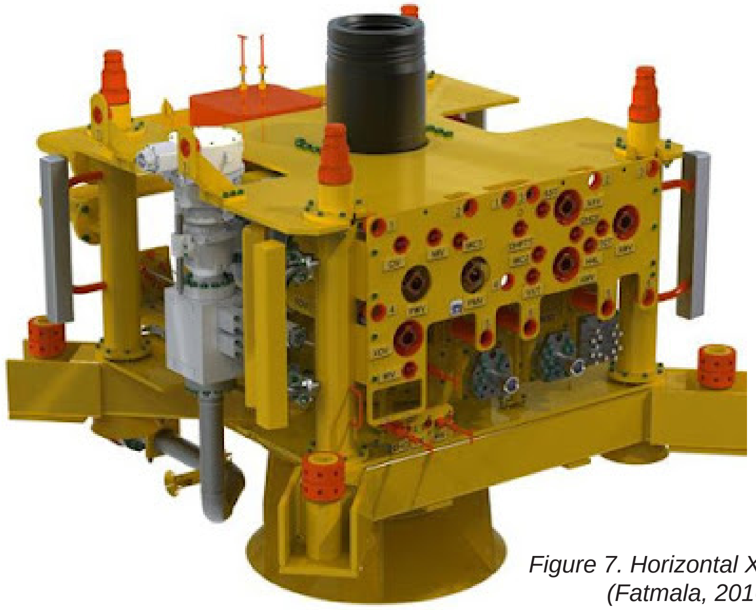


Figure 7. Horizontal Xmas tree (Fatmala, 2016)

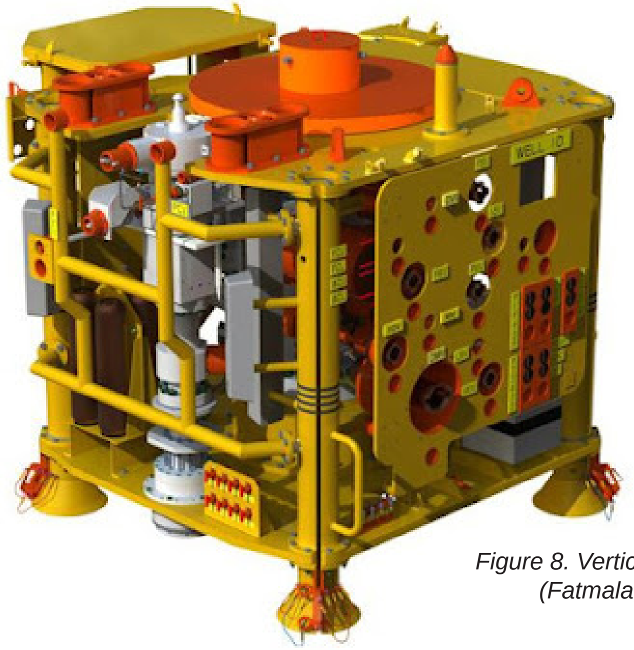
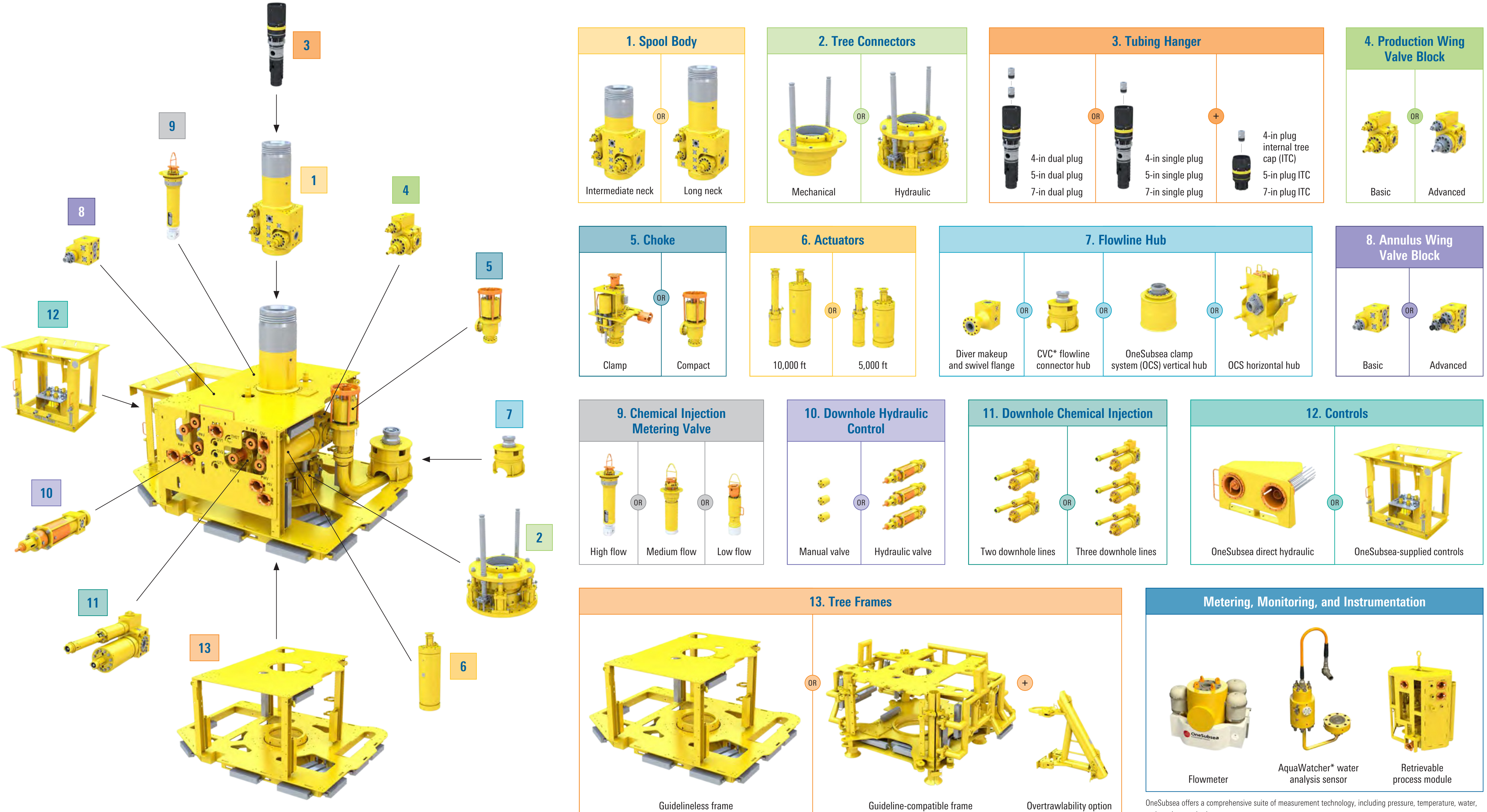


Figure 8. Vertical Xmas tree (Fatmala, 2016)

Standard Horizontal Tree



OneSubsea offers a comprehensive suite of measurement technology, including pressure, temperature, water, and erosion monitoring.

Figure 9. Overview of horizontal Xmas tree components (OneSubsea, 2020)

Standard Vertical Tree

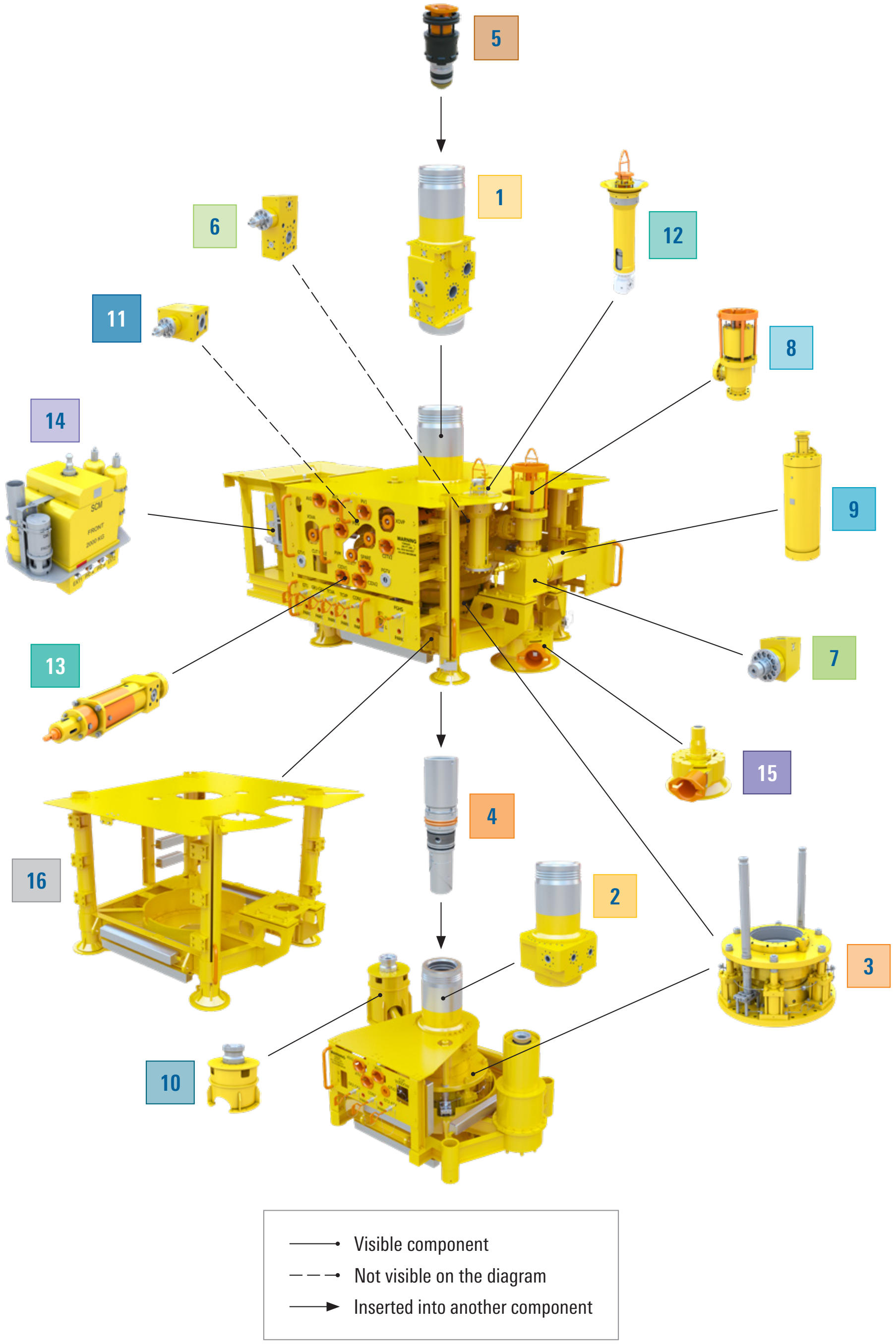
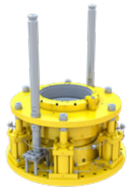


Figure 10. Overview of vertical Xmas tree components (OneSubsea, 2018)

1. XT Valve Block

2. THS Valve Block

3. Tree and THS Connector



4. Tubing Hanger

5- and 7-in nominal

5. Tree Cap

Lightweight tree cap

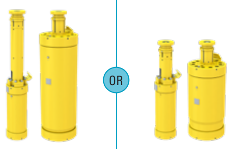
6. Crossover Valve Block

7. Flowline Isolation Valve Block

8. Choke

Compact choke

9. Actuators

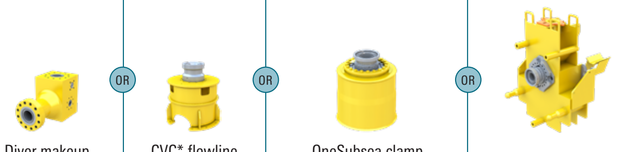


10,000 ft

OR

5,000 ft

10. Flowline Connector Hub



Diver makeup and swivel flange

OR

CVC* flowline connector hub

OR

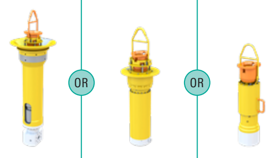
OneSubsea clamp system (OCS) vertical hub

OR

OCS horizontal hub

11. Annulus Wing Valve Block

12. Chemical Injection Metering Valve



High flow

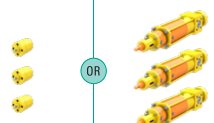
OR

Medium flow

OR

Low flow

13. Downhole Hydraulic Control and Chemical Injection

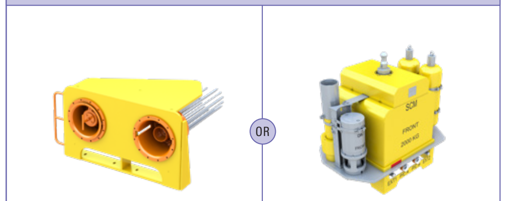


Manual valve

OR

Hydraulic valve

14. Controls



OneSubsea direct hydraulic controls

OR

OneSubsea-supplied controls

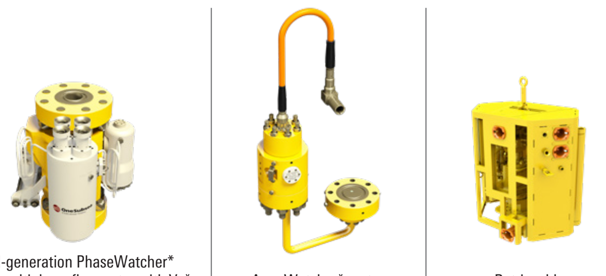
15. Tree-to-THS Clamp Connector

OCS-V 100

16. Tree Frames

Guidelineless frame (shown); guideline-installable design available.

Metering, Monitoring, and Instrumentation



Third-generation PhaseWatcher* subsea multiphase flowmeter with Vx* multiphase well testing technology

AquaWatcher* water analysis sensor

Retrievable process module

OneSubsea offers a comprehensive suite of measurement technology, including pressure, temperature, water, and erosion monitoring.

If you require a custom-tailored solution to meet your project objectives, please contact OneSubsea.

Manifolds

Subsea manifolds are used to minimize the use of pipelines and risers and optimize fluid flow. A manifold, as illustrated, arranges pipes and valves to distribute, combine, control, and monitor fluid flow. The subsea manifold is installed on the seabed within an array of wells to gather production or inject gas or water. (Bau and Bai, 2012, p. 18)

Wellheads

A wellhead is generally used to describe a pressure-containing component placed on the surface of an oil well. It provides the interface for completing, drilling, and testing all subsea phases. If the wellhead is located on an offshore/onshore platform, it is called a surface wellhead. If placed on the mudline, it is called a mudline wellhead or a subsea wellhead. A subsea well can be classified as either clustered wells or satellite wells. (Bau and Bai, 2012, pp. 20-22)

Transport

Subsea equipment is designed to withstand extensive climate changes. Aker Solutions deliver equipment worldwide, meaning the equipment must endure extreme cold and heat. This is essential to consider when designing products for subsea use where a climate difference can potentially destroy equipment.
While installing subsea systems offshore, wires are used to lower the production systems into the sea. The equipment must go through a splash zone when entering the surface. The splash zone is often defined as an area that poses significant challenges to offshore operations and is frequently considered non-accessible. (Oceantech, 2022) As DNVs offshore, Standard DNV-OS-C101 describes:

«The splash zone is the part of a support structure that is intermittently exposed to seawater due to the action of tides or waves. The splash zone separates the atmospheric zone and the submerged zone, and is determined by the influence of waves, tidal variations, settlements, subsidence, and vertical motions.» (Oceantech, 2022)

The splash zone is a harsh environment that the equipment must be able to withstand. It is, therefore, vital to reduce the number of loose cables (flying cables) to a minimum.

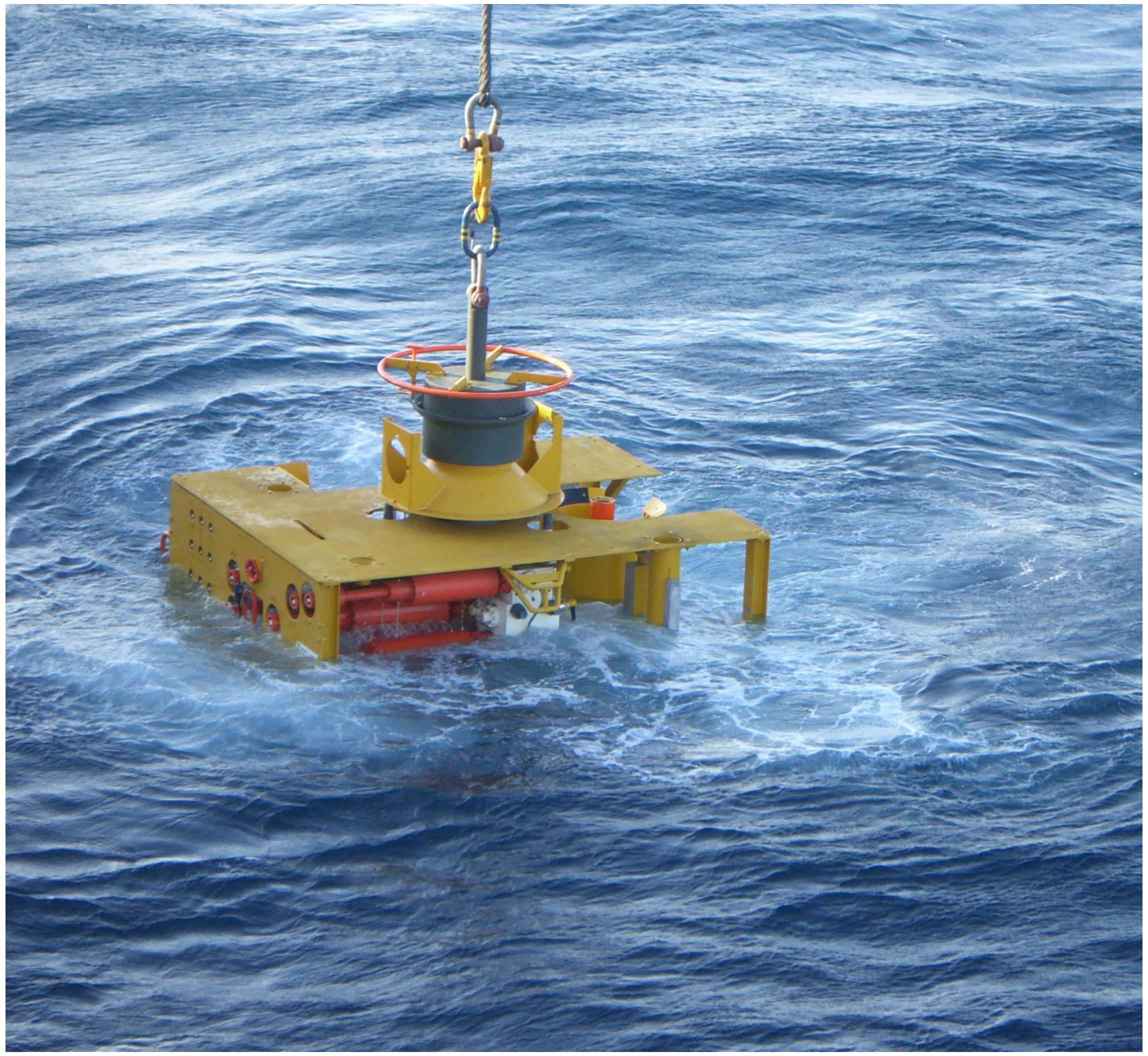


Figure 11. Module being lowered into the splash zone (Private picture, 2023)

Flow Control Module

FCM, also known as a flow control module, is a retrievable module installed on the Xmas tree. The module's main job is controlling the tree's different systems and flow while gathering system information. The SB ACM is one of several pieces of equipment placed on the FCM to control units and give system info. Just by making a few adjustments to the FCM, the Xmas tree can change between pumping oil, retrieving gas, or filling the well with water.

The illustrated FCM is a hydraulic type, excluding some equipment. This thesis will use this model since the electrical FCM is not yet designed. The electrical system will be similar to the hydraulic but with more space, meaning that if the SB ACM fits into the presented hydraulic FCM, it will also fit into the electrical system. To better understand the FCM, the essential equipment relevant to the SB ACM will be explained in the following chapters.

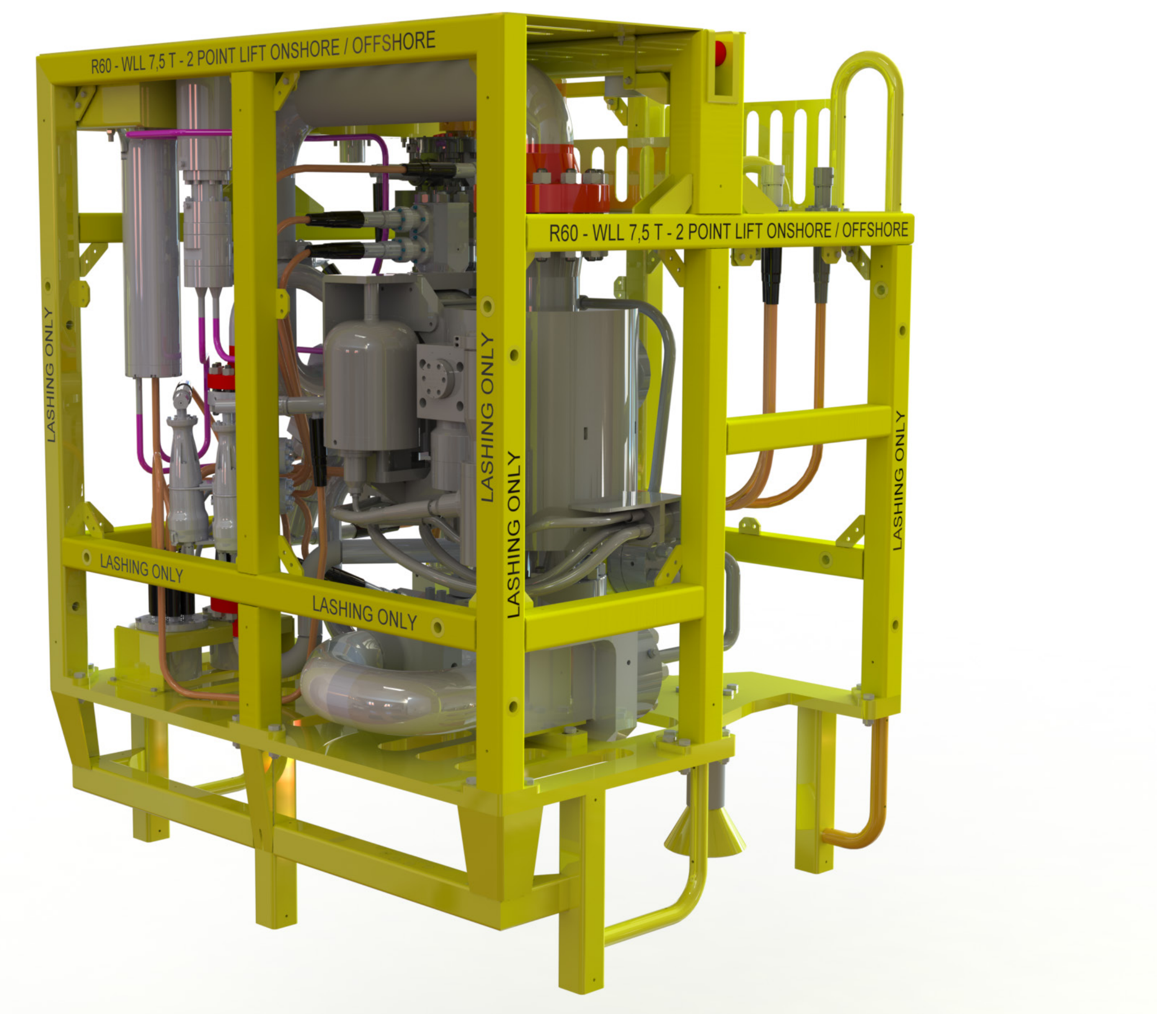


Figure 12. Render of hydraulic FCM (Private picture, 2023)

Transportation of FCM

Hooks are installed on the sides of the structure to lift and move the module. These are also utilized when the FCM is being installed onshore or offshore. The hooks are large and only placed in two locations, so it is vital to have some balance in the FCM during the immersion of the module. When the FCM is transported, hooks around the module are utilized to secure it.

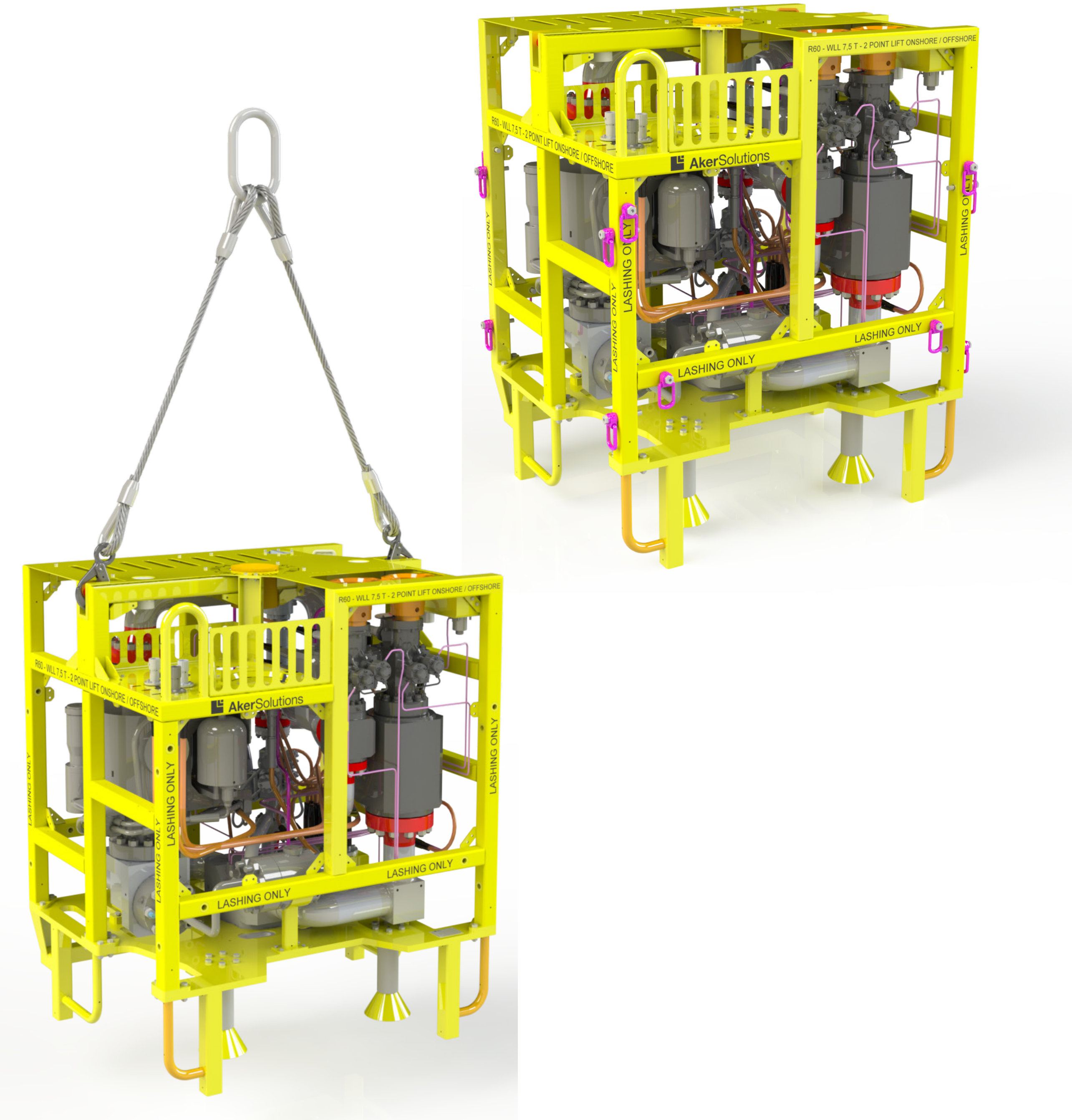


Figure 13. Renders of FCM being transported (Private picture, 2023)

Choke

The choke valve regulates the flow from the well by providing back pressure. A choke consists of two hydraulic actuators, one to open and one to close. The choke is moved by hydraulic pressure pulsating to the appropriate actuator. On each cycle, the choke moves one step, which regulates the flow. (Oil Field Wiki, 2020) The choke is a heavy and robust structure, so it is preferred that the choke is not rearranged.

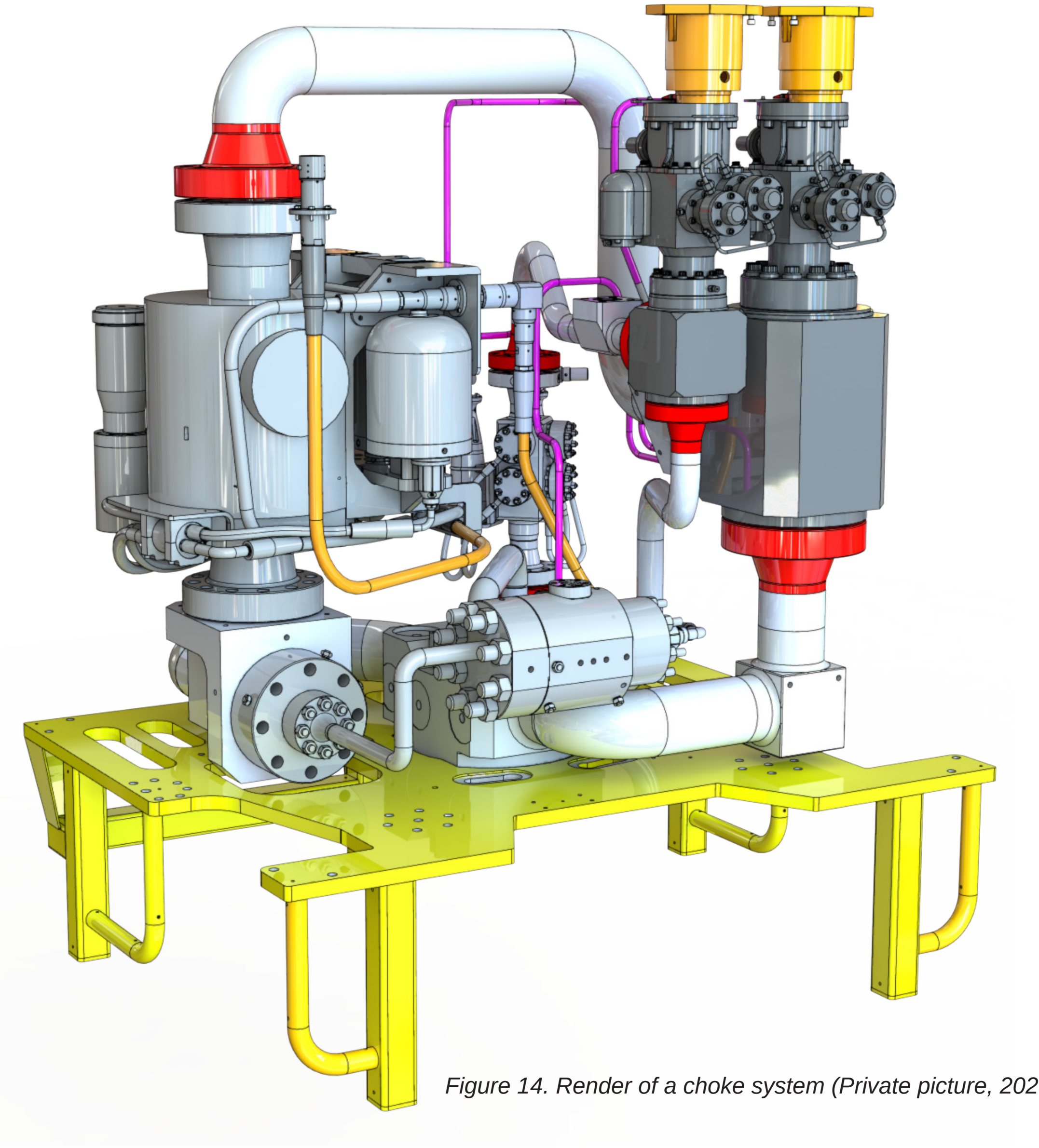


Figure 14. Render of a choke system (Private picture, 2023)

Drive Heads

The SB ACM controls valves through the use of electrical drive heads. An engine in the drive head creates a spinning motion, adjusting the connected valve to the desired position. This action can be converted to a linear motion for certain valves. A typical SB ACM message includes the number of revolutions the drive head should take during a given time and order. The current ACM can control two valves simultaneously, making it possible to be used on safety critical valves as these need to be closed within a short time limit.

Jumpers

In subsea production systems, a jumper is a short pipe that transports the production fluid between two subsea components, such as a manifold and a tree. (Bau and Bai, 2012, pp. 19-20) Jumper cables can also transfer data and power between modules and drive heads. The cables have wires in the center and oil surrounding them to avoid water damaging the wires and connectors.

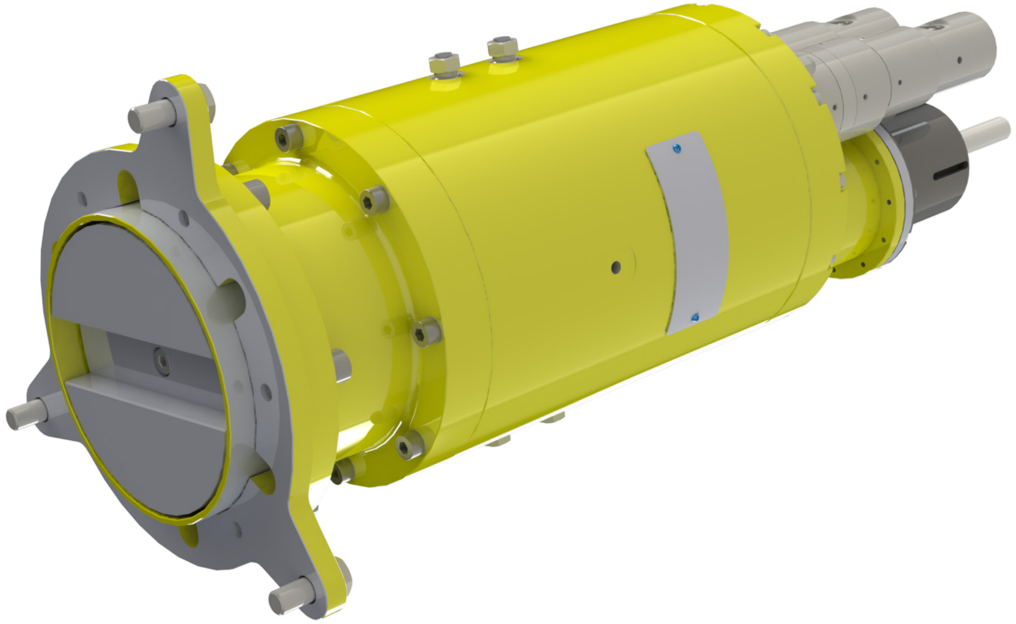


Figure 15. Render of the drive head (Private picture, 2023)

Figure 16. Flying ROV plug (Siemens-energy, u.y)

Subsea Control Module

A Subsea Control Module (SCM) is located on every Xmas tree. It is a control module that communicates with the master control stations. The signals the control module receives are fiberoptic and then transformed into electrical signals, which control the valves (Lervik, 2017). In the electrical Xmas trees, this module is replaced with smaller separated modules; PCGM and SB ACMs.

Figure 17. Picture of a subsea control module (Lervik, 2017)

Power and Communications Gateway Module

The Power and Communications Gateway Module (PCGM) is the new communication gateway that acts as a converter, distributing power to instrumentation and different ACMs. In a nutshell, the PCGM and ACMs replace the SCM by providing a variety of interfaces for communication and connection with the master control stations and external subsea devices.

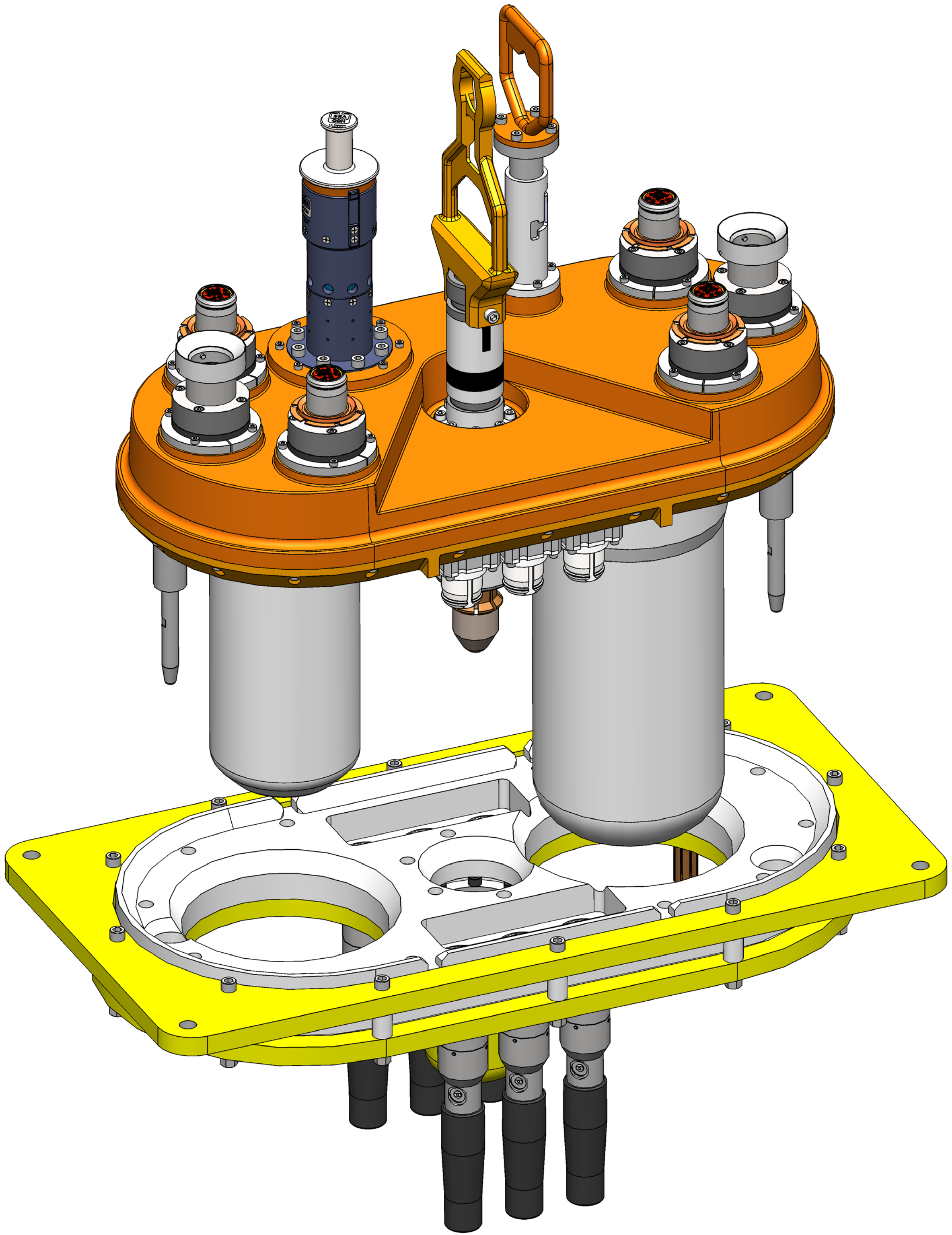


Figure 18. Illustration of PCGM (Private picture, 2023)

Small Bore Actuator Control Module

The Small Bore Actuator Control Module (SB ACM) controls drive heads, allowing for precise control of valve opening and closing positions. It receives communication from the PCGM to determine the desired valve positions. The SB ACM is specifically designed to control a variety of valves and is a component that can be used in all types of Xmas trees. There is a Large Bore Actuator Control module in addition to the SB ACM. However, this module differs greatly from the SB ACM and will not be discussed in this project. The SB ACM is therefore referred to as ACM throughout this thesis.

The current SB ACM is explicitly made for the Xmas tree and controls safety critical valves. This means the module must be retrievable in case of any errors that complicate the module’s design. Many solutions must be based on redundancy and remotely operated vehicle (ROV) interfaces, such as a complicated landing base. Following is a detailed exploration of the SB ACMs solutions and functionality.

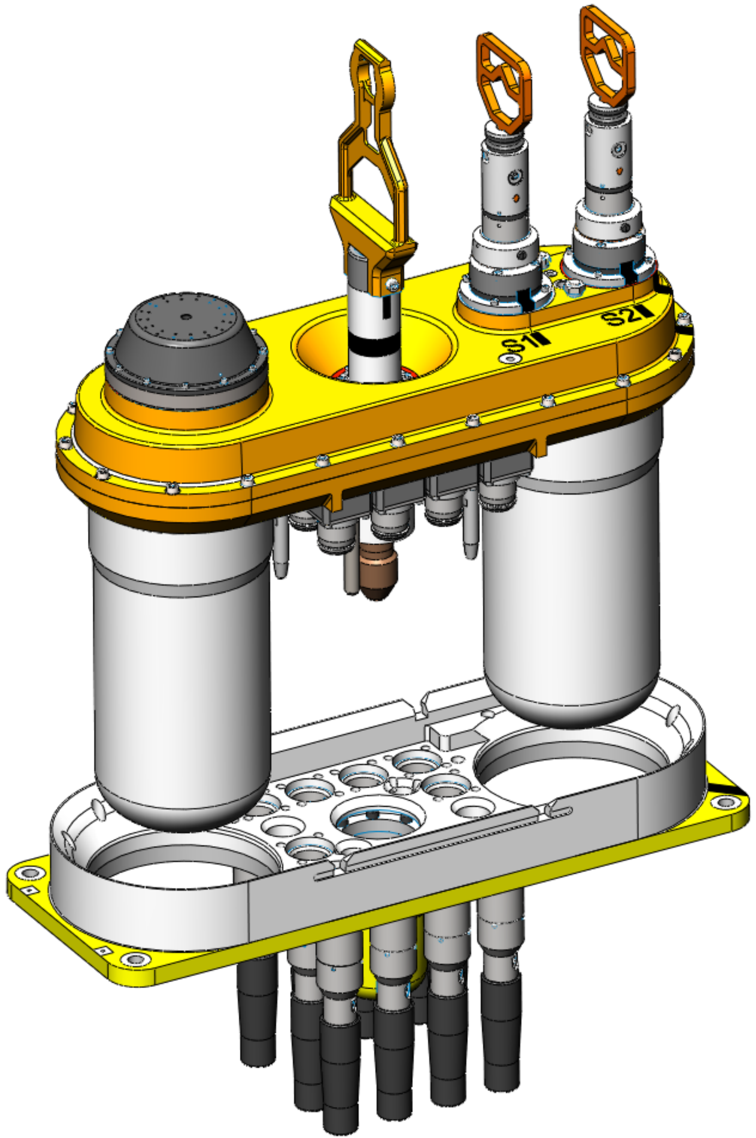


Figure 19. Illustration of the SB ACM with base (Private picture, 2023)

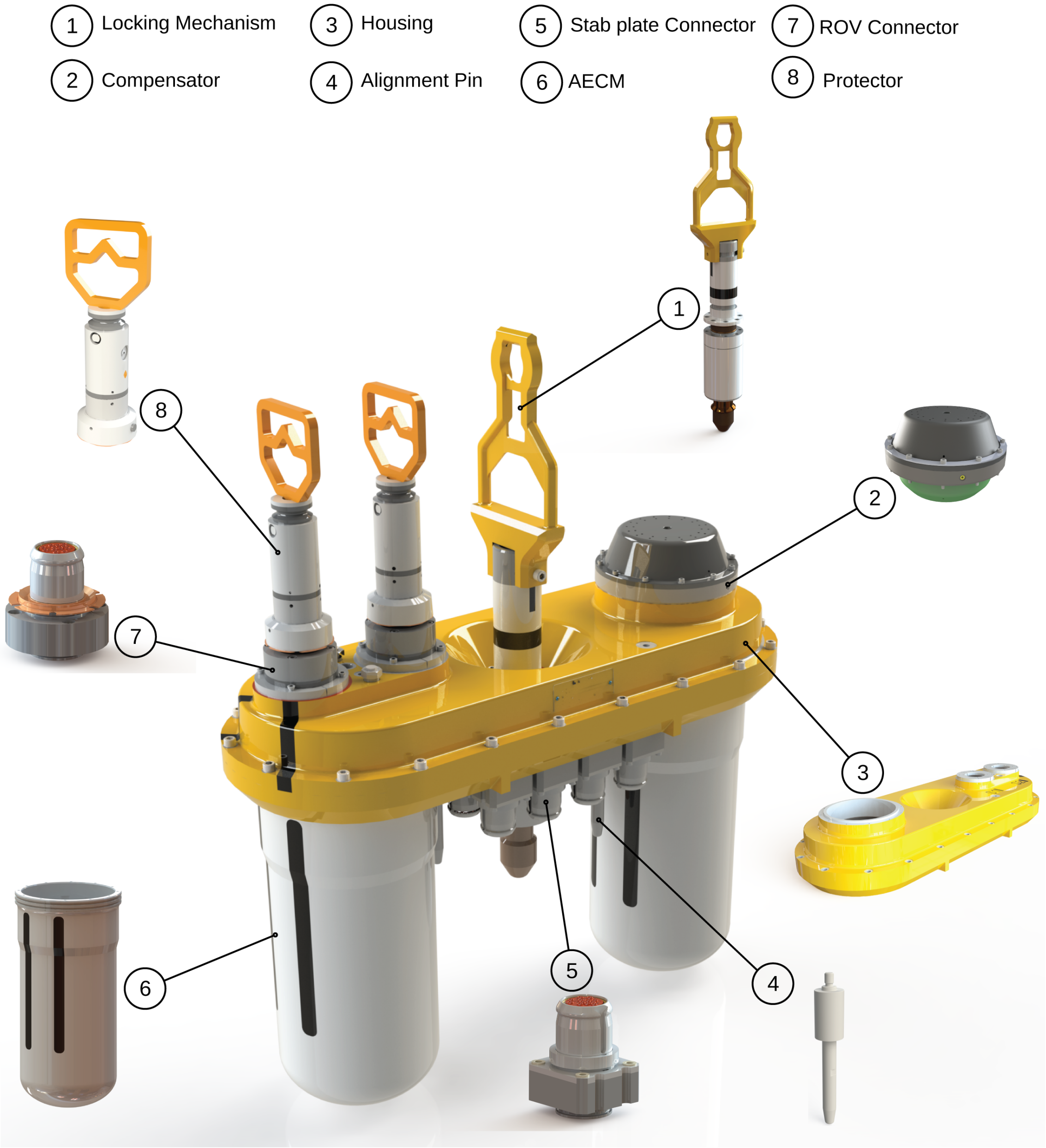


Figure 20. Overview of components in the SB ACM (Private picture, 2023)

1. The locking mechanism is a component needed for the module to be retrievable. It is a technical interface that also ensures earthing to the frame.
2. A compensator is utilized to achieve equal pressure inside the SB ACM housing by compensating dielectric fluid. This creates advantages where the housing can be hollow without high external pressure.
3. All components are mounted on the housing, two separate parts, screwed together on the middle section. It is essential that the housing does not have any trapped air inside the material due to a design or production failure.
4. The alignment pins simplify the ROV interfaction when installing or retrieving the module. It is merely there to align the product.
5. Eight stab plate connectors at the bottom of the housing connect to jumpers communicating to the driveheads.
6. AECM is the Actuator Electrical Control Module, where the circuit boards and batteries are located. The canister is not pressurized to prevent the batteries and electronics from getting crushed under high pressure. Therefore, a penetrator between the canister and housing makes transferring cables through the different pressurized sones possible.
7. ROV connectors are located at the top of the housing, creating a connection with different instruments on the Xmas tree.
8. The protector is an ROV dummy plug for protecting the connectors during transportation and deployment. The dummy plug is removed during the module’s installation, and a jumper is connected instead. The dummy is then stored on a “bus station” in the tree.

The redesigned module will be mounted to the FCM instead of the tree. This means the ACM has different interfaces for the FCM and the modules it controls. In the previous design, each drive head was controlled by two separate systems due to redundancy. This means the eight connectors underneath the ACM control four drive heads.

The illustration shows a system where two separate controls, A and B, are placed on two independent canisters. The A and B systems send power and operational info to two drive heads per canister, adding up to four. However, the new solutions do not need an A and B system for each drive head. Instead, it will only use one canister where system A controls two driveheads, and B controls two drive heads. This is possible since the redesigned SB ACM does not need to consider redundancy. Since the current solution is placed directly on the Xmas tree, there must be a failsafe if a system error occurs. In practice, system B can take over if system A breaks down on the current system. However, this is irrelevant to the redesign since the ACM will not control any critical safety valve; it will only control valves for injecting chemicals. In the worst case, the valve stays open or closed, which does not lead to immediate action. This is because chemicals do not stop production or ruin the product. An anti-corrosion fluid is an example of a chemical the new ACM can control. This means that the design does not need to account for redundancy. There can therefore be a reduced number of connections required for a drive head; where it was previously two connectors for each drive head, only one is needed.

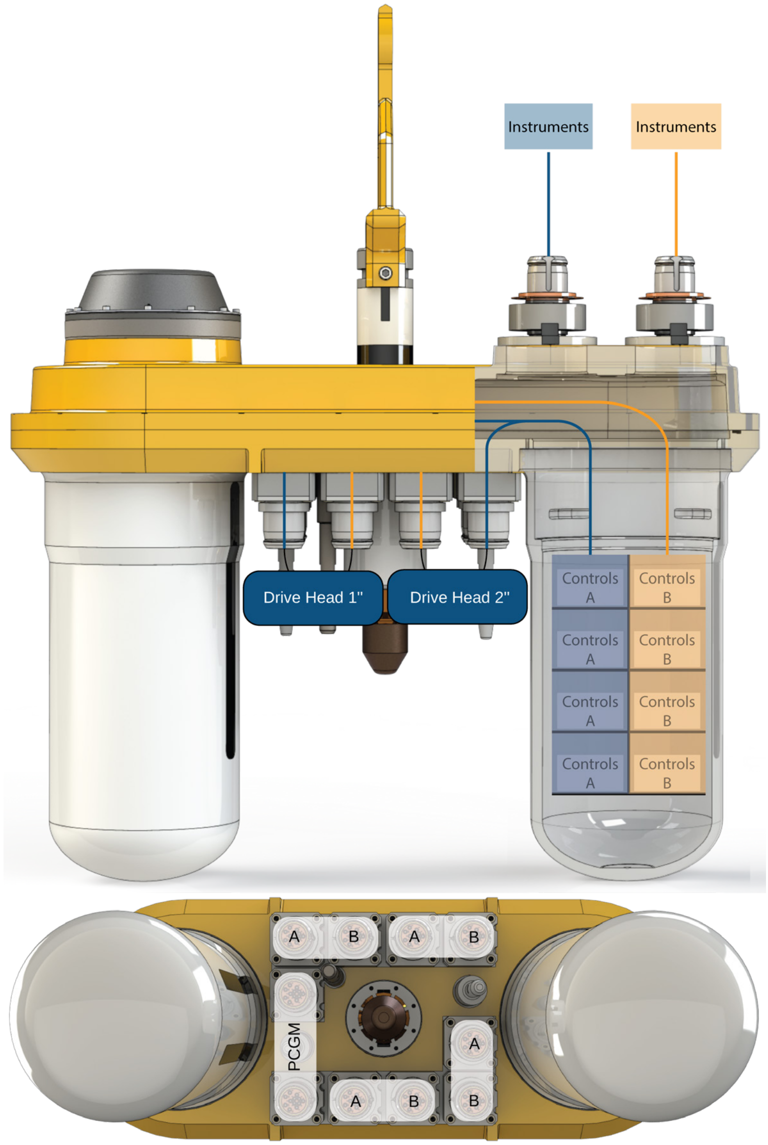


Figure 21. Illustration of the current electrical system (Private picture, 2023)

Due to reducing the number of systems and connectors needed, only one canister is necessary. Therefore, the new solution only needs four connectors to control four drive heads, one connector for ROV interaction with the PCGM, and the last connector in a spare for instruments or communication. The following illustration showcases how the new system will work in practice, with an example of what the connectors control.

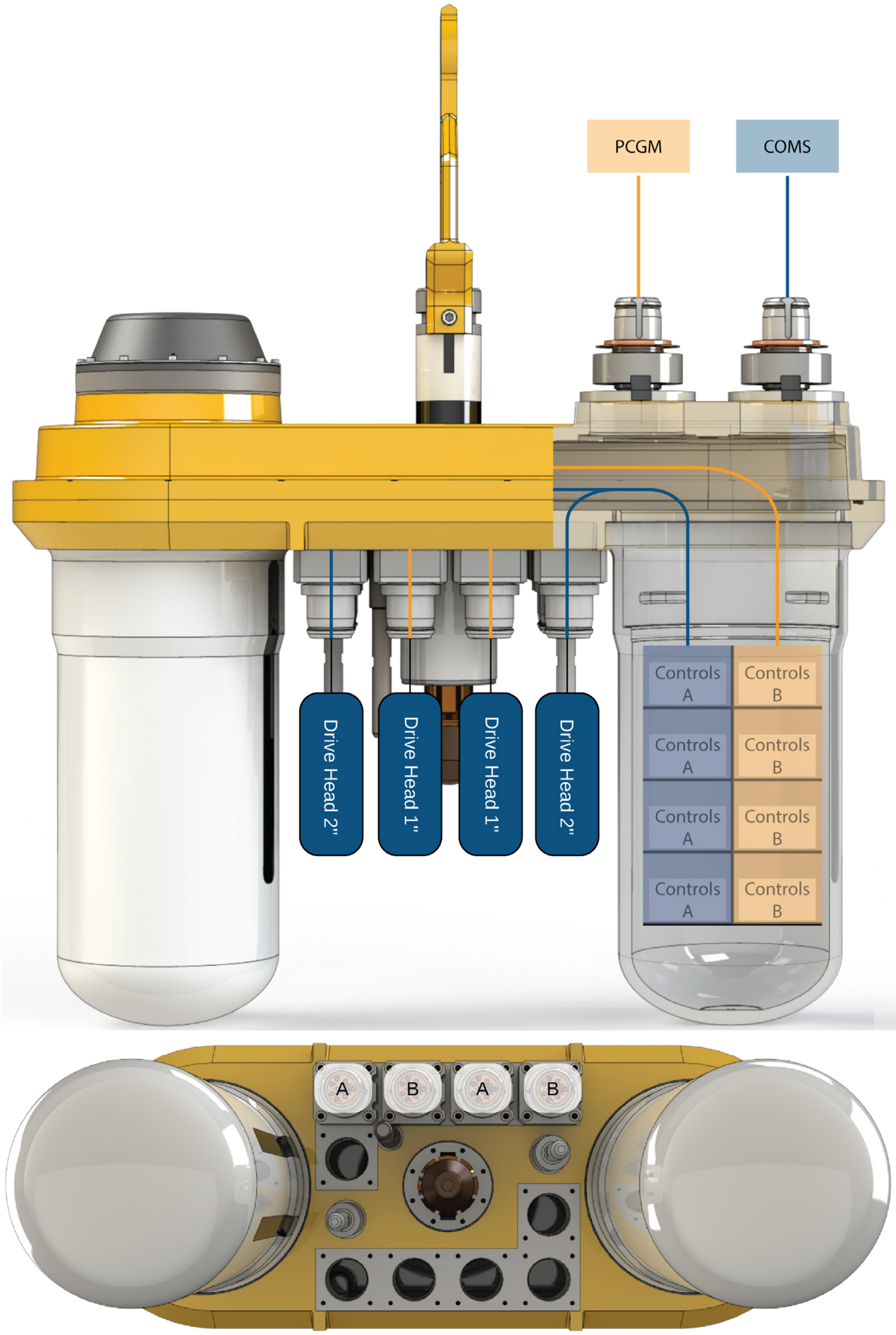


Figure 22. Illustration of the new electrical system (Private picture, 2023)

Researching how the module operates makes it possible to visualize the external components and the ACM's connection to them. This will give a better overview of the types of drive heads the ACM can operate and the valves it controls. It also shows power and communication, including earthing and cathodic protection to the Xmas tree. In the previous design, the earthing is done through the locking mechanism. The size of the drive heads can vary between 2" and ½" depending on the valve size they operate.

Weight and Size

The current ACM weighs 308kg, including all electronics. However, when evaluating concepts in this project that exclude internal electronic-related systems, using the weight of the CAD model is preferred. The CAD model weighs 214kg, representing the raw material without electronic systems. This approach allows for a more accurate assessment of weight reduction in a new solution.

The ACM is a sizable module, measuring 100cm in height and 90cm in length. This presents challenges in handling and transportation, as specialized equipment capable of supporting the module's weight and size is required. The current solution involves lifting the module using two points where hooks are mounted. These hooks are positioned at the diagonal points visible in the ACM overview.

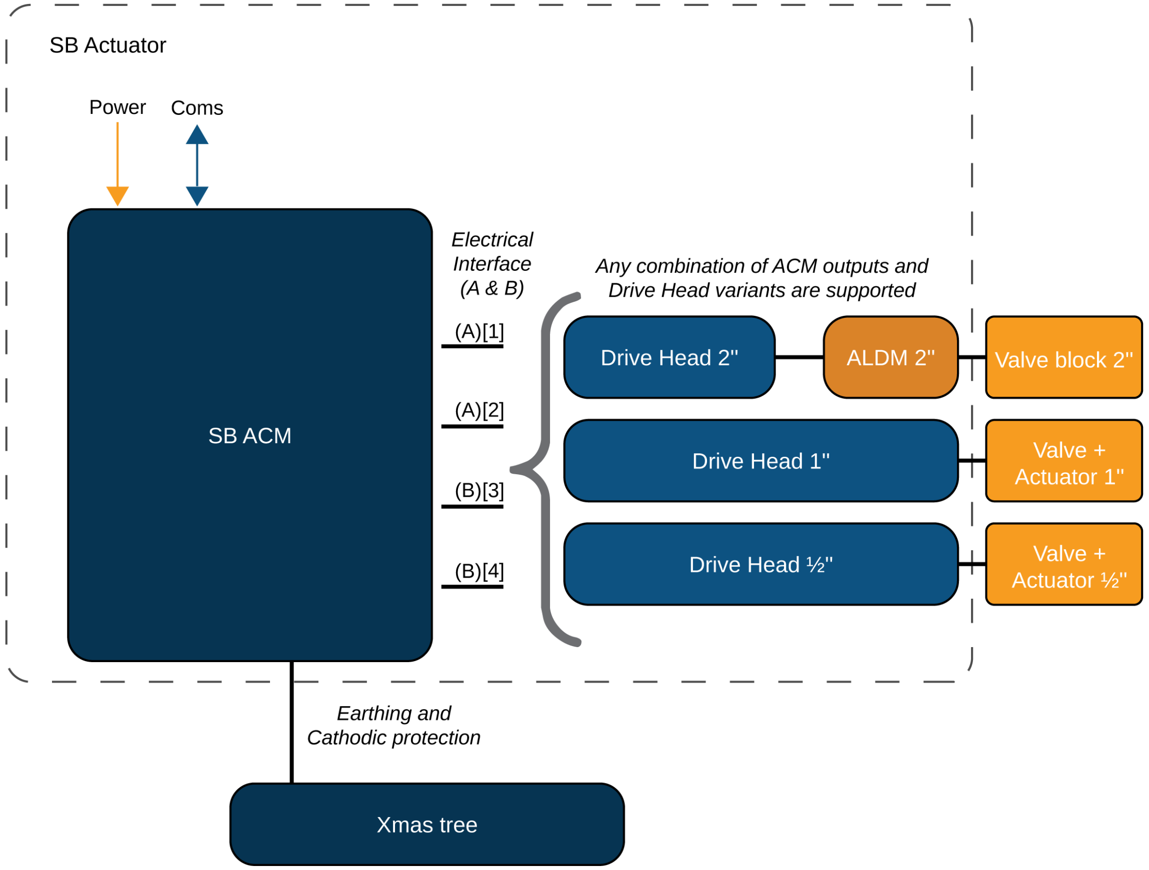
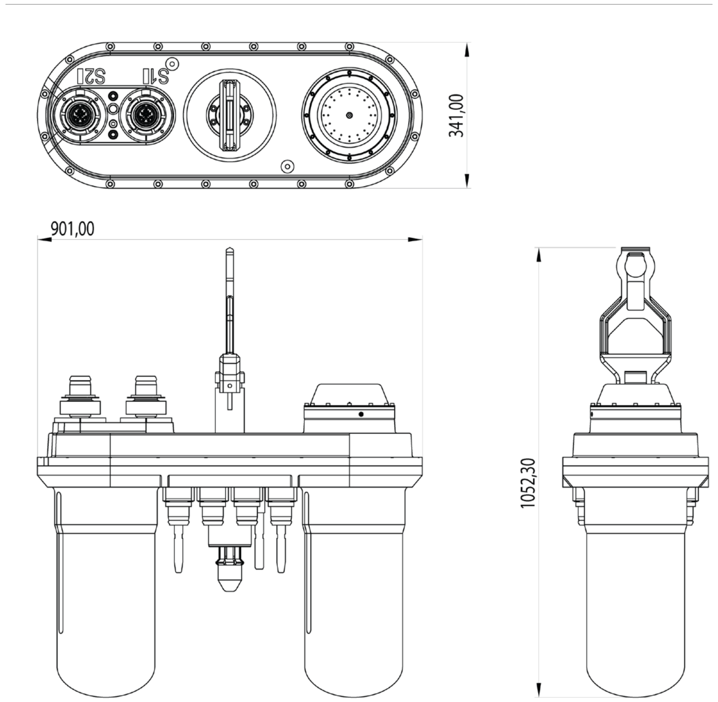


Figure 23. Overview of the redesigned ACM control system (Private picture, 2023)



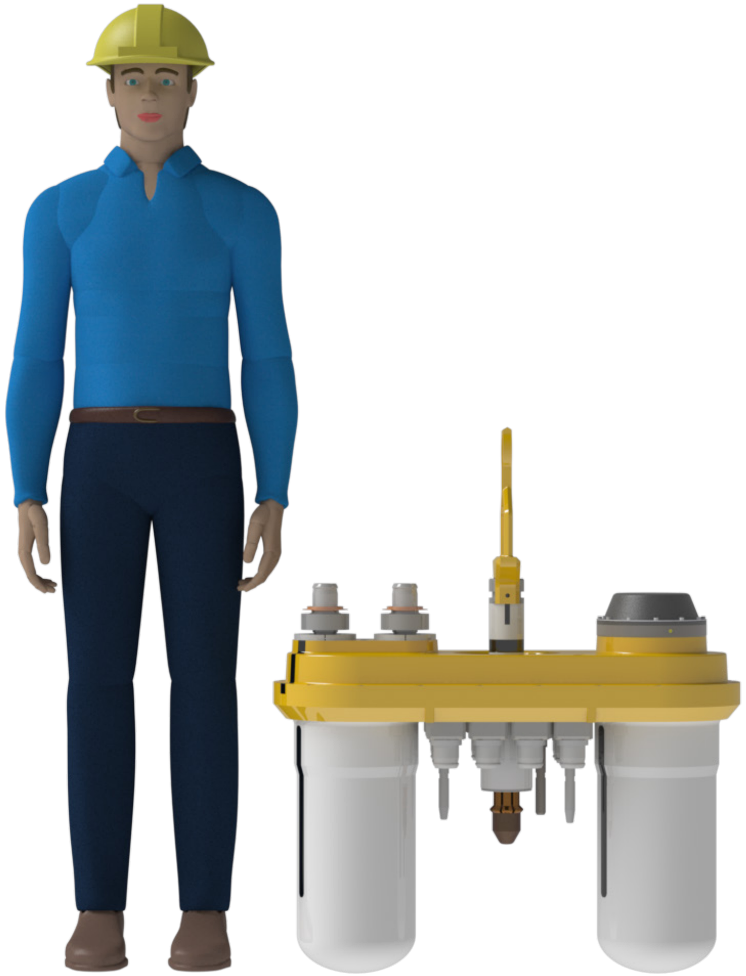


Figure 24. Size comparison of the ACM with average-height male (Private picture, 2023)

Materials and Production

The ACM module is composed of several parts made of different materials. While some parts are confidential and not subject to redesign, others will not undergo any changes. Therefore, evaluating the materials, the housing's bottom plate and top cover are most relevant.

The top housing is fabricated from ductile cast iron (GJS-400-15) with non-brittle characteristics. The part is relatively thick and therefore casted to achieve the wanted properties. After the casting, the part is machined to achieve the necessary tolerances and dimensions. The bottom housing is thinner than the top housing and is only machined from a carbon alloy steel plate (S355J2). Both materials must withstand significant stress due to the extreme conditions they are exposed to during transportation and deployment.

Coating

The product is coated following the NORSOK M-501 standard, system 7B. The coating makes the housing corrosion proficient, making it possible to reduce the number of anodes necessary on the Xmas tree and FCM. The coating secures optimal protection for subsea installations with minimum need for maintenance while being application friendly.

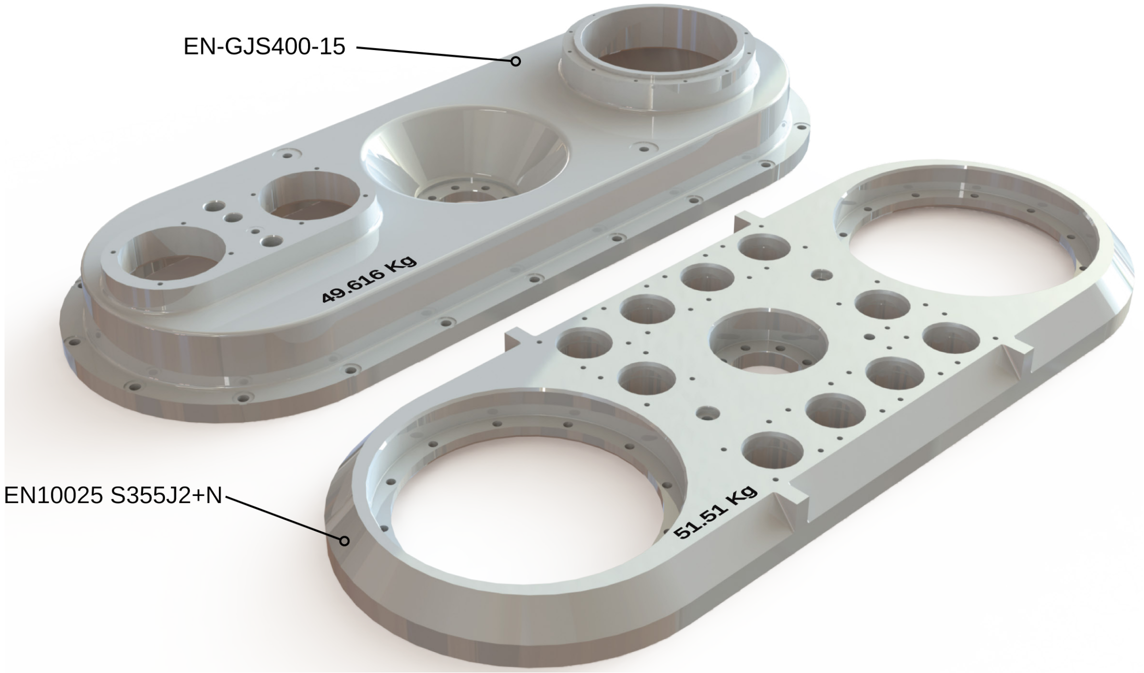


Figure 25. Illustration of material and weight for the housing (Private picture, 2023)

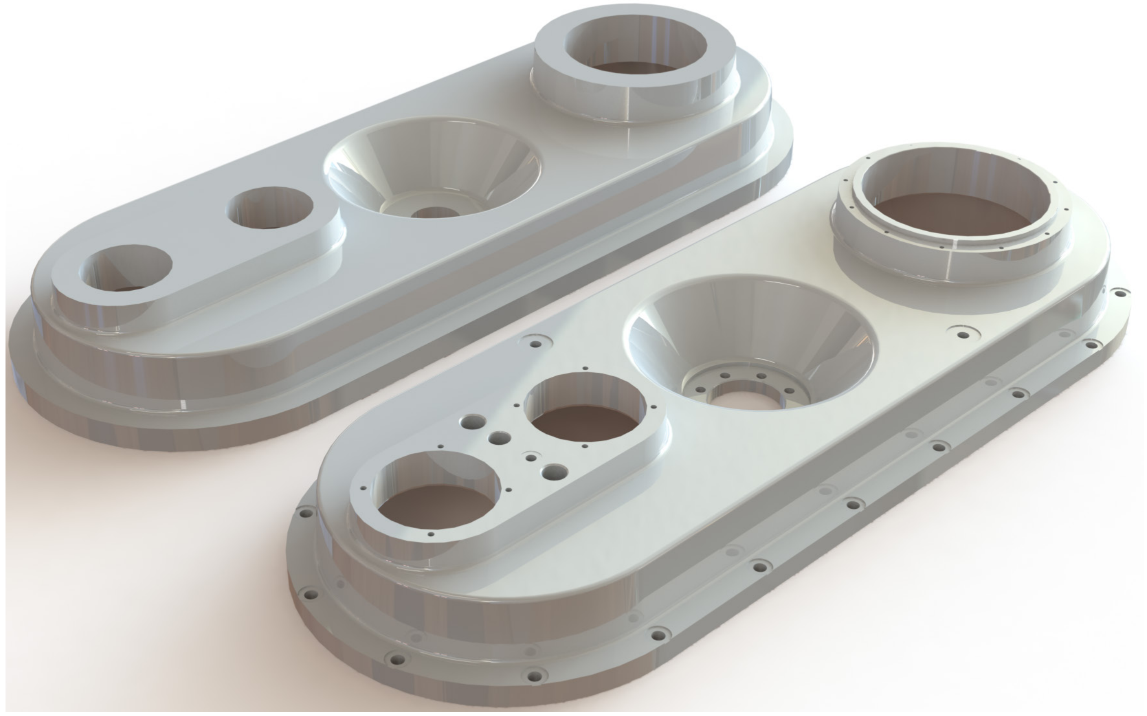


Figure 26. Render of casting and machining result (Private picture, 2023)

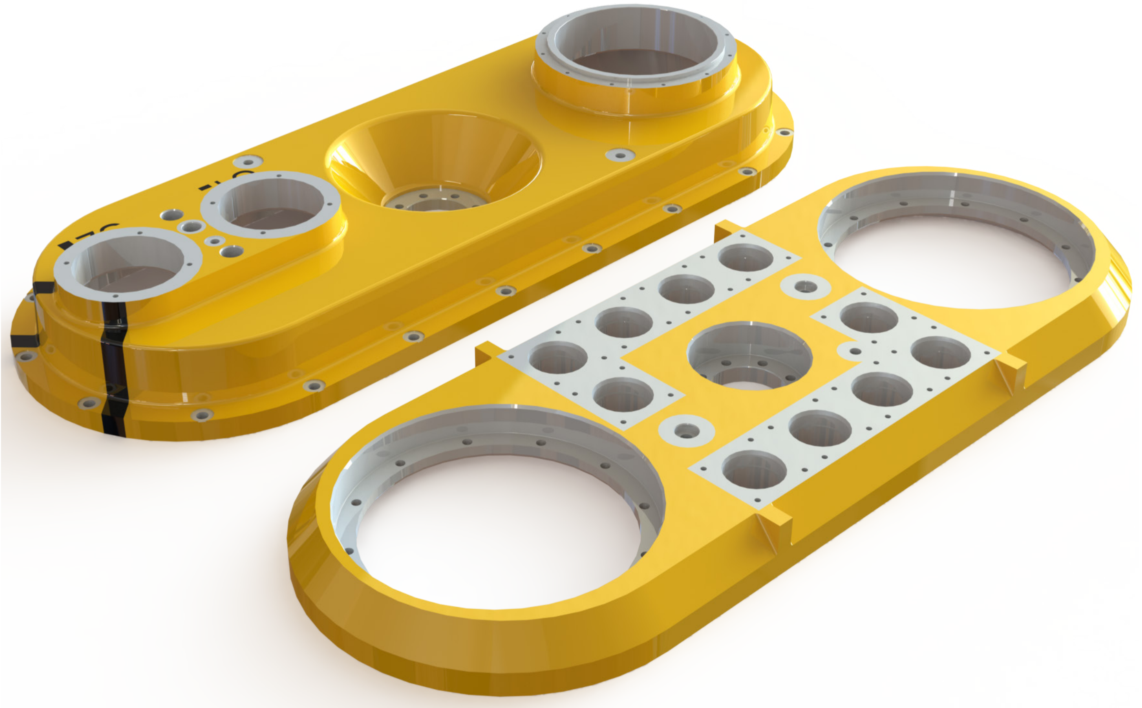


Figure 27. Render of coating on the housing (Private picture, 2023)

Standards

Standards play an essential role in ensuring safety, quality, and reliability. For this master's, the following standards are researched: NORSOK U001, API 6A, API 17A-H, API 17Q, ISO 13628-1, and DNVGL – RP – A203 (Used in chapter "Process"). These documents include several relevant fields within subsea production systems and give some demands to the product. The relevant findings are listed and rewritten to understand the project approach and decisions better.

API 6A

The specification API 6A (ASTM, 2018a) gives recommendations and requirements for the performance, functional and dimensional interchangeability, materials, design, testing, welding, marking, inspection, handling, shipment, storing, and purchasing of tree equipment and wellhead in natural gas and petroleum industries. The specification excludes field testing and use, including repair of tree equipment or wellhead, except for repairs to the weld in conjunction with manufacturing. (ASTM, 2018a)

- 5.3 Design documentation has to include methods, calculations, assumptions, and design requirements. This also includes criteria for size, possible test and operating pressures, environmental, material, and other conditions on which the design is based. (ASTM, 2018a)

NORSOK U001

The standard NORSOK U001 (Standard Norge, 2021) gives recommendations and requirements for developing a subsea production system. It includes every stage from define to abandonment or decommissioning within the Norwegian continental shelf.

- 5.2.1 A subsea production system should be designed by accounting for system testing and equipment, commissioning, installation, operation, maintenance, inspection, modification, repair, replacement, and abandonment. Nonreplaceable components must be designed with a lifetime corresponding to the field's operation time. (Standard Norge, 2021)

API 17A

API 17A (Compass, 2022) gives recommendations and requirements for the development and operation of subsea injection/production systems. The standard includes the phase from concept development to abandonment and decommissioning. The term "subsea production system" describes production and injection systems throughout this specification.

- 6.11 Designed equipment should not restrict the installation sequence of other subsea equipment. This includes pipelines, flowlines, risers, and umbilicals. Equipment size, shape, weight, and configuration may therefore be limited by installation and handling considerations, both offshore and onshore. (Compass, 2022) In addition to this, relevant components must;
    - Not rely on hydraulic pressure to achieve a locking force in connectors.
    - Allow eventual stops in installation operations without being a safety hazard.
    - Be tolerant of possible debris from the seabed between connections.
    - Be tolerant for potential hydrodynamic loads, specifically wave-induced currents.
    - Avoid harmful fluid escaping into the environment during installation.

- 6.12 Equipment must tolerate environmental conditions that it will be exposed to during testing, fabrication, transport, storage, installation, and operation without receiving any degradation or damage. (Compass, 2022)

- 6.14 Requirements regarding maintenance should influence the design of subsea equipment. (Compass, 2022)
    - Equipment that requires maintenance or periodic inspection should be designed to be retrieved independently.
    - Components in equipment that are exposed to wear during normal operating conditions and require intervention or maintenance should be configured and designed to a location that makes it possible for replacement or repair within that assembly.
    - Equipment that is made retrievable should be adapted for ROVs or divers for shallow water depths.
    - A solution for fastening loose cables should be provided near retrievable equipment.
    - Equipment that is designed with identical solutions should be fabricated so that they can be interchangeable.
    - ROV interfaces must comply with API 17H
    - There must be considerations regarding marine fouling on equipment that could make it hard to operate, retrieve, or install some components.

- 8.4 There should be plans for the transport, storage, and preservation of equipment that should address the following issues; Transportation, security, handling, preservation, testing, inspection, maintenance, repair, and refurbishment. (Compass, 2022)

API 17B

API 17B (ASTM, 2014) gives guidelines for the analysis, manufacture, testing, installation, design, and operation of flexible pipes and pipe systems for subsea, marine applications, and onshore. The standard does not apply to the controller in this project. However, it provides insight into the other subsea systems. (ASTM, 2014)

API 17C

The standard gives recommendations and requirements for the fabrication, design, and operation of flowline systems and equipment. (ASTM, 2002) The information in this standard does not affect the redesign of the ACM.

API 17D

This standard specifies mudline wellheads, subsea wellheads, drill-through mudline wellheads, and horizontal and vertical subsea trees. It also sets areas of design, welding, material, quality control, storing, shipping for individual equipment, marking, subassemblies, and subsea tree assemblies. (ASTM, 2021)

- 7.10.2.2.1 This chapter is a list of requirements regarding the design of subsea valve actuators. (ASTM, 2021) The following points are the most relevant requirements rewritten for this project.
    - Actuators must be designed to avoid functional impairment due to marine growth, calcareous deposit, fouling, hydrate formation at seawater boundaries, hydraulic operating or compensation fluids, deterioration/corrosion caused by

  - the environment, and the well stream fluid if exposed.
  - Designs shall comply with the effect of external hydrostatic pressure given by the manufacturer’s maximum rated water depth and the rated working pressure of the valve.
  - The actuator design should pressure compensate for all fluid-filled chambers, accounting for the maximum rated water depth pressure and thermal expansion coefficient in the liquid.

- 7.10.2.2.4 Electrical components and subassemblies such as rotors/winding stators, controllers, and energy storage units shall be under the requirements of API 17F or the applicable standards (such as IEC/CENELEC).

API 17E

This document gives recommendations and requirements for material selection, design, manufacture, design verification, installation, testing, and operation of umbilicals and other associated ancillary equipment within the natural gas and petroleum industries. This does not include topside hardware. (ASTM, 2017a) Findings in this standard are not relevant to the scope of the thesis.

API 17F

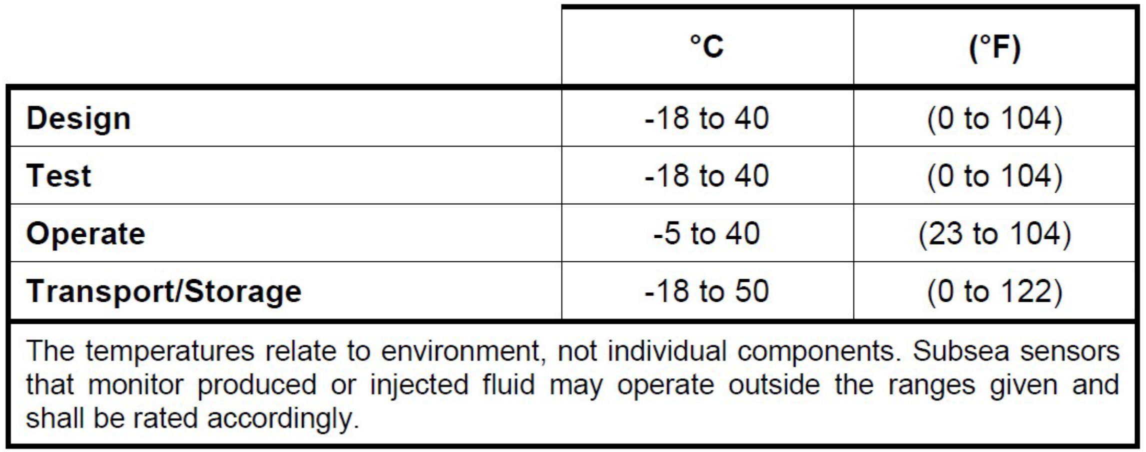
The standard applies to subsea production control systems’ testing, fabrication, installation, design, and operation. It covers surface control system equipment, control fluids, and subsea-installed control system equipment. (ASTM, 2017b)

- 4.2.2 The potential of horizontal integration in the equipment should be evaluated during the design of a subsea control system. To optimize this potential, equipment specification should include standard interfaces that allow various actuators to be used easily between different modes of operation. Horizontal integration can be seen as a way to use common products for different operation scenarios. (ASTM, 2017b)

- 4.2.16 Reliability, manufacturability, maintainability, and usability will affect the run-time behavior, user experience, and system design. They represent areas of concern with the potential of applicationwide impact through layers and tiers. (ASTM, 2017b)

- 4.3.1.1 Subsea control systems must be operated and designed with the external environment considered. This includes ambient pressure and temperature, corrosion, marine growth and fouling, currents, fishing activity or maritime operations, seafloor composition, and maintenance considerations. Suitability to the storage environment must also be considered, for example, ultraviolet radiation, ice, ozone, sand, wind, humidity, or temperature extremes. (ASTM, 2017b)

- 4.3.1.3 Subsea-installed equipment shall exceed or meet the required temperature ranges described in the table. Test temperature refers to pre-deployment testing environments where the equipment might be operated (systems integration test, deck testing). (ASTM, 2017b)



	°C	(°F)
Design	-18 to 40	(0 to 104)
Test	-18 to 40	(0 to 104)
Operate	-5 to 40	(23 to 104)
Transport/Storage	-18 to 50	(0 to 122)

The temperatures relate to environment, not individual components. Subsea sensors that monitor produced or injected fluid may operate outside the ranges given and shall be rated accordingly.

Figure 28. Overview of temperature requirement (ASTM, 2017b)

  - Electronics have a design temperature rating of 70 to -18 degrees Celsius. This refers to the atmosphere within the enclosure where the electronic equipment operates. (ASTM, 2017b)

- 4.3.6 General guidelines are made to take redundancy into account. (ASTM, 2017b) The A and B systems are an example of a solution made for redundancy, where backup cables can provide functionality to the drive heads if the main transmission line fails.
  - The redundancy level should prevent loss in subsea production caused by a common failure or a single component. (ASTM, 2017b)
  - The reliability and complexity influence the level of redundancy. An analysis calculates the expected benefit from redundancy and should be executed on all critical parts. (ASTM, 2017b)
  - The design of subsea electrical distribution systems should include spares or be redundant. (ASTM, 2017b)

- 4.5.1 Design must provide for safe and reliable operation of subsea equipment. It should provide means for the safe shutdown of failures or loss of control. (ASTM, 2017b)

- 6.2 Subsea-installed equipment must be designed to be safe to install and operate. Landing, running, and retrieving should minimize hazards to equipment, personnel, and the environment. (ASTM, 2017b)

- 6.4.8 Cable routing and installation should be detailed and defined through the design process and not be left for onsite installation. It is preferred that nonmetallic tie wraps fasten cables. Cable routing should allow retrieval and replacement if required. (ASTM, 2017b)

API 17G

This standard gives guidance for selecting a subsea well intervention system. It defines minimum requirements related to specific operations and environments to ensure that the selected system is optimized for its purpose. (ASTM, 2022) This specification does not affect the redesign of the ACM.

API 17H

API 17H provides recommendations for designing and developing remotely operated subsea tools and interfaces on production systems. The standard does not cover manned intervention, internal flowline inspection, tree running equipment, and internal wellbore intervention. (ASTM, 2019) The standard does not cover any crucial information for this project.

API 17Q

The standard gives contractors, suppliers, and operators process-level guidance to qualify equipment. It is not meant to replace company procedures or processes that already exist. (ASTM, 2018b) This standard is not relevant to the scope of the project.

ISO 13628-1

- B.1.1 Equipment on subsea production systems should have a marking and color system, creating unique and easy identification. (Standard Norge, 2006)

- B.1.2 Marking and color systems shall be a guidance map for operations by:
    - Identifying orientation and equipment.
    - Identifying equipment that is mounted to a structure.
    - Identifying the equipment's position relative to the overall structure.
    - Identifying the equipment's operational status. (Standard Norge, 2006)

- B.2.3 Dark and white colors shall be avoided on large structural elements. To prevent reflection, grating should be of darker colors, such as metallic grey. Furthermore, colors that are easily misinterpreted as shadows shall be avoided. (Standard Norge, 2006)

	Black	Red	Orange	Yellow [a]	Unpainted	White [a]	Grey
Paint code: RAL	9017		2004	1004	na	9002	7038
Paint code: Munsell	N 0,5		1,25YR 6/14	1,25Y 7/12	na	10Y 8 5/1	5Y 7/1
Paint code: US Federal Standard 595A [35]	27038	31136	32246	33655 33507	na	27875	26440

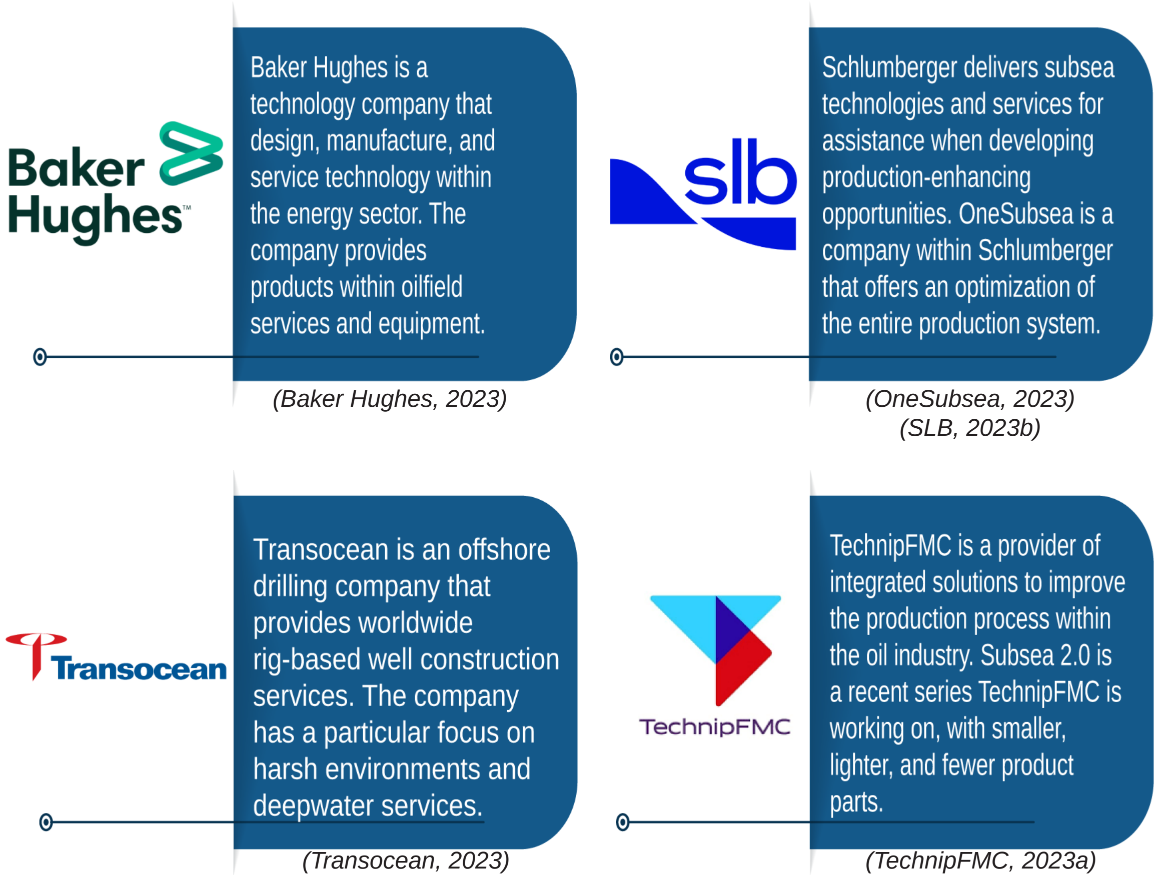
Figure 29. Example of colors that may be used (Standard Norge, 2006)

- B.12.1 Control systems shall be marked with regular intervals to create an easy recognition of all the control system components. (Standard Norge, 2006)

- B.12.1 To enable clear visibility for the ROV during an inspection, the control module shall be marked with its identification number. The character height shall be 100mm at a minimum. (Standard Norge, 2006)

Competitors

Subsea production systems are complex structures that require many resources, leading to high confidentiality within different components and how they work. For this reason, it is impossible to analyze competitors' products since they are unavailable to the public. However, these are some of Aker's competitors in subsea processing and production systems; Baker Hughes, Schlumberger, Transocean, TechnipFMC, and Aker Solutions.



Baker Hughes is a technology company that design, manufacture, and service technology within the energy sector. The company provides products within oilfield services and equipment.

(Baker Hughes, 2023)

Schlumberger delivers subsea technologies and services for assistance when developing production-enhancing opportunities. OneSubsea is a company within Schlumberger that offers an optimization of the entire production system.

(OneSubsea, 2023)
(SLB, 2023b)

Transocean is an offshore drilling company that provides worldwide rig-based well construction services. The company has a particular focus on harsh environments and deepwater services.

(Transocean, 2023)

TechnipFMC is a provider of integrated solutions to improve the production process within the oil industry. Subsea 2.0 is a recent series TechnipFMC is working on, with smaller, lighter, and fewer product parts.

(TechnipFMC, 2023a)
(TechnipFMC, 2023b)

Figure 30. Description of competitors

Field Trip

A field trip was executed at Aker Solution Tranby. Visiting the workplace provides opportunities to gain firsthand experience of the environment and production facilities. This improves the amount of information related to the product and develops a better preliminary understanding of it. The main goal of the field trip was to get a hands-on experience with the size and weight of the product, including interfering elements. The following text and pictures result from the field trips executed in Tranby on the following days: 07.02.23 / 08.02.23 / 30.03.23 / 31.03.23.

Aker Solutions in Tranby is a junction point for producing Xmas trees. A wide arrange of production and assembly lines for Xmas trees makes building and assembling between 35-70 tonnes of structures possible. The workspace consists of interdisciplinary competence, improving the workflow and communication within the different subjects. Engineers work closely with the production facilities and therefore have the opportunity to participate in testing and assembly.

Figure 31. Picture of Aker Solutions Tranby (Private picture, 2023)

Workshop Tour

A workshop tour was executed during the field trip to observe the production halls. The production line includes assembly and several large milling, lathe, and drill machines. In addition to Aker producing their products, smaller components are often built at external factories and sent for assembly at Tranby. This gave insight into the available production methods while getting a scale and accessibility understanding.

Figure 32. Picture of the workshop at Tranby (Dahl, 2021)

Xmas Trees Testing

Several testing hubs were placed at the end of the production line, allowing them to test and adjust the trees at the exact location they are built. This is a crucial step in mapping out and solving possible production or design issues. It is also a critical stage where a design mistake can, in the worst case, lead to an explosion damaging several components in the system.

Benestad Solutions - Penetrators

A go-through of the production of the Benestad penetrators located between the canister and housing was conducted. The production includes procedures for handling and shaping both glass and metal. The process is advanced and very costly. Benestad penetrators are highly confidential and expensive; it is impossible to change their design or discuss optimization during this master.

Figure 33. Xmas tree testing at Tranby (Dahl, 2021)

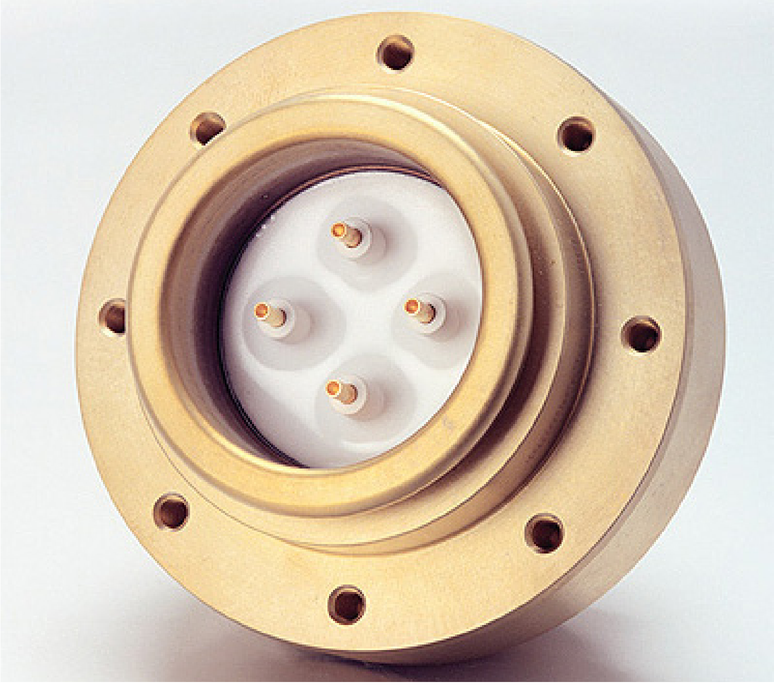


Figure 34. Penetrator from Benestad (Energy Oil Gas, u.y)

Jumpers and connectors

The ACM communicates with the drive heads and PCGM through jumpers and connectors. The jumpers are heavy and stiff, so they can not be bent more than 180mm radius. This is because the jumpers are filled with oil. Oil has several functions in the jumper, including compensation for the pressure and a barrier to the cables inside. In addition to this, the oil decreases water tear due to osmosis. Over the lifespan of a production system, water will pass through the gaskets and therefore enter the jumper. In this case, the lower point of the cable must be further down than the connectors themselves to prevent water from interfering with the electronics. Illustrated to the left are examples where water will gather within the connectors leading to interference with the electronics. In the right example, the connectors are going downwards, and the cable has a lower point where the water will not disturb the electronics.

Figure 35. Picture of jumpers (Private picture, 2023)

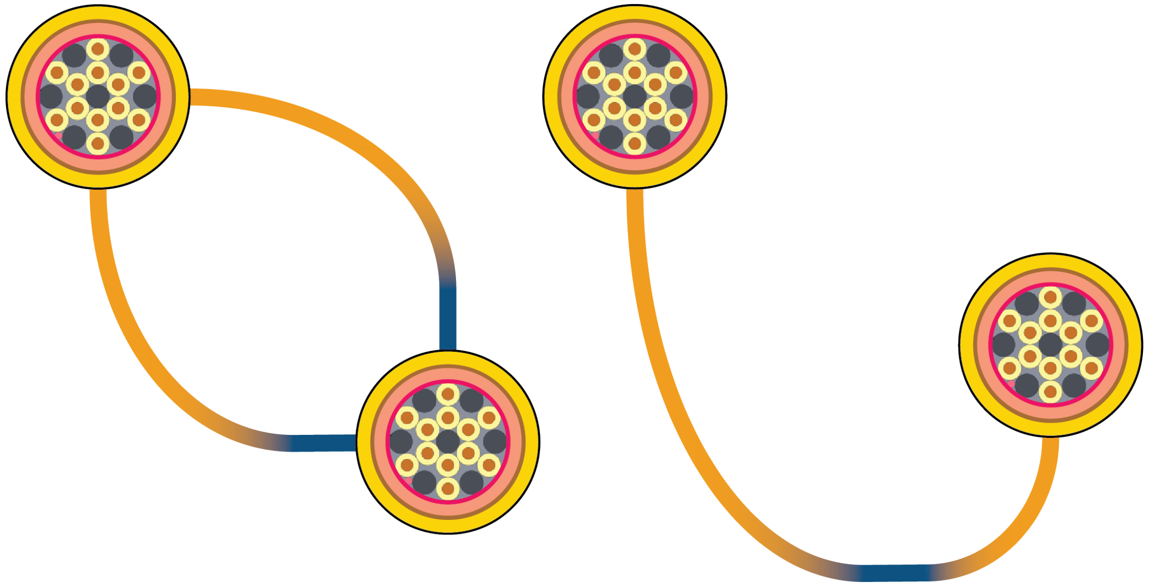


Figure 36. Showcase of water buildup in jumpers (Private picture, 2023)

Stab plate connectors are standardized equipment that can connect underwater and is a type of wet mate. ROV connectors, however, are a lot bigger due to the interface needed during installation through ROV. They are made for retrievable instruments and make it possible to move and connect jumpers to connectors after deployment. Both types of connectors are heavy and need a force of 75kg to create a connection.

Connectors follow a mechanical and electronic discipline. Mechanically the plug is given to the receptacle. Electronically the plug receives, and the receptacle gives. These disciplines are relevant when considering where to position the connectors since the receptacle has exposed pins. If power comes from the receptacle and it disconnects, the pins will be exposed to water and short the system. If power comes from the plug, however, the pins will not be exposed when disconnected and, therefore, not short the system. The plugs should be located on the module/jumper that provides the power.

Since the ACM gives power to all driveheads, the connectors on the module should consist of plugs. This is to avoid a short when disconnecting the driveheads from the ACM. However, the ACM receives power from the PCGM, which means that the ACM should have a receptacle for the PCGM jumper. The receptacle will not be modeled in CAD but must be utilized in the produced model.

Figure 37. Stab plate connector and ROV connector (Private picture)

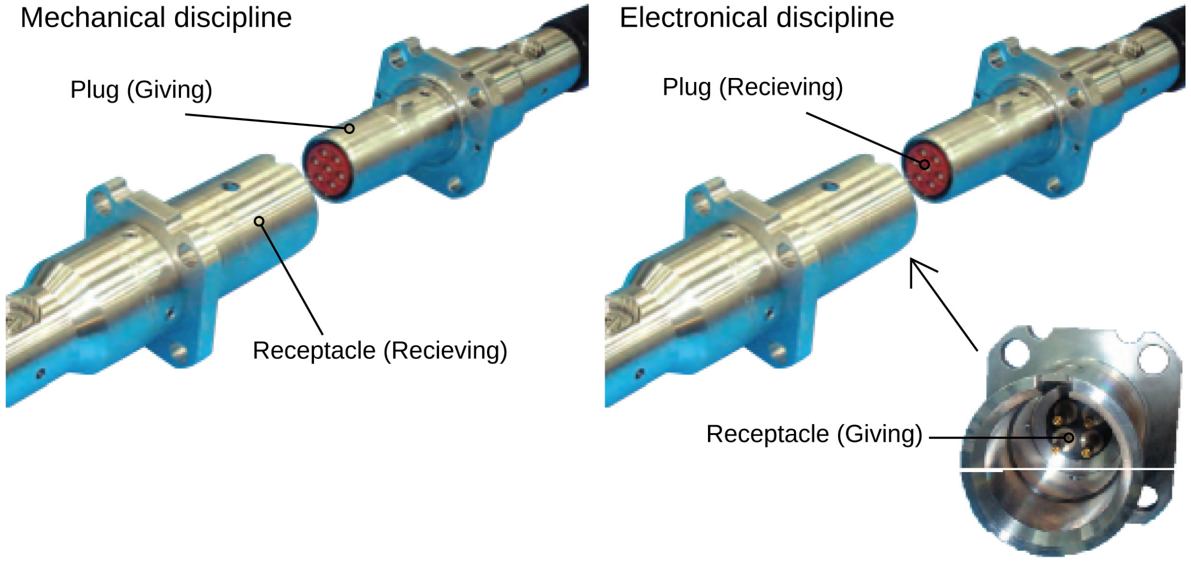


Figure 38. Explanation of connectors, edited picture from (Siemens-energy, u.y)

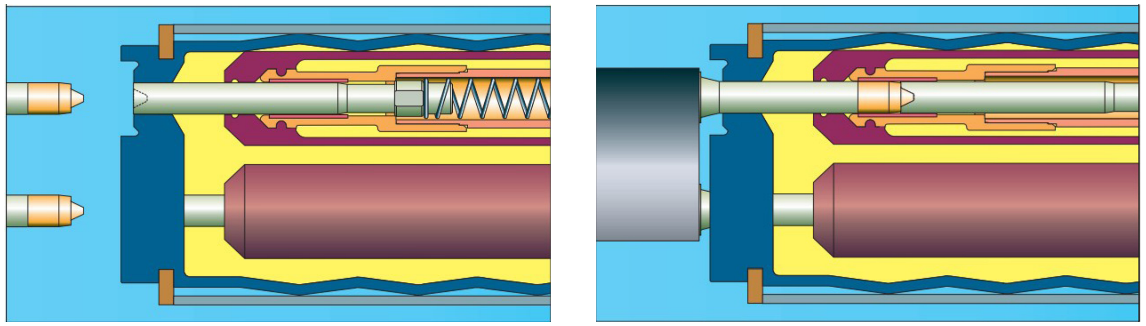


Figure 39. Illustration of electrical pins (Siemens-energy, u.y)

Drive Head

Drive heads are electrical engines that rotate to adjust valves to the desired position. They are connected directly to the ACM via jumpers. The ACM sends a message to the drive heads of the rotation needed during a specific time. Since the ACM is connected to the drive heads through jumpers, the placement of these components should be considered to satisfy the requirements for the jumper cables (180mm bend radius and drop point).

Junction Box

When installing a Xmas tree, numerous jumpers are required for effective communication among the system's equipment. However, a junction box can reduce the number of jumpers needed. Instead of having five loose and separate jumpers in the FCM before installation subsea, they can be connected to a junction box, resulting in only one loose jumper. The number of loose jumpers in the system is reduced by consolidating multiple jumpers into one. This is especially useful when considering the jumpers on the FCM who need to communicate with the PCGM.

Figure 40. Picture of drive head (Private picture, 2023)

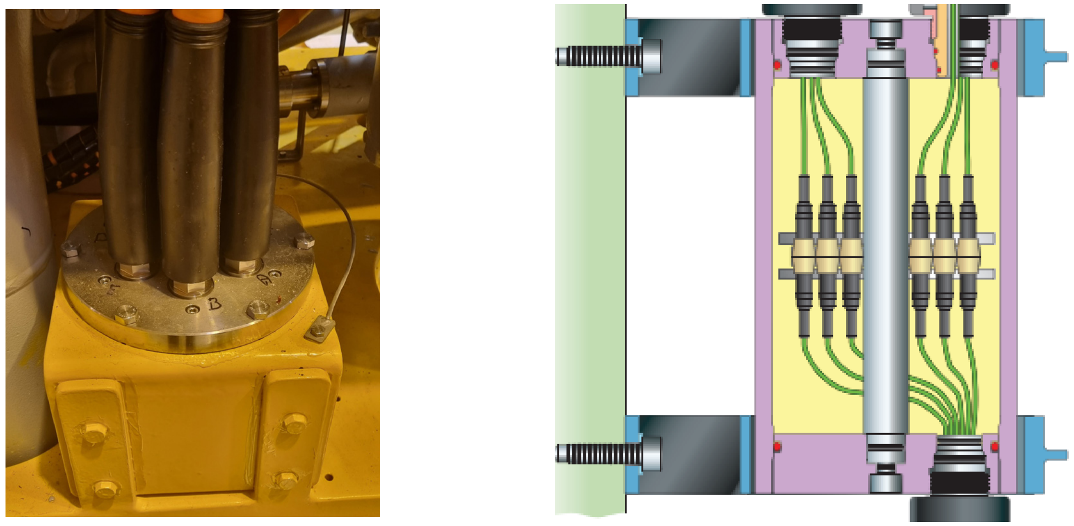


Figure 41. Illustration of junction box (Private picture, 2023)(Siemens-energy, u.y)

Small Bore Actuator Control Module

Aker is currently in a testing phase where they have produced a 1:1 model of the ACM. Due to the testing, some of the equipment on the module is missing in the pictures. As a result, observing how the module was assembled created a better understanding of how the product works. This led to an increased understanding of designing with assembly and testing in mind.

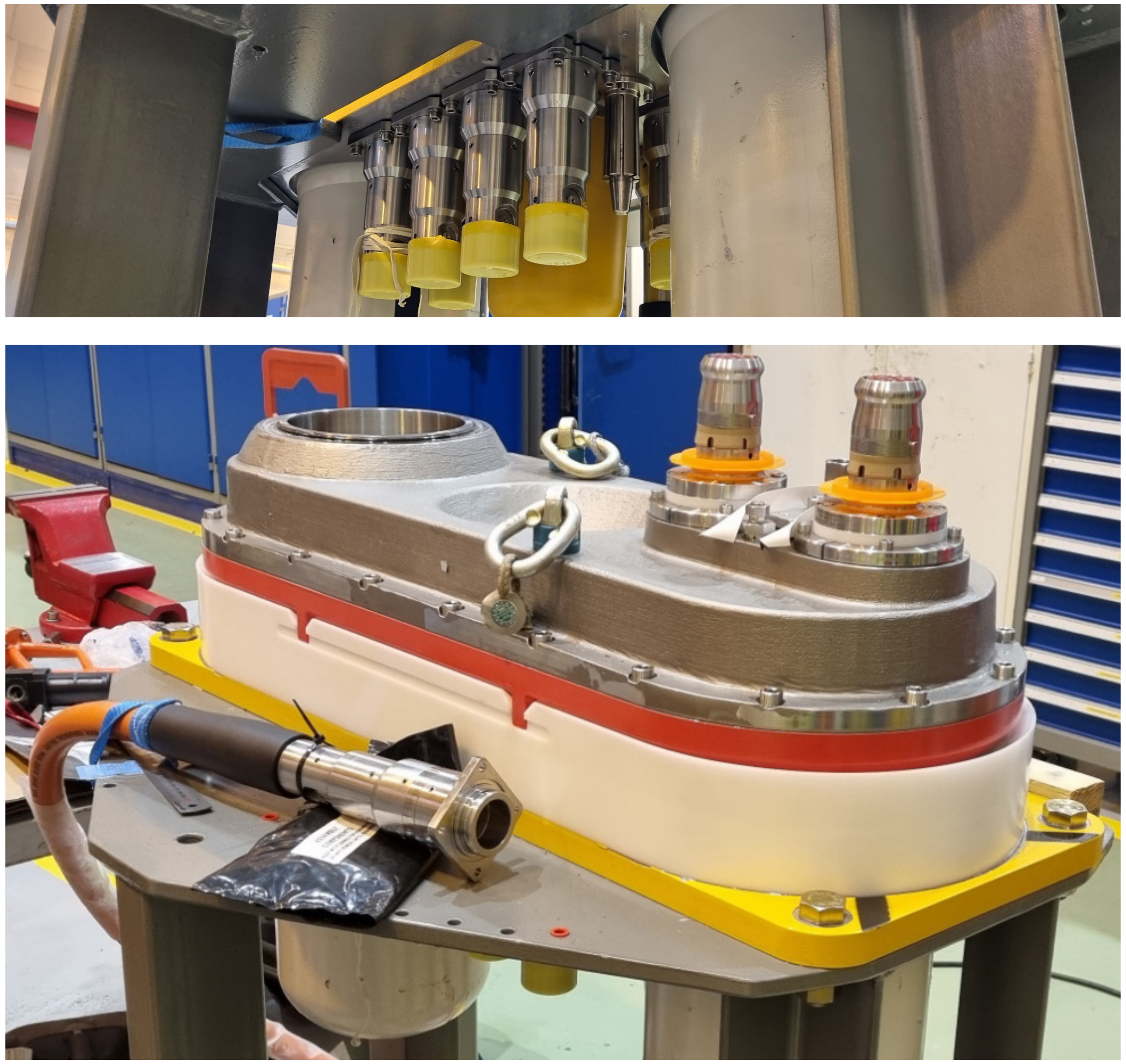


Figure 42. Picture of the ACM (Private picture, 2023)

Interviews

Interviews were conducted during the field trip to gather qualitative research. The interviews were structured beforehand to give insight into different opinions, experiences, or predictions (Rowley, 2012). All interviews are executed with anonymous participants concerning privacy.

Interview Mechanic

An assembly line employee was interviewed to understand the assembly process better. The interview candidate has experience in the assembly and testing of the FCM and has a background in industrial mechanics. The essential findings from the interview are listed:

- The designers rarely take available equipment into the design. They have to use advanced equipment because of bad design. If special equipment is needed, the designer should specify or even design it.
- The final product often deviates from the designer's model, meaning they often have to improvise to make the designer's choice possible.
- In general, there is a repeating problem with designers not considering the difficulties of assembling some of the products.
- Mounting and fixing jumpers are one of the most time and energy-demanding tasks. They use much time on jumper routing, adapting them to fit the desired design because of the weight and stiffness.
- All components have minimal space and availability.
- The ACM is mainly bolted and therefore requires no special equipment.

Interview Designers of FCM

This interview was conducted with two employees that have experience with FCM design and a combined 50+ years of experience in Subsea. The essential findings from the interview are listed:

- Ensure all functions achieve the desired result and remove unnecessary parts.
- Placement is essential, as this is linked to jumpers which should not be bent more than necessary. This is also important due to the splash zone under subsea installment.
- It is possible to make 90 degrees connections on the cables.
- The jumpers are filled with oil and have a 180mm bend radius limit.
- To avoid water gathering in the connectors due to osmosis, the connectors must be higher than the lowest point on the cable.
- There is a dropzone tolerance to the Xmas tree/FCM roof, meaning that components mounted to the ceiling must have a clearance of 300mm.
- The ACM is a heavy component and should balance the FCM if possible.

Interview Designer of PCGM

The interview candidate has been involved with the design review of the ACM and has designed the PCGM based on this module. A controls team conceptualized the PCGM and then passed it on to be improved and redesigned. The essential findings from the interview are listed:

- The ROV is tricky to control and can only reach equipment less than 600mm from the roof.
- Initially, the PCGM was curved and had a fancy design, which seemed unnecessary and cost-demanding. "The fish do not care about how the equipment looks like."
- A recurring mistake is evaluating bolt lengths, often done early in the design process. When slightly changing certain design parts, the bolt may no longer fit.
- All fixed components have little to no wear. The build of marine growth is often the only issue.
- The order of assembly can often be improved.

Interview Designer of ACM

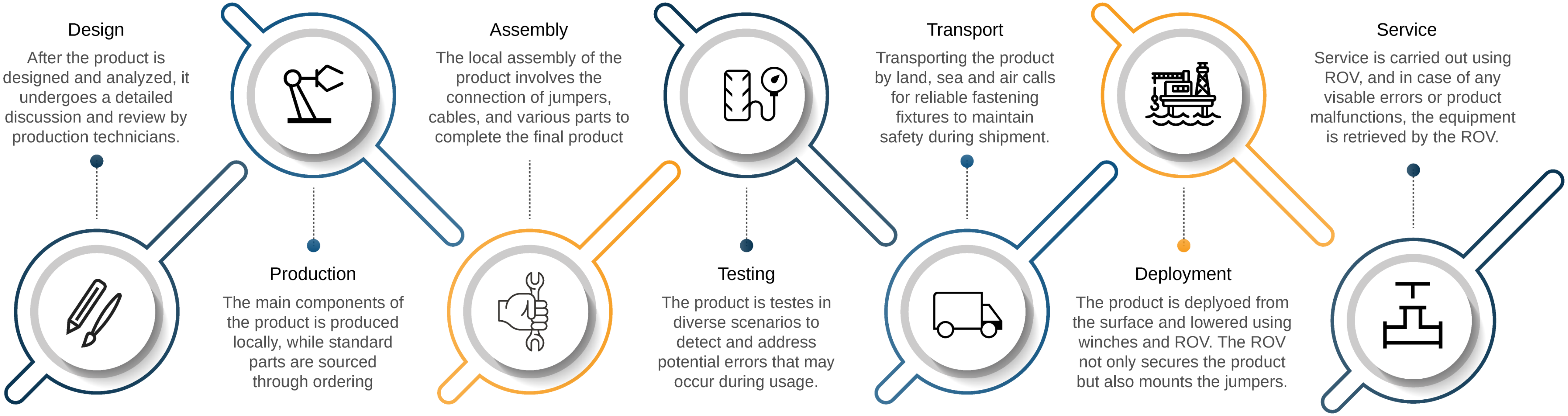
A lead engineer for the ACM was interviewed to improve insight into the current solutions. Another designer detailed the ACM, which was unavailable during this project. Before the interview, all concepts for the current ACM were presented and reviewed. The essential findings from the interview are listed:

- The ACM and PCGM replace the SCM (Subsea Control Module).
- Connectors and seals on the SB ACM are advanced and complex compared to the LB ACM.
- The current ACM can run two valves simultaneously.
- Minimize the housing volume to decrease the use of dielectric fluid. The compensator is made for a volume of 9 liters. The current ACM is 20 liters, so they use plastic (POM) in addition to the dielectric fluid for volume displacement.
- Casting is an excellent production method, but it needs to be processed and detailed. This comes down to several steps, with documents to approve and the deviation that must be addressed.
- Trees are recycled and not reused. Design should, therefore, not be based on reuse.

Product Journey

A product journey map is valuable for visualizing and understanding user interactions. It provides an overview of the user’s experience, showcasing their actions and interactions with the product. This map identifies opportunities for improvement and enhances the overall product experience. One type of journey map is current state map, which captures existing user interactions. It highlights the current user experiences while revealing areas that require attention or improvement (Userpilot, 2022). Analyzing the current state map helps identify pain points, inefficiencies, or areas where the user experience can be enhanced.

The current state map provides a clear overview of the scenarios that must be considered during the redesign process. It is essential to consider the machines and standard/available equipment that is available during an assembly at Aker Solutions, where some of the production is executed. Additionally, the product should incorporate secure fixtures to ensure safety during transportation and deployment. Finally, the product should be positioned on the FCM in a manner that facilitates easy ROV inspection.



Design
After the product is designed and analyzed, it undergoes a detailed discussion and review by production technicians.

Production
The main components of the product is produced locally, while standard parts are sourced through ordering

Assembly
The local assembly of the product involves the connection of jumpers, cables, and various parts to complete the final product

Testing
The product is testes in diverse scenarios to detect and address potential errors that may occur during usage.

Transport
Transporting the product by land, sea and air calls for reliable fastening fixtures to maintain safety during shipment.

Deployment
The product is deplyoed from the surface and lowered using winches and ROV. The ROV not only secures the product but also mounts the jumpers.

Service
Service is carried out using ROV, and in case of any visable errors or product malfunctions, the equipment is retrieved by the ROV.

Figure 43. Illustration of Current state map (Private picture, 2023)

3

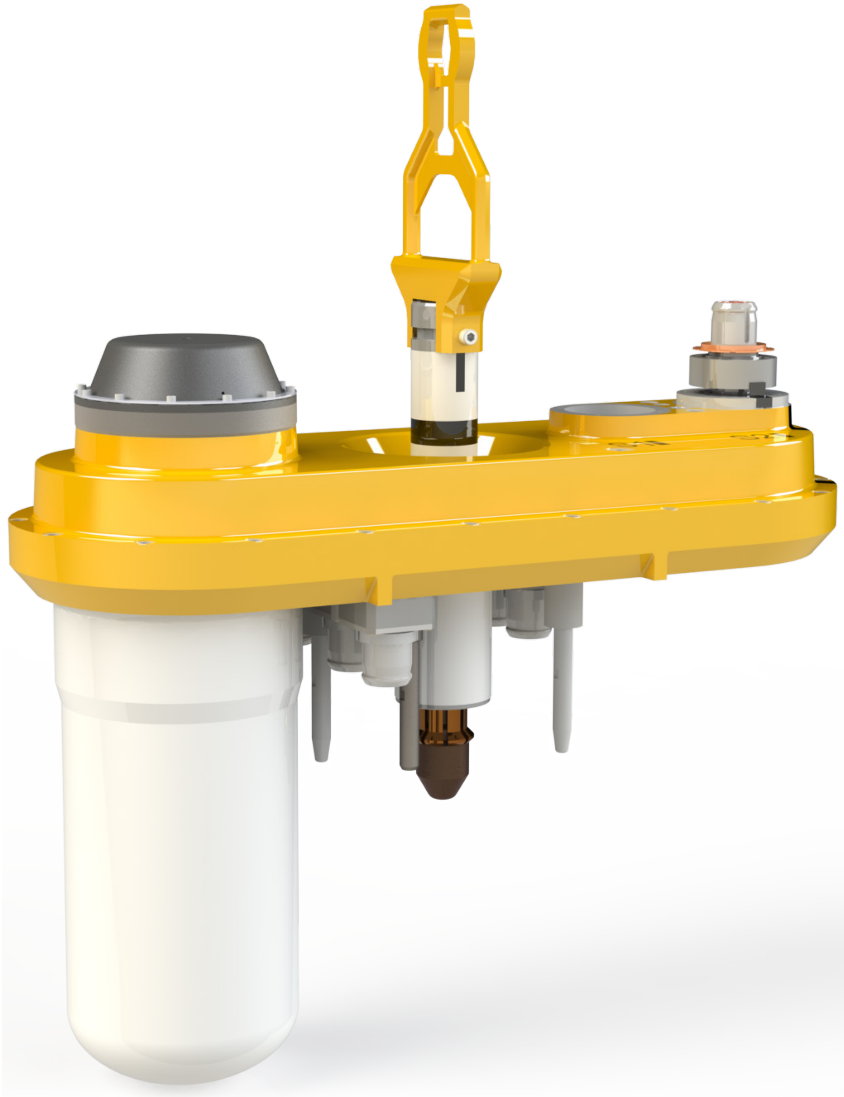
Qualification Basis

SB ACM Breakdown

From analyzing all findings, the ACM can be reduced to just the necessary components for keeping its functions intact while satisfying the literature findings. The following pictures show a step-by-step of removed components and explain why these components can be excluded in a redesign.

Figure 44. Render of ACM (Private picture, 2023)

Today’s solution has a double jumper and system set due to standard API17F 4.3.6 regarding redundancy and avoidance of production stop due to failure in one of the systems. The new ACM only needs six connectors and one canister because it is placed on the FCM and does not operate any critical safety valves. If the ACM fails, the chemical valves will stay in position, which rarely needs adjustment. As a result, an error will not significantly impact production.



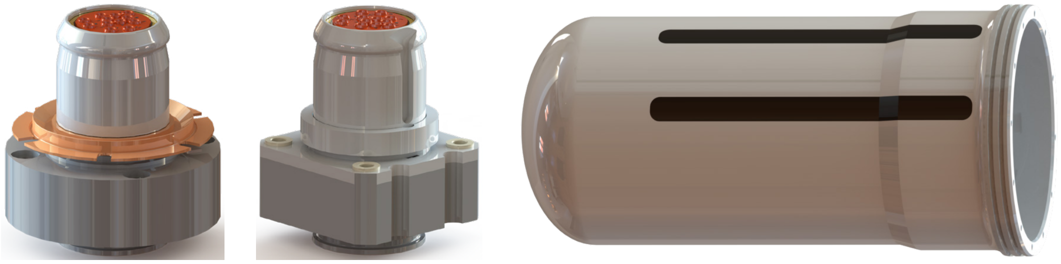


Figure 45. Render of the removed cylinder and connectors (Private picture, 2023)

Since the redesigned ACM does not control critical safety valves, it is no need for the module to be retrievable. This eliminates the need for several ROV interactions since the product can be installed on land. The pins and locking mechanism make the ACM retrievable and can therefore be removed as they are unnecessary in a fixed solution.

The black markings on the module can also be removed, as an ROV will no longer install the ACM. The markers are merely there for the ROV to ensure that the module is installed in its current position. As a result of the breakdown, the ACM only consists of three components; Connectors, Compensator, and Canister.

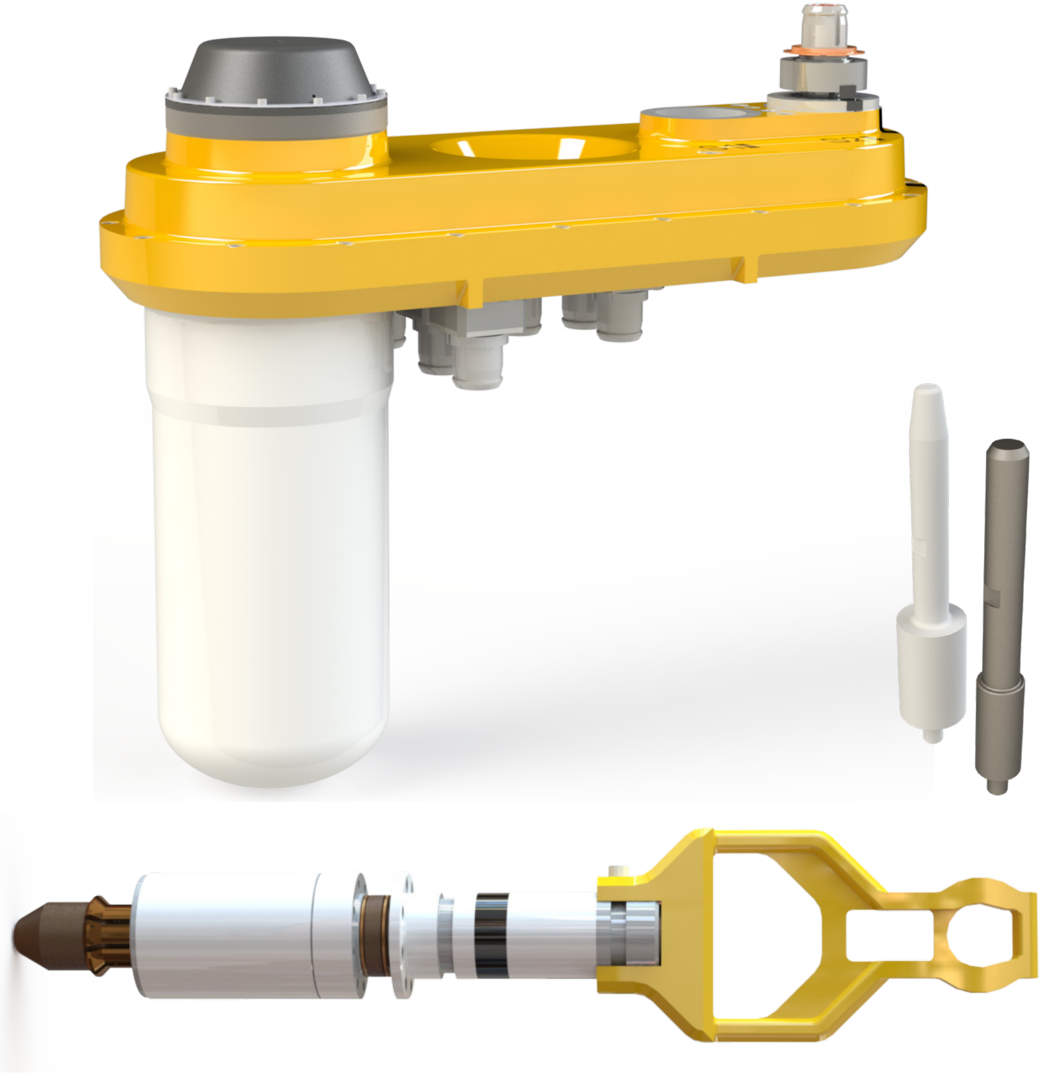


Figure 46. Render of the removed locking mechanism and pins (Private picture, 2023)

Functional Requirement

A functional requirement is used when designing and developing a reliable and robust product that works as intended. Through the interviews and analyses of the product, it becomes possible to gain a comprehensive overview of the functions and features necessary for the product to operate as expected. The functional requirement is separated into three categories: Essential Parts, Function, and External.

Essential parts

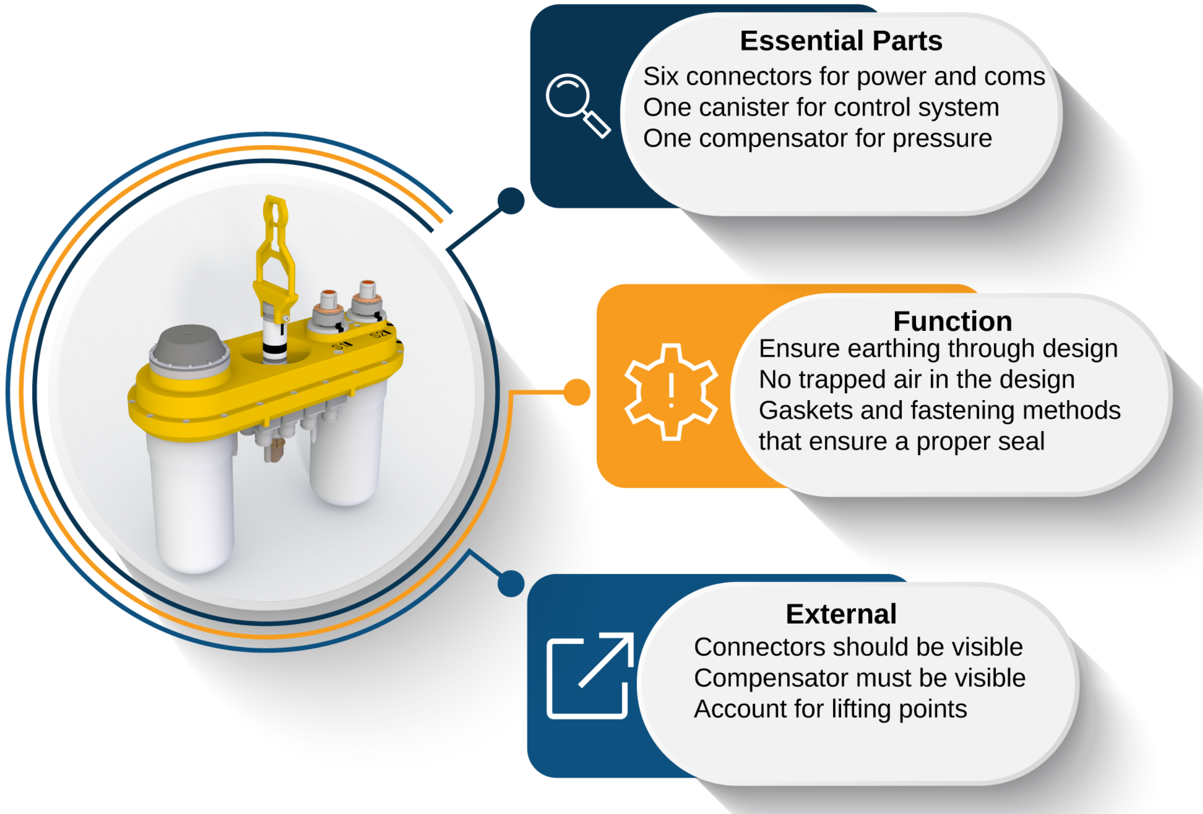
The essential parts are defined by what parts are needed to ensure operation. It is a given number of parts needed for the system to communicate with the different modules while withstanding extreme pressures.

Function

When developing solutions for the ACM to work as intended, it is crucial to consider its functions. These functions are the factors that need to be taken into account to ensure that the ACM operates optimally.

External

The external categories comprise factors critical to the ACM's external environment. This includes the transport and ROV interactions that must be considered. If the transport or ROV interactions are not considered, various problems may arise during the product's lifestyle.



Essential Parts

Six connectors for power and coms
One canister for control system
One compensator for pressure

Function

Ensure earthing through design
No trapped air in the design
Gaskets and fastening methods that ensure a proper seal

External

Connectors should be visible
Compensator must be visible
Account for lifting points

Figure 47. Functional requirement (Private picture, 2023)

Design Requirement

Apart from the functional requirements that ensure the product’s proper operation, additional requirements must be met to comply with Aker Solutions and the relevant standards. These requirements are determined through interviews, discussions with Aker, standards, and observations.

Since the design requirement includes standards, it is split into technical and practical requirements. The practical requirements (light blue) are adaptations to real-world scenarios marked with a blue color. In contrast, many technical requirements (dark blue) aim to prevent potential issues and enhance safety in production and handling.

Aker Solutions
Withstand pressure of 4000 meters
Jumpers must have a lower point than the connectors
Jumpers must have a minimum bend radius of 180mm
Equipment must have a 300mm - 600mm clearing to roof

API 6A
Design documentation of methods and assumptions including criteria for other conditions on which the design is based

NORSOK U001
Nonreplaceable components must be designed with a lifetime corresponding to the field’s operation time (25-30 years)

API 17A
Avoid harmful fluid escaping
Tolerate environmental conditions such as transport
Interchangeable solutions
Considerations regarding fouling

API 17D
Design must comply with the effect of external hydrostatic pressure
Design must compensate for all fluid-filled chambers

API 17F
Design for standard interfaces to optimize potential
The equipment must meet the required temperature range
Design must provide for safe and reliable operation

Design
Save space by creating a compact design
Follow color requirement given by standard ISO 13628-1
Product is designed as a module for easy maintenence and repair

Production
Designed with consideration of workshop tools
Assembly process is optimized by using standard fastening methods
Improve production by using available materials

Transport
Consider the compensator during the house redesign
Utilize fastening methods that fully secure the product
Lifting points should be placed to balance the ACM

Placement
Design fastening methods to the FCM that achieves interchangable design
The placement should provide easy access to the ACM
ROV can inspect the ACM without issue

Figure 48. Design requirement (Private picture, 2023)

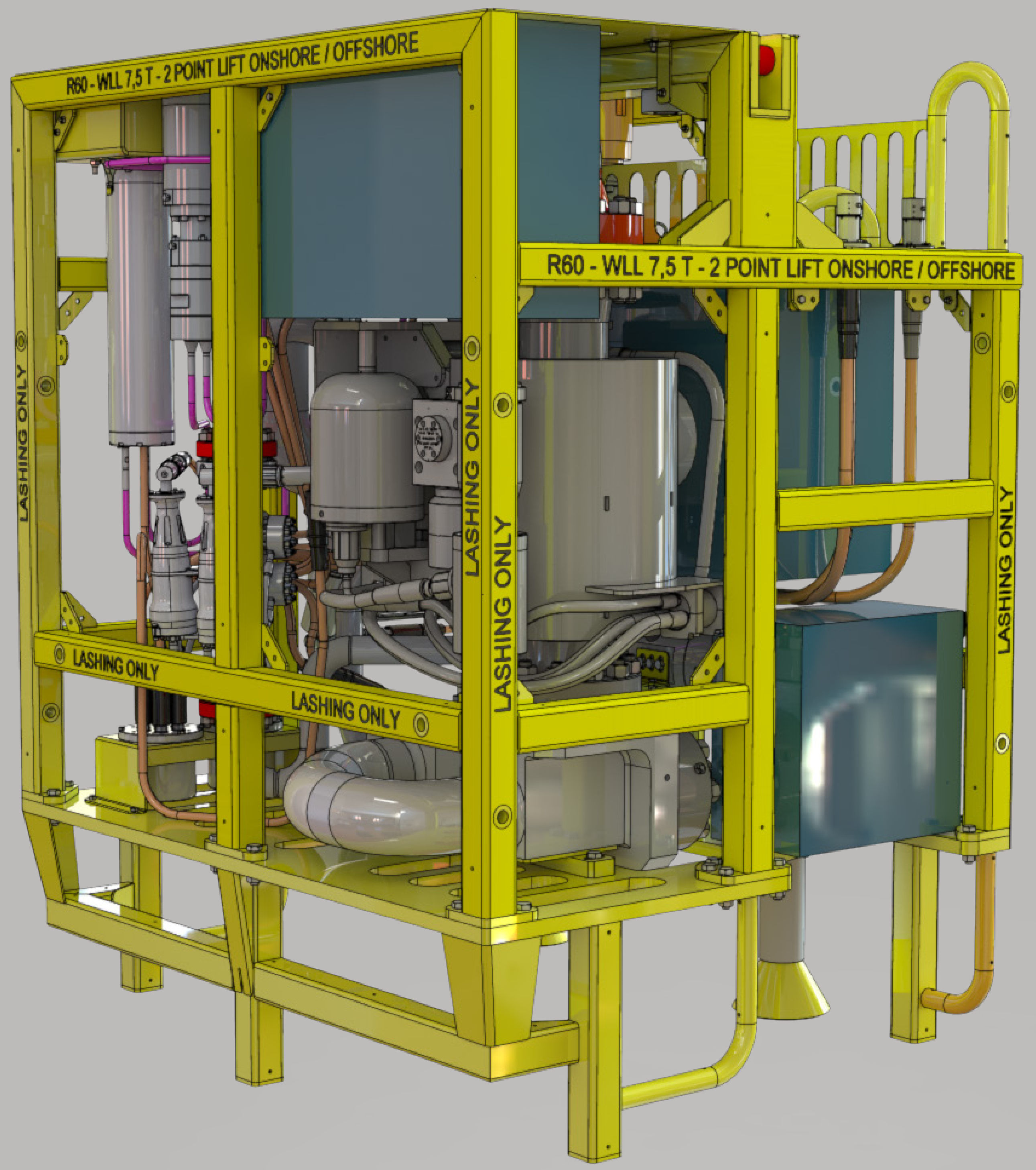
Limitations

Due to this project's scope, there are some limitations to what can be investigated during the given time. This leads to a choice where the essential components and functions are evaluated while others are just mentioned.

Evaluating materials would be time-consuming and irrelevant to this thesis, as the product is designed for long-term use in extreme conditions. While it is possible to suggest alternative materials, this aspect is not a primary focus of the redesign. It would not result in a suitable replacement for the material without thoroughly examining material technology.

The FCM for electric Xmas trees is not yet designed. This means testing and mounting the ACM in the electrical FCM is impossible. However, the hydraulic FCM gives some relation to the same system and is most likely more compact than the electric FCM.

The compensator is a complex part that has a strict confidentiality policy. As a result, it cannot undergo redesigning since the process cannot be documented as a master reference. The same principle applies to the canister, which contains advanced technology. Standardizing these parts can also be advantageous for future projects, leading to reduced overall production costs.


R60 - WLL 7,5 T - 2 POINT LIFT ONSHORE / OFFSHORE
R60 - WLL 7,5 T - 2 POINT LIFT ONSHORE / OFFSHORE
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4

Ideation

Develop Ideas

Using the essential parts from the functional requirement as a foundation simplifies experimenting with positioning while brainstorming ideas. This approach also ensures that the resulting design includes all necessary components for the module to operate, which means that most ideas can potentially function without requiring significant changes in principle. This method generates numerous ideas that explore various part placements and assess where the housing can be separated to access the electronics during assembly. The ideas are also rendered in CAD to understand the proposed solutions better.

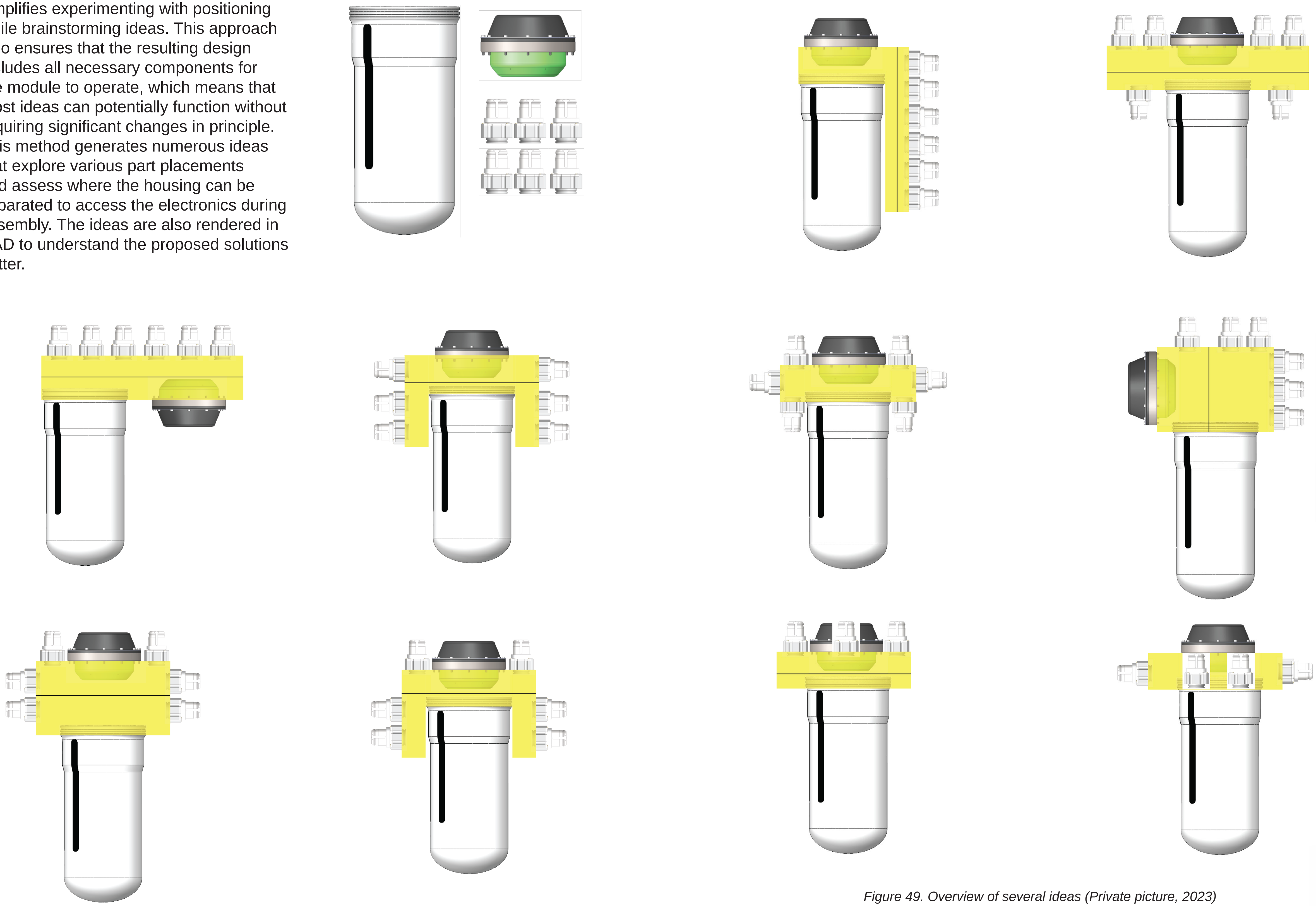
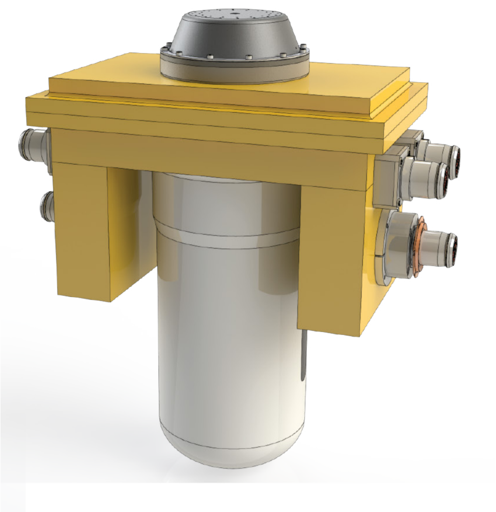
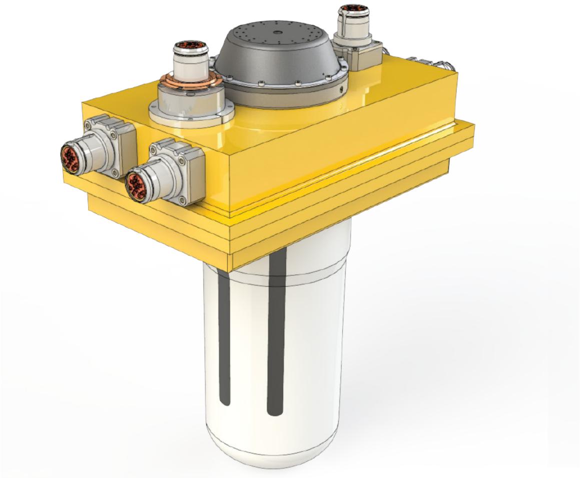
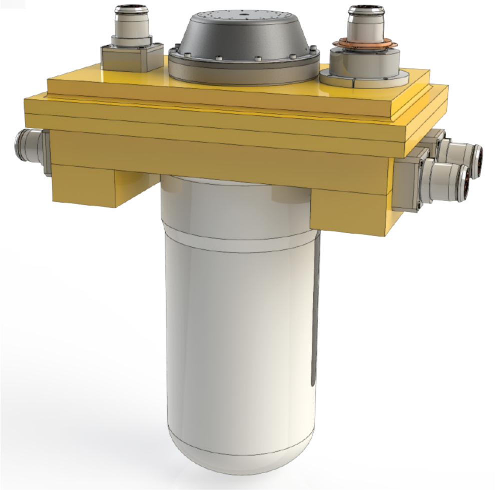
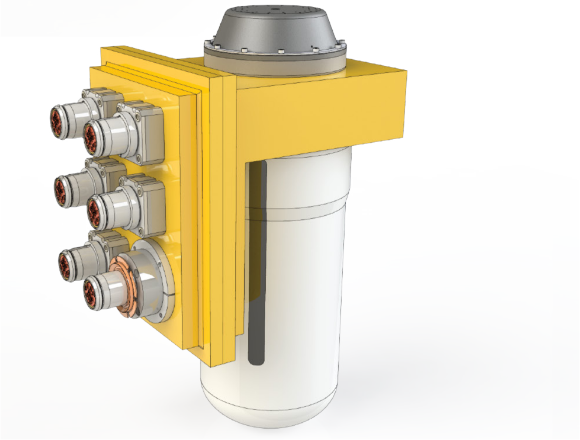


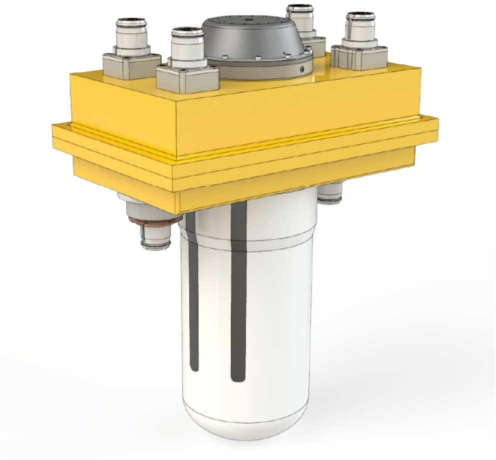
Figure 49. Overview of several ideas (Private picture, 2023)

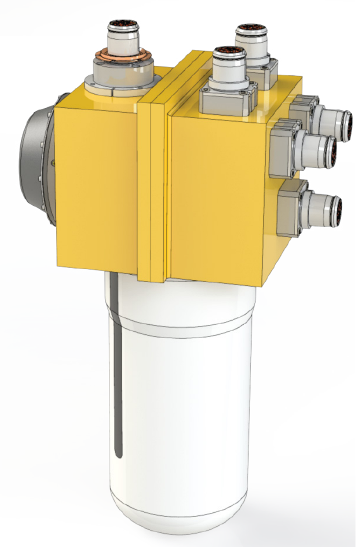


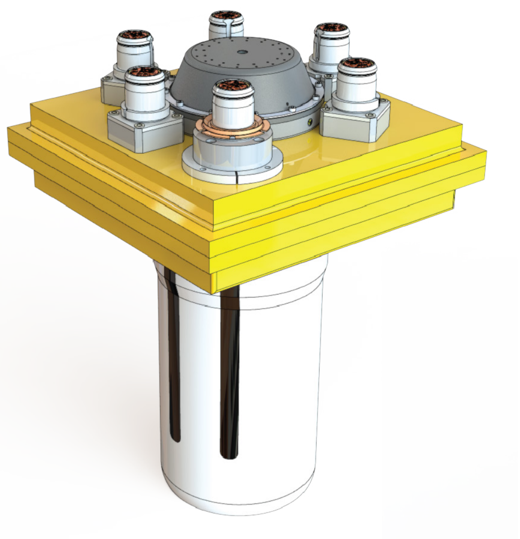












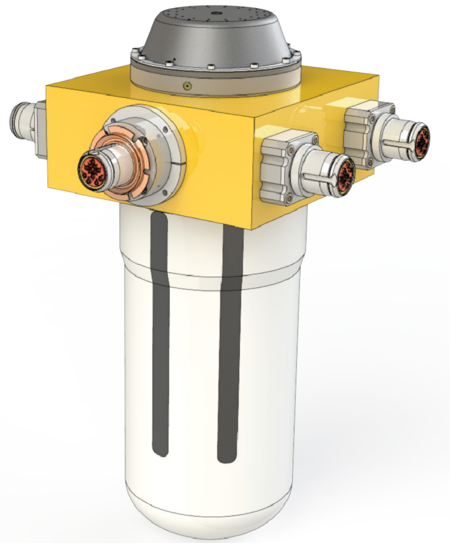


Figure 50. Render of presented ideas (Private picture, 2023)

Evaluation

Design Requirement

The “Jumpers and connectors” chapter mentions the importance of positioning connectors to avoid water interference caused by osmosis. This implies that connectors should not be oriented upwards, as it could create a low point where water may accumulate over time. In order to prevent this, it is crucial to accurately assess the rotation and placement of the presented ideas. The possible orientations for each idea are visually demonstrated through colored boxes in the evaluation.

The presented hydraulic FCM is used to determine the available space for mounting and installation. Boxes placed around available areas for mounting illustrate the volume that can be utilized without rearranging any existing components on the FCM. The canister and its outer measurements are depicted to provide size comparisons. The information is relevant to assess the size of each idea, as compact solutions can increase the number of possible areas to mount the solution.

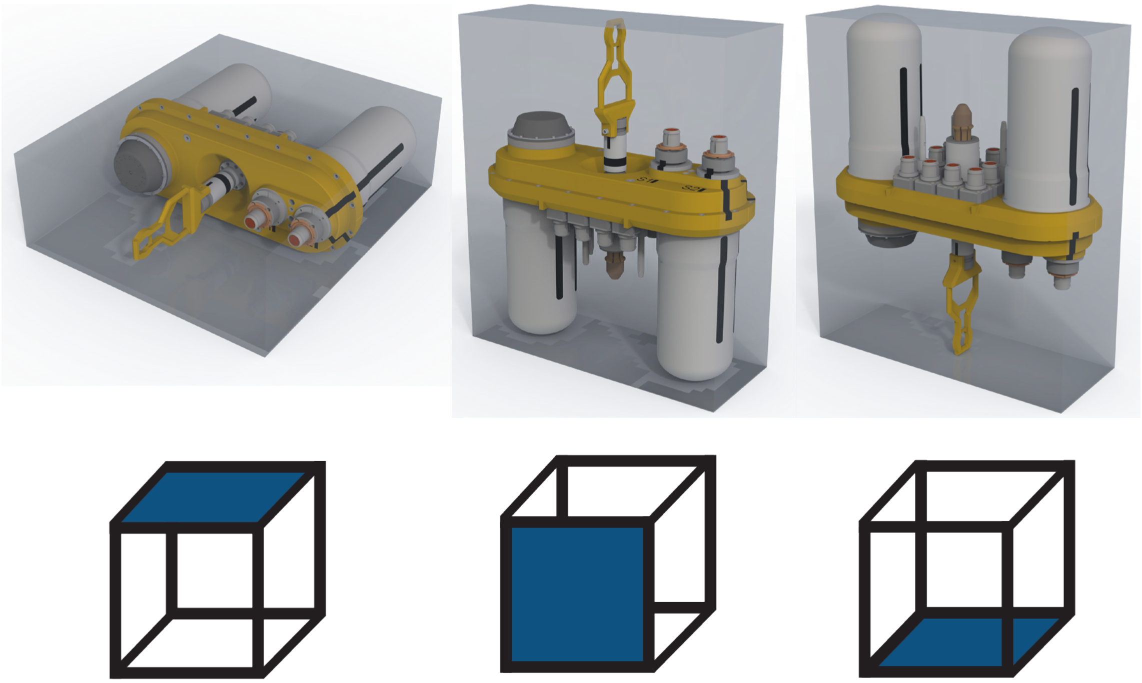


Figure 51. Illustration of rotational views (Private picture, 2023)

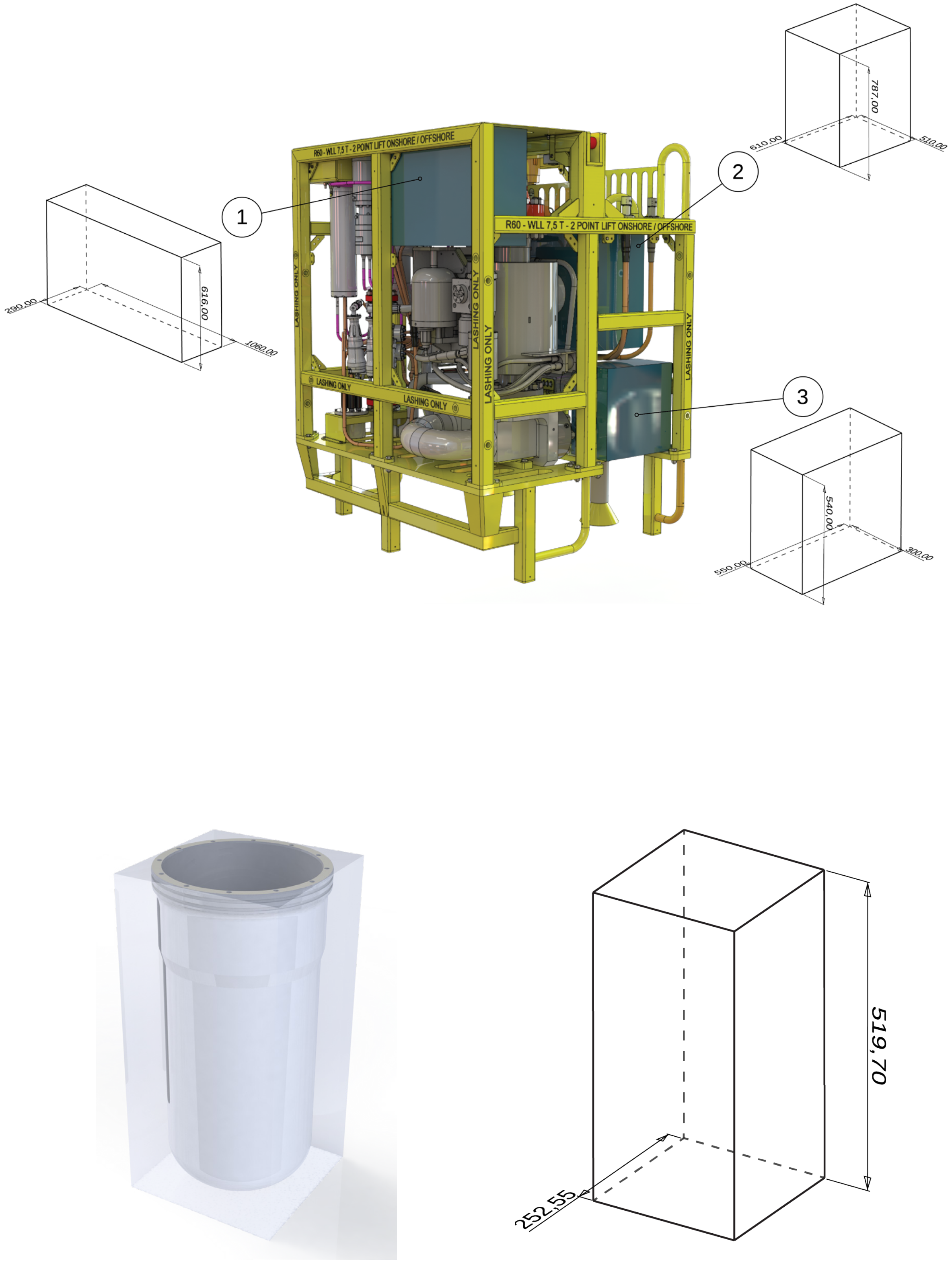
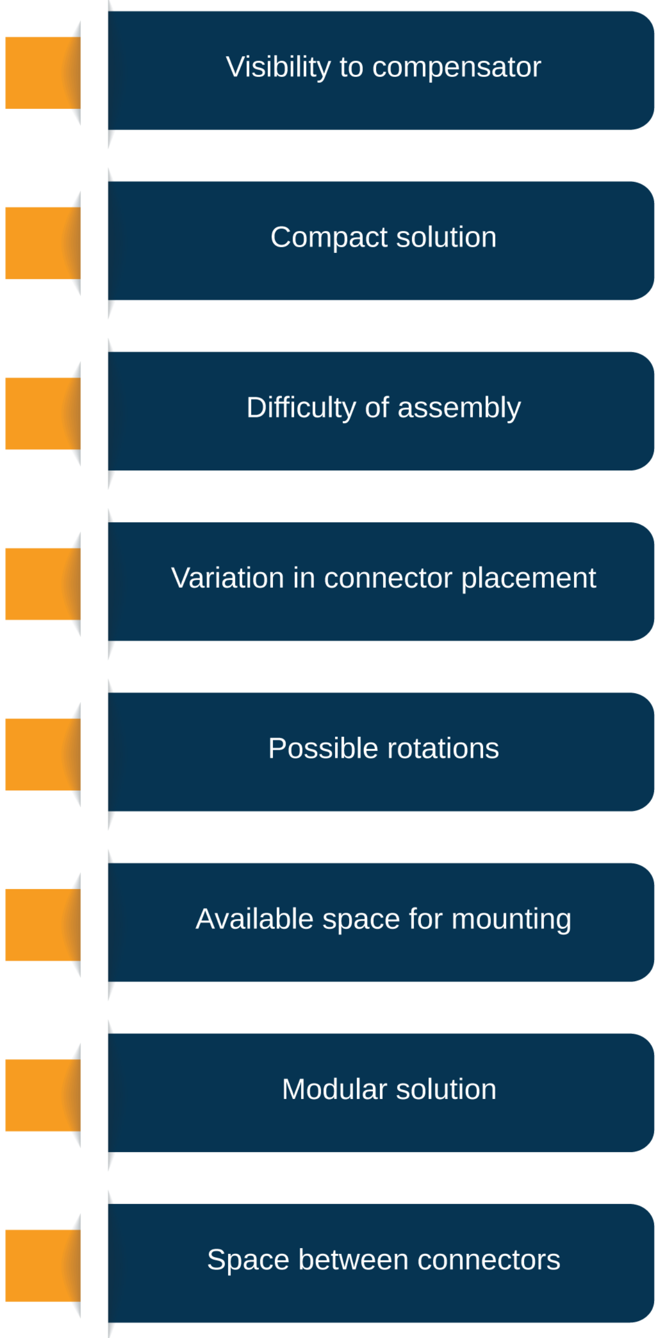


Figure 52. Render of available space in FCM (Private picture, 2023)

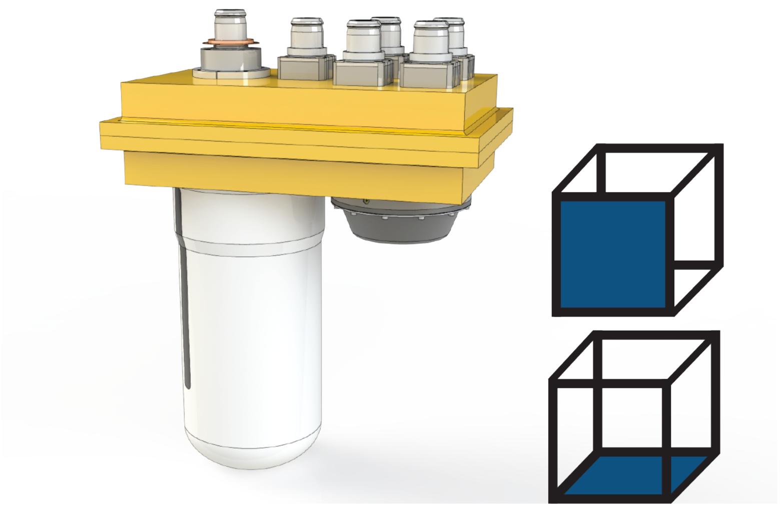
Pros and Cons

To assess each proposed idea, the design requirements are used to evaluate each solution's advantages (pros) and disadvantages (cons). For instance, if "visibility to compensator" is deemed an advantage, the solution provides visibility to the compensator. If "visibility to the compensator" is considered a disadvantage, the idea lacks or minimizes the visibility to the compensator.



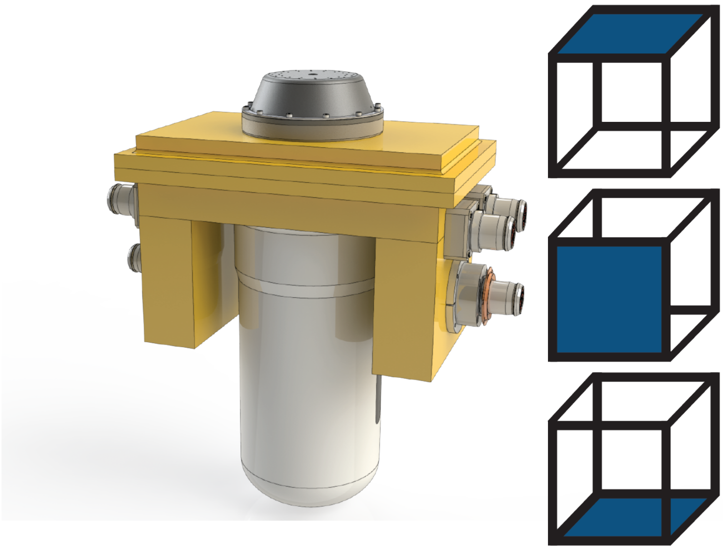
- Visibility to compensator
- Compact solution
- Difficulty of assembly
- Variation in connector placement
- Possible rotations
- Available space for mounting
- Modular solution
- Space between connectors

Figure 53. Points for evaluation of concepts (Private picture, 2023)



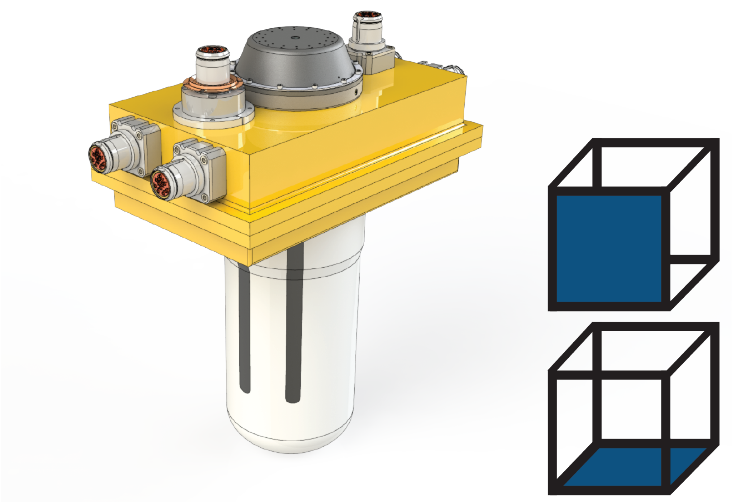
PROS:
- Visibility to compensator
- Difficulty of assembly
- Possible rotations
- Available space for mounting
- Modular solution

CONS:
- Compact solution
- Variation in connector placement
- Space between connectors



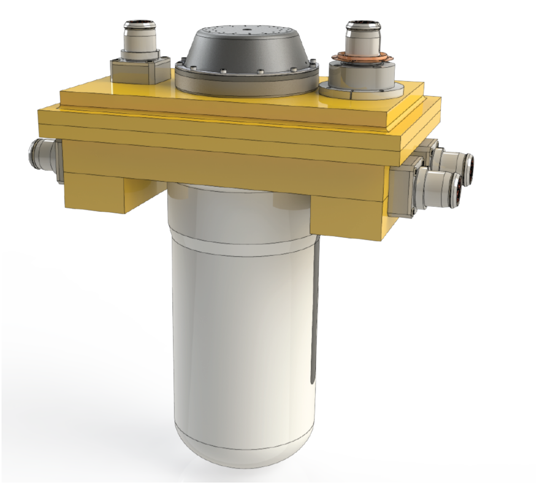
PROS:
- Visibility to compensator
- Variation in connector placement
- Possible rotations
- Available space for mounting
- Modular solution

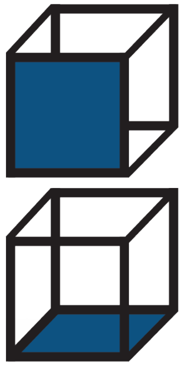
CONS:
- Compact solution
- Difficulty of assembly
- Space between connectors



PROS:
- Compact solution
- Difficulty of assembly
- Variation in connector placement
- Possible rotations
- Available space for mounting
- Modular solution
- Space between connectors

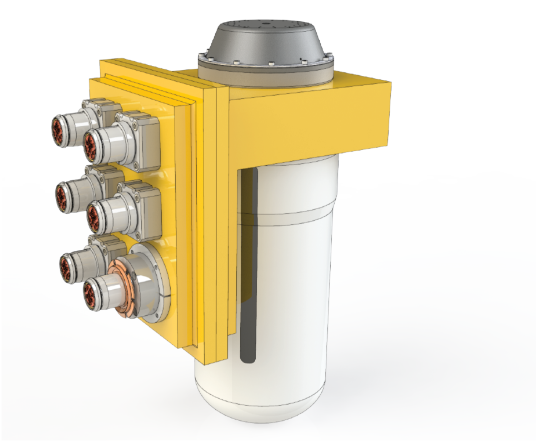
CONS:
- Visibility to compensator





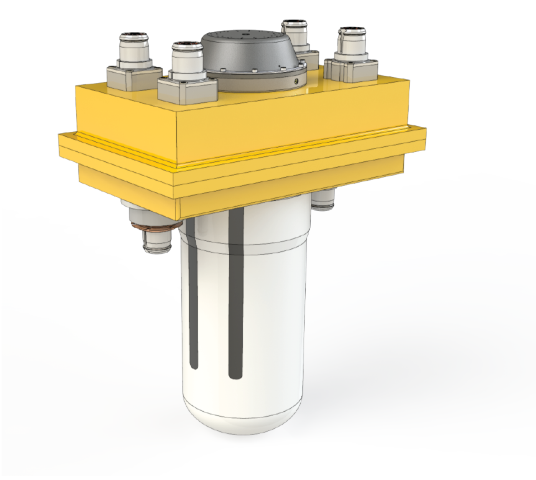
PROS:
- Compact solution
- Variation in connector placement
- Possible rotations
- Available space for mounting
- Modular solution
- Space between connectors

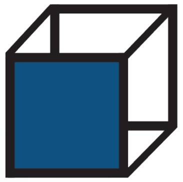
CONS:
- Visibility to compensator
- Difficulty of assembly



PROS:
- Visibility to compensator
- Possible rotations
- Available space for mounting
- Modular solution

CONS:
- Compact solution
- Difficulty of assembly
- Variation in connector placement
- Space between connectors





PROS:
- Compact solution
- Difficulty of assembly
- Variation in connector placement
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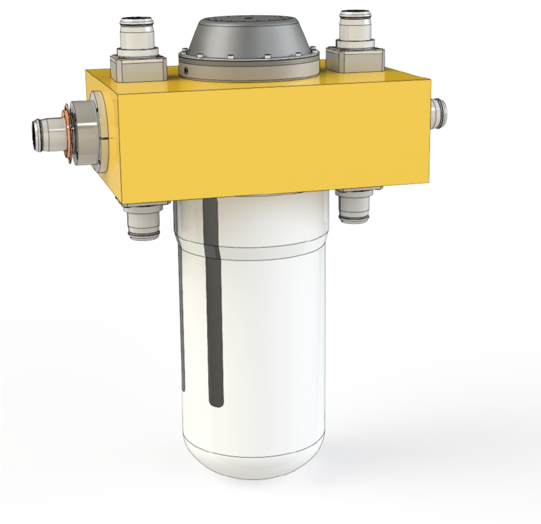
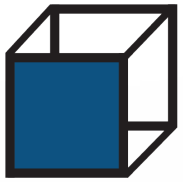
- Space between connectors

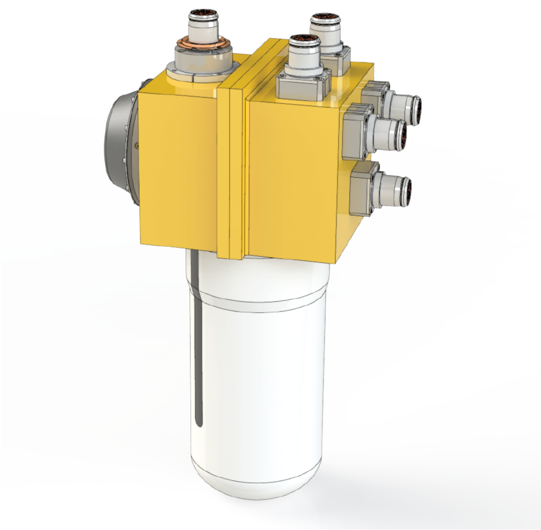
CONS:
- Visibility to compensator
- Possible rotations

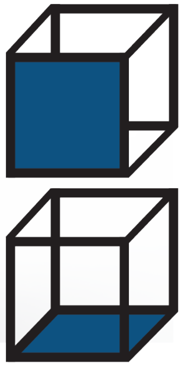




PROS:
- Compact solution
- Variation in connector placement
- Available space for mounting
- Space between connectors

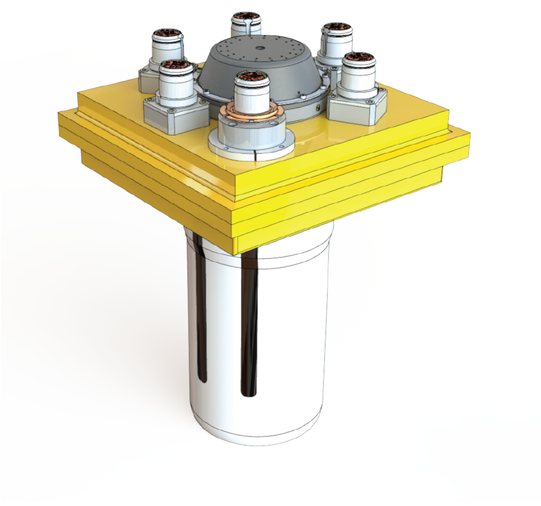
CONS:
- Visibility to compensator
- Difficulty ofassembly
- Possible rotations
- Modular solution

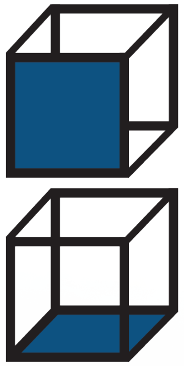




PROS:
- Visibility to compensator
- Difficulty of assembly
- Variation in connector placement
- Possible rotations
- Available space for mounting
- Modular solution

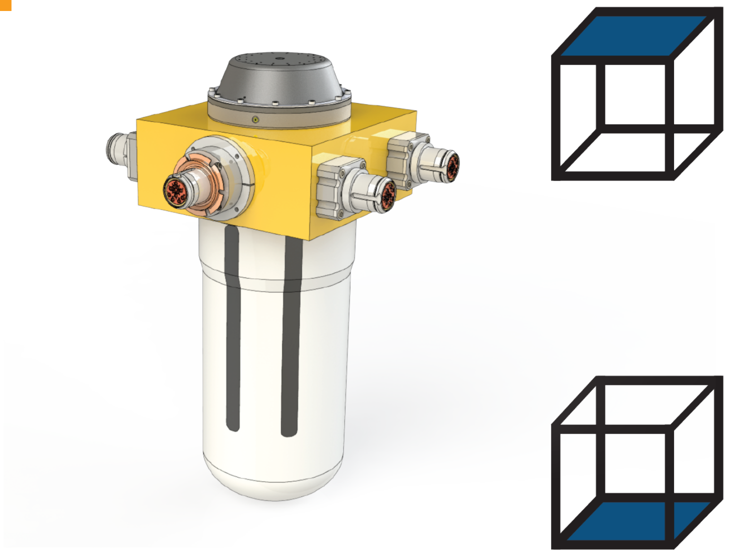
CONS:
- Compact solution
- Space between connectors





PROS:
- Compact solution
- Difficulty of assembly
- Possible rotations
- Modular solution

CONS:
- Visibility to compensator
- Variation in connector placement
- Available space for mounting
- Space between connectors



PROS:
- Visibility to compensator
- Compact solution
- Variation in connector placement
- Possible rotations
- Space between connectors

CONS:
- Difficulty of assembly
- Available space for mounting
- Modular solution

Figure 54. Overview of the evaluation process for concepts (Private picture, 2023)

Analyzing the evaluation result determines which idea only require minor modifications to achieve the desired result while not needing significant changes. Based on this evaluation, idea number three has the fewest drawbacks and, therefore, serves as the most promising foundation for concept development. The other ideas can still be used as inspiration when improving and developing a concept.

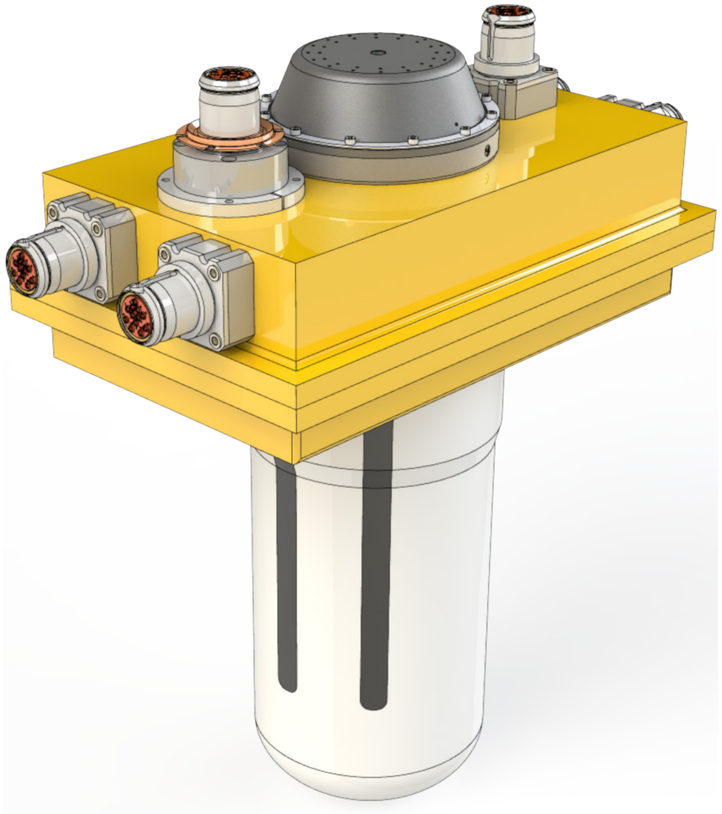


Figure 55. Render of chosen idea (Private picture, 2023)

Detailing Concept

As the selected idea has limited visibility to the compensator, adjustments must be made. One potential solution, inspired by the presented ideas, involves moving the connectors to the side of the housing. This approach creates a design with increased flexibility regarding connector placement while providing an unobstructed view of the compensator. The housing is designed to accommodate all electronics while being filleted to fit o-rings.

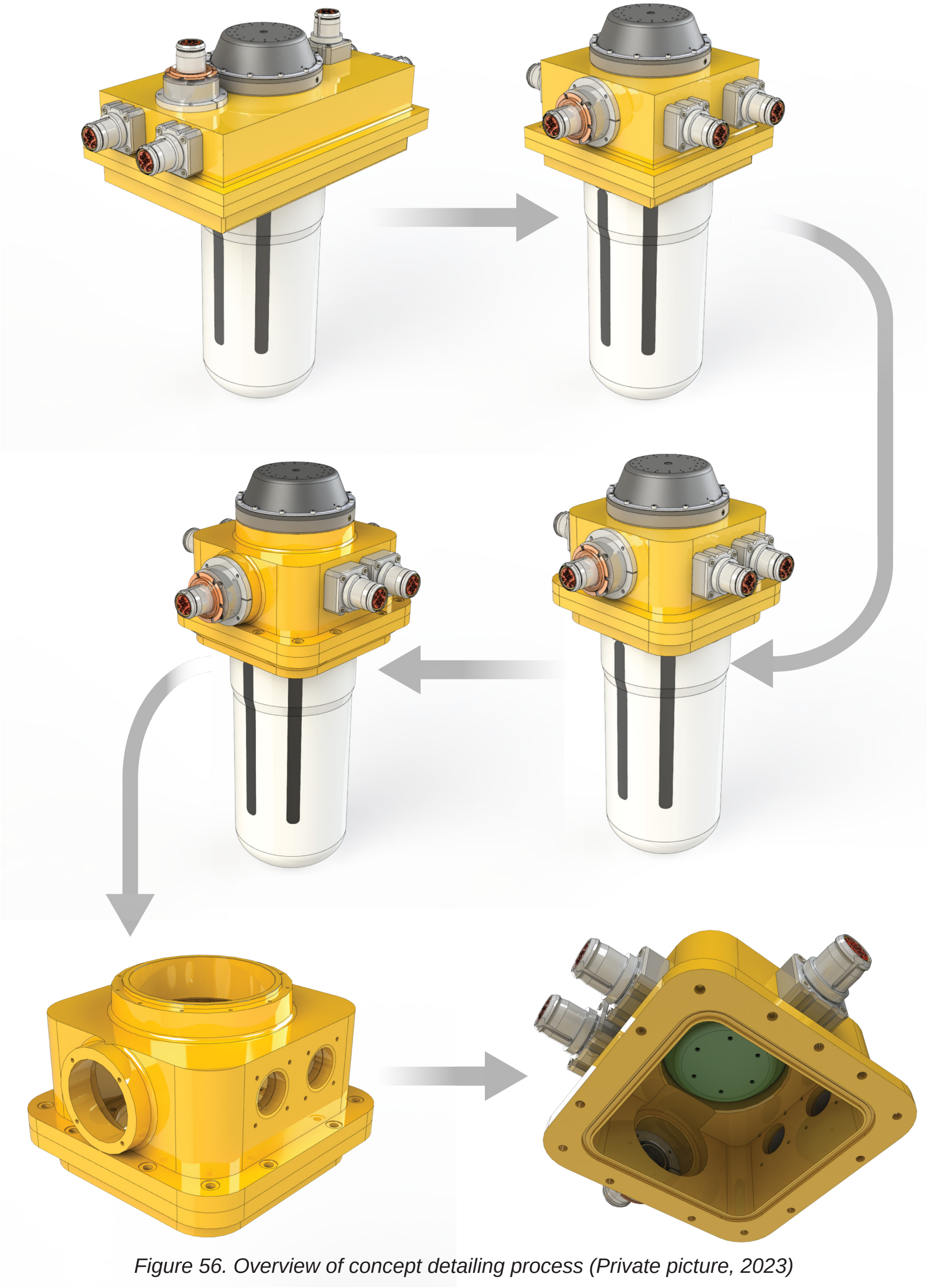


Figure 56. Overview of concept detailing process (Private picture, 2023)

Fastening

Due to the project aiming to redesign the ACM as a fully functional component, details such as screws will follow the same principles as the current ACM. For this reason, socket head cap screws will be the fastening devices for the top and bottom housing. These types of screws are already tested and verified through the current ACM.

Placement

The available areas on the FCM, as presented earlier, are now directly utilized to evaluate the placement of the concept. Due to the product's connectors, the concept can only be positioned vertically. Nevertheless, all available areas are tested with the concept to illustrate the possibilities and explore potential placement options.

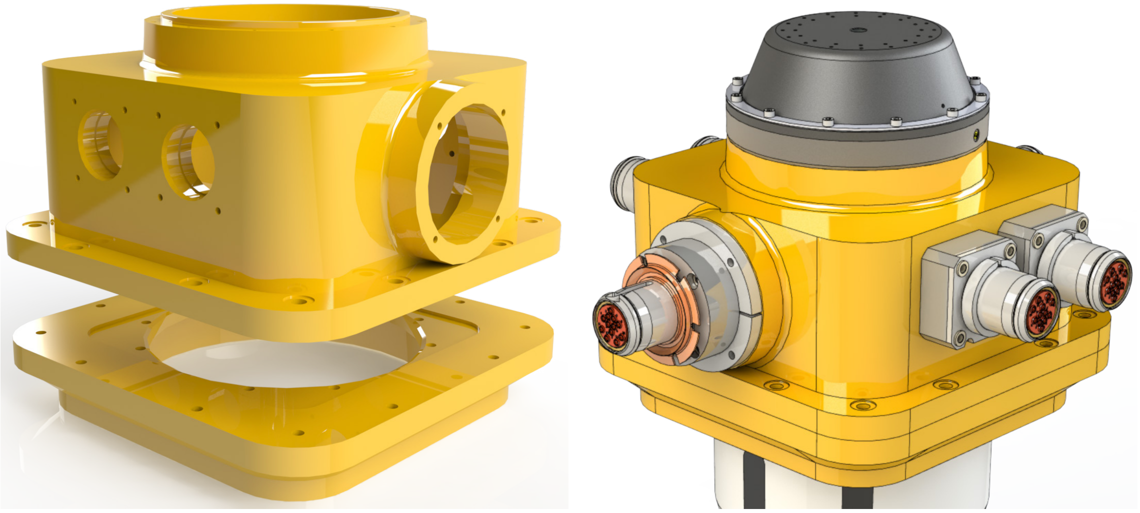


Figure 57. Render of housing fastening method (Private picture, 2023)

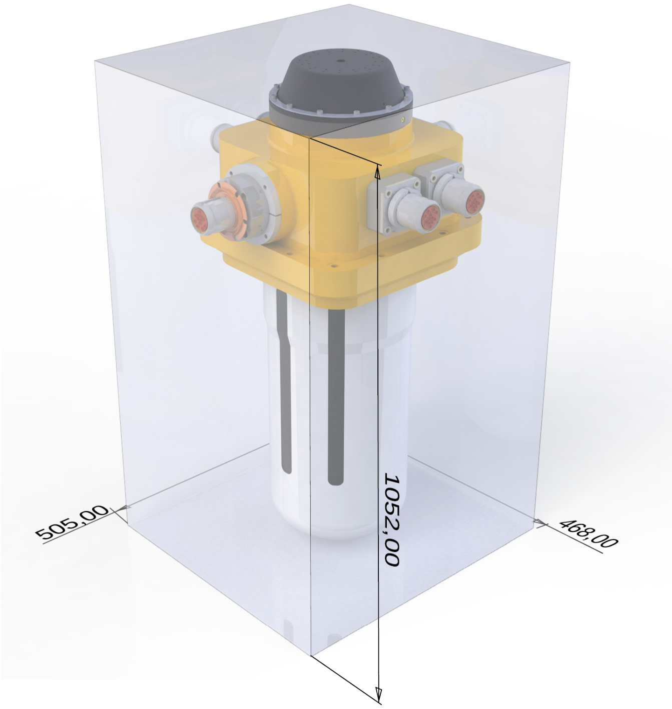


Figure 58. Render of the external volume of the concept (Private picture, 2023)

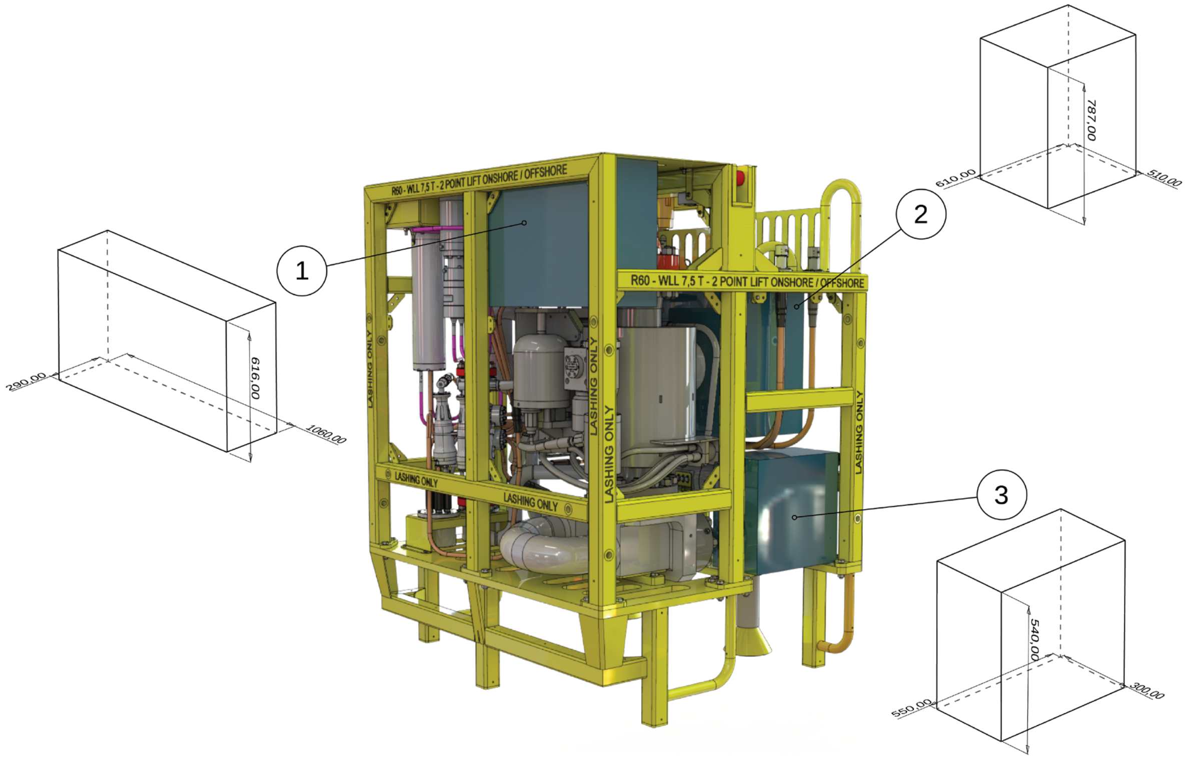


Figure 59. Render of available space on FCM (Private picture, 2023)

Although position one offers enough space to mount the concept horizontally, this orientation is not optimal since it would result in some connectors facing upwards. However, this position also provides an advantage in maintenance, as it improves the view for ROV inspections of the compensator. Furthermore, the chosen corner for placement has no jumpers associated with other components, making installation easier without any interfering elements.

Position two offers sufficient space to place the concept in an upward position. This configuration ensures that all connectors are oriented horizontally, preventing water buildup. However, a drawback of the position is that the compensator becomes challenging to inspect as it is squeezed between the ceiling and another component. Mounting the ACM to the FCM with such a reduced area is also not optimal. It can even prove impossible as equipment may be unable to access the area.

Position three offers enough space to position the module horizontally. However, it presents a similar challenge as placement number one, with some connectors facing upwards.

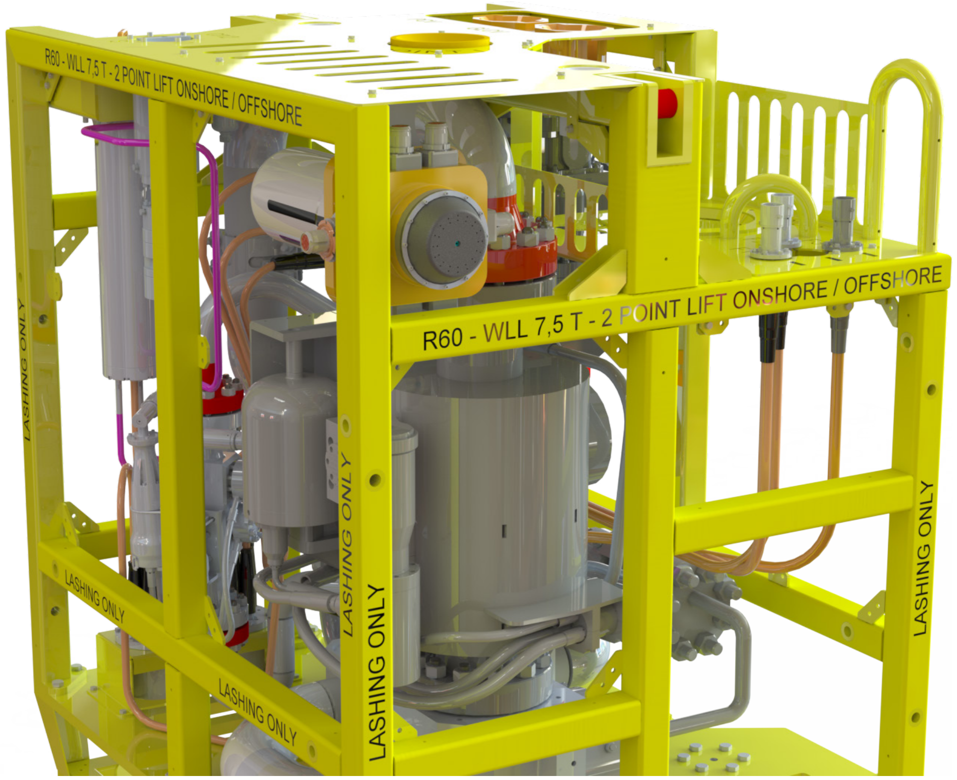


Figure 60. Render of concept placement in position one (Private picture, 2023)

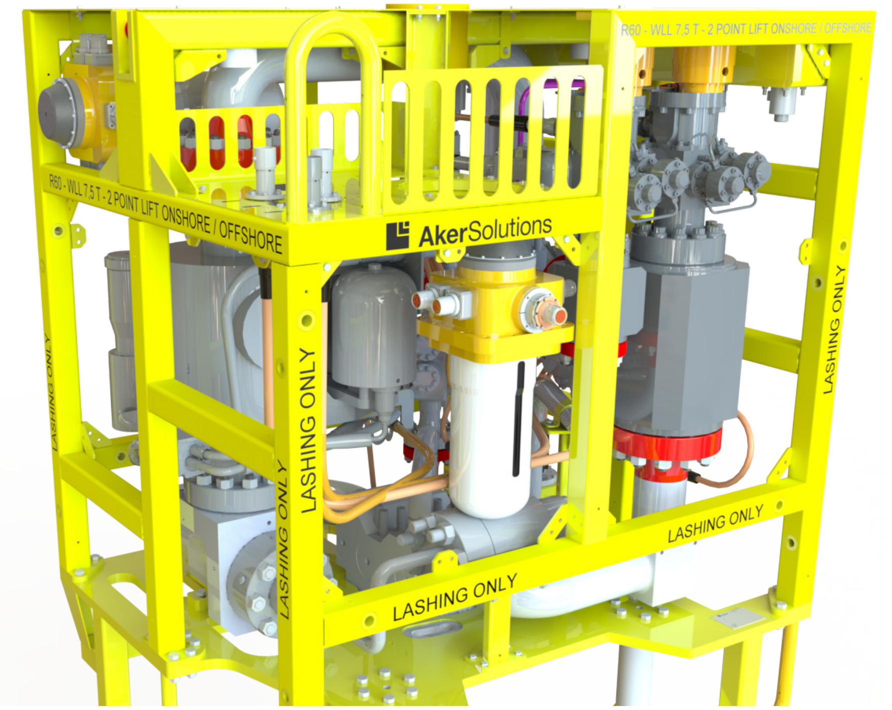


Figure 61. Render of concept placement in position two (Private picture, 2023)

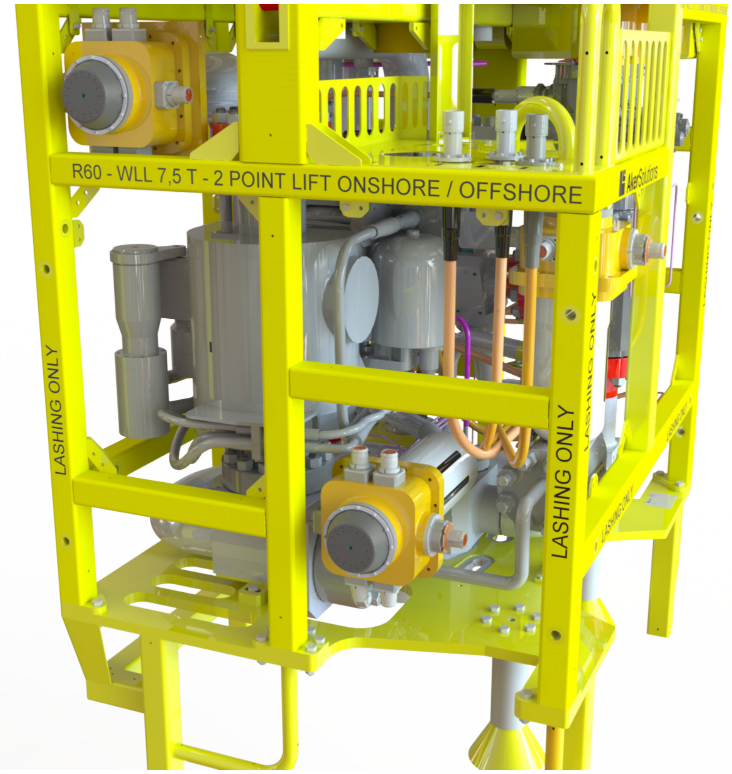


Figure 62. Render of concept placement in position three (Private picture, 2023)

After evaluating all potential positions, it becomes evident that position two is optimal for the concept to function as intended. This is because the ACM can be placed vertically while avoiding water buildup in the connectors. However, this area is relatively small and has reduced space for other components and jumpers. Upon analyzing and evaluating the hydraulic FCM, a suggestion is to move the jumpers in that area to create additional space. This needs to be assessed with Aker and potentially executed by the FCM designer.

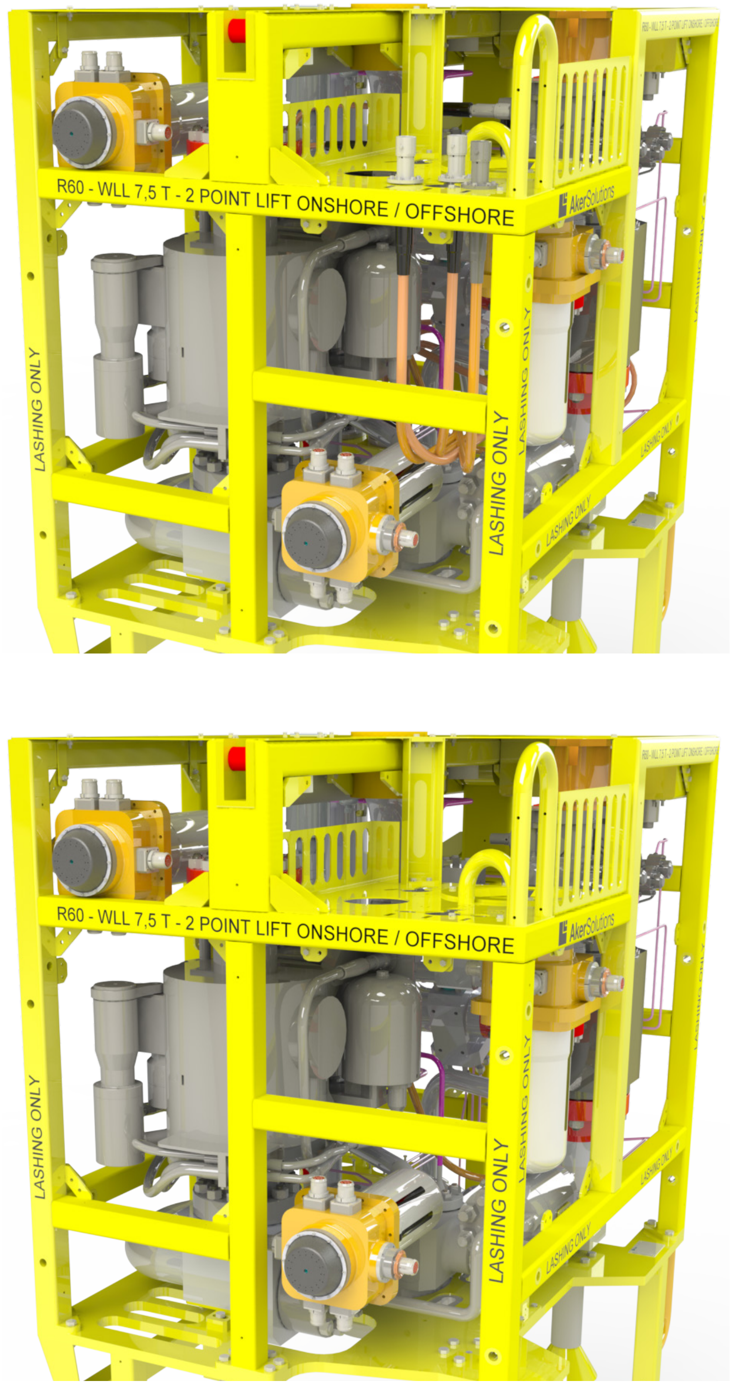


Figure 63. Render of removed jumpers for instruments (Private picture, 2023)

Moving the jumpers creates enough space for the concept to be vertical without the risk of interfering with existing components. This is an optimal placement for ROV inspection while accessing the ROV connector needed for the Xmas tree is possible. It places the module in the corner of the FCM, making it easier to guide the jumpers to different areas improving assembly time and accessibility to the module. In addition, the module is placed in a way that makes it natural for the jumpers to have a lower point than the connectors, meaning that water buildup in the connectors can be avoided.

The number of driveheads controlled by an ACM can vary from one to four. Consequently, when generating ideas for mounting the ACM to the FCM, solutions that involve horizontal fastening are considered even if the connectors are not optimally placed. This expands the range of options available for mounting the ACM to the FCM, depending on the specific control requirements of the module.

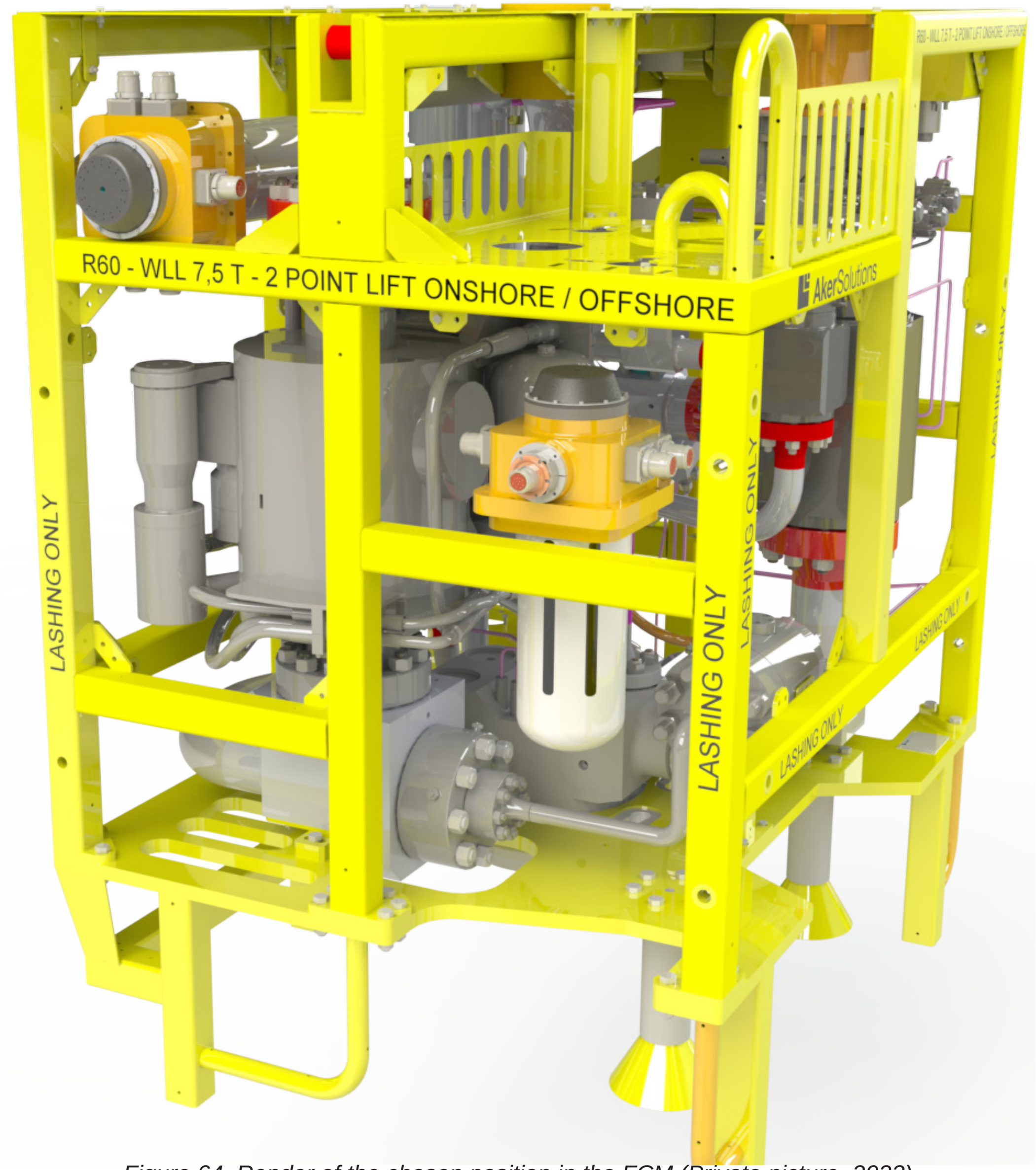


Figure 64. Render of the chosen position in the FCM (Private picture, 2023)

Mounting to Flow Control Module

Exploring various mounting methods for the ACM is crucial to achieving an interchangeable design. The following pages provide an overview of solutions corresponding to rotations and positions. The outcome will be a proposed solution for a horizontal mount and a separate solution designed explicitly for a vertical mount.

Horizontal mounting

The first suggestion is based on the horizontal positions of the ACM within the FCM. This solution involves a plate fastened to the top of the ACM. However, implementing this solution requires adding seven holes to the top housing, increasing assembly and production time. Moreover, this solution limits the view of the connectors when mounted, potentially posing challenges if a connector needs to be inspected.

This mounting method enhances the compensator's visibility while partially obstructing the view to the connectors. Nonetheless, this solution provides a straightforward and practical suggestion for mounting the ACM horizontally but will not be further developed.

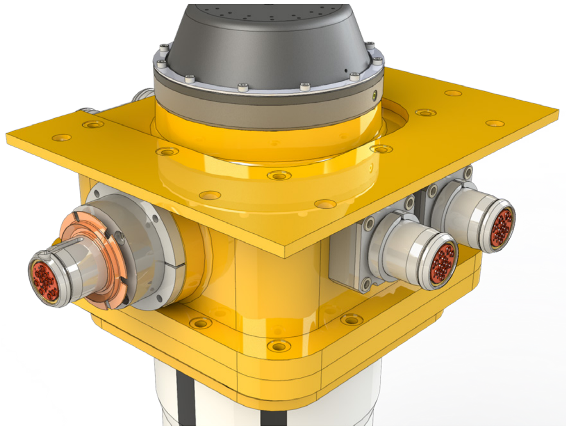


Figure 65. Render of a horizontal fastening idea (Private picture, 2023)

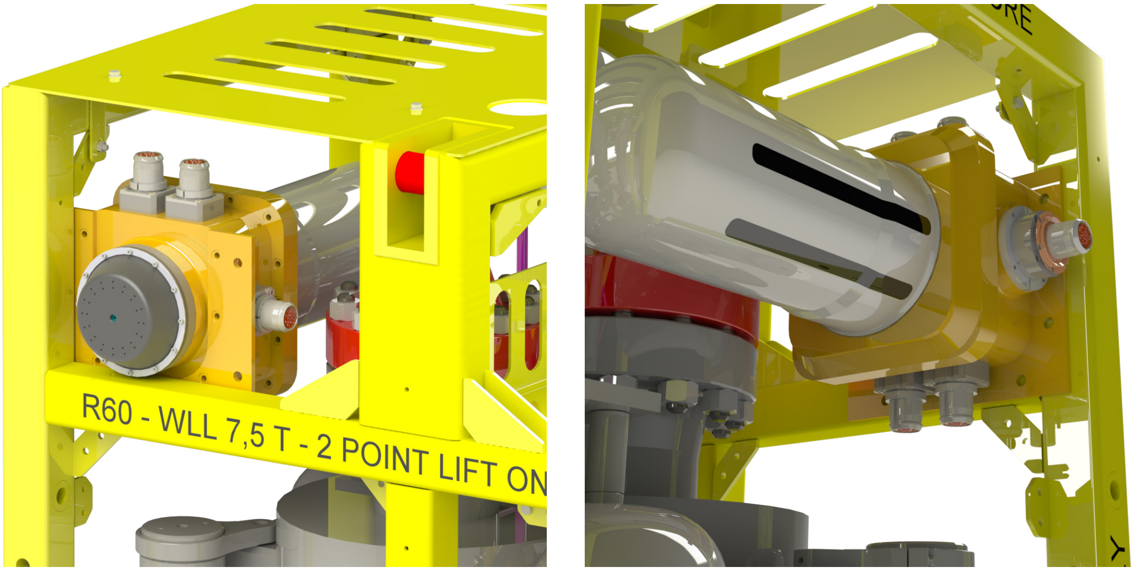


Figure 66. Render of horizontal fastening idea placed on FCM (Private picture, 2023)

The second solution takes advantage of the available space on the bottom housing. Similar to the first solution, it emphasizes the horizontal positioning of the ACM. The solution requires six holes around the bottom housing and achieves a more functional design. The solution provides enhanced visibility of the compensator while avoiding obstructing the connectors by the fastening plate.

During the assembly process, six holes are machined around the bottom housing. The bracket is then connected to the bottom housing using screws. The solution is adaptable to different trees by adjusting the size of the plate and its orientation on the ACM. Furthermore, it can be easily modified to accommodate rotations where the ACM is not positioned horizontally.

The bracket is redesigned to have an easier assembly feature around the bottom housing instead of being tightly fixed. Holes are added to the bracket, and the body is split to facilitate assembly and alignment. The result is a simple solution that can be easily modified by the FCM designer depending on the placement of the ACM.

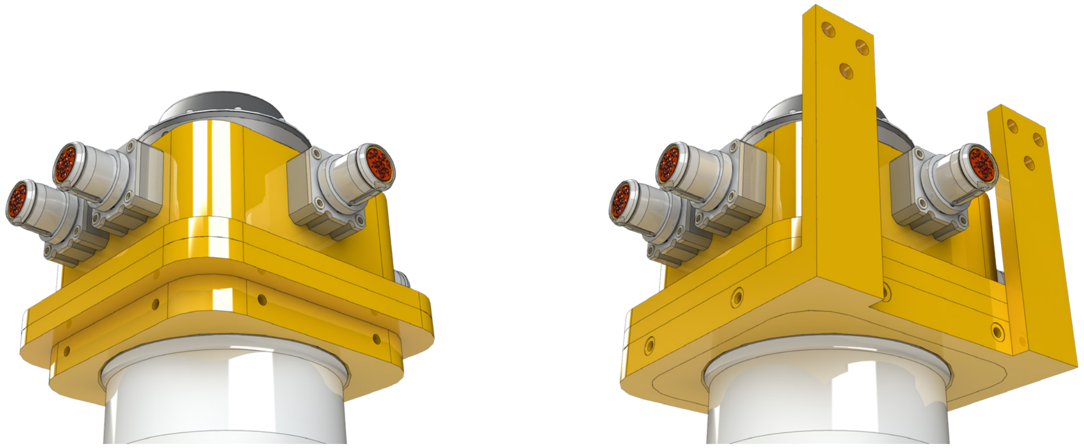


Figure 67. Horizontal fastening solution (Private picture, 2023)

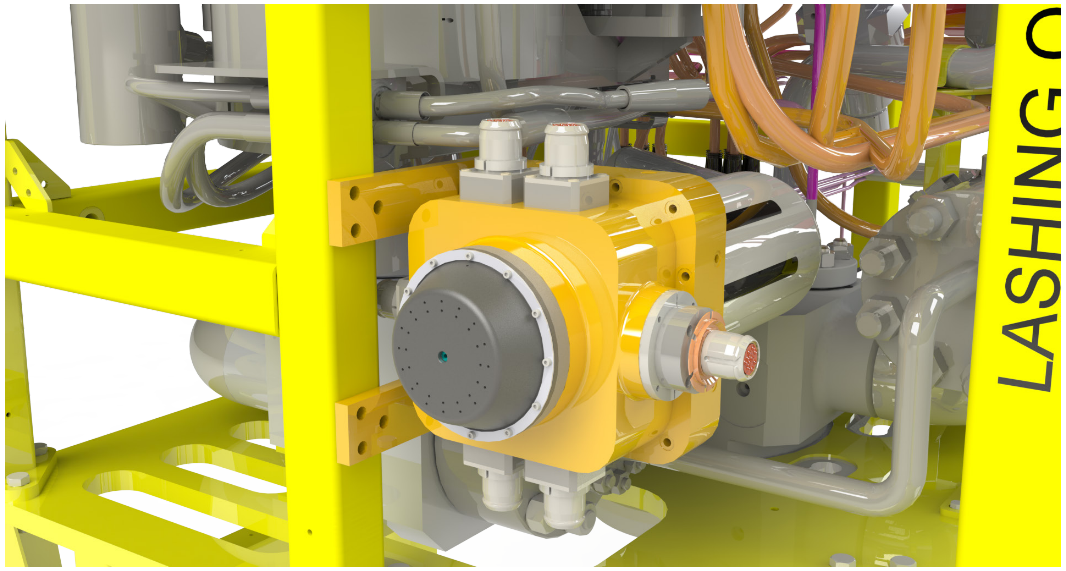


Figure 68. Horizontal fastening solution placed on FCM (Private picture, 2023)

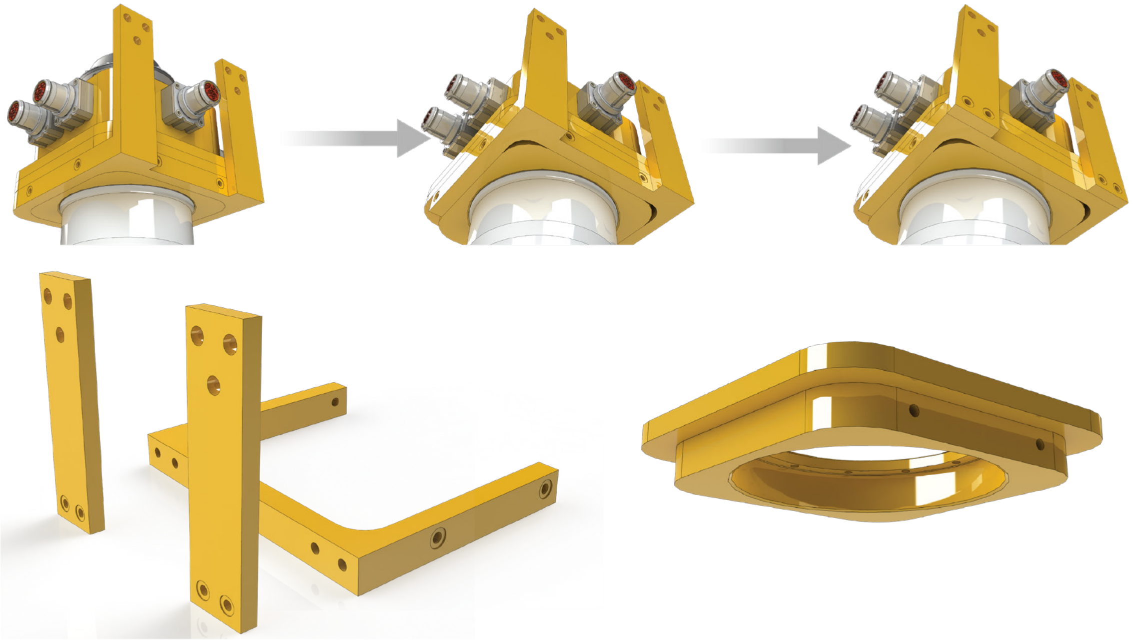


Figure 69. Detailing of horizontal fastening solution (Private picture, 2023)

Horizontal mounting

The optimal position for the ACM is when it is vertically placed in the FCM. This configuration prevents water buildup in the connectors and ensures the visibility of all components during an ROV inspection. Additionally, placing the ACM in this orientation enhances the handling of the module as it is easier to balance the weight.

The previously presented solution for horizontal orientation is the foundation for a vertical fastening method. Utilizing the same holes on the ACM as the horizontal solution ensures that the ACM does not need to be modified to accommodate different orientations, which will decrease production time and cost. The amount of holes is also reduced from six to four.

The simple design of the bracket allows for easy adjustment. The approach offers optimization by enabling more efficient and cost-effective changes to the fastening plate instead of modifying the ACM housing. It also simplifies the redesign process for the FCM designer and provides greater flexibility in adjusting the fastening method when exploring multiple potential positions for mounting the ACM on the electrical FCM

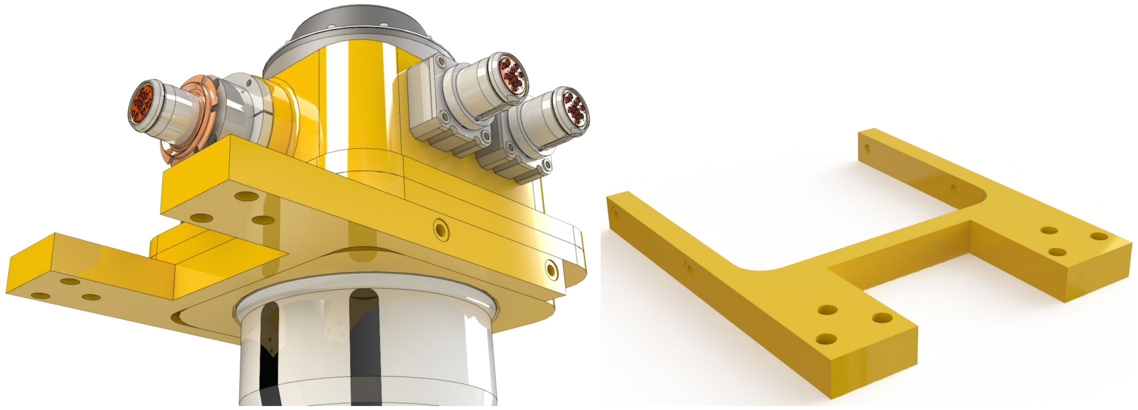


Figure 70. Render of vertical fastening solution (Private picture, 2023)

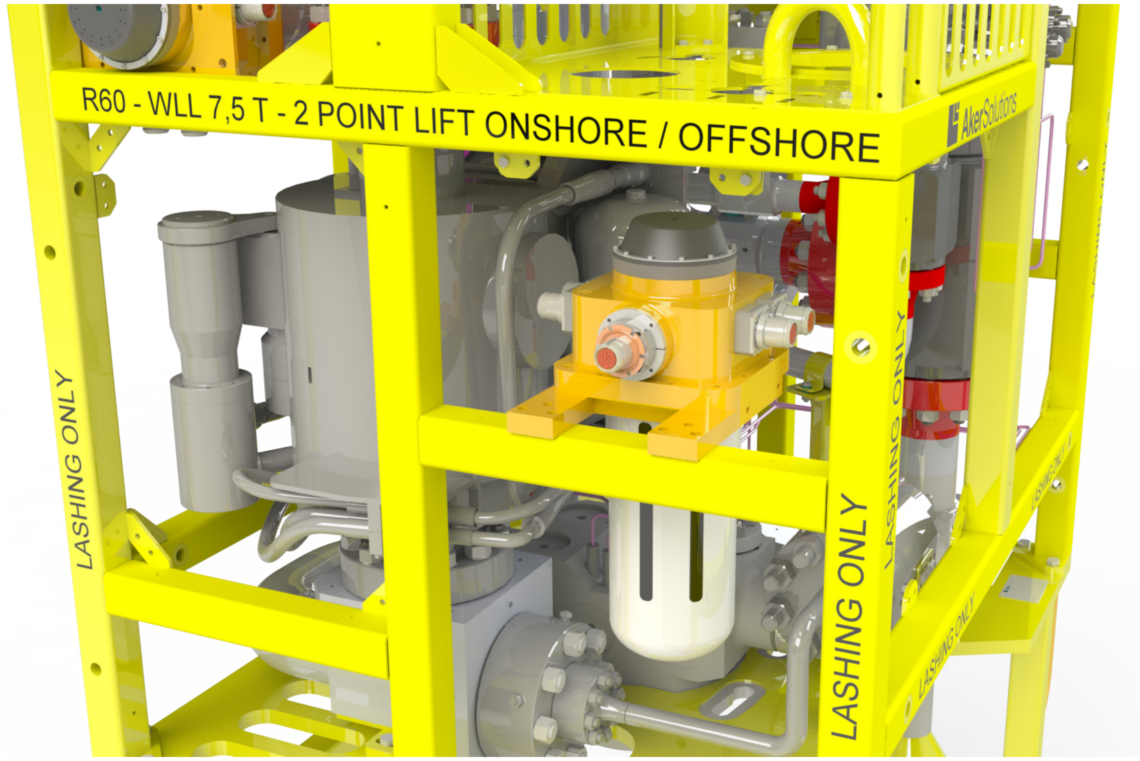


Figure 71. Horizontal fastening solution placed on FCM (Private picture, 2023)

Transport

For the transportation of the ACM, the current solution is used. This is because it is a straightforward and practical approach that does not require any modifications to the ACM housing other than adding two holes on the top housing. Utilizing the same hooks used in existing products helps reduce costs, as these are standardized parts.

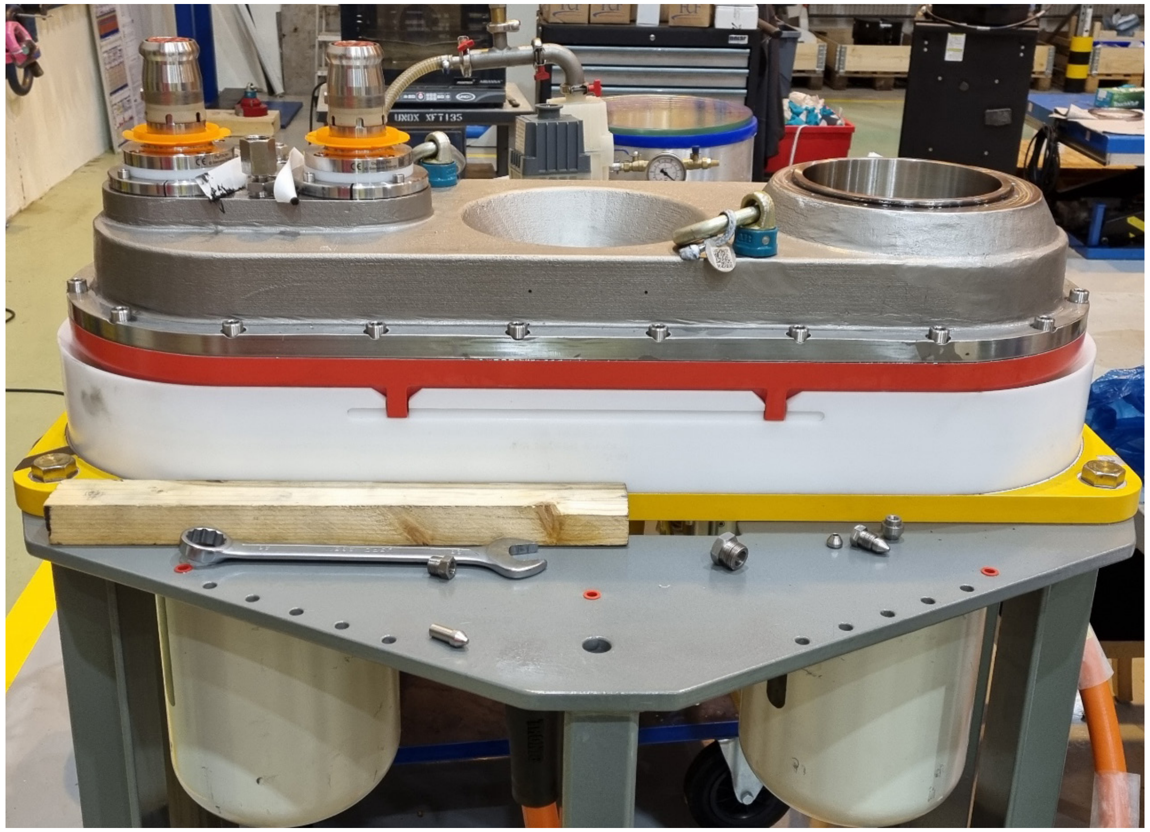


Figure 72. Picture of hooks in the current ACM (Private picture, 2023)

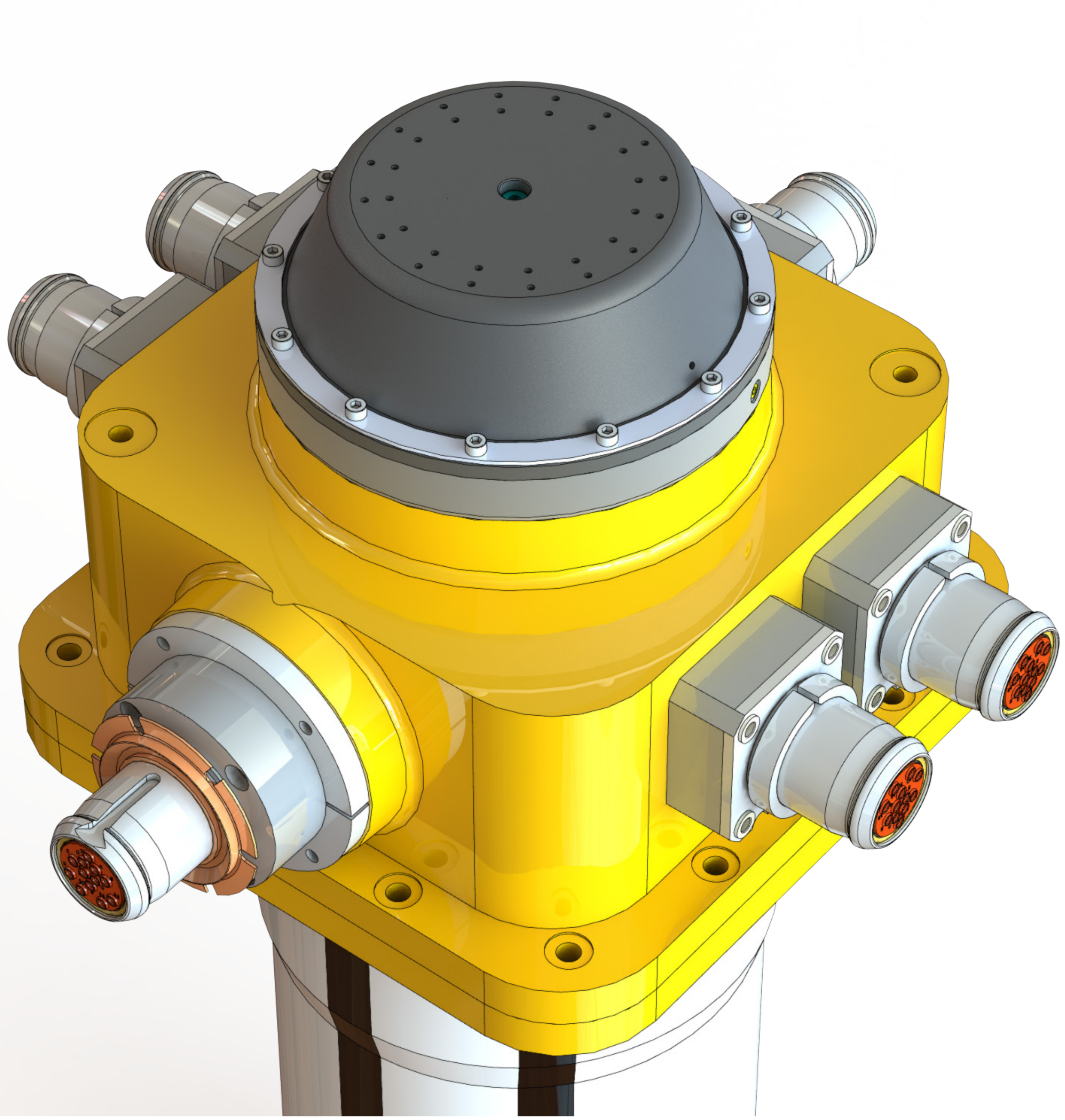


Figure 73. Render of holes created for hooks (Private picture, 2023)

(Seyferth, 2018)

5

Technology Assessment

Assess Technology

A technology assessment systematically evaluates the technical aspects of the presented concept. The assessment aims to discuss different components. Due to the aim of this thesis, only the most relevant components will be assessed to determine whether they should be retained or replaced.

Jumpers and Connectors

Aker Solutions utilizes oil-filled AquaTRON jumpers in their subsea equipment. A key advantage of utilizing these oil tubes is their ability to provide pressure compensation due to the flexibility of the tube material in combination with the oil. Furthermore, these jumpers can be integrated with junction boxes and different connectors. The jumpers are broadly utilized within all Xmas trees and FCMs, making it the established standard. Consequently, replacing the jumpers would result in heightened costs and inefficiencies.

Due to the jumpers being oil-filled tubes, the connectors must specifically be made for these jumpers. The connectors must also be configured to accommodate a 12-way cable. With this in regard, three different connector options are available; the stab plate connector, the diver connector, and the ROV connector.

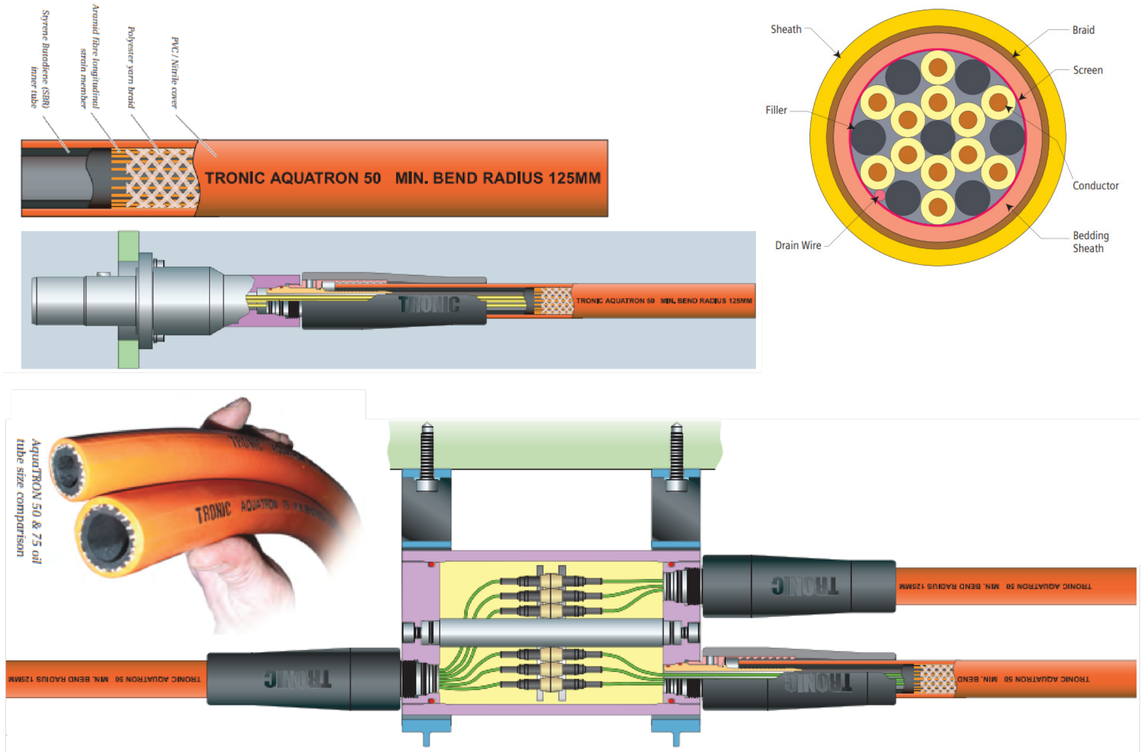


Figure 74. Overview of cables and types, edited pictures from (Siemens-energy, u.y)
Figure 75. Illustration of 12-way connection (Siemens-energy, u.y)

Stab plate connectors for oil tube

The existing ACM has stab plate connectors designed explicitly for aquatronic oil tubes and depths up to 4000 meters. These stab plates can accommodate misalignment, ensuring a secure connection. They provide clamping force and allow for movement during demate/mate processes. The stab plate connectors are also highly adjustable, as they offer different flanges for mounting to the product.

The current ACM utilizes conventional straight stab plate plugs and receptacles primarily because the current position allows all stab plate connectors to be downwards. However, in the proposed concept, this arrangement changes as several connectors are positioned horizontally. To prevent interference with other components in the FCM and to follow the requirement of a minimum bend radius of 180mm on the jumpers, it is necessary to incorporate 90-degree connectors. This adjustment ensures proper functionality and considers the geometrical constraints of the surrounding elements without increasing assembly time.

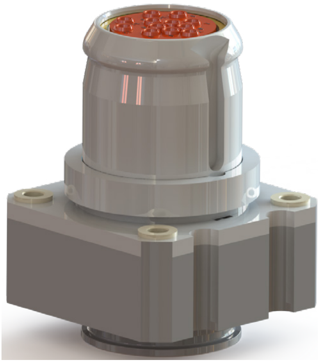


Figure 76. Render of 12-way connector (Private picture, 2023)

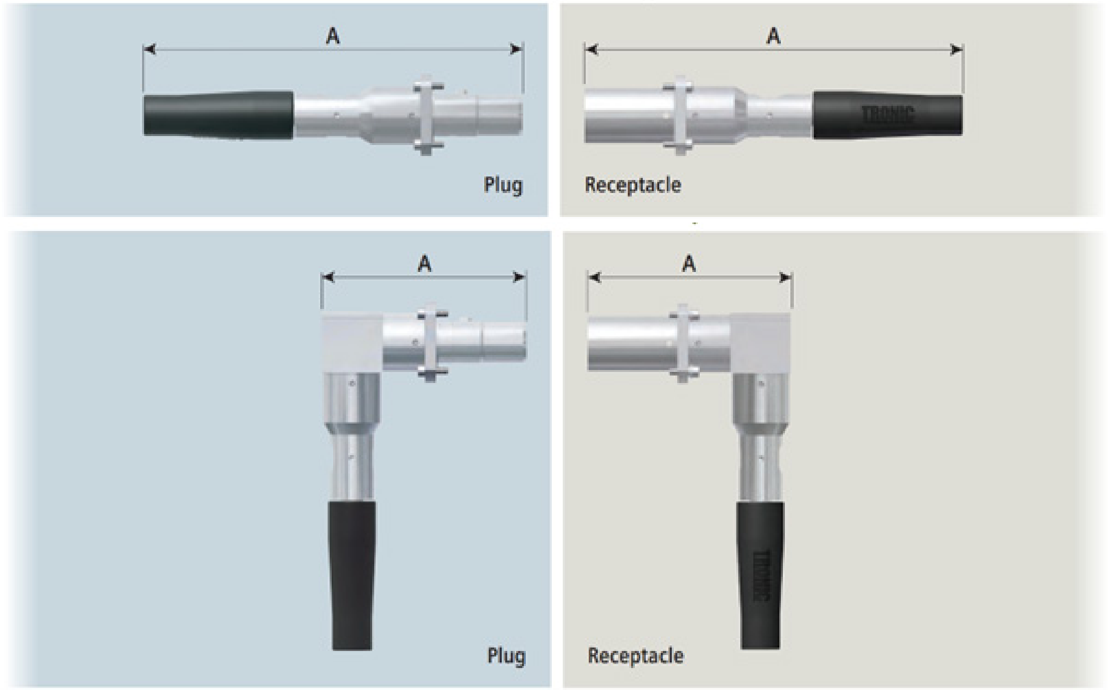


Figure 77. Illustration of stab plate connectors (Siemens-energy, u.y)

Diver connector

Diver connectors offer an alternative to stab plate connectors for depths up to 1000 meters. These connectors are cost-effective and eliminate wear caused by adhesion by utilizing a clamp ring that ensures secure fastening (Siemens-energy, u.y). Additionally, these connectors can be conveniently supplied in a 90-degree configuration similar to the stab plate.

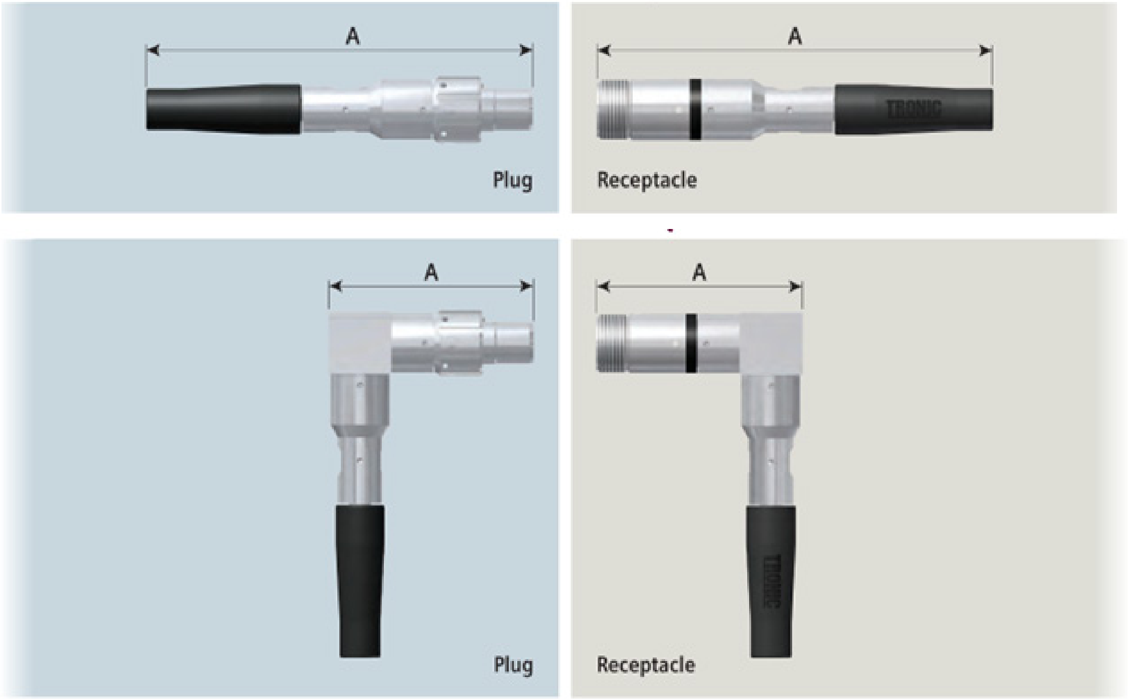


Figure 78. Illustration of diver connections (Siemens-energy, u.y)

ROV connectors

ROV connectors serve the purpose of establishing connections that cannot be made prior to deployment. As a result, the connectors require an ROV interaction that can attach jumpers once the module is in position. These specialized connectors feature a large catchment area to handle significant misalignment. The connectors also include a robust mating mechanism capable of withstanding challenging conditions.

The concept relies on a single ROV connection to communicate and receive power from the PCGM placed on the Xmas tree. It is worth noting that the ROV connector is larger than the stab plate and tends to be more expensive, primarily due to the higher cost of the product itself. There are also additional expenses associated with ROV intervention and operation.

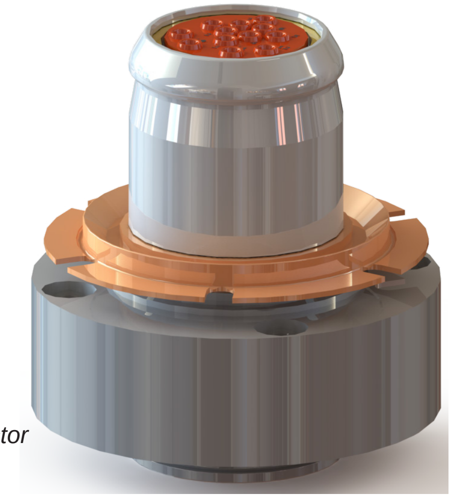


Figure 79. Render of ROV connector (Private picture, 2023)

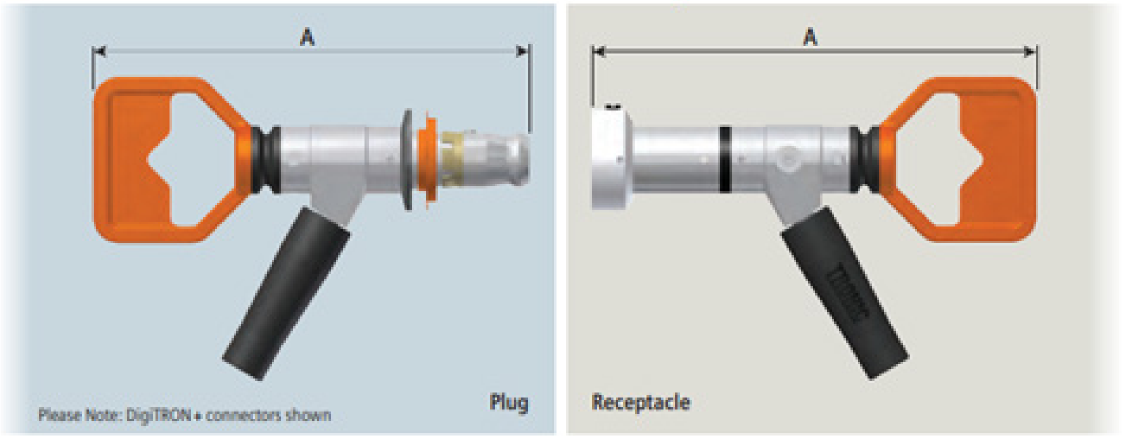


Figure 80. Illustration of ROV connector (Siemens-energy, u.y)

The current design and utilization of an ROV connector present several challenges that must be addressed. Apart from the higher cost and larger physical connector compared to a stab plate connector, there are potential issues during transport and deployment. A concern is that the ROV handle needed to grab the connector increases the total size, causing it to go outside the FCM. Equipment that goes outside the FCM structure is not acceptable.

Additionally, it is worth noting that the ROV typically carries out interventions from the ceiling when working with connectors. This allows access to the connectors while minimizing the risk of unintended drift. However, with the current concept, the ROV connector is positioned more than 600mm away from the tree, which means that the ROV cannot grab it, as indicated in the interviews.

Alternative solutions can be considered to address the issue of the connector being out of reach for the ROV. One option is to utilize existing equipment on the FCM. As previously mentioned, a junction box can serve as a gathering point where multiple jumpers are connected into a single jumper that extends to the top of the FCM, equipped with an ROV connector. By utilizing the junction box, the concept can achieve a more feasible and efficient solution while ensuring compatibility with the existing infrastructure on the FCM. This also removes an ROV interaction reducing deployment time while making the ACM cheaper overall.

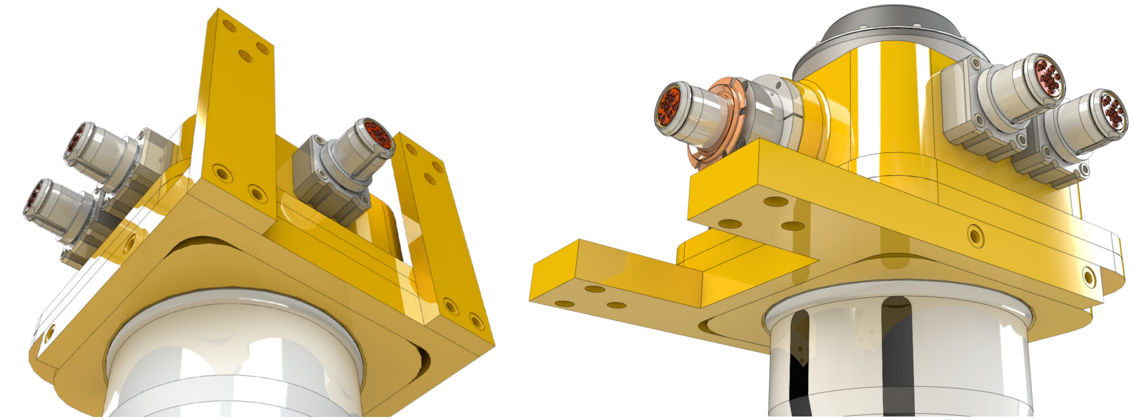
Figure 81. Render showing ROV connector (Private picture, 2023)

Mounting and Transport

When considering the mounting position, vertical mounting of the ACM proves to be the optimal solution due to the placement of connectors. This approach increases the installation efficiency of the module to the FCM. However, the horizontal solution can also be utilized in scenarios requiring multiple ACMs in a configuration, particularly since the ACM design remains unchanged. This flexibility is possible due to the bottom housing design, where four holes accommodate vertical and horizontal fastening brackets.

Regarding transportation, various options are available depending on the assembly location. For modules of this size, cardboard boxes are commonly used due to their affordability, accessibility, and ease of customization using foam inserts. A dedicated transport racket or structure can be designed to mount the equipment during transportation. Although this solution is costly, it ensures safe and reliable transport.

An alternative to these options is a Pelican case. Pelican cases are large, durable portable cases commonly utilized for equipment transportation. These cases are designed to be easily moved using a forklift, by hand, or with wheels. They come equipped with foam inserts that can be cut and customized to fit the specific equipment. Furthermore, they are equipped with water-resistant seals and automatic pressure equalization valves. (Pelican, 2023) This proves to be the optimal choice for the ACM, as Aker anticipates frequent transportation, necessitating a cost-effective and resilient solution.



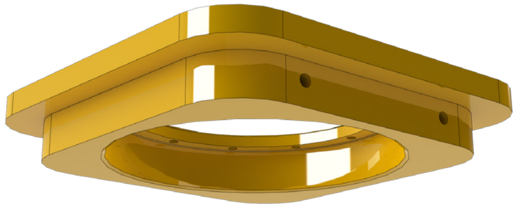


Figure 82. Render of mounting solution (Private picture, 2023)

Figure 83. Render of concept lower housing (Private picture, 2023)

Figure 84. Picture of the Pelican case (Pelican, 2023)

Compensator

As mentioned in the interviews, the compensator used on the ACM is initially made for volumes up to 9 liters, while the current ACM housing is 20 liters. This means that the existing ACM housing is filled with plastic (POM) for volume displacement in addition to the dielectric fluid.

The total volume of the concept is calculated to be a maximum of 8.57 liters, meaning that the standardized compensator can be utilized without the need for plastic. This eliminates an inconvenience while reducing costs and improving assembly efficiency.

Canister AECM

Diving into the specific technology and solutions would be unnecessary as the canister is a highly confidential and technical unit. The canister is a standardized unit utilized across multiple products, and altering its design or functionality would not result in favorable results.

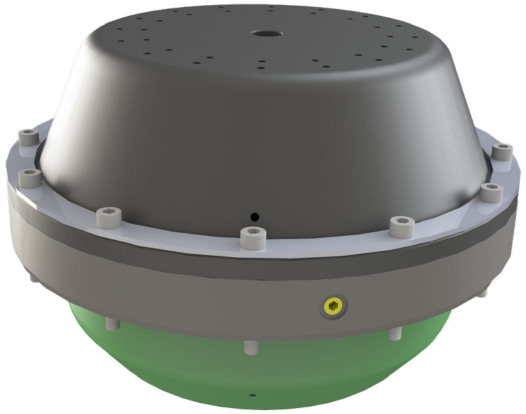


Figure 85. Render of the compensator (Private picture, 2023)

Figure 86. Render of the canister (Private picture, 2023)

Coating

The primary coating applied to the product will be the same as the one already utilized by Aker Solutions, following the standard NORSOK M-501. This coating is known for its corrosion resistance properties, resulting in decreased anodes needed. It minimizes the need for maintenance while being user-friendly during application.

In addition to the primary coating, nanotechnology-based coatings can be utilized for enhanced protection. Nanocoatings, known as biomimetic antifouling coatings, have previously demonstrated effectiveness in preventing biofouling. One such example is the coating provided by Sharklet, which effectively inhibits the accumulation of macro and micro-fouling species. (Santosh et al., 2021)

Applying an antifouling coating to essential areas such as the compensator and connectors is suggested for this concept. The additional layer will significantly reduce marine growth, ensuring clear visibility during inspections conducted by the ROV.

Color

The coloring of the ACM is based on the colors currently utilized on the existing ACM. The canister will be grey, while the housing will be colored orange, as commonly used for control modules. These colors adhere to the ISO 13268-1 standard, facilitating easy module identification.

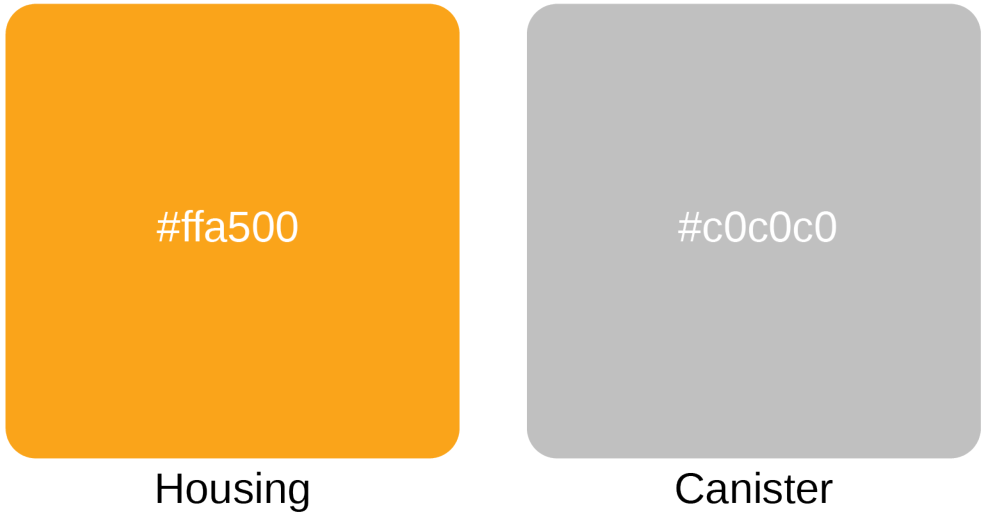


Figure 87. Illustration of colors used on ACM (Private picture, 2023)

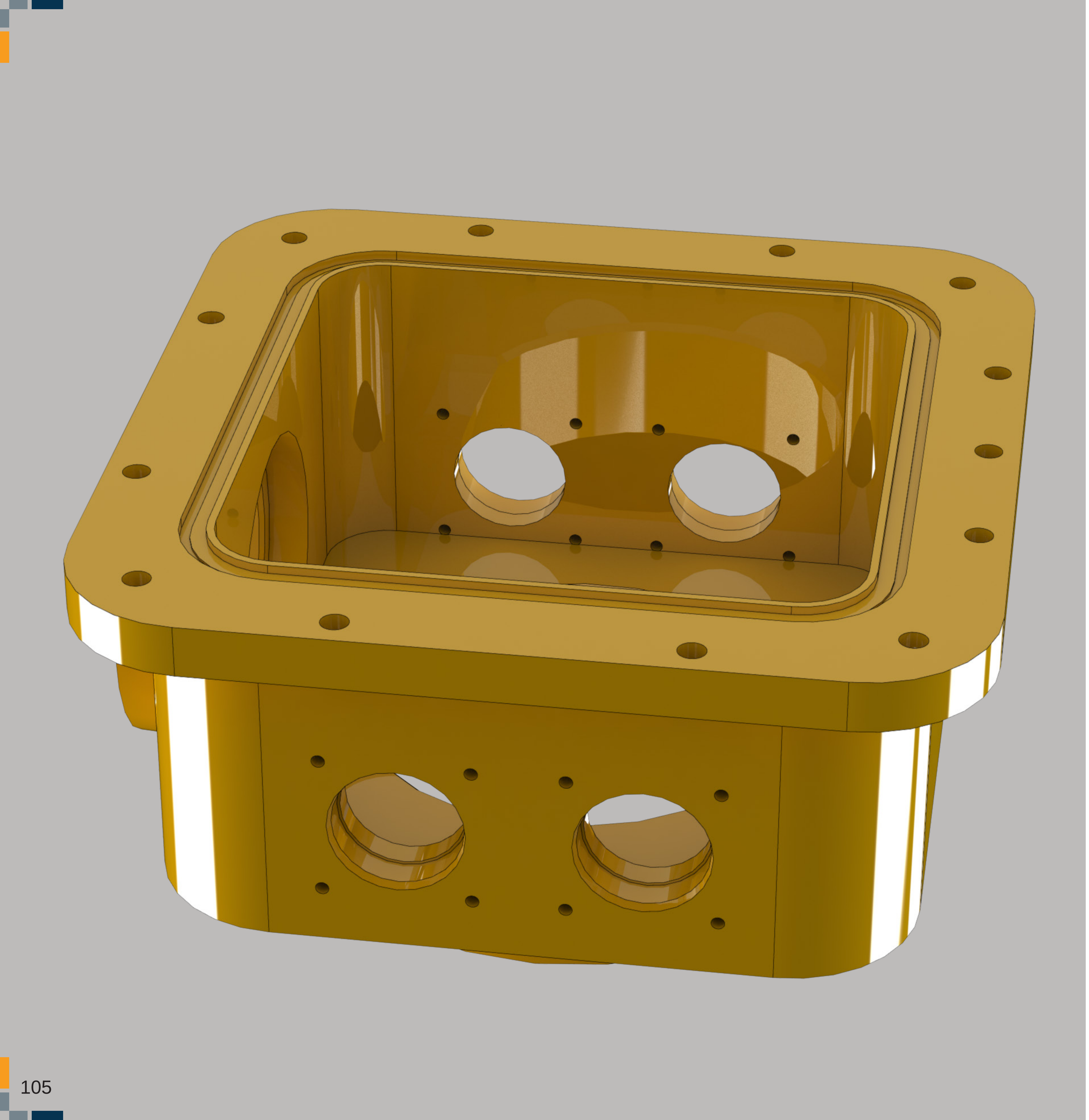
Production and Material

The concept utilizes the same material as the current ACM to ensure durability under extreme conditions. The top housing is constructed from a specialized cast iron (GJS400). This material offers excellent strength and resilience. The bottom housing is fabricated from a carbon alloy steel plate (S355).

A sand casting process will be used to manufacture the top housing, followed by machining to achieve the desired detailing. This combination of casting and machining ensures the housing’s dimensional accuracy and surface finish. The bottom housing will only undergo machining, contributing to cost-effectiveness compared to the casting process. The concept achieves improved durability, performance, and cost-efficiency by utilizing these production techniques. Following these methods, the top housing will be drafted on all necessary surfaces to enhance the casting process.

Figure 88. Picture of sand casting (Weld2cast, 2021)

Figure 89. Picture of machining (Seyferth, 2018)



6

Threat Assessment

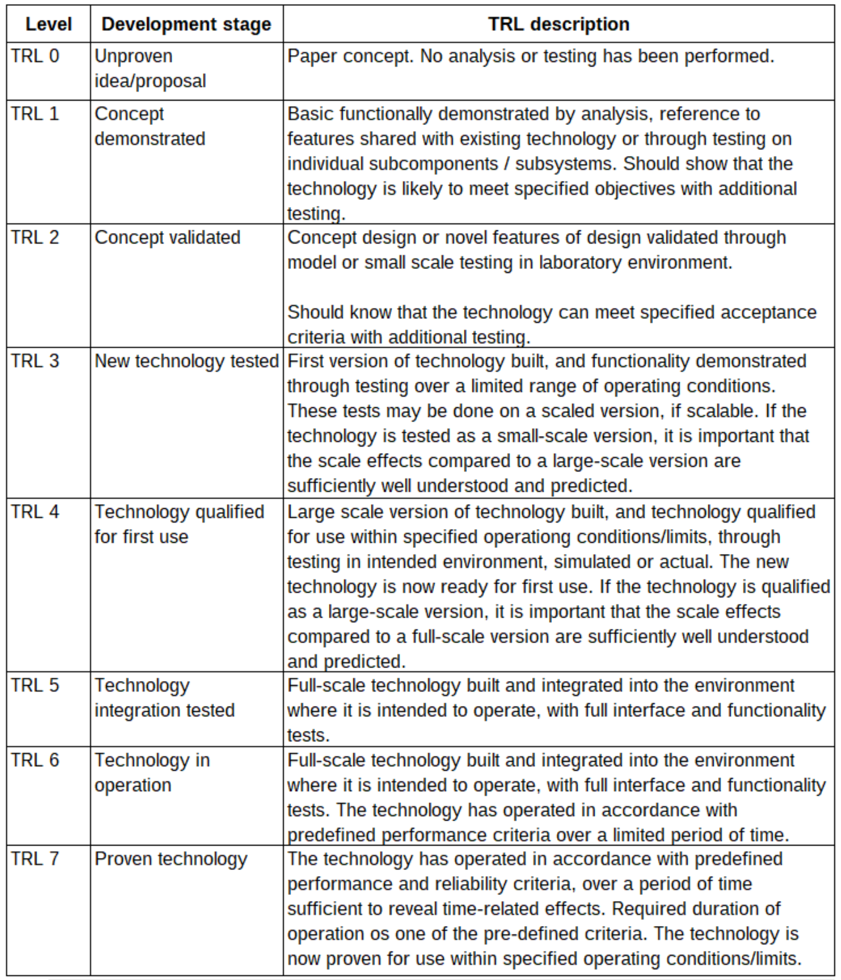
Risk Analysis

In addition to the technology assessment, a risk assessment is executed to identify potential risks associated with each component. The assessment will uncover the probability of an issue occurring and analyze the potential impact. This will lead to an overview of potential negative impacts, which minimizes the risk and increases the chances of a successful outcome.

For each component, the illustrated table will be used. The table categorizes the risk on a scale ranging from very low to very high while defining the technology readiness level. This determines whether the product is; ready for use, required development achievable within project time frame, contractual commitment with clear mitigating contractual outs, or no contractual commitment recommended, candidate for JIP or similar.

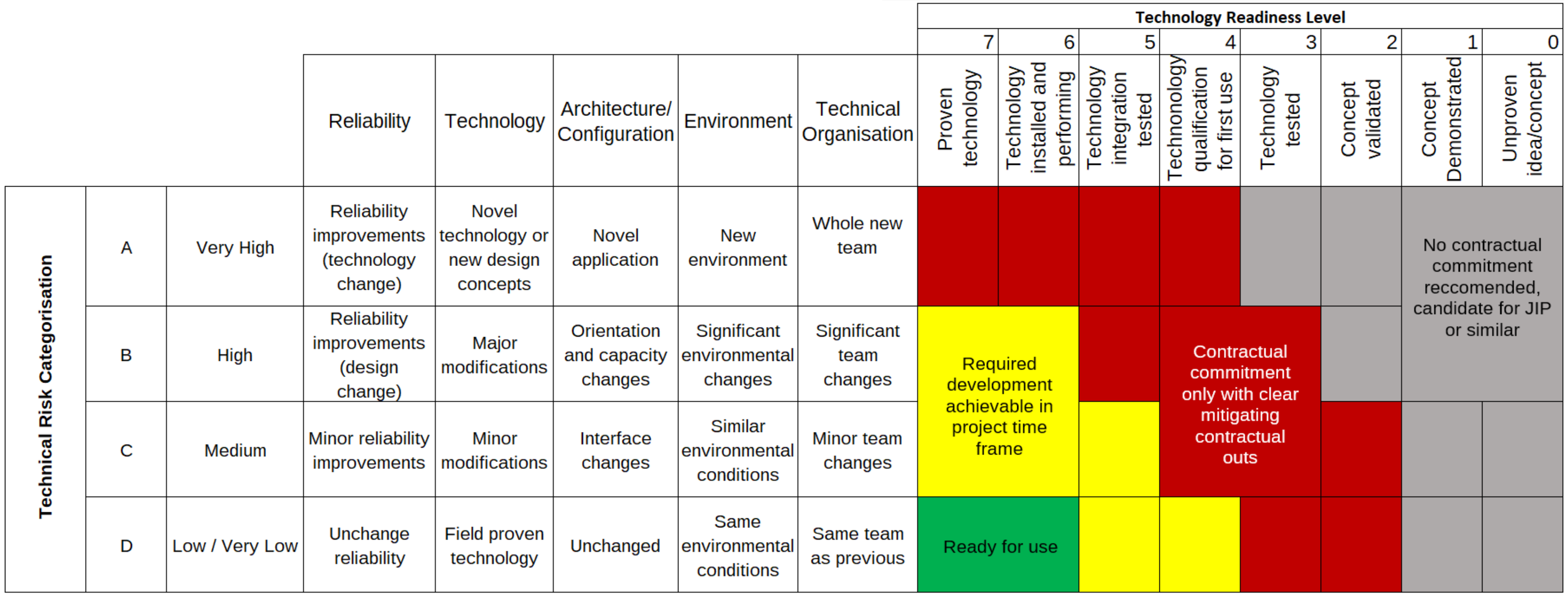
The result will be identified issues associated with each component. This makes it possible to achieve a targeted focus on what to improve with the current concept allowing a solid foundation to be established when evaluating solutions. This will minimize the potential issues and risks with the product.

During the evaluation of each component, the focus will be directed towards identifying and addressing the most significant issues and risks. Following the table, these risks will be targeted and assigned a value, such as A-1. In the table, (A) represents “very high risk,” while (1) represents “concept demonstrated.” The approach allows for a systematic overview of the components by highlighting relevant and critical risks while providing an understanding of the severity. By doing so, the major risks can be focused and addressed, making them easier to resolve.



Level	Development stage	TRL description
TRL 0	Unproven idea/proposal	Paper concept. No analysis or testing has been performed.
TRL 1	Concept demonstrated	Basic functionally demonstrated by analysis, reference to features shared with existing technology or through testing on individual subcomponents / subsystems. Should show that the technology is likely to meet specified objectives with additional testing.
TRL 2	Concept validated	Concept design or novel features of design validated through model or small scale testing in laboratory environment. Should know that the technology can meet specified acceptance criteria with additional testing.
TRL 3	New technology tested	First version of technology built, and functionality demonstrated through testing over a limited range of operating conditions. These tests may be done on a scaled version, if scalable. If the technology is tested as a small-scale version, it is important that the scale effects compared to a large-scale version are sufficiently well understood and predicted.
TRL 4	Technology qualified for first use	Large scale version of technology built, and technology qualified for use within specified operationg conditions/limits, through testing in intended environment, simulated or actual. The new technology is now ready for first use. If the technology is qualified as a large-scale version, it is important that the scale effects compared to a full-scale version are sufficiently well understood and predicted.
TRL 5	Technology integration tested	Full-scale technology built and integrated into the environment where it is intended to operate, with full interface and functionality tests.
TRL 6	Technology in operation	Full-scale technology built and integrated into the environment where it is intended to operate, with full interface and functionality tests. The technology has operated in accordance with predefined performance criteria over a limited period of time.
TRL 7	Proven technology	The technology has operated in accordance with predefined performance and reliability criteria, over a period of time sufficient to reveal time-related effects. Required duration of operation os one of the pre-defined criteria. The technology is now proven for use within specified operating conditions/limits.

Figure 91. TRL description (Private picture, 2023)



								Technology Readiness Level							
								7	6	5	4	3	2	1	0
			Reliability	Technology	Architecture/ Configuration	Environment	Technical Organisation	Proven technology	Technology installed and performing	Technology integration tested	Technonology qualification for first use	Technology tested	Concept validated	Concept Demonstrated	Unproven idea/concept
Technical Risk Categorisation	A	Very High	Reliability improvements (technology change)	Novel technology or new design concepts	Novel application	New environment	Whole new team	🟥	🟥	🟥	🟥	▨	▨	No contractual commitment reccomended, candidate for JIP or similar	
	B	High	Reliability improvements (design change)	Major modifications	Orientation and capacity changes	Significant environmental changes	Significant team changes	Required development achievable in project time frame		🟥	Contractual commitment only with clear mitigating contractual outs		▨		
	C	Medium	Minor reliability improvements	Minor modifications	Interface changes	Similar environmental conditions	Minor team changes			🟨			🟥	▨	▨
	D	Low / Very Low	Unchange reliability	Field proven technology	Unchanged	Same environmental conditions	Same team as previous	Ready for use		🟨	🟨	🟥	🟥	▨	▨

Figure 90. Risk analysis table (Private picture, 2023)

Stab plate connector

The concept consists of five stab plate connectors positioned around the top housing. These connectors are also used on the current ACM, meaning they are low-risk with proven technology. The only difference between the concept and the current ACM connectors is that the concept will consist of 90-degree connectors due to the placement. However, this does not change either the function or risk. The stab plate connectors are given the value D-7, which is ready for use. This value shows that the stab plate connectors are a dependable component within the concept.

ROV connector

There is only one ROV connector on the current concept, communicating and receiving power from the PCGM. As discussed in the technology assessment, the ACM is placed close to the FCM frame leading to the connector extending outside. This configuration poses a potential risk as it may obstruct external equipment. This can lead to the ROV connector or other equipment being destroyed, such as the jumper cable.

Based on the evaluation, the most considerable risk associated with this component lies within the architecture/configuration category, where there is an orientation and capacity change of proven technology. This evaluates the ROV connector as B-7, indicating a high risk but with proven technology. Considering the consequence of the identified risk, replacing the ROV connector with a stab plate connector is suggested. Implementing this solution reduces the risk and eliminates the need for an ROV interaction, as discussed in the technology assessment.

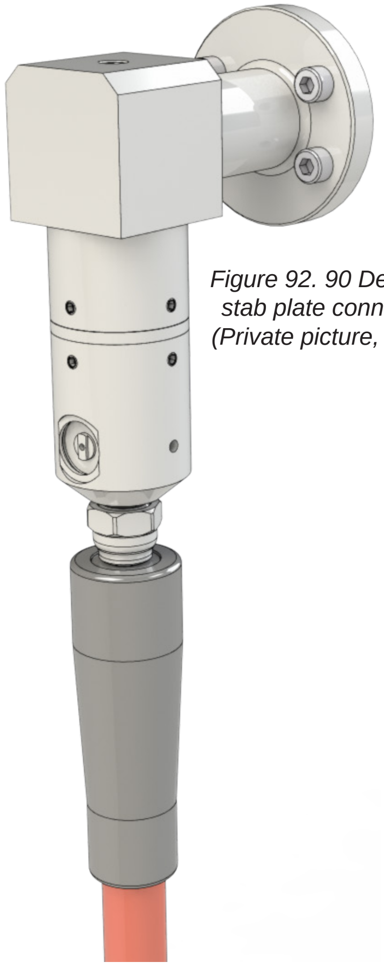


Figure 92. 90 Degrees stab plate connector (Private picture, 2023)

Figure 93. Picture of ROV connector (Private picture, 2023)

Mounting

The mounting solution is simple and contains no challenging solutions for assembly. The ACM is mounted to the FCM by utilizing two different brackets depending on the placement and orientation. There is no relevant risk regarding the fastening brackets, as it is a solid fixed component.

Transport

The same solution utilized on the current ACM is used to lift and transport the concept. Lifting eyes placed on the top housing and proper equipment with hooks ensure a safe and reliable lifting process. A Pelican case is used to transport the concept, as the module will most likely be moved several times. These solutions are of very low risk and proven technology, which means they are ready for use and placed in D-7 on the risk table.

Compensator

To achieve equal pressure inside the housing, a compensator is utilized. This compensator is a standard component made for volumes up to 9 liters. Since the current ACM is 7.12 liters, there is no need to use plastic (POM) for displacement. As the compensator is standardized, it is already tested. This places the compensator on ready for use in the risk table, D-7.

Figure 94. Overview of mounting solutions (Private picture, 2023)

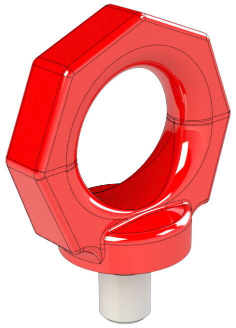


Figure 95. Render of lifting eye (Private picture, 2023)

Gaskets

Since the product is being submersed, it is essential to ensure the correct use of gaskets and that these will provide enough enclosure to avoid leaks. The concept follows the same gasket philosophy as the current ACM by utilizing similar solutions for the housing, connectors, and compensator.

The connectors are delivered with space for gaskets, meaning the ACM only needs to account for a proper surface. However, on the concept, the detailing includes chamfered edges where the connectors are mounted, leading to a small gap where the gasket will be placed. This will lead to the gasket escaping in this opening during high pressure, destroying the seal. This means that there is a required development of the solution. For this reason, the risk is high due to the design change, leading to an evaluation of the gaskets in the connectors being placed at B-7 on the risk analysis.

Housing

The housing is a solid and robust part that gathers all the components into one module. The most significant risks behind the housing are difficult to evaluate as the part is just a demonstrated concept and not developed or tested. Solutions such as fastening methods are a copy of the existing technology on the current ACM, leading to the most prominent risks being the uncertainties connected with the production and assembly of the housing. The risk of the housing is, therefore, B-1, with there being a high risk due to the design change, while the technology is likely to meet specified objectives with additional testing.

Canister

The canister is the most technical component of the module. It consists of batteries, circuit boards, and wiring. Through a penetrator, the wiring can go from a pressurized 1bar canister to a high-pressure environment. Within this penetrator is a valve in case of a thermal runaway in the electronics of the canister. If this happens, there will be an extreme development of pressure in the canister, leading to an explosion if not resolved. When the pressure increases, the penetrator will release the pressure into the housing of the ACM. In the concept, no solution releases this pressure, leading to the module exploding and damaging the whole production system. The consequence of this risk is severe and has to be resolved. This risk is therefore evaluated as A-7.

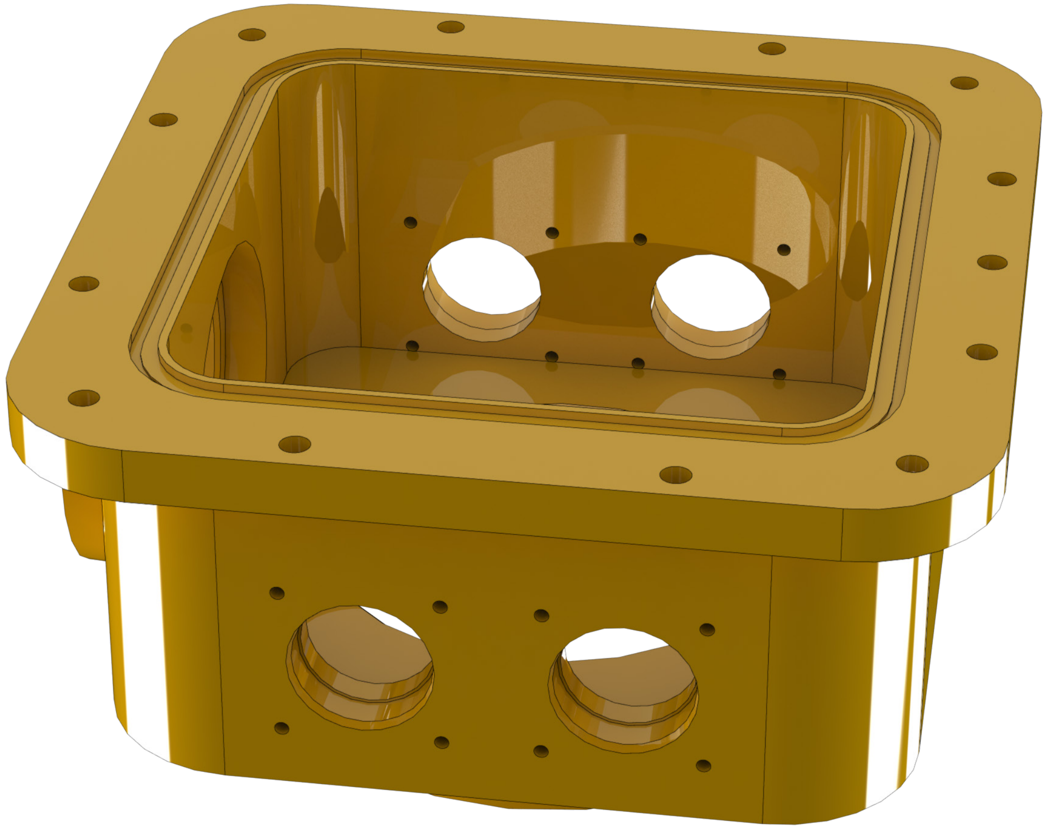


Figure 96. Render showing space for the gaskets in top housing (Private picture, 2023)

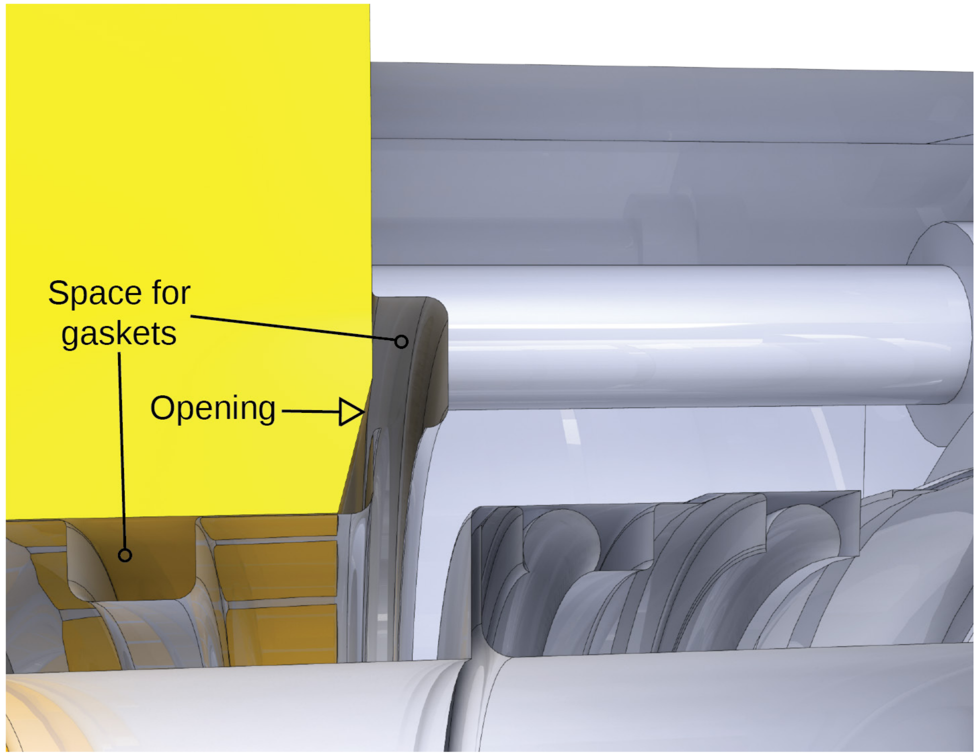


Figure 97. Illustration of gaskets inside the connector (Private picture, 2023)

Evaluating the Risk Analysis

The result of the risk analysis is an overview of the most considerable risk associated with each component. The overview is in the form of a table, including the component name, the issue with the current design concerning the component, the risk evaluated with the component, the consequence of the risk, and the solution to the problem. The coloring of the risk follows the explanations in the table:

Gray – No contractual commitment recommended, candidate for JIP (Joint industry project) or similar.

Red – Contractual commitment only with clear mitigating contractual outs.

Yellow – Required development achievable in project time frame.

Green – Ready for use.

Component	Issue	Risk	Consequence	Solution
Stab connector	Standard solution	🟩 D-7	None	None needed
ROV connector	Component outside FCM	🟨 B-7	Destroyed equipment	Use Stab connector
Mounting	No issues	🟩 Not relevant	None	None needed
Transport	Standard solution	🟩 D-7	None	None needed
Compensator	Standard solution	🟩 D-7	None	None needed
Gaskets	Detailing in connectors	🟨 B-7	Leaks in component	Improved detailing
Housing	New design	▨ B-1	Issues in production	Testing
Canister	Thermal runaway	🟥 A-7	Production stop	Valve on housing

Through this evaluation, it is clear that the risk is NOT ACCEPTABLE. This means there is a need to modify the concept before it can be presented.

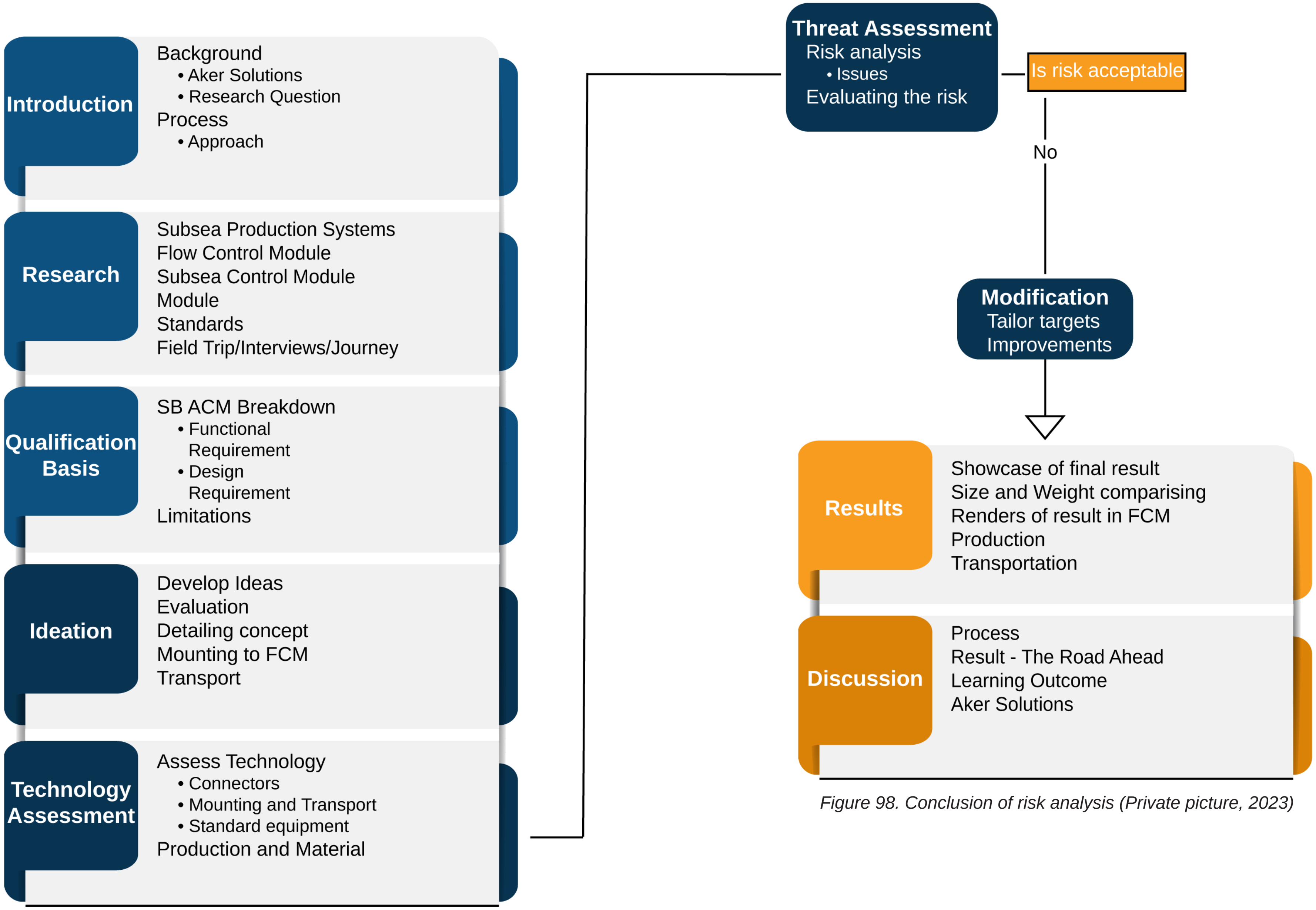


Figure 98. Conclusion of risk analysis (Private picture, 2023)

Modifications Based on Risk Analysis

The concept needs modifications to avoid high risks and achieve the suggested solutions from the risk analysis. Each modification aims to improve the concept reliability while reducing the risk and consequence of a potential failure.
The following text is an overview of the modifications needed to achieve this.

The technology and risk assessment heavily discuss using an ROV connector and the high risk following the solution. As mentioned, the connector is expensive and requires an ROV interaction to be installed. The suggestion is, therefore, to replace the connector with a stab plate connector by utilizing the junction box on the FCM. Doing so improves the concept, with one less ROV interaction during the installation of the FCM and a reduced risk within the ACM itself. The ROV connector is replaced with a stab plate connector.

Due to some chamfers, the gaskets needed to seal the space between the stab plate connectors and housing will not work. This is because the chamfer is expanding to the area where the gaskets are placed. This means that during the deployment of the ACM, the gasket can escape into the chamfer, reducing its effect. The detailing must ensure the functions of different components and solutions, and the chamfer has to be removed.

By executing the risk analysis, an issue regarding thermal runaway was enlightened. The concept does not include any solutions to deal with thermal runaways, meaning that the consequence of a thermal runaway will result in a production stop. A pressure-realizing valve must be added to the housing to solve this issue. The valve must relieve pressure during a thermal runaway.

Tailor targets

To tailor the targets, the design and functional requirements are used to evaluate the set requirements for the ACM. Doing so makes it easier to ensure that the product satisfies the research questions. The following illustration summarises the solutions regarding the different factors from the requirement.

Aker Solutions Withstand pressure of 4000 meters Jumpers must have a lower point than the connectors Jumpers must have a minimum bend radius of 180mm Equipment must have a 300mm - 600mm clearing to roof	**Solved** Compensator, materials Placement in FCM Placement in FCM More than 600mm
API 6A Design documentation of methods and assumptions including criteria for other conditions on which the design is based	**Solved** Design is documented
NORSOK U001 Nonreplaceable components must be designed with a lifetime corresponding to the field's operation time (25-30 years)	**Solved** Technology and philosophies are following existing solotions
API 17A Avoid harmful fluid escaping Tolerate environmental conditions such as transport Interchangeable solutions Considerations regarding fouling	**Solved** Gaskets Compensator and material Placement variation Antifouling coating
API 17D Design must comply with the effect of external hydrostatic pressure Design must compensate for all fluid-filled chambers	**Solved** Compensator Only one fluid-filled chamber
API 17F Design for standard interfaces to optimize potential The equipment must meet the required temperature range Design must provide for safe and reliable operation	**Solved** Utilizes available technology Materials follow standards No hazards connected to design change

Solved Design is compact Coloring is following standard The housing is two parts	**Design** Save space by creating a compact design Follow color requirement given by standard ISO 13628-1 Product is designed as a module for easy maintenence and repair
Solved Standard fastening methods Achieved through ISO screws Existing material used	**Production** Designed with consideration of workshop tools Assembly process is optimized by using standard fastening methods Improve production by using available materials
Solved House volume is reduced Pelican case Lifting points are diagonal	**Transport** Consider the compensator during the house redesign Utilize fastening methods that fully secure the product Lifting points should be placed to balance the ACM
Solved Adjusting brackets Not relevant due to change in the ROV connector	**Placement** Design fastening methods to the FCM that achieves interchangable design The placement should provide easy access to the ACM ROV can inspect the ACM without issue

Figure 99. Design requirement evaluated (Private picture, 2023)

The design requirement shows an overview of the factors that must be considered when redesigning the ACM module. Evaluating the requirement makes it easier to see how well the concepts follow the requirements and whether they are achieved. All the different categories within the requirements are solved as illustrated, but improvements and comments can still be made on a few points.

Under the requirements given by Aker Solutions, it is stated that equipment must have a 300mm – 600mm clearing to the ceiling of the FCM. The presented concept is placed around 800 mm from where the ROV will most likely land on the FCM ceiling. This is, however, no issue since the 300 millimeters are needed to avoid the product getting damaged from equipment that is dropped above the sea. The 600 millimeters are needed for the ROV to reach the product and connect the ROV connectors. However, the presented concept does not utilize any ROV connectors and therefore does not need to accommodate this measurement.

Under the API 17A requirements, it is mentioned that there should be interchangeable solutions. This requirement is marked as solved due to the variation in possible placements on the FCM. However, the module's interchangeability can still be enhanced by making parts that can replace connectors if the module controls fewer driveheads than four. There should be a solution where the customer can choose fewer connectors than four, resulting in the need for a type of plug. This will need to be improved on the concept.

Several requirements are marked solved based on the mentioned solutions being "placed on the FCM" and "materials." This is to emphasize the use of existing solutions in critical components. By utilizing existing and standard solutions, it is easy to asses that there is no issue in achieving the mentioned requirements as the material or solution is already tested and approved.

In addition to the design requirement, it is essential to evaluate the functional requirement to ensure that the concept can be correctly used while including all necessary parts and functions. Doing so increases reliability and secures a functioning and representable concept. Most requirements mentioned in the functional requirement are followed and discussed through the report as choices are made. However, there has not been any discussion regarding the earthing and trapped air in the design. There is no need to discuss the trapped air in the design, as this is more of something to avoid than achieve. However, earthing has to be included with the finalized concept, as this is essential to ensure reliable use.

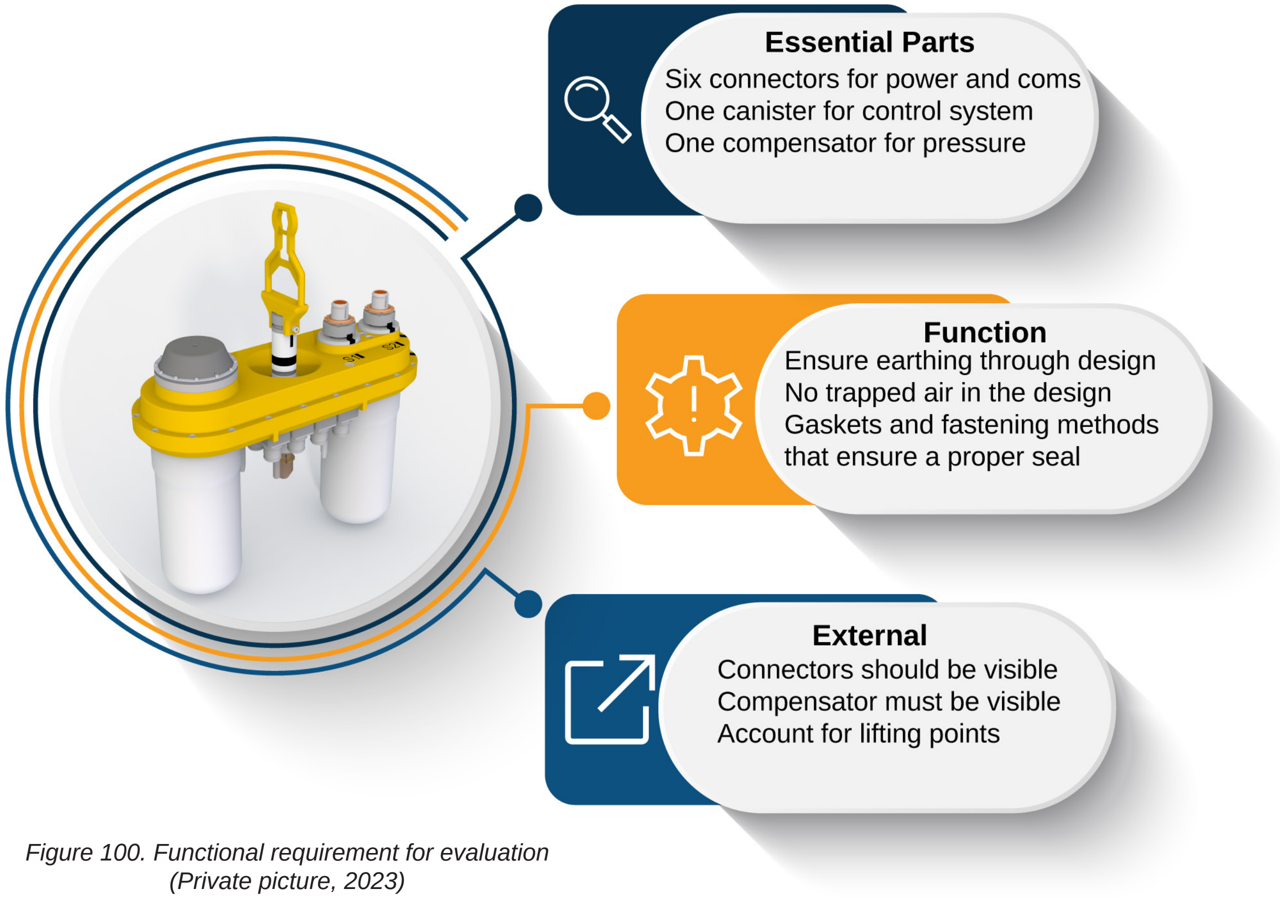


Figure 100. Functional requirement for evaluation (Private picture, 2023)

Concept Improvement

This chapter will review the changes regarding what was revealed in the technology assessment, risk analysis, and tailor targets.

Gaskets

As mentioned in the risk analysis, the concept housing has a flaw where there is a chamfered edge where the gasket between the connectors and the housing is. The improved version is, therefore, without chamfer, as illustrated.

Filets, Wall Thickness, and Screws

Due to the need for a total redesign in the house structure, the main fillet around the housing is doubled, from a 50mm to 100mm radius. This decreases the assembly time as it is easier to install the gaskets. Due to production effectiveness, the gaskets' space is moved from the top housing to the bottom housing.

In addition to the fillets, the wall thickness around the housing is reduced from 25mm to 15mm since there is no need for an ROV connector. This saves material in the casting process and slightly decreases the product's weight. The amount of screws around the housing is also decreased but is still more frequent than on the current ACM, ensuring a reliable fixture.

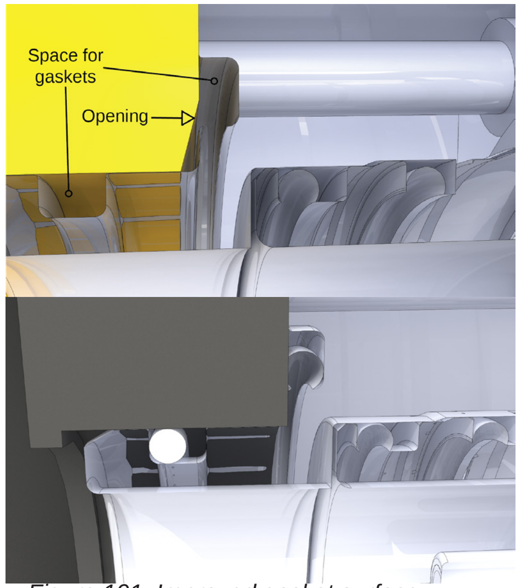


Figure 101. Improved gasket surface (Private picture, 2023)

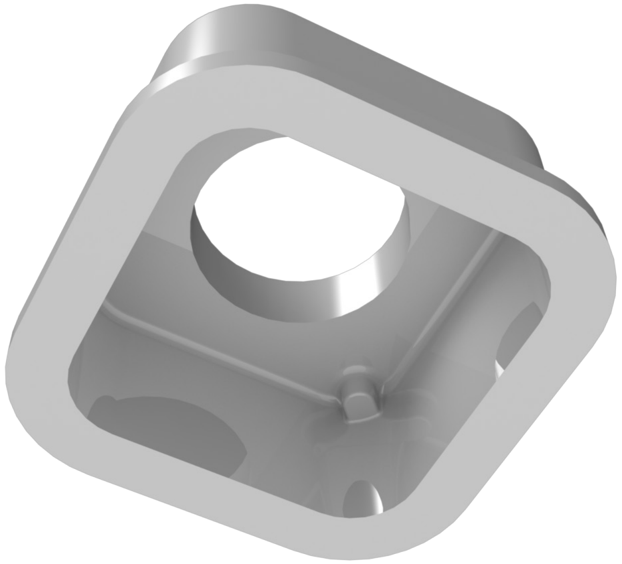


Figure 102. Render of housing to show thickness and fillets (Private picture, 2023)

ROV connector

Since the ROV connector is replaced with a stab plate connector, the placement of the connectors can be reconfigured. Instead of having connectors around the whole housing, they can be placed in pairs, leaving one side empty. By configuring the connectors as demonstrated, the product's interchangeability is improved by making it possible to change the orientation of the ACM.

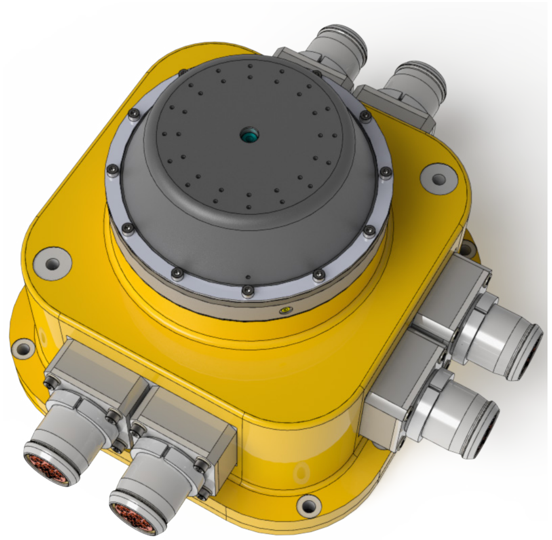


Figure 103. Render of reconfigured connector placement (Private picture, 2023)

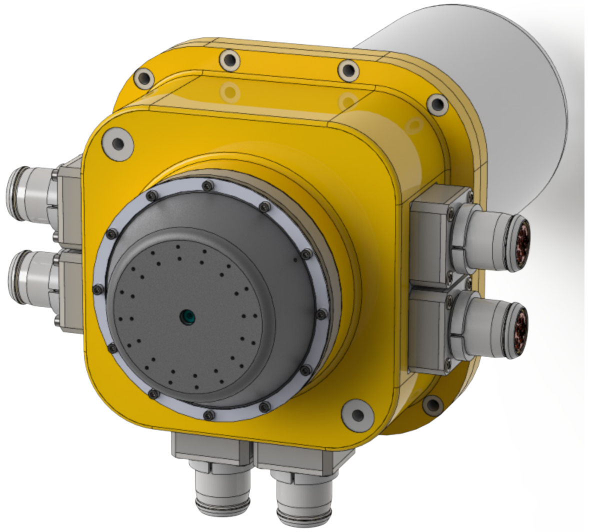


Figure 104. Render of improved concept horizontally (Private picture, 2023)

Canister

As discussed in the risk analysis, there must be a valve in case of a thermal runaway. Since the canister is a standard component in the current ACM, a solution for avoiding pressure buildup due to thermal runaway already exists. The presented solution for this concept is based on the existing solution, where a standard cap head screw is modified to have a metal profile fastened around the head. This metal profile extends over a hole, creating a seal. However, during a thermal runaway, the pressure will lead to the metal profile bending or breaking, opening the hole and releasing the pressure either way.

For filling the housing with a dielectric fluid, medium-pressure fittings delivered from AutoClave will be used. These fittings allow for removing a plug, filling the housing with dielectric fluid, and sealing the holes. There are two holes for this process, one to create a vacuum to ensure the liquid reaches all areas and one for filling in the liquid.

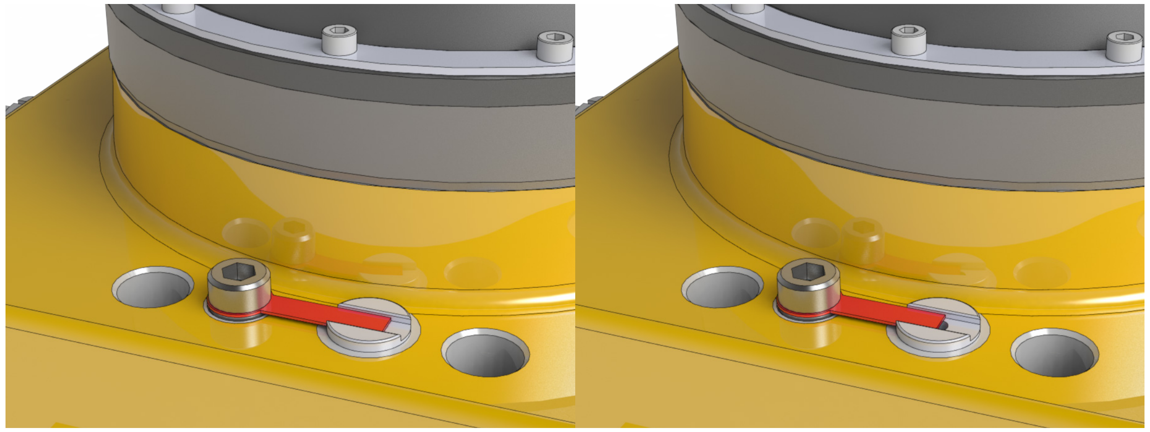


Figure 105. Render of the valve to prevent explosion (Private picture, 2023)

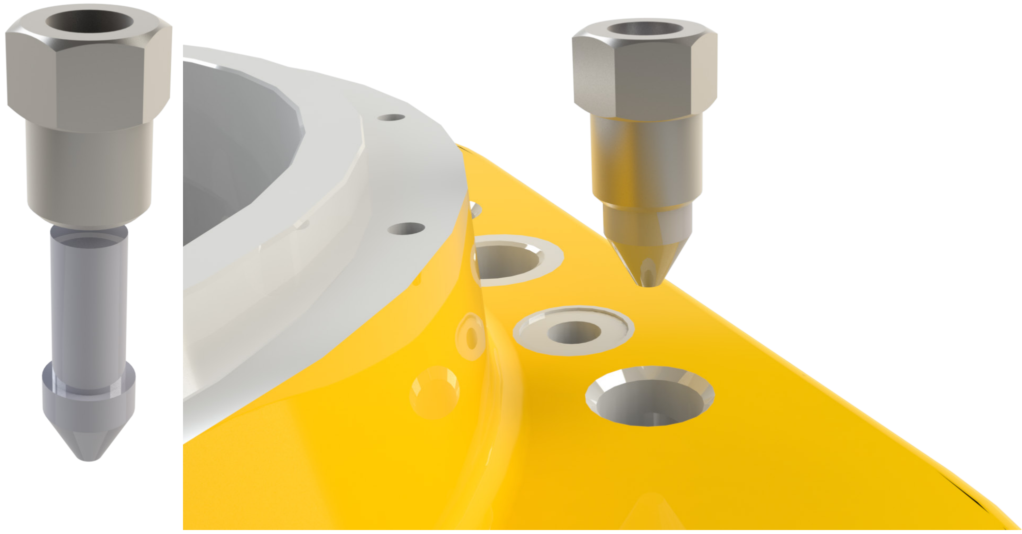


Figure 106. Render of medium-pressure fitting (Private picture, 2023)

Coating and Earthing

The housing is coated following the NORSOK M-501 in addition to antifouling coating where it is needed. There will not be a coating where components are mounted to the house since the coating can be uneven and reduce the efficiency of a seal.

In order to achieve earthing must, the contact surface between the housing and the mounting bracket will be without coating. The bracket must not be coated where mounted to the FCM to ensure the earthing with the whole system. If these contact surfaces are insufficient, earthing cables are a standard product that can provide the necessary amount of grounding.

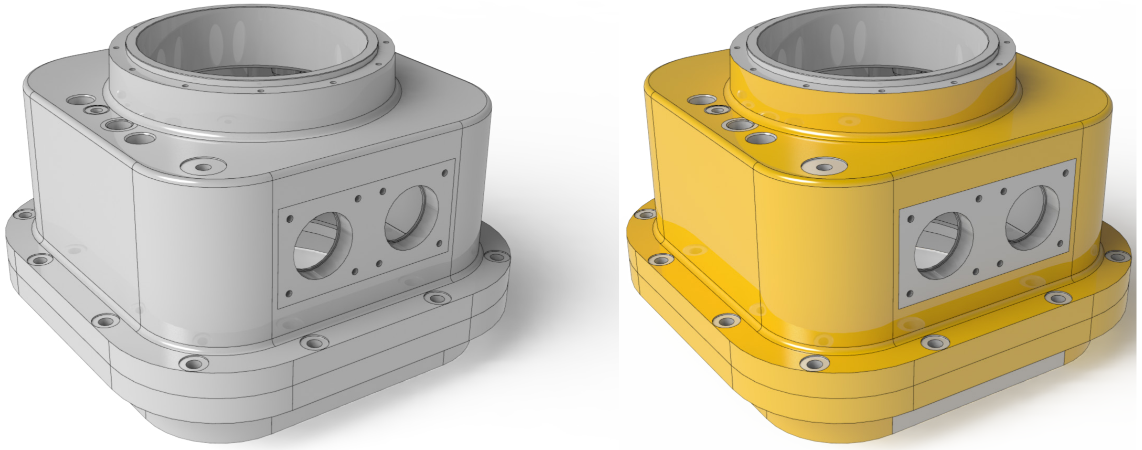


Figure 107. Render of before and after added coating (Private picture, 2023)

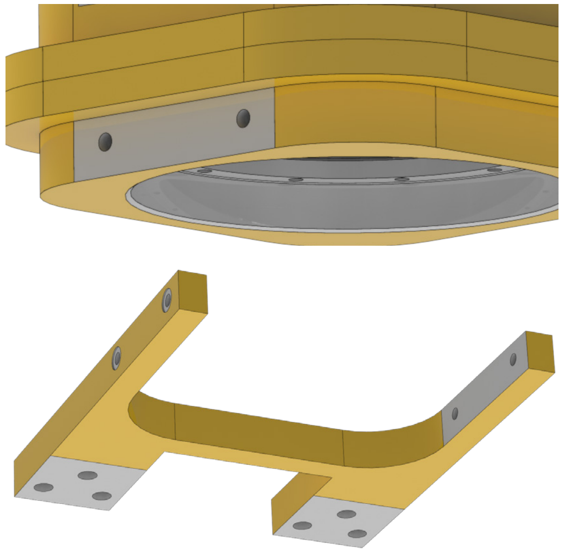


Figure 108. Render of the earthing surfaces (Private picture, 2023)

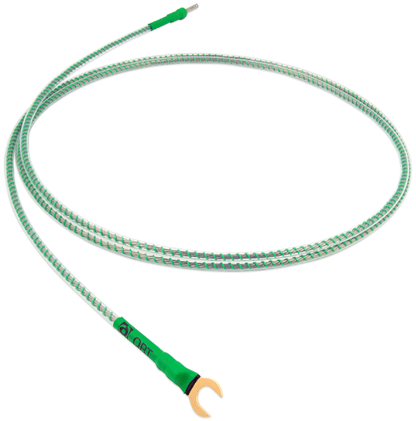


Figure 109. Picture of earthing cable (Analogue Seduction, 2023)

Compensator

Since the thickness in the housing was reduced, the volume has to be recalculated. When analyzing the mass properties of the inner volume, the result is estimated at 9.35 liters. This is 0.35 liters bigger than what the compensator is designed for. However, this can easily be fixed by increasing the wall thickness based on suggestions from a casting specialist. Since the housing has to be tested and detailed professionally, it is uncertain whether the walls must be thicker to be cast as desired. There will therefore be no changes concerning this issue.

Interchangeable

In order to improve the interchangeability of the concept, as stated from the evaluation of the design requirements, there needs to be a replacement for the connectors when they are not in use. The concept must adapt to different systems depending on the customer's needs since the ACM is used on various FCMs and Xmas trees. Therefore, a simple machined block with a gasket can replace a connector. This cheap and simple solution will create a seal while saving money.

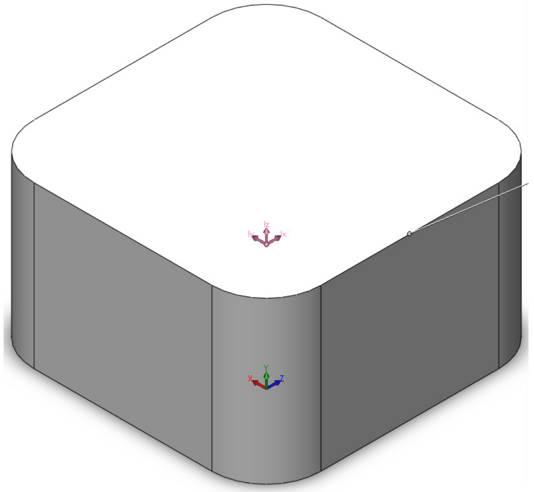


Figure 110. Illustration of the inner volume (Private picture, 2023)

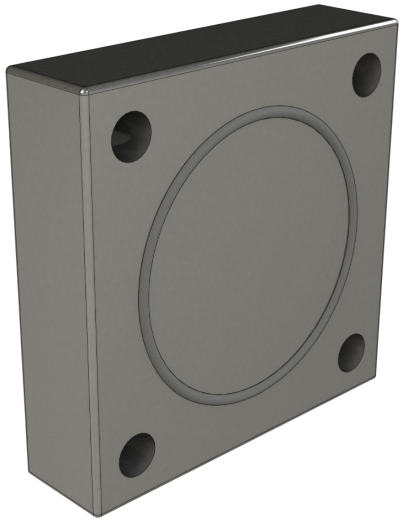


Figure 111. Render of seal for interchangeable design (Private picture, 2023)

Improved Concept

The improved concept is a complete redesign with additional solutions for issues mentioned in the technology assessment and risk evaluation. The improved concept is also detailed with screws and fastening methods for mounting and lifting.

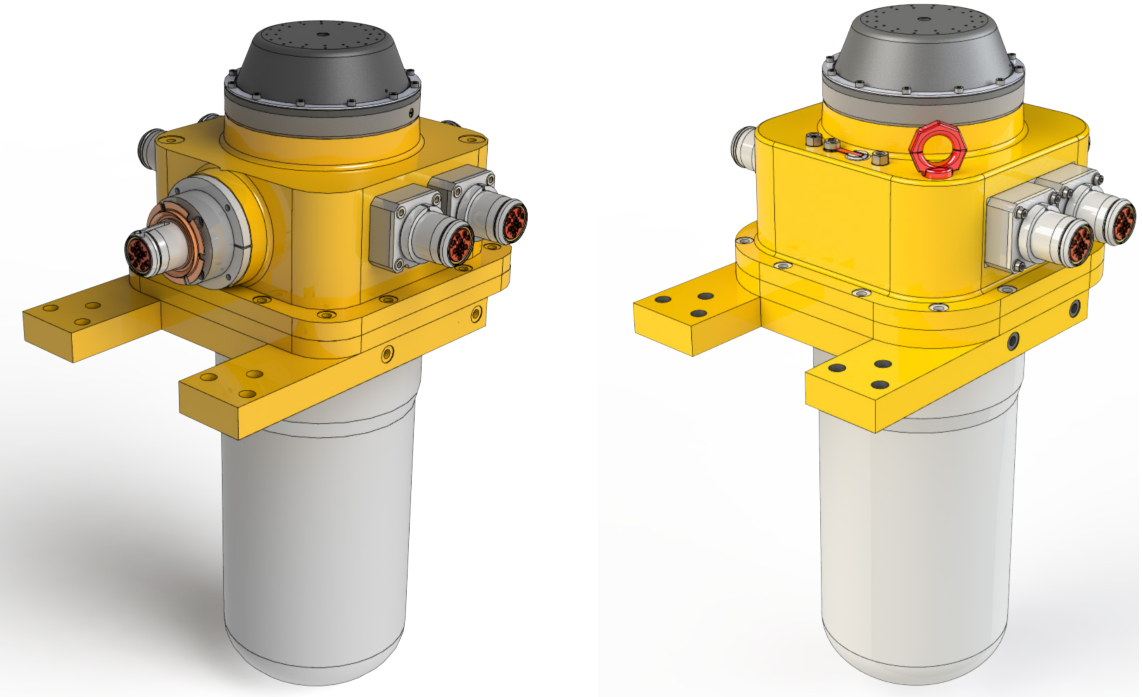


Figure 112. Concept before and after improvement (Private picture, 2023)

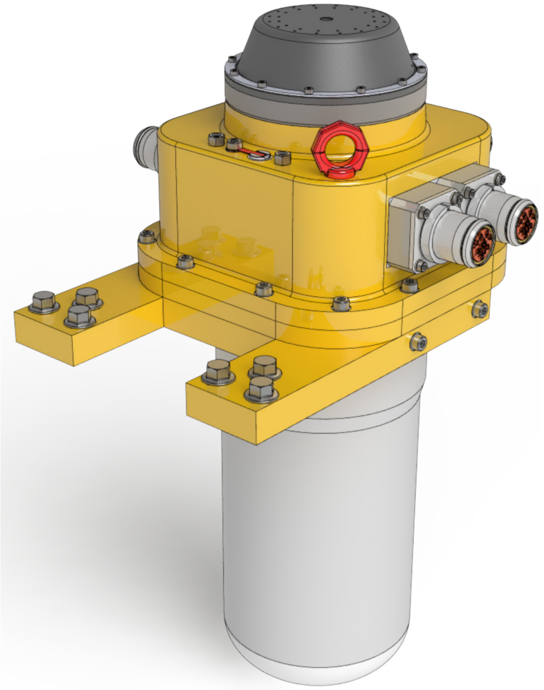


Figure 113. Render of the improved concept (Private picture, 2023)

Simulating Bracket

Since the mounting bracket will keep the concept in place during deployment and its lifetime, it is vital to simulate if the bracket can withstand the forces the module is exposed to. For locking the bracket in position is the surface where the bracket connects to the FCM (Blue surface) used. The force used to simulate the weight of the ACM is placed on the screw holes and is component-based.

The mesh is set as 4mm, and the analysis is directed toward structural responses. The material used for the bracket is ordinary structural steel. The simulation is done with three different forces, beginning at 4000N and 6000N and ending at 10 000N.

4000N is a good starting point since the module weighs around 200kg. However, during the testing, it appeared that 4000N made no deformations or structural impact on the bracket. Giving a high safety factor meaning that the bracket can handle much more. Simulating with a force of 6000N gave a similar result. Therefore the final testing was completed with 10 000N, equal to around a ton.

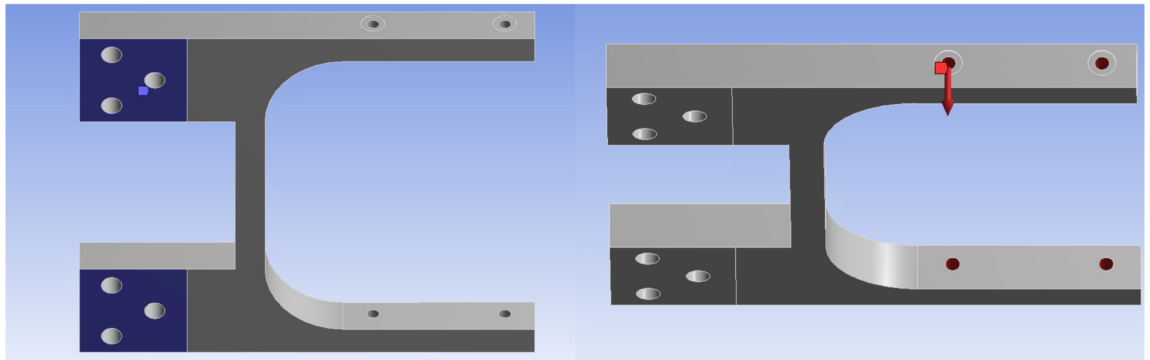


Figure 114. Picture of added fixture and force for simulation (Private picture, 2023)

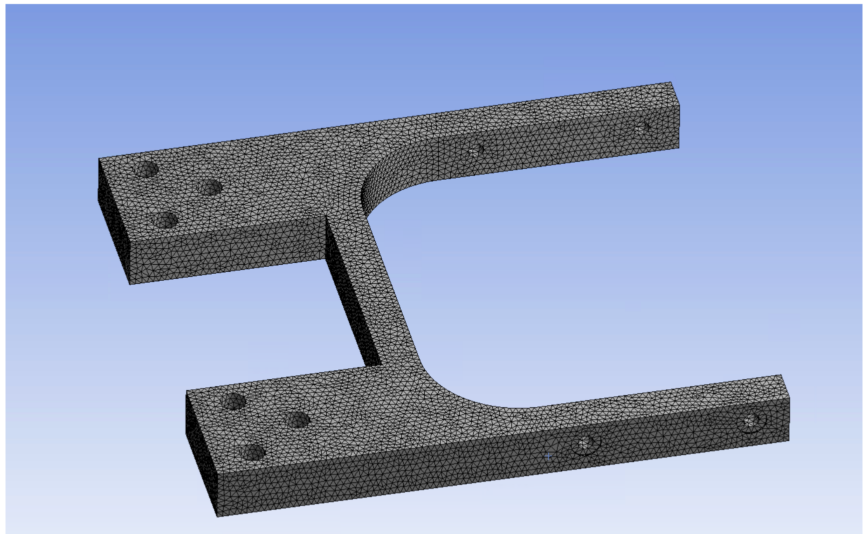


Figure 115. Mesh size in simulation (Private picture, 2023)

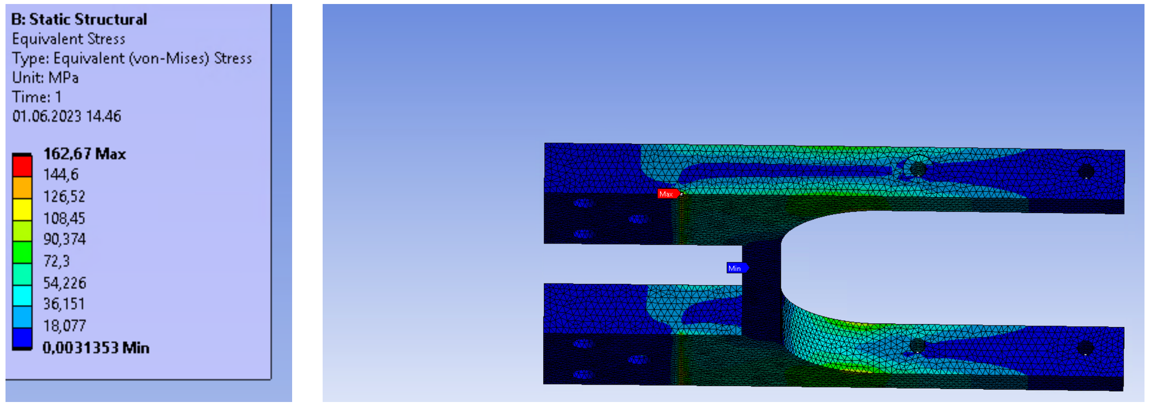


Figure 116. Picture of equivalent stress (Private picture, 2023)

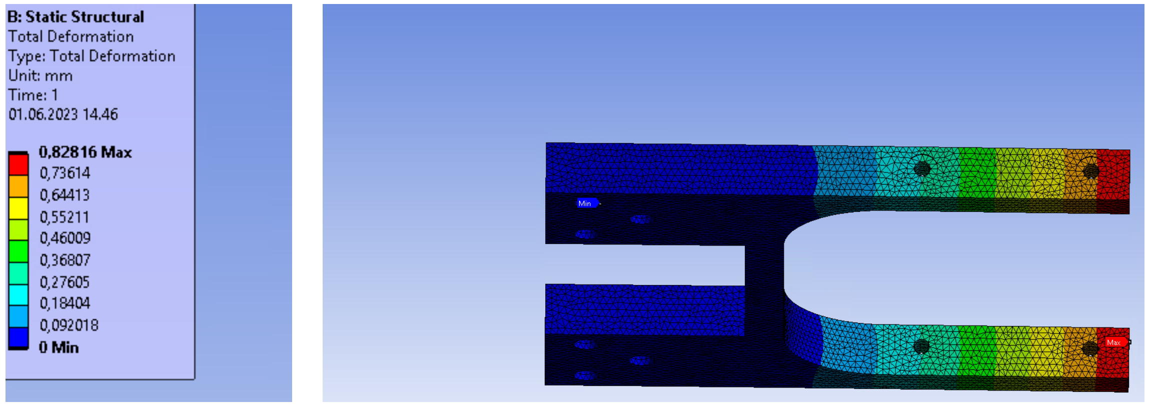


Figure 117. Picture of total deformation (Private picture, 2023)

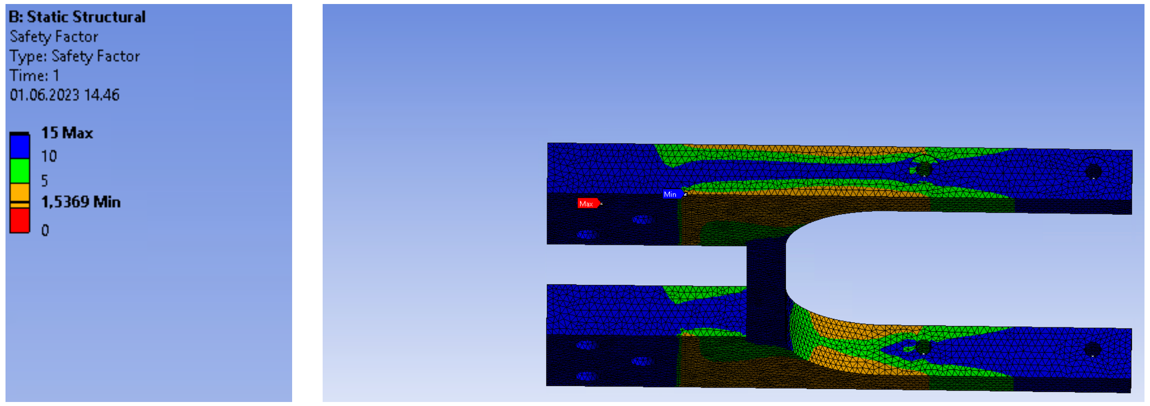


Figure 118. Picture of safety factor (Private picture, 2023)

When analyzing the simulation results completed with 10 000N, it can be concluded that a single pressure of 10 000N on the screw holes can be tolerated without creating a deformation in the material. As a final simulation to ensure reliable use over time, the bracket is tested with a force of 10 000N repeating five times. This means that the force is added and removed several times, simulating wear on the bracket over time.

After the 5th test, the product has no deformations and can still withstand the force without any sign of changes in the material. This means the material is tough enough for the intended use. However, since the bracket is over-dimensioned following the simulations, the breaking point will likely be the screws mounting the bracket to the FCM. However, deep diving into what screws to use is irrelevant since an expert will evaluate and test this.

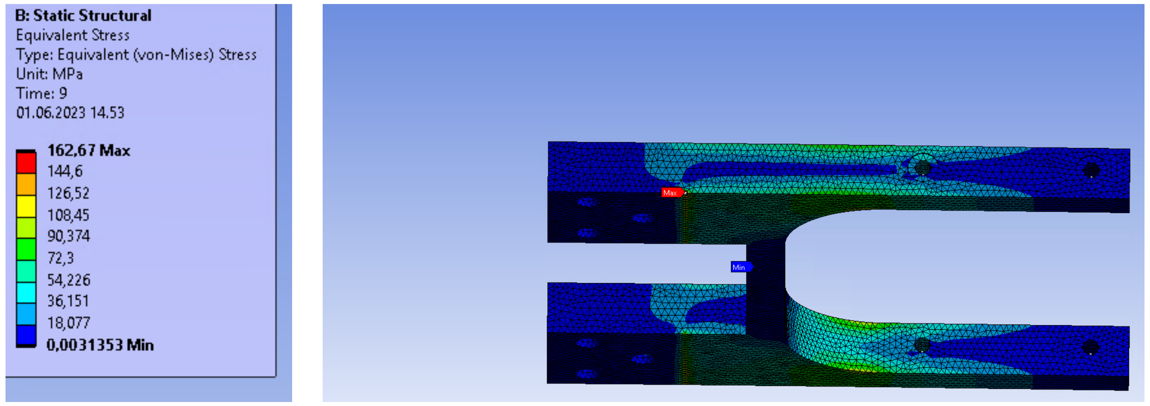


Figure 119. Picture of equivalent stress after 5th test (Private picture, 2023)

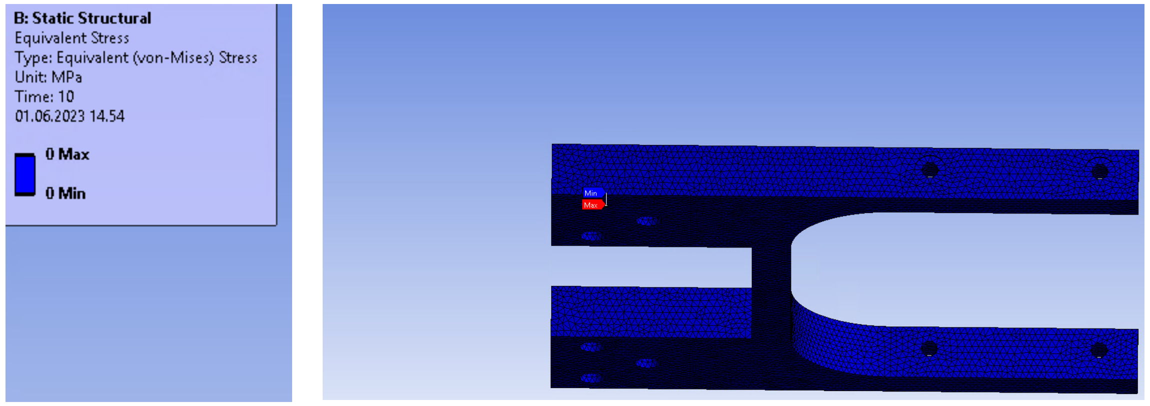


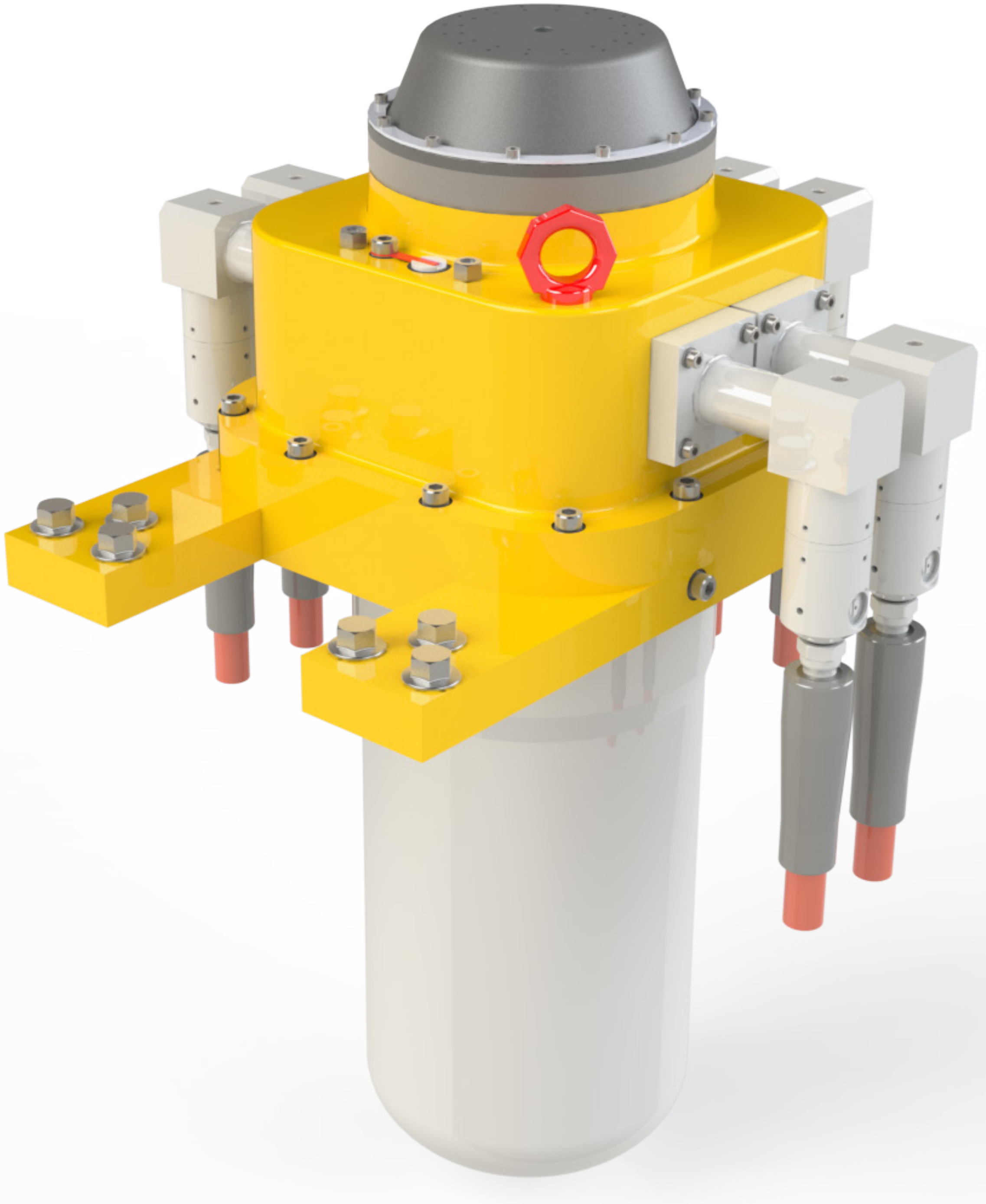
Figure 120. Picture of changes in material (Private picture, 2023)

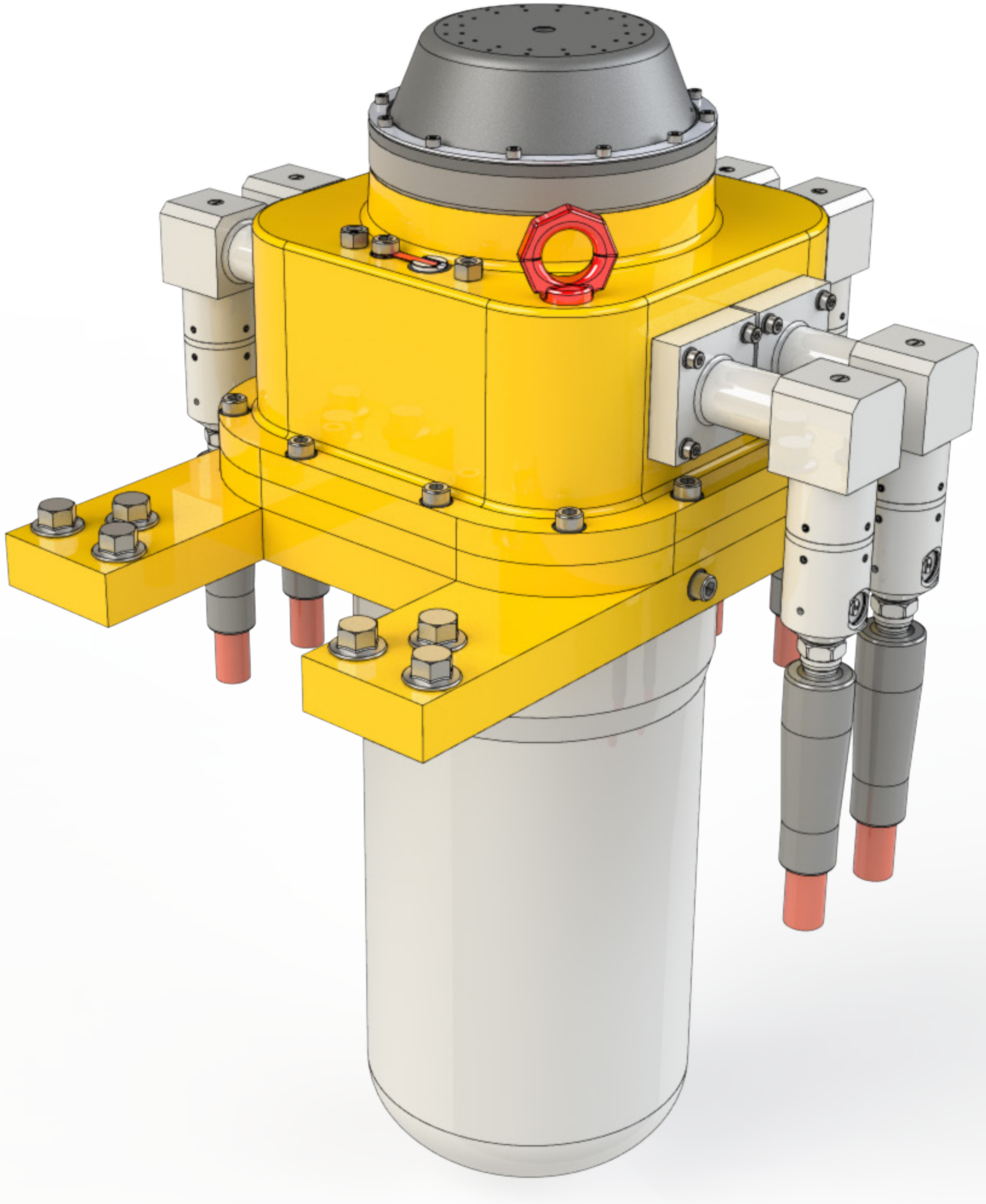
Evaluating cost

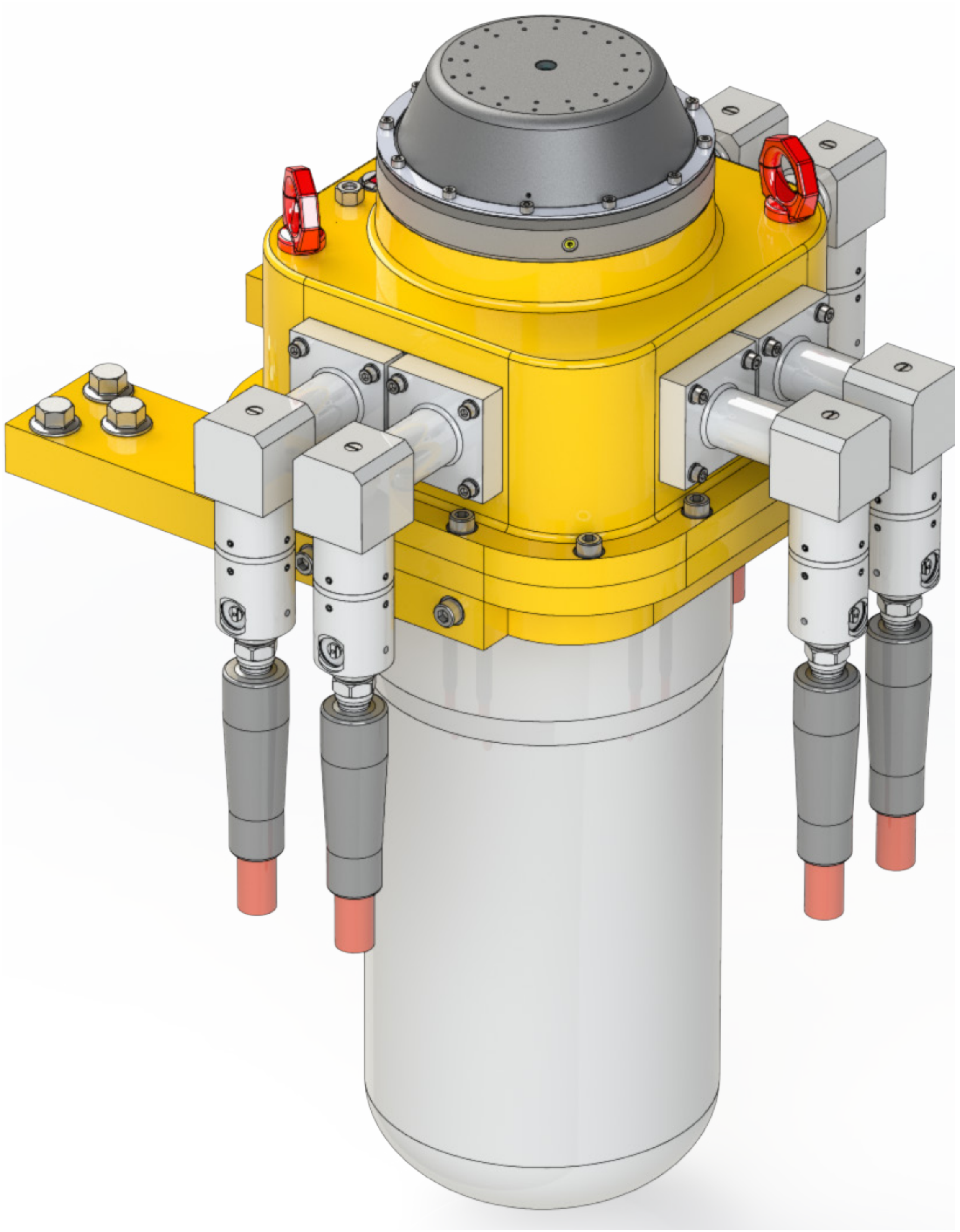
It is essential to prove a potential cost reduction to evaluate the benefit of the presented concept. This is achieved through detailed budgets that calculate the cost of the concept based on the ACM. The result of the cost evaluation shows that the concept reduces the price by an estimated 29% which is a significant change. However, it is possible to utilize dry mates on the concept instead of stab plate connectors (wet mates) since it is installed on land. Dry mates are cheaper and reduce the total cost by 35%. Therefore the final result will consist of dry mates instead of wet mates. The detailed budget and a more thorough explanation can be viewed in Appendix 1 and is only available in some versions due to confidentiality.

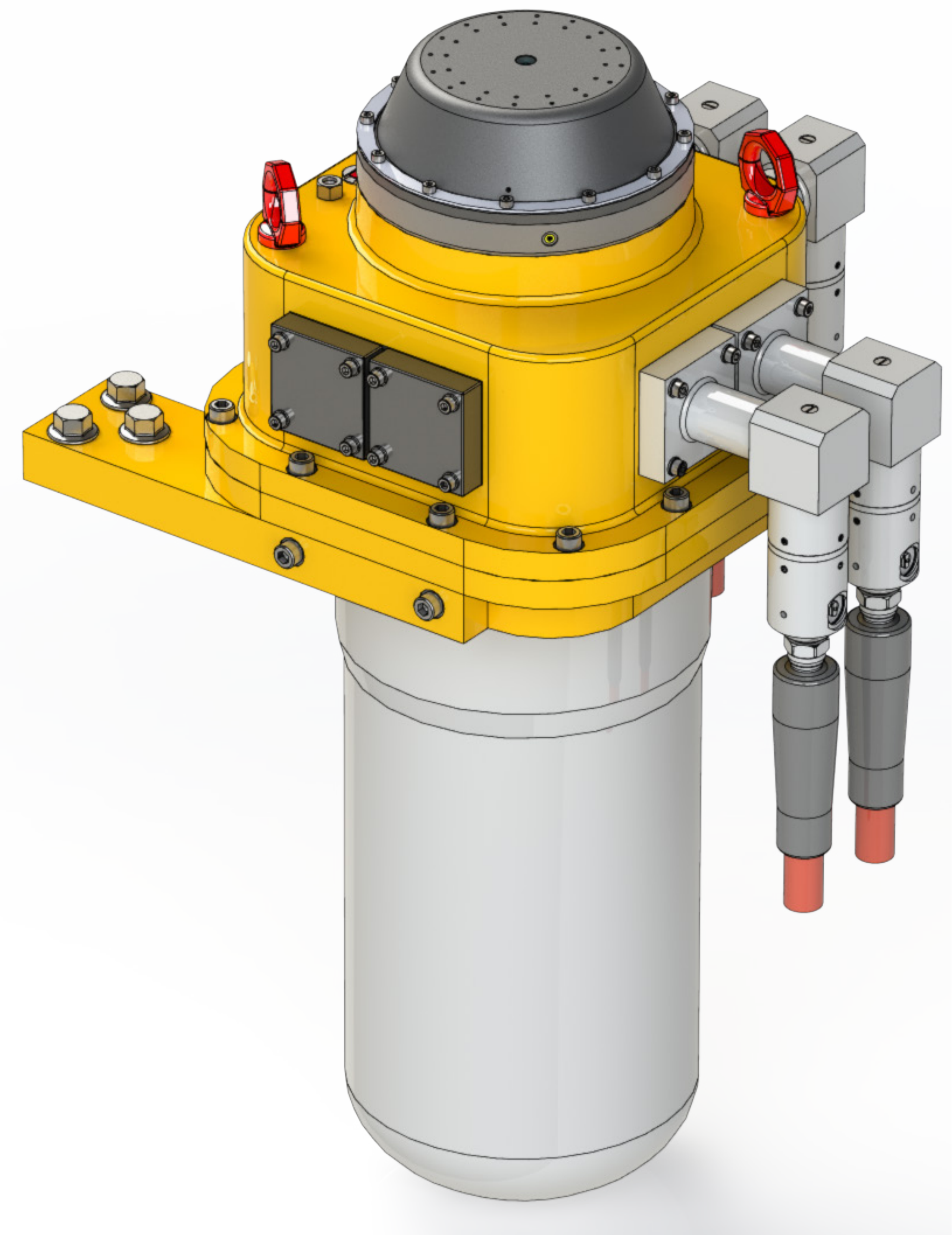
7

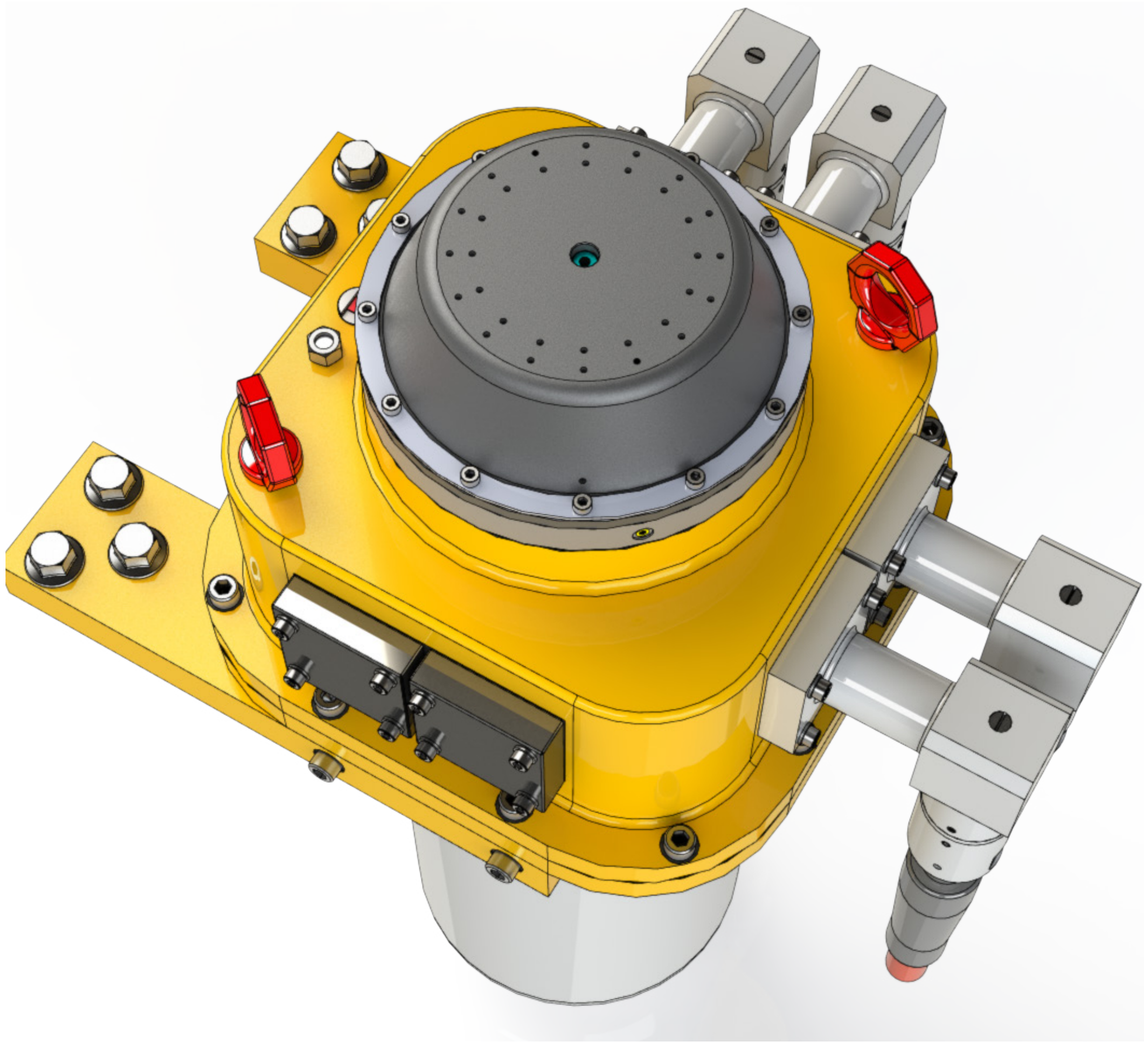
Result

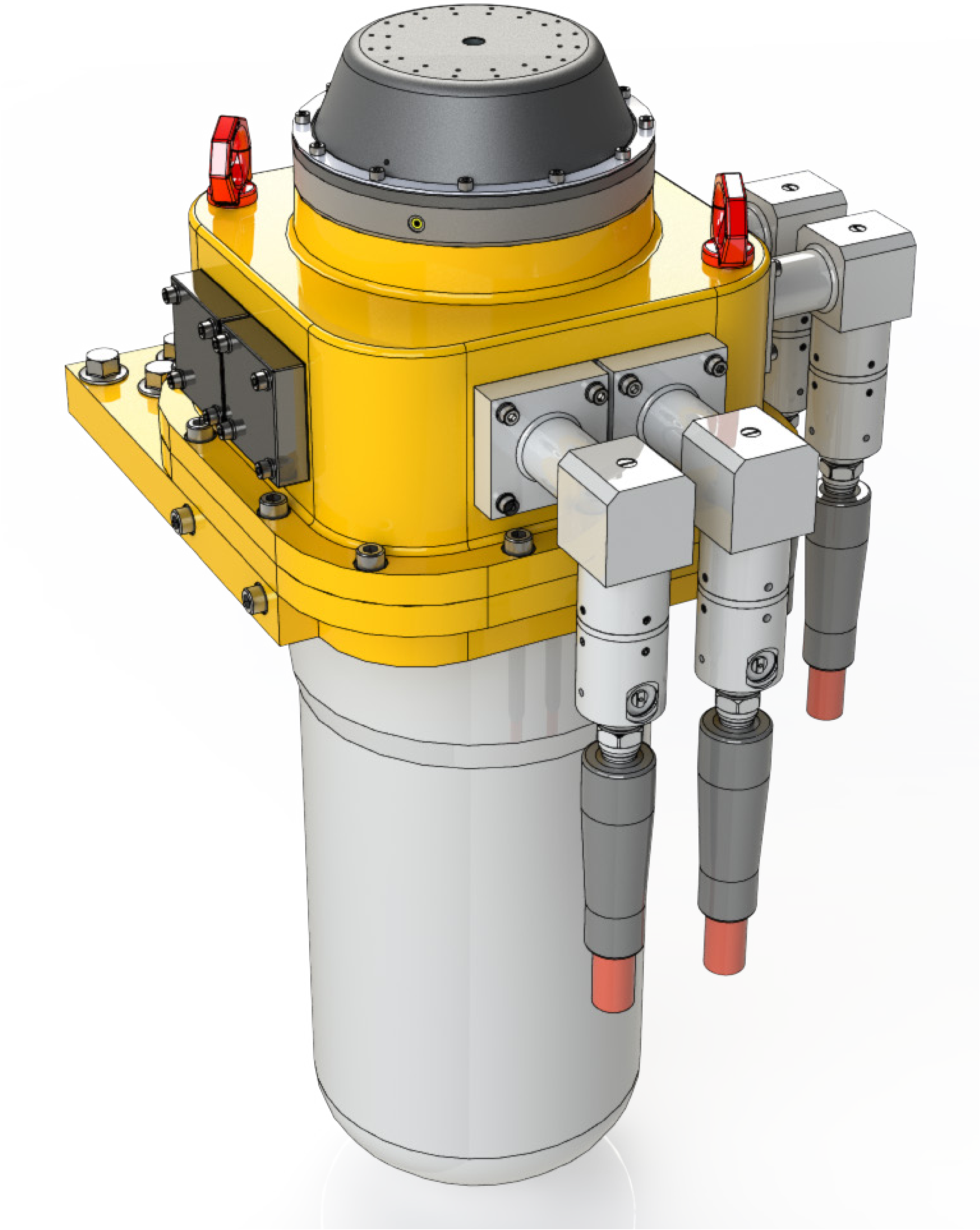


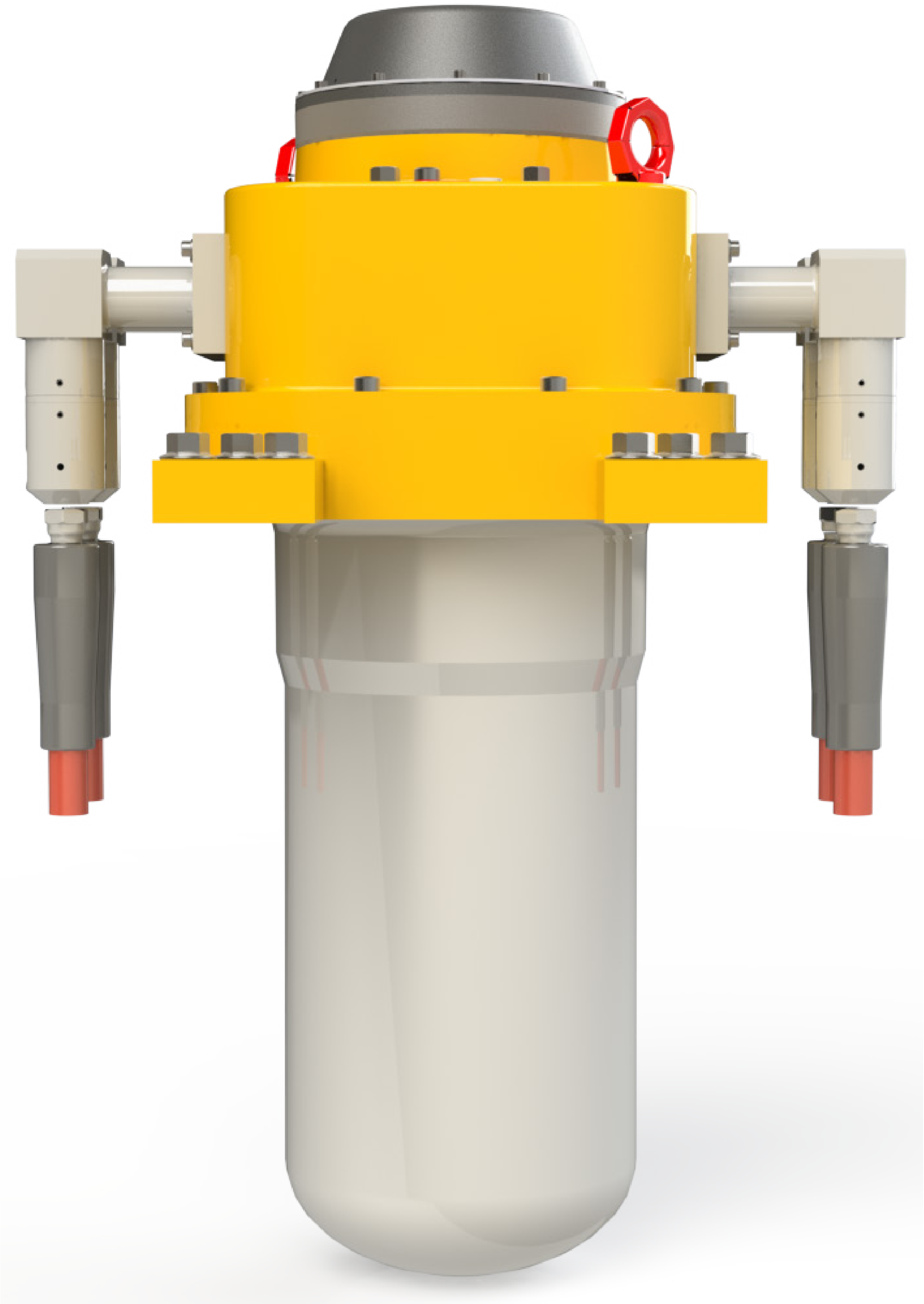


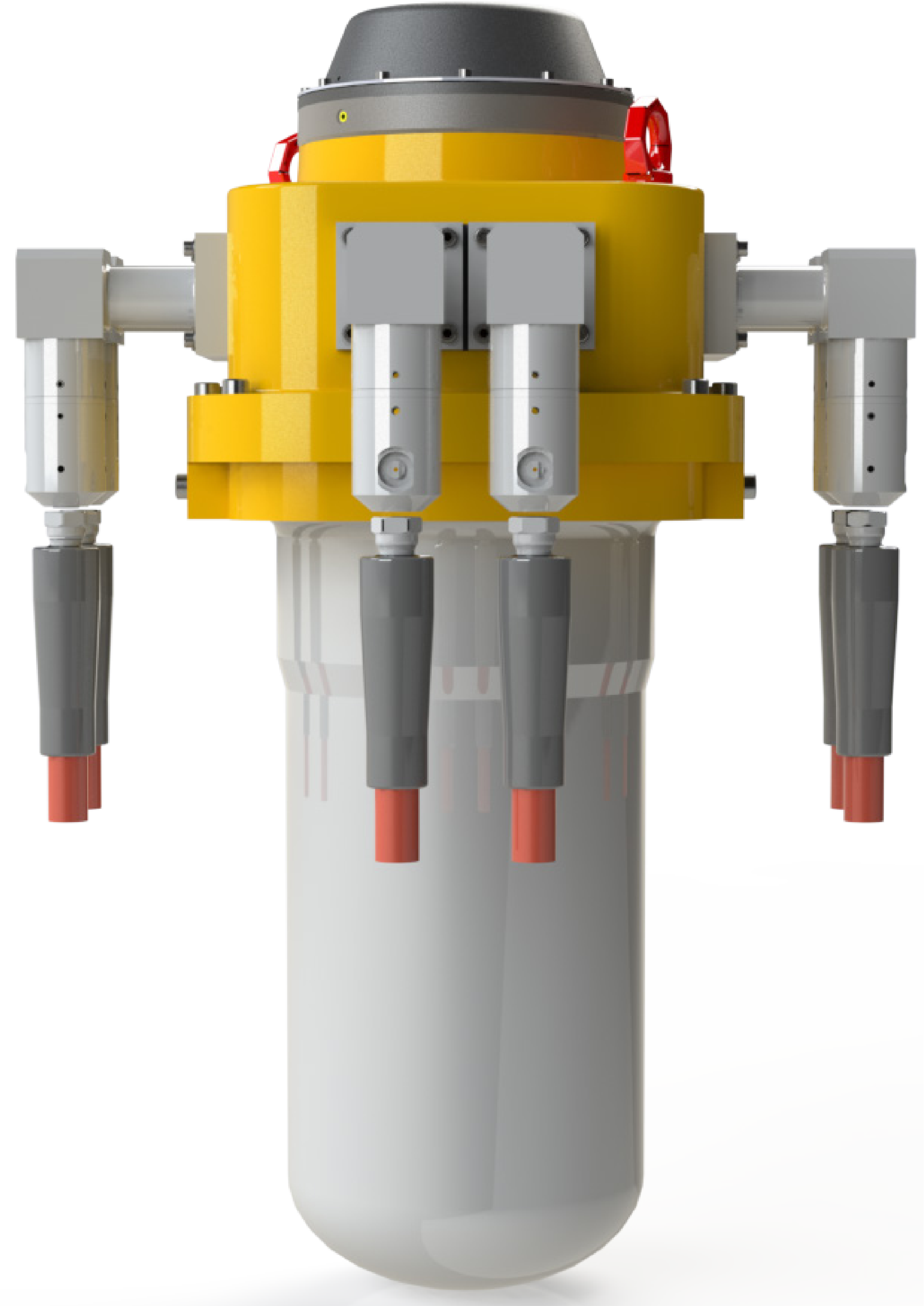


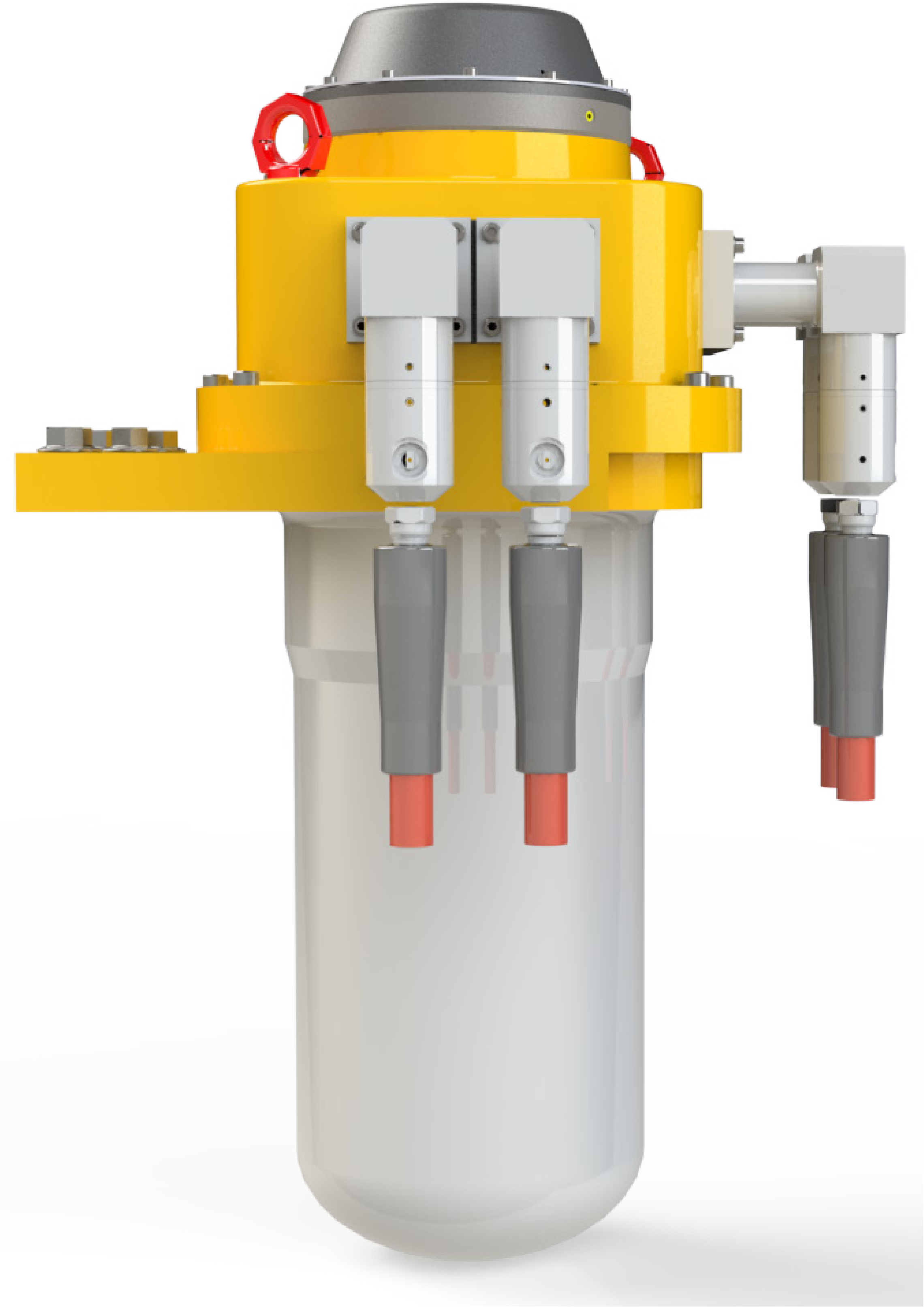


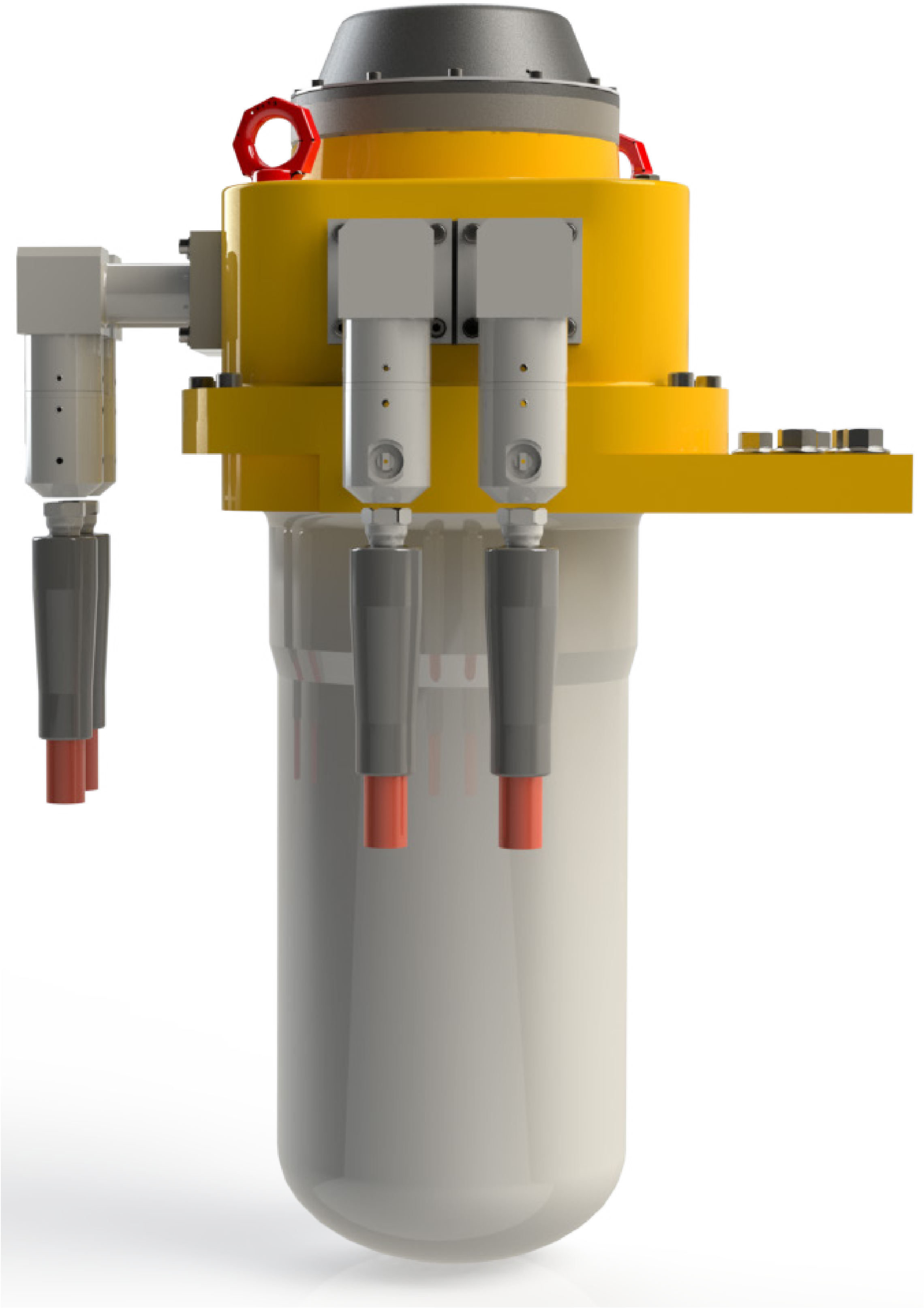






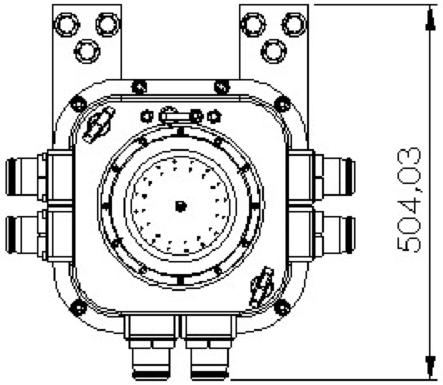


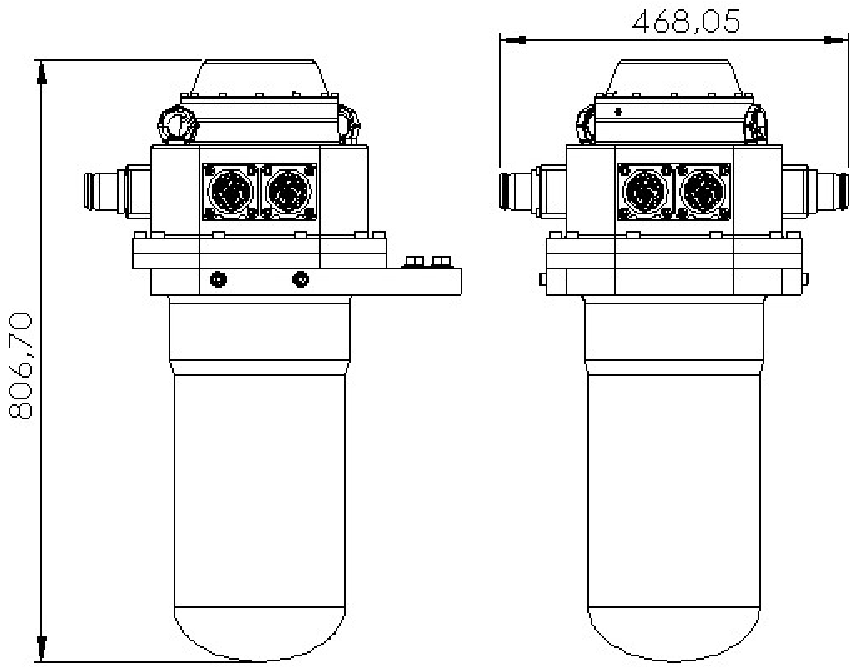


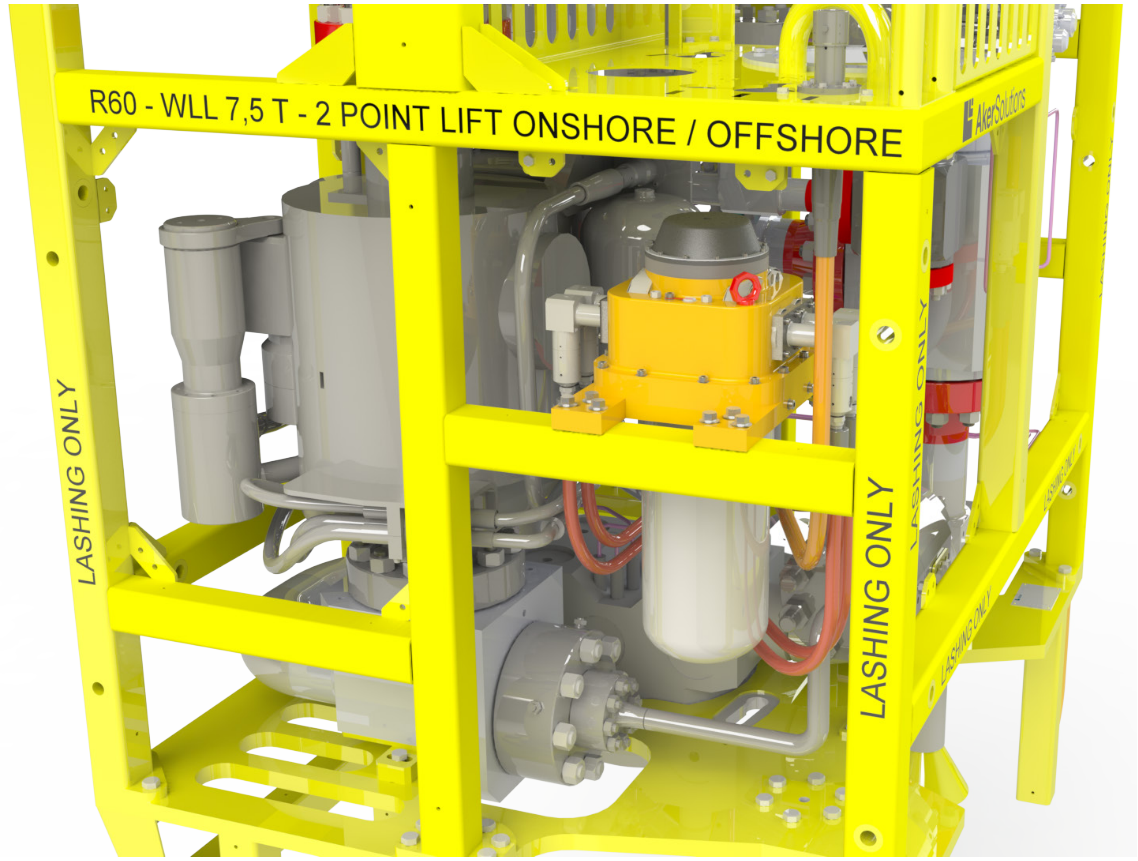


Weight

Housing:	53.89kg
Total:	100.48kg
Weight reduced from current ACM:	113kg



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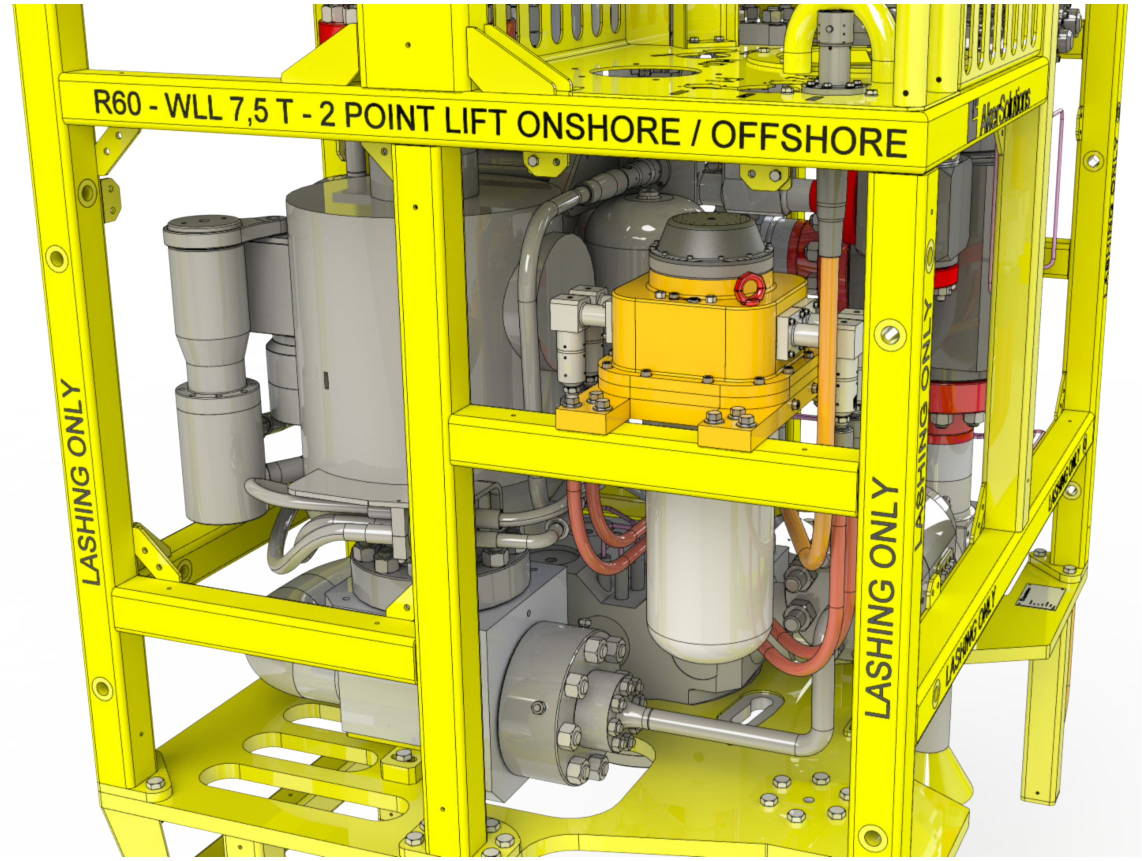
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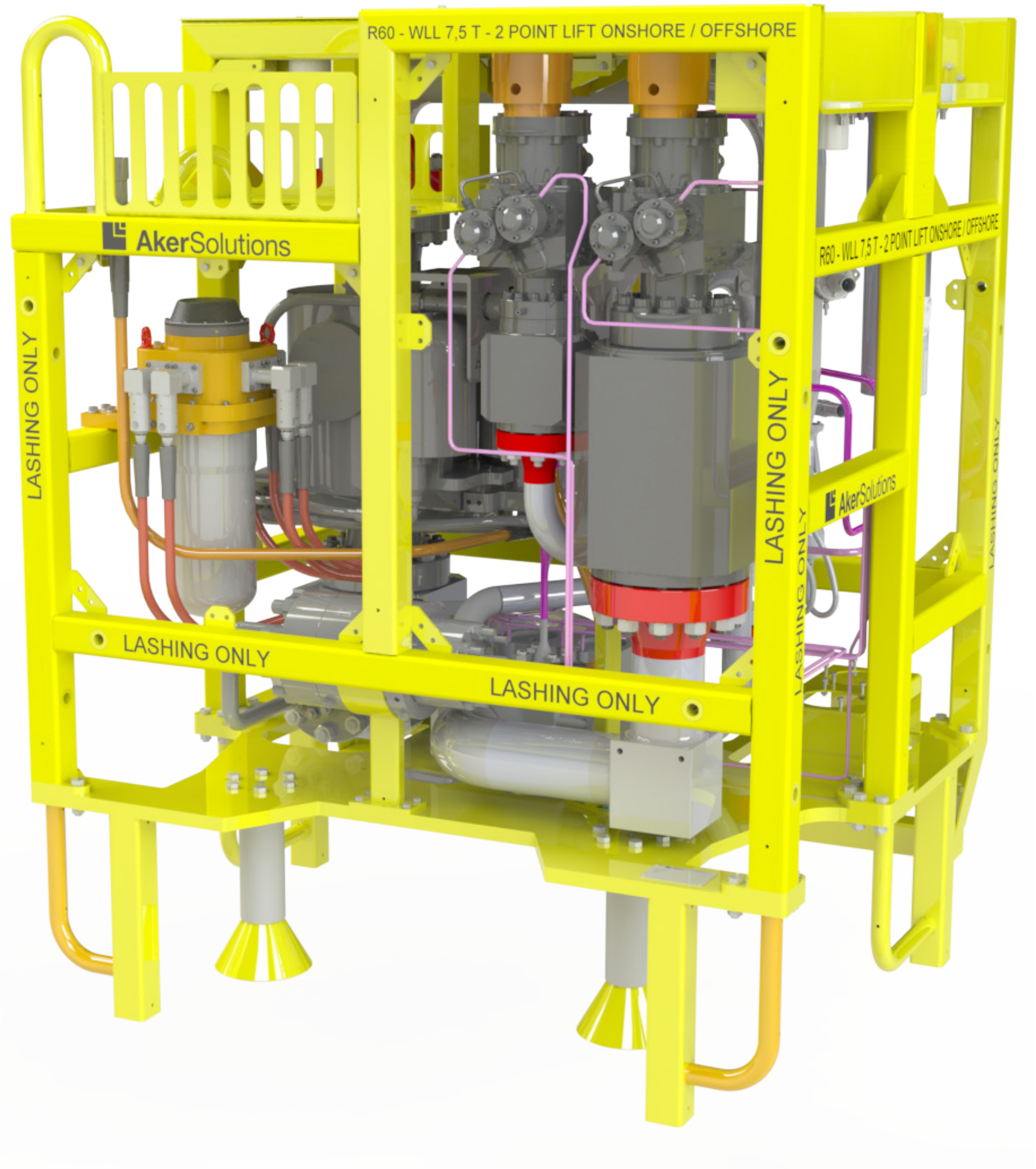
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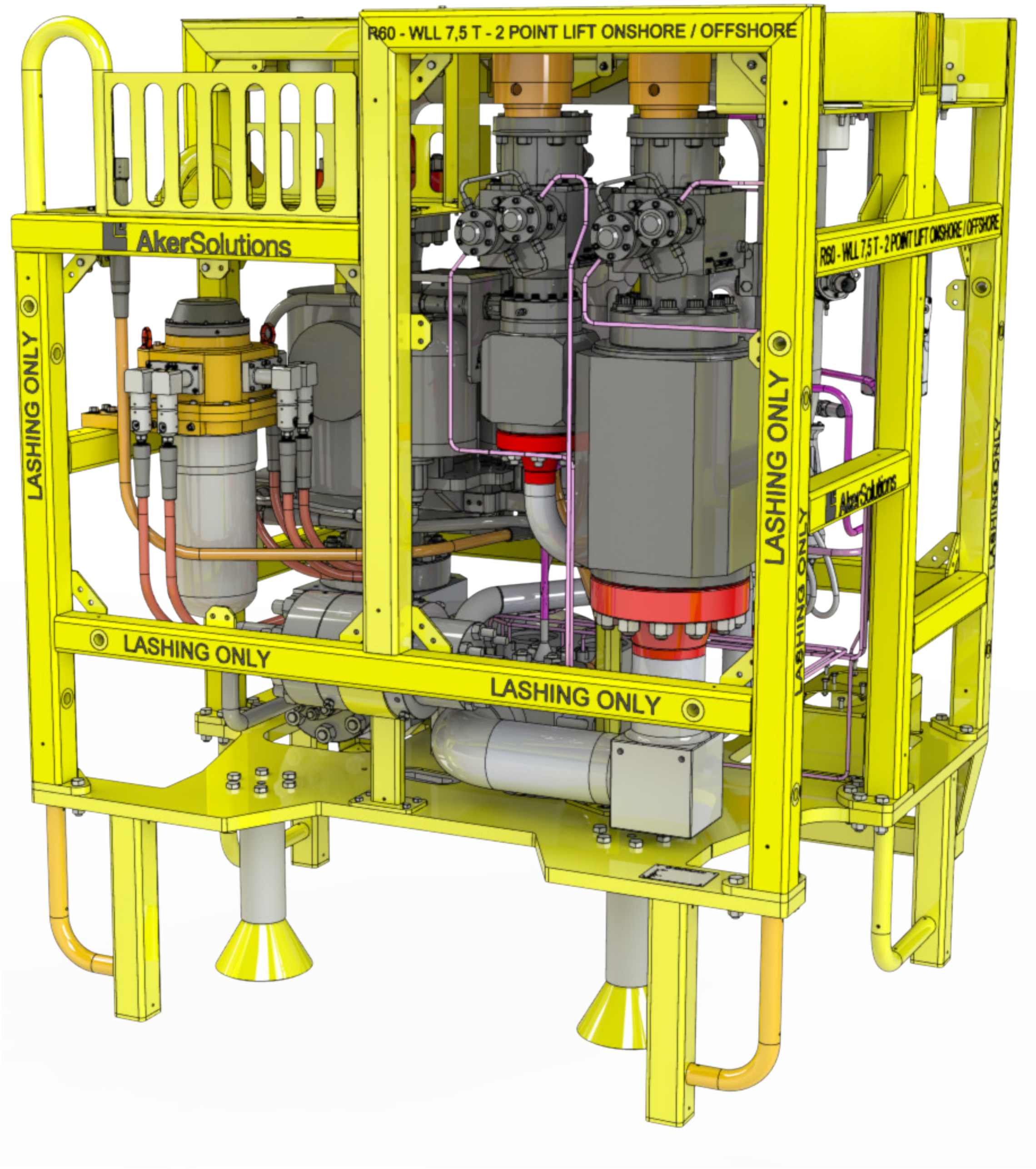
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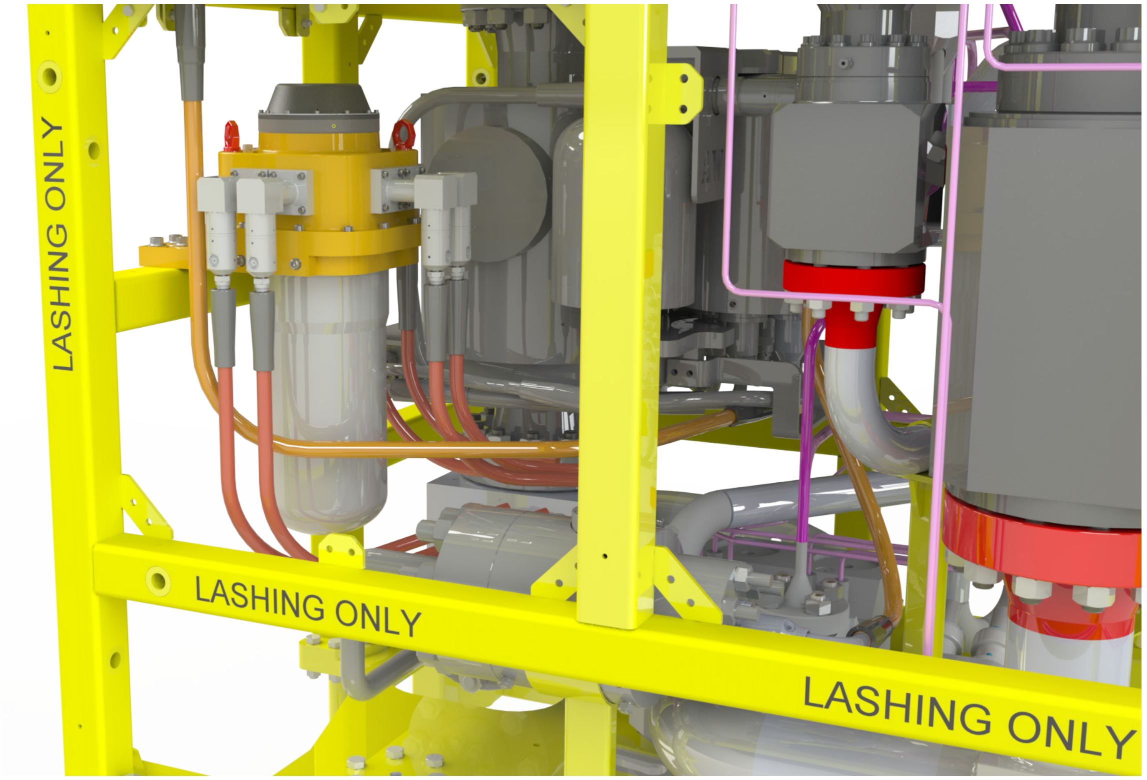
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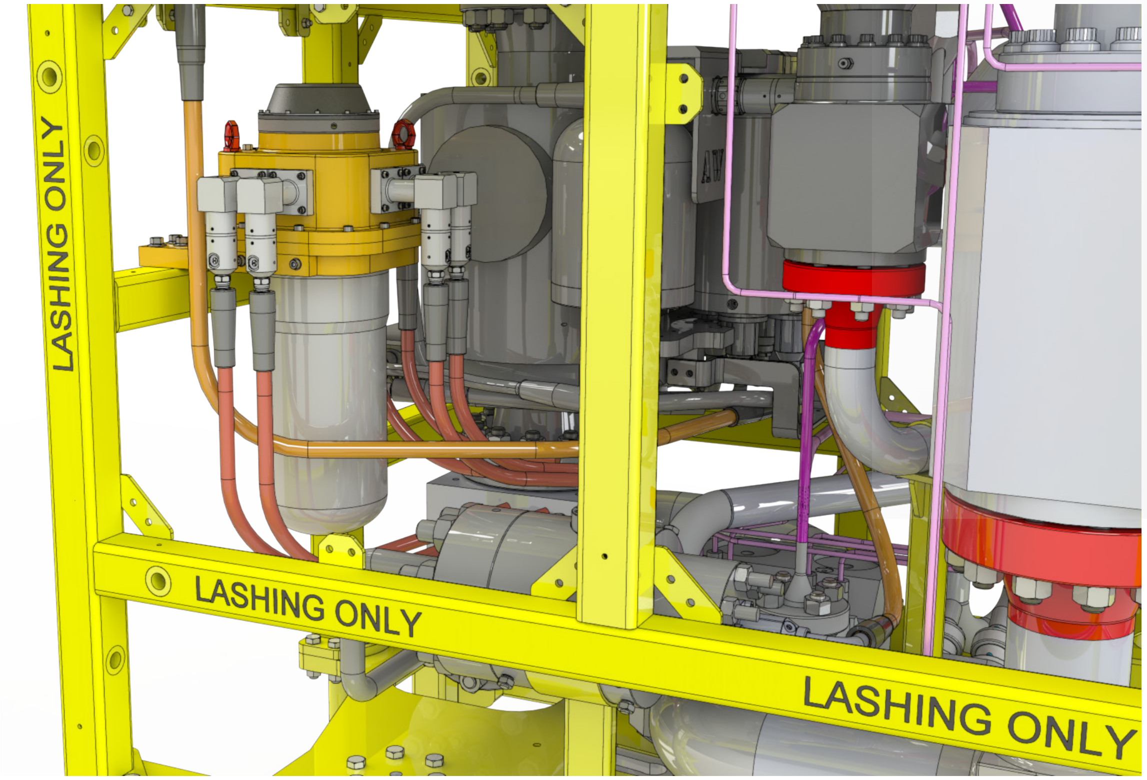
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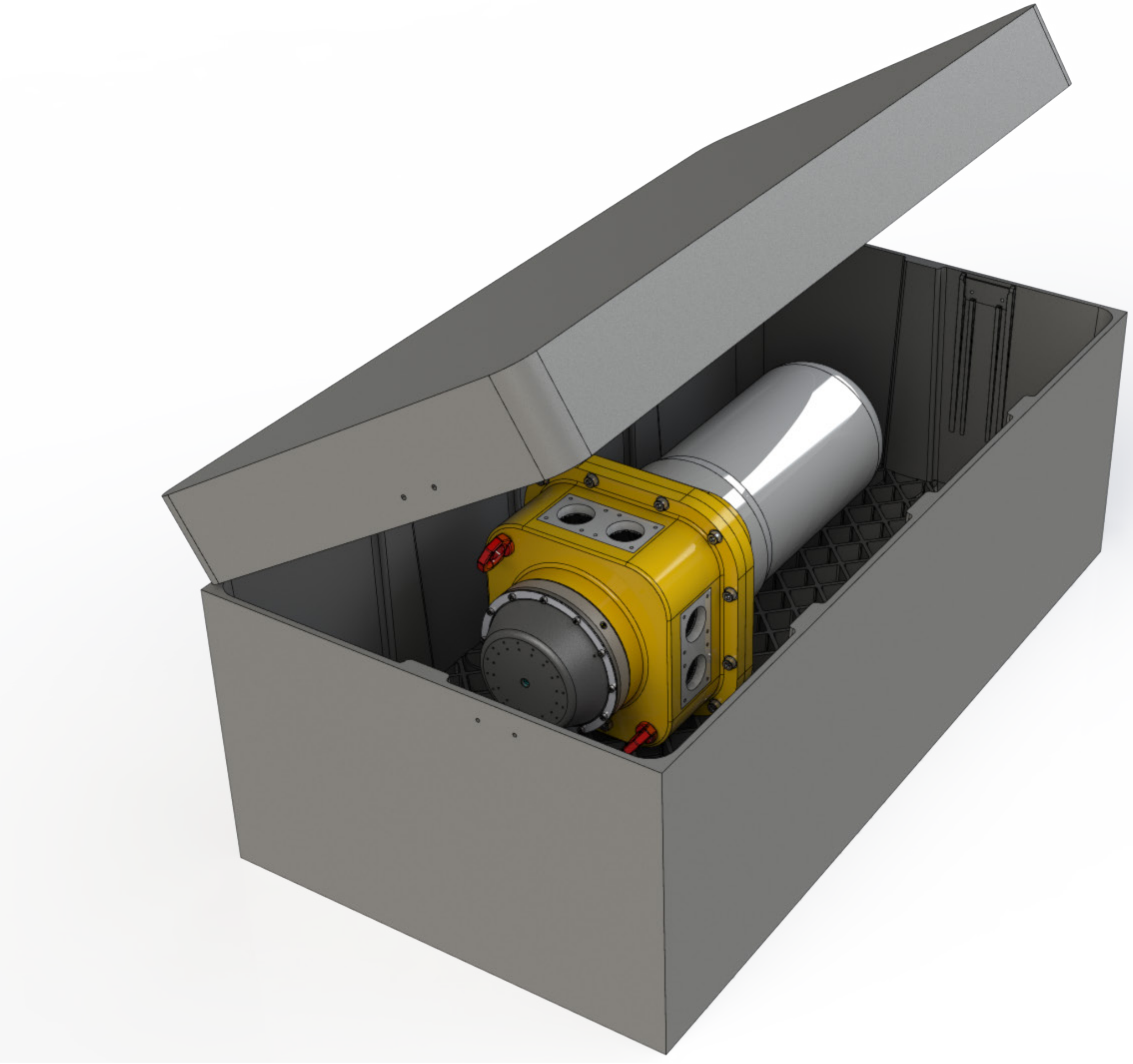
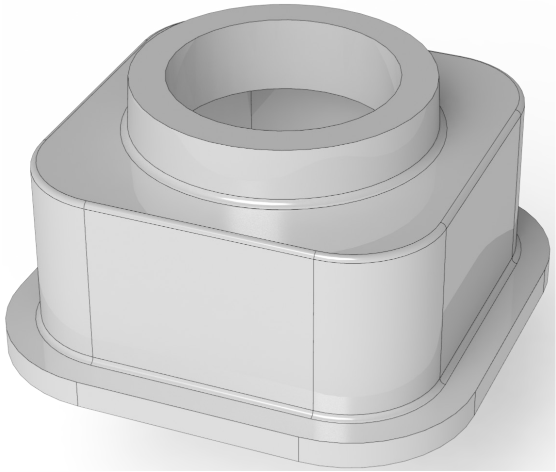
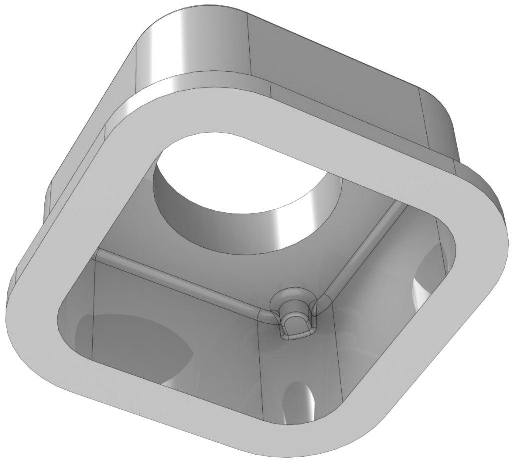
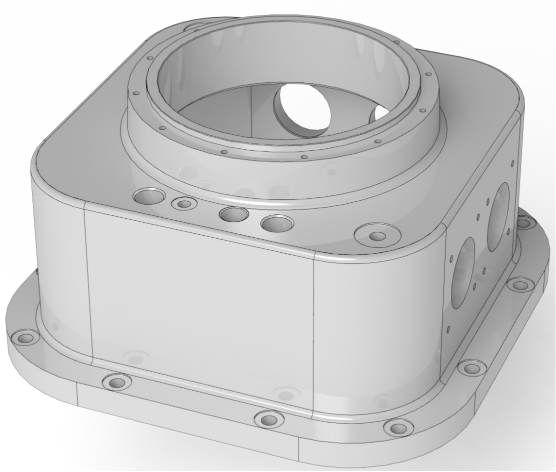
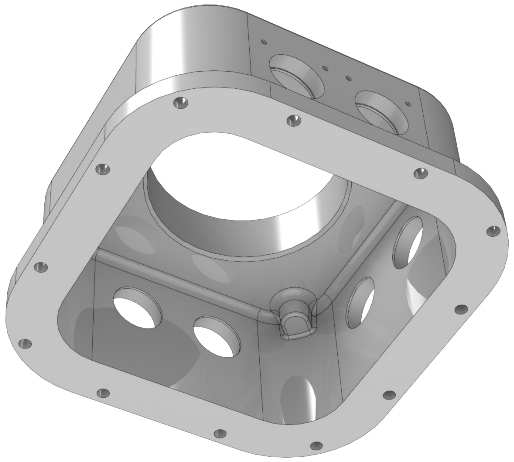


The top housing of the ACM will be cast in ductile cast iron GJS-400-15. Due to the casting process, the housing is drafted, including the mount for the compensator and hooks, to remove the sand cast easier after the process. The next step is machine chamfers, fillets, holes, and gasket canals into the housing.

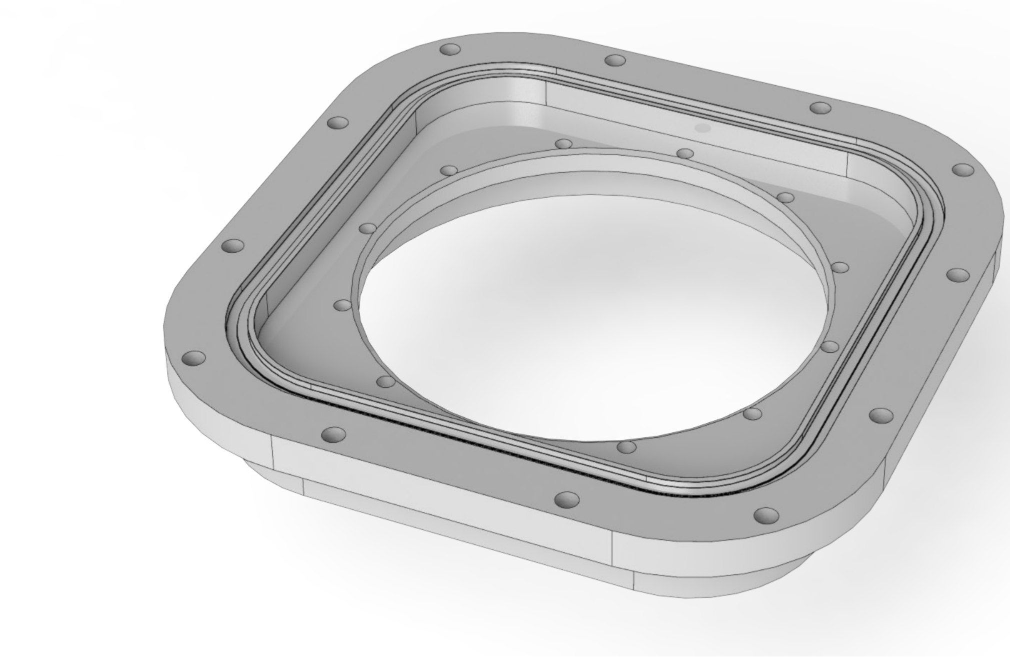


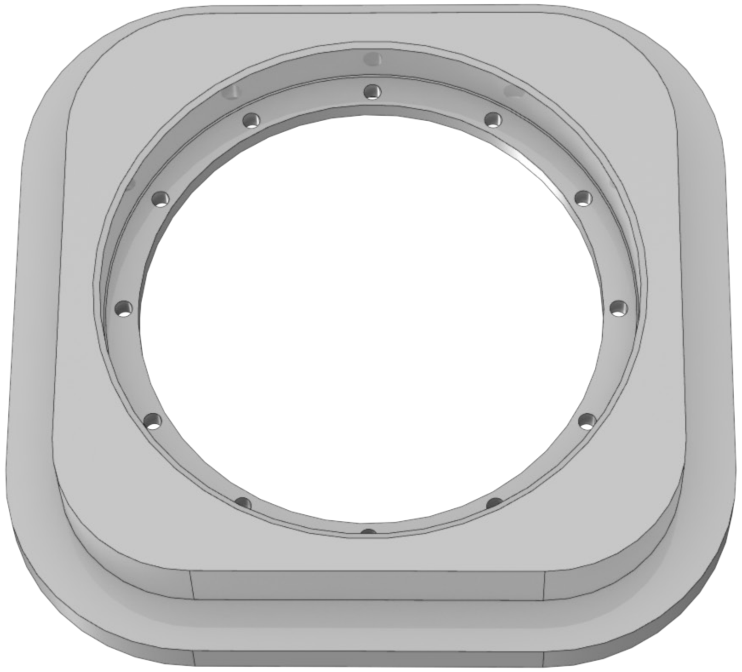






The bottom housing is only machined from a regular carbon alloy steel plate S355 and is a quick process that does not need any other production methods.





8

Discussion

Process

Certain limitations are accounted for since the project revolves around a highly complex and technical system. The FCM used throughout the project is a hydraulic configuration and will differ from the electrical FCM. Therefore, it has been impossible to design routes for the jumpers as no drive heads are in the module. However, this has not limited the presented result; perhaps quite the opposite. Designing the ACM for a compact hydraulic FCM has led to a space-effective solution that can fit into most systems without altering the FCM layout.

During the interviews and field trips, the detailing engineer of the ACM was unavailable. Interviewing the engineer that designed the previous ACM could increase a better understanding of the previous design and related issues.

In the assignment agreement, it is specified that the concept will be justified through testing and simulation. However, during the product development, it became clear that it was more relevant for Aker and the project's approach to analyze the concept. The analysis provided an overview of potential issues and was essential to improving the concept. One component was simulated regardless, the mounting bracket, but this was merely to explore the solution's potential and test the program Ansys for exploration and self-interest.

The title stated in the assignment agreement was also adjusted from being “Redesign of actuator SB ACM Package” to a more fitting title “Redesign of a Small Bore Actuator Control module”. This is a more accurate representation of the thesis.

The cost analysis is based on numbers provided by Aker regarding the current ACM and is discussed and approved by a chief engineer. However, some estimates are based on simple calculations to achieve a total budget. For estimating the cost of the concepts' housing, the housing price for the current ACM was calculated to a cost per liter material volume. This made estimating the concept's housing cost possible by calculating its material volume and multiplying it by the price per liter. This is inaccurate as the production and material cost is affected by many factors that can not be estimated by calculating material volume. However, the housing cost is meager compared to the other components and therefore does not significantly change the result. The budgets are still very precise.

Result – The Road Ahead

The master thesis has resulted in a conceptualized flow control variant of the Small Bore Actuator Control Module justified through theory and analysis. This has led to a reliable, cost-optimized, and interchangeable solution that can utilize both wet- and dry mates.

Since the product is part of a larger system consisting of several components that connect in one system, a natural next step would be to discuss with specialists and designers within the material, production, flow control module, and technology to evaluate the presented solutions and possible adjustments. Discussing with the assembly personnel to map out cable routes and assembly would also be relevant. A deeper analysis of the risk and technology would then be executed to enlighten all possible failure modes and risks connected to the improved solutions. If all parts are satisfied, the product can then be prototyped in a 1:1 model for proper testing. After the testing, the next step would be to mark the module following the presented standard and test it in a complete subsea system.

Learning Outcome

Due to the project's scope, much material and information had to be studied and described in a simplified and detailed manner without any experience in the field. This has led to a lot of time used to understand how a subsea system works and all the technology within it. Doing so established a new understanding of subsea production systems and how to design a product in a highly complex technical system. The project has several illustrations on every subject to improve understanding while documenting the process and choice following standards.

Aker Solutions

This master would not have been possible without Aker Solutions. The cooperation with the company has made it possible to accurately map out, design, and analyze the product resulting in a competitive cost-optimized result. The collaboration has provided insight into how an engineering company designs and evaluates solutions through interviews, discussions, and field trips. It has proved the importance of discussing solutions and technology with personnel that has field experience and interdisciplinary backgrounds. Following is feedback on the collaboration from the primary external supervisor for this project:

“The joint work with Markus has been a great success: together we managed to achieve our target, with quality and at a professional level.
Markus was very engaged, showed a great learning capacity and a positive attitude during the project, which were key for our accomplishment.
The experience supporting a master thesis with Markus shows how relevant the engagement with universities and early career professionals can be.
We are now very lucky to have him in our team in Aker Solutions. It was more than a thesis, it is the start of a career. “

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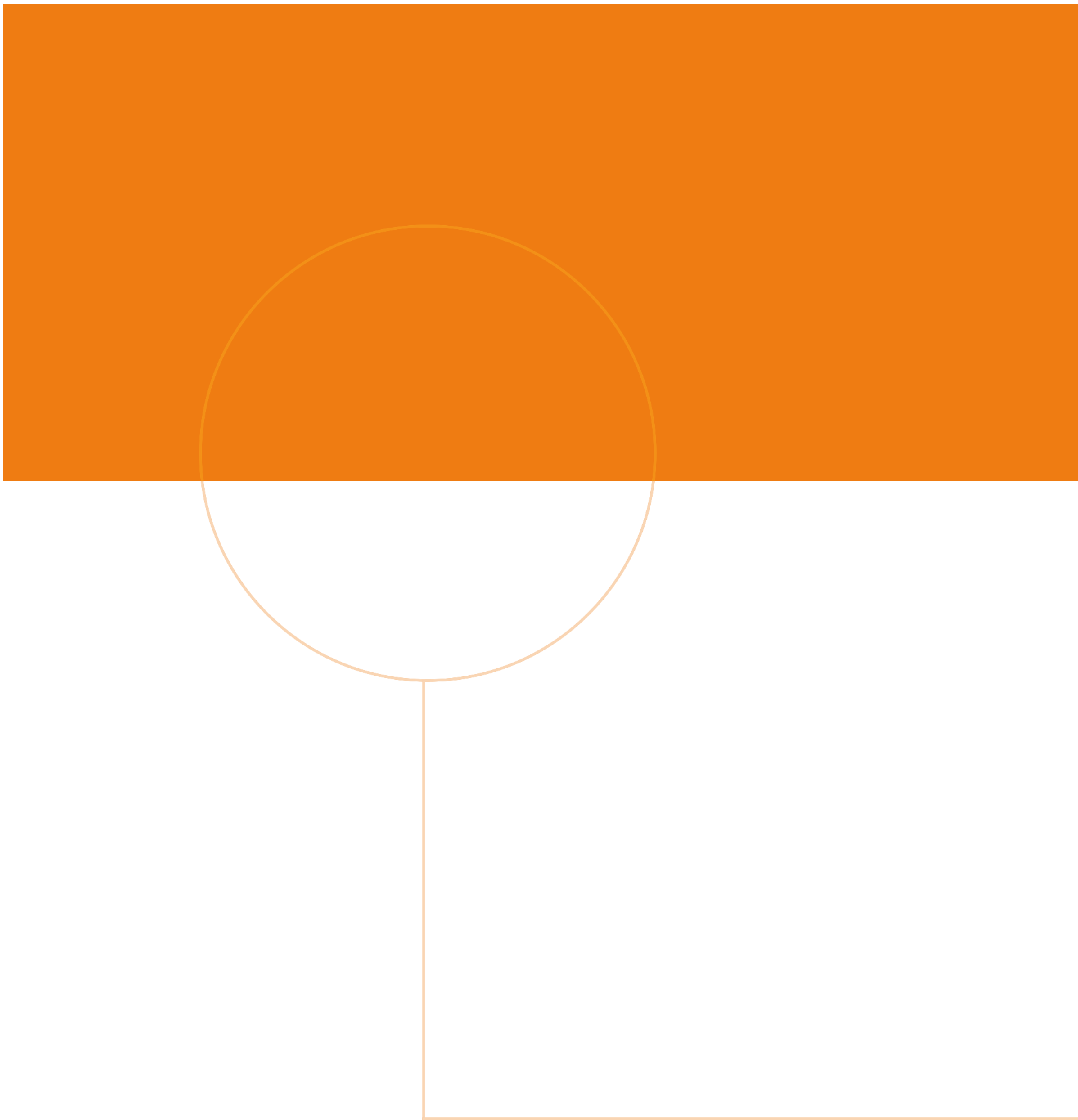

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