Sensur av hovedoppgaver

Høgskolen i Buskerud og Vestfold
Fakultet for teknologi og maritime fag

Prosjektnummer: **2015-03**
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Emnekode: **SFHO3201**

Prosjektnavn
ROV operert SPO kompakt flens for undervanns sammenstilling.
ROV operated SPO compact flange for subsea assembly.

Utført i samarbeid med: Freudenberg Oil & Gas Technologies

Ekstern veileder: David Robertson

Sammendrag: We have designed a system that can assemble a SPO compact flange subsea with the use of a ROV. The compact flange will be assembled using hydraulic bolt turning tools, and have automatically nut entering capabilities. Bolts will be pre-loaded using hydraulic tension nuts, and the seal ring inside the flange is made replaceable.

Stikkord:
- ROV compatible
- 3D modelling
- Hydraulics

Tilgjengelig: JA

Prosjekt deltagere og karakter:

Navn	Karakter
Mathilde Schinnes	
Laila E. Andersland	
Jørgen B. Borgersen	
Marit Skjørestad	

Dato: 4. Juni 2015

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Kjell Enger	Karoline Moholth	Przemyslaw Lutkiewicz
Intern Veileder	Intern Sensor	Ekstern Sensor

Bachelor Thesis

ROV operated SPO compact flange for subsea assembly in deep water

Document No.:	Version No.:	Date:	Document responsible:	Group:	Status:
0.0	1.0	15.05.2015	-	3	Completed

Group members: Mathilde Schinnes, Laila Andersland, Jørgen Borgersen, Marit Skjørestad

Document List

1) Vision Document

2) Project Plan

3) Requirements Specification

4) Test Specification

5) Concept Study

6) Design Document

7) Calculation Document

8) Test Plan

9) FEM Analysis Report

10) Test Report

11) Installation and Assembly Procedure

12) After Analysis

Vision Document

ROV operated SPO compact flange for subsea assembly in deep water

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1.0	3.0	15.05.2015	Marit Skjørestad	3	Completed

Group members: Mathilde Schinnes, Laila Andersland, Jørgen Borgersen, Marit Skjørestad

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1.1 Document History

Table 1: Document history

Revision	Description of change	Date
0.1	Document created	14.01.15
0.2	Updated project purpose and goals, corrected language	02.02.15
1.0	**First release**	**04.02.15**
1.1	Added chapter 4.3 system functions	11.03.15
2.0	**Second release**	**11.03.15**
3.0	**Final release**	**15.05.15**

1.2 Abbreviations

Table 2: Abbreviations

Abbreviation	Description
FPSO	Floating Production, Storage and Offloading
HBV	Høgskolen i Buskerud og Vestfold
ROV	Remotely Operated Vehicle
SPO	Compact Flange name prefix (From former company name Steel Products Offshore)

2.0 Scope

This document is made in the start of our final Bachelor project within machine and product development at HBV. The goal with this document is to give a clear and distinct understanding of the assignment as well as the function of the final product. It will cite the project guidelines to be followed and the project goals and expectations that need to be met. This document will also give a small presentation of our contractor; Freudenberg Oil & Gas Technologies as well as their products.

3.0 Contractor

3.1 Freudenberg Oil & Gas Technologies

The student project is executed in collaboration with Freudenberg Oil & Gas Technologies. This is a global provider of innovative seal solutions and they produce a wide assortment of seal products to the global oil and gas industry. In January 2013, Freudenberg acquired Vector Technology Group as a part of their company which is currently operating out of their local offices in Drammen. The Vector sealing technology and products are used in some of the most demanding applications in oil- and gas-industry worldwide, including offshore oil & gas platforms, FPSOs, refineries, riser and swivel applications, flow-lines and subsea installations and chemical and petrochemical plants. Some of their featured products are the SPO Compact Flange, TECHLOK Clamp Connector and the ROV-operated OPTIMA Subsea Connector.

3.2 SPO Compact Flange

The Vector SPO Compact Flange has been in use onshore, offshore and subsea since 1989. A compact flange is a bolted pipe connection, which include two flanges where the bolt loads are transferred through metal-to-metal contact between the flange-faces. SPO Compact Flanges offers the following advantages over conventional flanges used in subsea piping systems:

- <u>Reduced size and weight.</u> The SPO compact flange offers significant weight and space savings compared to conventional flanges, because of its smaller size and lighter weight. It typically weighs between 70 - 82% less than a conventional flange.
- <u>Static bolted pipeline connection.</u> The SPO compact flange is a 100% static connection due to its metal-to-metal sealing system and beveled flange faces. There is no relative movement of SPO components even under extreme loads. Loads are transferred via metal-to-metal contact points between the flange faces. This eliminate

the potential for movement between the assembled flanges when subjected to a dynamic load.

- Exceptional fatigue characteristics. The SPO compact flange has better fatigue properties than even the pipe welds. The flanges are designed to be stronger than the pipe they are connected to and its double sealing action prevents hydrocarbon releases.
- Full flush bore. This reduces the likelihood of flow disturbance as the flange-faces have full contact so nothing can disturb the flow.
- Limited leakage probability. There is no leakage and no re-tightening of bolts required.
- High integrity sealing. The SPO compact flange incorporates two independent metal-to-metal sealing mechanisms. Also the seal ring is a non-load carrying seal which is unaffected by flange loads.
- High pressure flanges. The SPO compact flange is suitable for both high pressure and high temperature situations.

4.0 Project

4.1 Purpose

The purpose of the assignment is to design a system that can assemble a SPO compact flange subsea with the use of a ROV. As of today there is no existing system for performing this task seeing as all SPO compact flanges are assembled either topside or subsea by a diver. Using divers is a high-risk safety issue and it is therefore applied governmental restrictions limiting the use of divers in the North Sea today. This creates the need for a system that utilizes a ROV for subsea assembly of the SPO compact flange.

The product will especially be used in dynamic scenarios, for example in dynamic risers. Seeing as the SPO compact flange is characterized as a static connection, the bolts see no fatigue loading and the fatigue issues completely disappear. The product will be aimed towards a niche-marked, making it a highly specialized solution, but still a profitable one.

4.2 Goals

Our main goal is to find a way to assemble the compact flange using a ROV as well as verify that a correct connection is made. It is important to note that we are not inventing the compact flange all over again, but rather making minor to -moderate modifications for it to be ROV compatible. The assembly should be kept as simple as possible, and the design shall provide a quick, safe and reliable make-up/splitting of the flange.

The compact flange will be assembled using hydraulic tools with both bolt pre-loading and bolt entering capabilities. The compact flange have 20 bolts that needs to come together and be tightened simultaneously. The tool can be made integrated or kept separate from the SPO Compact Flange.

The flanges needs to be positioned face to face and bolt hole to bolt hole. The swivel flange will provide the bolt hole alignment capabilities and the design must have a guiding mechanism which will rotate the swivel ring into position.

The seal ring inside the flanges will also be made replaceable. This should be possible to change using the ROV.

The system shall be used subsea, which apply certain requirements with regards to material design. The product will function as a pipe coupling and it is important that we do not make changes that may affect the sealing. The system shall be able to withstand both high pressure and corrosion. The system shall be assembled by an ROV and it is therefore important to design the system with standard ROV interfaces and connections.

Ideally, the group should make a prototype in form of a 3D printed model of the system. This way we will be able to show the functionality of the system. It is also a good tool to visualize the internal compatibility of the system.

4.3 System Functions

Our system have several different functions that needs to be satisfied. The different functions are:

- Seal ring installation and replacement
- Seal ring retainment
- Flange alignment
- Flange assembly
- Flange preload
- Flange lock
- Flange un-lock and dis-assembly

4.4 Challenges

The assignment include challenges in

- design of mechanical components
- design of hydraulic components
- strength calculations
- material selection
- adaptation to the ROV

5.0 References

[1] http://www.vectortg.com/company/who-we-are/?style=264

[2] http://www.vectortg.com/Media/SPO_Subsea-A4-V003-2014.pdf

[3] http://www.vectortg.com/spo-compact-flange/?style=264

Project Plan

ROV operated SPO compact flange for subsea assembly in deep water

Document No:	Version No:	Date:	Document responsible:	Group:	Status:
2.0	3.0	15.05.2015	Mathilde Schinnes	3	Completed

Group members: Mathilde Schinnes, Laila Andersland, Jørgen Borgersen, Marit Skjørestad

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1.1 Document History

Table 1: Document history

Revision	Description of change	Date
0.1	First layout	21.01.15
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1.0	**First Release**	**04.02.15**
1.1	Moved chapter 7.0 till 5.0. Updated system risks.	16.02.15
1.2	Updated chapter 6.0 till new project model.	11.03.15
2.0	**Second Release**	**12.03.15**
2.1	Updated chapter 11. Website address	01.05.15
2.2	New activities: 10.5 and10.6	02.05.15
3.0	**Final release**	**15.05.15**

1.2 Abbreviations

Table 2: Abbreviations

Abbreviation	Description
CAD	Computer Assisted Design
CD	Compact Disc
FEA	Finite Element Analysis
FEM	Finite Element Method
FO&GT	Freudenberg Oil & Gas Technologies
HBV	Høgskolen i Buskerud og Vestfold
IIM	Iterative Incremental Model
J. B. B.	Jørgen Bårnes Borgersen
L. E. A.	Laila Egbocha Andersland
MOM	Minutes of Meeting
M. Sc.	Mathilde Schinnes
M. Sk.	Marit Skjørestad
ROV	Remotely Operated Vehicle
SPO	Compact Flange name prefix (From former company name Steel Products Offshore)
UP	Unified Process
SW	SolidWorks

2.0 Scope

The purpose of this document is to gather all the relevant information needed to manage the final project at HBV. The project plan will provide an insight in how we will plan our work during this project. It sets specific goals, and distinct limits to be able to satisfy our contractor and secure a good result. A more detailed overview of the different responsibilities will be described. This is to ensure that every part of the project work is covered, and one person holds the overall responsibility.

The plan provides a structure for how the group will record the number of hours spent on the different activities, and how we will ensure that progress follows the estimated time. The group envisions how the follow up with internal and external supervisors will be. We have made a time and activity plan to relate activities against an overall schedule. This way we can keep track of resources needed for each activity. The time plan will be the basis for the progress to the group, and will be updated throughout the project. We are planning our work based on a particular project model, and it is described how we envision to solve the assignment according to this.

3.0 Objectives and Limitations

3.1 Project Background

The bachelor project is a part of a three-year engineering bachelor at HBV, Kongsberg. The purpose of the project is to teach students good work habits and project management techniques. This will be the closest we will get to a real life situation in a school environment. It will have a practical approach, and we will be able to test our theoretical knowledge in practice.

HBV sets a number of requirements for execution of the project. The Bachelor project count 20 credits, and it is expected that we use the number of hours according to this. We will have in total three presentations. The first will include a presentation of the assignment and organization of the further work. The second will be a presentation of different concept studies, leading up to a final design. The last presentation will be a technical presentation of the final product.

3.2 Prerequisites

For us to be allowed to conduct the Bachelor project, all earlier courses at HBV needs to be passed. This is important because we will use the knowledge acquired during earlier courses. Now we will be able to use the theory in a more realistic work situation.

We are depending on access to important and underlying standards, documents and models from FO&GT. FO&GT is a global company, and they write all their documentation in English. Neither our external supervisor nor examiner speaks Norwegian fluently; therefore, all our documentation and presentations will be in English.

3.3 Task Description

The student project is executed in collaboration with Freudenberg Oil & Gas Technologies. The purpose of the assignment is to design a system that can assemble a SPO compact flange subsea with the use of a ROV. As of today there is no existing system for performing this task. The assignment consists of several parts that needs to be fulfilled. Our main goal is to find a way to assemble the compact flange using a ROV as well as verify that a correct connection is made.

The compact flange will be assembled using hydraulic tools with both bolt pre-loading and bolt entering capabilities. The tool can be made integrated or kept separate from the SPO Compact Flange. We need to customize the tool to fit to the flange and to be operable by a ROV.

The flanges needs to be positioned face to face and bolt hole to bolt hole. We need to think about the fine adjustments to make this possible. This include positioning the flange correctly both in an axial and rotational direction.

The seal ring inside the flanges will also be made replaceable. This should be possible to change using the ROV.

3.4 Project Group Goals

- Deliver a final product that meets customer requirements and specifications.
- Increased experience and expertise within project work.
- Challenge the knowledge we have gained throughout the study, and test it out in a more realistic work situation.
- Gain a satisfying final grade.

3.5 Project Limitations

There are some limitations related to the project. The main factors include limited resources, limited background knowledge, and limited time. This is a student project, thus none of us have any earlier experience or knowledge with the products or working with a project of this size. This requires research and our biggest limitation will most likely be time. Allocated time are five months and there is much work to be done during this time. Due to the limited time frame, it will not be realistic to plan to construct an actual physical product. The outcome of this assignment will be 3D models in SolidWorks, and hopefully a printed 3D model of the final product.

4.0 Project Organization

4.1 Group Members

Mathilde Schinnes

Mechanics, Product development

mathildeschinnes@gmail.com

Tel: 412 06 092

Project leader

Marit Skjørestad

Mechanics, Product development

marit_skj@hotmail.com

Tel: 476 36 789

Document responsible
Economy responsible

Jørgen Borgersen

Mechanics, Product development

jorgen-borgersen@hotmail.com

Tel: 477 50 804

Design responsible
Technical responsible

Laila E. Andersland

Mechanics, Product development

lailander88@hotmail.no

Tel: 908 97 580

Test responsible
Web responsible

4.2 Responsibilities

We have divided our work into several different areas of responsibility to ensure a safe execution of the project. When our responsibilities cover all parts of the project, we make sure nothing is forgotten because no one had responsibility for this. Specifically, everyone will have one or several areas of responsibility.

Project Leader:

The project leader will function as the overall leader for the entire duration of the project. She will have full overview of the project. This include knowledge about where we are in the process, and to make sure that we are on schedule according to the plan. She will also have the overall responsibility for the quality of the project. The leader will be responsible for delegating tasks to other group members, and make sure that everyone have something to work with. She will take care of all communication and contact between internal and external examiner and supervisor, and stakeholders. This include all e-mail contact, booking and schedule meetings, and distribute MOM afterwards.

Document Responsible:

The purpose of this position is to have the overview of all the documents made during the project. This include to create a simple and easily understood storage system, and to place the documents in suitable folders. She will create standard layouts for all the documents, and make sure every documents follow the same standard. Document responsible will make sure that everything is saved in Dropbox, and take an extra backup of all the documents once every week. She is also responsible for the end report.

Technical Responsible:

Technical responsible will handle all technical issues we will meet during the project. He will make sure everything is according to requirements specifications, and standards we have to follow. He will make sure that everything is technical correct, and achievable. He will also be responsible for the quality of the final product.

Design Responsible:

The purpose of the design responsible shall be to have the overall charge of 3D design, and to make sure that all 3D models are according to specifications. Our design will mainly be made in SolidWorks, and the data will be based on results from requirement specifications and concept studies. He will also be in charge of the 3D printing.

Test Responsible:

Test responsible is in charge of how to verify and validate the requirements. She will be responsible for the test specification and test plan documents. This include creating and supervising the tests needed to complete the project according to the requirements. She will also have the overall supervision with the FEM analysis.

Economy Responsible:

Economy responsible is in charge of creating and updating the budget. She will also be in charge of acquiring money from our contractor and have control over the actual money spent.

Web Responsible:

Web responsible will be responsible for the website of the project. This include creating and continuous updating the website.

4.3 Supervisors and Examiners

External Supervisor:

David Robertson

Engineer manager

david.robertson@fogt.com

The external supervisor will function as a representative for our contractor. He is responsible for ensuring that the necessary resources are made available to the project group. This may include equipment, software and technical information and guidance. He will also be present at the mandatory presentations, but will have no direct responsibility for setting the final grade.

External Examiner:

Przemyslaw Lutkiewicz

Senior FEA Engineer, MSc and PhD.

przemyslaw.lutkiewicz@fogt.com

The purpose of the external examiner is to evaluate this specific bachelor project. He will attend all three presentations, and be part of the panel setting the final grade.

Internal Supervisor:

Kjell Enger

kjell.enger@hbv.no

The internal supervisors' purpose is to function as the groups mentor at HBV. He will support and guide the group during the entire project period, with questions and advice in connection with project work and project management. The group will schedule meetings with internal supervisor once a week. This way he will continuously stay updated on the group's progress and ensure that the project is going according to the plan. He will also be present at all three presentations and be a part of the panel setting the final grade.

Internal examiner:

Karoline Moholth

karoline.moholth@hbv.no

The internal examiner purpose is to evaluate all bachelor projects. She will evaluate the groups work and process during the entire project period. She will attend all three presentations and we will provide her with all the documentation from the project. She will be part of the panel setting the final grade.

5.0 Meetings

Several different meeting will be held during the project period. This includes internal group meetings, meetings with internal and external supervisor as well as stakeholders. Meetings are important to ensure the project's progress and that we are moving in the right direction.

5.1 Meeting with Internal Supervisor

Meetings with the internal supervisor is held once a week. This is for the supervisor to keep track of the group's work and that the project is progressing and moving in the right direction. These meetings are also a good time for the group to get input and advice. The supervisor will especially be available when it comes to project organizational issues. It is the groups' responsibility to summon and plan the meetings. The role as the chairman will vary for each meeting. This is important because of the valuable experience this provides.

5.2 Meeting with External Supervisor

Meetings with the external supervisor will not be scheduled weekly, but rather when we need extra help and guidance. In the high-level design and detailed design phase this is expected to be more often than the rest of the project. The external supervisor holds a lot of experience and knowledge that we might need for implementing the project. He is a representative from our contractor and knows what is required to meet the employers' requirements.

5.3 Meeting with Stakeholders

There are several stakeholders with an interest in, or in direct contact with our system. It is important for us to satisfy their needs and requirements and therefore it can be relevant to meet with some of the different stakeholders. These can typically involve ROV companies and supplier of hydraulic tools. These meetings will be held when the group needs to acquire new information.

5.4 Internal Group Meetings

The group will start every morning with a short meeting. This is to get an overview of the plan for the day. What critical activities needs to be done and what tasks each team member will work with. This way we ensure that everyone have something specific to work with. In the same way, we will summarize todays work at the end of the day. This is to check if we have managed to perform the planned tasks during the day.

5.5 Minutes of Meeting

After every meeting there will be created a MOM. This will be distributed to all meeting participants within 24 hours after each meeting. This will include time and date of the meeting, place and participants, agenda for the meeting and points of interest. The job as the referent will vary between the group members.

5.6 Follow-up Document

Once a week we will create a follow-up document. This will be delivered internal supervisor prior to the weekly supervisor meeting. This document will inform the supervisor the work done by every team member the last week and what is scheduled to be done the following week. This document will also give information of the current project phase and the general state of the project.

6.0 Project Model

6.1 From Vee- Model+ to Iterative Incremental Model

When the project first started, the very first thing to do was to analyze the assignment and try to find the right project model for this specific project. Different models were discussed and evaluated, mainly the three models learned in the course “Systems Design and Engineering”; Vee-model, Spiral model and Waterfall model. At the beginning the assignment was considered as relative small, clear and with well-defined requirements. Therefore we chose to use the Vee-model for this project. This is a system-developed model designed to facilitate the understanding of the complexities associated with developing systems. The model was customized in different ways to make it more suitable for the project, and was called the Vee-model+. It was made an activity list and a Gantt-chart which followed the project model phases throughout the whole project time. This worked perfectly at the beginning of the project, but after some time it became clear that the requirements had to be updated and reviewed many times during the project. It also became clear that many of the requirements could not be set before a specific concept had been chosen. It became more and more apparent that the Vee- model gives little room for mistakes. Given the little time we have available, this is not beneficial. We thought the first plan and Gantt-chart was well-planed and good, but after some weeks there were changes that forced us to change this. If the Vee-model should have been followed perfectly, the model would not allow us to go back to make changes in earlier phases. It also became clear that it would be more parallel working through the different phases then first assumed. Therefore it was decided to change the model at the beginning of week 8, from the Vee- Model+ to a custom process model inspired by the Unified Process. This model was called: “Iterative Incremental Model”.

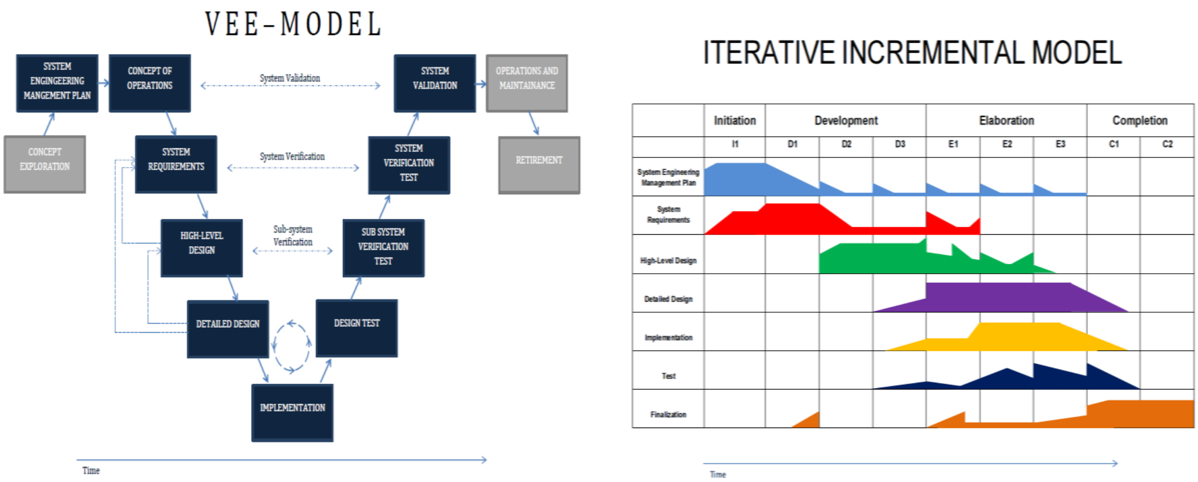

Figure 1: From Vee-model+ to Iterative Incremental Model

6.2 Iterative Incremental Model

The Iterative Incremental Model, hereafter IIM, is a project development model that emphasizes the iterative and incremental process way of working. Iteration is the act of repeating a process with the goal to get closer and closer to a result every iteration. The definition of incremental is the process of increasing in number, size, quantity or extent. The IMM is strongly inspired by the UP, but there are many differences. The originally UP is based very much on Use Cases, which is not suitable for this project. The UP should be viewed as a framework which should be customized for the specific project.

The IMM is divided into mainly four phases: initiation, development, elaboration and completion. This phases are then again divided into a series of time boxes (I1, D1, D2...) Every time box will last for two weeks, except from the initiation phase, which last for three weeks. Each time box is an iteration that results in an increment, where the system contains added or improved functionality. Even though most iterations include work in most of the process disciplines (requirements, design, testing), the emphasis will change over the course of the project.

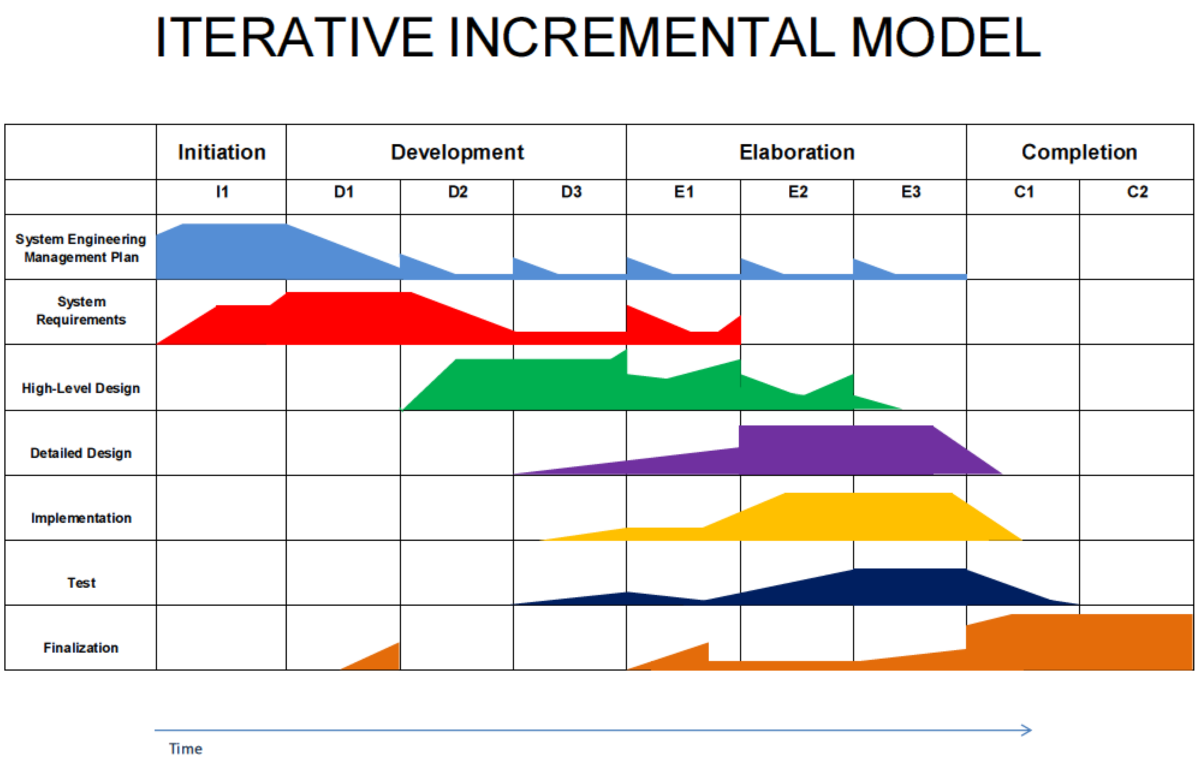

Figure 2: Iterative Incremental Model

6.3 Phases of the Iterative Incremental Model

6.3.1 Initiation

Initiation I1

The very first phase of the project is the initiation. This normally is the smallest phase, but where the foundation of the whole project is established. Typical goals for the initiation phase are to establish a justification for the project and to establish the project scope and boundaries. It is also important to identify risks and make a risk analysis. This phase also includes making a preliminary project schedule, a Gantt-chart and a cost estimate.

6.3.2 Development

The second phase in this project model is the development phase, which is divided into three smaller phases (D1, D2 and D3), each with duration of two weeks. The main focus in this phase is to create and design concepts, and at the end of the phase try to decide one concept to work further with.

Development D1

At the D1 it is expected to create and validate the system architecture and create most of the system requirements. It is very important to try to set good and clear requirements at the very beginning of the project. The system requirement is the main focus in this phase. The first presentation will take place at the end of D1. The agenda of the presentation is to present the assignment, the project plan and project model, requirements and test specifications.

Development D2

At the D2-phase, the main focus is the concept brainstorming and concept development. In this phase it is very important to be creative and innovative. No ideas are wrong to suggest in this phase. There will be many sketches, both drawn on paper, but also in SW.

Development D3

In the last part of the development phase, the main focus will be to narrow down the number of concepts. First weed out the irrelevant suggestions and so work down the number with decision making-matrices and other remedies into two or three good concepts. The final thing done in the development phase is to make a plan for the Elaboration phase. It is important to validate the chosen concepts, to make sure that the right product is being built.

6.3.3 Elaboration

The elaboration phase is normally the largest phase in the project where construction and physically building the product is taking place. Since time is not our friend in this project, there will not be time to physically build anything in scale. The elaboration phase is a phase where the detailed design of the chosen concepts is in focus. Every part has to be designed, construct and tested. The project model still allows changes in the high level design at this phase. If a new idea is *brought up*, it still room to integrate this idea and change the concept. An important thing to keep in mind is the requirements, so we are sure that we are building the product right. To make sure that the right product is being built.

Elaboration E1

The detailed design is the main focus in this phase. Here we need to go deeper into the design, and start detailed drawing in SolidWorks. The second presentation will be held in the middle of this phase. This presentation will have a clear technologic focus and the agenda for the presentation will be concept drawings and present the plan for further work with the chosen concepts. The phase will start with an iteration of the requirements specification for the chosen concepts.

Elaboration E2

The plan for the E2-phase is to do implementation of the detailed designed parts from the E1. The high level design will still be the largest focus, but there will also be spent some time testing the components. The E2-phase will be ended with Concept document writing. The goal for this phase is to decide a final concept, so it could be possible to fulfill the detailed design and the testing.

Elaboration E3

The E3 phase is a very important phase. Everything that is started will be fulfilled. The goal for this construction phase is to be finished with the detailed design of the chosen concept, and to have approved tests for every single part, and the total assembly.

6.3.4 Completion

Completion is the last part of the project. The goal is to finish all of the detailed design, construction and testing very early of this phase, but it is a buffer, so it is possible to shorten this period if some of the other phases need more time.

Completion C1

The goal will be to complete all of the constructions and design very early in this phase. The project model visualize that it will be time to finalize the design and tests in this phase. There will be printed a 3Dprint of the product in this phase, when the design is finished. The final report will be a main focus, and the goal is to be finished with the final report at the end of this phase.

Completion C2

This is the very last phase of the project. In the middle of the phase, the final report shall be handed inn. At the end of the phase it will be time for the third and final presentation. The third presentation will include a sales part, a technical part and a questioning part. The C2 will be ended with graduation.

6.4 Stages of the Iterative Incremental Model

The project is divided into 7 main stages. These stages are different weighted in the various phases of the project. This is visualized in the project model.

6.4.1 System Engineering Management Plan

System Engineering Management Plan contains several administrative tasks, such as project planning, vision document writing, Gantt chart and meetings with internal and external supervisor. It is natural to assume that the System Engineering Management Plan stage is going to include the greatest work amount in the beginning, in the inception phase. As the project model visualize, the project plan will be updated at the beginning of every phase.

6.4.2 System Requirements

In the initiation phase, there will be some initial work with the system requirement with the use of use case scenarios, requirements document and stakeholder analysis. The systems requirements will make the foundation for the whole product design and development. The requirements will be the framework for all of the project work. There will be written a Requirement Specification Document early in the project. The System Requirements will be updated when the actual concept have been chosen. The requirements will become more specific during every iteration.

6.4.3 High-Level Design

High-Level design will begin in the start of the D2 phase. There will first be done some concept brainstorming with sketches on paper. The different ideas and concept will then be discussed with the contractor. Every concept will be given pros and cons, and with the help of decision making matrices there will be written a technical Concept Document. Some of the ideas will be roughly drawn in SW. Throughout iterations there will be chosen one concept to continue to work with. This is a very important phase in our project, and may be the hardest task in the project.

6.4.4 Detailed Design

There will be done some detailed design at the end of the development phase, but the real focus on detailed design will first start at the beginning of the elaboration phase. This stage includes development of the chosen concept and detailed 3D design. Every component will be calculated and designed in detail.

6.4.5 Implementation

Since the implementation stage includes integration of parts in 3D design, the stage can only begin after we in the detailed design stage have some results that are possible to work further with. This stage also includes the implementation of the 3D print.

6.4.6 Test

Test includes different activities depending on how far the project has come. There will be done some test specification already in the initiation phase to ensure that the requirements written this early are possible to verify. After the requirements will be updated in the early elaboration phase, the test will consequently also be updated. There will be written a Test Plan document containing a detailed understanding of workflow and test acceptance [4]. This will be relevant after detail design.

6.4.7 Finalization

The school requires submissions before each presentation; where there is in total three submissions. The 1st presentation was held at the end of the Inception phase, the 2nd presentation will be at the end of the Elaboration phase. This will result in a significant amount of document writing, proofreading, print and assemble of the hand in. This is why we have created a stage that is called Finalization, which includes all of these activities. There will therefore be most amount of work the week before the presentations, and most quantity before the last presentation.

7.0 Activities

The project phases will be divided into many different activities, to assure proper progress documentation. This list will be used in correlation with a Gantt chart which is a visual tool used in project planning. The chart will visualize at what time every activity should be performed, thus helping us to set deadlines to follow. The amount of work advised for each task was somewhere between 5 and 75 hours, which is something the project group will try to accomplish.

7.1 Activity list

Table 3: Activity list

Activity nr	Activity Description
1.0	**Administrative tasks**
1.1	Project planning
1.2	
1.3	Vision Document writing
1.4	Project Plan document writing
1.5	Update Project Plan document
1.6	Create budget
1.7	Update budget
1.8	Working hours
1.9	Research
1.10	Risk Analysis
2.0	**Requirements specification**
2.1	Stakeholder analysis
2.2	Define requirements
2.3	Requirements Specification Document writing
2.4	Update Requirements Specification Document
3.0	**Test**
3.1	Define test methods
3.2	Test Specification Document writing
3.3	Update Test Specification Document
3.4	Test Plan Document writing
3.5	Update Test Plan Document
3.6	Execute testing
3.7	Evaluate test results
3.8	Test Report Document writing
4.0	**High-level design**
4.1	Concept brainstorming
4.2	Concept 3D drawing
4.3	Concept studies
4.4	Concept selection
4.5	Concept Document writing
4.6	Concept development
4.7	Update Concept document
5.0	**Detail design**

5.1	Part development
5.2	Design Calculation
5.3	Detailed 3D design
5.4	Design document writing
6.0	**Implementation**
6.1	Integrate parts in 3D design
6.2	3D print
6.3	Implementation of 3D print
7.0	**Meetings**
7.1	Meetings with internal supervisor
7.2	Meetings with external supervisor
7.3	Internal meetings with group members
7.4	Stakeholder meetings
7.5	Write Follow up documents
7.6	Write MOM's
7.7	Third party contact
8.0	**Web design**
8.1	Create web site
8.2	Update web site
9.0	**Presentation**
9.1	1st presentation
9.2	Create power point for presentation
9.3	2nd presentation
9.4	Create power point for presentation
9.5	3rd presentation
9.6	Create power point for presentation
10.0	**Finalization**
10.1	Final Report Writing
10.2	Review Final Report
10.3	Print and hand in Final Report
10.4	Create project poster
10.5	User Manual
10.6	After Analysis

7.2 Activity Time Estimation

7.2.1 Administrative Tasks

Table 4: Time estimation

Activity no.	Description	Start date	End date	Resp.	Est. hours
1.1	Project planning	07.01.2015	28.01.2015	M. Sc.	100
1.2					
1.3	Vision Document writing	12.01.2015	30.01.2015	M. Sk.	30
1.4	Project Plan document writing	12.01.2015	04.02.2015	M. Sc.	80
1.5	Update Project Plan document	09.02.2015 06.02.2015	13.02.2015 08.02.2015	M. Sc.	20
1.6	Create budget	21.02.2015	21.02.2015	M. Sk.	4
1.7	Update budget	27.02.2015	27.02.2015	M. Sk.	4
1.8	Working hours	05.01.2015	18.05.2015	M. Sk.	10
1.9	Research	05.01.2015	01.05.2015	L. E. A.	50
1.10	Risk Analysis	21.01.2015	29.01.2015	J. B. B	30
Sum					**328**

7.2.2 Requirements Specification

Activity no.	Description	Start date	End date	Resp.	Est. hours
2.1	Stakeholder analysis	07.01.2015	27.01.2015	J. B. B.	40
2.2	Define requirements	07.01.2015	27.01.2015	J. B. B.	40
2.3	Requirements Specification Document writing	15.01.2015	30.02.2015	M. Sk.	90
2.4	Update Requirements Specification Document	09.02.2015	13.02.2015	M. Sk.	10
Sum					**180**

7.2.3 Test

Activity no.	Description	Start date	End date	Resp.	Est. hours
3.1	Define test methods	22.01.2015	30.01.2015	L. E. A.	30
3.2	Test Specification document writing	22.01.2015	04.02.2015	L. E. A.	40
3.3	Update Test Specification Document	09.02.2015 16.02.2015	11.02.2015 16.02.2015	L. E. A.	10
3.4	Test Plan Document writing	11.03.2015 18.03.2015 23.03.2015	12.03.2015 20.03.2015 14.04.2015	L. E. A.	50
3.5	Update Test Plan Document	20.04.2015	22.04.2015	L. E. A.	10
3.6	Execute testing	23.03.2015	01.05.2015	J. B. B.	90
3.7	Evaluate test results	26.03.2015	01.05.2015	L. E. A.	40
3.8	Test Report Document Writing	20.04.2015	08.05.2015	L. E. A.	80
Sum					**350**

7.2.4 High-level Design

Activity no.	Description	Start date	End date	Resp.	Est. hours
4.1	Concept brainstorming	16.02.2015 04.03.2015 18.03.2015	20.02.2015 04.02.2015 18.03.2015	J. B. B.	90
4.2	Concept 3D design	23.02.2015 18.03.2015	06.03.2015 24.03.2015	J. B. B.	90
4.3	Concept studies	23.02.2015	27.02.2015	J. B. B.	90
4.4	Concept selection	27.02.2015	12.03.2015	M. Sc	60
4.5	Concept Document writing	26.02.2015	12.03.2015	M. Sk	40
4.6	Concept Development				90
4.7	Update Concept Document	18.03.2015	22.04.2015	M. Sk	20
Sum					**390**

7.2.5 Detail design

Activity no.	Description	Start date	End date	Resp.	Est. hours
5.1	Part development	09.03.2015	27.04.2015	J. B. B.	100
5.2	Design Calculation	09.03.2015	27.04.2015	J. B. B	40
5.3	3D design	09.03.2015	01.05.2015	J. B. B	130
5.4	Design document writing	20.04.2015	08.05.2015	J.B.B	60
Sum					**330**

7.2.6 Implementation

Activity no.	Description	Start date	End date	Resp.	Est. hours
6.1	Integrate parts in 3D design	11.03.2015	04.05.2015	J. B. B	50
6.2	3D print	04.05.2015	08.05.2015	M. Sc.	5
6.3	Implementation of 3D print	06.05.2015	08.05.2015	M. Sc	5
Sum					**60**

7.2.7 Meeting

Activity no.	Description	Start date	End date	Resp.	Est. hours
7.1	Meeting with internal supervisor	05.01.2015	01.05.2015	M. Sc.	80
7.2	Meeting with external supervisor	05.01.2015	01.05.2015	M. Sc.	40
7.3	Internal meeting with group members	05.01.2015	01.05.2015	M. Sc.	30
7.4	Stakeholder meetings	09.02.2015	27.02.2015	M. Sc.	40
7.5	Write Follow up Documents	12.01.2015	15.05.2015	M. Sc.	40
7.6	Write MOM's	05.01.2015	01.05.2015	L. E. A.	30
7.7	Third party contact	05.01.2015	01.05.2015	M. Sc.	30
Sum					**290**

7.2.8 Web Design

Activity no.	Description	Start date	End date	Resp.	Est. hours
8.1	Create web site	05.02.2015 18.03.2015	06.02.2015 21.03.2015	L. E. A.	20
8.2	Update web site	15.04.2015	15.04.2015	L. E. A.	20
Sum					**40**

7.2.9 Presentation

Activity no.	Description	Start date	End date	Resp.	Est. hours
9.1	1st presentation	09.02.2015	09.02.2015	M. Sc.	6
9.2	Create power point for 1st presentation	02.02.2015	06.02.2015	M. Sc.	50
9.3	2nd presentation	17.03.2015	17.03.2015	M. Sc.	6
9.4	Create power point for 2nd presentation	13.03.2015	16.03.2015	M. Sc.	60
9.5	3rd presentation	11.05.2015	15.05.2015	M. Sc.	10
9.6	Create power point for 3rd presentation	04.05.2015	18.05.2015	M. Sc.	90
Sum					**222**

7.2.10 Finalization

Activity no.	Description	Start date	End date	Resp.	Est. hours
10.1	Final Report document writing	27.04.2015	08.05.2015	M. Sk	110
10.2	Review Final Report document	11.05.2015	14.05.2015	J. B. B	50
10.3	Print and hand-in Final Report document	14.05.2015	15.05.2015	M. Sc.	20
10.4	Create project poster	27.04.2015	01.05.2015	M. Sc	10
10.5	User Manual	04.05.2015	15.05.2015	M. Sc	15
1.11	After Analysis	11.05.2015	15.05.2015	M. Sc	20
Sum					**225**

Activity no.	Description	Total est. hours
1.0	Administrative task	328
2.0	Requirement specification	180
3.0	Test	350
4.0	High-level design	390
5.0	Detail design	330
6.0	Implementation	60
7.0	Meeting	290
8.0	Web design	40
9.0	Presentation	222
10.0	Completion	190
	Sum	**2435**

7.3 Working Hours

Every group member is responsible for register his or her hours spent on project work. A working hour spreadsheet is made in Microsoft Excel, and everyone have their own sheet to fill in. All the hours will be split up in different activities, shown in chapter 6.1. Each row in the sheet will only contain one activity. Therefore it will sometimes be necessary to use several rows in one day. Figure 1 shows an example from week 4.

Name:	**Marit Skjørestad**					
Week No:	**Date**	**From**	**To**	**Hours**	**Activity No:**	**Description**
4	19.01.2015	09:00	12:00	3	1.3	Vision document
4	19.01.2015	12:00	13:00	1	6.1	Meeting with Kjell
4	19.01.2015	13:00	16:00	3	1.3	Vision document
4	21.01.2015	09:00	12:00	3	2.2	Define Requirements
4	21.01.2015	12:00	14:00	2	1.6	Budget
4	21.01.2015	14:00	16:00	2	1.2	Project plan document writing
4	22.01.2015	09:00	16:00	7	1.2	Project plan document writing
4	23.01.2015	10:00	14:00	4	1.9	Project planning lecture
			Total time:	**25**		

Figure 3: Working hours

8.0 Plan

8.1 Gantt Chart

A Gantt chart is a type of bar chart illustrating a complete project schedule. A Gantt diagram will typically show the start and end dates of all the activities/tasks of the project. Our total Gantt chart is attached in the end of the document.

8.2 Milestones

- **First presentation**
  By the time of the first presentation we will finish the first release of the following documents:

- **Vision document**

  The goal with this document is to give a clear and distinct understanding of the assignment as well as the function of the final product. It will cite the project guidelines to be followed and the project goals and expectations that need to be met.

- **Requirement Specification Document**

  The goal of this document is to specify the requirements that are developed by the project group based on the requirements given by FO&GT. The requirements specification will give an indication of what the system shall satisfy and be able to provide.

- **Test Specification Document**

  The test specification document is going to give an overview of how the project group will test whether or not the system requirements has been met.

- **Project plan Document**

  The purpose of this document is to gather all the relevant information needed to manage the final project at HBV. The project plan will provide an insight in how we will plan our work during this project. It sets specific goals, and distinct limits to be able to satisfy our contractor and secure a good result.

- **Second presentation**
  By the time of the second presentation we will have developed a set of solution concepts, evaluated and chosen which concept we will proceed developing.

- **Completion and hand-in**

By the time of the hand-in deadline we will have finished testing and hopefully verified and validated that our chosen design is of satisfying quality.

- **Third presentation**
  By the time of the third presentation we will have made and rehearsed both a sales-oriented presentation as well as a technical presentation.

9.0 Risk Analysis

Risk analysis is a technique used to identify and assess factors that may jeopardize the success of a project or achieving a goal.

This technique also helps to define preventive measures to reduce the probability of these factors from occurring and identify countermeasures to successfully deal with these constraints when they develop to avert possible negative effects on the project [1]

This chapter will focus on the two key activities of a risk analysis; risk assessment and risk management.

9.1 Risk Assessment

Consequence

The consequence analysis (table 4) provides a characterization of risk severity as well as a quick description of impact to simplify the process of ranking different project risks. When a risk increase in severity it will consequently get a higher score.

Table 5: Consequence analysis

Consequence	Impact	Score
Severe	A breaking point in the project (critical status). All means must be utilized towards a quick fix, so that the project may continue.	5
Significant	The project comes to a stop and progress will become challenging. Continuous measures must be made.	4
Moderate	The project will have to stop and actions must be taken to assure further progress.	3
Minor	There will be some adversity, but project progress will not be affected in any noticeable degree	2
Minimal	The project can proceed without further problems	1

Probability

The probability analysis (table 5) provides a characterization of risk probability and a short description of what each grouping means. In addition, each respective probability is given a score in correlation with their degree of probability.

Table 6: Probability analysis

Probability	Description	Score
Near certainty	Happens daily	5
Highly likely	Happens once every week	4
Likely	Happens once every month	3
Low likelihood	Happens once every quarter	2
Not likely	Happens once every year	1

Risk categorization matrix

Each individual risk will be evaluated and scored both in severity(S) and probability (P); variables we will use to calculate a level of risk(R) by utilizing the following formula:

$$S + P = R$$

These calculations will let us objectively compare each individual risk and furthermore help us decide what assessments needs to be made. In the following risk matrix (table 6), one can see that increasing levels of either severity and/or probability will affect each individual risk level, thus making every risk comparable.

Table 7: Risk matrix

Likelihood	5	6	7	8	9	10
	4	5	6	7	8	9
	3	4	5	6	7	8
	2	3	4	5	6	7
	1	2	3	4	5	6
		1	2	3	4	5
	Consequence					

Risk level

In the previous risk matrix, the different levels of risk were given a color code in correlation with the magnitude of L, with the intention of simplifying the evaluation process of each risk. In the color code chart (table 7), each risk category is given a specific degree of assessment and one can easily calculate the risk level, identify the color code and finally check what actions/precautions must be made.

Table 8: Color code chart

Risk level	Color Code	Assessment
High	RED	There is a high risk present and immediate actions should be made
Moderate	YELLOW	The risk is slightly above acceptable levels and actions must be considered in each individual case.
Low	GREEN	The risk is below acceptable levels and there is no need for any actions.

9.2 Risk Management

Project risk management

Table 9: Project risk management

Scenario	Cause	S	P	R	Assessment
Minor data-loss	Malware Faulty software	1	3	3	Install and utilize proper anti-malware software. Use well-known document software (office, etc.).
Major data-loss	Faulty Hardware Physical damage to PC.	4	2	6	Use an online cloud service (dropbox, googledocs). Make weekly backups.
Minor Sickness	Several.	1	4	5	Make sure the entire group is up-to-date with on-going activities, so that any member can continue any work.
Major Sickness	Several.	4	1	5	Re-assess the project goals and project plan.
Indifferences	Bad communication, external factors, stress, etc.	3	2	5	Assure good internal communication and immediate arbitration when disputes arises.
Tardiness	Flat tire, bad weather, broken alarm-clock.	1	3	4	Always account for unforeseen incidents by estimating to arrive early.
Avoidance	Indifferences, lack of motivation, lack of knowledge, lack of skill.	2	2	4	Make sure the entire group is up-to-date with on-going activities, so that any member may detect evasiveness.
Behind schedule	Unsufficient project planning, unforeseen problems.	3	3	6	Assure high quality project planning and time managing. Update project plan as changes arises, help us to detect situations where we will have to work more.
Stuck	Lack of knowledge, lack of motivation.	3	3	6	Utilize external and internal resources excessively. Make an effort to be highly aware of these situations and seek help as soon as it is needed.

Inadequate external guidance	Linguistically difficulties, down prioritizing of our project.	4	1	5	Make sure everything is understood the way it were intended. Explain to often rather than too rarely.
Inadequate internal guidance	Sickness, bad communication.	4	1	5	Assure good communication
Motivation	Challenging project, stress.	3	3	6	Talk regularly and openly about personal experiences working with the project. Assure good teamwork.

System risk management

Table 10: System risk management

Scenario	Cause	S	P	R	Assessment
Not meeting the A requirements	Major design errors	5	1	6	Make sure all design decisions is in correlation with the A requirements
Not meeting the B requirements	Major design errors Minor design errors	3	3	6	Make sure all design decisions is in correlation with the B requirements
Not meeting the C requirements.	Major design errors Minor design errors Limited time	1	5	6	Assure high quality project planning and time managing.
Seal ring installation failure	Special unforeseen incident, preventing the system from working properly.	5	1	6	Incorporate seal-ring changeability function.
Bolt entering failure	Damage to bolt and/or threads.	5	1	6	Incorporate bolt changeability function
Leakage	Seal failure due to damaged seal-ring.	5	1	6	Incorporate seal-ring changeability function.
Leakage	Seal failure due to damaged flange seal surface	5	2	7	This should be a major driver when designing, as the consequence severity of this scenario is extreme.
Collision accident with ROV	Water current pushing the ROV	3	1	3	Design without protrusions. Make everything robust.

Dropped object	Object have been dropped from above. f. ex. from a FPSO.	2	2	4	Make a robust design
Dropped seal-ring	Seal ring installation failure.	1	2	3	Bring a spare seal ring.

10.0 Economy

During this project, we will not construct an actual physical model of the system we are creating. This is due to time limitations, and this will limit the expenditure. Hopefully we will be able to print out a 3D model of the product. The expenses will mainly concentrate on the 3D print and administrative issues. This include different types of hand-ins material, such as paper, folders and CDs, and expenses related to printing the final poster.

Table 11: Budget

Item No.	Description	Quantity	Unit	Cost (NOK)
1	Paper for hand-ins	2500	pages	2000
2	Folder for hand-ins	4	pieces	150
3	CDs for hand-ins	5	pieces	100
4	Poster	1	piece	245
5	Bound folder	1	piece	50
6	3D printing	1	piece	2500
			Total cost:	**5045**

11.0 Web Site

During this Bachelor project, we are assigned to create a web site. This is a good way to communicate with the external supervisor, and therefore it is nice to keep the website updated during the entire project. Seeing as we have spent a lot of time working at our contractors offices in close dialog with our external supervisor, the website have not been updated quite as much as first intended. The address of the website is: https://home.hbv.no/web-gr3-2015/.

The website contain information about:

- Group members
- Contractor
- Project description
- Dates for the project presentations

12.0 References

[1] http://www.researchtoaction.org/2012/05/stakeholder-analysis-a-basic-introduction/

[2] http://en.wikipedia.org/wiki/Risk_analysis_(business)

[3] Vision Document; ROV operated SPO compact flange, Bachelor thesis 2015.

[4] http://en.wikipedia.org/wiki/Test_plan

13.0 Attachments

[1] Gantt chart

Requirements Specification

ROV operated SPO compact flange for subsea assembly in deep water

Document no.:	Version no.:	Date:	Document responsible:	Group:	Status:
3.0	3.0	15.05.2015	Jørgen Borgersen	3	Completed

Group members: Mathilde Schinnes, Laila Andersland, Jørgen Borgersen, Marit Skjørestad

Table of Contents

List of Tables

1.0 Document

1.1 Document History

Table 1: Document history

Revision	Description of change	Date
0.1	Document created	14.01.15
0.2	Re-arranged existing requirements. Rewrote requirements after contractor meeting. Added chapter 4.0	29.01.15
0.3	Changed several requirements, compared with test plan	30.01.15
1.0	**First release**	**04.02.15**
1.1	Update requirements after contractor meeting, removed chapter 3.4, requirement 4.1 was given new ID 1.9, 4.2 became 2.7 and 4.3 to 2.8.	16.02.15
1.2	Updated 2.1 and 2.2 to A priority. Added requirements 2.9 and 2.10	11.03.15
2.0	**Second release**	**11.03.15**
2.1	Added requirement 2.11 and 3.11 as a result from concept document.	13.04.15
2.2	Added requirement 3.12, 2.13, updated 2.10 and 3.4	06.05.15
2.3	Updated 2.6 and 2.9, removed “any”	13.05.15
3.0	**Final release**	**15.05.15**

1.2 Abbreviations

Table 2: Abbreviations

Abbreviation	Description
API	Application Programming Interface
ASTM	American Society for Testing and Materials
CF	Compact flange
FO&GT	Freudenberg Oil & Gas Technologies
HBV	Høgskolen i Buskerud og Vestfold
HISC	Hydrogen induced stress cracking
HX	“H” profile seal ring name
ROV	Remotely operated vehicle
SPO	Compact Flange name prefix (From former company name Steel Products Offshore)
WN/SW	Weld neck/swivel

2.0 Scope

The goal of this document is to specify the requirements that are developed by the project group based on the requirements given by FO&GT. The requirements specification will give an indication of what the system shall satisfy and be able to provide. This way we form a common understanding between all parts involves of the conditions and requirements for the product. This is important to create early in the process, seeing as it creates the foundation for further work.

The requirements will form the basis for the test specification. By testing the requirements, we can conclude whether or not the product meets the system requirements and client's expectations.

3.0 Requirements

To define the requirements in a proper manner, the project group will follow a set of rules. A good requirement should not have more than one interpretation. This will be achieved by avoiding abstract language, so that the requirements are completely unambiguous. The requirements also needs to be crystal clear, meaning that every interpretation is easily understandable and only has one way of being read.

Further on, the requirements does not have much value if they are incorrect. In other words, they should describe something that the system is in fact required to do. The requirements should not include any unnecessary information and be as concise as possible. Statements of "how to" is also not allowed when creating the requirements so consequently it should be completely solution free. No requirement should specify neither a particular solution, nor a portion of a particular solution.

One of the most important characteristics of a requirement traceability. Meaning that every single requirement should relate to a document or statement of need from the stakeholders. These characteristics goes hand in hand with the derived requirements need for good numbering, so that every requirement can be easily and specifically referenced.

The ability to verify and evaluate the system throughout the whole development process is an important point. For this to be achieved, requirements needs to be quantifiable and verifiable, meaning that a requirement should include quantities that can easily be checked using a cost-effective process to verify if it has be attained. We will therefore avoid adjectives like "the component must be appealing" or "the component needs to be simple to use" and rather use measurable quantities.

In conclusion, we will take into consideration following characteristics when creating the requirements:

1. Unambiguous
2. Understandable
3. Correct
4. Concise
5. Solution Free
6. Independent requirements
7. Traceability
8. Numbered
9. Quantifiable
10. Verifiable

The different requirements will be named with an individual ID number, a source and its creation date. The source will primarily be FO&GT, although some requirements are created from stakeholder analysis performed by group members.

We have classified the requirements into different categories we found suitable. These include:

- System requirements, which will be the overall requirements our system will fulfill. We define our system as the tool used to assemble the SPO CF, and all parts we will add or change to the original WN/SW SPO CF.
- The functional requirements tell us the function of the system or pats of the system.
- Design requirements are requirements concerning the design and structure of the product.

The requirements will also be classified in accordance to priority.

Table 3: Requirements priority

Priority	Description
A	Absolute minimum requirement for the system. Requirements that are critical for the system to work.
B	Important, but to a less extent that A-requirements. Should be included, but not critical for the system to work.
C	Could be a part of the system, but the system can be complete without this.

3.1 System Requirements

ID:	Source:	Origin date:	Update:	Priority:
1.1	FO&GT	29.01.2015	-	**A**
Description: The system shall be operated with the use of a ROV.				
Related test: 1.1				

ID:	Source:	Origin date:	Update:	Priority:
1.3	FO&GT	29.01.2015	-	**A**
Description: The system shall be located subsea, up to 3000 meters depth.				
Related test: 1.4				

ID:	Source:	Origin date:	Update:	Priority:
1.4	Stakeholder analysis	29.01.2015	16.02.2015	**C**
Description: The system shall be able to withstand ocean current up to 0.6 m/s.				
Related test: 1.5				

ID:	Source:	Origin date:	Update:	Priority:
1.5	Stakeholder analysis	29.01.2015	-	**B**
Description: The system shall withstand 25 years of anticipated design life subsea.				
Related test: 1.6				

ID:	Source:	Origin date:	Update:	Priority:
1.6	Stakeholder analysis	29.01.2015	-	**B**
Description: The system shall not experience failure due to HISC throughout its 25-year long lifetime.				
Related test: 1.6				

ID:	Source:	Origin date:	Update:	Priority:
1.8	Stakeholder analysis	29.01.2015	-	**C**
Description: The system could be able to withstand anticipated collision forces from a ROV.				
Related test: 1.8				

ID:	Source:	Origin date:	Update:	Priority:
1.9	FO&GT	29.01.2015	16.02.2015	**A**
Description: The weld neck flange shall have an inter seal test port for an assembly verification test.				
Related test: 1.9				

3.2 Functional Requirements

ID:	Source:	Origin date:	Update:	Priority:
2.1	FO&GT	29.01.2015	11.03.2015	**A**
Description: The system should have bolt entering capabilities.				
Related test: 2.1, 2.9				

ID:	Source:	Origin date:	Update:	Priority:
2.2	FO&GT	29.01.2015	11.03.2015	**A**
Description: The system should have hydraulic bolt pre-loading capabilities.				
Related test: 2.2				

ID:	Source:	Origin date:	Update:	Priority:
2.3	FO&GT	29.01.2015	16.02.2015	**B**
Description: The pre-loading tool shall be able to give a residual pre-load of 75% of yield of the chosen bolt.				
Related test: 2.3				

ID:	Source:	Origin date:	Update:	Priority:
2.5	FO&GT	29.01.2015	**-**	**A**
Description: It shall be possible to change the seal ring.				
Related test: 2.5				

ID:	Source:	Origin date:	Update:	Priority:
2.6	FO&GT	12.02.2015	13.05.2015	**A**
Description: Pre-load must be evenly distributed around the flange.				
Related test: 2.6				

ID:	Source:	Origin date:	Update:	Priority:
2.7	Stakeholder analysis	29.01.2015	16.02.2015	**C**
Description: There could be a visual indicator when pipe alignment has been achieved.				
Related test: 2.7				

ID:	Source:	Origin date:	Update:	Priority:
2.8	Stakeholder analysis	29.01.2015	16.02.2015	**C**
Description: There could be a visual indicator when the bolts have been pre-loaded.				
Related test: 2.8				

ID:	Source:	Origin date:	Update:	Priority:
2.9	FO&GT	11.03.2015	13.05.2015	**A**
Description: The system shall be able to account for angular bolt misalignment.				
Related test: 2.10, 2.13				

ID:	Source:	Origin date:	Update:	Priority:
2.10	FO&GT	11.03.2015	13.05.2015	**A**
Description: The stud bolts shall protrude 3 threads from the nuts surface at both sides.				
Related test: 2.11				

ID:	Source:	Origin date:	Update:	Priority:
2.11	Concept document	13.04.2015	13.05.2015	**A**
Description: There shall be individual tightening on the locking collar on the hydraulic tool.				
Related test: 2.12				

3.3 Design Requirements

ID:	Source:	Origin date:	Update:	Priority:
3.1	FO&GT	29.01.2015	-	**A**
Description: The connection shall be a swivel ring to weld neck SPO type Compact Flange.				
Related test: 3.1				

ID:	Source:	Origin date:	Update:	Priority:
3.2	FO&GT	29.01.2015	-	**B**
Description: The swivel flange design should have a guiding mechanism, which will rotate the swivel ring into the right position.				
Related test: 3.2, 3.8				

ID:	Source:	Origin date:	Update:	Priority:
3.3	FO&GT	29.01.2015	-	**A**
Description: The seal ring shall be retained in one of the flanges.				
Related test: 3.3				

ID:	Source:	Origin date:	Update:	Priority:
3.4	FO&GT	29.01.2015	06.05.2015	**B**
Description: The seal ring should be retained in the swivel flange.				
Related test: 3.3, 3.9				

ID:	Source:	Origin date:	Update:	Priority:
3.5	FO&GT	29.01.2015	-	**A**
Description: The HXL seal surfaces shall not be changed.				
Related test: 3.4				

ID:	Source:	Origin date:	Update:	Priority:
3.6	FO&GT	29.01.2015	16.02.2015	**C**
Description: The bolts could be replaceable.				
Related test: 3.5				

ID:	Source:	Origin date:	Update:	Priority:
3.7	Stakeholder analysis	29.01.2015	16.02.2015	**A**
Description: The system should incorporate necessary ROV handles.				
Related test: 3.6				

ID:	Source:	Origin date:	Update:	Priority:
3.8	Stakeholder analysis	29.01.2015	16.02.2015	**B**
Description: All ROV interfaces shall be painted in high visibility colors.				
Related test: 3.7				

ID:	Source:	Origin date:	Update:	Priority:
3.10	Stakeholder analysis	29.01.2015	**-**	**C**
Description: The system could incorporate lifting points.				
Related test: 3.7				

ID:	Source:	Origin date:	Update:	Priority:
3.11	Concept document	13.04.2015	**-**	**B**
Description: All the freedom should be on one side.				
Related test: 3.10				

ID:	Source:	Origin date:	Update:	Priority:
3.12	The project group	06.05.2015	**-**	**A**
Description: All new design choices made during the development process shall be functional.				
Related test: 3.11				

4.0 Case Study Specifications

We are given several specifications from FO&GT including material specifications, size and pressure class of the flange, and thickness of the pipe. All of these are not specific requirements, but will be used as a case study. These specifications will vary depending on the system, where it will be used, client specification, and medium inside. This is just a suggestion, and for us they will function as a basis for further work. As stated earlier we will not make big changes on the existing flange, but our concern is the hydraulic tool used for the assembly. We are using a 16" flange, but we should have in mind that this could be scaled both up and down. Our case study specifications are:

- Flange material shall be ASTM A694 F65.
- Pipe material shall be API 5L X65.
- The seal material shall be alloy 625 with silver coating.
- The bolts shall be of type ASTM A320 L7.
- SPO Compact Flange shall be of size 16".
- The flange shall be of pressure class CL900.
- The seal ring shall be of type HXL-435. (This will probably be modified).
- Wall thickness of the pipe will be 20mm.

5.0 References

[1] Test Specification; ROV operated SPO compact flange, Bachelor thesis 2015.

[2] Vector SPO Compact Flange Designer's Manual – Installation and assembly procedure.

[3] Concept Study Document; ROV operated SPO compact flange, Bachelor thesis 2015.

Test Specification

ROV operated SPO compact flange for subsea assembly in deep water

Document No.:	Version No.:	Date:	Document responsible:	Group:	Status:
4.0	3.0	15.05.2015	Laila E. Andersland	3	Completed

Group members: Mathilde Schinnes, Laila Andersland, Jørgen Borgersen, Marit Skjørestad

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List of Tables

1.0 Document

1.1 Document History

Table 1: Document history

Revision	Description of change	Date
0.1	Document created	14.01.15
0.2	Updated abbreviations, removed priority, last updated added, rewrote tests and defined new tests	30.01.15
0.3	Elaborated 2.0, general spell check. Rewrote some tests.	02.02.15
1.0	**First release**	**04.02.15**
1.1	Updated test after contractor meeting, removed chapter 4.4, test 4.1 was changed to 1.9, new to 2.6, 4.2 to 2.7, 4.3 to 2.8, new to 2.9, new to 3.8 and new to 3.9.	16.02.15
1.2	Added test 2.10 and 2.11	11.03.15
2.0	**Second release**	**11.03.15**
2.1	Added test 2.12 and 3.10	13.04.15
2.2	Added test 3.11 and 2.13	06.05.15
2.3	Edited test 2.5, 2.6, 3.2 and 3.5 (changed simulation to motion study). Updated 2.11.	13.05.15
3.0	**Final release**	**15.05.15**

1.2 Abbreviations

Table 2: Abbreviations

Abbreviation	Description
FEM	Finite Element Method
FO&GT	Freudenberg Oil & Gas Technologies
HX	"H" profile seal ring name
ISO	International Organization for Standardization
SW	Solid Works
SWS	Solid Works Simulation
ROV	Remotely Operated Vehicle
SPO	Compact Flange name prefix (From former company name Steel Products Offshore)

2.0 Scope

The test specification document is going to give an overview of how the project group will test whether or not the system requirements have been met.

In the early phases of any project, the system requirements is drawn up. These consist of short specific sentences describing, often in detail, what is required of the system for it to qualify as an acceptable solution. However, when the concept has been chosen and detailed designing has commenced it is important to verify that the system is actually performing as the customer had planned it would do.

3.0 Test and Verification Methods

The discipline of verification is determining whether the system meets its original specifications [1]. In other words; verification involves checking the product against the requirements and making sure that you are making the product accordingly. In essence what you're asking is; are we building the product right? The two principal objectives of verification is to discover defects in the system and evaluate if the system is usable in an operational situation.

Generally, there are four fundamental methods for verifying a requirement. These are as following: **inspection, analysis, demonstration and test.** The type of test and verification methods vary according to what we want to verify. The following chapter will explain in more detail what the different methods involve, and how they will be applied to our project.

3.1 Inspection

Inspection includes visual examination or a review of project documentation such as; data, drawings and models. Inspection is done by using standard control methods, without the use of special laboratory procedures or equipment. This would also include feedback from experienced personnel at Freudenberg to verify that our solutions and results are accurate and feasible.

3.2 Analysis

Analysis is the evaluation of data by accepted analytical techniques to determine that the item meets specified requirements. Typically this method will be performed by 3D simulation tools, such as SWS, executing a FEM analysis on parts or system of interest. SWS allow us to analyze effect of weight, temperature, pressure and internal and external forces on the product. We can define the time-period our system is affected by these parameters as well as the chosen materials. Analysis is selected when test or demonstration techniques cannot adequately or cost-effectively address all the conditions where the system must perform.

3.3 Demonstration

Demonstration determines compliance to system requirements through showing particular functions or abilities of a product or a system. We are not planning to produce or fabricate a final product due to time limitations, but if we would be able to create a 3D printed model we will use this to demonstrate system interfaces and mechanical functions.

3.4 Test

Test is a verification method that mainly consist of physical tests, such as pressure tests, strength tests, weight tests, sealing tests. These tests will test the operation of the system under a limited set of controlled conditions. This is to determine that quantitative design or performance parameters have been met. Testing is the preferred method of requirements verification for any component directly associated with critical system interfaces. However, testing requires a prototype to perform the tests on and as mentioned before this project will not be able to go into the fabrication phase, hence these type of tests will not be conducted by us.

4.0 Test Specifications

4.1 Structure

Every test specification will get an individual ID and the requirement that is related to this test will be stated. The origin date, priority and test type will also be stated as well as a short description of how the specific test will verify the related requirement.

4.2 Test Specifications: System Requirements

Test ID:	Origin Date:	Last Update:	Test type:
1.1	30.01.2015	-	Inspection
Description: This requirement will be tested by visual examination. The project group will obtain current ISO Standard for ROV and check if the hydraulic connections and interfaces are according to the Standard.			
Related requirement ID: 1.1			

Test ID:	Origin Date:	Last Update:	Test type:
1.4	30.01.2015	16.02.2015	Analysis
Description: The project group will carry out a FEM analysis that will simulate up to 3000 meter water pressure.			
Related Requirement ID: 1.3			

Test ID:	Origin Date:	Last Update:	Test type:
1.5	30.01.2015	-	Analysis

Description:
The project group will carry out a FEM analysis that will simulate ocean current up to 0.6 m/s.

Related Requirement ID: 1.4

Test ID:	Origin Date:	Last Update:	Test type:
1.6	30.01.2015	-	Inspection

Description:
This requirement will be tested by inspection of FO&GT, where they will observe the 3D model and its materials. FO&GT experience and expertise will give a good indication whether the system will withstand 25 years of anticipated external corrosion or internal erosion.

Related Requirement ID: 1.5, 1.6

Test ID:	Origin Date:	Last Update:	Test type:
1.8	30.01.2015	16.02.2015	Analysis

Description:
The project group will carry out a FEM analysis that will analyze potential force concentrations on logical parts of the system due to unexpected water flow pushing the ROV or other unwanted events.

Related Requirement ID: 1.8

Test ID:	Origin Date:	Last Update:	Test type:
1.9	30.01.2015	-	Inspection
Description: FO&GT will examine the system and verify that it includes an intern seal test port.			
Related Requirement ID: 1.9			

4.3 Test Specifications: Functional Requirements

Test ID:	Origin Date:	Last Update:	Test type:
2.1	30.01.2015	-	Inspection
Description: The project group will inspect a 3D simulation to verify that the system includes adequate bolt entering capabilities.			
Related Requirement ID: 2.1			

Test ID:	Origin Date:	Last Update:	Test type:
2.2	30.01.2015	16.02.2015	Inspection
Description: This test include an examination of a 3D model to visualize that the system includes hydraulic bolt pre-loading capabilities.			
Related Requirement ID: 2.2			

Test ID:	Origin Date:	Last Update:	Test type:
2.3	30.01.2015	-	Analysis
Description: To test if the pre-loading tool is able to give the exact load it will be designed to give the exact hydraulic power needed and analyzed with FEM and calculations.			
Related Requirement ID: 2.3			

Test ID:	Origin Date:	Last Update:	Test type:
2.5	30.01.2015	13.05.2015	Inspection
Description: The 3D motion study of the function of changing the seal ring will be examined in SW.			
Related Requirement ID: 2.5			

Test ID:	Origin Date:	Last Update:	Test type:
2.6	16.02.2015	13.05.2015	Inspection
Description: This test include an examination of a 3D motion study to visualize the flange pre-load being evenly distributed.			
Related Requirement ID: 2.6			

Test ID:	Origin Date:	Last Update:	Test type:
2.7	30.01.2015	-	Inspection
Description: There will be a visual examination to verify if the 3D model includes an indicator for when satisfactory pipe alignment is achieved.			
Related Requirement ID: 2.7			

Test ID:	Origin Date:	Last Update:	Test type:
2.8	30.01.2015	-	Inspection
Description: There will be a visual examination to verify if the system includes a flag indicator for when satisfactory pre-loading is achieved.			
Related Requirement ID: 2.8			

Test ID:	Origin Date:	Last Update:	Test type:
2.9	16.02.2015	-	Demonstration
Description: The project group will print a 3D model of the system showing the bolt entering capabilities.			
Related Requirement ID: 2.1			

Test ID:	Origin Date:	Last Update:	Test type:
2.10	11.03.2015	-	Inspection
Description: The project group will conduct an inspection of the system accounting the angular bolt misalignment.			
Related Requirement ID: 2.9			

Test ID:	Origin Date:	Last Update:	Test type:
2.11	11.03.2015	06.05.2015	Inspection
Description: There will be an inspection that shows the stud bolts protruding three threads from the nuts at both sides of the flanges.			
Related Requirement ID: 2.10			

Test ID:	Origin Date:	Last Update:	Test type:
2.12	13.04.2015	-	Inspection
Description: There will be a visual examination to verify if the system includes a locking collar on the hydraulic tool.			
Related Requirement ID: 2.11			

Test ID:	Origin Date:	Last Update:	Test type:
2.13	06.05.2015	13.05.2015	Demonstration
Description: The project group will make a 3D print that will show the system accounting the angular bolt misalignment.			
Related Requirement ID: 2.9			

4.4 Test Specifications: Design Requirements

Test ID:	Origin Date:	Last Update:	Test type:
3.1	30.01.2015	13.05.2015	Inspection
Description: The will be an examination of the 3D model, to verify that it includes a connection type is a swivel ring to weld neck SPO Compact Flange.			
Related Requirement ID: 3.1			

Test ID:	Origin Date:	Last Update:	Test type:
3.2	30.01.2015	13.05.2015	Inspection
Description: There will be made a 3D motion study of the rotation of swivel ring in to right position.			
Related Requirement ID: 3.2			

Test ID:	Origin Date:	Last Update:	Test type:
3.3	30.01.2015	-	Inspection
Description: The 3D model will show that the seal ring is retained in one of the flanges, preferably in the swivel flange.			
Related Requirement ID: 3.3, 3.4			

Test ID:	Origin Date:	Last Update:	Test type:
3.4	30.01.2015	-	Inspection

Description:
The 3D model will not include change of the HXL seal surfaces, this will verified by inspection.

Related Requirement ID: 3.5

Test ID:	Origin Date:	Last Update:	Test type:
3.5	30.01.2015	13.05.2015	Inspection

Description:
It will be an examination of a 3D motion study showing the bolts being replaced.

Related Requirement ID: 3.6

Test ID:	Origin Date:	Last Update:	Test type:
3.6	30.01.2015	-	Inspection

Description:
There will be an inspection of the 3D model too verify that the system includes ROV handles.

Related Requirement ID: 3.7

Test ID:	Origin Date:	Last Update:	Test type:
3.7	30.01.2015	-	Inspection

Description:
There will be an inspection of the 3D model that it includes ROV interfaces with high visibility colors and lifting points.

Related Requirement ID: 3.8, 3.10

Test ID:	Origin Date:	Last Update:	Test type:
3.8	16.02.2015	-	Demonstration

Description:
The 3D printed model will show the rotation of swivel ring in to right position.

Related Requirement ID: 3.2

Test ID:	Origin Date:	Last Update:	Test type:
3.9	16.02.2015	-	Demonstration

Description:
The 3D printed model will demonstrate that the seal ring is retained in the swivel flange, preferably the swivel flange.

Related Requirement ID: 3.4

Test ID:	Origin Date:	Last Update:	Test type:
3.10	13.04.2015	-	Inspection

Description:
The system will be inspected to verify that the freedom is on one side.

Related Requirement ID: 3.11

Test ID:	Origin Date:	Last Update:	Test type:
3.11	06.05.2015	-	Analysis

Description:
It shall be conducted a FEM analysis on all new features to verify its functionality.

Related Requirement ID: 3.12

5.0 References

[1] Stevens, R. Brook P. Jackson K. Arnold S. (1998). Systems engineering, Coping with complexity. Prentice Hall Europe
[2] Requirements Specification; ROV operated SPO compact flange, Bachelor thesis 2015.

Concept Study

ROV operated SPO compact flange for subsea assembly in deep water

Document No.:	Version No.:	Date:	Document responsible:	Group:	Status:
5.0	2.0	15.05.2015	Marit Skjørestad	3	Completed

Group members: Mathilde Schinnes, Laila Andersland, Jørgen Borgersen, Marit Skjørestad

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1.0 Document

1.1 Document History

Table 1: Document history

Revision	Description of change	Date
0.1	First layout	04.03.15
0.2	Corrected language, rearrange order of some chapters	11.03.15
1.0	**First release**	**12.03.15**
1.1	Subjective→objective, refer to figures in the text, corrected numbering on headings, sequence explanation on figure 19, 20, 21. Adding chapter 3.1 General design choices	18.03.15
1.2	Added text to chapter 3.3 Seal ring retainment	24.04.15
1.3	Added chapter, nut retainment system	07.05.15
1.4	Corrected language, added chapter 7.2.1 and 7.2.2	13.05.15
1.5	Corrected spelling	14.05.15
2.0	**Final release**	**15.05.15**

1.2 Abbreviations

Table 2: Abbreviations

Abbreviation	Description
FO&GT	Freudenberg Oil and Gas Technologies
ROV	Remotely operated vehicle
SPO	Compact Flange name prefix (From former company name Steel Products Offshore)
STT	Stud Turning Tool
STTH	Stud Turning Tool Holder
STWT	Subsea Torque Wrench Tool
SW	SolidWorks
WN	Weld neck

2.0 Scope

This document will describe the work carried out in the initial concept stage of the project. It will go through the different thoughts and ideas, the considered concepts, and how we have worked during this stage of the project. The concept phase started with a big brainstorming session where out-of-the-box thinking were encouraged. Following you will find a description of the functions our system will need to have, with corresponding ideas to satisfy them. On some problems we have several concepts to choose from, while we have fewer choices on others. This document will describe advantages and disadvantages of the different concepts, and how we were able to choose which concept to proceed with in the next stage of the project. To be able to make objective decisions concerning which concepts are best suited, decision-making matrixes have been utilized.

To ease the concept brainstorming the system have been broken into each function it must possess. The reason behind this being that the internal dependencies could possibly restrain extravagant ideas, which initially is exactly what we want to achieve.

The system were broken down into the following functions.

- Seal ring installation and replacement
- Seal ring retainment
- Flange alignment
- Flange assembly
- Flange preload
- Flange lock
- Flange un-lock and dis-assembly

Some thought were also put in to which order design decisions should be made, as choices made regarding one function may put crippling limitations on several others. This is to, in the best way possible, assure a high quality design process by not obliviously excluding good solutions. The general strategy is to first make the decisions that we feel we can easily justify and that in our opinion has the least risk of being “wrong”. Following we will work through the design choices, presenting the result and conclusion for each choice.

3.0 General Design Choices

3.1 Threaded Flange

One possibility when designing our system is to make one of the flanges threaded, see *figure 1.* This flange will need to be about 10% thicker than normal, to assure the same free length of the bolts. This will give us one less nut that needs to be controlled witch is an advantage concerning the assembly of the flange. The disadvantage when you only have one nut is that if it gets stuck, it will be difficult to loosen the bolt when un-locking and dis-assembling the flanges. If there is two nuts, there will be two possibilities too loosen the bolt as it can be done from both sides. With the threaded flange, the flange will be thicker and thus heavier. Another possible disadvantage is that the system need to have all its freedom on one side which again could make it difficult to create a fully integrated tooling system. You also have to be aware that you would need some sort of drainage system inside the threaded flange. When entering the bolt subsea there will be water inside and when you push it in, the water will build up pressure inside the flange if you do not have a way of draining it out.

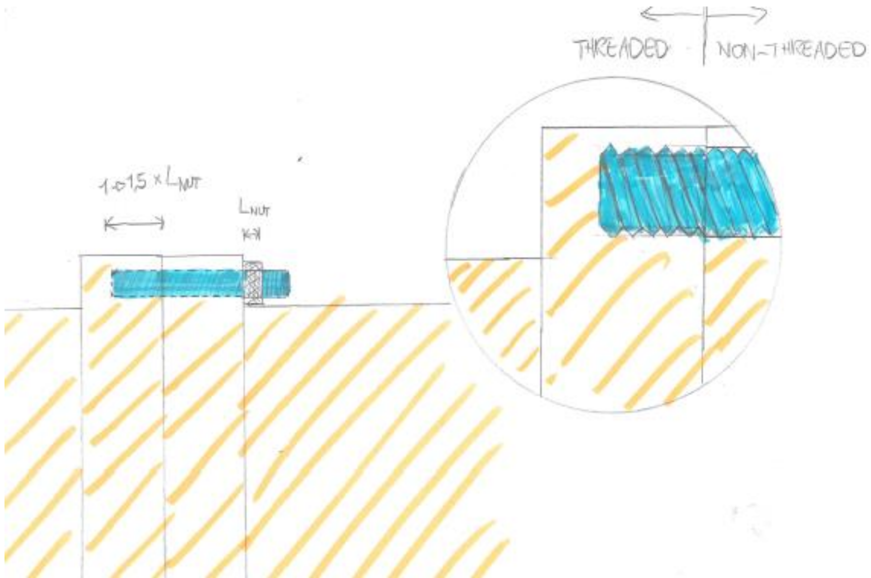


Figure 1: Threaded flange

Adding all these advantages and disadvantages together, the drawbacks will outweigh the benefits. Comparing the two solutions in a decision matrix, it is shown that the non-threaded flange is the best solution. See *table 3.*

Table 3: Pugh matrix: Threaded flange

Description:		**Threaded Flange**		**Non-threaded Flange**	
Criteria:	**Weight:**	**Score:**	**Weighted score:**	**Score:**	**Weighted score:**
Cost	*2*	3	6	4	8
Weight	*3*	3	9	4	12
Process time-consumption	*4*	5	20	3	12
Complexity	*3*	4	12	2	6
Freedom	*5*	2	10	5	25
Risk of jam	*5*	2	10	5	25
SUM			**67**		**88**

(Weight 1-5, Score 1-5)

3.2 Size of the Flange

When using hydraulic tools, the size of each tooling is a challenge seeing as the distance between each bolt hole is quite small, and the hydraulic tool requires a certain surface. With the current size of the flange and hydraulic tools there would not be enough room to fit all the tools on one side. Discussing this issue, we've discovered the two following solutions; one being that each bolt have the tool on alternating side of the connection and the other make customized hydraulic tools with different geometries, see *figure 2.* The intension and the advantage of this being the ability of fitting all tools on one side of the connection. However, the drawbacks of this solution is that there is not enough room on the standard flange, and you do not achieve a uniform stress-area.

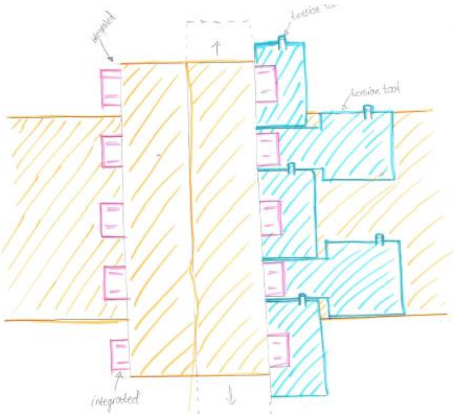
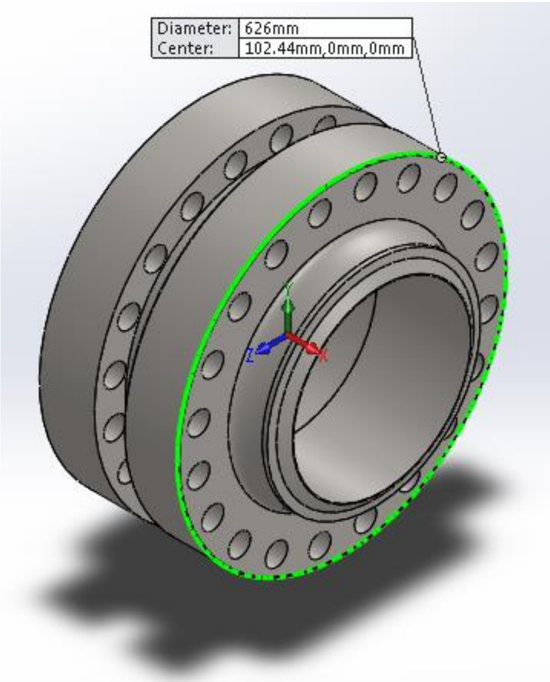


Figure 2: Alternating tool geometry

An apparent solution for this problem is to expand the original compact flange as it removes the space limitations. The hub will be standard part, but the weld neck and the swivel ring will have an extended outer diameter. The mechanics of how the flange function is left intact even though the diameter is increased, but the system will need customized parts.

In the following figures, we have shown the difference between the original flange, *figure 3,* and an example of how the flange can look like with an increased diameter, *figure 4.*



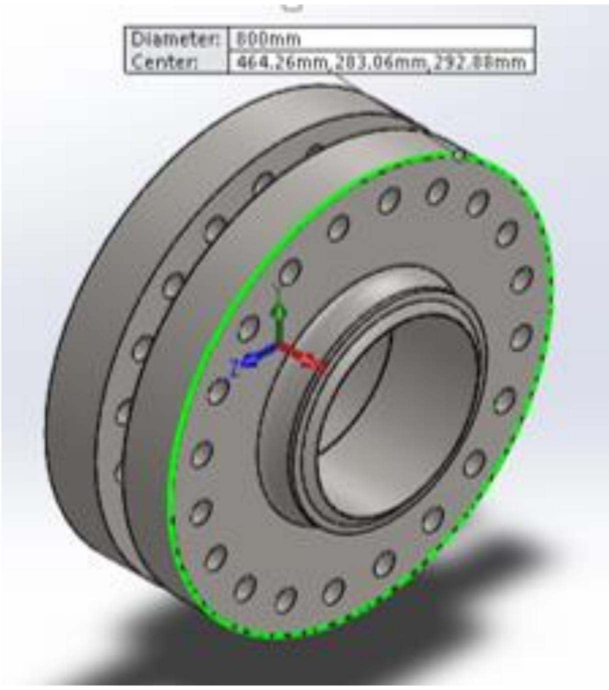


Figure 3: Original compact flange

Figure 4: Increased diameter

3.3 Fastener Type

The flange is a bolted connection, consisting of either a bolt with a rigid head and a nut on the other side, or a stud with two loose nuts. Since the concept most likely will end up using a hydraulic tension tools, there have to be either a stud and a nut, or a bolt, on the other side. Both of the alternatives have been discussed.

3.3.1 Bolt

If the system utilizes bolts, they will have to be pre-installed in the weld-neck side of the system. This leads to the need of having a system that can provide freedom to the bolt so it will be possible to enter the threads of an integrated and rigid tool on the other side. The advantage of using bolt is that there is just one part to consider, if the bolt head is being rotated, the whole bolt will be rotating. The disadvantage however is that if jam occurs and it is impossible to get the bolt out of the flange, you are completely stuck, see *figure 5 and 6.*

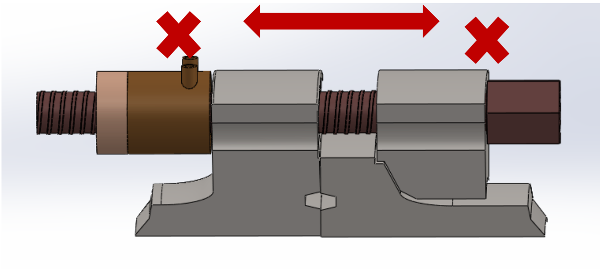
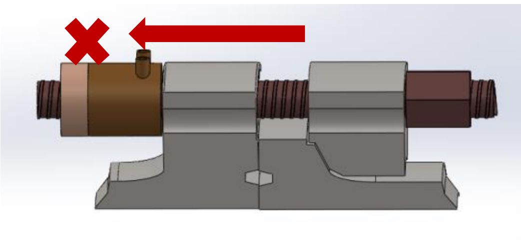


Figure 5: Bolt with rigid head

Figure 6: Bolt stuck

3.3.2 Stud and Nut

The stud and nut will have the same qualities as the bolt; the difference will be the possibility to adjust the “bolt head” up and down on the stud. The advantage with the use of stud and nut is that if jam occurs in the hydraulic tool and it is impossible to turn the stud out of the flange, you still have the possibility to turn the opposing nut out, and thereafter just pull the flanges apart, see *figures 7, 8 and 9.*



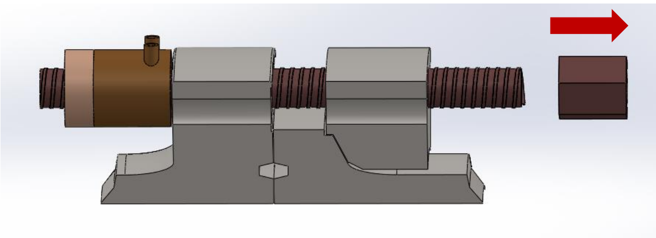


Figure 7: Stud stuck

Figure 8: Loosen nut

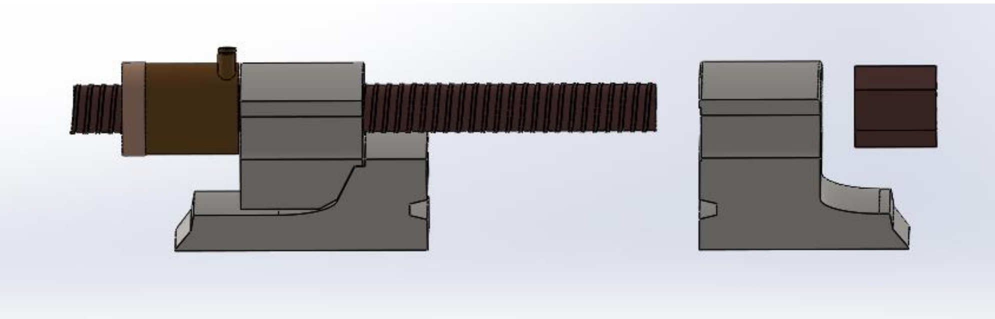


Figure 9: Dis-assemble flange

Both variants fulfill the systems most important functions; pre-load and lock, and could be used. Because this is a subsea installation, the consequences if the system will get stuck and impossible to dis-assemble will be huge. Since the stud and nut reduce the risk of total jam, we chose to continue with this, see *figure 10.*

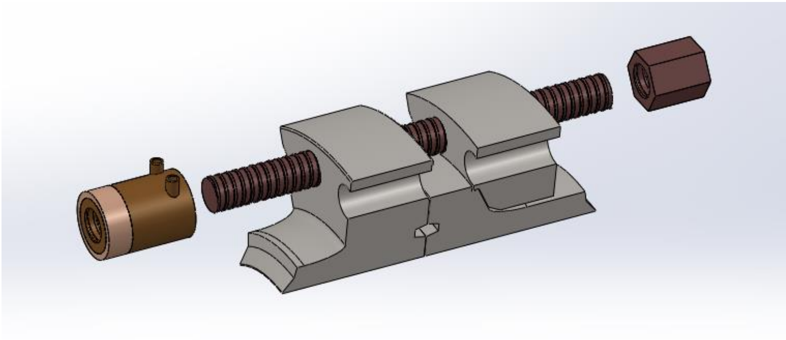


Figure 10: Stud and nut

4.0 Seal Ring Installation and Replacement

The ROV shall be able to install the seal ring in the flange subsea. This can be done using a ROV tool with a wire that can be removed when the ring is in place, *figure 11.*

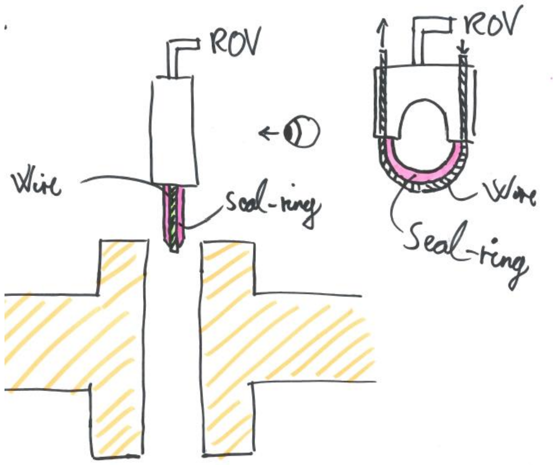


Figure 11: Seal replacement tool

The creation of a seal replacement tool is outside the scope for this project, however we need to make sure that the seal ring possess the ability to be picked up by the tool. This can be as easy as milling a groove in the seal ring which will be looked further into in the design phase of the project.

5.0 Seal Ring Retainment

5.1 Magnets

The seal ring will have to be retained in the flange after installation. Our first thought was to install magnets in the flange. See *figure 12.* This could be a possibility, but most likely we would need big magnets to be able to retain the ring. We would have to show that there is magnetism in the seal ring as well as calculate how good the seal ring would sit.

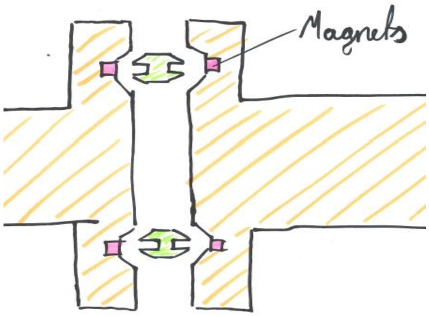
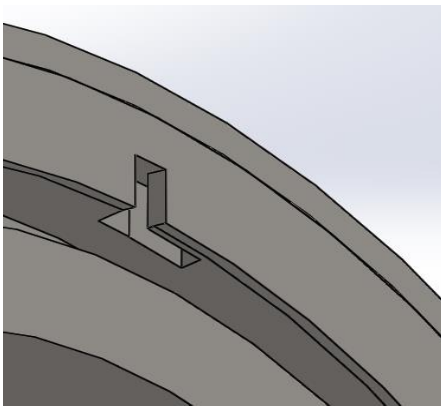


Figure 12: Seal retaining magnets

5.2 Rotational Groove

Another idea was to make a groove in the flange, and a tap on the seal ring, shown in *figure 13 and 14.* The tap would be turned into the groove, similar to what you can find when fastening a whisk in a food processor.



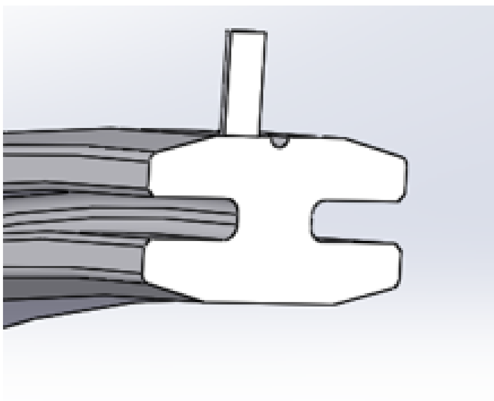


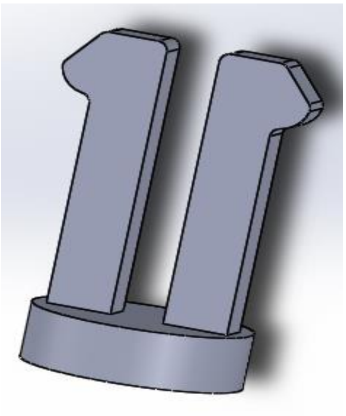
Figure 13: Rotational groove

Figure 14: Seal ring tap

The disadvantages with this solution is that you initially do not have anything that locks the ring in this possition. The ROV would also need to provide both the pushing motion into the groove in the flange as well as a rotational movment. This is a rather complex operation for the ROV to perform and the groove in the flange will be expensive and complicated to machine.

5.3 Snap-in Clips

The idea with the snap-in clips comes from the thought of a reactive ring and/or system that snaps-in, snaps-out. In other words, something that demands a bigger power to loosen than is used to retain it. The thought would be to insert 4 of the clips, seen in *figure 15,* in the groove in the flange, see *figure 16,* and then make a slot with an opening in the seal ring to clip them in.



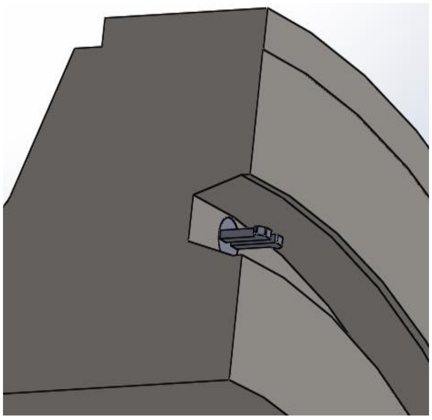


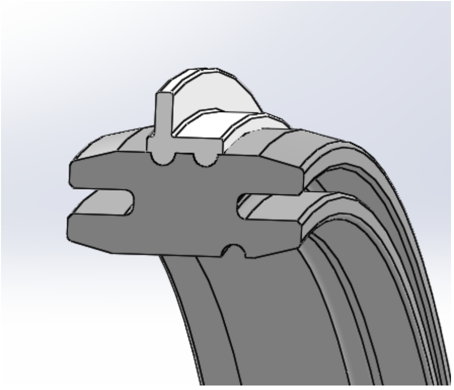
Figure 15: Clip

Figure 16: Clip in groove

The disadvantages with this solution is that the clips would be very small and fragile as the groove in the seal ring where the clips would be pushed into is originaly only 4 mm big. The possibility of the ROV to fit the clips right at once is small, and there would also need to be some rotational movement to position it properly.

5.4 Rubber Ring

The last solution we thought of was a rubber ring embracing the seal-ring. This ring would fit in two grooves around the whole seal ring, see *figure 17.* Then we would have to make a special opening in the flange to push the rubber ring through, and a room to fit in, see *figure 18.*



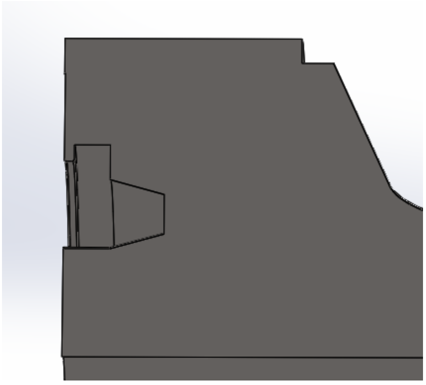


Figure 17: Rubber ring

Figure 18: Flange groove

The disadvantages with this concept is that you will need quite a lot of extra room in the flange for the rubber tip to bounce up after the deflection on the way in.

To make a choice between the different concepts, we compare them in a Pugh matrix. As we can see from *table 4*, it turns out that the rubber ring will be the best solution. This provides the ability to retain the seal ring, and it is simple to push into the flange either topside or subsea. The new groove in the flange will be rather simple to machine and only small design changes will have to be made in the seal ring.

Table 4: Pugh matrix: Seal ring retainment

Description:		**Magnets**		**Rotational groove**		**Snap-in clips**		**Rubber ring**	
Criteria:	**W**	**Score:**	**WS**	**Score:**	**WS**	**Score:**	**WS**	**Score:**	**WS**
Ability to retain	*5*	1	5	2	10	5	25	5	25
Complexity of operations	*4*	5	25	2	8	2	8	4	20
Complexity of parts	*4*	2	8	3	12	2	8	3	12
Nr of parts	*2*	4	8	4	8	2	4	3	6
Cost	*1*	2	2	2	2	3	3	4	4
SUM			**48**		**40**		**48**		**67**

(Weight 1-5, Score 1-5)

6.0 Flange Alignment

6.1 Swivel Flange

SPO Compact Flanges are available as a swivel design in all sizes and pressure classes. This means that on one side of the flange, we have a swivel hub with a swivel ring fitted over the hub. The bolt holes is placed in the swivel ring, and this ring can be rotated. Swivel flanges are very convenient in connection flanges subsea since its design eliminates the challenges of aligning the bolts holes of the two mating flanges [7]. *Figure 19* shows a typical design for swivel flanges.

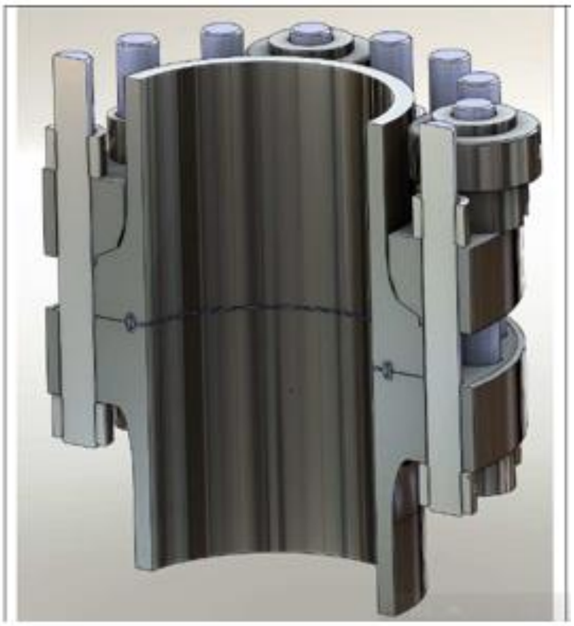


Figure 19: Swivel flange [7]

6.2 Alignment

When solving this assignment we assumed that a crude system will properly align the flanges in the horizontal, vertical, and axial plane. Leaving our main concern to be rotational alignment as well as managing the small off-set tolerances of the crude system. The flange connection consist of one conventional weld neck flange and one swivel flange, providing the rotational alignment by being able to turn around its own axis. Forcing this motion will be done by incorporating a guiding mechanism, acting as the crude system pulls the flanges towards each other. This is solved by having a male guide tap on the swivel ring and a female slot in the weld neck, shown in *figure 20.* The male follows the groove into the female counterpart, see *figure 21.* Advantages with this guiding mechanism is that it is simple, easy and inexpensive.

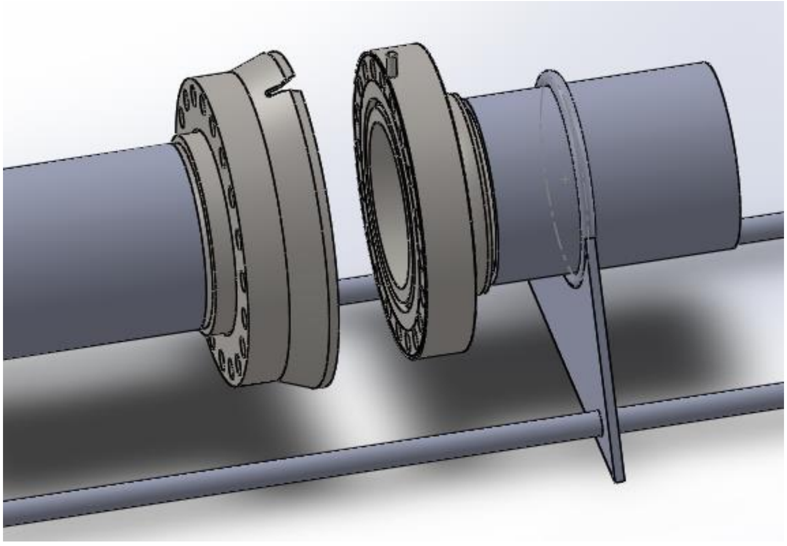


Figure 20: Alignment system

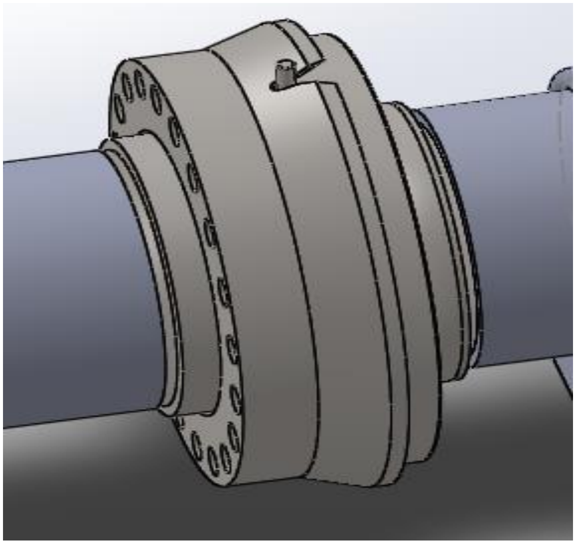


Figure 21: Tap and groove

7.0 Flange Assembly

If we find a way to thread the studs and nuts, the tightening will assemble the flanges as the axial forces increase. This seems simple enough, however there are a few obstacles we need to cross, for this solution to be viable. First of all the bolts needs to be installed in the first flange, second of all the bolts need to be pushed through the other flange and finally the bolt needs to pick up the threads on the opposing tooling and/or nut.

7.1 Install the Bolts in the Flange

We quickly realized that there were two possibilities in solving this; either pre-install the bolts topside before submersion, or install the bolts subsea. Having the bolts installed topside would subtract one operation subsea, which makes it an easier solution. When the bolts are preinstalled topside they can either be installed in the weld neck flange, or set in a parking position in the integrated hydraulic tool in the swivel flange.

7.1.1 Subsea Installation

We came up with a concept where the studs will be installed subsea, as shown in the following *figure 22*. Because of the weight of the studs they are carried at the center of gravity in a circular clamp setup. This stud holder will ensure that you do not need to fit 20 studs in the flange separately, but make it possible with just one operation. The disadvantage with this concept however is that you need to fit all of the bolts in the bolt holes simultaneously. In addition the ROV will have to fit the stud holder on the flange, which can be a difficult operation to perform.

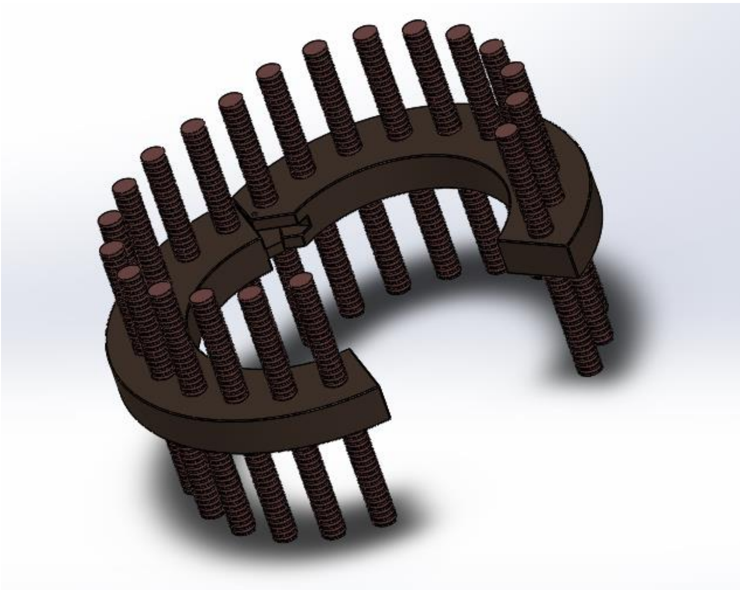


Figure 22: Subsea installation

7.1.2 Installed in the Weld Neck Flange

If the bolts would be installed in the WN, they need to be retained in the flange on the way down. This means we need to find a way to fasten the bolts in the flange so that they will not disconnect and get lost on the way down. The advantages with this concept is that you do not need a special system to retain the nuts, as the nuts will be turned onto the stud topside. This also makes it easier to achieve freedom on the weld neck side. The disadvantages is that it will be heavy to support the bolts during submersion, and you have a higher risk of damaging the threads in the integrated tool during assembly. See *figure 23.*

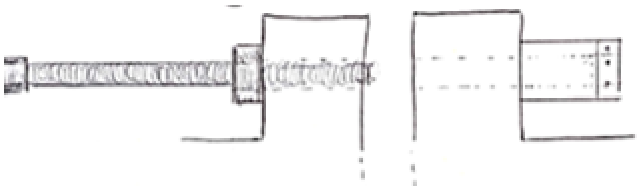


Figure 23: Installed in WN

One concept that makes it possible to sea-set the system with pre-installed studs is to temporarily lock the stud inside the flange with the help of different sized threads. Meaning that one can enter a few set of threads with a larger circumference to lock the bolt, but being able to “free” the bolt from said threads when screwed further in. This concept is best shown using an illustration, see *figure 24.*

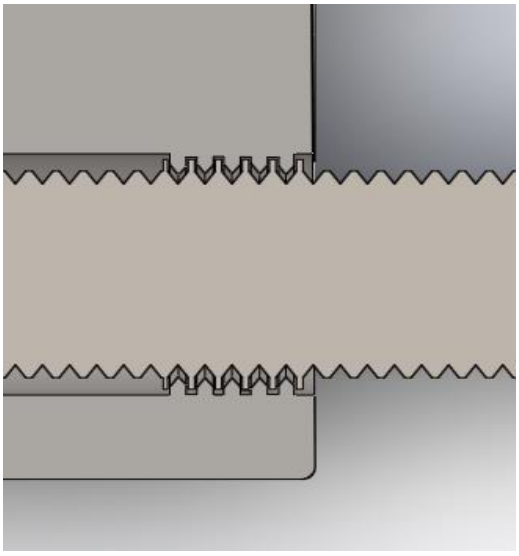


Figure 24: Different sized threads

7.1.3 Installed in the Integrated Tool

If the bolts would be installed in the swivel flange they would be turned into the threads in the integrated tool, see *figure 25.* The advantages with this is that the studs would be more supported during submersion, and you have less risk of damaging the threads in the tool during assembly when the studs are already in place. The biggest advantage is that you will have all the components that needs to be operated by the ROV on one side. The disadvantages is that you need a system to retain the nuts on the weld neck side, and that it will be more difficult to achieve freedom on this side.

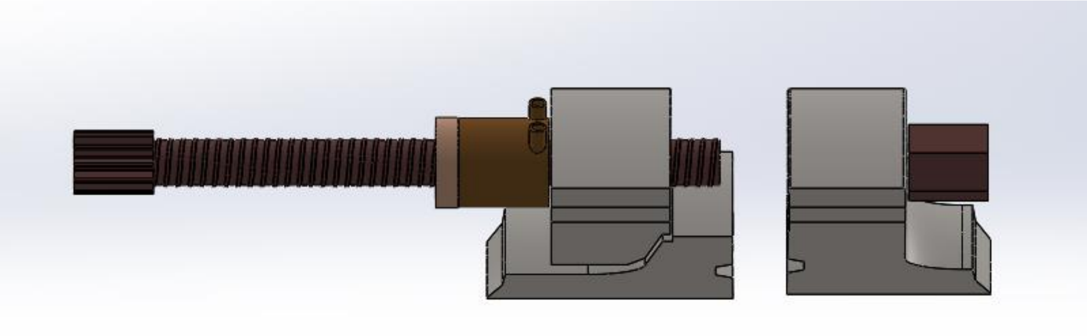


Figure 25: Installed in integrated tool

These three concepts were compared in a matrix, and as you can see from the table below, the best solution will be to have the bolts installed in the integrated tool in the swivel ring. This leaves us with the need of something to turn the bolts through the opposing flange, and a system to retain the nut on the weld neck side.

Table 5: Pugh matrix: Bolt installation

Description:		**Installed subsea**		**Installed in WN**		**Installed in SW-tool**	
Criteria:	**Weight:**	**Score:**	**Weighted score:**	**Score:**	**Weighted score:**	**Score:**	**Weighted score:**
Cost	*2*	2	4	3	6	3	6
Process time-consumption	*5*	1	5	3	15	3	15
Complexity	*4*	2	8	4	16	4	16
Freedom	*5*	3	15	5	25	4	20
Failure consequence	*5*	2	10	2	10	4	20
SUM			**42**		**72**		**77**

(Weight 1-5, Score 1-5)

7.2 Enter the Bolts through the Opposing Flange

The bolts need to be turned through the hydraulic tool and we considered several solutions before making a decision. The different alternatives were to turn each bolt individually, to turn two and two bolts that would be connected together with a gear, turn half of the bolts in one operation, or turn all the bolts in one operation.

Looking at the two extremities; if we turn one and one individual bolt the advantages will be that they are all independent of each other, and we will need less power to turn one at a time. The disadvantages is that this method will be highly time consuming and more difficult for the ROV to turn all the 20 bolts individually.

If we would turn all the bolts at once the advantages is that it would be very timesaving and easier for the ROV to operate. This way the ROV only have to perform one operation, opposed to the 20 operations needed for the other solution. The disadvantages however is that if one fails, the whole system will fail. We will also need more power to turn all the bolts down at the same time.

With the advantages and dis-advantages in mind these four concepts were compared together, and the results is shown in *table 6*. As we can see we will make a system that can turn the bolts through the flange in one or two operations.

Table 6: Pugh matrix: Turn bolts

Description		**One operation**		**Two operations**		**Ten operations**		**Twenty operations**	
Criteria:	**W**	**Score:**	**WS**	**Score:**	**WS**	**Score:**	**WS**	**Score:**	**WS**
Cost	*1*	4	4	4	4	2	2	1	1
Risk of failure	*4*	1	4	2	8	3	12	5	20
Failure severity	*4*	1	4	2	8	4	16	5	20
Nr of parts	*3*	5	15	4	12	2	6	1	3
Nr of operations	*5*	5	25	4	20	3	15	1	5
SUM			**52**		**52**		**51**		**49**

(Weight 1-5, Score 1-5)

Studs will be pre-installed in the hydraulic nut, and the hydraulic nut will integrated on the swivel side. There will not be threads in the flange, only in the hydraulic nut, and the stud will be locked in a starting position. The threads causes that the system do not need a mechanism to push the studs through. When the stud rotates, the threads will force the stud to move through.

7.2.1 Gear Ring

As written in 7.1.3 the decision matrix for number of operations of the stud running system, did not give any clear winner concept. However, it goes without saying that if one is able to create a system that can turn all the studs with only one operation and still make it safe, reliable and not too complicated, it will be the best solution. This will radically improve the process time consumption. This is an important factor when time is a costly factor regarding subsea operations.

One of the ideas for a one-operation system is the “gear ring”. The top of the stud will be formed as a gear and the gear is driven by another gear ring that goes around the whole system. All of the studs will then be connected to the same gear ring so that if the gear ring turns, all of the studs will be turned simultaneously. The gear ring will have both inner and outer gears. The inner gears will be in contact with the gear on top of the studs, and the outer gears will be driven by a new gear, which again is driven by the ROV.

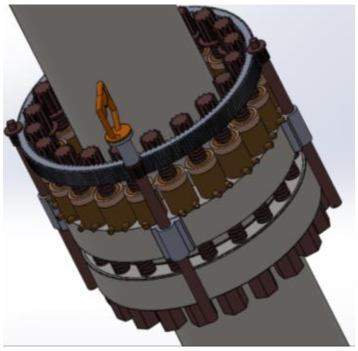
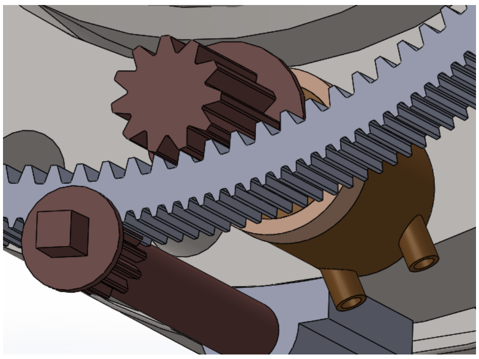
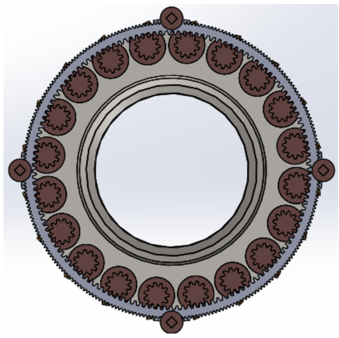




Figure 26: Gear ring system

Figure 27: Gear ring system in assembled position

Figure 28: System seen from above

There are several advantages with the gear ring system:

- It is a well-functioning system.
- It is easy for the ROV to connect.
- All movement is done by only one operation.
- Process time-consumption is low.

However, there are also some dis-advantages with this system. The gear will be very expensive and hard to machine because of all the gear teeth. The requirement for accuracy is great both in terms of calculation and machining of the teeth. They will also be hard to assemble, even with topside assembly and free gears. The teeth will also be prone to damage because of its exposed positioning. The whole system would then be in need of some protection, both from collision forces from the ROV, but also from other disturbances in the sea.

7.2.2 Stud Turning Tool System

During the development of the gear ring system, the group was introduced for a new tool. A continuous rotary tool with adjustable speed, which can run in both directions. This tool can quickly be connected to the top of the stud and run the stud through the threads, only with the help of hydraulic. This hydraulic tool will hereafter be called Stud Turning Tool (STT).

Stud Turning Tool Holder

The best solution of turning the studs will be to turn as many of them at the same time as possible. One suggestion is to run them all at the same time. This means that the system will be in need of 16 STT. The best solution would then most likely be to have the tools installed on the studs, like the hydraulic nuts. If the tools would not be installed on the studs, the system would then only be in need of a tooling holder, or a belt. The belt must have a function so that it is possible to open and grip around the pipe. The belt would also be quite heavy, as each tool weighs 3.5 kg each. Another and maybe better solution is to make a belt that can turn half of the studs at the same time. The belt would then include 8 STT, and go halfway around the pipe.

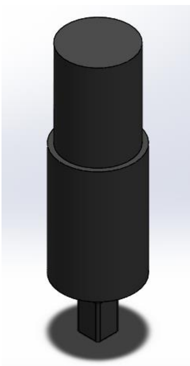
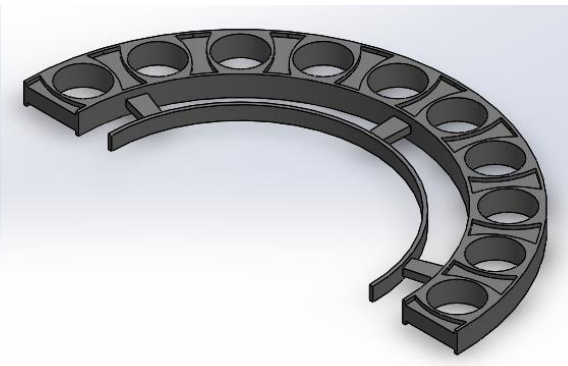



Figure 29: Simplified model of STT

Figure 30: Halfway belt

The first drawings of the STT holder included a belt, a support ring and some support blocks. This is a well-functioning system, but it may be complicated and time-consuming to assemble. The chosen way to do it is to make the whole system as one part.

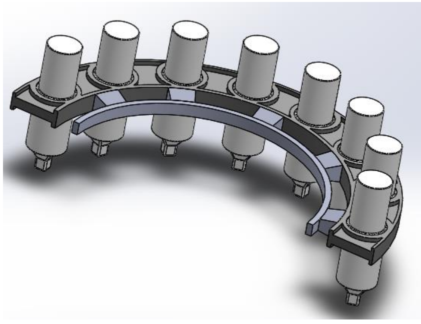
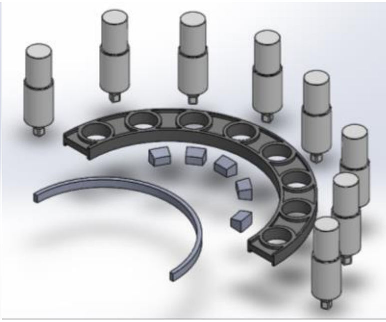
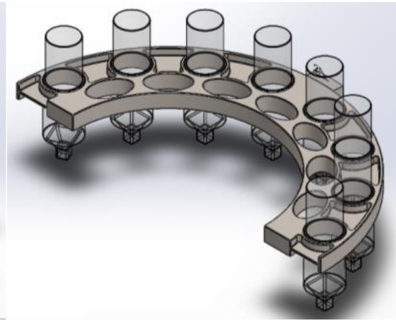




Figure 31: STT Holder assembly

Figure 32: STT Holder assembly dis-assembled

Figure 33: STT Holder machined

ROV handle

One very important part of the assembly procedure is that everything have to be ROV compatible. The position and direction of the handle is decided based on how easy it is for the ROV operator to grab the handle. The figures below shows the considered configurations. The handle placed both in position 1 and 2 will make it hard for the ROV to grab around due to cramped space. Placing the handle straight out from the system will be the best and easiest solution. Position 3 will therefore be the final solution.

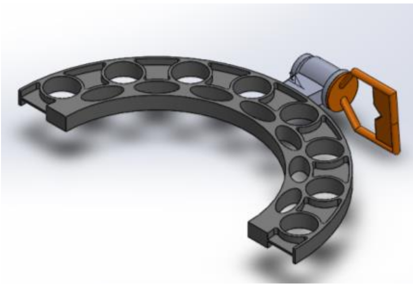
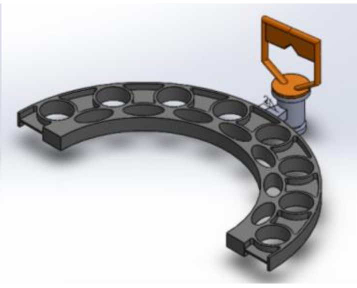
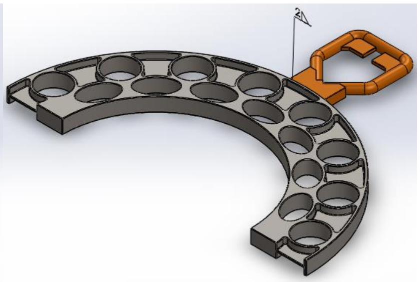




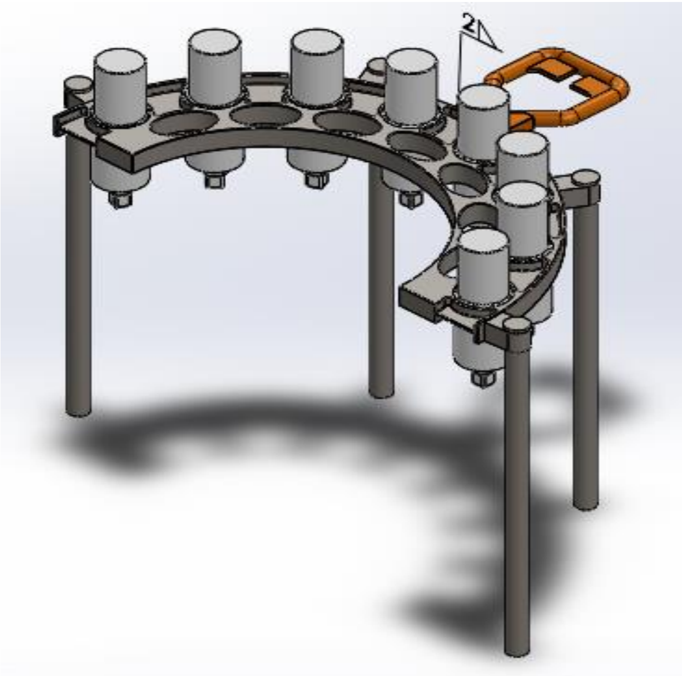
Figure 34: ROV handle position 1

Figure 35: ROV handle position 2

Figure 36: ROV handle position 3

Guidance

The ROV do not have any depth vision, so there have to be a guiding system that can guide the STT in place. The first step is to get the inner diameter in contact with the pipe. This guidance will just be used to get the STT in an approximately correct position. The first idea was to have some guide pins fasten on the outer diameter of the tool. The pins will be carried into a funnel fasten on the flange. When we started the implementation, it became clear that this would crash with the alignment system.



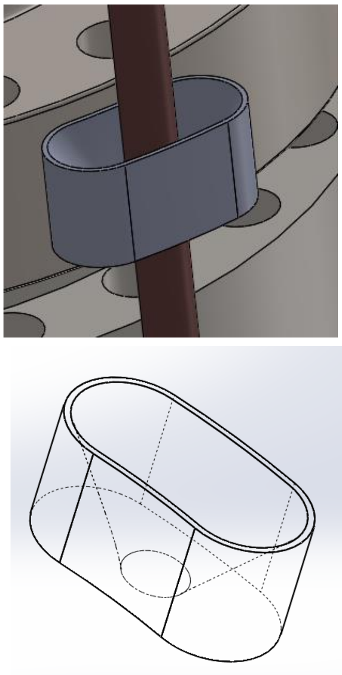


Figure 37: STTH with guide pins

Figure 38: Funnel

The only possible way was to incorporate the guidance is on the top of the swivel flange. Then the funnel effect had to be made in the STT holder itself. Because of the sloping cut on each side of the STT, the STT are able to hit 7 guiding pins regardless of position. The guiding pins will be threaded and sitting in a threaded hole on the swivel flange.

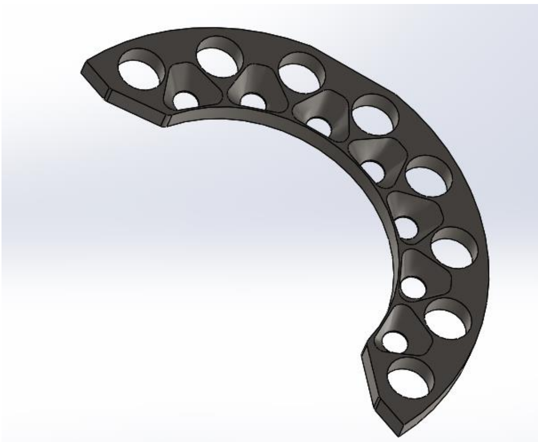


Figure 39: STT holder with guiding funnel seen from below

7.3 Connect with the Threads in the Opposing Nut

The further we've come, the more we've realized that this might be the most challenging obstacle, as entering the threads by hand is a simple feat. However, building a system without the sense of feeling makes it challenging. The ROV does not have this ability, which means that the system will need to provide it. In addition, the flanges have an angled face, which means that when the flange faces are aligned they will not be perfectly perpendicular on each other. In practical terms all of this means that the assembly system must have freedom to pick up any off-set angles and make sure that the threads are neither cross threaded nor miss threaded. We worked on four different concepts for achieving this necessary freedom on the weld neck side. An alignment washer will be used in all of the concepts.

7.3.1 Threaded Washer with Belt

A customized washer will be placed over the bolt holes, in the right position. The washer will be threaded and have a spherical surface, *figure* 40. The hexagonal nut, with a spherical surface on the top and the bottom, will be placed on top of the washer, *figure 41*, before a hexagonal threaded chamber will be turned and locked on the washer *figure 42*.

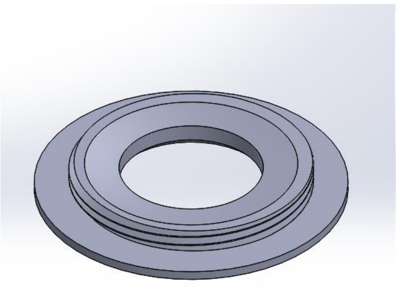
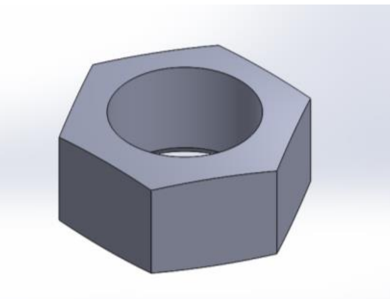
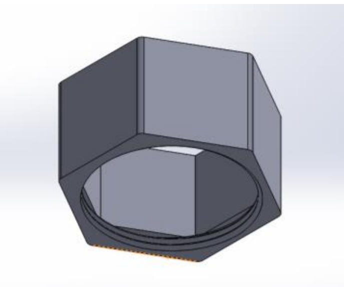




Figure 40: Customized washer

Figure 41: Hexagonal nut

Figure 42: Threaded chamber

A retainer belt will be placed over the nuts to keep them in place, see *figure 43*. A lid with a spherical under-surface will then be mounted on top of the chamber, *figure 45.*

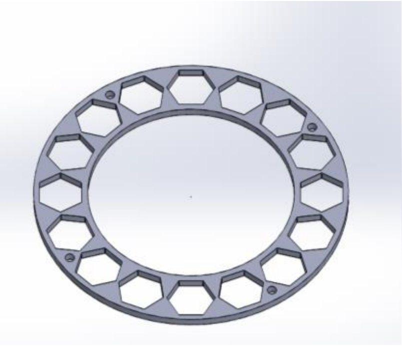
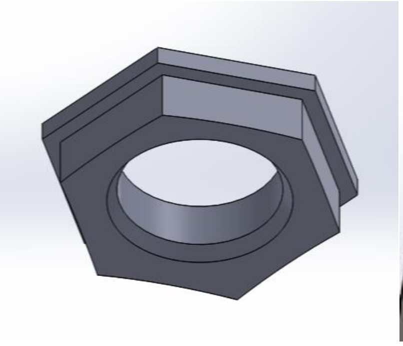
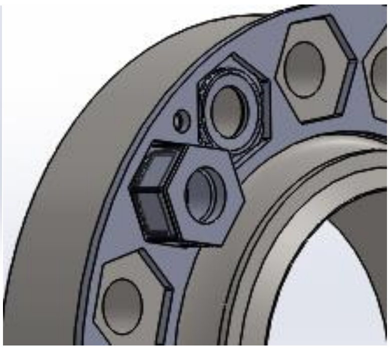




Figure 43: Retainer belt

Figure 44: Lid

Figure 45: Belt assembly

Since the nut has spherical surfaces and are not fixed on the washer, the nut will slide with the angle of the bolt when the bolt is tightened. Because of the offset between the nut and chamber, the bolt will not receive any bending pressure when entering the nut. One of the positive things with this concept is that it makes the assembly feasible and simple. The chambers hexagonal shape will make the hexagonal nut locked in the circular direction.

7.3.2 Chamber Welded on Flange

There will be used a bottom spherical washer that will be placed on the flange, concentric to the bolt holes, see *figure 46*. Then a customized nut will have a bottom part integrated that will work as the top part of the spherical washer, *figure 47*. A chamber will be placed over the nut and washer and will be welded to the flange, *figure 48*.

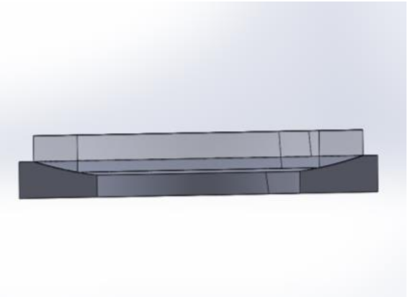
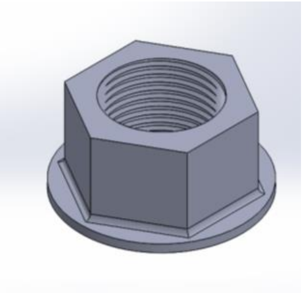
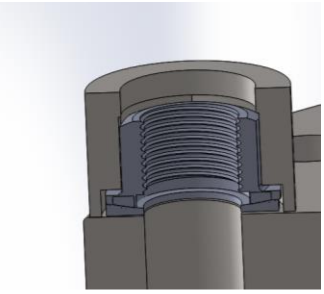




Figure 46: Spherical washer

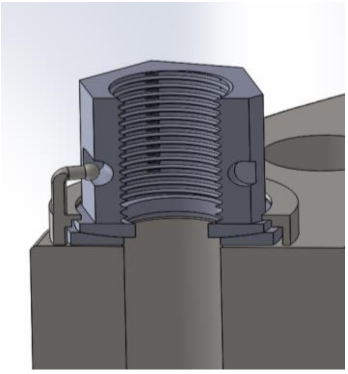
Figure 47: Customized nut

Figure 48: Chamber

There will be an offset between the chamber and the nut, so that the nut can be tilted when the stud enters, and then follow the bolt angle when it is tightened. The bottom part of the nut will retain the nut in the chamber, and will slide into the angle of the stud when it is tightened.

7.3.3 Rods

With this solution three rods will be placed in slots in a chamber. Spherical washers are placed concentric on the bolt holes before the chamber will be placed over and welded to the flange, see *figures 49 and 50.*



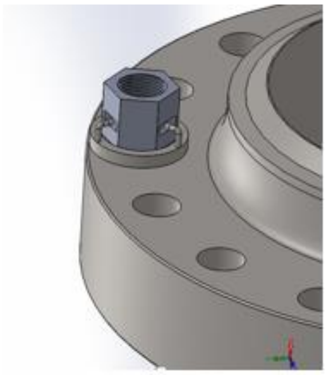


Figure 49: Cross sectional view

Figure 50: Rods

The rods will have three functions working in the systems favor. The first and simplest being that they keep the nut from falling off. The rods will also ensure the nut will be locked in a circular direction, so that the stud can effectively be turned through the nut. The last function the rods will have is caused by the difference between the rod ball size and sloth size. Because of this offset the nut can be tilted freely when the stud enters and are tightened.

7.3.4 Customized Nut

First, the bottom part of a spherical washer is placed concentric on the bolt holes. Then the special made nut is placed on top of the washer. A chamber split in half are wrapped around the nut and washer and welded to the flange, see *figure 51.*

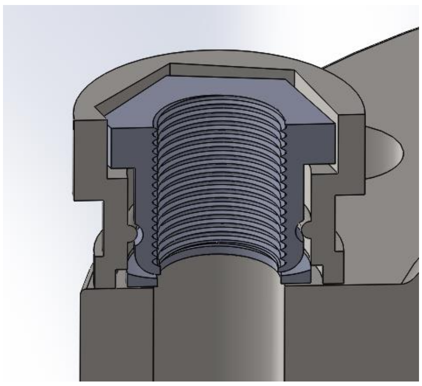
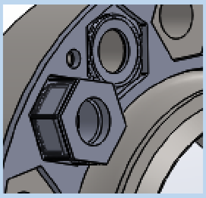
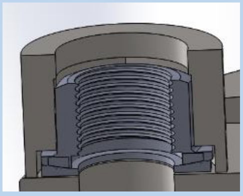
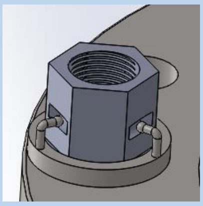
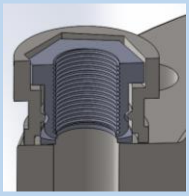


Figure 51: Nut and chamber

The sloth in the nut will be smaller than the bulk, and there will be a small offset in the entire chamber. This sloth also makes sure that the nut will stay in place and will not simply fall out when the stud enters the threads. The top part of the nut is to ensure that the nut will stay fixed in a circular direction when the stud enters. The distance between the top part of the nut, and the opposing chamber face will be large enough so that they never will touch.

All of these concepts are functional, however some have more positive features than others. To be sure that we choose the right concept we utilized a Pugh Matrix, as shown in *table 7.* The second concept seems to be the best solution, and our result will be a configuration of this concept.

Table 7: Pugh matrix: Nut retainment

Description		Concept1 		Concept2 		Concept3 		Concept4 	
Criteria	**Weight**	**Score:**	**WS:**	**Score:**	**WS:**	**Score:**	**WS:**	**Score:**	**WS:**
Good functionality	4	4	16	4	16	1	4	3	12
Robust	5	3	15	4	20	2	10	4	20
Feasible assembly	5	3	15	4	20	1	5	2	10
Feasible machining	5	3	15	4	20	2	10	2	10
Number of parts	2	2	4	4	8	3	6	5	10
Cost	3	2	6	4	12	1	3	3	9
Weight	2	2	4	3	6	4	8	3	6
Total:			**75**		**102**		**41**		**77**

(Weight 1-5, Score 1-5)

7.3.5 Tapered Threads

Having tapered threads will ease the assembly quite a bit as it offers good guiding possibilities and doesn't require as many turns as a regular bolt. However, one can make the argument that if the system can turn once, turning several more isn't a disadvantage. *Figure 52* shows an example of a tapered bolt.

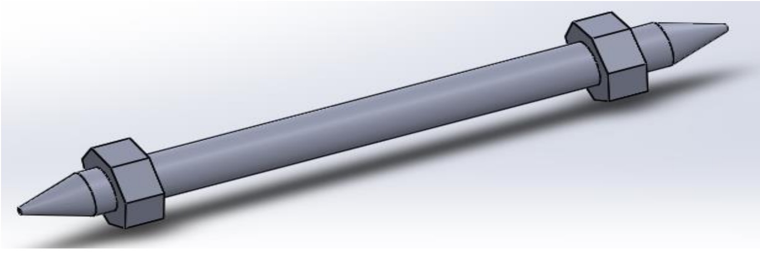


Figure 52: Tapered bolt

Utilizing a decision matrix we've decided that tapered threads is a possibility we want to look further into. See *table 8 below.*

Table 8: Pugh matrix: Tapered threads

Description:		**Tapered threads**		**Parallel threads**	
Sketch:					
Criteria:	**Weight:**	**Score:**	**Weighted score:**	**Score:**	**Weighted score:**
Req. Rot.	2	4	**8**	1	**2**
Guiding	4	4	**16**	2	**8**
Capacity	5	-	**0**	-	**0**
Cost	1	1	**1**	4	**4**
SUM			**25**		**14**

(Weight 1-5, Score 1-5)

8.0 Flange Preload

In general, it is necessary to tighten the bolts with a certain preload to avoid that leakage will occur when the flange connection is loaded. Thus, the connection will begin to leak if they are not tightened properly. The preload required on each bolt to avoid leakage is dependent on several factors, one being how the actual sealing is carried out. However, the pressure acting on the nut must not exceed the yield point of the material in the connection [1].

A bolt that have the correct preload in relation to the working pressure, will only get a fraction of the working forces as the preload and pressure will equalize each other. These forces will in most cases be dynamic so fatigue issues are also a concern. One can achieve the lowest fatigue strain by using elastic bolts, and the application of the recommended preload [2]. In general the parts that will be connected should be as stiff as possible. A high preload is the best precaution to ensure that the bolt connection does not loosen as insufficient preload, caused by an inaccurate tightening method, is a frequent cause of bolted joint failure.

8.1 How to Apply Preload

When discussing the application of the flange preload we spent some time trying to identify different methods other than the conventional bolt/stud and nut connection. Thoughts that came up were solutions like the over center cam you find on downhill ski boots, *figure 53,* the strap bindings you find on snowboards, *figure 54,* or a large screw cap, *figure 55*. We did however quite early realize that the forces involved would require gigantic systems for it to be functional. In addition, creating an approximately uniform stress situation would be challenging with solutions like these. In addition to these disadvantages, the solutions does not deal with how the load would be “locked”, nor would they account for the general mechanic of how the flange works.

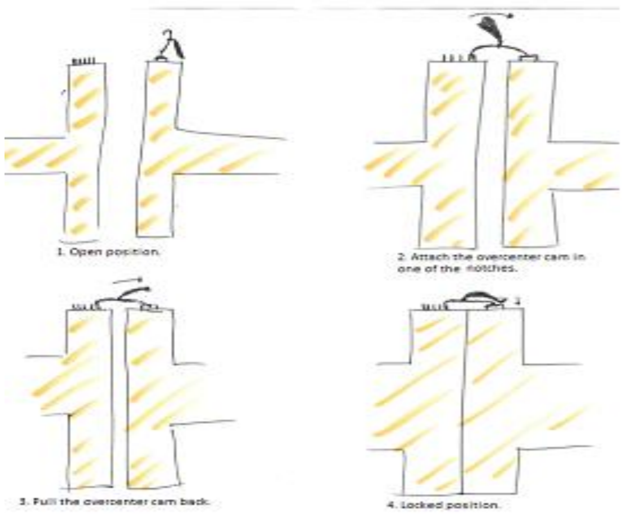


Figure 53: Over center cam

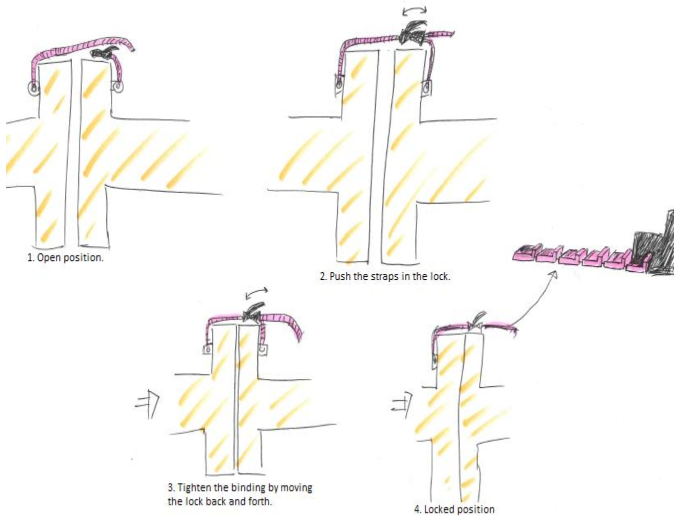


Figure 54: Strap bindings

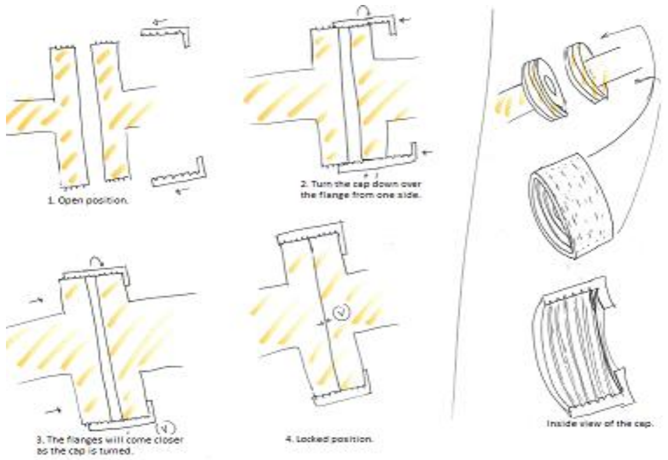


Figure 55: Screw cap

Going in another direction, we were also thinking of the possibility of using one or several hydraulic cylinders to apply the preload to the flange. The idea were to make a non-integrated system with several cylinders that will push the flanges towards each other and apply the needed preload, use regular bolts for locking and then removing the system. In the following figures you can see how we worked our way from a sketch, *figure 56,* to a drawing in SW, *figure 57 and 58.* Working further with this concept it became apparent that the power needed would result in gigantic hydraulic cylinders as well as the inability to produce an even force-load around the flange.

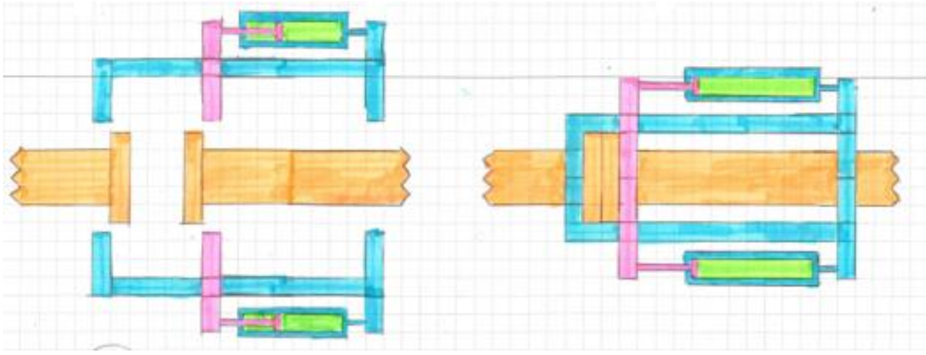


Figure 56: Hydraulic cylinder sketch

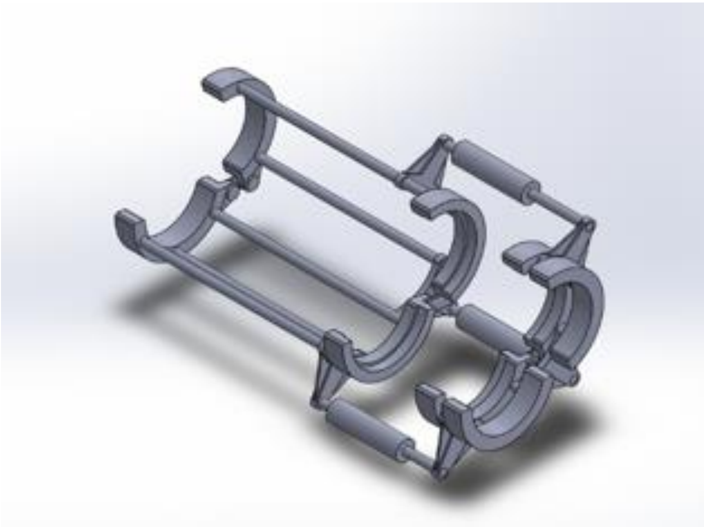


Figure 57: Hydraulic cylinder

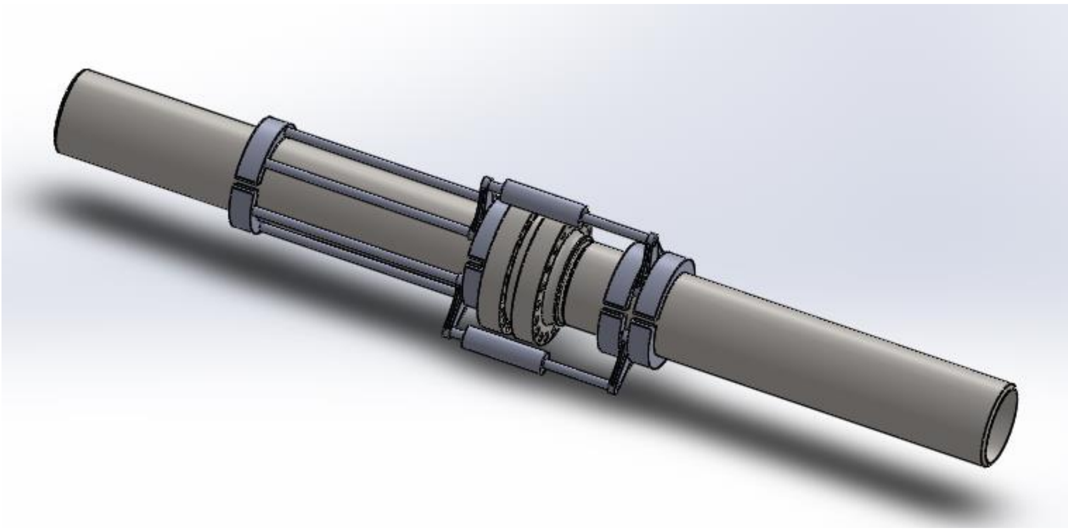


Figure 58: Hydraulic cylinder assembled on flange

These four concepts were compared with the hydraulic tool in a Pugh matrix, to be able to make an objective decision. See *table 9 below.*

Weight is always an important criteria point when designing and this assignment is no exception. Since the over-centre cam and the strap binding is both new concepts in this application, it is not perfectly certain how big they would actually need to be, but one can safely assume it would need to be unpractically big. The hydraulic tool alternative is assumed to be a hydraulic tool on each individual nut (resulting in 20 tools) which explains its score in terms of weight.

The hydraulic tool and the hydraulic cylinder is considered to give relatively accurate loads as it is based on well-known and well defined science.

Further, the complexity is here defined as the amount of interactions required to complete the process of the specific solution. Neither the over center cam, strap binding, or screw cap, is a complete solution regarding application of preload as the actuating force running the mechanism are not specifically defined. We decided it was reasonable to think that these ideas would be fairly complex when the concepts would be expanded to entire solutions, hence the low scores.

The accurate load capability criteria was classified as the most important criteria in terms of weight, and this is one of the main reasons why the hydraulic tool became a clear winner.

Table 9: Pugh matrix: Preload

Description:		Over-centre cam		Strap binding		Screw cap		Hydraulic tool		Hydraulic cylinder	
Criteria:	**Weight**	**Score**	**Weighted score**	**Score**	**Weighted score**	**Score**	**Weighted score**	**Score**	**Weighted score**	**Score**	**Weighted score**
Weight	3	3	9	3	9	4	12	3	9	1	3
Accurate load capabilities	5	2	10	2	10	2	10	5	25	4	20
Complexity	3	2	6	2	6	2	6	3	9	2	6
Process time	3	3	9	3	9	2	6	4	12	4	12
SUM			**34**		**34**		**34**		**55**		**41**

(Weight 1-5, Score 1-5)

8.2 Hydraulic Tool

Knowing that we would proceed with the hydraulic tool, we needed to make a decision on which type of tool to use. There are in general two different types of hydraulic tool used to give the flange its required preload. These are tension tools and torque tools. Hydraulic nut is a form of a tension tool that will also be considered.

8.2.1 Hydraulic Tensioning Tool

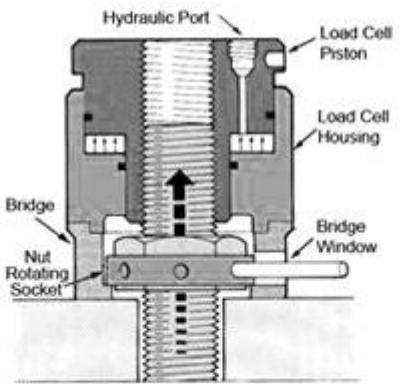


Figure 59: Hydraulic tensioning tool [3]

The Hydraulic tensioning tool works on the same principles as any hydraulic system; pressure applied to an area results in directional forces, which we can utilize. The hydraulic pressure is fed into a small chamber that sits between the load cell and the load housing, which creates forces acting upwards. These forces is then used to stretch the bolt/stud, so that when the nut is twisted face to face with the flange and the pressure released, the bolt will pick up the tension created by the hydraulic pressure. The bolt is now preloaded in the same way as if it were tightened by torque.

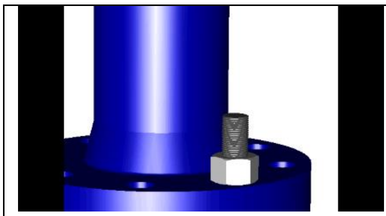
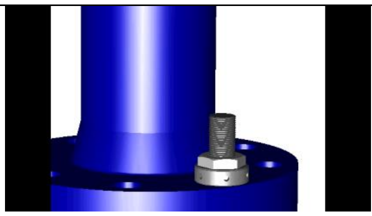
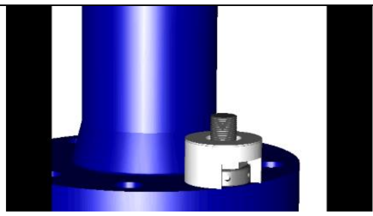
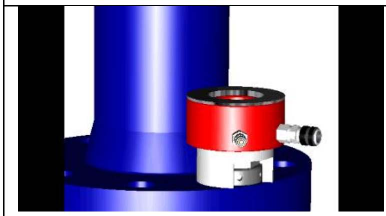
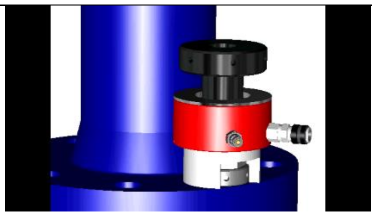
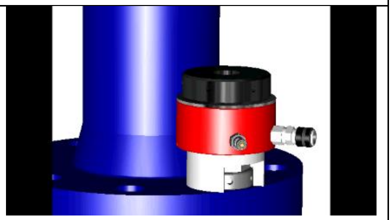
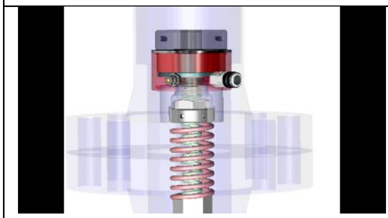
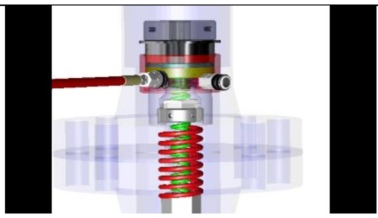
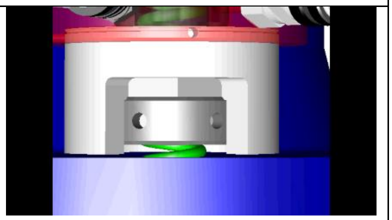
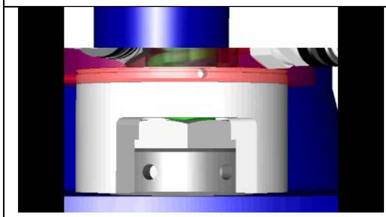
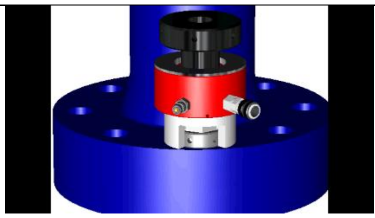
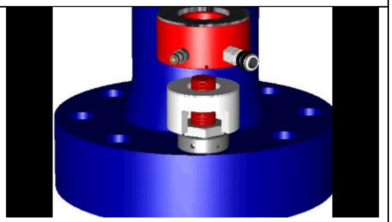
		
A flange is held together with a nut threaded onto a stud, however the connection needs to be preloaded for it to function properly.	An outer nut is introduced and surrounds the initial nut.	A load bridge is placed around the nut(s).
		
A load cell housing is placed on top of the load bridge.	A load cell piston is screwed on to the stud-threads.	The piston is screwed all the way down, until it is face to face with the housing.
		
The tool is applied hydraulic pressure through the hydraulic port. The bolt load is proportional to the pressure applied.	The stud is stretched as the pressure increases.	The nut(s) are no longer in contact with the flange, as the stud is stretched.
		
The nut(s) are screwed until they are again face to face with the flange.	The tool can now be de-pressurized.	The tool is finally disasembled, leaving only the original nut and stud.

Figure 60: Working principle of tension tool [4]

8.2.2 Hydraulic Nuts

Figure 61: Hydraulic nut [5]

A Hydraulic nut works much in the same way as a hydraulic tensioning tool, but will apply a more accurate load seeing as the nut is applied flush with the free length of the stud. This means that when the pressure is released there is no contraction of the stud above the nut as all the tension is acting below it. This means that more or less all of the forces applied will be kept as a preload in the stud and nut, as nothing is dispersed when the system is de-pressurized. In a tension tool the stud is stretched above the nut as well, so some contraction will occur and result in a preload loss, which is why a hydraulic nut is considered more reliable.

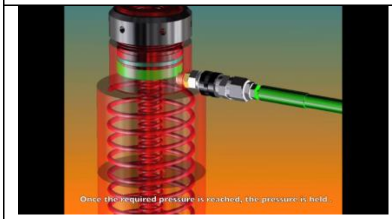
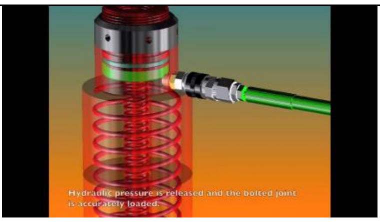
		
A flange-section with a boreholes is pierced with a threaded stud.	The hydraulic nut is assembled onto the bolt.	The bolt and joing can be considered to act like two very strong springs.
		
Hydraulic pressure is applied to the hydraulic nut and the bolt is accurately stretched. The bolt load is proportional to the pressure applied.	When required pressure is reached, it is held and the load collar is screwed down until it is again face to face with the load bridge.	Pressure is released and the bolted joint is accurately loaded.

Figure 62: Working principle of hydraulic nut [6]

8.2.3 Hydraulic Torque Tooling

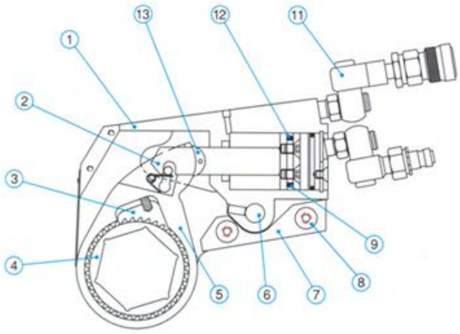
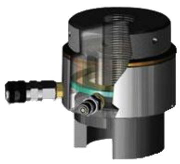


Figure 63: Hydraulic torque tool

Shown in the illustration above, *figure 63,* is a hydraulic torque tool used in the application of preload in studs or bolts. The tooling combines two simple hydraulic and mechanical concepts. The system works by a hydraulic cylinder pushing on a ratchet wheel, much like a car jack, where the circular motion is done in small increments.

From the Pugh matrix in *table 10,* we can see that the hydraulic nut turns out to be the best solution. We will most likely end up using a hydraulic nut.

Table 10: Pugh matrix: Hydraulic tools

Description:		**Tensioning Tool**		**Torque Tool**		**Tensioning Nut**	
Sketch:							
Criteria:	**Weight:**	**Score:**	**Weighted score:**	**Score:**	**Weighted score:**	**Score:**	**Weighted score:**
Load-Accuracy	5	4	20	1	5	4	20
Price	1	1	1	3	3	2	2
Process time-consumption	3	3	9	2	6	5	15
Complexity	5	2	10	2	10	3	15
Weight	3	3	9	2	6	4	12
Size	4	2	8	3	12	4	16
SUM			**57**		**42**		**80**

(Weight 1-5, Score 1-5)

8.3 Integrated or Non-integrated Tool

Even though the usage of hydraulic tools are decided, there are still the different possibilities of including them as an integrated part of the flange connection or having them as a non-integrated stand-alone tool.

8.3.1 Integrated Tool

As an integrated part of the flange, changes would have to be made to the original compact flange. In addition the twenty hydraulic tools will be located subsea for up to 25 years and still have to be operable. This sets certain requirements to the material used in the tooling in terms of corrosion resistance. However the advantages of having the tool integrated is that it will be timesaving as the tools will already be in place and the ROV will have to perform fewer operations. *Figure 64* shows a 3D model of the hydraulic tool integrated as a part of the flange, all on one side.

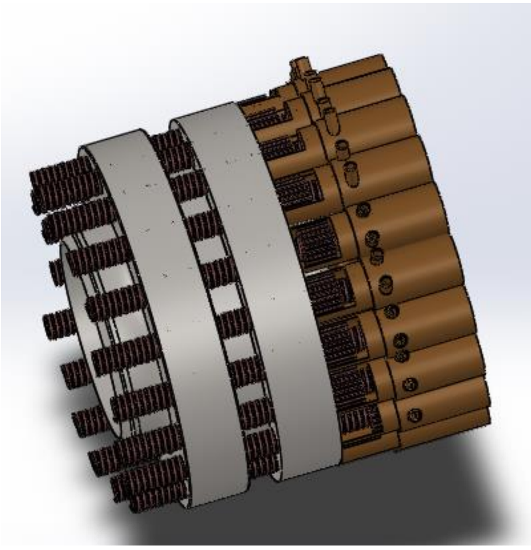
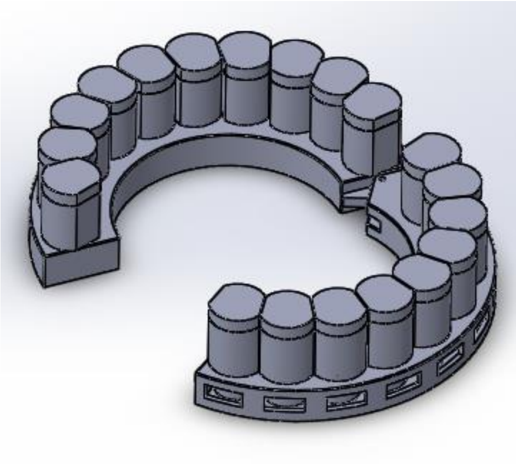


Figure 64: Integrated tool

8.3.2 Non-integrated Tool

The other solution would be to have a non-integrated tool which in principle will be less expensive than the integrated tooling. However, with a standalone tool, either as several single tools or as a belt consisting of several tools, the ROV will have to fit the tooling on the nuts on the flange. This operation can be difficult to conduct for an ROV as well as highly time consuming. The fact that this leads to multiple operations the ROV will have to perform is a big disadvantage. *Figure 65 and 66* on the following page shows an example of a concept with a belt that can latch onto the pipe connection and apply the pre-load from one side.



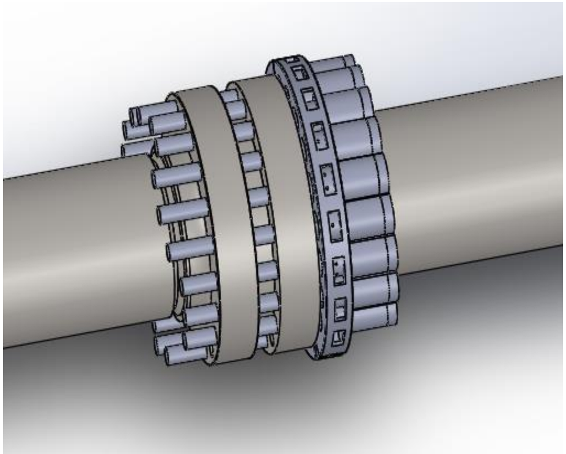


Figure 65: Tool belt

Figure 66: Non-integrated tool

The integrated and the non-integrated solutions were compared together in *table 11.* All though a rather close call the decision matrix calculates the integrated tool as the victor. The tool would be installed in the swivel side on the flange. This would be to keep all the ROV operated components gathered on one side.

Table 11: Pugh matrix: Integrated tool

Description:		**Integrated Tool**		**Non-integrated Tool**	
Criteria:	**Weight:**	**Points:**	**Weighted points:**	**Points:**	**Weighted points:**
Cost	2	2	4	4	8
Process time-consumption	3	4	12	1	3
Complexity	4	4	16	1	4
Customized for subsea lifetime	3	2	6	5	15
SUM			38		30

(Weight: 1-5, Score: 1-5)

9.0 Flange Lock

Seeing as we will be using a hydraulic tension tool or hydraulic nut to preload the flanges, we will have to find a solution to tighten the nut after the stud is stretched. This turning of the nut is usually done by putting a small pin in the hole and turning it, but this operation will be quite difficult to perform by an ROV.

Different solutions and problems were discussed and we've come up with several ideas concerning how to solve this. One idea shown in *figure 67,* was to make gear teeth either on top or around the nut, with a corresponding tool to turn it. This is a simple solution with the possibility of several angles of interaction, but this will also make the nuts more complex, and create the need for a special tooling.

Figure 67: Locking nut

Another solution is to make the gear ring embracing the nut as a gear, with the teeth facing in the vertical direction. The tension tool will have an opening for the gears to be exposed, and we will have to make a corresponding tool to turn the nuts, see *figure 68.*

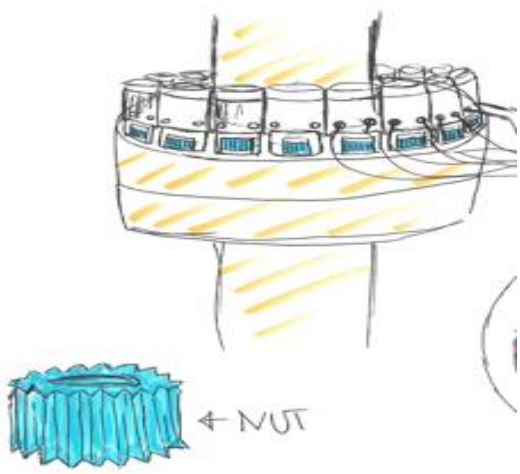


Figure 68: Locking system

As a continuation of this concept we thought of a gear-ring that will drive all of the gears, by being placed around all the tension tools in alignment with the gear-nuts. This will make it easier for the ROV, because you can tighten all of the nuts in one single operation. The disadvantages with this concept is however that they are all highly inter-dependent. If one gear fails, they will all fail. There is also no guarantee that all of the nuts needs to be tightened equal amounts, which means that each gear must be able to disengage when fully tightened, but still make it possible for the rest to turn. Designing such a reactive system may prove to be highly challenging. With this in mind the solution will be to turn all the nuts individually.

10.0 Flange Un-lock and Dis-assembly

During the whole process we have to think about the possibility of un-lock and dis-assemble of the flange. This system is in principle made to be placed subsea for 25 years, but we must have the ability to change the seal ring or a bolt during the flanges lifecycle.

To un-lock and dis-assemble the flange, the lock and assemble phase will be performed in reverse. This will be further explained in the Installation and Assembly Procedure [9].

11.0 Conclusion

Working with the concept development we've really started to realize the complexity of the system and because of all the internal dependencies, how hard it is to put together complete, compatible solutions. By gradually working through design choices, while considering the order we do so, sets us of with better defined limits when continuing into the next iteration.

We have decided to use a bolted connection, with studs and nuts. The studs will be tightened using hydraulic tooling, more specifically a hydraulic nut. The diameter of the flange will be expanded, so that it will be easier to fit an integrated tooling system in terms of space. The studs will be preinstalled in the hydraulic tool, and we will turn the studs through the opposing flange in one or two ROV operations. We will utilize tapered threads on the studs to ease the connection with the threads in the opposing nut. The nut retainment system will provide the necessary freedom to be able to pick up the threads. The locking of the nuts after stretching the stud, will be performed individually on each hydraulic nut. The seal ring will be retained using a system with a rubber ring.

Further explanation will be carried out in the Design document [8].

12.0 References

[1] http://www.boltscience.com/pages/basics2.htm

[2] http://www.hydraulicjackind.com/hydraulic_torque_wrench_tx_series1.htm

[3] http://www.htico.com/images/fixed-tensioner-illustration.jpg

[4] https://www.youtube.com/watch?v=ef9CXDhzH-U

[5] http://www.lacozaandam.com/uploads/images/option2/Hydraulische-moeren-1.jpg

[6] https://www.youtube.com/watch?v=7MOqo9QNEO0

[7] http://www.vectortg.com/Media/VECTOR-2533_-_SPO_CF_for_subsea_applications_revF.pdf

[8] Design Document; ROV operated SPO compact flange, Bachelor thesis 2015.

[9] Installation and Assembly Procedure; ROV operated SPO compact flange, Bachelor thesis 2015.

Design Document

ROV operated SPO compact flange for subsea assembly in deep water

Document No.:	Version No.:	Date:	Document responsible:	Group:	Status:
6.0	1.0	15.05.2015	Jørgen Borgersen	3	Completed

Group members: Mathilde Schinnes, Laila Andersland, Jørgen Borgersen, Marit Skjørestad

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1.0 Document

1.1 Document History

Table 1: Document history:

Revision	Description of change	Date
0.1	Document created	27.03.15
0.2	Merge the different themes and related subsystems	12.05.15
0.3	Elaborated	12.05.15
0.4	First draft	13.05.15
0.6	Re-arranged and fixed spelling errors	15.05.15
0.7	Added chapter 14 Material	15.05.15
1.0	**Final release**	**15.05.15**

1.2 Abbreviations

Table 2: Abbreviations

Abbreviation	Description
ASTM	American Society for Testing and Materials
BCD	Bolt Circle Diameter
CF	Compact flange
FO&GT	Freudenberg Oil & Gas Technologies
HBV	Høgskolen i Buskerud og Vestfold
HISC	Hydrogen induced stress cracking
HX	"H" profile seal ring name
ROV	Remotely operated vehicle
SPO	Compact Flange name prefix (From former company name Steel Products Offshore)
STT	Stud Turning Tool
STTH	Stud Turning Tool Holder
SW	Solidworks
WN/SW	Weld neck/swivel
VASI	Verktøy Industri AS

2.0 Scope

This document will elaborate on the design choices made during the development of the ROV operated SPO compact flange assembly system.

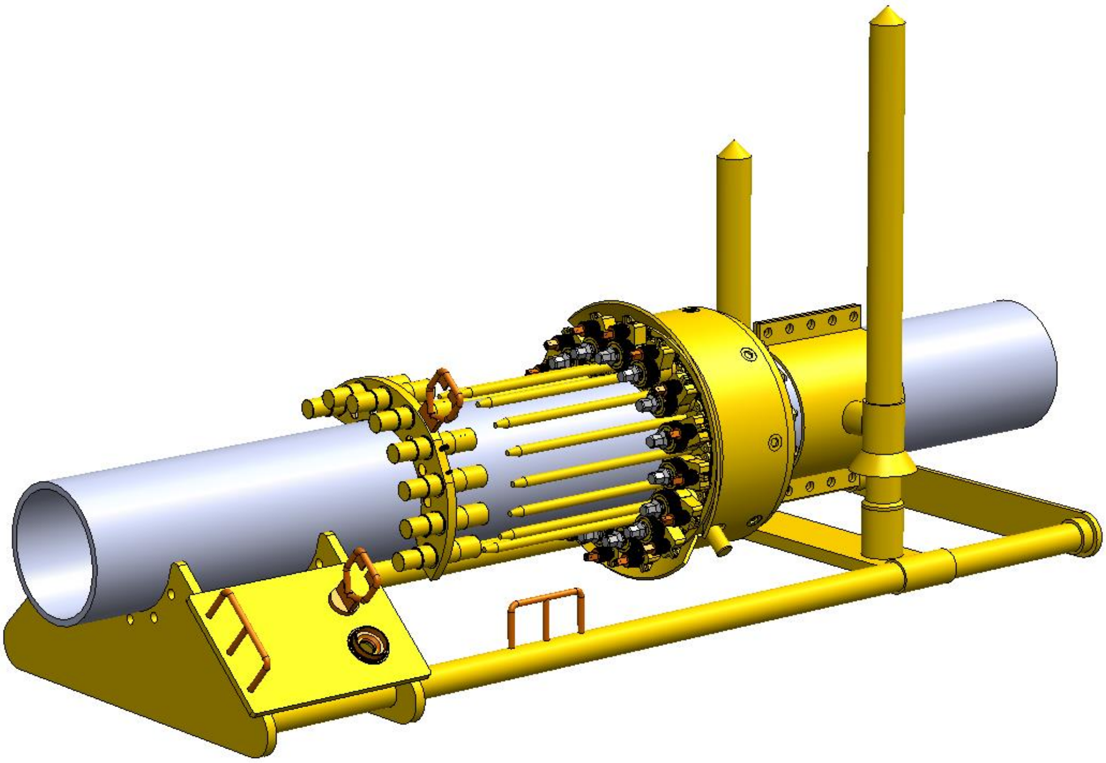


Figure 1: Complete system

2.1 ROV Operated Assembly System

The system will perform the assembly in a series of operations, which will all be further explained during the course of this document, as well as in the Installation and Assembly Procedure document [18]. These consist of the following:

- The crude guide system pushes the flanges to their correct position. Starting with the vertical direction and then the horizontal. As the flanges move towards each other, a rotational guiding system forces the swivel ring to turn the bolts into their preferred positions.
- Once the flanges have come face to face, the studs will be screwed trough the opposing flange using a special stud turning tool.
- Once the studs reaches the outer flange face it will screw itself into a specially designed nut freedom and retainment system, assuring proper threading in all cases of entry.
- When the studs are properly positioned, they will be stretched by special hydraulic tension nuts. Once the pressure is released, the tension is transferred to a load collar that encircles the tension tool. This load collar will be turned by its own system.

In addition, the seal ring that sits in between the flanges is changeable, made possible by a re-design of the seal ring and the addition of a rubber retainment ring.

3.0 Crude Alignment System

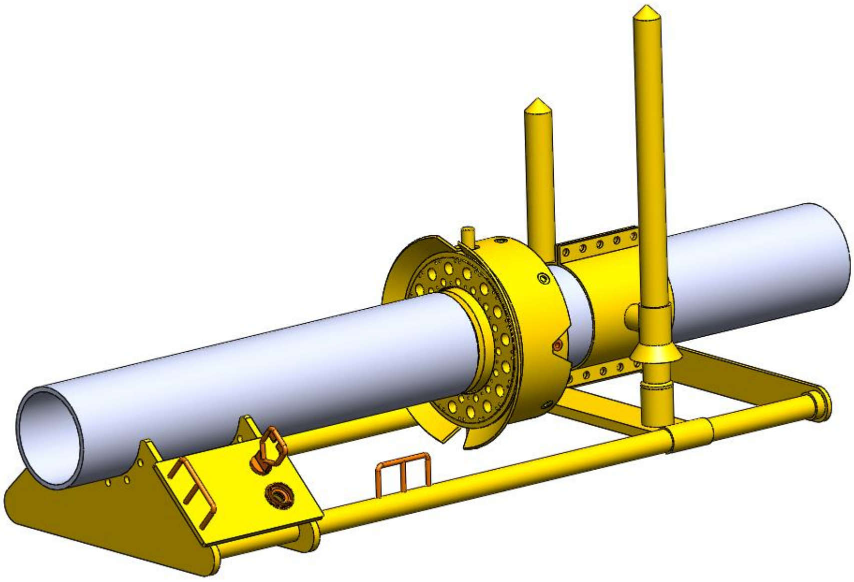


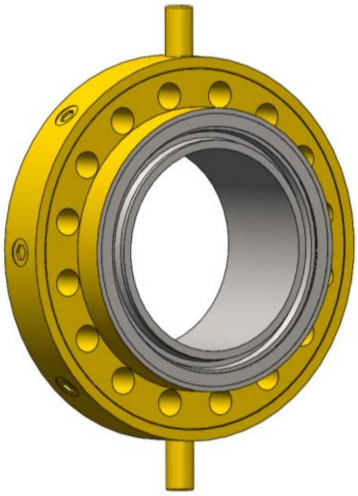
Figure 2: Crude alignment system

The crude alignment system will assure adequate positioning of the flanges in the vertical and horizontal planes. In addition, it will force the swivel to rotate into the correct position so that the bolts are able to enter with ease.

3.1 Parts

The alignment system consist of several parts, which will be explained in detail.

3.1.1 Collars



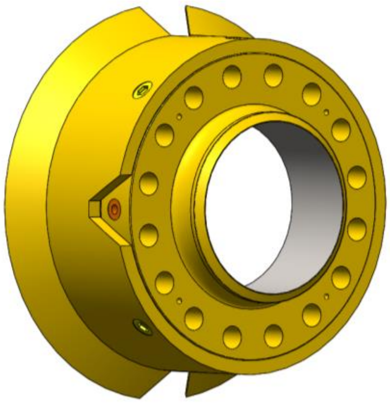


Figure 3: Swivel collar (lhs)

Figure 4: Weld neck collar (rhs)

The rotational alignment will be ensured by a set of collars that encircle both the swivel ring and the opposing weld neck flange. They will both be fastened to its respective positions using bolts screwed into machined holes in the flange.

3.1.2 Guide Frame

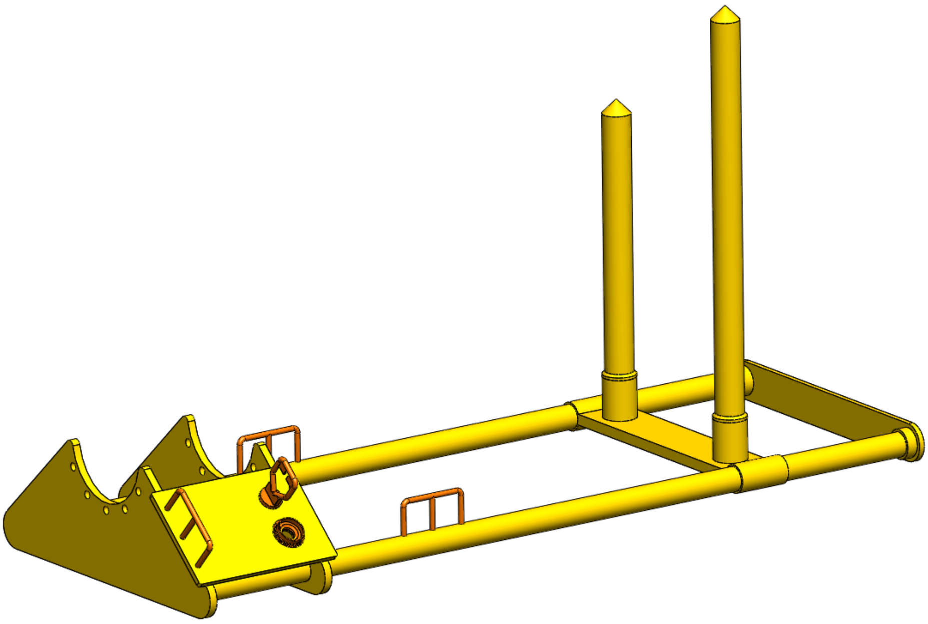


Figure 5: Guide frame

The vertical and horizontal alignment will be provided by a guide frame equipped with a moveable slider. The guide poles will co-operate with a collar hub mounted on the pipe, so that the weld neck side may be guided to its optimal positioning.

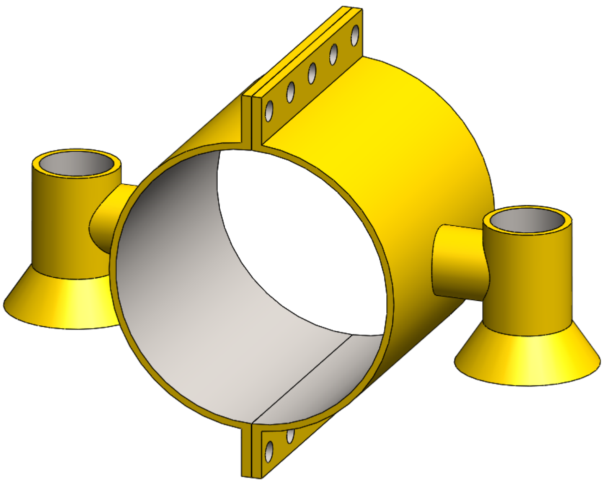
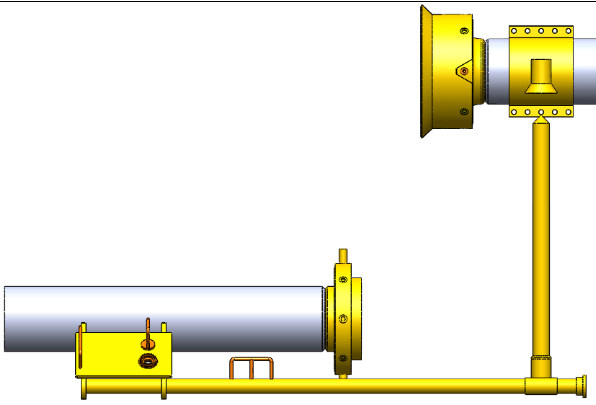
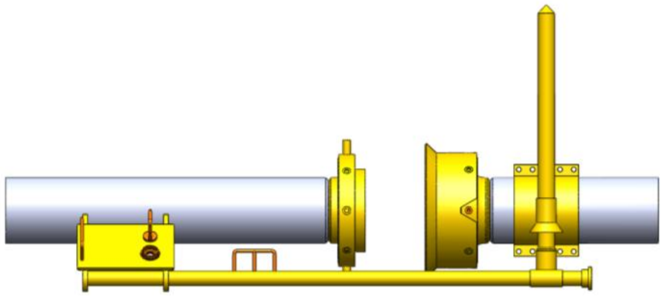
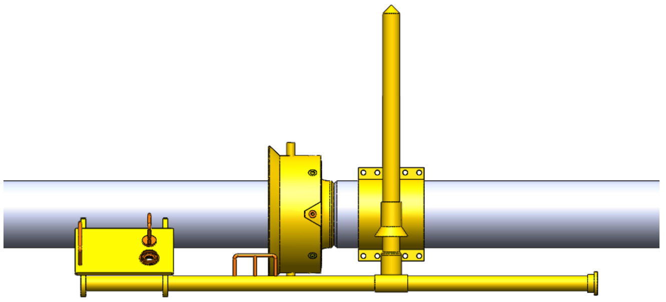


Figure 6: Collar hub

3.2 Operation

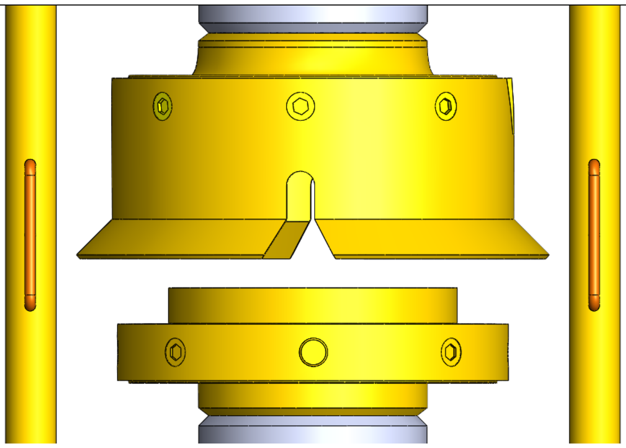
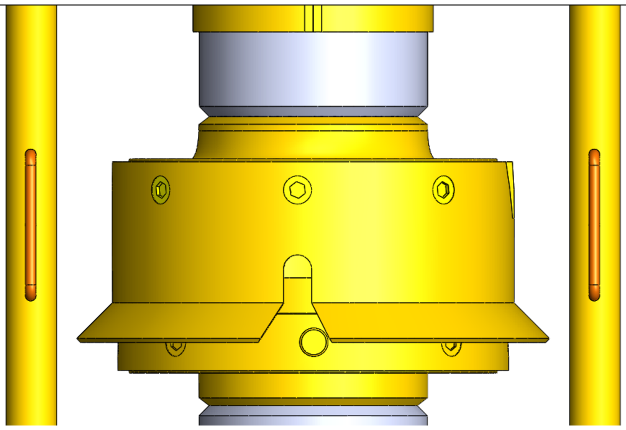
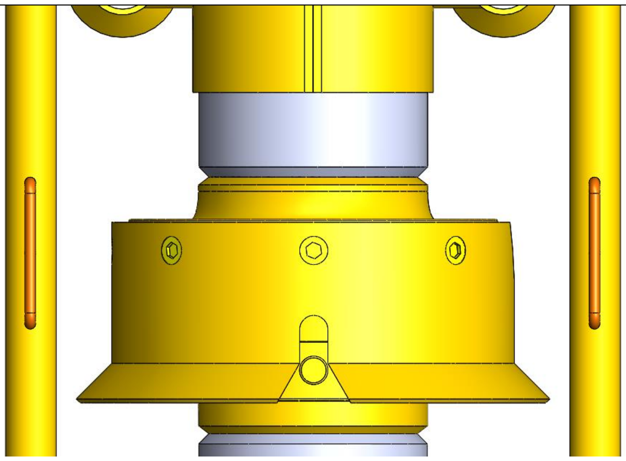
3.2.1 Axial Alignment

Table 3: Axial alignment

 *Figure 7: Free*	Once the swivel and guide frame is installed in its correct position, the weld neck flange may be lowered down onto the guide poles.
 *Figure 8: Aligned horizontally*	When the pipes are properly aligned in the vertical direction, the guide slider will be pulled/pushed towards the opposing flange, bringing the system together.
 *Figure 9: Fully aligned*	When the guide slider reaches the collars, a rotational alignment system will react and assure bolthole alignment.

3.2.2 Rotational Alignment

Table 4: Rotational alignment

 *Figure 10: Free*	As the swivel and hub flange moves towards the opposing flange, the boltholes will possibly be in a misaligned position.
 *Figure 11: First contact*	When the guide pin enters the groove in the opposing collar, it is continuously forced towards its final position as the flanges comes together.
 *Figure 12: Aligned*	Once the boltholes are properly aligned the flanges will move straight towards the opposing flange until contact is made and the bolts can be entered.

4.0 HX Seal Ring for ROV Installation

4.1 HX Seal Specifications

The HX Seal Ring is an elastic seal which is energized by the deformation of the seal flanges towards the seal center line as the flanges comes together during pre-stressing. This deformation is governed by the groove and seal geometries. In addition, the seal will be pressure energized when subjected to pressure either from the inside or the outside.
The HX seal is symmetric and seals equally good from both sides, and it is therefore ideal for deep-water subsea applications, where also large external pressures can occur. This is a robust seal used in the most demanding applications, with no practical limit for pressure that can be managed [1].

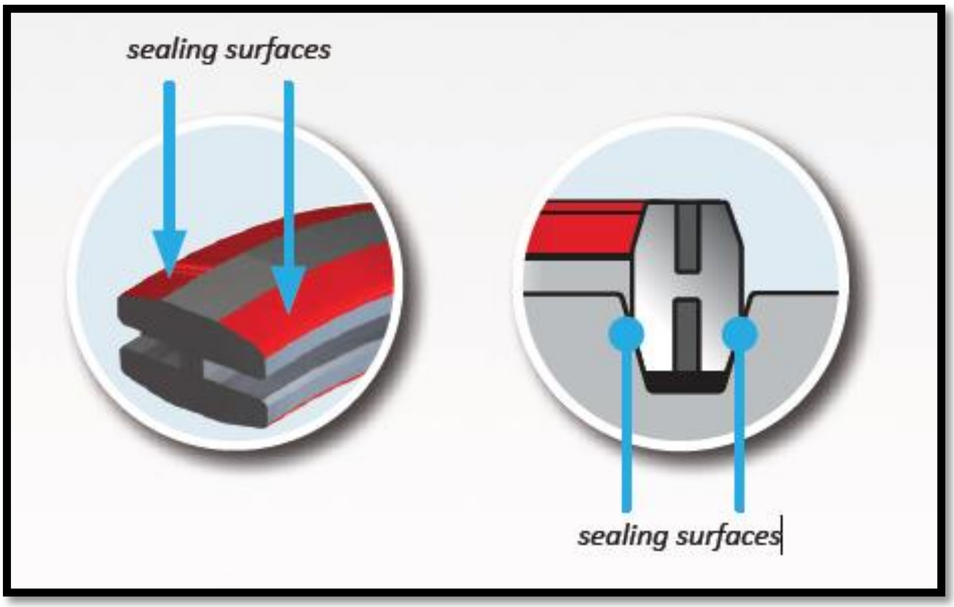


Figure 12: HX Seal Ring Cross-Section View

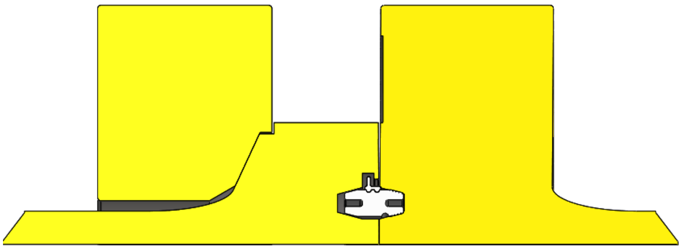
4.2 Seal Ring Installation and Replacement

A seal replacement tool will make it possible to change the seal ring. The tool will be inserted into the HX seal ring by the ROV manipulator and be hydraulically actuated to grip onto the inside diameter of the seal ring. The groove on the inside of the ring gives the tool a way to lock onto the seal ring prior to actuations to reliably remove it from the hub and hold until the ROV is ready to release it. The seal ring is released automatically when the hydraulic actuation has been released.

4.3 Seal Ring Retainment System

When designing the seal ring we need to take make sure that the seal ring have the possibility to be installed in the flange by the ROV. We also must have a system to retain the seal ring in the swivel flange during assembly of the flange. In practical terms this means that the seal ring needs to be retained by an axial force that demands a bigger power to loosen than is used to retain it.

After circling different solutions described in the Concept Study [2], we landed on a concept with a rubber ring. The rubber ring will be strapped around the seal ring and fitted into two grooves in the seal. A rubber tap will stand up, which will have to be pushed through an opening in the swivel hub.



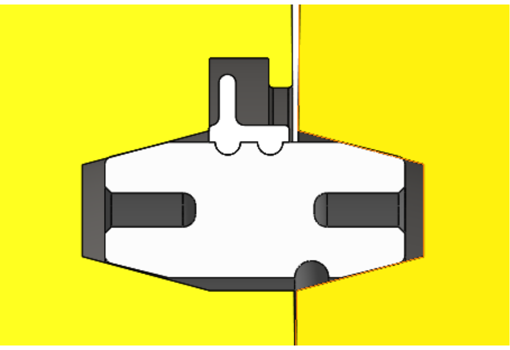


Figure 13: Seal ring and rubber ring inside the flanges (lhs)

Figure 14: Close-up (rhs)

4.3.1 Seal Ring

The dimensions of the original seal ring have been changed to fit the retainment system, however, the four seal surfaces and the thickness of the ligaments is kept constant as no changes can be made to these. On the contrary, the length of the ring can be changed as we wish. *Figure 14* shows the size of the original seal ring, and *figure 15* shows the size of the new seal ring. As you can see the ring is made longer in the mid-section, and the total length of the ring is increased 10 mm, from 25,4mm to 35,4mm. The single groove on top of the ring is replaced with two bigger grooves, which will retain the rubber ring that will embrace the seal ring. On the inside of the ring a new groove is made so that there exist a griping ledge for installing and replacing the seal ring.

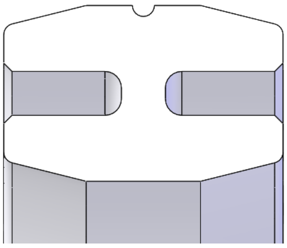


Figure 14: Original seal ring

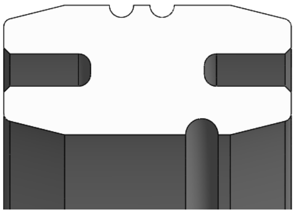


Figure 15: Re-designed seal ring

4.3.2 Rubber Retainment Ring

Natural rubber is a versatile and adaptable material which has been successfully used in engineering for over a hundred years. Good weathering resistance ensures that natural rubber last for many years, and it can store more elastic energy than steel. Installation is simplified by the flexibility of rubber springs, and subsequently no maintenance is required. Natural rubber is a member of the class of substances known as high polymer, where the distinguishing feature is the ability to deform elastically.

Natural rubber has many advantages over other materials subsea – very high tensile strength, resilience and ability to absorb dynamic stresses, and abrasion resistance [3]. In material science, resilience is the ability of a material to absorb energy when it is deformed elastically, and release that energy upon unloading. The area under the linear portion of a stress-strain curve is the resilience of the material [4].

The NRX (Natural rubber extreme) is a rubber type specially used for subsea applications, and this rubbers offer temperature resistance in the range -50 to +80 degrees centigrade, which is why we have chosen this material for our application.

4.3.3 Swivel Hub

The groove in the swivel hub needs to be changed for the rubber tip to be able to deflect in to the groove. The groove is in total made 10mm deeper, and a part of the inside ceiling is cut out, shown in *figure 16 and 17.* The size of the necessary cut in the ceiling is calculated in the calculation document [5].

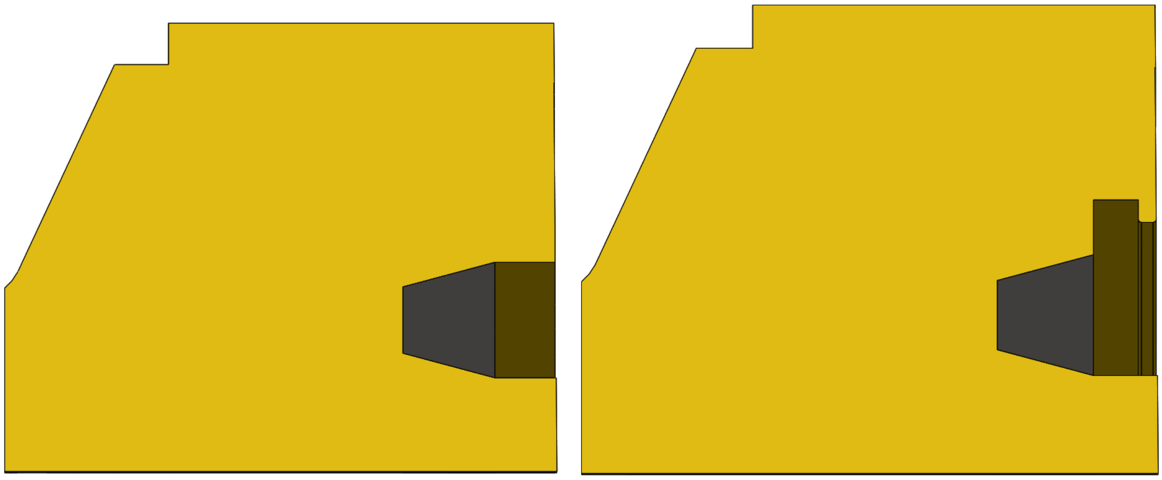


Figure 16: Original seal ring groove

Figure 17: Re-designed seal ring groove

As shown in the Calculation document [5], equation (1) we need at least 5,7 mm of room for the rubber tip to deflect up inside the flange. We make the room inside the metal tip 7 mm deep. This is to be sure that the rubber tip will bounce up after deflection.

To compensate for the removed material in the ceiling of the groove, to fit the rubber ring in the swivel hub, we need to increase the length of the hub. This will be increased the same amount as were removed. In total the flange is made 10mm longer.

The angle of the beveled faces in the groove is kept constant, to fit the angled face of the seal ring and assure that the functionality of the flange and seal-ring interaction is kept untouched.

5.0 Stud Turning System

The ROV SPO compact flange system includes a set of hydraulic nuts, studs, and nuts with a special freedom system. Earlier in the process of making a system to assemble this subsea, it was decided that the stud would be pre-installed in the hydraulic nut, on the swivel side. In addition the nut retainment system will be integrated in the weld neck side.

Initially the system were meant to accommodate 20 bolt, as this is the standard configuration for the 16 inch pipe flange. However, because the size of the hydraulic nuts and the nut system on the weld neck side, the system was forced to change the number of bolt-holes to 16 [6].The change of number of bolt holes did not affect the different solutions in any notable degree, however, some calculations, drawings and number of parts had to be changed.

5.1 Turning Mechanism

To simplify the operation it was decided in the concept study that the stud will be pre-installed in the hydraulic nut and that the hydraulic nut will be pre-installed and integrated on the swivel side. The stud will be installed in a position as shown in Figure *18.* The flange will be standard non-threaded, however, the tooling will have its threads. The stud will therefore be locked in the starting position as it is screwed into the hydraulic nuts. The system will be in need of a system to rotate the stud, as the stud will then be automatically screwed through both the flange and the nut on the weld neck side, seeing as the threaded tooling guides the axial motion.

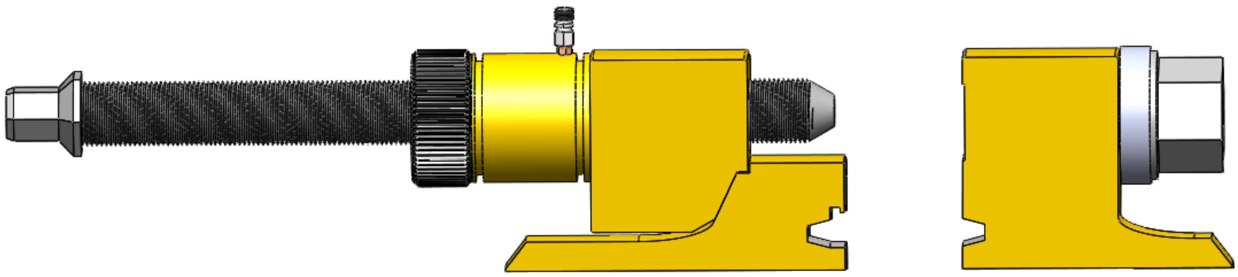


Figure 18: Starting position

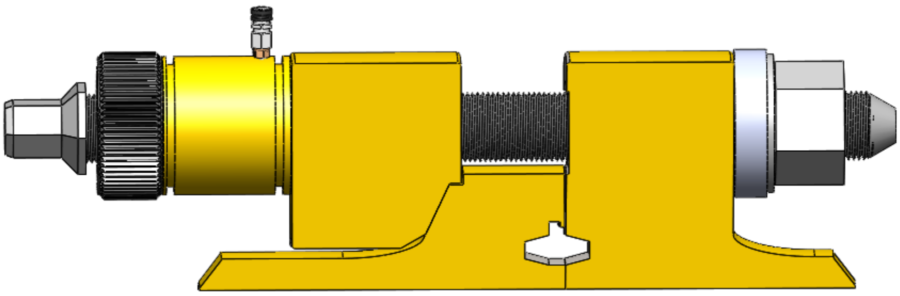


Figure 19: Assembled position

5.2 Stud Turning Tool

During the development of the stud turning system, the group was introduced to a special stud turning tool called Syclone. We were advised by our resources at Freudenberg that the company Hytorc could provide the needed tools and that we should look into what they might have to offer. What Hytorc can offer by way of Syclone is a continuous rotary tool with adjustable speed, which can run in both directions. This tool can quickly be connected to the top of the stud and run the stud through the threads, only with the help of hydraulic pressure. After some research we found that several companies had the same type of tool in their assortment. This tooling will from hereafter be called Stud Turning Tool (STT).

5.2.1 Stud Turning Tool Holder

Instead of using only one STT to run all of the 16 studs, the STT will be placed in a Stud Turning Tool Holder. This is a kind of a belt that goes halfway around the pipe and includes 8 STT. The STT will only be used for the one assembly, and will not be located or integrated in the system subsea. This means that there will not be a requirement for the system to withstand 25 years of its anticipated life subsea. One solution could be to have the tools installed on the studs, like the hydraulic nuts. But then both the tooling and the system around would have to be of the quality and type that could withstand 25 years of seawater. This is both costly and demanding, together with the fact that every assembly would be in need of a full set of tools. However, by using a STT Holder, a standard STT can be used and also reused in another assembly. This is very cost effective.

There could also be a solution to make a belt for all of the 16 STT. This belt must have had a function so it was able to open and grip round the pipe. The belt would be quite heavy, when each tool have the weight of 3.5 kg. It were decided that a better solution was to make the belt that could turn the half of the studs at the same time.

Unlike the pre-load, there is not a requirement that all of the studs should be turning at the same time, which makes this in-line with the system requirements as well as a practical solution. The stud runner system are not responsible for neither the alignment nor the pre-load. The Stud Turning systems only matter is to turn the studs, through the threads in the hydraulic nut, through both of the flanges and at the end through the Nut Freedom system. Because of this it's irrelevant if the studs will be turning equally or not, which is why we've ruled the combination of several tools viable.

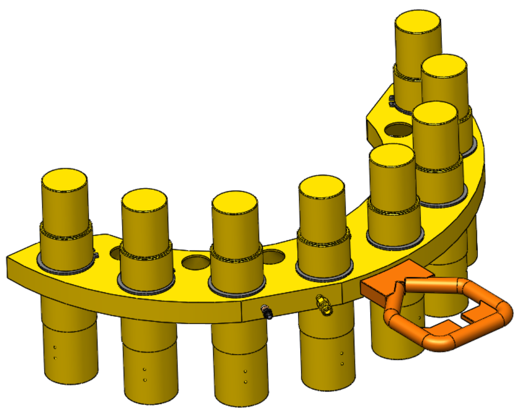


Figure 20: Stud turning tool holder

5.2.2 Installation

Shown in the following figures are the installation process of the STT.

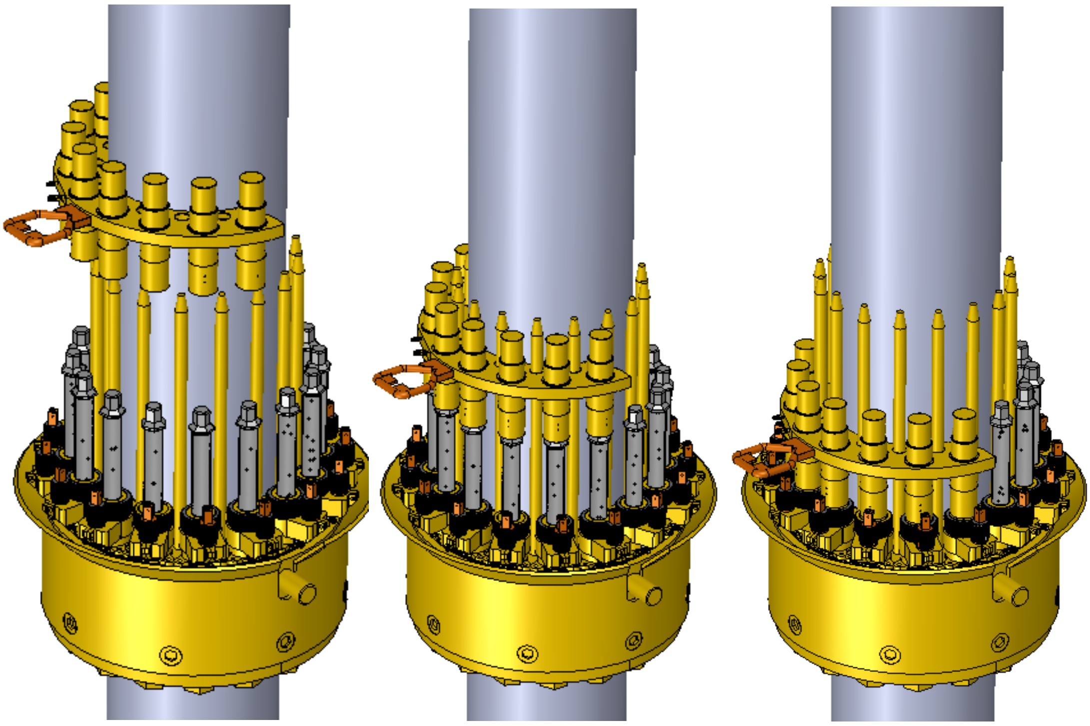


Figure 21: ROV carries the STT holder (lhs)

Figure 22: STT holder leans against the pipe (middle)

Figure 23: STT is connected to the top of the stud (rhs)

5.2.3 Guiding System

One very important part of the whole assembly procedure is that every movement have to be done with the help of a ROV. There are specific requirements of what the ROV are capable of doing, and maximum weight the ROV can lift. In addition, the ROV operator does not have neither depth vision nor feeling of the environment as a human has.

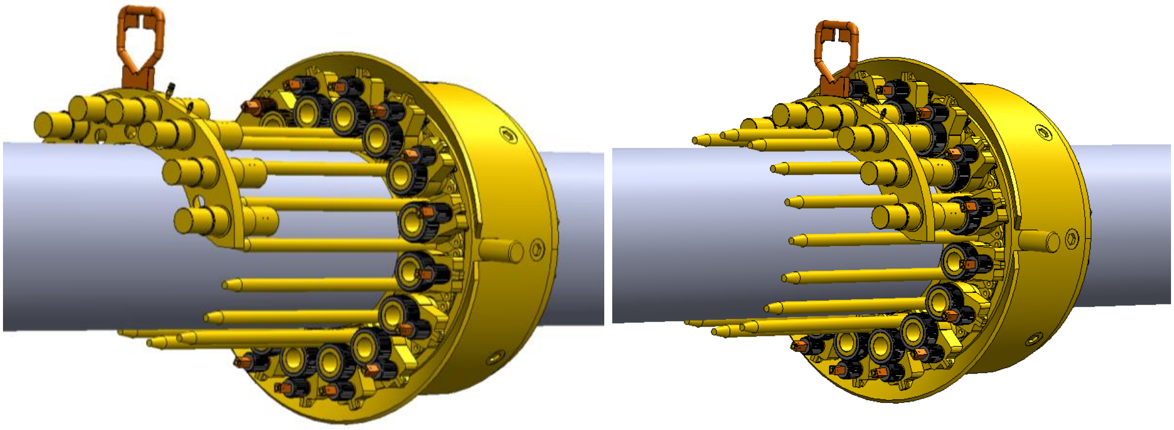


Figure 24: Initial position (lhs)

Figure 25: Final position (rhs)

The STT Holder will not be pre-installed in the flange. Therefore, the system need a guiding mechanism to get the STT in place on each stud. The first step is to get the inner diameter in contact with the pipe. The ROV will then lean the whole STT Holder onto the pipe and move it along the surface of the pipe. In the swivel flange, there will be installed guiding pins that slide into corresponding holes on the STT Holder as it moves towards the studs.

For this to be possible the ROV need a handle to grip and lift the tool to the right position. The position and direction of this handle is considerations that effect how easy it is for the ROV operator to perform the process. Because of the weight it will be best to place the handle as close as possible to the center of gravity. Different configurations were considered and in the end it were simple practicality that helped decide which one to choose. Finally it were decided that placing the handle straight out from the system will be the best and easiest solution.

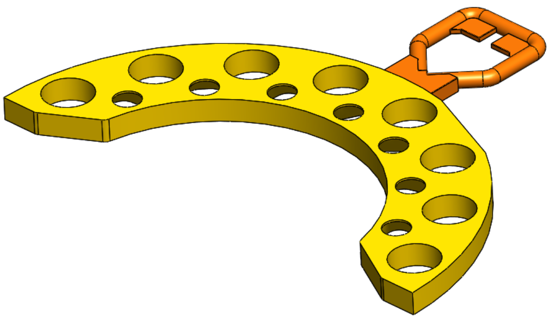
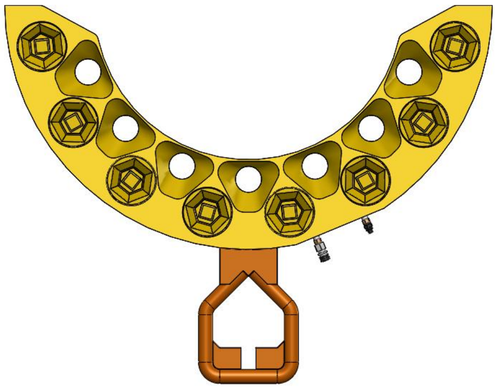



Figure 26: Stud turning tool holder (lhs)

Figure 27: Stud turning tool holder, frog perspective (rhs)

The final ROV tool are made according to the recommended practice described in the Remotely Operated Tools and Interfaces on Subsea Production Systems standard [7].

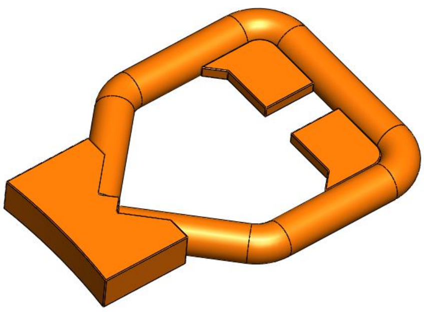


Figure 28: ROV handle

6.0 Nut Retainment System

As stated in the Concept Study Document [2] we decided that the bolt would be integrated in the hydraulic tool in the SW flange and consequently, the nut must be on the opposing side. The nuts will be integrated on the weld neck, however this presents some challenges. The result will be a customized flange with nut retainment possibilities.

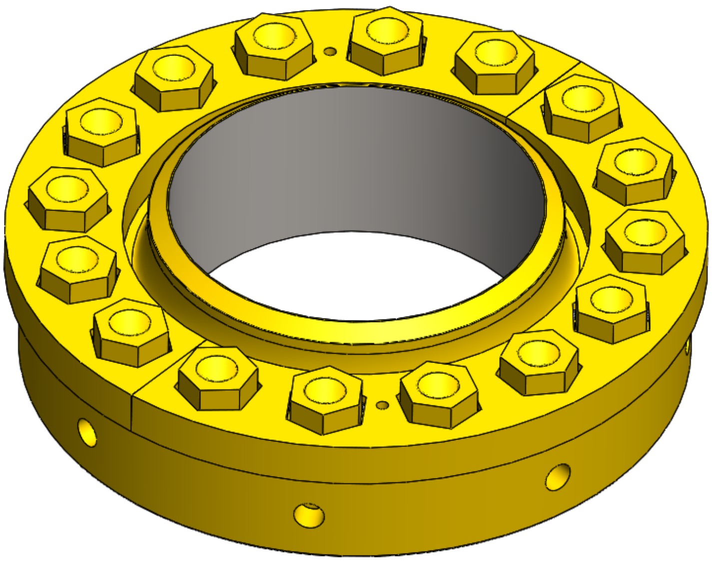


Figure 29: Nut retainment system

6.1 Freedom

For the nut to be able to pick up the threads of the stud, there cannot be any angle on the bolt, the bolt must be completely concentric, and in line with the nut.

The bolt will be fixed on the swivel side, and since there will be a small angle between the flange faces, the bolt holes are slightly bigger than the stud threads outer diameter, to ensure no bending forces acting on the stud.

Since the flanges have an angle, the bolt must be able to travel through the flange hole without being exposed to bending forces. The bolt is going to be stretched up to 95% of its yield strength [7] and this cannot be done if there are supplementary bending forces applied.

6.1.1 Angular Freedom

Further there is the challenge of having the nut retained all the while allowing angular freedom. When the stud enters the nut it will be tilted and therefore try to bend the nut in the same tilted angle. To avoid bending forces on the stud there will be used special spherical indented washers so that the nut may slide according to the direction the axial forces are acting in.

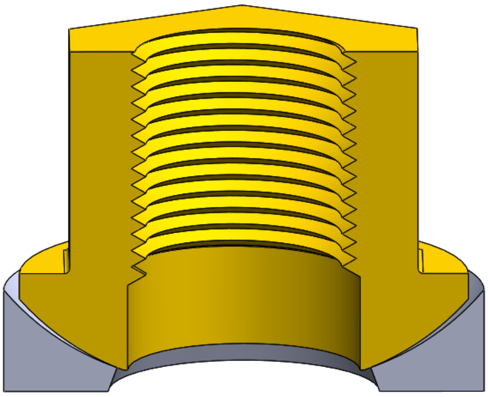


Figure 30: Spherical washer and corresponding nut

In the bolt and tooling configuration document [6] it is decided that the bolt is going to be a 1 ¾ 8UN which is equivalent to 44,45mm in diameter. According to the FO&GT's Designers Manual [8], the bolt hole consequently has to be 49mm. This results in a maximum angle the bolt can be in when in the bolt hole. With some simplified calculation we find this angle to be approximately 1.27 degrees [5]. The design of the nut retainer is therefore designed to be able to cope with this angle.

6.1.2 Horizontal Freedom

The project group decided to proceed with a solution where the washers and nuts are placed in individual chambers in a belt. The washers and nuts will be placed over the bolt holes on the flange, and the belt will be fixed to the flange using bolts.

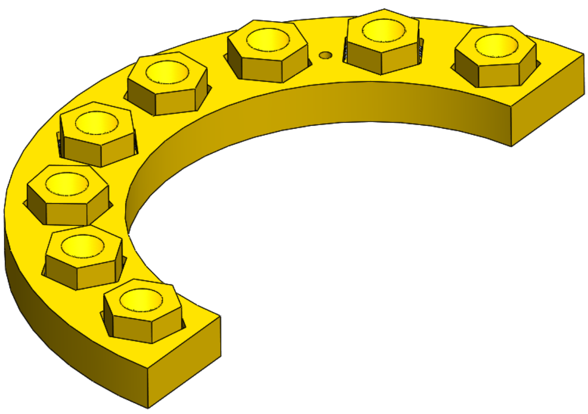


Figure 31: Nut retainer belt

The belt will be machined with a round hole on the face that will be placed on the flange, this will be where the washer and the bottom part of the nut will be placed. On the other side of the belt, the hole will be in a hexagonal shape, so that it's able to stop the hex-nut from turning when the stud have picked up the threads, but still allow movement in the horizontal plane.

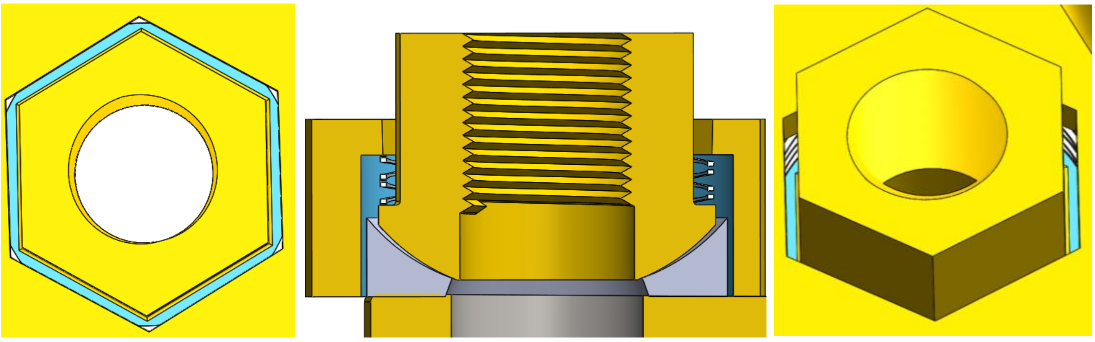


Figure 32: Top view (lhs)

Figure 33: Section view (middle)

Figure 34: Tilted view (rhs)

6.1.3 Vertical Freedom

The nut need to be fixed in the washer in the vertical direction. The washer and the nut need to be held face to face with the flange for the system to operate correctly. If they wouldn't be there, the nut might float up and be fixed in the top position. The reason this is unwanted is that when the bolt enters, if the nut threads doesn't pick up the stud treads the first time it will still have room enough to pick it up before the stud runner forces it through. Seeing as the stud turning system will keep pushing the stud even though the threads have not entered a lack of vertical freedom might damage the system. If the nut is fixed in the washer when the stud enters, the threads can fail the first time the thread-opening comes around, and still push the nut a pitch in height without damaging the system.

After further discussion it were decided that a single large spring will be placed over the nut before the fastening belt will be mounted on top. This spring will assure the vertical retainment, but still allow it freedom to move.

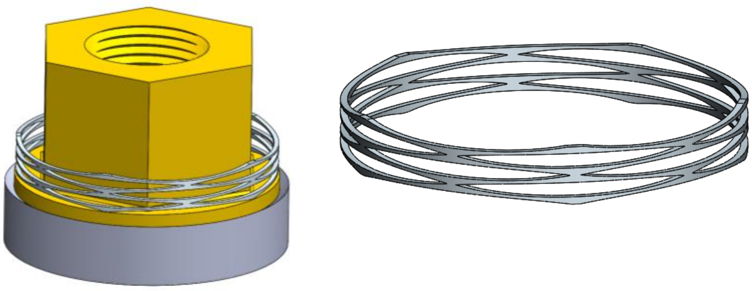


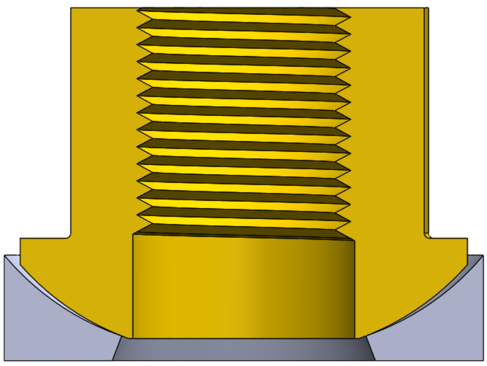
Figure 35: Spring placed on nut (lhs)

Figure 36: Spring (rhs)

6.2 Conical Studs

To line up the stud and the nut, i.e. utilizing the angular freedom, the tip of the studs are going to be machined down to a conical edge.

The washer must have dimensions that fit the surroundings. The angle in the inlet hole is meant to be a guiding property, so that the difference between the diameter of the bolt hole in the flange and the bolt hole in the nut has a smoother transition. The angle is set to be the same as the angle of the conical inlet of the bolt, which is 30º.



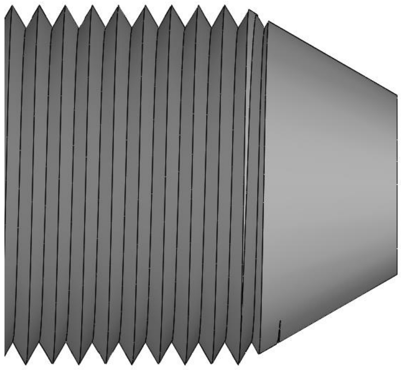


Figure 37: Washer angle

Figure 38: Conical stud

7.0 Hydraulic Tension Nuts

In the concept study it were decided that hydraulic nuts were best suited for our system, however there are several manufacturers that could supply us with these tools. During the start-up of our project, Freudenberg advised us to contact VASI, a hydraulic tool company situated in Oslo, as they have been a long time business partner with Vector. VASI is mainly a TenTec dealer and because of this, we saw it practical to use hydraulic tools provided by TenTec. In addition, TenTec has a good assortment of tools and solutions and they offer special design upon request if their commercial products is not suitable.

7.1 Load Collar Configurations

TenTecs Hydraulic Nuts comes in the following two configurations; top collar or bottom collar. Seeing as we will be fastening the hydraulic tooling onto the swivel ring, the bottom collar will not be suitable and we will therefore be utilizing a top collar hydraulic nut [9].

Figure 39: Bottom collar (lhs)

Figure 40: Top collar (rhs)

7.2 Tooling Capacities

The maximum capacities for each tooling given in the TenTec hydraulic nut datasheet shows that the tools specified for the current bolt diameter will not be able to give the required pre-tension. However, looking into the mechanics of how the tool works, as well as seeking advice from our resources at Freudenberg it is apparent that a simple re-design of the tools, so that they have two pressure faces instead of one, will double its capacity. This is a well-known technique and is applied to regular tension tools daily, known as multi-step tension tools. On the grounds of what is previously stated, we rule it viable to neglect these capacity issues and focus solely on the size of the tools. However if it should prove to be a problem, it is possible to choose a larger tooling, but with the same internal diameter. This will result in a diameter of at least 102mm, which is still within practical limits.

Specified in the Flange and bolt configuration document [6] we will be utilizing 1 ¾ inch bolts. The specific TenTec tooling for this bolt-size is therefore chosen for further customization.

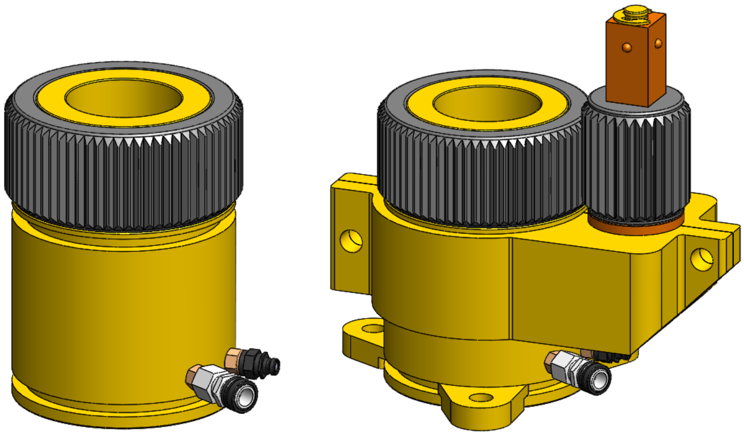


Figure 41: Customized hydraulic nut (lhs)

Figure 42: Load collar lock system (rhs)

As shown in the figure the hydraulic nuts are customized to accommodate for the second pressure surface. The height is increased, more specifically; doubled, as well as a relocation of the hydraulic inlets and outlets. In addition there are machined two grooves that encircle the tooling. These grooves will provide the necessary gripping surface for fixing the tools. It was suspected that these grooves could compromise the structural integrity of the tooling and it were therefore performed a FEM analysis with positive results, shown in the Test Report [10].

8.0 Load Collar Locking System

When all of the studs are screwed through the flanges and through the nut freedom system, the pressure is supplied to the hydraulic nuts. The hydraulic pressure will stretch the stud and the load collar on the hydraulic tool will need to be screwed down until it reaches its locking position. When screwed face to face with the tooling bridge, the system may be bled empty, as the load collar can maintain the forces. This motion needs to be automated as it is only performable after the bolt tensioning.

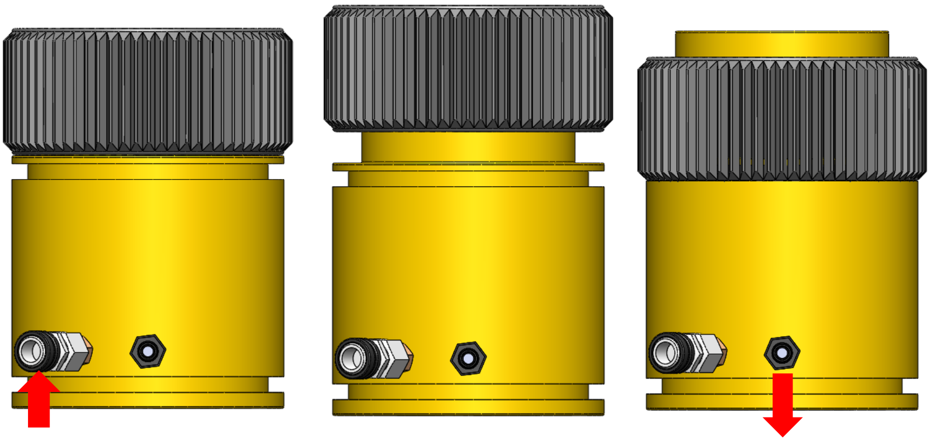


Figure 43: Hydraulic nut, starting position (lhs)

Figure 44: Hydraulic pressure is supplied and the system is stretched (middle)

Figure 45: Collar is turned down, the pressure is released and the system is locked

8.1 Individual Turning

Even though the stud material, the length of the stud, threads and pitch will be the same on each stud, and all of the hydraulic nuts will be given the same amount of hydraulic pressure, the studs may be stretched differently. This is due to internal defects and stresses in the stud material. When the stud will be pre-loaded up to 95% of yield, which is very high, the internal defects will give small differences in the stretch length. Therefore it have to be individual tightening on the load collar, also stated in the requirement specification document under requirement 2.11 [11].

8.2 Counter Gear Assembly

It was decided that the load collar would get machined gear teeth and that an opposing counter gear would be able to turn it. The counter gear will be operated by a hand held ROV tool that causes the turning motion.

One of the challenges of the design of the counter gear is to make it stationary, but still free to move in rotational direction. To solve this we made the counter gear as four parts. At first we made a stem. This will be fixed in the flange and not able to move or turn. Then we designed a seat that will sit on a shelf on the stem. This seat is free to move in the rotational direction, but also upwards in vertical direction. The gear will sit onto the seat where it will be glued with a type of Loctite. When the seat is turned around, the gear will follow this movement because of the squared profile. To hinder that the seat will fall out from its place if the system is turned upside down, a standard retaining washer is installed on the top of the stem. The counter gear are then locked in position, but free to rotate.

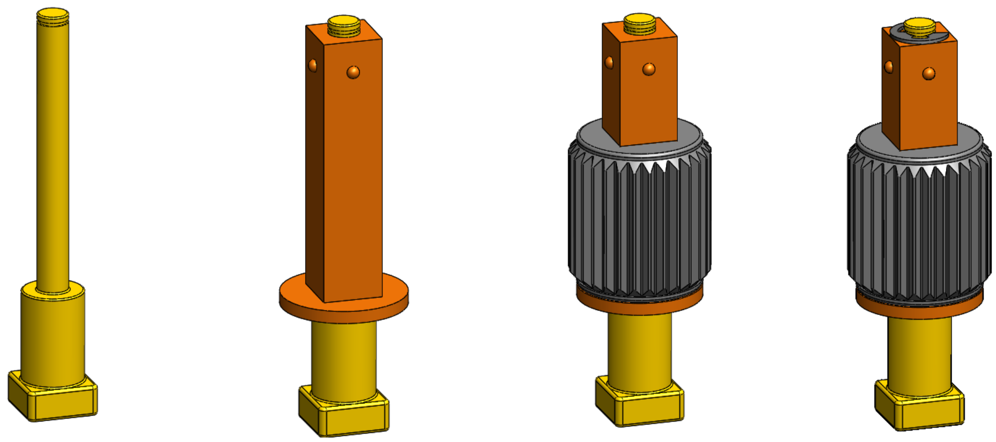


Figure 46: Stem (1. from the left)

Figure 47: Seat (2.)

Figure 48: Counter gear (3.)

Figure 49: Retaining washer (4.)

8.3 Counter Gear Retainment

The counter gear is retained by having a clamp around the hydraulic nut itself. The bottom of the stem will then be forced in a locked position in the clamp, as seen in the figure below.

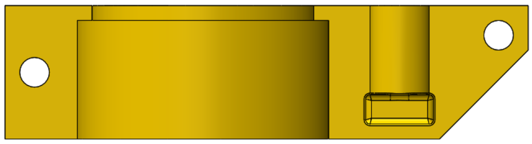
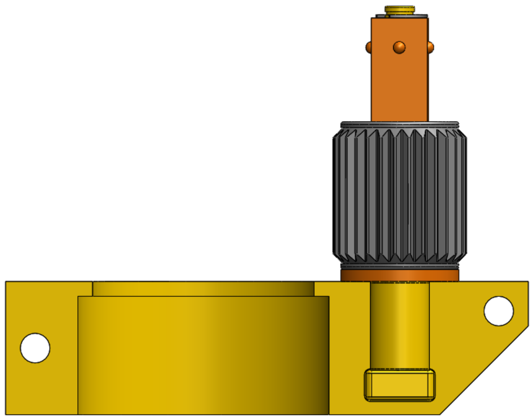



Figure 50: Counter gear clamp, section view (lhs)

Figure 51: Counter gear system, section view (rhs)

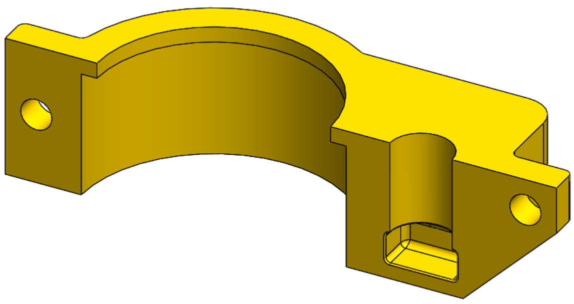
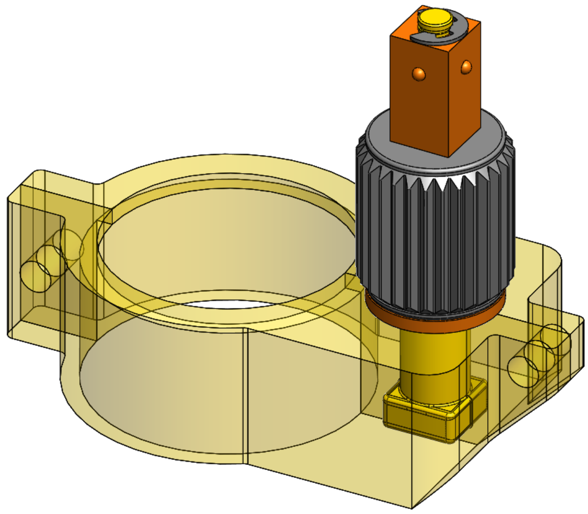



Figure 52: Counter gear clamp, isometric view (lhs)

Figure 53: Counter gear system, isometric view (rhs)

This clamp is made of two mirrored parts and will clamp around the hydraulic nut. Before the two parts will be boltet together, the stem will be put inside one of the clamps. The square root wil hinder the stem from rotating. There willl be a circular slit in the hydraulic nut where the circular tap on the clamp will sit. This tap together with the clamping force will hold the clamp in place.

8.4 ROV Tool

As mentioned the counter gear will be driven by a hand-held ROV tool. This tool is held by a standard ROV handle and attached is a square collar that can slide onto the squared part of the counter gear assembly.

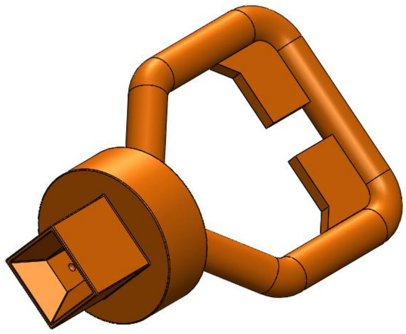


Figure 54: ROV handle

9.0 Flange Modifications

9.1 Possible Tooling and Bolt Configurations

The general idea is to keep the flange as compact as possible, but looking into the current tool sizes it is apparent that we will need to increase the diameter of the flange. However, it might be viable to decrease the number of bolts and instead increase their thickness. In addition reducing the number of bolts will reduce the number of operations that our system needs to perform, which is a great advantage in subsea operations.

9.2 Number of Bolts

Freudenberg's SPO compact flange is scaled up in size by increasing its number of bolts by increments of four [8]. This means that we are somewhat limited in how many possible configurations we can utilize. Increasing the number of bolts is inexpedient and decreasing the number of bolts further than 12 bolts could result in an inadequate deformation distribution. However, it is possible to compensate for this by increasing the flange stiffness. This is done by either increasing the flange bevel angle or increasing its thickness. When consulting with Freudenberg we were told that this would most likely have to be either proved or disproved in a special case study. Because of this it were decided that possible inadequate changes in the deformation distribution is negligible, seeing as there are several possibilities to account for it.

This topic is further discussed in the Bolt and Tooling Configuration document [6], where it is stated that we will proceed with a reduced number of bolts, but with an increased thickness.

9.3 Bolt Reduction

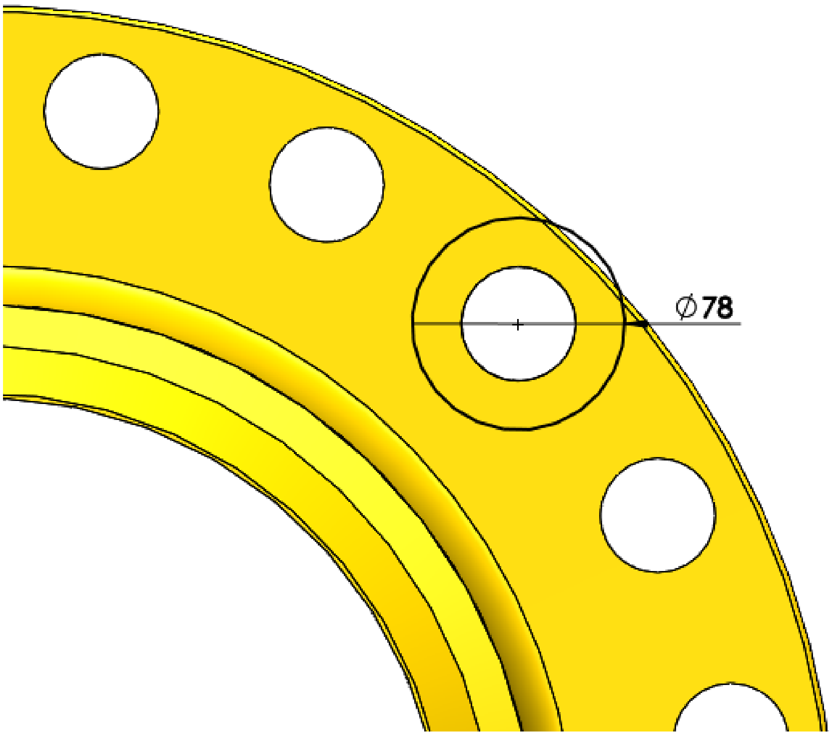


Figure 55: Original outer diameter

According to the TenTec Hydraulic Nut Data Sheet [9] the appropriate tool for the original bolt size has an outer diameter of 78mm.

As shown in the picture, the hydraulic nut will not be able to have all of its face coincident with the flange face so the outer diameter will need to be increased until the tooling is completely covered. However the BCD must first be increased, so that the studs doesn't intersect with the outer edge of the swivel hub, located on the opposing flange (not pictured).

Further discussed in the Bolt and Tooling Configuration document [6] the number of studs have been decreased to sixteen. Accordingly the nominal diameter of the bolt have increased to 1 ¾, which again leads to a needed bolt hole diameter of 49mm [8].

The new BCD is calculated by adding the hub outer diameter, the bolt-hole diameter and a 2mm clearance.

$$BCD_1 = D_0 + D_H + 2mm$$

$$BCD_1 = 512.7 + 49 + 2 = 563.7mm$$

The outer diameter of the flange will have to be calculated for it to accommodate the width of the tools. According to the TenTec Data Sheet [9], the appropriate tool for the current bolt size has an outer diameter of 86mm. The new outer diameter is then calculated as follows:

$$Dw2_1 = BCD_1 + 2 \cdot r_t + 2 \cdot r_{fillet}$$

$$Dw2_1 = 563.7mm + 2 \cdot 43mm + 2 \cdot 2mm = 653.7mm$$

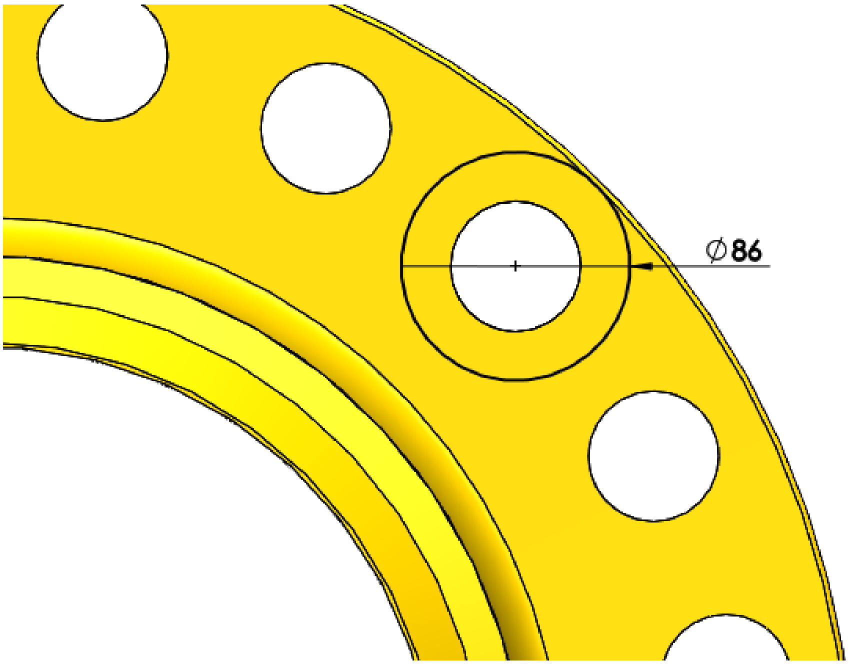


Figure 56: Revised outer diameter

Seeing as the bolt holes, BCD and outer diameter are increased, the flange inner recess diameter must also be changed. The purpose of the recess is merely to prevent surface roughness from the bolt-hole production affecting the functionality of the flange so the diameters can be chosen based on esthetics as it serve no structural function.

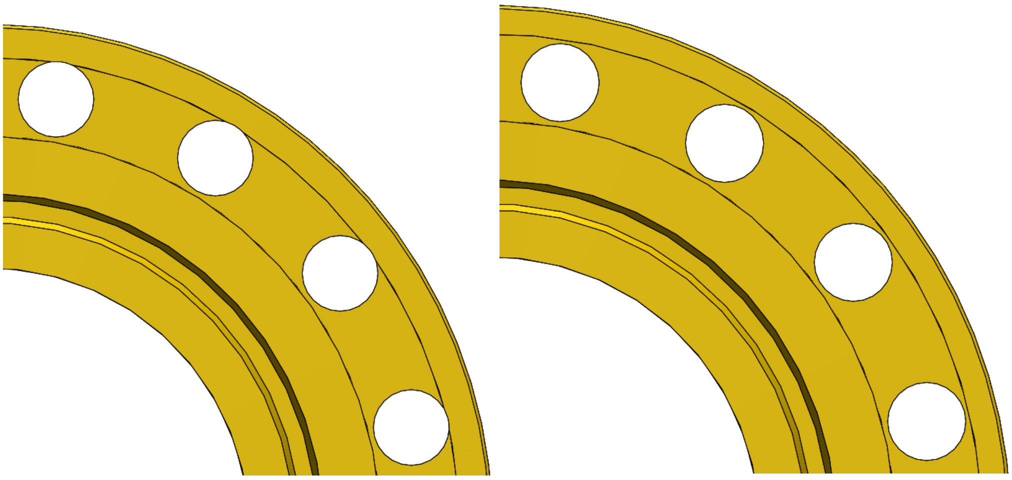
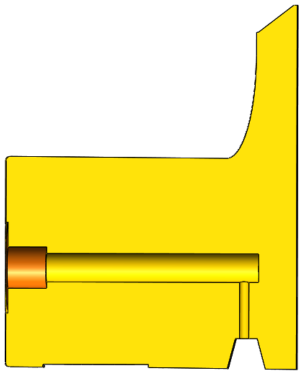


Figure 57: Old recess (lhs)

Figure 58: New recess (rhs)

10.0 Test Port

According to requirement 1.9 [11] the system must be able to verify that an acceptable seal have occurred once the flanges have been energized. This will be done by machining a test port into the flange making it possible to pressurize the groove in the seal ring. This way, it is possible to verify its seal after the pre-loading. In the inlet of the test-port there will be inserted an Autoclave fitting, after recommendation from our advisor at Freudenberg, as they have good experiences with this particular fitting.



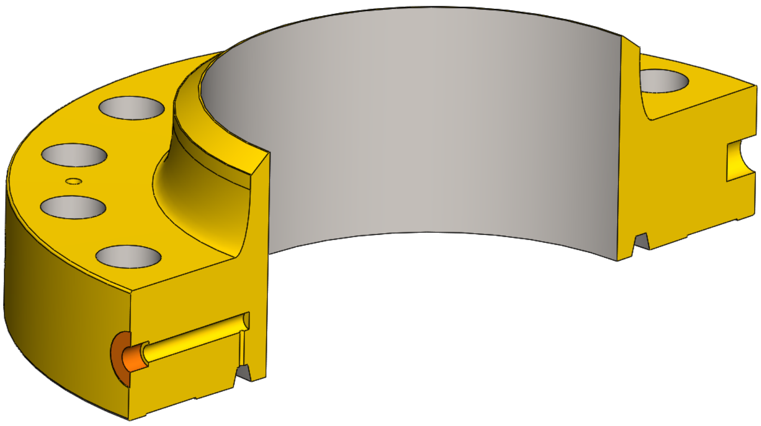


Figure 59: Test port, section view (lhs)

Figure 60: Test port, isometric view (rhs)

11.0 Hydraulics

11.1 Control Panel

The hydraulic tensioning system will be operated by a ROV-panel located on the guiding frame of the crude alignment system. This panel will include a hot stab for supplying hydraulic power, a valve for locking the nuts in its pressurized state, a barometer displaying the pressure currently working on the tools and a grabber bar for the ROV to grab.

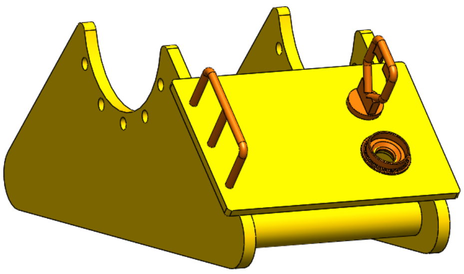


Figure 61: ROV control panel

11.2 Pressure Booster

As the ROV is not able to provide enough hydraulic pressure to operate the tension nuts on its own, it will bring down a pressure booster making it possible.

11.3 Hydraulic Nuts

The hydraulic nuts will be connected in a single series, starting and ending with the ROV panel. They will need a working pressure of 2275 bar [9], for proper operation, which will be provided by the aforementioned pressure booster.

The hydraulic nuts will be activated from the ROV-control panel. The ROV will grab hold of the grabber bar and connect the hydraulic power into a hot-stab port located on the panel. The nuts will be pressurized by opening a valve and kept in its pressurized state by closing the valve after adequate pre-load is achieved. Once the load collars have been turned, the ROV can return to the panel and release the valve, de-pressurizing the tools.

11.4 Stud Turning Tool

The stud runner tooling are able to operate on the working pressure supplied by the ROV and will therefore not be needing an external pressure increase. This is because the STT operate with low pressure hydraulics. The hydraulic is normally connected with stab and receptacle with a pressure side and a return side for the hydraulic motor to be able to rotate. The tools will be connected in series with one input and one output.

12.0 Visual Indicators

12.1 Pipe Alignment

According to requirement 2.7 [11], there could be a visual indicator for verifying that the flanges are properly aligned. This will be achieved by having black lines painted on the guide collar and guide pins, so that they form a collinear line when the flanges are aligned.

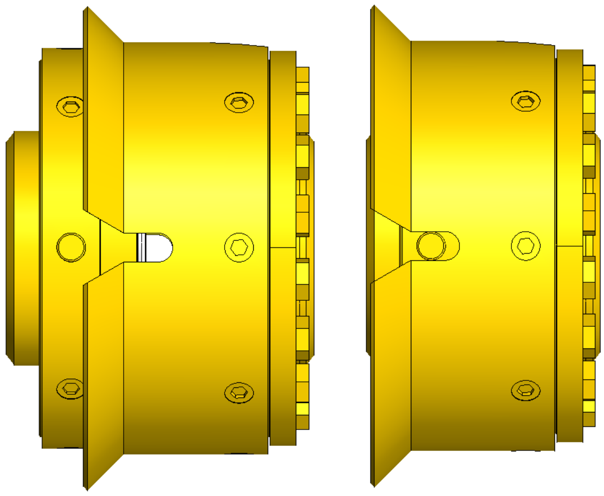


Figure 62: Flange connection pre-alignment (lhs)

Figure 63: Flange connection, aligned (rhs)

12.2 Pre-load

According to requirement 2.8 [11], there could be a visual indicator for verifying that adequate pre-load have been achieved.

A Hydraulic nut works much in the same way as a hydraulic tensioning tool, but will apply a more accurate load seeing as the nut is applied flush with the free length of the stud. This means that when the pressure is released there is no contraction of the stud above the nut as all the tension is acting below it. This means that more or less all of the forces applied will be kept as a pre-load in the stud and nut, as nothing is dispersed when the system is de-pressurized. Seeing as there is a well-defined linear relationship between the axial forces, the pressure and the pressure area, a barometer will provide the necessary information for verifying adequate pre-load. The barometer will located on a ROV-panel, visible for the operator to see as he performs the pre-load operation.

13.0 ROV Interfaces

13.1 Grabbers

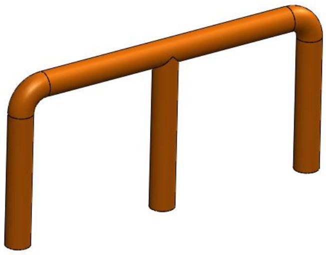
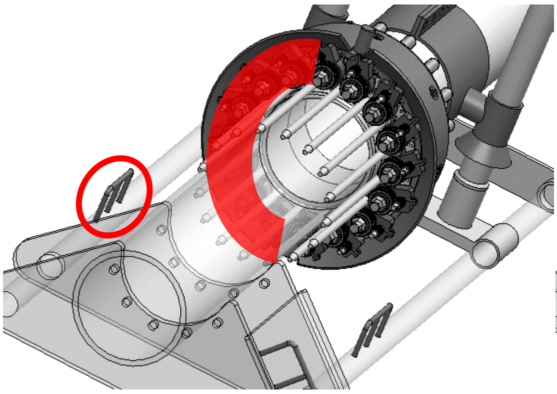


Figure 64: ROV handle

According to API Recommended Practice 17H – Remotely Operated Tools and Interfaces on Subsea Production Systems there are two different types of grabber-bars that can be used. The handles incorporated are according to said standard.

13.1.1 Load Collars

For the ROV to be able to operate and access the load collar systems there are placed grabber handles on both sides of the crude system.



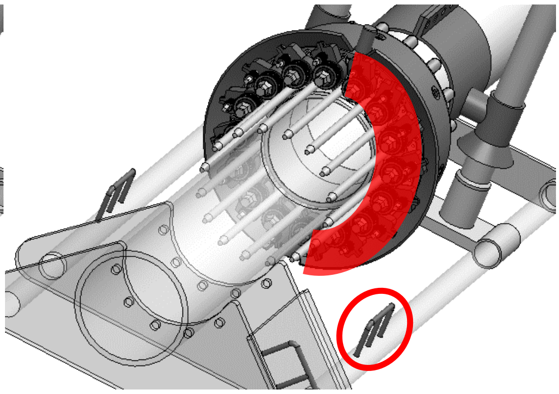


Figure 65: ROV grabs the left handle and turn down half of the load collar

Figure 66: ROV grabs the other handle and turn down the other half.

13.1.2 ROV Panel

This is described and illustrated in section 9.1

14.0 Material

One of the main steps in designing a physical concept is material selection. The main goal in material selection is to minimize cost while meeting product performance requirements.

14.1 Nut Retainment System

14.1.1 Bolt Material

According to the project description, the bolt material will be ASTM A320 L7. This is a ferritic steel material for low-temperature services. The material has been subjected to a heat treatment, where it has been quenched and tempered with a minimum tempering temperature of 593^{o}C. The minimum tensile strength is 860Mpa and minimum yield strength is 725Mpa. [12]

14.1.2 Nut Material

In accordance with the ASTM standard, the bolts of grade L7 shall be equipped with ferritic alloy nuts conforming to Grade 4 or Grade 7 of specification A194/A194M or a grade of steel similar to the nuts. [13] Grade 7 nuts have a higher availability than Grade 4, and it is therefore reasonable to choose the A194 Grade 7 nut. [14]

14.1.3 Washer Material

In accordance to the ASTM, standard washer for use with ferritic steel bolting shall conform to specification F436. [15]

Made from heat treated, hardened steel, F436 washers are capable of withstanding a broad range of environments including low temperature service.

14.1.4 Belt and Belt Screw Material

Based on recommended standard [17], the belt will be made of ISO 10423.

The screw that will fasten the belt to the flange will be of the ASTM A320 L7 material as well.

14.1.5 Spring Material

The spring material will be 17-7PH Stainless steel [17]

14.2 Stud Turning Tool

14.2.1 Material Stud Turning Tool

The hydraulic tooling is nothing FO&GT will design and make by themselves. The tooling is items to order from hydraulic tooling companies. The material for the SST is therefore not given.

14.2 2 Material Stud Turning Tool Holder

There are no strict requirements for the material selection of material for this STTH. Since the time the components will be surrounded by seawater is relatively short, the water will not have a significant effect on the material. However, to prevent rust and corrosion there have to be some means to prevent that. A simple solution to this is utilizing a stainless material, which is what we've done.

The chosen material for the SST belt is therefore AISI 321 Annealed Stainless Steel.

14.3 Seal Ring

14.3.1 Seal Ring

The material of the seal ring is alloy 625 with silver coating. Alloy 625 is used as both corrosion resistant and heat resistant material. The alloy has outstanding strength and toughness at temperatures ranging from cryogenic to elevated temperatures in the range of 2000°F (1 093 °C). Alloy 625 also has exceptional fatigue resistance. The silver coating pack out microscopic irregularities between the seal and the flange.

14.3.1 Rubber Ring

Natural rubber is used for the rubber ring. NRX is a rubber type specially used for subsea applications, which is why we have chosen this material for our application.

14.4 Hydraulic Tool

14.4.1 Gear Lock System

The gear lock system will need to have corrosion resistance as it will be located in a salt water environment throughout its lifespan. Because of this, a stainless steel material have been chosen. More specifically; AISI 321 Annealed Stainless Steel will be used.

14.4.2 Hydraulic Fixings

See 14.4.1

15.0 References

[1] http://www.vectortg.com/Media/DM5-HX-sealring-rev4-VECTOR-3890.pdf

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[8] DM10 SPO CF CL900 VECTOR-3659r2.pdf

[9] TenTec Hydraulic Nut Data Sheet TDR11 A4.pdf

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[14] http://www.portlandbolt.com/technical/faqs/astm-a320-grade-l7-nuts-and-washers/

[15] Annual Book of ASTM Standards, Section One: Iron and Steel Products: ISBN: 978-1-6220-4275-3, ISSN 0192-2998, page 199

[16] http://www.standard.no/pagefiles/1174/m-dp-001r1.pdf

[17]http://www.leespring.com/uk_wave_springs_spec.asp?springType=WS&forWhat=Search

[18] Installation and Assembly Procedure; ROV operated SPO compact flange, Bachelor thesis 2015.

Calculation Document

ROV operated SPO compact flange for subsea assembly in deep water

Document No.:	Version No.:	Date:	Document responsible:	Group:	Status:
7.0	1.0	15.05.2015	Laila E. Andersland	3	Completed

Group members: Mathilde Schinnes, Laila Andersland, Jørgen Borgersen, Marit Skjørestad

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1.0 Document

1.1 Document History

Table 1: Document history

Revision	Description of change	Date
0.1	Document created	01.04.15
0.2	Filled in MathCad calculations files	15.05.15
1.0	**Final release**	**15.05.15**

1.2 Abbreviations

Table 2: Abbreviations

Abbreviation	Description
ASME	American Society for Mechanical Engineers
STTH	Stud Turning Tool Holder

2.0 Introduction

This document is a collection of the calculations used during the development process. The project group have used the program Mathcad [1], which is a mathematical software that allows users to define, analyze and calculate in the same program. This document is divided into the different subsystems, with related calculations made in the process.

3.0 Compact Flange

NORSOK STANDARD L-005 2.0 May 2006

The flange capacity can be calculated using the equations below. The strength terms in the warping moment limit load capacity is as follows: the first term is the flange ring capacity, second term is the support effect of the shear force from the pipe to the flange ring and the last term is the neck wall thickness warping resistance.

The reduction factors cM and cS take into account the reduction of the bending-carrying capacity and the shear force capacity of the neck cross section as a result of existing neck wall membrane stresses based on von Mises criterion by the factor δQ. The capacity equation is as given in a former revision of EN 1591-1, with a slight modification. The correction factor dδR accounting for axial tension force has been neglected and cM has been simplified. Bolt interaction effects have been added. Comparison with elastic plastic finite element analysis has shown a good fit with the proposed simplified equations
The capacity method complies with the requirements of ASME VIII Div.2, Appendix 4 and Appendix 6 [3].

3.1 Specifications

$A := 406.4\ mm$	pipe/neck outer diameter
$B := 386.4\ mm$	Bore diameter
$BCD := 563.7\ mm$	Bolt circle diameter
$Hw3 := 104\ mm$	Flange ring thickness
$Dw2 := 617\ mm$	Flange outer recess diameter
$Dw3 := 653.7\ mm$	Flange outer diameter
$L := 49\ mm$	Bolt hole diameter
$f_y := 450\ MPa$	Flange material yield strength at temperature
$t := 20\ mm$	Pipe/neck wall thickness
$p := 15.52\ MPa$	Internal pressure in N/mm^2

*All values are gathered from a 3D model provided by Freudenberg

3.2 Capacity

The axial load capacity of the flange can be calculated to be according to equation (D.1) for the flange only and equation (D.2) for flange and bolt interaction (bolt prying).

$$F_f := \frac{W_F}{e} \tag{D.1}$$

$$F_{fp} := \frac{W_F}{e_p} + F_{cB} \cdot \frac{e_B}{e_p} \tag{D.2}$$

The warping moment capacity of the flange including support from the neck is given by:

$$W_F := \frac{\pi}{4} \cdot f_y \cdot \left[2 \cdot b \cdot Hw3^2 + 2.2 \cdot c_s \cdot Hw3 \cdot t \cdot \sqrt{d_p \cdot t} + c_M \cdot d_p \cdot t^2 \right] \tag{D.3}$$

Where,

$$\delta_Q := \frac{p \cdot d_p}{2 \cdot f_y \cdot t} \tag{D.4}$$

$$c_M := \sqrt{1 - 0.75 \cdot \delta_Q} \tag{D.5}$$

$$c_S := \sqrt{c_M \cdot (0.5 - 0.4 \cdot \delta_Q)} \tag{D.6}$$

$$b := \frac{(Dw3 - B)}{2} - L \tag{D.7}$$

$$e_B := \left[\frac{(Dw3 + Dw2)}{2} - BCD \right] \cdot 0.5 \tag{D.8}$$

$$e_p := \left[\frac{(Dw3 + Dw2)}{2} - d_p \right] \cdot 0.5 \tag{D.9}$$

3.3 Loads

$$F_{End} := \frac{\pi \cdot DG4^2}{4} \cdot p \tag{D.10}$$

$$F_R := F_A + \frac{4}{BCD} \cdot M_A \tag{D.11}$$

$$\psi := \frac{F_{End} + F_R}{min\left(F_{cB}, F_{fp}\right)} \tag{D.12}$$

$$d_p := \frac{(A+B)}{2} \qquad d_p = 0.396\ m$$

$$b := \frac{(Dw3 - B)}{2} - L \qquad b = 84.65\ mm$$

$$\delta_Q := \frac{p \cdot d_p}{2 \cdot f_y \cdot t} \qquad \delta_Q = 0.342$$

$$c_M := \sqrt{1 - 0.75 \cdot \delta_Q} \qquad c_M = 0.862$$

$$c_s := \sqrt{c_M \cdot \left(0.5 \cdot 0.4 \cdot \delta_Q\right)} \qquad c_s = 0.243$$

$$W_F := \frac{\pi}{4} \cdot f_y \cdot \left[2 \cdot b \cdot Hw3^2 + 2.2 \cdot c_s \cdot Hw3 \cdot t \cdot \sqrt{d_p \cdot t} + c_M \cdot d_p \cdot t^2\right]$$

$$W_F = [730.47]\ kN \cdot m$$

$$e := BCD - d_p \qquad e = 167.3\ mm$$

$$F_f := \frac{W_F}{e} \qquad F_f = [4.366]\ MN$$

$$e_p := \left[\frac{(Dw3 + Dw2)}{2} - d_p\right] \cdot 0.5 \qquad e_p = [0.119]\ m$$

$$A_r := 1132.675\ mm^2 \qquad n := 16 \qquad \sigma_{yield} := 723.95\ MPa$$

$$F_{cB} := A_r \cdot n \cdot \sigma_{yield} \qquad F_{cB} = \left(1.312 \cdot 10^7\right) N$$

$$F_{fp} := \frac{W_F}{e_p} + F_{cB} \cdot \frac{e_B}{e_p}$$

$$F_{fp} = \left(1.005 \cdot 10^7\right) N$$

$$DG4 := 434.70\ mm$$

$$F_{End} := \frac{\pi \cdot DG4^2}{4} \cdot p \qquad F_{End} = \left(2.303 \cdot 10^6\right) N$$

$$F_A := 0\ N \qquad M_A := 0\ N \cdot m$$

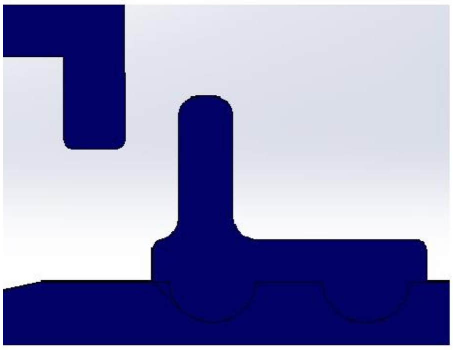
$$F_R := F_A + \frac{4}{BCD} \cdot M_A \qquad F_R = 0\ N$$

$$\psi := \frac{F_{End} + F_R}{min\left(F_{cB}, F_{fp}\right)} \qquad \psi = 0.229$$

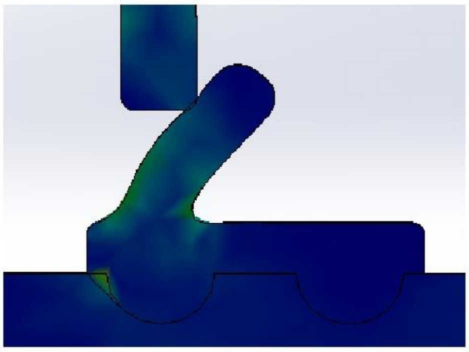
$F_a :=$	Applied axial load
$F_{cB} :=$	Bolt totalt plastic capacity (root area x number of bolts x yield strength)
$F_f :=$	Flange axial load capacity without effect of bolt prying
$F_{fp} :=$	Flange axial load capacity including the effect of bolt prying
$F_{end} :=$	End cap force calculated to seal ring diameter
$F_R :=$	Resulting force from external tension force Fa and external bending moment M
$DG4 :=$	Seal ring seal diameter
$M_A :=$	Applied bending moment
$d_p = 0.396\ m$	Average diameter of pipe/neck = (A+B)/2
$e :=$	Radial distance between BCD and dp
$e_B :=$	Radial distance from flange outer rim to bolt circle diameter
$e_p :=$	Radial distance from flange outer rim to pipe mean diameter
$\psi :=$	Flange utilisation ratio

4.0 Rubber Ring

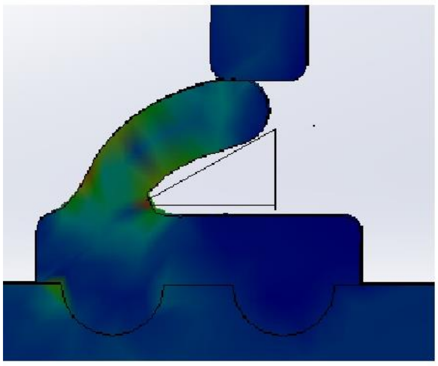
4.1 Rubber Deflection



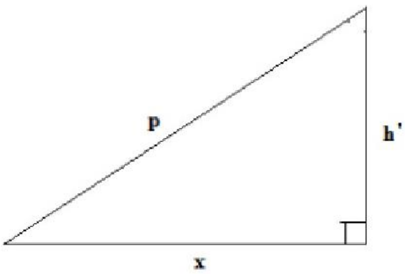
1. The rubber ring is faceing the flange



2. The ring is deflecting, and sliding under the tip



3. The rubber is almost through the passage



4. We need to calculate the deflexion x

h=opening metal tip to rubber $h := 3.90\ mm$

t=thickness of rubber $t := 2\ mm$

$h' := h - t$ $h' = 1.9\ mm$

p=height of rubber tip $p := 6\ mm$

From Pytagoras: $$x := \sqrt{p^2 - h'^2} \quad (1)$$

x=deflextion $x = 5.691\ mm$

The length the rubber tip need to be deflexted to fit in the flange is 5,691 mm

4.2 Shear Mounting

Knowing the dimensions of the rubber tip, and the size of the deflection it will undergo, we can calculate the shear stiffness, shearing force, shear strain and shear stress. All the equations are collected from engineering design with natural rubber, J.E Duncan [4].

l=length of rubber $l := 6\ mm$
t=thickness of rubber $t := 2\ mm$
x=shear deflextion $x := 5.691\ mm$

a=acceleration of gravity $a := 9.81\ \frac{m}{s^2}$

G=Shear modulus (From table 3) $G := 1.73\ \frac{N}{mm^2}$ Bruker hardness 70, etter Metflex NRX

A=cross sectional area $A := l \cdot t$

$A = 12\ mm^2$

K=Shear stiffness $K := \frac{G \cdot A}{l}$ (2)

$K = 3.46\ \frac{N}{mm}$

F=shearing force $F := K \cdot x$ (3)

$F = 19.691\ N$

m=weight $m := \frac{F}{a}$ (4)

$m = 2.007\ kg$

e=Shear strain $e := \frac{x}{l}$ (5)

$e = 0.949$

q=Shear stress $q := \frac{F}{A}$ (6)

$q = 1.641\ \frac{N}{mm^2}$

4.3 Factor of Safety

UTS=ultimate tensile strength $\qquad UTS := 20 \frac{N}{mm^2}$

SF=factor of safety $\qquad SF := 3$

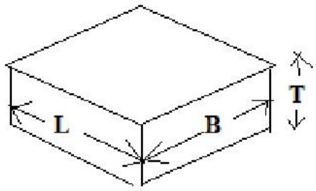
σ =safe working stress $\qquad \sigma := \frac{UTS}{SF} \qquad (7)$

$$\sigma = 6.667 \frac{N}{mm^2}$$

When calculating with a safety factor of 3, we can see that safe working stress is a lot higher that than the actual shear stress the material is subjected to during deflection. This way we can conclude that the material will not break during installation.

4.4 Tension of the Ring

We can also make some calculations on the whole rubber ring. Then the rubber tip is not taken into consideration. The rubber ring will not experience compression, but tension as it will be stretched to fit over the seal ring.



T=thickness of ring $T := 2\ mm$

L= With of the ring $L := 9.50\ mm$

B=length of the ring $B := 432\ mm$

E=Young's modulus, from table 3 $E := 7.35\ \frac{N}{mm^2}$

S=shape factor $S := \frac{L \cdot B}{2 \cdot T \cdot (L+B)}$ (8)

$S = 2.324$

A=cross-sectional area $A := L \cdot T$

$A = 19\ mm^2$

F=tensile force

Tensile forces satisfying the following are insufficient to cause internal flaws to be formed:

$F < \frac{1}{4} \cdot A \cdot E$ for S < 2 (9)

$F := \frac{1}{2} \cdot A \cdot E \cdot \left(1 - \frac{1}{S}\right)$ for S > 2 (10)

$F = 39.778\ N$ If F<39,778 N there is no problem causing internal flaws.

5.0 Nut Retainment System

5.1 Bolt Calculation

5.1.1 1 ¾" 8UN Specifications

$d := 44.45\ mm$	Basic major diameter (large diameter)
$d_m := 42.39\ mm$	Basic pitch diameter (mean diameter)
$d_s := 40.67\ mm$	Minor diameter; external thread (small diameter)
$A := 1277.4\ mm^2$	Minor diameter area
$A_s := 1341.9\ mm^2$	Tensile stress area
$P := 3.175\ mm$	Pitch
$Y := 725\ \dfrac{N}{mm^2}$	Yield Strength

5.1.2 Preload

$A_{TS} := 1341.9\ mm^2$ Tensile stress area

$$Y_{s75} := Y \cdot 0.75 = 543.75\ \frac{N}{mm^2} \quad \text{75\% of yield strength} \tag{11}$$

$$Y_{s95} := Y \cdot 0.95 = 688.75\ \frac{N}{mm^2} \quad \text{95\% of yield strenght} \tag{12}$$

$$A_{TS} \cdot Y_{s75} = 729.658\ kN \tag{13}$$

$$A_{TS} \cdot Y_{s95} = 924.234\ kN \tag{14}$$

5.1.3 Torque

$$F := A_{TS} \cdot Y_{s95} = \left(9.242 \cdot 10^{5}\right) \, N \quad \text{Axial force} \tag{15}$$

$$r_m := \frac{d_m}{2} = 0.021 \, m \qquad \text{Mean radius of thread} \tag{16}$$

$\varepsilon_1 :=$ Angel of friction, $\varphi :=$ Pitch angle of thread

$$\mu := 0.2 \;\; \text{Coefficient of friction,} \;\; \alpha := \frac{60 \, °}{2} = 30 \;\; \text{Profile angle of thread} \tag{17}$$

$$tan\left(\varepsilon_1\right) := \frac{\mu}{\cos(\alpha)} = 0.231 \;\; \textbf{(18)} \qquad \varepsilon_1 := \operatorname{atan}\left(\frac{\mu}{\cos(\alpha)}\right) = 0.227 \;\; \textbf{(19)}$$

$$\tan(\varphi) := \frac{P}{\pi \cdot d_m} = 0.024 \;\; \textbf{(19)} \qquad \varphi := \operatorname{atan}\left(\frac{P}{\pi \cdot d_m}\right) = 0.024 \;\; \textbf{(20)}$$

The moment of force/torque required to tighten a threaded screw.

$$M_v := F \cdot r_m \cdot \tan\left(\varepsilon_1 + \varphi\right) = 467.031 \, N \cdot m \tag{21}$$

5.1.4 Bolt Length

The length of the bolt should be designed so that we have minimum three threads more than the width of the entire system when assembled.

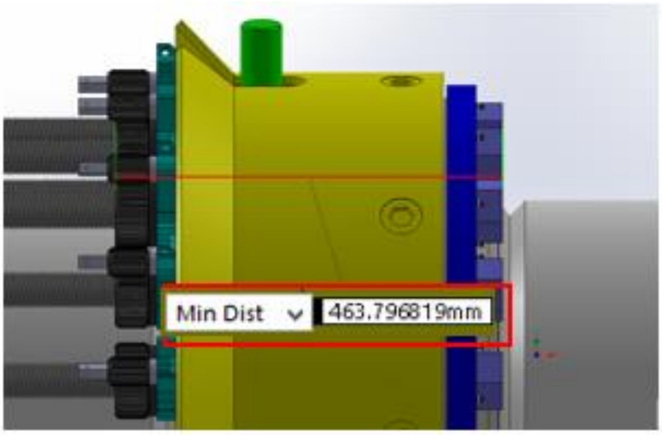


Figure 1: Bolt length

This width is, as shown in the illustration, approximately 464mm. The pitch of the bolt is 3.175mm according to the previous chapter. The length of three threads is then 9.525mm. On both sides gives 19.05mm. The bolt also has an unthreaded conical part.

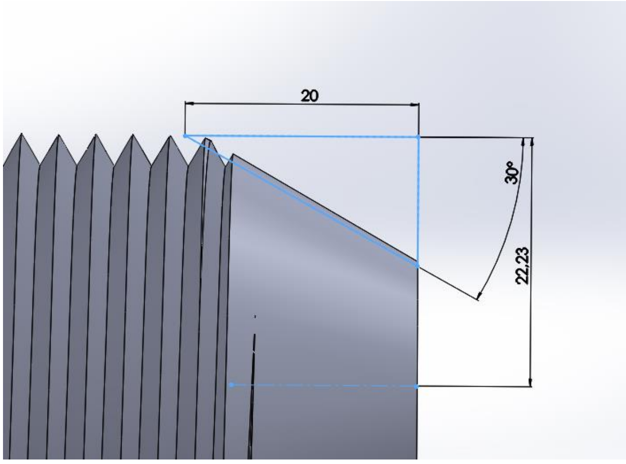


Figure 2: Conical bolts

As shown in the illustration above, the length of this conical part is 20mm. The result is a minimum length of 503mm.

5.2 Stud and Bolt Hole Difference

A simple calculation is done to approximate the maximum hole diameter, when the angle of the flanges is known. As shown in calculation 24, we can see that calculated size of the bolt will be 44,6mm.

$\alpha := 1.2\ °$

$h := 105\ mm$

$A := 90\ ° - \alpha = 88.8\ °$

$$b := \frac{h}{\sin(A)} = 105.023\ mm \qquad \textbf{(22)}$$

$$\Delta x := \cos(A) \cdot b = 2.199\ mm \qquad \textbf{(23)}$$

$2\ \Delta x = 4.399\ mm$

$D_H := 49\ mm$

$$D_{BM} := D_H - 2\ \Delta x = 44.601\ mm \qquad \textbf{(24)}$$

5.3 Maximum Stud Angle

$a := 102.3\ mm$ The height of the flange

$\alpha := 1.2\ deg$ The angle between the flanges ($2 \cdot 0.6$ deg).

$b := \tan(\alpha) \cdot a = 2.143\ mm$ The differens created by the angle **(25)**

$z := 4.55\ mm$ The maximum diffrense on both sides of the stud

$$\beta := \mathrm{atan}\left(\frac{z}{2 \cdot a}\right) = 1.274\ deg \qquad \textbf{(26)}$$

6.0 Stud Turning System

6.1 Ocean Current

This chapter is related to test 1.5 "The project group will carry out a FEM analysis that will simulate ocean current up to 0.6 m/s". To not make the calculations heavy and time-consuming some simplifications will be done consider the effected from the ocean current.

Flow towards fixed surfaces

ρ water = Density of water	$\rho_{water} := 1000 \ \frac{kg}{m^3}$
U = Ocean current	$U := 0.6 \ \frac{m}{s}$
S = Cross section area of the ocean current	
Mf = Mass flow rate	$Mf := \rho_{water} \cdot U \cdot S$
$\hat{\imath}$ = Vector	$\hat{\imath} := 1$
I = Momentum	$I := Mf \cdot U \cdot \hat{\imath}$
P = Pressure forces	$P := I$
F = Force	$F := P$

$h_{STTH} := 650\ mm$

$b_{STTH} := 340\ mm$

$S_{STTH} := h_{STTH} \cdot b_{STTH} = 0.221\ m^2$

$$Mf_{STTH} := \rho_{water} \cdot U \cdot S_{STTH} \cdot \hat{\imath} = 132.6\ \frac{kg}{s} \quad (27)$$

$$F := Mf_{STTH} \cdot U \cdot \hat{\imath} = 79.56\ \frac{kg \cdot m}{s^2} \quad (28)$$

The force acting on the surfaces of the STTH with ocean current of $0.6\ m/s^2$ is $F = 79.56\ N$

7.0 References

[1] http://www.ptc.com/product/mathcad

[2] Dahlvig G. Christensen S. Strømsnes G. (1991) 2.utgave, *Konstruksjonselementer,* Yrkesopplæring ans.

[3] ASME VIII Div.2, Appendix 4 and Appendix 6

[4] Engineering design with natural rubber. J.E Duncan

Test Plan

ROV operated SPO compact flange for subsea assembly in deep water

Document No.:	Version No.:	Date:	Document responsible:	Group:	Status:
8.0	1.0	15.05.2015	Laila E. Andersland	3	Completed

Group members: Mathilde Schinnes, Laila Andersland, Jørgen Borgersen, Marit Skjørestad

Table of Contents

List of Tables

1.0 Document

1.1 Document History

Table 1: Document history

Revision	Description of change	Date
0.1	Document created	18.03.15
0.2	Redefined and added subsystems	11.05.15
0.3	Corrected spelling errors	15.05.15
1.0	**Final release**	**15.05.15**

1.2 Abbreviations

Table 2: Abbreviations

Abbreviation	Description
FO&GT	Freudenberg Oil & Gas Technologies
HBV	Høgskolen i Buskerud og Vestfold
J.B.B	Jørgen B. Borgersen
L.E.A	Laila E. Andersland
M.Sch	Mathilde Schinnes
M.SKj	Marit Skjørestad
SW	Solid Works
FEM	Finite Element Method

2.0 Scope

This document is going to give a detailed description of the systematic approach to test the system. The content of this document is closely related to the Test Specification [2], and the Requirement Specification [3], and it is recommended to have these documents available when reading this document.

As stated in the Test Specification, we will use three fundamental methods for verifying the requirements: inspection, analysis and demonstration. All the result of the tests will be documented in a test report. The inspection and demonstration will be fully described in the test report. The FEM analyses will be assessed in the test report, with a more detailed description in a FEM analysis report.

The goal is to complete all the tests specified in the Test Specification Document, and to meet all of the specified requirements.

2.1 Assumptions and Constraints

2.1.1 FEM-tests

The group's "end product" will be a 3D model made in SW. The tests made on the 3D model will be the best way to demonstrate the real setting of the flange connection.

2.1.2 Inspection of FO&GT

Some of the tests depend on FO&GT's expertise and will be qualified as approved if FO&GT approve.

2.1.3 3D Print

The 3D print of the system will only work as a help to visualize the concept, it is however not possible to test the functionality on these 3D-prints.

2.1.4 Prototype

The project group decided early in the process that a prototype of the system would not be possible to create.

2.2 Risks

We have to consider several risks concerning testing, and whether the risk might threaten the ability to complete the project.

2.2.1 Time

One thing we have tried to be aware of is that FEM tests can be very time consuming, some times more than expected.

2.2.2 SW Error

Another threat is that the computers we use to conduct the FEM test might malfunction. This can threaten our deadline and shorten the quantity and quality of the work we will deliver at the end of the project. To cope with this the project group will have to frequently save and upload to shared external storage.

2.2.3 Quality

It is also important to realize that, although considered carefully, the assumptions of the system might not be an adequate representation of reality. This is why we have implemented a quality assurance, where it is considered if the requirement is fulfilled in a proper way, and if the related test is fulfilled in a proper way.

3.0 Resource Requirements

3.1 Staff Requirement

Table 3: Staff Requirement

Resource	Skills Required	Responsibilities
Mathilde Schinnes	Fundamental SW and FEM skills	Hydraulic Tension System, Stud Turning System
Laila Andersland	Fundamental SW and FEM skills	Nut Retainment System
Jørgen Borgersen	Fundamental SW and FEM skills	Hydraulic Tension System, Flange System
Marit Skjørestad	Fundamental SW and FEM skills	Seal Retainment System
FO&GT personnel	Advanced SW and FEM skills	Acquire expertise advice
HBV personnel	Multidiscipline staff and guidance experience	Acquire expertise advice and guidance

3.2 Hardware and Software Requirement

Table 4: Hardware & Software requirement

Part name	Owner	Status
Computer	Jørgen Borgersen	Medium/good
Laptop	Marit Skjørestad, Mathilde Schinnes and Laila Andersland	Medium
3D printer	HBV	Good
SW	All group members	License out 2015

4.0 Test Schedule

4.1 Seal Retainment System

Table 5: Seal retainment test schedule

Subsystem Test	Related Requirement	Related Test	Test Type	Test date	Test Responsible
Seal Retainment System	1.1, 2.5, 3.3, 3.4, 3.5	1.1, 2.5, 3.3, 3.9, 3.4	Inspection	05.05.2015-12.05.2015	M.Skj
Seal Retainment System	3.4	3.9	Demonstration	27.04.2015-04.05.2015	M.Skj
Rubber ring	3.12	3.11	FEM analysis	22.04.2015-30.04.2015	M.skj

4.2 Hydraulic Tension System

Table 6: Hydraulic tension test schedule

Subsystem Test	Related Requirement	Related Test	Test Type	Test date	Test Responsible
Hydraulic Tension Nut	1.1, 2.2, 2.3	1.1, 2.2, 2.3	Inspection	29.04.2015-30.04.2015	J.B.B
Hydraulic Tension Nut	1.3, 3.12	1.4, 3.11	FEM-analysis	28.04.2015-30.04.2015	J.B.B
Locking System	1.1, 3.6, 3.8, 2.11	1.1, 3.5, 3.7, 2.12	Inspection	05.05.2015-12.05.2015	M.Sch

4.3 Stud Turning System

Table 7: Stud turning test schedule

Subsystem Test	Related Requirement	Related Test	Test Type	Test date	Test Responsible
ROV Interfaces	1.1, 3.7, 3.8	1.1, 3,6, 3.7	Inspection	05.05.2015-12.05.2015	M.Sch
Stud Turning System	1.5, 1.6	1.4, 1.6	Inspection	22.04.2015-30.04.2015	M.Sch
Stud Turning System	1.3, 1.4, 1,8	1.4, 1.5, 1.8	FEM-analysis	22.04.2015-30.04.2015	M.Sch

4.4 Nut Retainment System

Table 8: Nut retainment test schedule

Subsystem Test	Related Requirement	Related Test	Test Type	Test date	Test Responsible
The Nut Retainment function	2.9	2.9, 2.13	Demonstration	05.05.2015-12.05.2015	L.E.A
The Nut Retainment function	2.1, 2.10, 3.6, 3.11	2.1, 2.11,3.5, 3.10	Inspection	22.04.2015-30.04.2015	L.E.A
The Washer	3.12	3.11	FEM analysis	20.04.2015-30.04.2015	L.E.A
The Nut	3.12	3.11	FEM analysis	20.04.2015-30.04.2015	L.E.A
The Bolt	3.12	3.11	FEM analysis	22.04.2015-30.04.2015	L.E.A
The Belt	3.12	3.11	FEM analysis	22.04.2015-30.04.2015	L.E.A

4.5 Flange System

Table 9: Flange test schedule

Subsystem Test	Related Requirement	Related Test	Test Type	Test date	Test Responsible
Flange System	2.6	2.6	FEM-analysis, inspection	20.04.2015-30.04.2015	J.B.B
Flange System	3.1	3.1	Inspection	05.05.2015-12.05.2015	J.B.B
Flange System	3.12	3.11	FEM analysis	20.04.2015-30.04.2015	J.B.B

4.6 Verification System

Table 10: Verification test schedule

Subsystem Test	Related Requirement	Related Test	Test Type	Test date	Test Responsible
Test Port System	1.9, 3.8	1.9, 3.7	Inspection	05.05.2015-12.05.2015	J.B.B
Visual Indicator: Pipe Alignment	2.7	2.7	Inspection	05.05.2015-12.05.2015	J.B.B
Flag Indicator: Pre-load	2.8	2.8	Inspection	05.05.2015-12.05.2015	J.B.B

4.7 Crude System

Table 11: Crude test schedule

Subsystem Test	Related Requirement	Related Test	Test Type	Test date	Test Responsible
Guiding System	3.2	3.2	Inspection	05.05.2015-12.05.2015	J.B.B
Guiding System	3.2	3.8	Demonstration	05.05.2015-12.05.2015	J.B.B
Lifting Points	3.10, 3.8	3.7, 3.7	Inspection	05.05.2015-12.05.2015	J.B.B
ROV handles	3.7	3.6	Inspection	05.05.2015-12.05.2015	J.B.B

5.0 References

[1] http://en.wikipedia.org/wiki/Test_plan

[2] Test Specification; ROV operated SPO compact flange, Bachelor thesis 2015.

[3] Requirement Specification; ROV operated SPO compact flange, Bachelor thesis 2015.

[4] Test Rapport; ROV operated SPO compact flange, Bachelor thesis 2015.

FEM Analysis Report

ROV operated SPO compact flange for subsea assembly in deep water

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Group members: Mathilde Schinnes, Laila Andersland, Jørgen Borgersen, Marit Skjørestad

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1.0 Document

1.1 Document History

Table 1: Document history

Revision	Description of change	Date
0.1	First layout	14.04.15
0,2	Corrected spelling	15.05.15
1.0	**Final release**	**15.05.15**

1.2 Abbreviations

Table 2: Abbreviations

Abbreviation	Description
ASTM	American society for testing and materials
FEA	Finite element analysis
FEM	Finite element method
ROV	Remotely operated vehicle
STTH	Stud turning tool holder
SW	SolidWorks
SWS	SolidWorks simulation

2.0 Scope

The purpose of this document is to give an insight of the tests conducted to verify our system, and validate that the requirements are met. This document concentrate on the FEM analysis conducted in SWS. The analysis' are performed on the different subsystems, and we will work our way through these systematically.

3.0 Seal Ring Retainment System

In this test, the elasticity and deformation of the rubber ring is analyzed. It investigates whether it will be able to fit through the opening in the flange, and make sure that the seal ring is retained in the swivel hub during installation and assembly of the flange.

We will look at the deformations both on the way in and on the way out of the flange. On the first analysis, the ring will sit in the neutral position, and the analysis will also be performed with the seal ring in a resting position on the floor of the groove in the flange.

The most important concept to recognize about rubber is that its deformation is not directly proportional to its applied load, in other words, it exhibits a 'nonlinear' behavior [1].The force-displacement curve is no longer linear; stress is never proportional to strain.

Rubber-like materials, which are characterized by a relatively low elastic modulus and high bulk modulus are used in a wide variety of structural applications. These materials are commonly subjected to large strains and deformations. Hyper elastic materials experience large strains and deformations.

Figure 1 shows the stress-strain plot of the extension of a typical elastomer tensile specimen. After considering the huge percent deformation, its most obvious feature is its non-linearity [2].

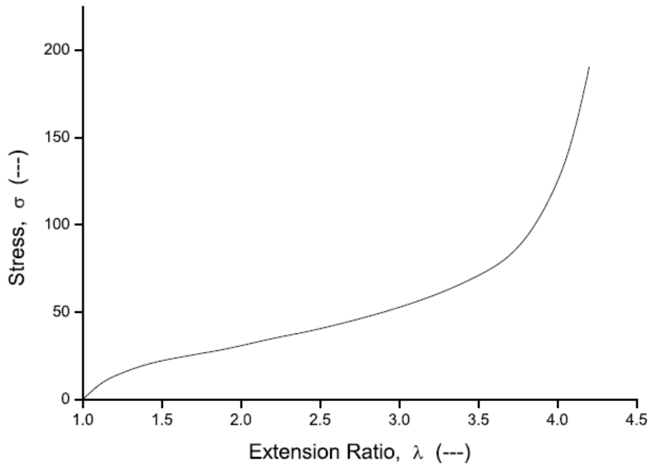


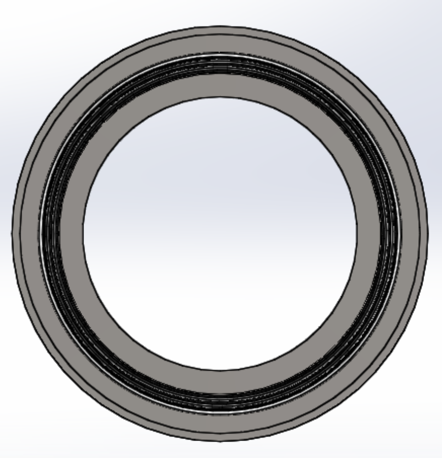
Figure 1: Stress-strain curve rubber

3.1 Simplifications and Assumptions

Material models predict large-scale material deflection and deformations. There are two different types of models to choose from, being incompressible and compressible. Natural rubber is characterized as incompressible and the Mooney-Rivlin model works with incompressible elastomers with strain up to 200%. This is popular for modeling the large strain nonlinear behavior of incompressible materials, i.e., rubber. The calculated strain the rubber in our case will experience is 95%, see equation (5), Calculation document. [7]. Therefor this model will fit our tests.

It is necessary to assess the Mooney-Rivlin constants of the materials to obtain successful results of a hyper elastic material. The FEA program knows how stiff the rubber is based on the values of the constants. These constants can be contained from laboratory testing. We have used two Mooney-Rivlin constants in our analysis, which are also used in the simulation tutorials in Solid Works. This is a huge simplification.

Since our model has rotational symmetry, *figure 2*, we can carb out a 1 degree section of the model and analyze this, *figure 3*.



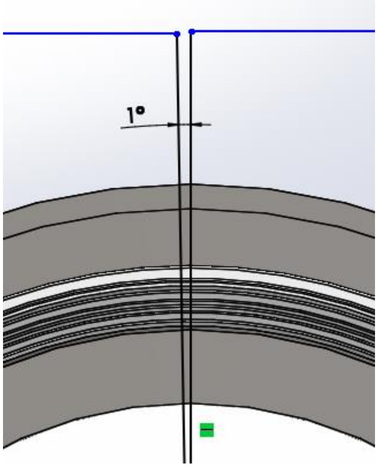


Figure 2: Rotational symmetry

Figure 3: Carb out section

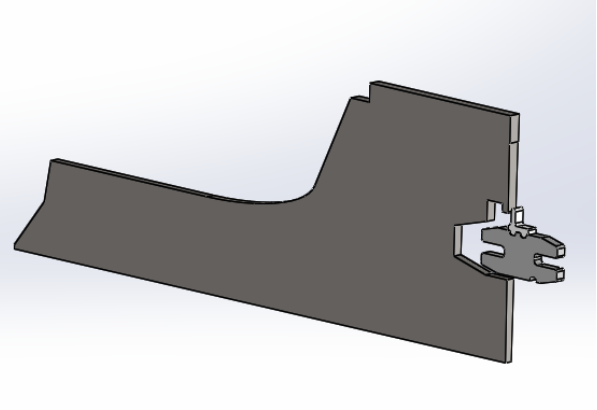
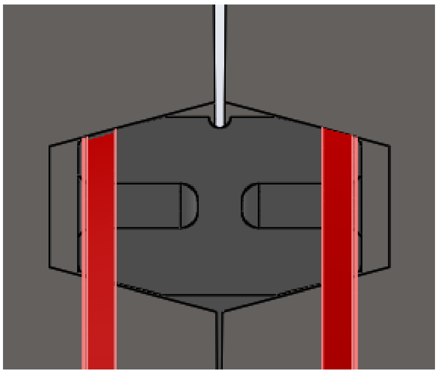


Figure 4: 1 degree section

The non-linearity experienced is in the large displacement through rigid body movement of the seal and rubber ring, large deformation of material of the rubber ring, and contact between the rubber ring and the flange. We also assume that there is no friction.

When it comes to the seal ring, we have to show that we have interference similar to the original design. Then the changes made to the seal ring will be by comparison effective, and no further test is necessary to perform. Shown in *figure 5 and 6,* we can see that the interference is nearly identical in the new seal ring as in the original design.



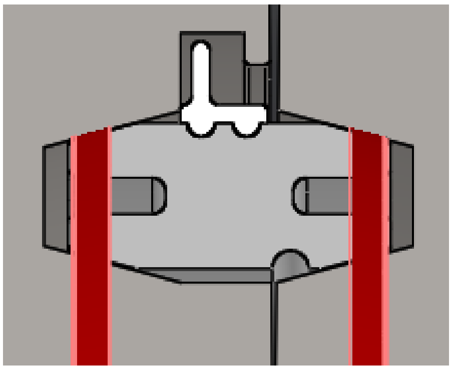


Figure 5: Original seal surfaces

Figure 6: New seal surfaces

3.2 Material

The material used on the rubber ring is custom defined rubber. See *table 3* for material specifications. The Poisson ratio is the negative ratio of transverse to axial strain. A perfectly incompressible material deformed elastically at small strains would have a Poisson's ratio of exactly 0.5. The Poisson ratio of rubber lies between 0, 48 and 0, 5.

Table 3: Material rubber ring

Property	Value	Units
Poisson's Ratio	0.49	N/A
Thermal Expansion Coefficient		/K
First Material Constant	0.97	N/mm^2
Second Material Constant	0.58	N/mm^2
Mass Density	1107	kg/m^3
Tensile Strength	13.79	N/mm^2

Table below from reference [3], shows that filled rubber has a tensile strength on 21 N/mm^2.

Table 4: Properties of rubber

Description	Gum rubber	Filled rubber	Mild steel	Water
Hardness IRHD	45	65	100	0
Tensile strength N/mm^2	28	21	420	
Elongation at break %	680	420	40	
Young's modulus N/mm^2	1,9	5,9	210000	
Shear modulus N/mm^2	0,54	1,37	81000	
Bulk modulus N/mm^2	1000	1200	176000	2100
Poisson's ratio	0,4997	0,4997	0,29	
Resilience %	80	60	100	
Velocity of sound transmission m/s	37	37	5000	1430
Specific gravity	0,93	1,16	7,7	1
Specific heat	0,45	0,41	0,116	1

3.3 Connections

The contact type is set to no penetration. This means that when the elements are in contact with each other we will get a deflection of the rubber, and avoid that the rubber ring will just move through the metal tip. The blue set 1 is the outer and under side of the metal tip of the flange, and the purple set 2 is the side and top of the rubber ring.

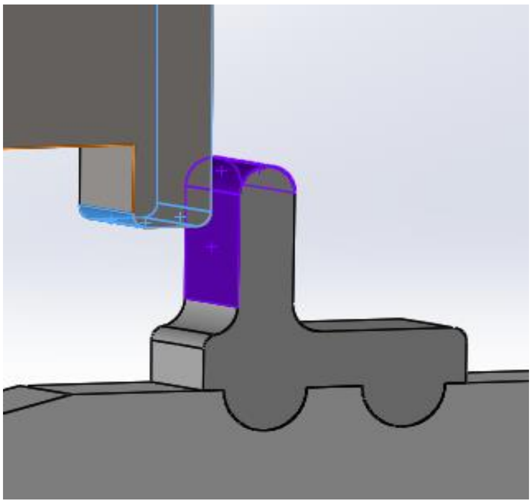


Figure 7: Contact set

3.4 Fixtures

The first fixture is a normal restraint on the end of the pipe. This serves to fix the assembly in the horizontal direction.

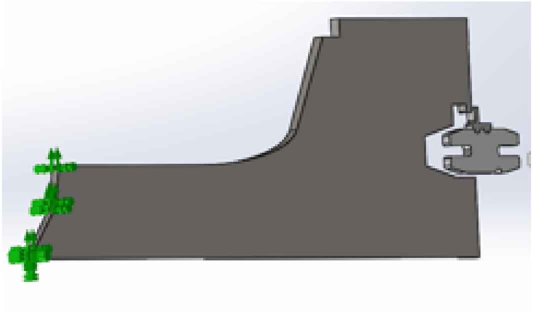


Figure 8: Normal restraint fixture

A radial restraint is set on the inside surface of the pipe. This is installed to help stabilized the model and reduce the solution time.

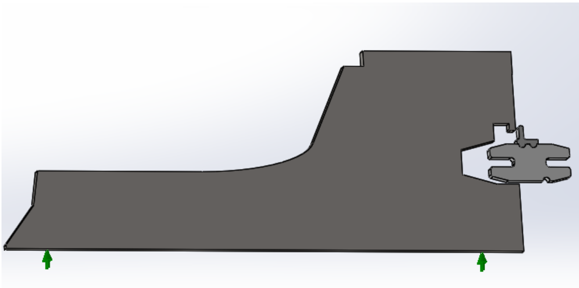


Figure 9: Radial restraint

The third fixture is an advanced fixture on the cut faces. This fixture keeps the cut faces from moving out of their own plane.

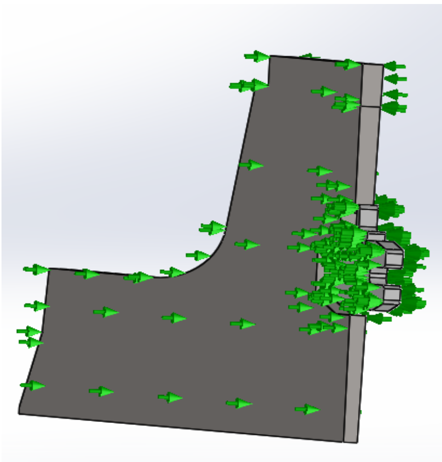


Figure 10: On flat faces fixture

The last fixture is to make the seal and rubber ring move. We set up a controlled displacement instead of a force. We know the distance the seal ring have to move to get in place and therefore we have used an advanced fixture to cause the software to move the seal ring into the flange in the horizontal direction.

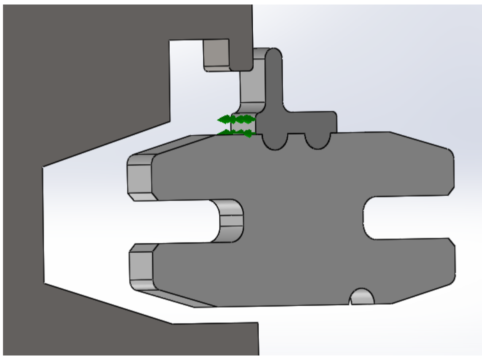
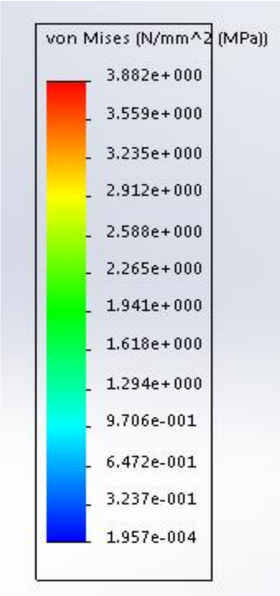


Figure 11: Controlled displacement

3.5 Results - Pushed in

3.5.1 Stresses

From probing the areas with the highest tension, we can see that the highest occurrence is 3,882 N/mm^2. We can see that there are no areas on our model that will obtain these values higher than the rubbers tensile strength.21 N/mm^2.



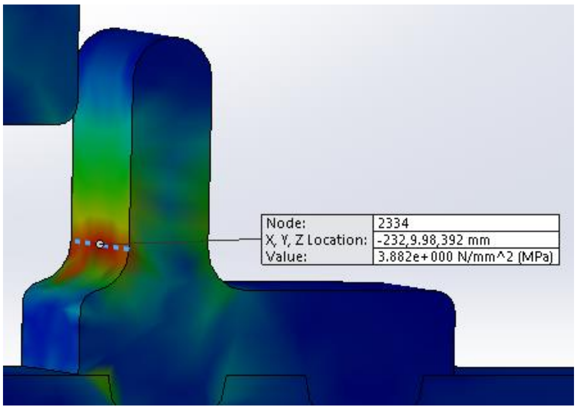


Figure 12: Von Mises table

Figure 13: Stress concentration

3.5.2 Deformations

As we can see from the figures below the rubber tip will undergo a large deformation from step one until step 4. The simulation also shows us that the deformation is possible to obtain, and that the rubber tip will have enough room to bounce up on the inside of the flange after the deflection.

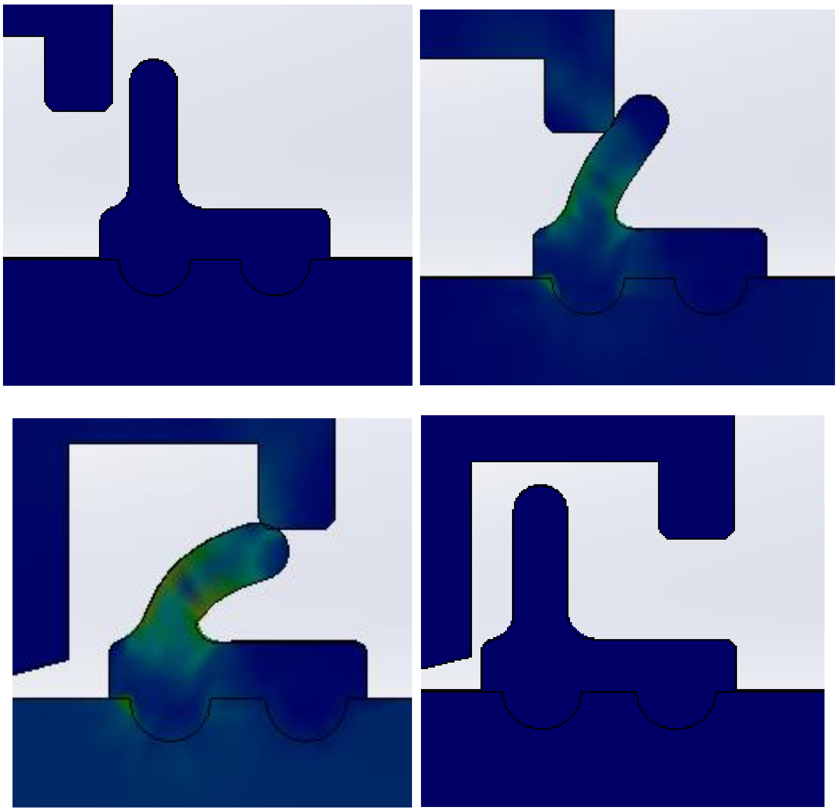


Figure 14: Deflection of rubber ring pushed in, step 1-4

3.5.3 Displacements

Looking at the displacement of the rubber tip, we can probe a node on the tip, and draft its displacement over the total integration time. We can observe the non-linearity of the response of the rubber, see *figure 15*.

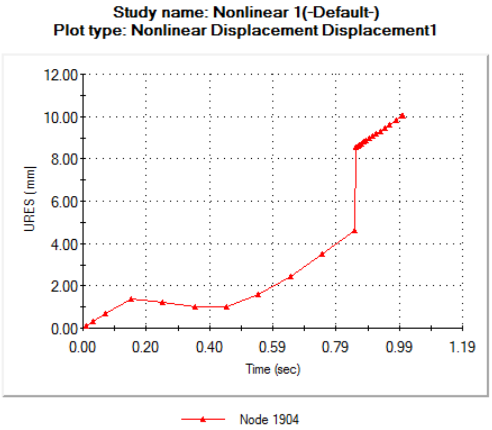
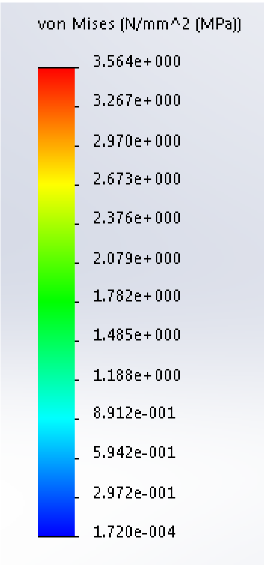


Figure 15: Nonlinear displacement plot

3.6 Results – Pulled out

3.6.1 Stresses

We can look at the tension when the tip is moving out, and see that the highest tension is on the side of the rubber tip that experience tension during the deflection, *see figure 17*. The highest value observed is 3,56 N/mm^2.



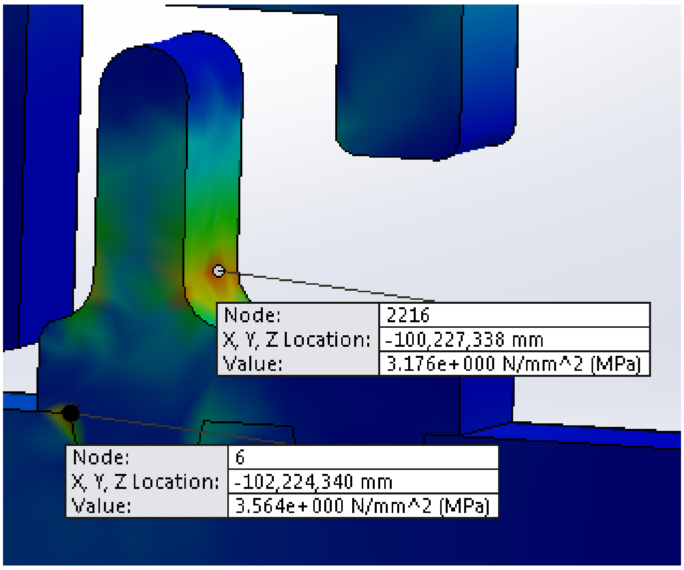


Figure 16: Von Mises table

Figure 17: Stress concentration

3.6.2 Deformations

Figure 18 shows the deformation of the rubber tip during replacement. We can see that the tip will also be able to deflect on the way out.

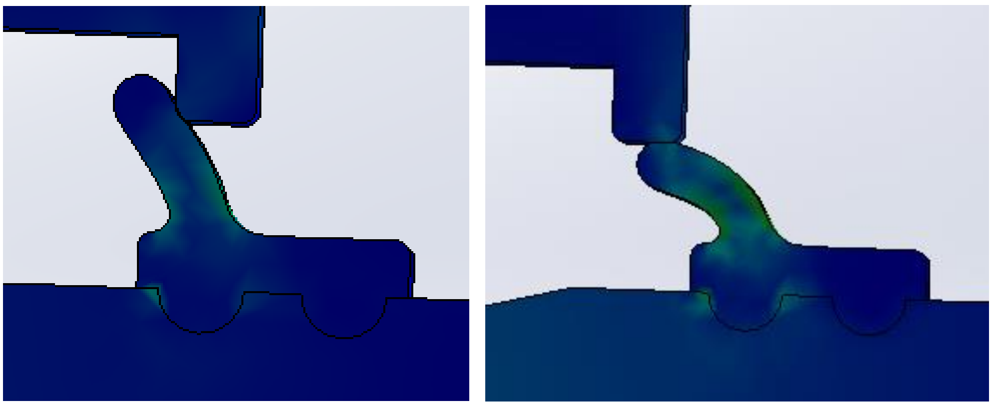
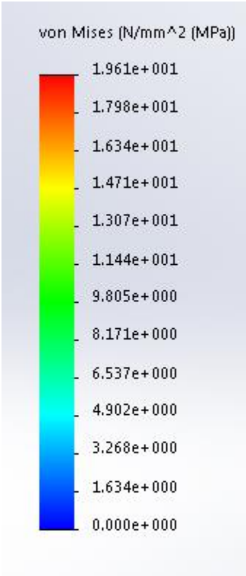


Figure 18: Rubber ring deflection pulled out

3.7 Results - Rest Position

3.7.1 Stresses



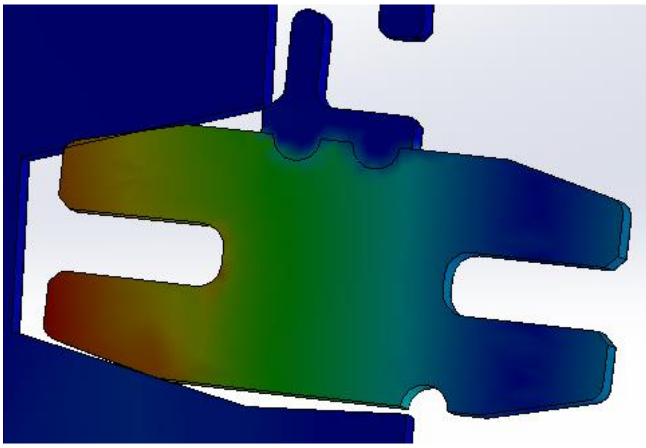


Figure 19: Von Mises table

Figure 20: Stress concentration

From the table we can see that the highest stresses we get is 19,6 N/mm^2. These stresses mostly appears on the seal ring when it is pushed into the groove.

3.7.2 Deformations

When placing the seal ring in a rest position on the floor of the groove, we can see that the rubber tip deflect and that the ring slides into place.

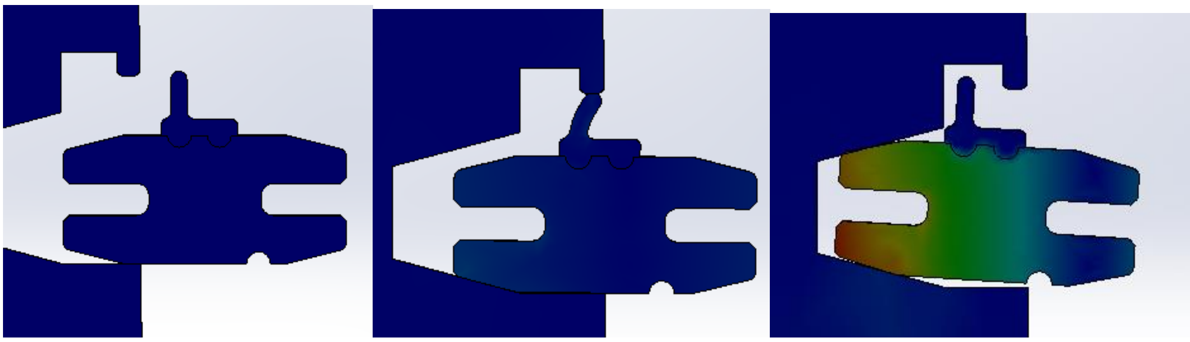


Figure 21: Seal ring deflection, rest position

3.8 Conclusion

From this simplified study, we can conclude that the rubber ring will work as planned. It will deflect under the metal tip in the flange, and have enough room on the inside to bounce up again, and provide the retainment.

4.0 Stud Turning Tool

There are made two different analysis on the stud turning tool, and then especially on the stud turning tool holder.

The first one is regarding the ocean current in the sea, and whether the tool can withstand this. The second analysis will investigate if the stud turning tool could be able to withstand anticipated collision forces from a ROV.

The material of the stud turning tool holder is set to be AISI 321 Annealed Stainless Steel. This has to be specified in SW. The table below shows the properties of the material.

Table 5: Material STTH

Property	Value	Units
Elastic Modulus	193000	N/mm^2
Poisson's Ratio	0.27	N/A
Tensile Strength	620	N/mm^2
Yield Strength	234.42	N/mm^2
Tangent Modulus		N/mm^2
Thermal Expansion Coefficient	1.7e-005	/K
Mass Density	8000	kg/m^3
Hardening Factor	0.85	N/A

4.1 Ocean Current

4.1.1 Simplifications and Assumptions

The first analysis on the stud turning tool will simulate that the system shall be able to withstand ocean currents up to 0.6 m/s. To not make the calculations heavy and time-consuming some simplifications will be done consider the effect from the ocean current.

p_{water}= density of water $\rho_w = 1000\frac{kg}{m^3}$

U=Ocean current $U = 0{,}6\frac{m}{s}$

M_f =Mass flow rate $M_f = \rho_w \cdot U \cdot S$

h=height of tool $h = 650mm$

b=width of tool $b = 340mm$

S=area of tool $S = h \cdot b = 0{,}221m^2$

Mf_{tool} = Mass flow rate $M_f = \rho_w \cdot U \cdot S = 132{,}6\frac{kg}{s}$

F=force acting on the tool $F = \rho_w \cdot U^2 \cdot S = 79{,}56\ \frac{kg*m}{s^2}$

The force acting on the surfaces of the stud turning tool system with ocean current of 0,6 m/s is 79,56 N.

4.1.2 Fixtures

The geometry is fixed in the place where the ROV handle is mounted. The ROV handle is illustrated with a brick.

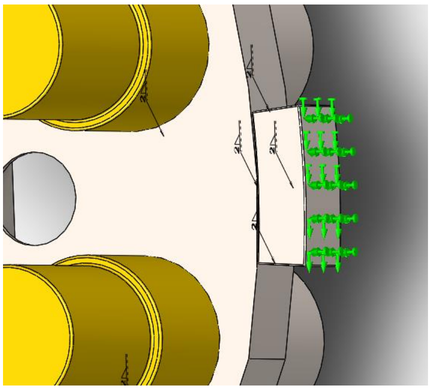


Figure 22: Fixed geometry

4.1.3 External Loads

Gravity

A force of gravity is placed on the tool, with the size of 9.81 m/s^2.

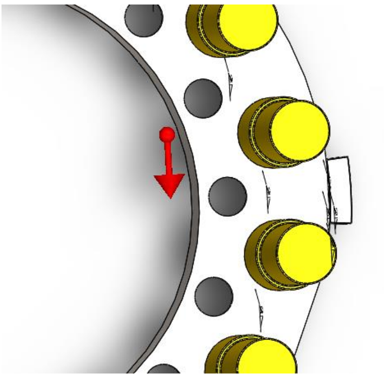
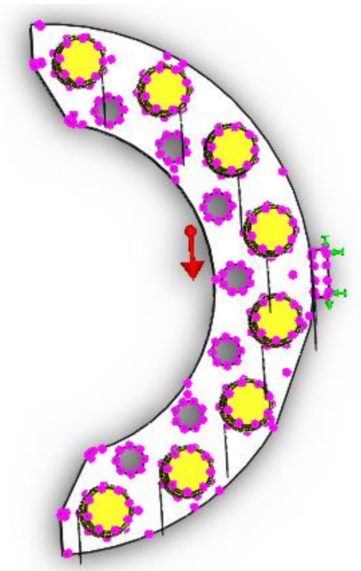


Figure 23: Gravity

Force

The forces of the ocean current is acting on one surfaces of the tool, straightforward. Assuming that the current works from only one direction. The size of the force is 79,56 Newton, see calculations in chapter 4.1.



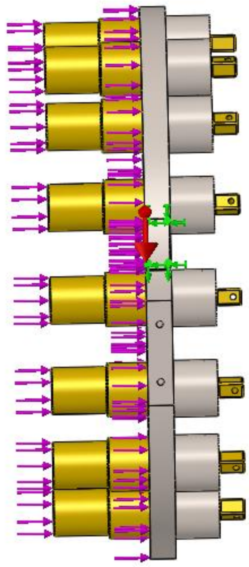
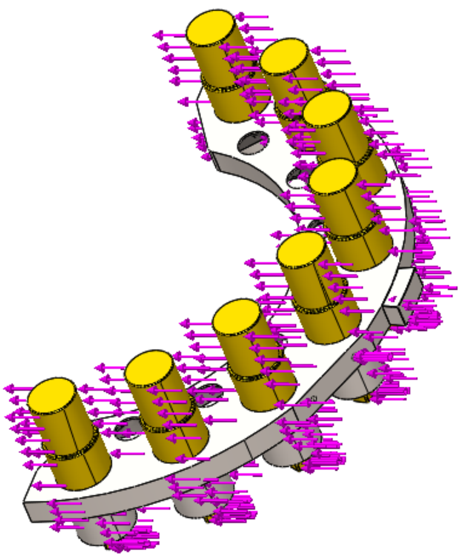


Figure 24: Force distribution direction 1, top view

Figure 25: Force distribution direction 1, side view



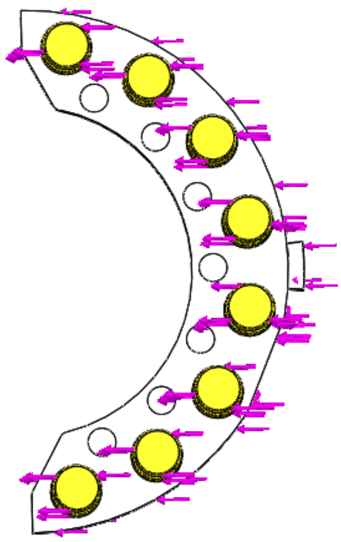


Figure 26: Force distribution direction 2, side view

Figure 27: Force distribution direction 2, top view

4.1.4 Results

Two different analysis is performed, one of two different directions of the ocean current.

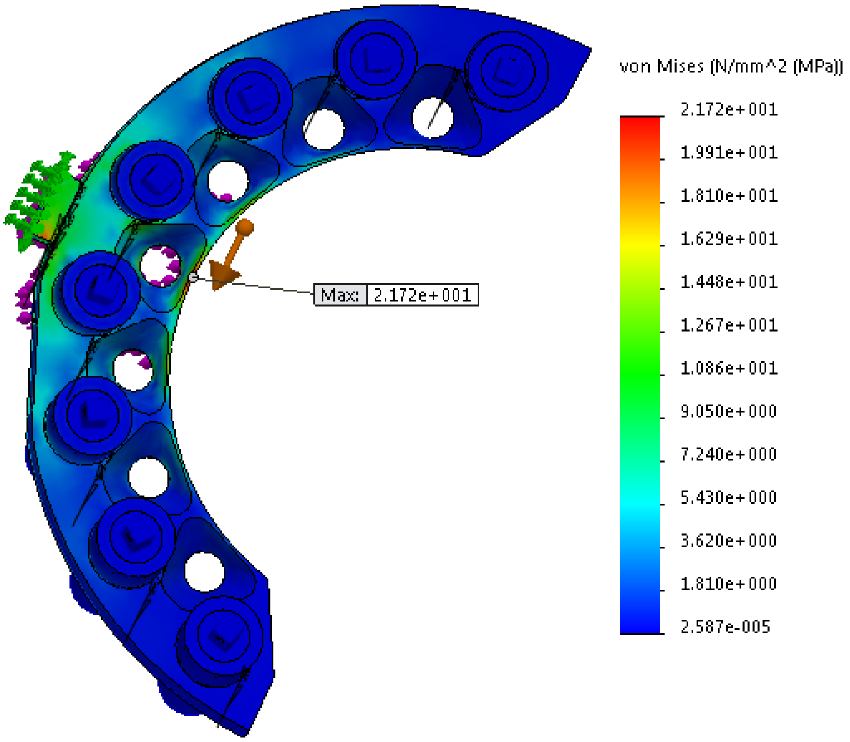


Figure 28: Max annotation direction 1: 21,72 N/mm2

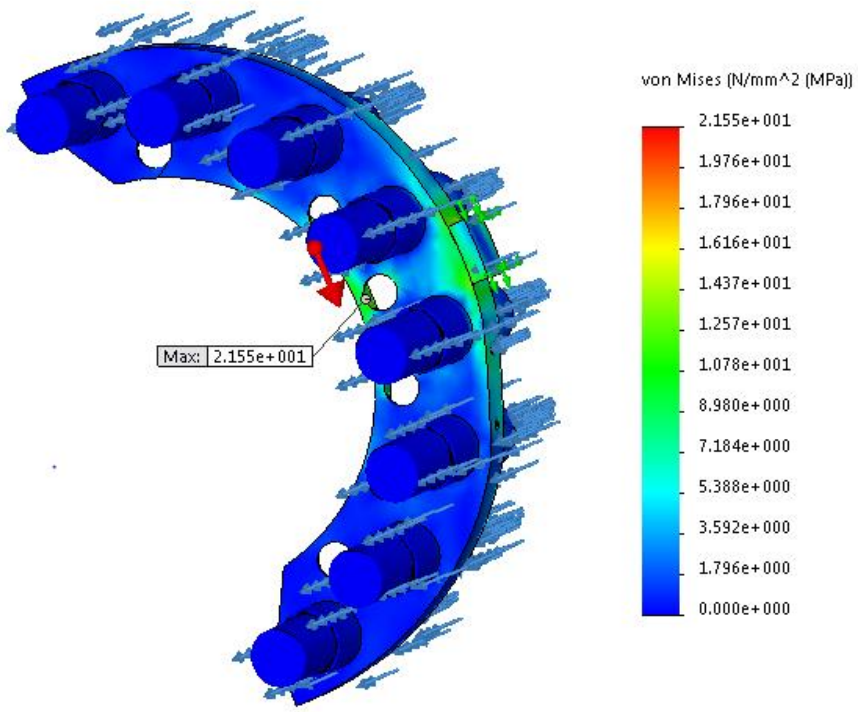


Figure 29: Max annotation direction 2: 21,55 N/mm^2

The yield strength of the material is 234 N/mm^2, and as we can see from the figure none of the stresses on the stud turning tool holder exceeds the materials yield strength. Max stresses obtained is 21,72 N/mm^2. The results of the static FEM analysis for ocean current did not result in any unexpected results. Max annotation of stress is below the yield strength for the tool material. The ocean current will therefore not have any effect or damage on the stud turning tool system.

4.2 ROV Collision Forces

4.2.1 Simplifications and Assumptions

Concerning the collision forces from the ROV, the stud turning system will be carried by the ROV itself and the system will therefore not be exposed to any collision forces. On the contrary, the system will be moved into the pipe surface and use the pipe as a guidance.

Since the system will be guided along the pipe, it have been executed a static FEM analysis to confirm that the system endure this sort of collision. It is assumed that the ROV moves the tool with a speed of 1,39 m/s witch equals 5 km/h. The time for the deceleration from 1,39 m/s to 0 m/s is assumed to be 0,3 s.

m=mass of the tool	$m = 36\ kg$
v= speed of the tool (from the ROV)	$v = 1{,}39\frac{m}{s}$
t=time for the tool to decelerate	$t = 0{,}3\ s$
P=change of momentum of the tool	$P = 36\ kg \cdot (-1{,}39)\left(\frac{m}{s}\right) = -50{,}04\ \frac{kg*m}{s}$
F=force	$F = \frac{P}{t} = \frac{-50{,}04\left(\frac{kg*m}{s}\right)}{0{,}3s} = -166{,}8\ N$

The negative sign shows that the force works in opposite direction of the speed.

4.2.2 Fixtures

The geometry is fixed in the place where the ROV handle is mounted, same as in the previous analysis.

4.2.3 External Loads

Gravity

A force of gravity is placed on the tool, with the size of 9.81 m/s^2.

Force

A normal force acting on the surface that will collide with the pipe. The size of the force is set to be F=166,8 Newton, see chapter 4.2.1.

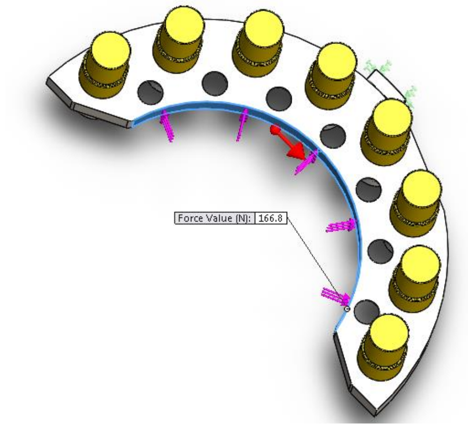


Figure 30: Force on STTH

4.2.4 Results

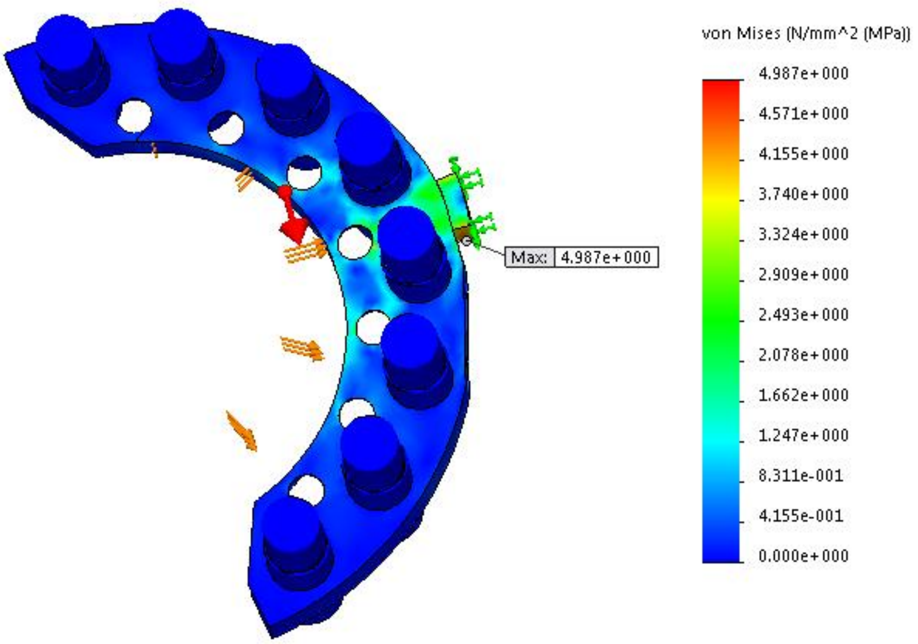


Figure 31: Max annotation: 4.987 N/mm²

Yield strength of the material is also here 234 N/mm^2. As the figure shows, the highest annotation is 4,987 N/mm^2. From this, we can conclude that there will not be any damage on the system if the face of the belt collide with the face of the pipe. The highest concentration of stress is found in the welded connection to the ROV handle.

4.3 Conclusion

As we can conclude from this two simplified analysis of the stud turning system, we can see that the tool belt will withstand the anticipated forces applied from the environment.

5.0 Nut Retainment System

On the nut retainment system, there are executed individual FEM analyses on the different parts of the system. All of the analysis are made to investigate whether the parts will withstand the loads they are exposed to when the bolt is stretched.These will be gradually worked through in this chapter.

The preload working on the system is used in all the analyses, and therefore the calculation is shown here.

The stud will be pre-loaded with as much as 95% of the yield strength of the stud. We can calculate the size of this by multiplying the tensile stress area with 95% of the yield strength.

Y= Yield strength of stud	$Y = 725 \frac{N}{mm^2}$
A_{TS}=Tensile stress area	$A_{TS} = 1341{,}9\ mm^2$
95% of yield strength	$Y_{95} = Y \cdot 0{,}95$
	$Y_{95} = 688{,}75 \frac{N}{mm^2}$
P=Preload	$P = A_{TS} \cdot Y_{95}$
	$\underline{\underline{P = 924{,}234\ kN}}$

5.1 Washer

In this test, we will demonstrate the effect of the forces put on the washer including the angle in the inlet. The surface of the washer will be spherical so that the bottom of the nut, which also is spherical, will fit perfectly on the washer. The washer will be exposed to a force from the nut when the stud is tightened. This test will show if the washer will withstand this force.

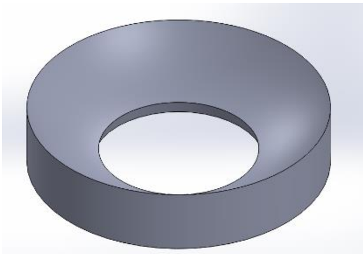


Figure 32: Washer

5.1.1 Simplifications and Assumptions

The distribution of the load will be simplified, seeing as the nut will push the washer on a spherical surface. It is assumed that the most significant load direction will be in an axial direction.

5.1.2 Material

It were decided to use an ASTM F436 washer, which is commonly made by the use of AISI 1045 Carbon Steel [8]. This material are not specified in the SolidWorks library so AISI 1045 Carbon Steel was added as a customized material with specifications found on the web [9].

Table 6: Material washer

Property	Value	Units
Elastic Modulus	205000	N/mm^2
Poisson's Ratio	0.29	N/A
Shear Modulus	80000	N/mm^2
Mass Density	7858	kg/m^3
Tensile Strength	1213.48	N/mm^2
Compressive Strength		N/mm^2
Yield Strength	350	N/mm^2
Thermal Expansion Coefficient	1.2e-005	/K
Thermal Conductivity	52	W/(m·K)
Specific Heat	486	J/(kg·K)
Material Damping Ratio		N/A

5.1.3 Fixtures

The washer will be fixed on the bottom face.

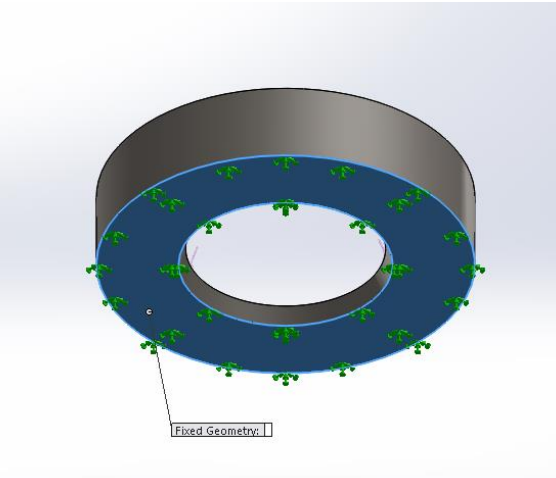


Figure 33: Fixture on washer

5.1.4 External Loads

We can see that the size of the preload will be 9,242 x 10^5 N., see chapter 5.0. The stud will be stretched with 9,242 x 10^5N and the nut will therefore be pulled with the same force. The washer, which is seated directly under the nut, will then receive the same force. The washer will absorb some of this so that there will be a stress relief on the flanges. The nut will sit in the washer and push on all the spherical surfaces on the washer.

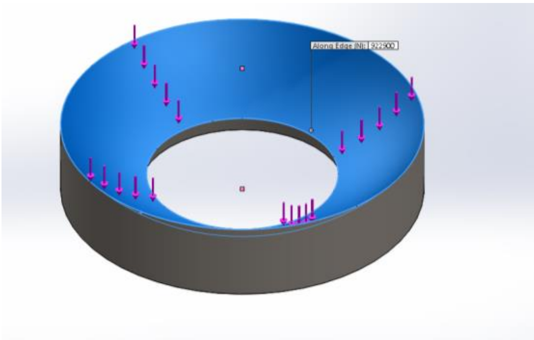


Figure 34: Force distribution, washer

5.1.5 Results

The yield strength of the washer is 350 N/mm^2. As seen in the figure below, the washer will not experience stress over the yield strength of the washer. The highest stresses is located on the bottom of the washer.

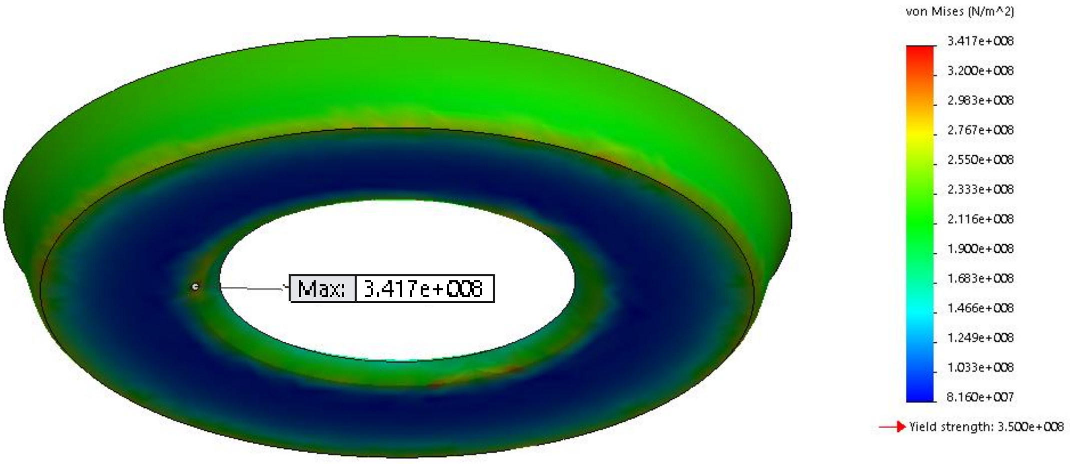
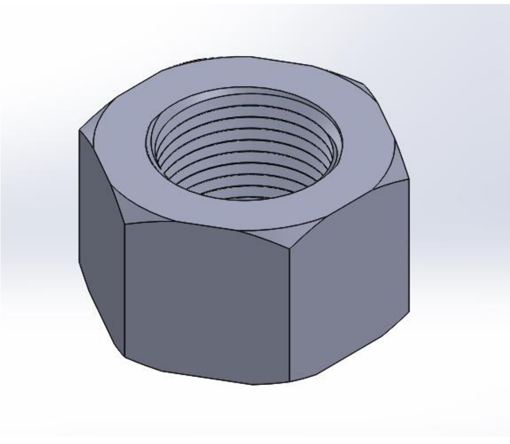


Figure 35: Stress washer, bottom view

5.2 Nut

The top part of the nut is a standard part, but it is necessary to analyze the effect of changing the bottom part of the nut.



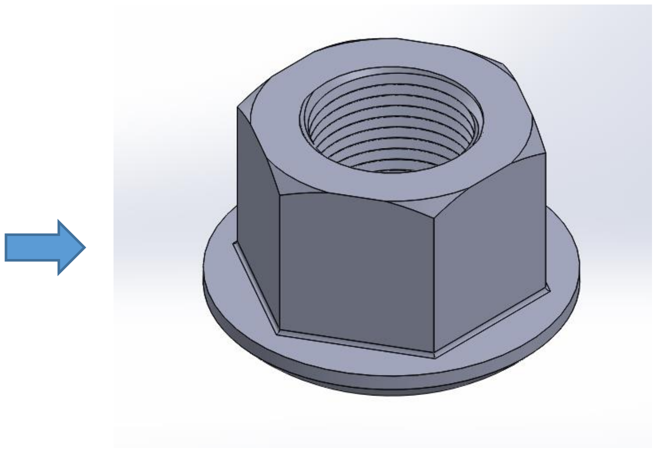


Figure 36: Original nut

Figure 37: Customized nut

5.2.1 Simplifications and Assumptions

The design is simplified by removing the threads in the nut.

5.2.2 Material

As specified in the detailed design document, the nut will be of the material ASTM A194 Grade 7, which is not specified in the SolidWorks library. A customized material is made according to the specifications shown here [10].

Table 7: Material nut

Property	Value	Units
Elastic Modulus	201000	N/mm^2
Poisson's Ratio	0.3	N/A
Shear Modulus	77221	N/mm^2
Mass Density	7850	kg/m^3
Tensile Strength		N/mm^2
Compressive Strength		N/mm^2
Yield Strength	732.9	N/mm^2
Thermal Expansion Coefficient		/K
Thermal Conductivity	0.2256	W/(m·K)
Specific Heat	1386	J/(kg·K)
Material Damping Ratio		N/A

5.2.3 Fixtures

Fixtures are placed on the bottom face of the nut.

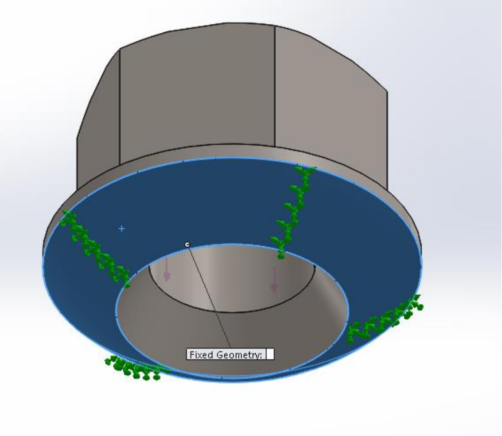


Figure 38: Nut fixtures, bottom view

5.2.4 External Loads

The load is specified in the detailed design document to be 924,2kN. The load is set to work along the hole, instead of on the threads.

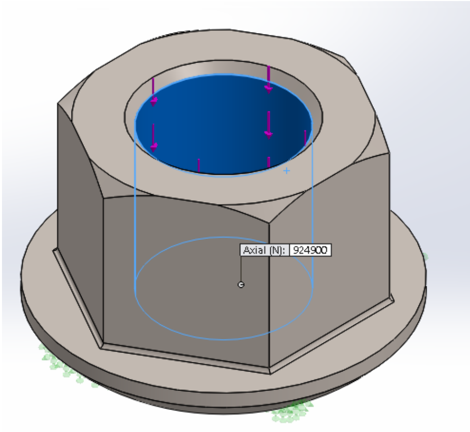


Figure 39: External load, nut

5.2.5 Results

The purpose off the test was to see if the nut would withstand the forces applied when the stud is tightened. In this test, the nut is exposed by the maximum possible force that might occur in reality. The highest concentration of stress is 676 N/mm^2 and is found in the transition to the new bottom part, se figure below. We conclude that the current part design is acceptable for its application.

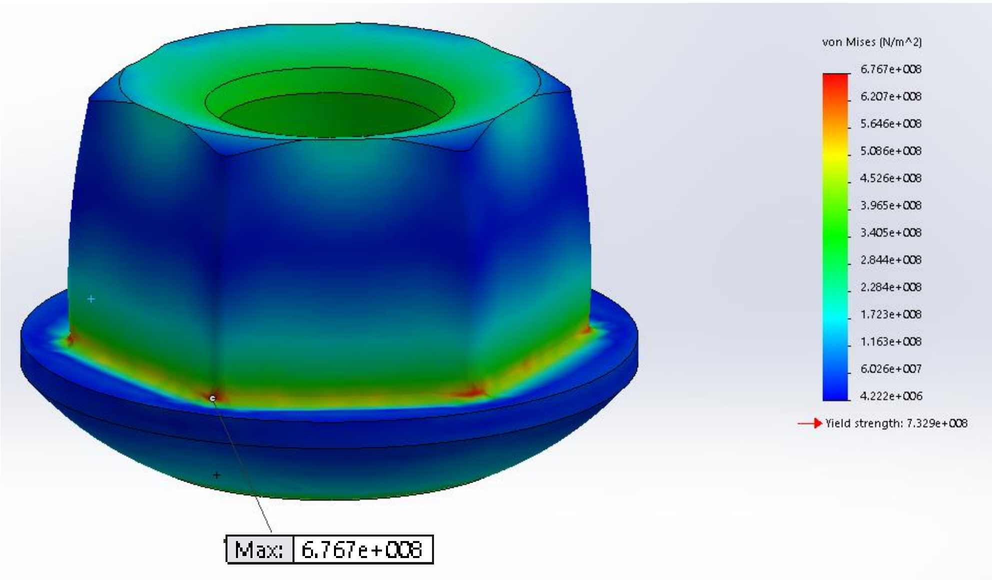


Figure 40: Stress concentration, nut

5.3 Bolt

5.3.1 Simplifications and Assumptions

The design is simplified by removing the threads and the conical part. This results in a simple rod. This analyze will show what happens when one pulls the rod in an axial direction.

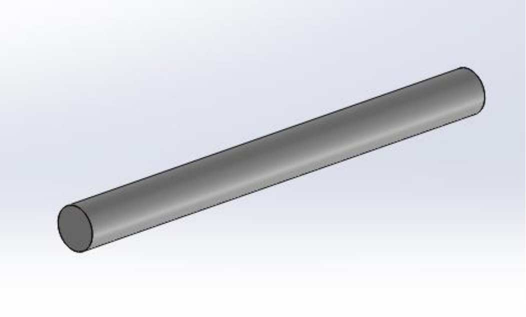


Figure 41: Simplified stud

5.3.2 Material

As specified in the project description, the stud will be of the material ASTM A320 L7.

Table 8: Material stud

Property	Value	Units
Elastic Modulus	2000	N/mm^2
Poisson's Ratio	0.394	N/A
Shear Modulus	318.9	N/mm^2
Mass Density	1020	kg/m^3
Tensile Strength	30	N/mm^2
Compressive Strength		N/mm^2
Yield Strength	723.95	N/mm^2
Thermal Expansion Coefficient		/K
Thermal Conductivity		W/(m·K)
Specific Heat		J/(kg·K)
Material Damping Ratio		N/A

5.3.3 Fixtures

The stud will be fixed in one end.

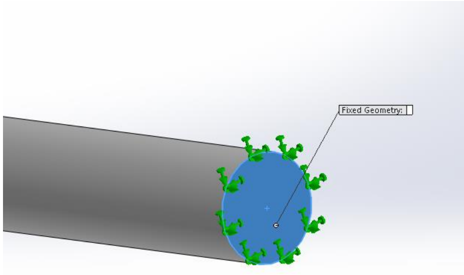


Figure 42: Fixtures, stud

5.3.4 External Loads

The maximum percentage to achieve a residual preload of 75% is to apply a preload that subjects the stud to 95% of its yield strength. This will result in a maximum load of 942,2kN that the bolt will be subjected to. The load will be acting on the top face of the stud.

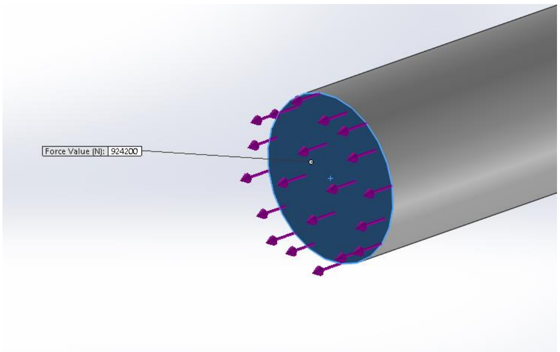


Figure 43: External loads, stud

5.3.5 Results

The rod is deliberately stretched to about 95% of the yield strength. This is also shown in the figure below. The yield strength of the stud is 723,95 N/mm^2, and the maximum stress in the stud is measured to be 630,5 N/mm^2.

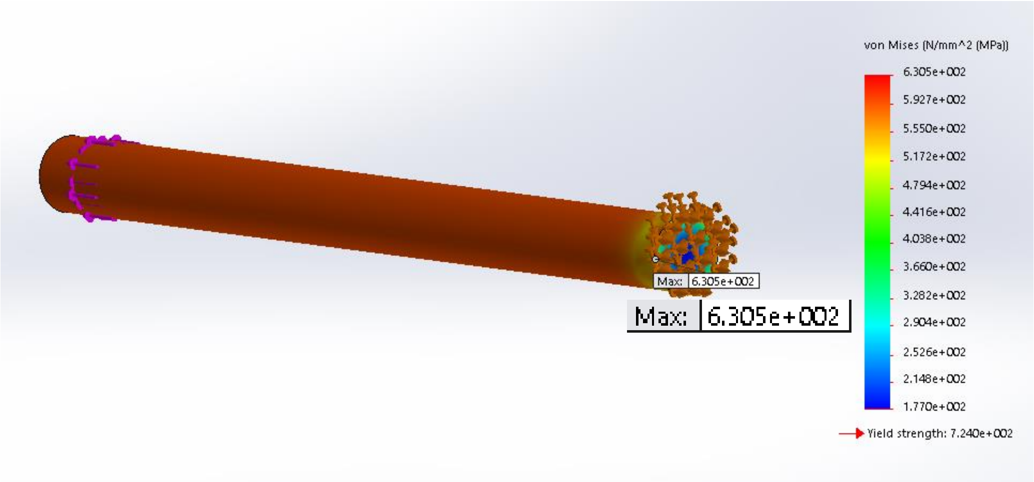


Figure 44: Stress concentration stud

5.4 Belt

The belt was designed with the goal to fasten the nut and washer, whilst giving a degree of freedom as well.

5.4.1 Simplifications and Assumptions

It will only be conducted a test on one half of the belt.

5.4.2 Material

The material is decided to be ISO 10423. The material used in SolidWorks is Stainless Steel (ferritic), since this material has similar specifications.

Table 9: Material belt

Property	Value	Units
Elastic Modulus	200000	N/mm^2
Poisson's Ratio	0.28	N/A
Shear Modulus	77000	N/mm^2
Mass Density	7800	kg/m^3
Tensile Strength	513.61	N/mm^2
Compressive Strength		N/mm^2
Yield Strength	172.34	N/mm^2
Thermal Expansion Coefficient	1.1e-005	/K
Thermal Conductivity	18	W/(m·K)
Specific Heat	460	J/(kg·K)
Material Damping Ratio		N/A

5.4.3 Fixtures

Fixtures are placed on the inside of the belt fastening bolt hole, since these bolts will be fixing the belt to the flange.

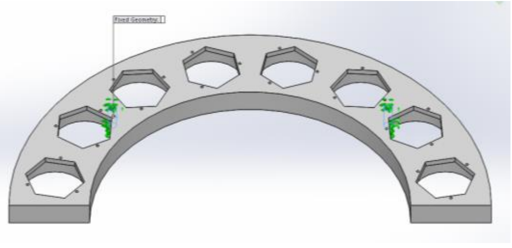


Figure 45: Fixtures, belt

5.4.4 External Loads

The load will be acting on the roof of the chamber as this is where forces will act when the studs is pushed through the nuts. The size of this load is depending on the force that the stud turning tool will push with when entering the studs. Since it was very hard to find out exactly what the quantity of this force would be, we agreed that it was reasonable to assume that the stud turning tool wouldn't push more than 100 Newton. The size of this force is then set to be 200 Newton to incorporate a safety factor.

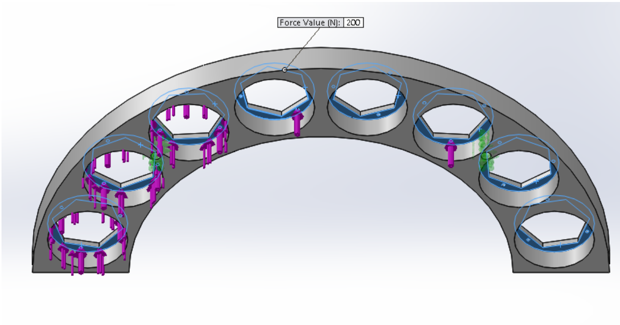


Figure 46: External loads, belt

5.4.5 Results

Yield strength of the material is 172 N/mm². As seen in the figure below, there are no occurring stresses above the yield strength of the material. The highest stresses occurring is 8.596 N/mm². These are found under the belt, in connection with the points of fixture. Since the force from the stud turning tool might possible be greater than assumed, having quite a significant safeguard seems reasonable.

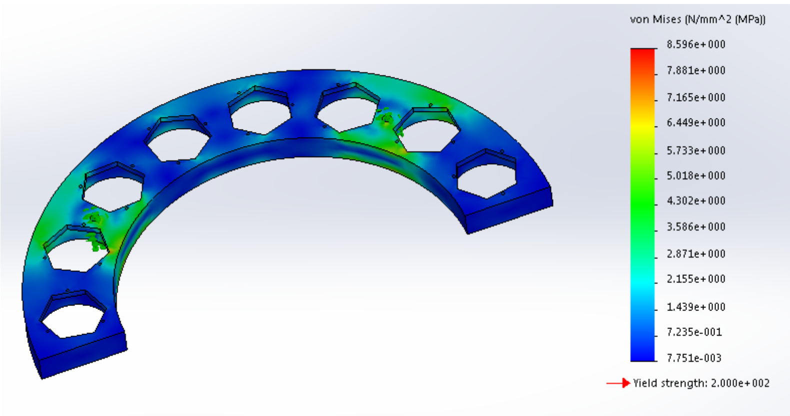


Figure 47: Stresses, belt

5.5 Conclusion

The FEM analysis of the nut retainment system shows us that different parts will withstand the forces applied to them when the stud is stretched.

6.0 Hydraulic Tool

6.1 Simplifications and Assumptions

This test is performed with the intention of verifying that the intended changes made to the hydraulic tooling will not affect its structural capacity to such a degree that it is no longer applicable to its function. The hydraulic nuts chosen for applying the bolt pre-load are going to be fastened to the swivel flange by machining a groove in the tooling, which will act as a grip-ledge for three specially designed fastening hinges. This groove will cause a stress concentration that could possibly result in stresses above the yield strength of the tooling material, thus calculation and testing will be performed focusing on this area.

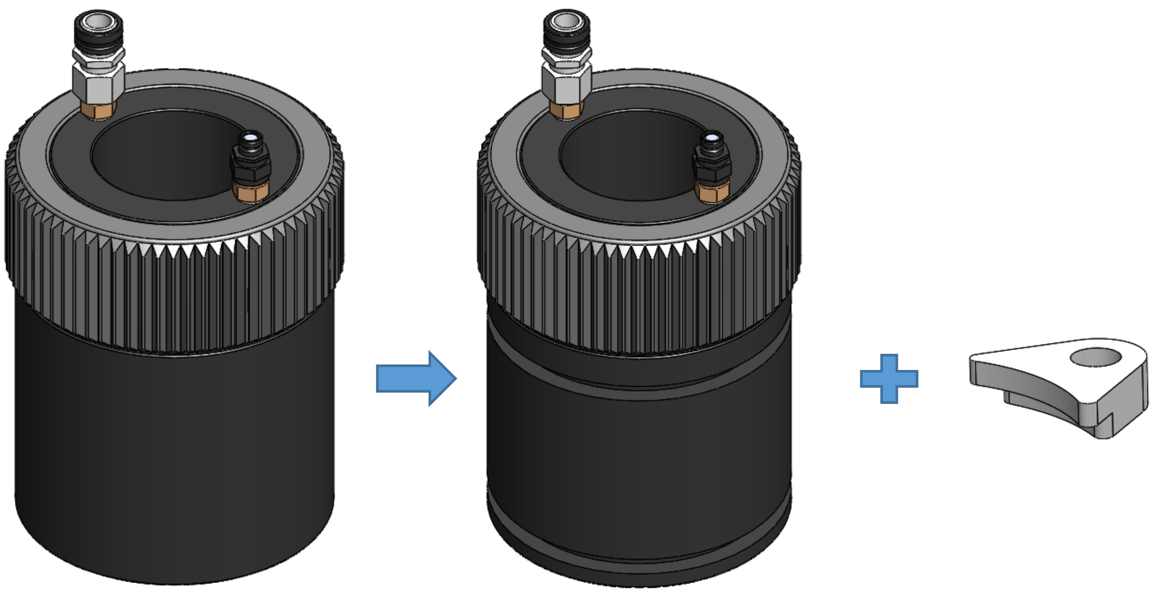


Figure 48: Hydraulic nut change

To perform this analysis the scenario were simplified into a representative model and several assumptions were made.

- The bending stresses caused by the angled flange faces (0.6°) is so small that it is negligible. Therefore the model is simplified such that the forces will be acting perpendicular to the contact faces.
- The shear stress caused by the difference in bolt hole and tooling internal diameter is negligible. This assumption is made on the grounds that in general; ductile materials will fail in shear, whereas brittle materials will fail due to tension [6].
- The connection, once made up, will apply a static pre-load and therefore is assumed not to create any fatigue issues.
- As the tooling material isn't defined in the TenTec datasheet it has been assumed that the tooling material will need to be stronger than that of the flange, thus the

tooling has been given the same material properties. This assures that the results is still applicable, as there is not a possibility of the material being weaker.

The stress concentration will appear where the stress area is the smallest, which is at the smallest diameter. As mentioned, the machined groove will create this reduced stress area.

$$A_\sigma = A_{tooling} - A_{bolthole}$$

$$A_\sigma = \pi \cdot r_{tooling}^2 - \pi \cdot r_{bolthole}^2$$

$$A_\sigma = \pi \cdot 43^2 - \pi \cdot 24.5^2 = 3929\ mm^2$$

The stresses that will act on the connection is a result of the pre-load applied to the bolt. This is defined as the force needed to produce tensions at 0.95 x Yield strength of the chosen bolt material. The yield strength of an ASTM A320 8-UN 1 ¾" bolt is 105,000 psi/ 723 MPa.

$$\sigma_{bolt} = 0.95 \cdot \sigma_{yield}$$

$$\sigma_{bolt} = 0.95 \cdot 723 \frac{N}{mm^2} = 686.85 \text{ MPa}$$

According to the Bolt and tooling configuration document the stress area of the chosen bolt is 1132.67 mm^2. Using these values we can calculate the axial force that will be applied to the bolt.

$$F = \sigma_{bolt} \cdot A_s$$

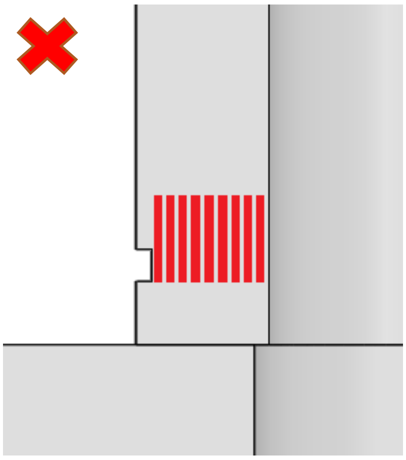
$$F = 686.85 \frac{N}{mm^2} \cdot 1132.67 mm^2 = 778993\ N = 778.993 kN$$

The average tension that will appear in the stress concentration are calculated using the following equation.

$$\sigma_{average} = \frac{F}{A_\sigma}$$

$$\sigma_{average} = \frac{778993N}{3929mm^2} = 198MPa$$

This value is well under the yield strength of the tooling (450MPa), however the stress distribution can't be expected to be uniform, which means there are possible amplitude stresses that exceed the strength of the material.



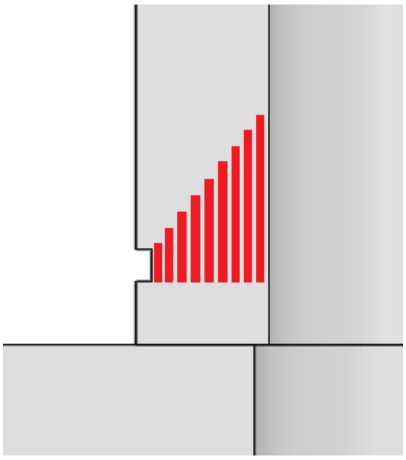
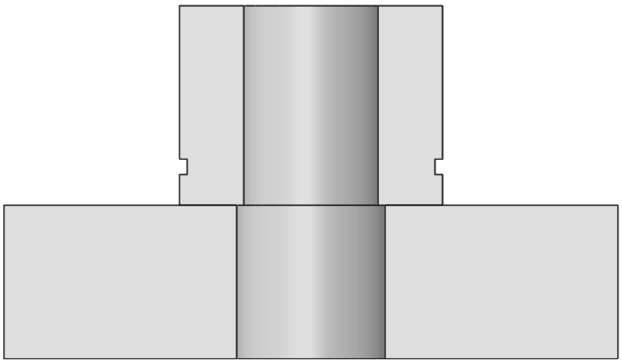


Figure 49: Stress distribution simplified

Figure 50: Stress distribution realistic

Because of this, we want to further analyse the topic in a Finite Element Analysis. For the sake of this analysis, the tooling and flange connection have been simplified into the following model.



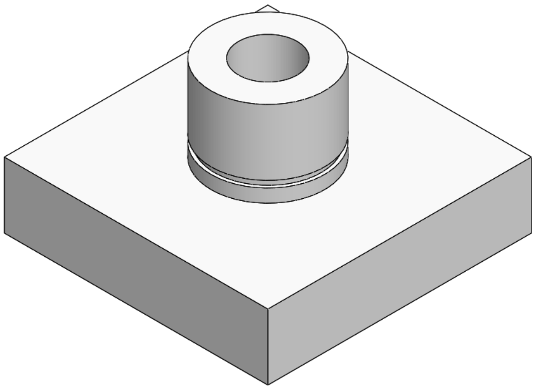


Figure 51: Cross section view simplified model

Figure 52: Isometric view simplified model

6.2 Material

The material used in both the tooling and the flange has the following properties:

Table 10: Material hydraulic nut

Property	Value	Units
Elastic Modulus	190000.01	N/mm^2
Poisson's Ratio	0.26	N/A
Shear Modulus	79000	N/mm^2
Mass Density	7850	kg/m^3
Tensile Strength		N/mm^2
Compressive Strength		N/mm^2
Yield Strength	450	N/mm^2
Thermal Expansion Coefficient	1.5e-005	/K
Thermal Conductivity	37	W/(m·K)
Specific Heat	520	J/(kg·K)
Material Damping Ratio		N/A

6.3 External Loads

As calculated earlier, the axial forces that will be acting on the tooling is 778.99kN. This force will be acting in a downward direction across the inner surface of the tooling, as this is a close representation of where the forces will be applied to the threads.

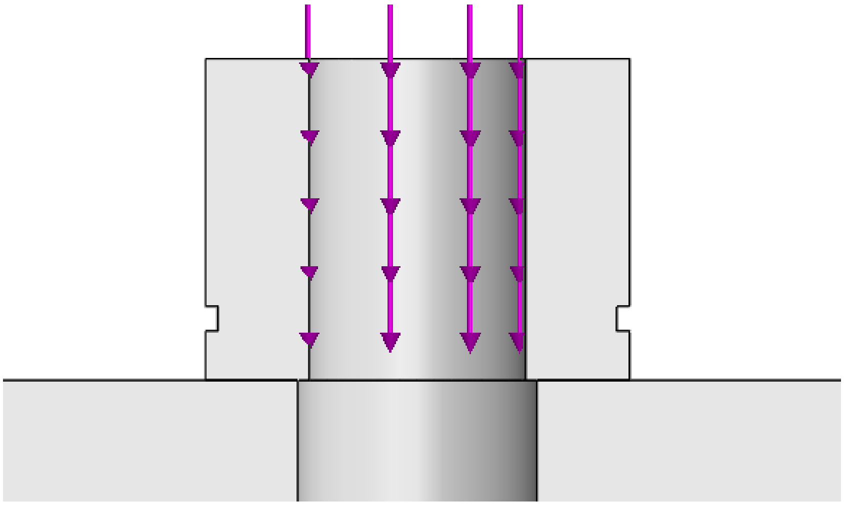


Figure 53: Load, hydraulic nut

6.4 Results - Static analysis

6.4.1 Stresses

As shown in the figure below the colors for the most part indicate a stress level of roughly 200 MPa, which concurs with the calculations made previously in this report. Further, one can see in the following illustration that our suspicion of higher stress concentrations closer to the center also have been correct. It appears that some shear stresses occurs at the inner edges of the tooling as the stress levels increases at a greater pace where the tooling and flange is not coincident.

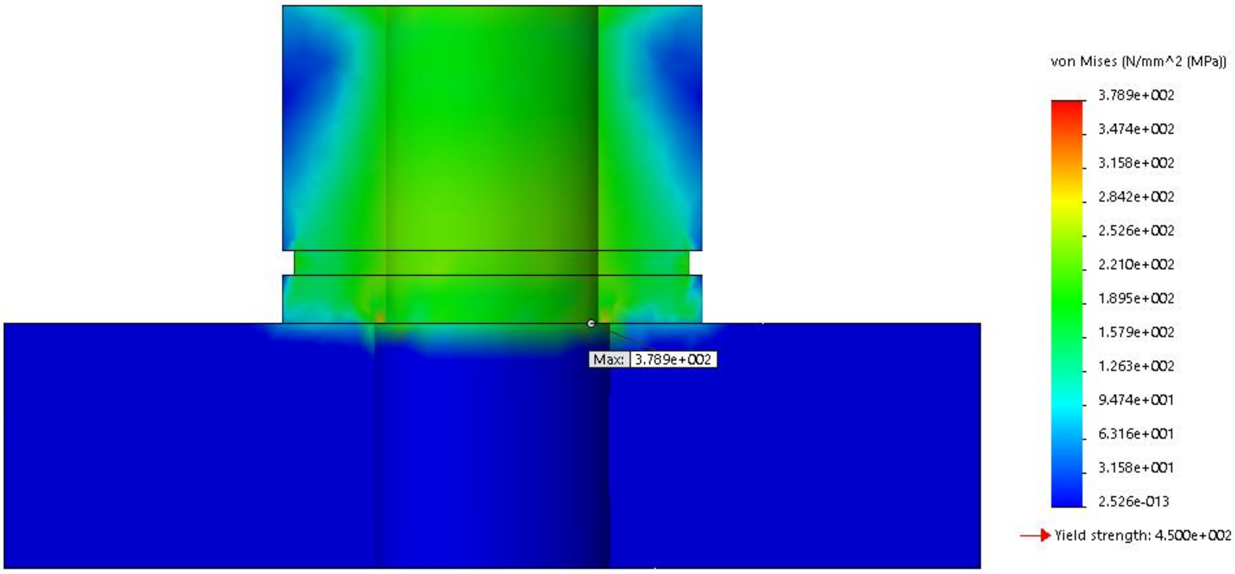


Figure 54: Stress distribution, hydraulic nut

6.5 Conclusion

The FEM analysis has both confirmed our calculations of average stresses, as well as confirmed our suspicions of higher tension concentrations appearing in the inner regions of the tooling. The highest value of stress is as mentioned 380MPa, which is below the tooling materials yield strength. Seeing as the tooling most likely will be produced using a higher strength material and that there is no occurrence of plastic deformation the tooling dimensions is deemed viable for its application and no changes needs to be made.

7.0 References

[1]http://www.mscsoftware.com/sites/default/files/wp_elastomer_ltr_w_0.pdf

[2] http://files.hanser.de/hanser/docs/20081113_281113144257-93_978-3-446-41681-9_extract.pdf

[3] Engineering design with natural rubber. J.E Duncan

[6] http://en.wikipedia.org/wiki/Shear_strength

[7] Calculation Document, ROV operated SPO compact flange for subsea assembly, Bachelor Thesis 2015

[8] http://www.boltmfg.com/bocp.asp?id=78#

[9] http://www.azom.com/article.aspx?ArticleID=6130

[10] http://www.jwbolts.com/en/pronew14.asp

Test Report

ROV operated SPO compact flange for subsea assembly in deep water

Document No.:	Version No.:	Date:	Document responsible:	Group:	Status:
10.0	1.0	15.05.2015	Laila E. Andersland	3	Completed

Group members: Mathilde Schinnes, Laila Andersland, Jørgen Borgersen, Marit Skjørestad

Table of Contents

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1.0 Document

1.1 Document History

Table 1: Document history

Revision	Description of change	Date
0.1	Document created	06.05.15
0.2	Filled inn requirements and elaborated	13.05.15
0.3	Corrected spelling	13.05.15
0.4	Moved the FEM analysis to a separate document	14.05.15
1.0	**Final release**	**15.05.15**

1.2 Abbreviations

Table 2: Abbreviations

Abbreviation	Description
BCD	Bolt circle diameter
FEM	Finite Element Method
FO&GT	Freudenberg Oil & Gas Technologies
HX	"H" profile seal ring name
ISO	International Organization for Standardization
LHS	Left hand side
RHS	Right hand side
ROV	Remotely Operated Vehicle
SPO	Compact Flange name prefix (From former company name Steel Products Offshore)
SW	Solid Works

2.0 Scope

The purpose of this document is to give an insight of the tests conducted to verify our system. The document serves a validation and a verification purpose, where it is questioned if the project group meets the requirement, and if the requirement was tested in a fulfilling manner.

The structure of this document is an elaboration of the Test plan schedule, in the Test Plan [4], where the system is divided into the various subsystems. Some of the requirements only regard one of the subsystems, while other requirements are more overall system related. Because of this, some of the requirements will be repeated several times.

The requirements and the related tests will be stated, followed with the documentation of the conducted test. As specified in the Test Plan [4], there will be conducted a quality assurance after every test. All though all the tests are commented in this document, the FEM-analyses are described in more detailed in a separate FEM Analysis Report [5].

3.0 Seal Ring System

3.1 Requirement 1.1

ID:	Source:	Origin date:	Update:	Priority:
1.1	FO&GT	29.01.2015	-	**A**

Description: The system shall be operated with the use of a ROV.
Related test: 1.1

Test ID:	Origin Date:	Last Update:	Test type:
1.1	30.01.2015	-	Inspection

Description: This requirement will be tested by visual examination. The project group will obtain current ISO Standard for ROV and check if the hydraulic connections and interfaces are according to the Standard.
Related requirement ID: 1.1

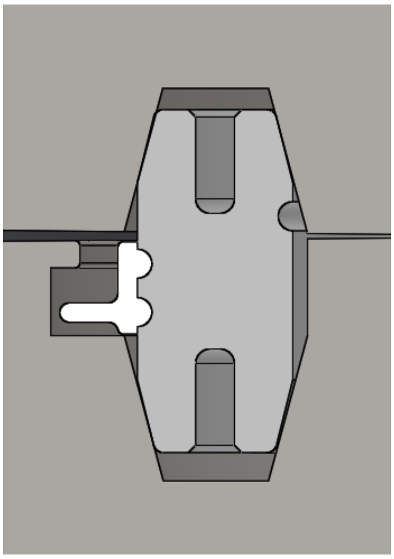


Figure 1: Rubber ring mounted around the seal ring (lhs)

Figure 2: Seal ring placed in the flanges (rhs)

The Seal Ring System will be in indirect contact with the ROV, seeing as there will be a system that will mount the seal ring in place.

- The rubber ring is designed so that a ROV operated tool can easily push the seal ring in to the flange.
- The seal ring is designed so that it is possible for a seal replacement tool to grip onto the inside diameter of the seal ring, where the groove is.

Test ID:	**Test type:**	**Designer:**	**First Inspection:**	**Second Inspection:**
1.1	Inspection	M.Skj.	J.B.B.	L.E.A.

Quality assurance test 1.1	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

3.2 Requirement 2.5

ID:	Source:	Origin date:	Update:	Priority:
2.5	FO&GT	29.01.2015	-	**A**
Description: It shall be possible to change the seal ring.				
Related test: 2.5				

Test ID:	Origin Date:	Last Update:	Test type:
2.5	30.01.2015	13.05.2015	Inspection
Description: The 3D simulation of the function of changing the seal ring will be examined in SW.			
Related Requirement ID: 2.5			

As mentioned in the detailed design document, a seal replacement tool will make it possible to change the seal ring subsea. The groove on the inside of the seal ring gives the tool a way to lock onto the seal ring prior to actuations to reliably remove from the hub and hold it in place until the ROV is ready to release it.

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
2.5	Inspection	M.Skj.	M.Sch.	L.E.A.

Quality assurance test 2.5	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

3.3 Requirement 3.3 and 3.4

ID:	Source:	Origin date:	Update:	Priority:
3.3	FO&GT	29.01.2015	**-**	**A**
Description: The seal ring shall be retained in one of the flanges.				
Related test: 3.3				

ID:	Source:	Origin date:	Update:	Priority:
3.4	FO&GT	29.01.2015	06.05.2015	**B**
Description: The seal ring should be retained in the swivel flange.				
Related test: 3.3, 3.9				

Test ID:	Origin Date:	Last Update:	Test type:
3.3	30.01.2015	-	Inspection
Description: The 3D model will show that the seal ring is retained in one of the flanges, preferably in the swivel flange.			
Related Requirement ID: 3.3, 3.4			

As showed in *figure 3,* the seal ring is designed to be retained in the swivel flange after being pushed into position using the tap and rubber ring.

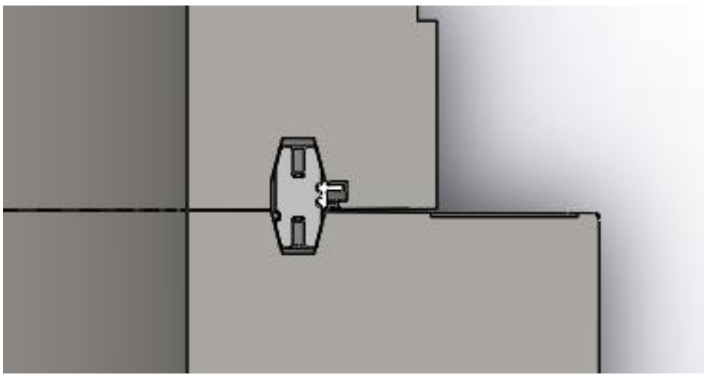


Figure 3: Seal ring fixed in the flange

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
3.3	Inspection	M.Skj.	M.Sch.	L.E.A.

Quality assurance test 3.3	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

Test ID:	Origin Date:	Last Update:	Test type:
3.9	16.02.2015	-	Demonstration
Description: The 3D printed model will demonstrate that the seal ring is retained in the swivel flange, preferably the swivel flange.			
Related Requirement ID: 3.4			

When this test was created, the project group expected that it would be a possibility to print the seal retaining system. As this consists of a rubber ring, it is not possible to show the functionality with a 3D print. We would have to mold the ring. We evaluated the remaining time of the project against the value of the test and decided to not proceed with this test.

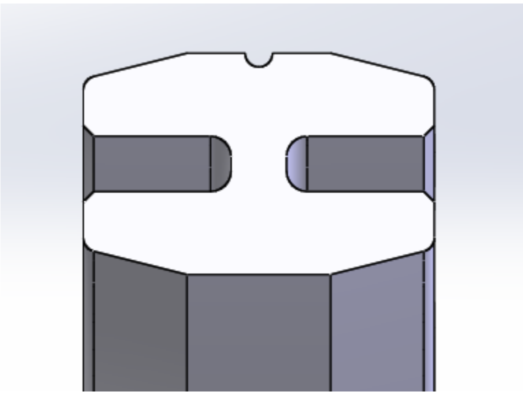
Quality assurance test 3.9	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	No

3.4 Requirement 3.5

ID:	**Source:**	**Origin date:**	**Update:**	**Priority:**
3.5	FO&GT	29.01.2015	**-**	**A**
Description: The HXL seal surfaces shall not be changed.				
Related test: 3.4				

Test ID:	**Origin Date:**	**Last Update:**	**Test type:**
3.4	30.01.2015		Inspection
Description: The 3D model will not include any changes of the HXL seal surfaces, which will be verified by inspection.			
Related Requirement ID: 3.5			

The four seal surfaces and the thickness of the ligaments is kept constant, and no changes are made to these. *Figure 4* shows the size of the original seal ring, and *figure 5* shows the size of the new seal ring.



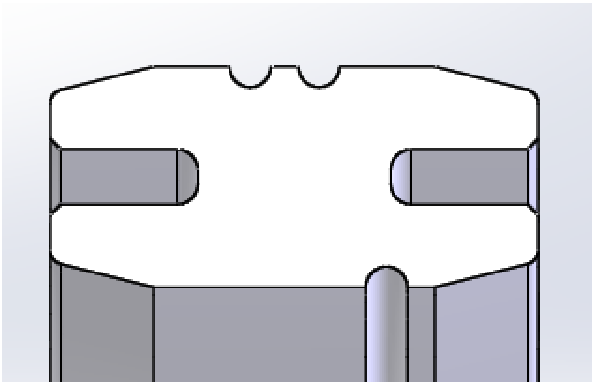


Figure 4: Original seal ring (lhs)

Figure 5: New seal ring (rhs)

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
3.4	Inspection	M.Skj.	L.E.A.	David

Quality assurance test 3.4	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

3.5 Requirement 3.12

ID:	Source:	Origin date:	Update:	Priority:
3.12		06.05.2015		**A**
Description: All new design choices made during the development process shall be functional.				
Related test: 3.11				

Test ID:	Origin Date:	Last Update:	Test type:
3.11	06.05.2015		Analysis
Description: Is shall be conducted a FEM analysis on all new features to verify its functionality.			
Related Requirement ID: 3.12			

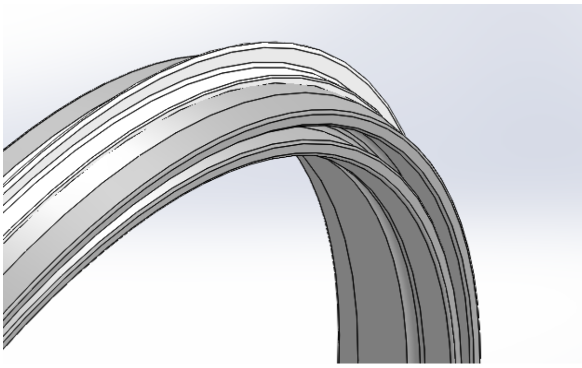


Figure 6: Rubber ring on the seal ring

Referring to the FEM analysis report [1], the conclusion of the conducted analysis is that the rubber ring will work as planned. It will deflect under the metal tip in the flange, and have enough room on the inside to bounce up again and provide the retainment.

Quality assurance test 3.11	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

4.0 Stud Turning System

4.1 Requirement 1.1

ID:	Source:	Origin date:	Update:	Priority:
1.1	FO&GT	29.01.2015	-	**A**
Description: The system shall be operated with the use of a ROV.				
Related test: 1.1				

Test ID:	Origin Date:	Last Update:	Test type:
1.1	30.01.2015	-	Inspection
Description: This requirement will be tested by visual examination. The project group will obtain current ISO Standards for ROV and check if the hydraulic connections and interfaces are according to the Standard.			
Related requirement ID: 1.1			

An insert of a ROV handle to the STTH fulfills this requirement. The ROV handle is placed close to the center of gravity, so that the system is symmetrical on both sides, which leads to equilibrium. The design of the ROV handle is according to the API ROV standard [2]. Maximum weight ROV are able to lift is 50 kg. The weight of the system is 45,7 kg.

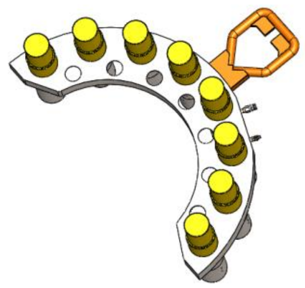
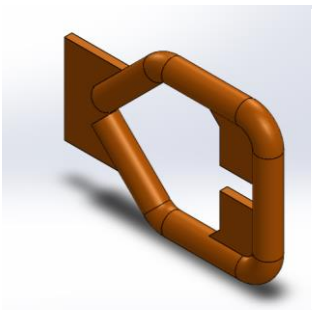
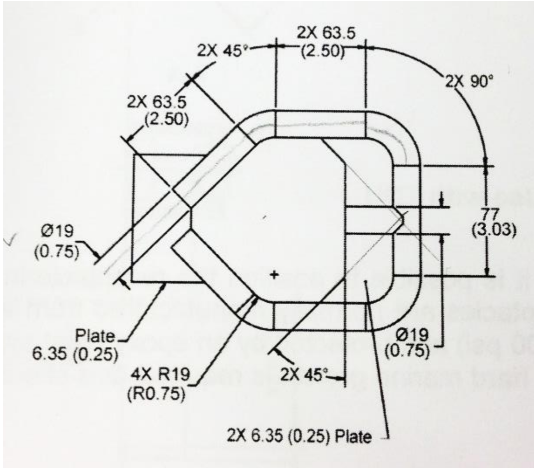




Figure 7: STTH (lhs)

Figure 8: ROV handle (middle)

Figure 9: ROV grabber bar (rhs)



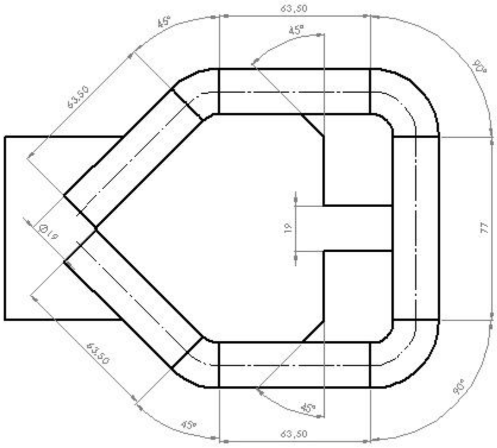


Figure 10: 2D drawing, API standard (lhs)

Figure 11: 2D drawing, designed ROV handle (rhs)

The incorporated guiding system is also made to make it easier for the ROV to hit the guide pins.

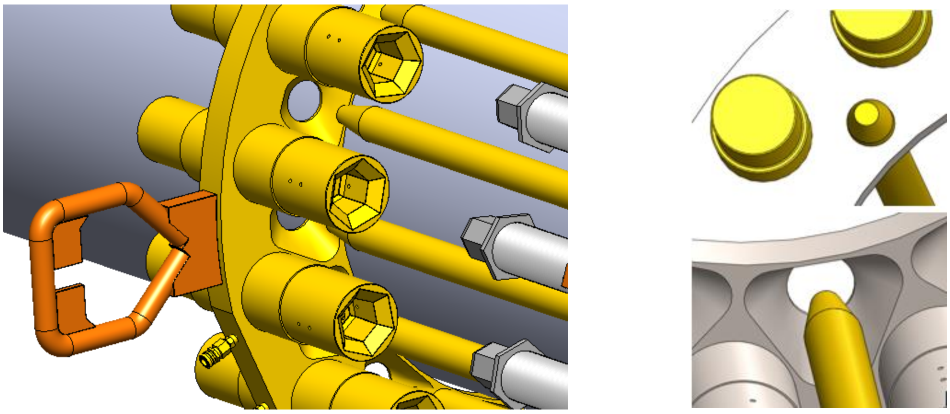


Figure 12: Guide pins in integrated guide funnels in STTH

Test ID:	**Test type:**	**Designer:**	**First Inspection:**	**Second Inspection:**
1.1	Inspection	M. Sch	M. Skj	L. E. A

Quality assurance test 1.1	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

4.2 Requirement 1.3

ID:	Source:	Origin date:	Update:	Priority:
1.3	FO&GT	29.01.2015	-	**A**
Description: The system shall be located subsea, up to 3000 meters depth.				
Related test: 1.4				

Test ID:	Origin Date:	Last Update:	Test type:
1.4	30.01.2015	16.02.2015	Analysis
Description: The project group will carry out a FEM analysis that will simulate up to 3000-meter water pressure.			
Related Requirement ID: 1.3			

Requirement 1.3 is fulfilled in the way the system is designed. Every part of the system is massive and is designed without any hollow space. This do not include the hydraulic turning tools, as the design of the tool is not the project groups' responsibility. The tooling company guarantee that the tool is designed to operate subsea and the tooling's behavior subsea is therefore the company's concern.

Since the system is designed without any hollow space, the pressure in the water of the depth of 3000 meter will not have any affect. The pressure will be acting on all surfaces with the same amount. The pressure will therefore be balanced. Based on the pressure balance theory, there have not been performed FEM analysis for test 1.4.

Quality assurance test 1.4	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	No

4.3 Requirement 1.4

ID:	**Source:**	**Origin date:**	**Update:**	**Priority:**
1.4	Stakeholder analysis	29.01.2015	16.02.2015	**C**
Description: The system shall be able to withstand ocean currents up to 0.6 m/s.				
Related test: 1.5				

Test ID:	**Origin Date:**	**Last Update:**	**Test type:**
1.5	30.01.2015	-	Analysis
Description: The project group will carry out a FEM analysis that will simulate ocean current up to 0.6 m/s.			
Related Requirement ID: 1.4			

As shown in the FEM analysis report the ocean current will not have any effect or damage on the stud turning system. Therefor the test is fulfilled.

Quality assurance test 1.5	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

4.4 Requirement 1.5 and 1.6

ID:	Source:	Origin date:	Update:	Priority:
1.5	Stakeholder analysis	29.01.2015	-	**B**
Description: The system shall withstand 25 years of anticipated design life subsea.				
Related test: 1.6				

ID:	Source:	Origin date:	Update:	Priority:
1.6	Stakeholder analysis	29.01.2015	-	**B**
Description: The system shall not experience failure due to HISC throughout its 25-year long lifetime.				
Related test: 1.6				

Test ID:	Origin Date:	Last Update:	Test type:
1.6	30.01.2015	-	Inspection
Description: This requirement will be tested by inspection of FO&GT, where they will observe the 3D model and the materials. FO&GT experience and expertise will give a good indication whether the system will withstand 25 years of anticipated external corrosion or internal erosion.			
Related Requirement ID: 1.5, 1.6			

The stud turning system is only designed for assembly and dis-assembly. The system is not integrated in the flange and will not be placed at the seabed. Because of this, the system do not need to fulfill requirement 1.5 and 1.6. However, these requirements still have influence over the design choices, especially the choice of material.

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
1.6	Inspection	M. Sch	M. Skj	L. E. A

Quality assurance test 1.6	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	No

4.5 Requirement 1.8

ID:	Source:	Origin date:	Update:	Priority:
1.8	Stakeholder analysis	29.01.2015	-	**C**
Description: The system could be able to withstand anticipated collision forces from a ROV.				
Related test: 1.8				

Test ID:	Origin Date:	Last Update:	Test type:
1.8	30.01.2015	16.02.2015	Analysis
Description: The project group will carry out a FEM analysis that will analyze some potential force concentrations on logical parts of the system due to unexpected water flow pushing the ROV or other unwanted events.			
Related Requirement ID: 1.8			

The stud turning system will be carried by the ROV itself. The system will therefore not be exposed for any collision forces. On the contrary, the system will be moved onto the pipe surface and use the pipe as a guidance. Because the system will be guided along the pipe, it have been executed a static FEM analysis to confirm that the system endure this sort of collision.

As shown in the FEM analysis report [1], there will not be any damage on the system when the face of the belt collide with the face of the pipe.

Quality assurance test 1.5	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

4.6 Requirement 3.7

ID:	Source:	Origin date:	Update:	Priority:
3.7	Stakeholder analysis	29.01.2015	16.02.2015	**A**
Description: The system should incorporate necessary ROV handles.				
Related test: 3.6				

Test ID:	Origin Date:	Last Update:	Test type:
3.6	30.01.2015	-	Inspection
Description: There will be an inspection of the 3D model too verify that the system includes ROV handles.			
Related Requirement ID: 3.7			

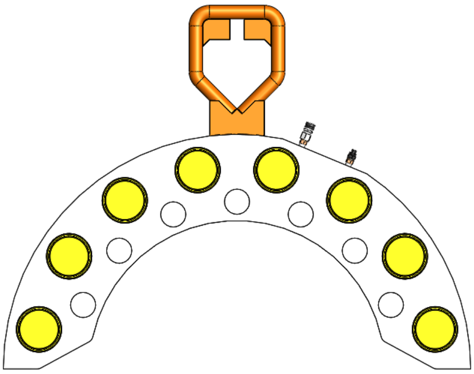


Figure 13: ROV handle

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
3.6	Inspection	M. Sch	M. Skj	L. E. A

Quality assurance test 3.6	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

4.7 Requirement 3.8

ID:	Source:	Origin date:	Update:	Priority:
3.8	Stakeholder analysis	29.01.2015	16.02.2015	**B**
Description: All ROV interfaces shall be painted in high visibility colors.				
Related test: 3.7				

Test ID:	Origin Date:	Last Update:	Test type:
3.7	30.01.2015	-	Inspection
Description: There will be an inspection of the 3D model that it includes ROV interfaces with high visibility colors and lifting points.			
Related Requirement ID: 3.8, 3.10			

As seen in *figure*, the ROV handle for the Stud Turning System is in a high visible color.

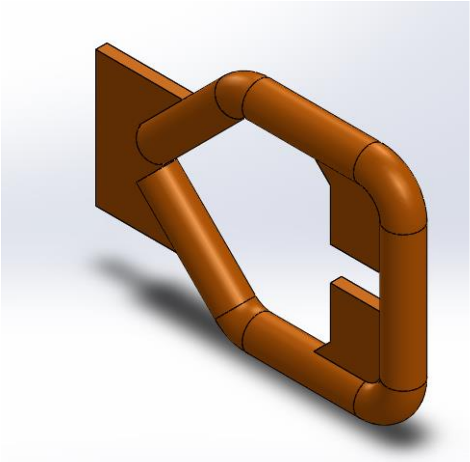


Figure 14: ROV handle

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
3.7	Inspection	M. Sch	L.E.A.	J.B.B.

Quality assurance test 3.7	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

5.0 Nut Retainment System

5.1 Requirement 2.1

ID:	Source:	Origin date:	Update:	Priority:
2.1	FO&GT	29.01.2015	11.03.2015	**A**
Description: The system should have bolt entering capabilities.				
Related test: 2.1, 2.9				

Test ID:	Origin Date:	Last Update:	Test type:
2.1	30.01.2015		Inspection
Description: The project group will inspect a 3D model to verify that the system includes adequate bolt entering capabilities.			
Related Requirement ID: 2.1			

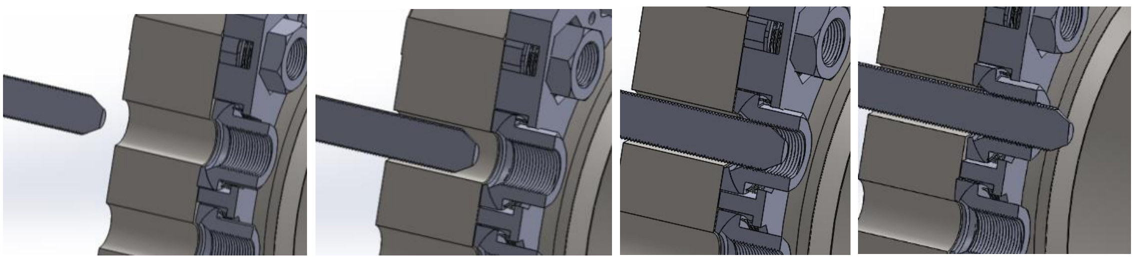


Figure 15: Stud entering, step 1-4

As shown in *figure 15,* we can see that the bolt enters the flange.

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
2.1	Inspection	L.E.A	M.Sch.	M.Skj.

Quality assurance 2.1	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

Test ID:	Origin Date:	Last Update:	Test type:
2.9	16.02.2015		Demonstration
Description: The project group will print a 3D model of the system showing the bolt entering capabilities.			
Related Requirement ID: 2.1			

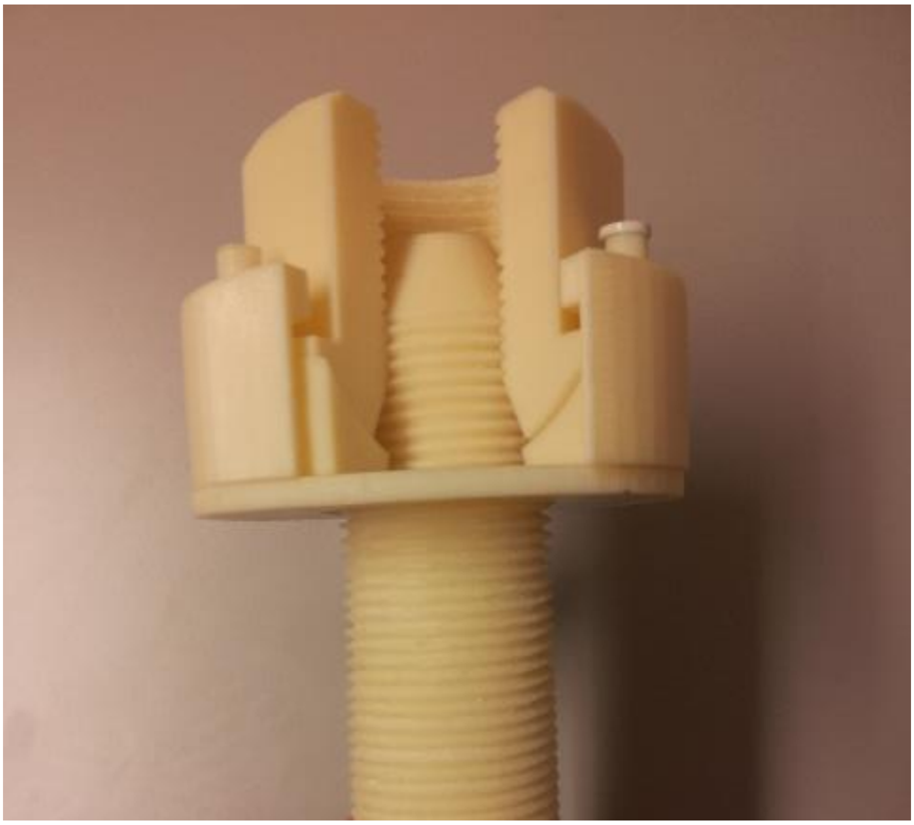


Figure 16: 3D print, nut retainment system

A 3D model of the nut retainment system was printed before it was decided to remove the three spring pistons and use a single spring instead. Since the surface of the material of the 3D print is quite different from the metal that the system will be made of, it did not give the smooth entering that was expected. It is also hard to simulate the stud turning tool, giving a constant speed at a fixed angle of 1.27 degrees.

Quality assurance 2.9	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	No

5.2 Requirement 2.9

ID:	Source:	Origin date:	Update:	Priority:
2.9	FO&GT	11.03.2015	13.05.2015	**A**
Description: The system shall be able to account for angular bolt misalignment.				
Related test: 2.10, 2.13				

Test ID:	Origin Date:	Last Update:	Test type:
2.10	11.03.2015	-	Inspection
Description: The project group will conduct an inspection of the system accounting the angular bolt misalignment.			
Related Requirement ID: 2.9			

The nut retainment system includes a solution for angular bolt misalignment, discussed further in the design document [3].

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
2.10	Inspection	L.E.A	David	J.B.B.

Quality assurance 2.10	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

Test ID:	Origin Date:	Last Update:	Test type:
2.13	06.05.2015	13.05.2015	Demonstration
Description: The project group will make a 3D print that will show the system accounting the angular bolt misalignment.			
Related Requirement ID: 2.9			

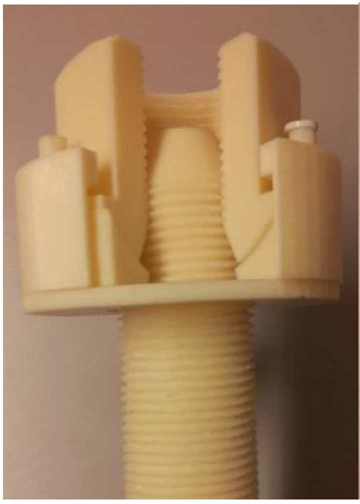
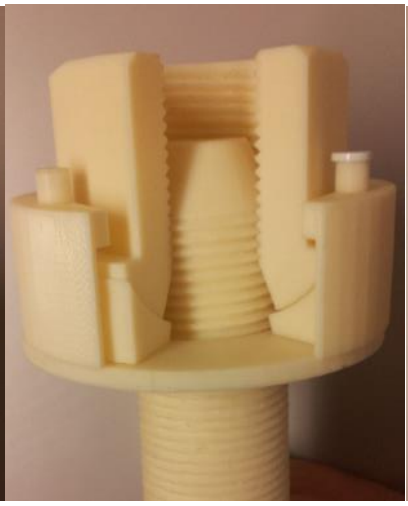
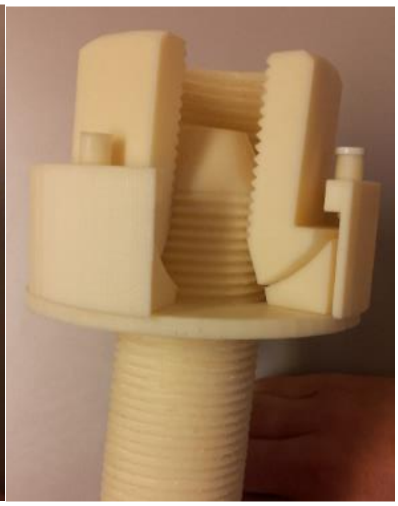




Figure 17. 3D print, no angle (lhs)

Figure 18: 3D print, tilted to the right (middle)

Figure 19: 3D print, tilted to the left (rhs)

The main issue of the nut retainment system is if the nut can pick up the stud threads if the stud is in an angle. The 3D print shows that the nut follows the stud, when the stud is pushed in an angle.

Quality assurance 2.10	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

5.3 Requirement 2.10

ID:	Source:	Origin date:	Update:	Priority:
2.10	FO&GT	11.03.2015	13.05.2015	**A**
Description: The stud bolts shall protrude 3 threads from the nuts surface at both sides.				
Related test: 2.11				

Test ID:	Origin Date:	Last Update:	Test type:
2.11	11.03.2015	06.05.2015	Inspection
Description: There will be an inspection that shows the stud bolts protruding three threads from the nuts at both sides of the flanges.			
Related Requirement ID: 2.10			

From the Calculation document [6], it is decided that the bolt will be 503mm long. As shown in *figure* 20, this will be enough to protrude three threads from the nut on the weld neck side.

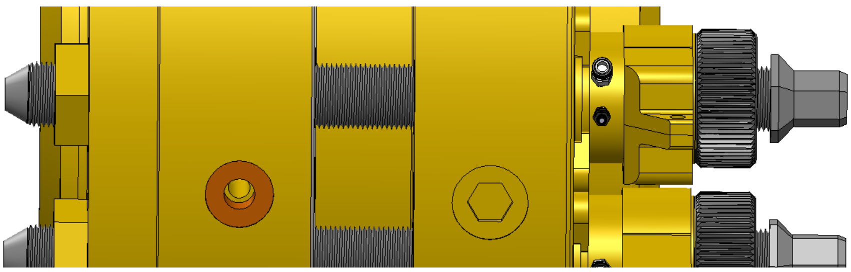


Figure 20: Stud protrusion

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
2.11	Inspection	L.E.A	J.B.B.	M.Skj.

Quality assurance 2.10	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

5.4 Requirement 3.6

ID:	Source:	Origin date:	Update:	Priority:
3.6	FO&GT	29.01.2015	16.02.2015	**C**
Description: The bolts could be replaceable.				
Related test: 3.5				

Test ID:	Origin Date:	Last Update:	Test type:
3.5	30.01.2015	13.05.2015	Inspection
Description: It will be an examination of a 3D motion study showing the bolts being replaced.			
Related Requirement ID: 3.6			

The design is made in a way so that the process can be reversed, and the bolts can be replaced if needed.

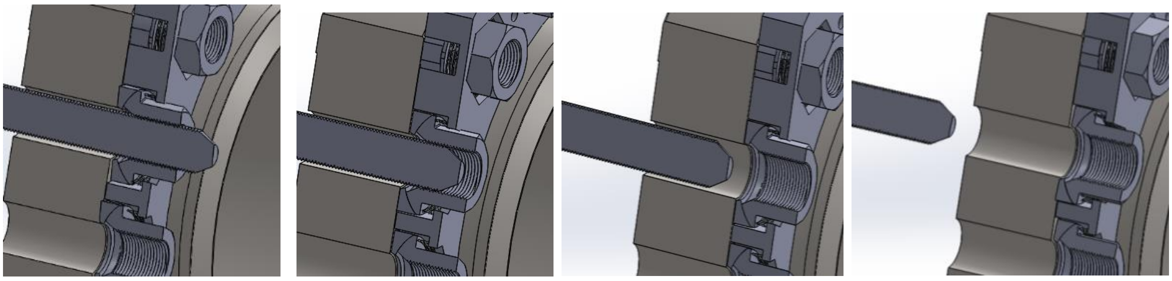


Figure 21: Stud exiting, step 1-4

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
3.5	Inspection	L.E.A	J.B.B.	M.Skj.

Quality assurance 3.5	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

5.5 Requirement 3.11

ID:	Source:	Origin date:	Update:	Priority:
3.11	Concept document	13.04.2015	**-**	**B**
Description: All the freedom should be on one side.				
Related test: 3.10				

Test ID:	Origin Date:	Last Update:	Test type:
3.10	13.04.2015	-	Inspection
Description: The system will be inspected to verify that the freedom is on one side.			
Related Requirement ID: 3.11			

All the freedom is in the nut retainment system on the WN flange. The hydraulic tools on the Swivel flange are rigid tools, and provides no degree of freedom.

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
3.10	Inspection	L.E.A	M.Skj.	J.B.B.

Quality assurance 3.10	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

5.6 Requirement 3.12

ID:	Source:	Origin date:	Update:	Priority:
3.12	The project group	06.05.2015	-	**A**
Description: All new design choices made during the development process shall be functional.				
Related test: 3.11				

This requirement concerns the washer, the nut, the belts and the spring, and they will all be tested with test 3.11.

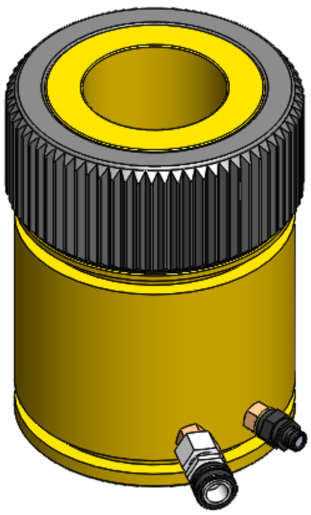
Test ID:	Origin Date:	Last Update:	Test type:
3.11	06.05.2015	-	Analysis
Description: It shall be conducted a FEM analysis on all new features to verify its functionality.			
Related Requirement ID: 3.12			

As we can see from the FEM analysis report [1], the washer, nut, bolt and belt fulfill the requirement of being functional. As the spring is a standard part and will be ordered, we have not executed FEM analysis on this part.

Quality assurance: Requirement 3.12	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

6.0 Hydraulic Tension System

The entire system consist of a SPO compact flange that will be tightened with the use of 16 bolts and a special hydraulic tension system. The Hydraulic Tension System includes hydraulic nuts and a load collar locking system.



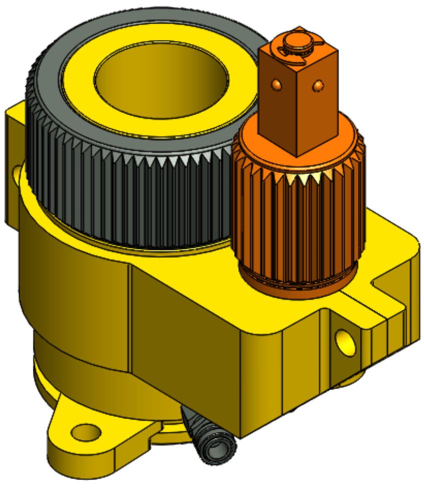


Figure 22: Hydraulic nut (lhs)

Figure 23: Hydraulic nut with load collar locking system (rhs)

6.1 Requirement 1.1

ID:	**Source:**	**Origin date:**	**Update:**	**Priority:**
1.1	FO&GT	29.01.2015	**-**	**A**
Description: The system shall be operated with the use of a ROV.				
Related test: 1.1				

Test ID:	**Origin Date:**	**Last Update:**	**Test type:**
1.1	30.01.2015	-	Inspection
Description: This requirement will be tested by visual examination. The project group will obtain current ISO Standard for ROV and check if the hydraulic connections and interfaces are according to the Standard.			
Related requirement ID: 1.1			

The hydraulic nuts will be connected to the locking system, which will be in direct contact with the ROV. The ROV will be connected to the square tap on top of the counter gear. The ROV handle is designed to perfectly embrace this square, so that it is operable.

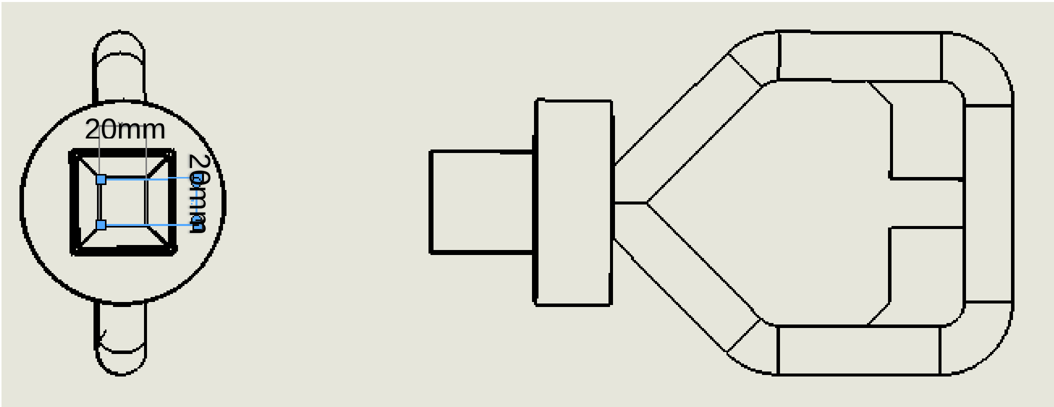


Figure 24: 2D drawing of the ROV interface dimensions

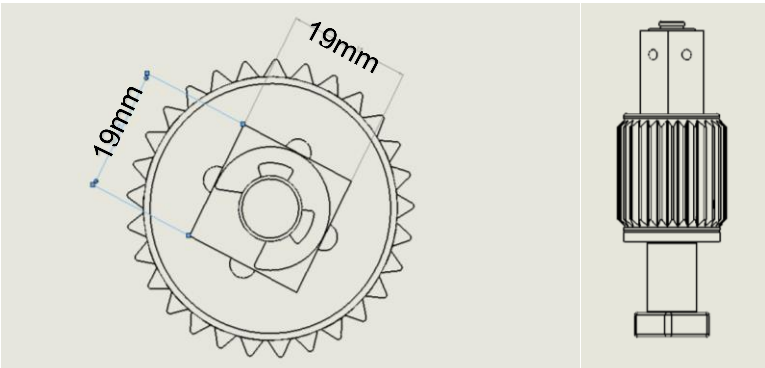


Figure 25: 2D drawing of the counter gear dimensions

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
1.1	Inspection	M.Sch.	J.B.B.	L.E.A.

Quality assurance 1.1	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

6.2 Requirement 1.3

ID:	Source:	Origin date:	Update:	Priority:
1.3	FO&GT	29.01.2015	**-**	**A**
Description: The system shall be located subsea, up to 3000 meters depth.				
Related test: 1.4				

Test ID:	Origin Date:	Last Update:	Test type:
1.4	30.01.2015	-	Analysis
Description: The project group will carry out a FEM analysis that will simulate up to 3000 meter water pressure.			
Related Requirement ID: 1.3			

Since there will be a pressure difference between the inside of the hydraulic nut and the water outside this requirement is relevant to the tooling. The hydraulic tools will be bought from a company that specializes in subsea tools. The project group agreed that it is fear to assume that this precaution is dealt with from the tool company side.

Quality assurance 1.4	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	No

6.3 Requirement 2.2

ID:	Source:	Origin date:	Update:	Priority:
2.2	FO&GT	29.01.2015	11.03.2015	**A**
Description: The system should have hydraulic bolt pre-loading capabilities.				
Related test: 2.2				

Test ID:	Origin Date:	Last Update:	Test type:
2.2	30.01.2015	16.02.2015	Inspection
Description: This test include an examination of a 3D model to visualize that the system includes hydraulic bolt pre-loading capabilities.			
Related Requirement ID: 2.2			

The hydraulic nut does the pre-loading. As showed in *figure 24,* the hydraulic nuts are placed on the flange.

Figure 26: Hydraulic nuts

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
2.2	Inspection	J.B.B.	L.E.A.	M.Sch.

Quality assurance 2.2	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

6.4 Requirement 2.3

ID:	Source:	Origin date:	Update:	Priority:
2.3	FO&GT	29.01.2015	16.02.2015	**B**
Description: The pre-loading tool shall be able to give a residual pre-load of 75% of yield of the chosen bolt.				
Related test: 2.3				

Test ID:	Origin Date:	Last Update:	Test type:
2.3	30.01.2015	-	Analysis
Description: To test if the pre-loading tool is able to give the exact load it will be designed to give the exact hydraulic power needed and analyzed with FEM and calculations.			
Related Requirement ID: 2.3			

As enclosed in the design document, [3] the hydraulic nut will be customized, so that we can choose the preload needed. The hydraulic nut will have following specifications:

Table 3: Hydraulic nut specifications

16 bolts	
Tooling	
Name	TCHW:1750
Diameter	86mm
Capacity	445kN
Flange	
Diameter	653.7mm
Bolt Hole	49mm
BCD	563.7mm
Recess in	510mm
Recess out	617mm
Bolt	
Area	1132.67mm^2
Size	1 ¾ inch

A barometer will provide the necessary information for verifying adequate pre-load. The barometer will be located on a ROV-panel, visible for the operator to see as he performs the pre-load operation.

Quality assurance 2.3	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	No

6.5 Requirement 2.11

ID:	Source:	Origin date:	Update:	Priority:
2.11	Concept document	13.04.2015	**-**	**A**
Description: There shall be individual tightening on the locking collar on the hydraulic tool.				
Related test: 2.12				

Test ID:	Origin Date:	Last Update:	Test type:
2.12	13.04.2015	-	Inspection
Description: There will be a visual examination to verify if the system includes a locking collar on the hydraulic tool.			
Related Requirement ID: 2.11			

This requirement is solved with the gear-locking collar that the ROV will operate individually.

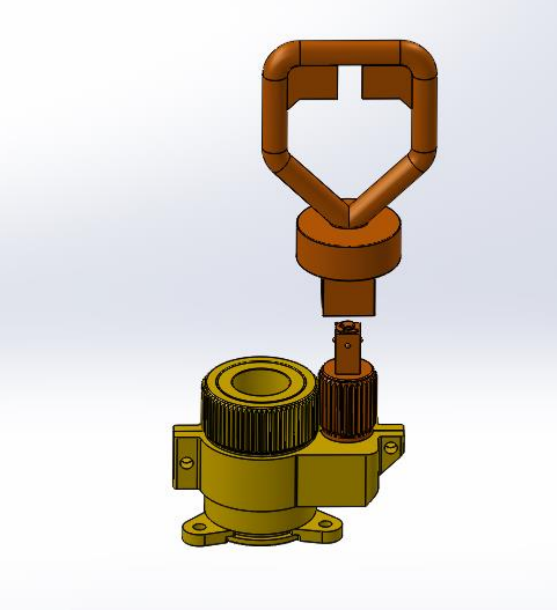


Figure 27: Locking collar on the hydraulic tool

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
2.12	Inspection	J.B.B.	M.Skj.	L.E.A.

Quality assurance 2.12	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

6.6 Requirement 3.8

ID:	Source:	Origin date:	Update:	Priority:
3.8	Stakeholder analysis	29.01.2015	16.02.2015	**B**
Description: All ROV interfaces shall be painted in high visibility colors.				
Related test: 3.7				

Test ID:	Origin Date:	Last Update:	Test type:
3.7	30.01.2015	-	Inspection
Description: There will be an inspection of the 3D model that it includes ROV interfaces with high visibility colors and lifting points.			
Related Requirement ID: 3.8, 3.10			

As shown in *figure 28,* the counter gear that will be in direct contact with the ROV is painted in an orange color. This is also according to the ROV standard [2].

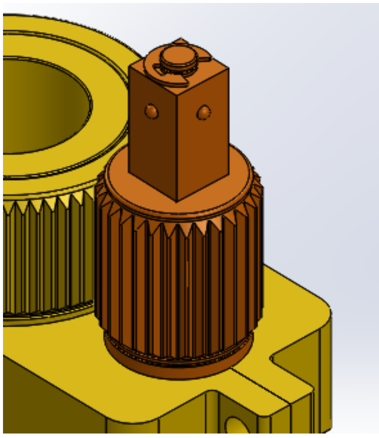


Figure 28: High visible color

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
3.7	Inspection	M.Sch.	M.Skj.	L.E.A.

Quality assurance 3.7	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

6.7 Requirement 3.12

ID:	Source:	Origin date:	Update:	Priority:
3.12	The project group	06.05.2015	**-**	**A**
Description: All new design choices made during the development process shall be functional.				
Related test: 3.11				

Test ID:	Origin Date:	Last Update:	Test type:
3.11	06.05.2015	-	Analysis
Description: It shall be conducted a FEM analysis on all new features to verify its functionality.			
Related Requirement ID: 3.12			

As commented in the FEM analysis report [1], the design changes on the hydraulic tool will not have a big effect on the tool.

Quality assurance: Requirement 3.12	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

7.0 Flange System

7.1 Requirement 2.6

ID:	Source:	Origin date:	Update:	Priority:
2.6	FO&GT	12.02.2015	13.05.2015	**A**
Description: Pre-load must be evenly distributed around the flange.				
Related test: 2.6				

Test ID:	Origin Date:	Last Update:	Test type:
2.6	16.02.2015	13.05.2015	Inspection
Description: This test include an examination of a 3D motion study to visualize the flange pre-load being evenly distributed.			
Related Requirement ID: 2.6			

The matter were discussed with our external examiner, who informed us that our incorporation of 16 studs would provide a more than satisfactory load distribution.

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
2.6	Inspection	J.B.B.	M.Sch.	L.E.A

Quality assurance test 2.6	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

7.2 Requirement 3.1

ID:	Source:	Origin date:	Update:	Priority:
3.1	FO&GT	29.01.2015	-	**A**
Description: The connection shall be a swivel ring to weld neck SPO type Compact Flange.				
Related test: 3.1				

Test ID:	Origin Date:	Last Update:	Test type:
3.1	30.01.2015	13.05.2015	Inspection
Description: The will be an examination of the 3D model, to verify that it includes a connection type is a swivel ring to weld neck SPO Compact Flange.			
Related Requirement ID: 3.1			

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
3.1	Inspection	J.B.B.	M.Sch.	L.E.A

Quality assurance test 3.1	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

7.3 Requirement 3.12

ID:	Source:	Origin date:	Update:	Priority:
3.12	The project group	06.05.2015	**-**	**A**
Description: All new design choices made during the development process shall be functional.				
Related test: 3.11				

Test ID:	Origin Date:	Last Update:	Test type:
3.11	06.05.2015	-	Analysis
Description: It shall be conducted a FEM analysis on all new features to verify its functionality.			
Related Requirement ID: 3.12			

The project group have worked close with FO&GT personnel, and consulted with them about satisfying this requirement regarding the flanges. This is something FO&GT can easily do better themselves, and the value of us doing a FEM analysis on the flange is therefore of little value.

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
3.11	Inspection	J.B.B.	M.Skj.	M.Sch.

Quality assurance test 3.1	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	No

8.0 Verification System

8.1 Requirement 1.9

8.1.1 Test Port

ID:	Source:	Origin date:	Update:	Priority:
1.9	FO&GT	29.01.2015	16.02.2015	**A**
Description: The weld neck flange shall have an inter seal test port for an assembly verification test.				
Related test: 1.9				

Test ID:	Origin Date:	Last Update:	Test type:
1.9	30.01.2015	-	Inspection
Description: The project group will examine the system and verify that it includes an intern seal test port.			
Related Requirement ID: 1.9			

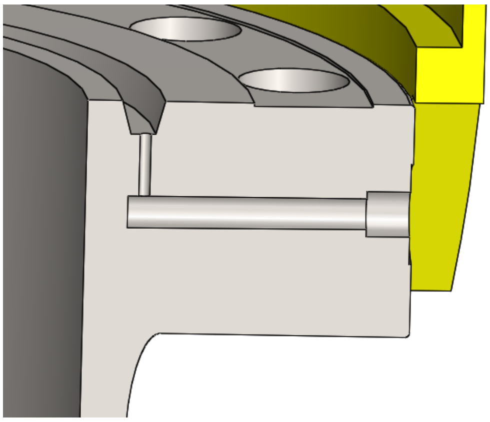


Figure 29: Test port

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
1.9	Inspection	J.B.B.	M.Sch.	L.E.A

Quality assurance test 1.9	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

8.2 Requirement 3.8

8.2.1 Test Port

ID:	Source:	Origin date:	Update:	Priority:
3.8	Stakeholder analysis	29.01.2015	16.02.2015	**B**
Description: All ROV interfaces shall be painted in high visibility colors.				
Related test: 3.7				

Test ID:	Origin Date:	Last Update:	Test type:
3.7	30.01.2015		Inspection
Description: There will be an inspection of the 3D model that it includes ROV interfaces with high visibility colors and lifting points.			
Related Requirement ID: 3.8, 3.10			

The test port system is designed with high visible colors.

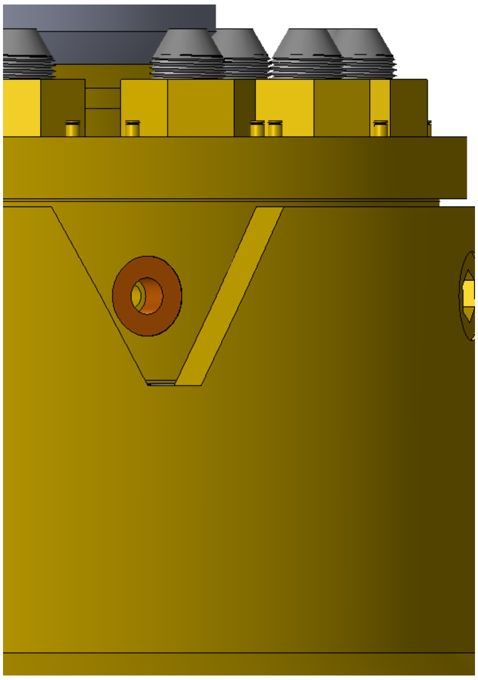


Figure 30: High visibility, test port

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
3.7	Inspection	J.B.B.	M.Skj.	M.Sch

Quality assurance test 2.8	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

8.3 Requirement 2.7

8.3.1 Pipe Alignment

ID:	Source:	Origin date:	Update:	Priority:
2.7	Stakeholder analysis	29.01.2015	16.02.2015	**C**
Description: There could be a visual indicator when pipe alignment has been achieved.				
Related test: 2.7				

Test ID:	Origin Date:	Last Update:	Test type:
2.7	30.01.2015	-	Inspection
Description: There will be a visual examination to verify if the 3D model includes an indicator for when satisfactory pipe alignment is achieved.			
Related Requirement ID: 2.7			

As stated in the Design Document [3], this will be achieved by having black lines painted on the guide collar and guide pins, so that they form a collinear line when the flanges are aligned.

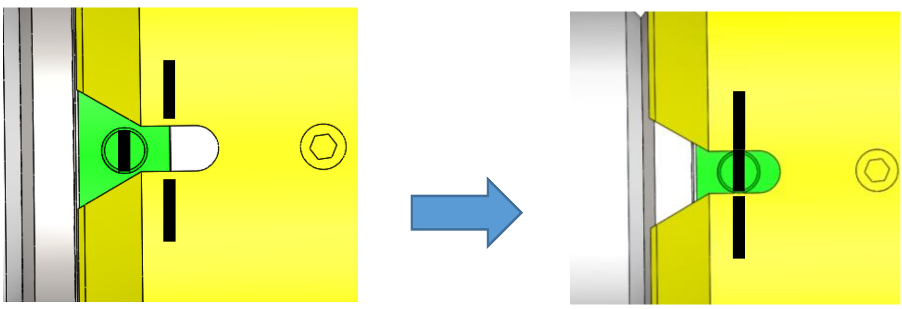


Figure 31: Visual indicator, pipe alignment

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
2.7	Inspection	J.B.B.	M.Skj.	L.E.A.

Quality assurance test 2.7	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

8.4 Requirement 2.8

8.4.1 Pre-load

ID:	Source:	Origin date:	Update:	Priority:
2.8	Stakeholder analysis	29.01.2015	16.02.2015	**C**
Description: There could be a visual indicator when the bolts have been pre-loaded.				
Related test: 2.8				

Test ID:	Origin Date:	Last Update:	Test type:
2.8	30.01.2015		Inspection
Description: There will be a visual examination to verify if the system includes a flag indicator for when satisfactory pre-loading is achieved.			
Related Requirement ID: 2.8			

As stated in the Design Document [3], a barometer will be located on a ROV-panel, visible for the operator to see as he performs the pre-load operation.

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
2.8	Inspection	J.B.B.	L.E.A.	M.Skj.

Quality assurance test 2.8	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

9.0 Crude System

9.1 Requirement 3.2

ID:	Source:	Origin date:	Update:	Priority:
3.2	FO&GT	29.01.2015	-	**B**
Description: The swivel flange design should have a guiding mechanism, which will rotate the swivel ring into the right position.				
Related test: 3.2, 3.8				

Test ID:	Origin Date:	Last Update:	Test type:
3.2	30.01.2015	13.05.2015	Inspection
Description: There will be made a 3D motion study of the rotation of swivel ring in to right position.			
Related Requirement ID: 3.2			

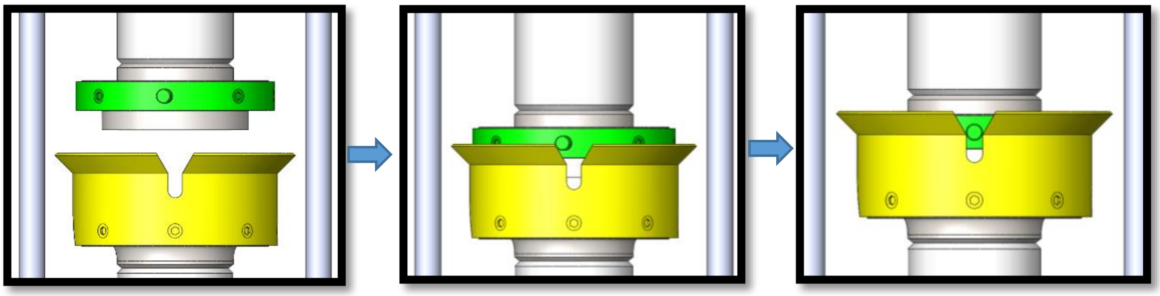


Figure 32: Guiding mechanism

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
3.2	Inspection	J.B.B.	David	L.E.A.

Quality assurance test 3.2	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

Test ID:	Origin Date:	Last Update:	Test type:
3.8	16.02.2015	-	Demonstration
Description: The 3D printed model will show the rotation of swivel ring in to right position.			
Related Requirement ID: 3.2			

The project group initially planned to print the entire system to show the mechanical functions, but the value of the print was considered as less important than other tasks and was therefore down prioritized.

Quality assurance test 3.8	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	No

9.2 Requirement 3.10

ID:	**Source:**	**Origin date:**	**Update:**	**Priority:**
3.10	Stakeholder analysis	29.01.2015	**-**	**C**
Description: The system could incorporate lifting points.				
Related test: 3.7				

Test ID:	**Origin Date:**	**Last Update:**	**Test type:**
3.7	30.01.2015	-	Inspection
Description: There will be an inspection of the 3D model that it includes ROV interfaces with high visibility colors and lifting points.			
Related Requirement ID: 3.8, 3.10			

Test ID:	**Test type:**	**Designer:**	**First Inspection:**	**Second Inspection:**
3.7	Inspection	J.B.B.	L.E.A.	M.Skj.

Quality assurance test 3.7	
Are the requirement fulfilled in a proper way?	No
Are the related test(s) fulfilled in a proper way?	Yes

9.3 Requirement 3.8

ID:	Source:	Origin date:	Update:	Priority:
3.8	Stakeholder analysis	29.01.2015	16.02.2015	**B**
Description: All ROV interfaces shall be painted in high visibility colors.				
Related test: 3.7				

Test ID:	Origin Date:	Last Update:	Test type:
3.7	30.01.2015	-	Inspection
Description: There will be an inspection of the 3D model that it includes ROV interfaces with high visibility colors and lifting points.			
Related Requirement ID: 3.8, 3.10			

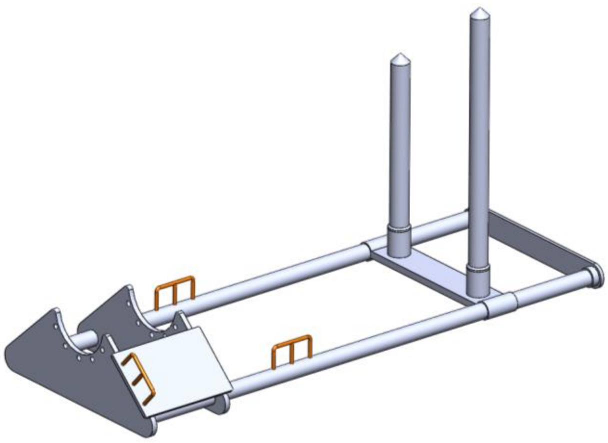


Figure 33: High visibility ROV interfaces, Crude System

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
3.7	Inspection	J.B.B.	M.Sch	M.Skj.

Quality assurance test 3.7	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

9.4 Requirement 3.7

ID:	Source:	Origin date:	Update:	Priority:
3.7	Stakeholder analysis	29.01.2015	16.02.2015	**A**
Description: The system should incorporate necessary ROV handles.				
Related test: 3.6				

Test ID:	Origin Date:	Last Update:	Test type:
3.6	30.01.2015	-	Inspection
Description: There will be an inspection of the 3D model too verify that the system includes ROV handles.			
Related Requirement ID: 3.7			

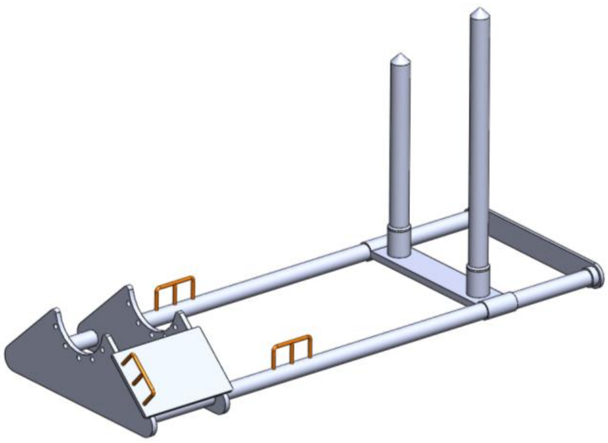


Figure 34: ROV handle, Crude System

Test ID:	Test type:	Designer:	First Inspection:	Second Inspection:
3.6	Inspection	J.B.B.	M.Sch	M.Skj.

Quality assurance test 3.6	
Are the requirement fulfilled in a proper way?	Yes
Are the related test(s) fulfilled in a proper way?	Yes

10.0 Conclusion

The project group have tried to have a close working relationship with the contractor, to ensure to meet their need and because of this; some of the tests are more complementary than others.

Eight of the test and one requirement were not fulfilled. In the cases where the tests are not conducted properly, the reason was a combination of limited time and value of the test. Some of the tests were made before we knew if it was a necessary test to conduct. In the case where the requirement (crude system: requirement 3.10, test 3.7) is not met, we did not have time to work with the design of the lifting points.

In conclusion, we had to cut our loses, and complete the documentation. Since this project is tailored to follow HBV guidelines, and not a completely real development process, there are much more work to do to complete a realistic test-process.

11.0 References

[1] FEM Analysis Report; ROV operated SPO compact flange, Bachelor thesis 2015.

[2] Remotely Operated Tools and Interfaces on Subsea Production Systems, API Recommended Practice 17H, Second edition, June 2013.

[3] Design Document; ROV operated SPO compact flange, Bachelor thesis 2015.

[4] Test Plan; ROV operated SPO compact flange, Bachelor thesis 2015.

[5] FEM Analysis Report; ROV operated SPO compact flange, Bachelor thesis 2015.

[6] Calculation Document; ROV operated SPO compact flange, Bachelor thesis 2015.

Installation and Assembly Procedure

ROV operated SPO compact flange for subsea assembly in deep water

Document No.:	Version No.:	Date:	Document responsible:	Group:	Status:
11.0	1.0	15.05.2015	Marit Skjørestad	3	Completed

Group members: Mathilde Schinnes, Laila Andersland, Jørgen Borgersen, Marit Skjørestad

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1.0 Document

1.1 Document History

Table 1: Document history

Revision	Description of change	Date
0.1	First layout	08.05.15
0.2	Corrected spelling	14.05.15
1.0	**Final release**	**15.05.15**

1.2 Abbreviations

Table 2: Abbreviations

Abbreviation	Description
CF	Compact flange
FO&GT	Freudenberg Oil & Gas Technologies
HSE	Health, Safety and Environment
HX	"H" profile seal ring name
ROV	Remotely operated vehicle
SPO	Compact Flange name prefix (From former company name Steel Products Offshore)
SW	Swivel flange
WN	Weld neck
WROV	Work class ROV

2.0 Scope

The purpose of this document is to describe the general procedure for the installation and assembly of the ROV operated SPO Compact Flange. At first it will go through the assembly of the product to make it ready for installation. Then it'll go through the preparatory procedures that need to be performed topside before submersion. In the end it will specify the assembly and installation procedures that will be performed subsea.

The SPO Compact Flange is particularly advantageous in subsea applications, because the double seal system greatly reduces the probability of leaks and the fatigue strength and corrosion resistant design eliminates maintenance and repair [2]. SPO Compact Flanges are far more convenient to install subsea because of the high level of pre-stress as it provides increased bolt force for pulling in flanges and accommodating misalignment. The specialized ROV operated SPO CF will have a hydraulic stud turning system and a nut retainment system for the stud bolt to automatically pick up the threads in the nut. The stud bolts will be tensioned by an integrated hydraulic nut, and mechanically locked. All operations are designed to be performed by a ROV.

3.0 Responsibilities

The project group is responsible for the revision of this procedure. The company assembling the connections is responsible for the proper implementation of this procedure. All work shall be performed to established HSE routines ensuring that no people will be harmed during the assembly or dis-assembly of ROV operated SPO Compact Flanges.

4.0 System Definition

Swivel Flange

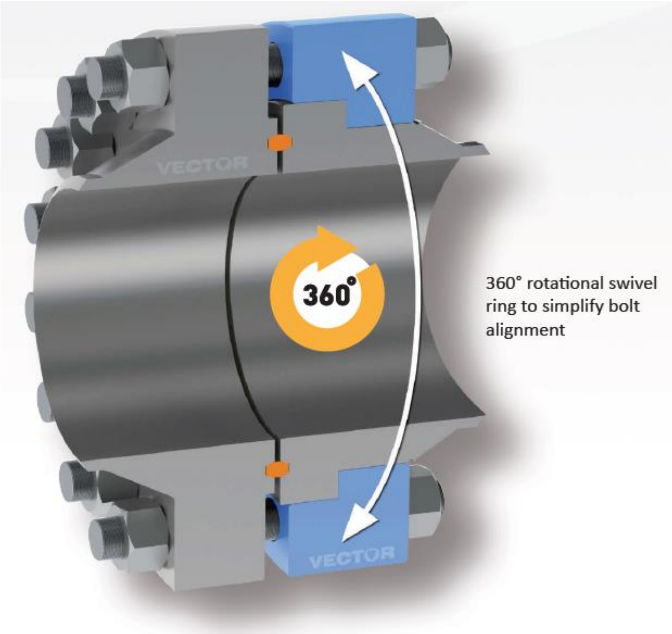


Figure 1: Swivel flange

HX Seal Ring with Rubber Ring

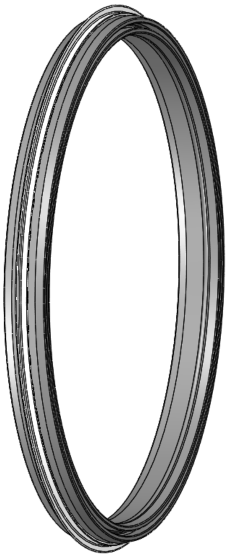


Figure 2: HX seal ring with rubber ring

Stud Turning System

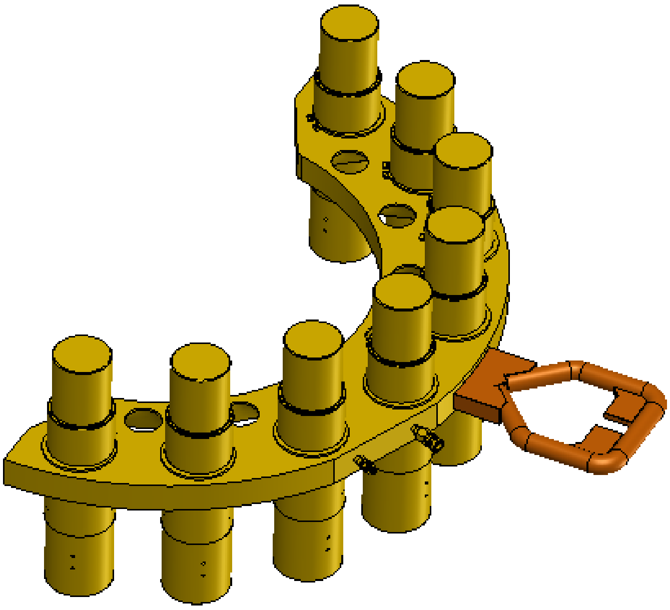


Figure 3: Stud turning system

Nut Retainment System

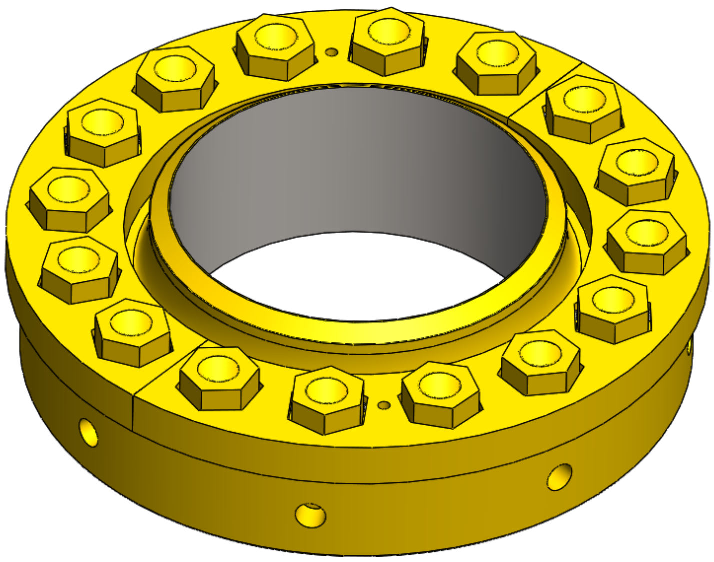


Figure 4: Nut retainment system

Hydraulic Tool

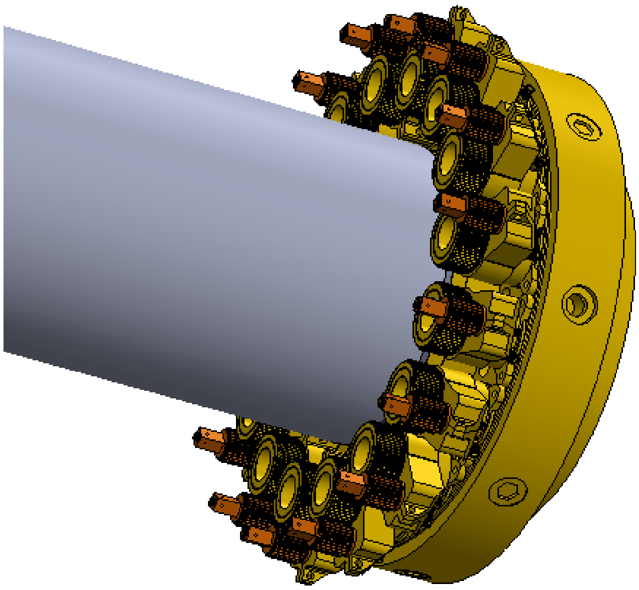


Figure 5: Hydraulic tool

Work Class ROV

Figure 6: Work class ROV

5.0 Equipment

The following table lists the minimum equipment requirements for normal installation and dis-assembly.

Table 3: Equipment list

Description	Quantity
Mating flanges	2
HX seal ring	1
Rubber ring	1
Non-abrasive soft cloths	1
Cleaning solvent	1
Seal ring replacement tool	1
Stud bolt set to suit	16
Swivel retaining circlip	1
Seat	16
Stem	16
Counter gear	16
Retainment washer	16
Loctite	1
Tension tools	16
Tool retainer + suitable fixings	48
Tool clamp + suitable fixings	16
Nuts	16
Washers	16
Springs	16
Semicircle belts + suitable fixings	2
Guide pins	16
Male alignment ring	1
Female alignment collar	1
Stud turning tool system	1
WROV	1

6.0 Preparatory Procedure Topside

6.1 Verify Components

6.1.1 Verify that all components are of correct material, type and size.

6.1.2 Size of flange, material and required seal ring type and size are marked on the outside diameter of all loose flanges.

6.1.3. Seal ring is marked with size and material.

6.1.4. Bolting shall be marked with a material code.

6.1.5. Ensure correct quantity and size of washers and nuts [1].

6.2 Flange Inspection

6.2.1 Remove the flange face protection.

6.2.2 Use a nonabrasive clean soft cloth and solvent to clean all components to remove grease, preservation and dirt from all surfaces (Take special care on sealing faces and contact areas, see *figure 7*).

6.2.3 The suitable solvent must not damage the metal surface and must meet any local HSE requirements.

6.2.4 Examine all sealing surfaces for mechanical damage and rust. Run a fingertip over seal surfaces to detect any dents, scratches, gouges etc.

6.2.5 Ensure the bolt holes are clean and free of any debris.

6.2.6 Re-apply protection cover before further handling and alignment [1].

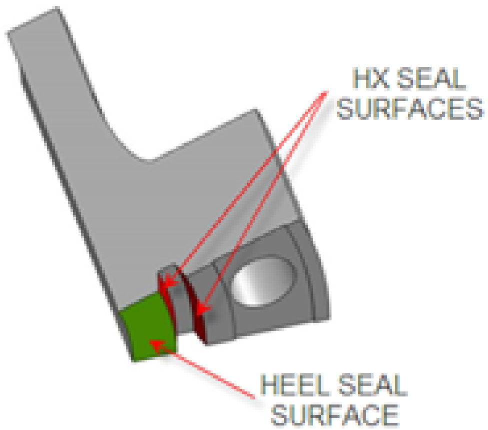


Figure 7: Flange seal surfaces

6.3 Seal Ring Inspection

6.3.1 Carefully unpack seal ring from packaging.

6.3.2 Examine the seal ring sealing surfaces for any damage. If found then replace the seal ring.

6.3.5 Place seal ring on a clean, dry surface and protect prior to use. (E.g. use original packing) [1].

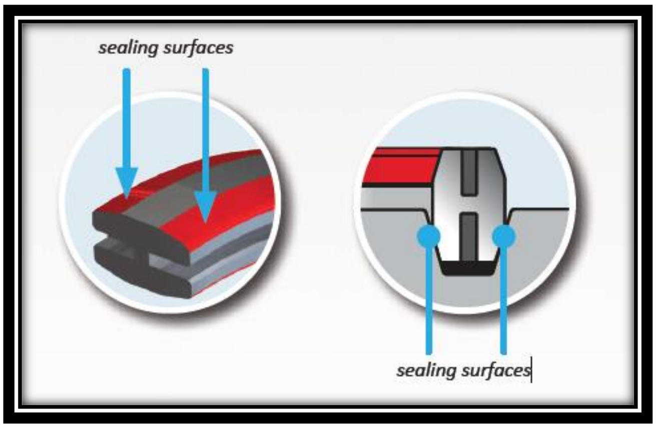


Figure 8: Seal ring seal surfaces

6.4 Stud Bolt Inspection

6.4.1 Examine every stud and nut to ensure they are clean and free from damage or corrosion.

6.4.2 Replace if necessary [1].

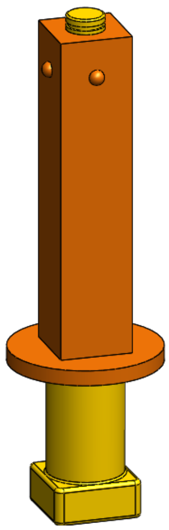
7.0 Assembly of the Flange Topside

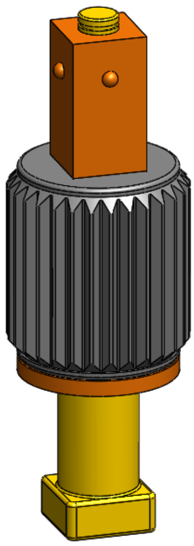
7.1 Assembly of Counter Gear

7.1.1 Place the seat over the stem, resting on the shelf of the stem.

7.1.2 Glue the counter gear to the seat with Loctite.

7.1.3 Push the retainment washer on top of the stem.





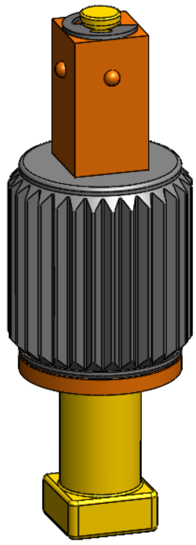


Figure 9: Seat

Figure 10: Counter gear

Figure 11: Retainment washer

7.2 Fasten Hydraulic Tool and Counter Gear on SW Flange

7.2.1 Place the hydraulic tools over the bolt holes in the swivel ring. Make sure that the hydraulic connections on the tool is facing outwards.

7.2.2 Place the three tool retainers in the bottom slot in the tool, and over the small bolt holes in the flange.

7.2.3 Fasten the retainers with bolts. The hydraulic tool is now fixed on the flange.

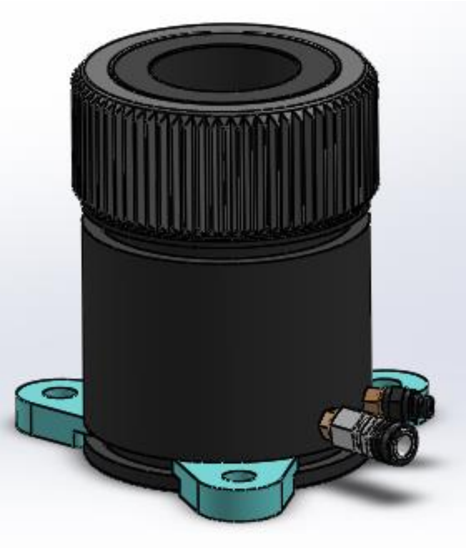
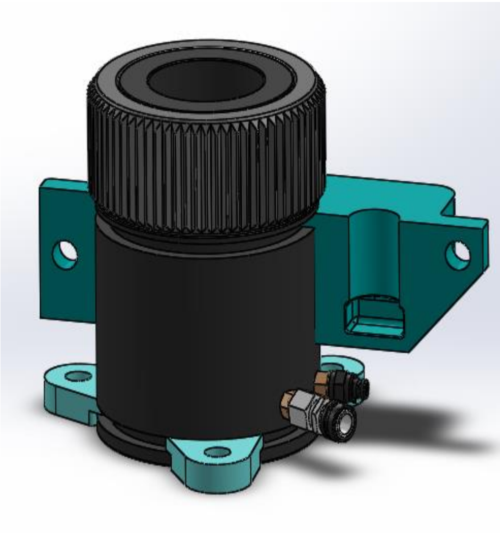


Figure 12: Hydraulic tool

7.2.4 Place the half clamp in the top slot in the hydraulic tool.

7.2.5 Place the counter gear in the groove in the clamp.



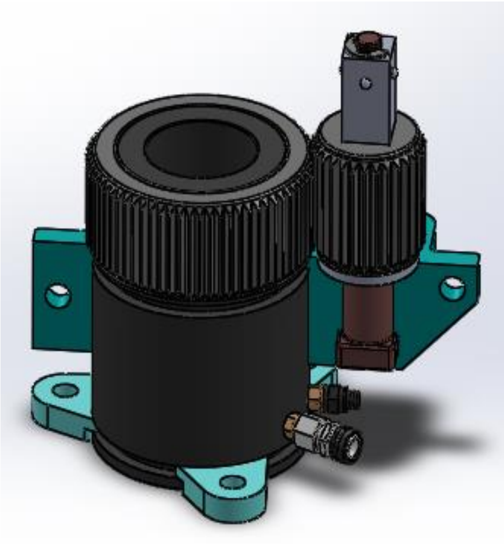


Figure 13: Hydraulic tool with clamp

Figure 14: Hydraulic tool with counter gear

7.2.6 Place the other half of the clamp on the opposite side, and fix the clamp with two bolts and nuts. The counter gear is now fixed on the tool.

7.2.7 Connect the hydraulic tools in series.

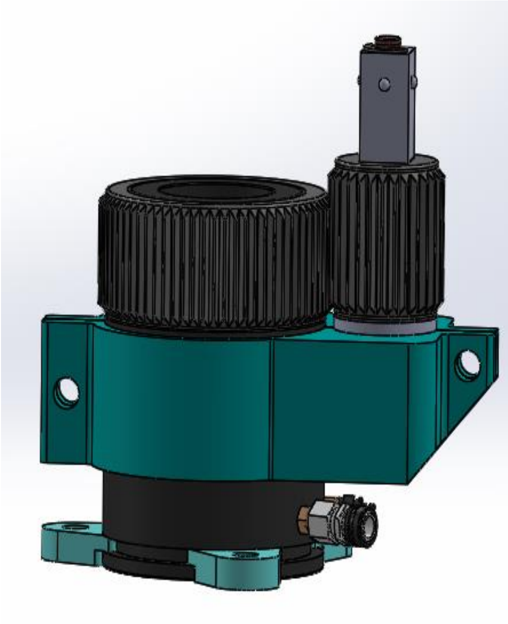


Figure 15: Hydraulic tool assembly

7.3 Fasten Guide Pins in SW Flange

7.3.1 Turn the 16 guide pins down in the holes in the SW flange. These holes are threaded and the pins need to be turned till they stop.

7.4 Fasten Nut Retainment System on WN Flange

7.4.1 The washer and nut must be placed over the bolt holes on the WN flange.

7.4.2 Place the spring over the nut.

7.4.3 Place the two semicircle belts over the washers and nuts.

7.4.4 Fasten the belts to the flange with two bolts each.

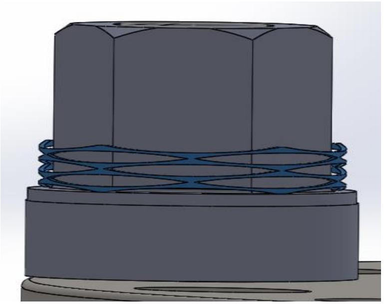
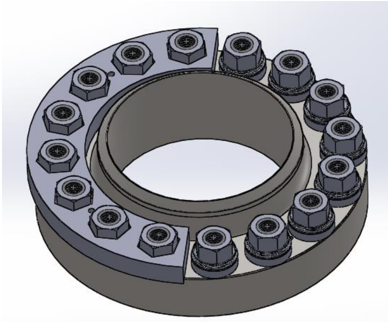
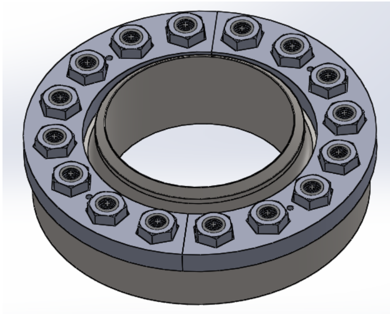
  

Figure 16: Spring over washer and nut

Figure 17: Semicircle belt

Figure 18: Nut retainment system assembly

7.5 Fasten Alignment System on Flange

7.5.1 Thread the male collar around the swivel ring, and fasten with 6 bolts.

7.5.2 Thread the female collar around the WN flange, and fasten with 7 bolts.

7.5.3 It is important that the test port is available in the slot in the female collar.

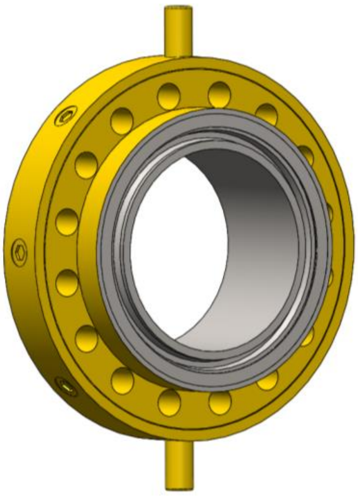
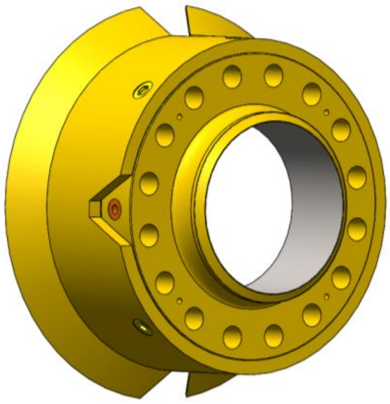
 

Figure 19: Male alignment ring

Figure 20: Female alignment collar

7.6 Pre-install Stud Bolts in Hydraulic Tool

7.6.1 When the hydraulic tool is fixed on the swivel ring, the stud bolts can be pre-installed in the hydraulic tool.

7.6.2 Turn the studs in so far that they are aligned with the edge of the hub, as shown in *figure 21.*

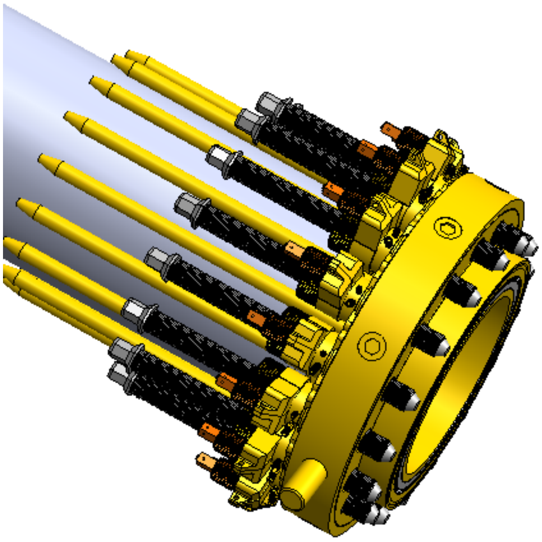


Figure 21: Pre-installation of stud bolts

7.7 Welding

7.7.1 Ensure that the sealing faces are protected from scratching and weld splatter and surface oxidisation.

7.7.2 Keep flange face protected during welding. Seal off with protection plastic cap or plywood with strong adhesive tape [1].

7.7.3 FO&GT swivel flanges also feature a stainless steel retaining circlip that holds the swivel ring in place during assembly. This can be easily removed and refitted, allowing the swivel ring and hub interface to be lubricated for easy rotation during installation.

7.7.4 It is important to remember to fit this on the swivel flange before welding the flange on to the pipe.

Figure 22: Protection during welding

Figure 23: Retaining circlip

8.0 Assembly and Installation Procedure Subsea

8.1 Submersion

8.1.1 The flanges will be submerged and fitted on to the crude system with the help of the ROV.

8.1.2 The ROV will guide the flanges on to the crude system by the guide pins on this system.

8.2 Insert Seal Ring

8.2.1 The ROV will insert the seal ring with the help of a seal replacement tool. The tool is held by the ROV manipulator, and hydraulically actuated to grip onto the groove on the inside diameter of the seal ring.

8.2.2 The ROV then pushes the ring into the SW flange. It is important to make sure that the rubber ring is pushed into the groove in the SW flange.

8.2.3 You can now start the alignment procedure.

8.3 Alignment

8.3.1 An approximate misalignment guidance is as follows:

Flange diameter < ø300 mm: $\Delta a = a_1 - a_2 \leq 1.5$ mm.

Flange diameter > ø300 mm: $\Delta a = a_1 - a_2 \leq 1$mm per ø200mm

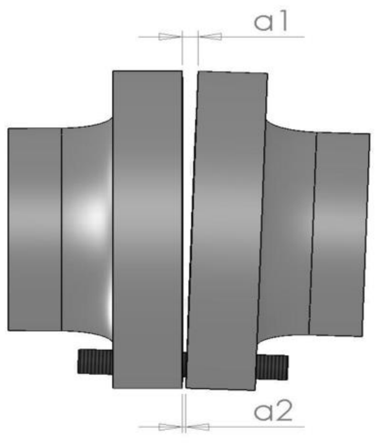


Figure 24: Misalignment guidance

It is assumed that the crude system will align the flanges to this minimum.

8.3.2 It is recommend that, where possible, most of the misalignment is removed as this will ease the rest of the assembly procedure.

8.3.3 When pushing the flanges together the alignment system will automatically equalize the rotational alignment, and the flanges will be placed bolt hole towards bolt hole.

8.4 Turn Stud Bolts through the Opposing Flange

8.4.1 The ROV have to fit the bolt turning tool on the guide pins. This have to be done in two operations, one on each side of the pipe.

8.4.2 The turning tool will be pushed on to the stud bolts.

8.4.3 The ROV will then apply hydraulic pressure. The tool can be directly connected to the ROV, because the tool only require low pressure hydraulics.

8.4.4 The turning tool will turn the studs down automatically, and they are simultaneously entered through the opposing flange, and will pick up the threads in the nuts in the WN flange.

8.4.5 Step 8.4.1 – 8.4.4 will be repeated on the opposite side of the pipe.

8.4.6 The stud bolts must protrude 2 threads from the nut at the opposite side where the tool is used, see *figure 25.*

8.4.7 The flange is now ready for the studs to be tensioned.

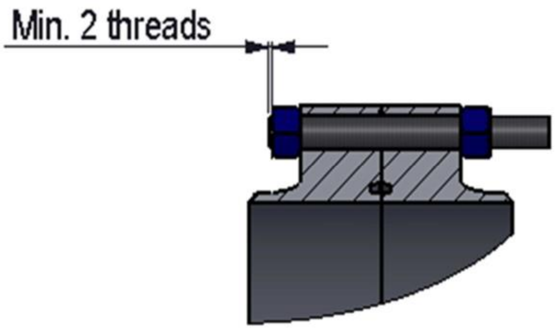


Figure 25: Stud bolts protrusion from nut

8.5 Tensioning Studs

8.5.1 Tension tools are set on all studs on the swivel side. These are connected in series, and will be tensioned simultaneously.

8.5.2 ROV will apply hydraulic tension tool pressure set to full installation value, on the inlet on the ROV panel.

8.5.3 ROV will turn a valve on the ROV panel to maintain the hydraulic pressure.

8.5.4 All nuts to be tightened. See chapter 8.6 for instructions.

8.5.5 Release the tension tool pressure by turning the valve.

8.5.6 A seal test will be performed at the end of the installation, see chapter 8.7.

8.6 Lock Hydraulic Nut

8.6.1 Every hydraulic nut have to be tighten individually.

8.6.2 The ROV will use a tool made to fit the top of the counter gear, and mechanically turn down the load collar on the hydraulic nut.

8.6.3 This have to be done individually on every 16 nuts.

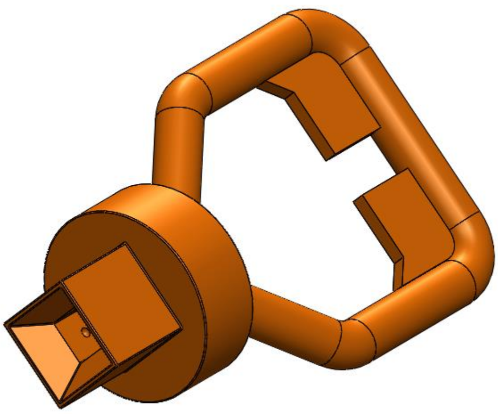


Figure 26: ROV tool

8.7 Seal Test

8.7.1 Through the test port a pressure test is performed after flange assembly in order to verify that the seals are intact. Normally this would be a low pressure 10bar 10minutes test using Nitrogen.

8.7.2 The test port is located in the cut in the alignment collar on the WN flange, as shown in *figure 26.*

8.7.3 For HX seal ring, it is possible to put the test-port between the inner and outer seal surface of the seal ring.

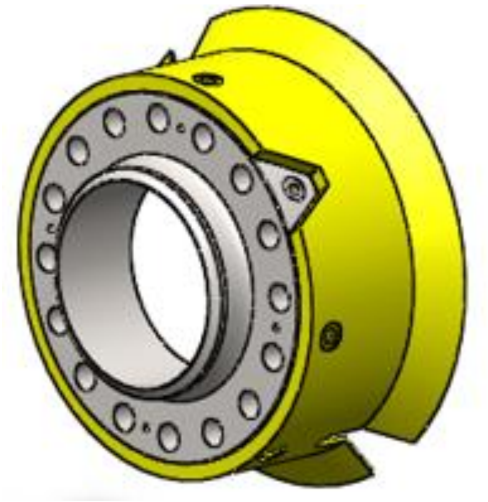


Figure 27: Test port inlet

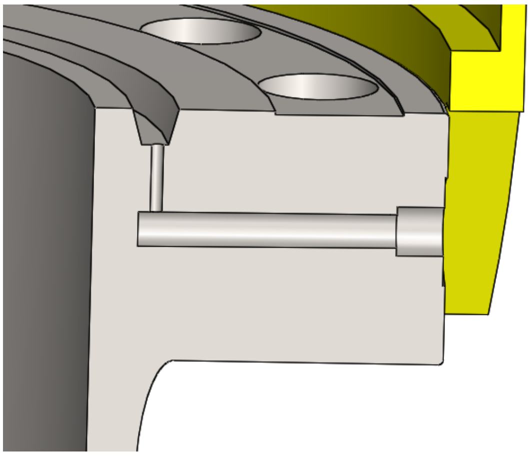


Figure 28: Cross section view of test port

9.0 Dis-assembly Procedure Subsea

9.0.1 Apply tension (applying increasing tension up to 95% of yield) until all nuts are loose. ROV will apply hydraulic tension on the inlet on the ROV panel.

9.0.2 Loose the load collars. The ROV will use the handle made to fit the top of the counter gear, and mechanically loosen the load collar on the hydraulic nut. This have to be done individually on all 16 nuts.

9.0.3 Reduce tool pressure to zero.

9.0.4 Use the bolt turning tool to pull the studs back. The ROV will apply hydraulic pressure directly to the tool.

9.0.5 The crude system will pull the flanges apart.

9.0.6 Verify that the contact between the seal ring and flanges is broken.

9.0.7 Remove seal ring, with the help of the seal replacement tool.

9.0.8 The flanges are now completely disassembled, and ready to install new seal ring.

10.0 References

[1] http://www.vectortg.com/Media/DM-Assembly_Procedure-rev2-VECTOR-3792.pdf

[2] VECTOR-2533 - SPO CF for subsea applications

After Analysis

ROV operated SPO compact flange for subsea assembly in deep water

Document No.:	Version No.:	Date:	Document responsible:	Group:	Status:
12.0	1.0	12.05.2015	Mathilde Schinnes	3	Completed

Group members: Mathilde Schinnes, Laila Andersland, Jørgen Borgersen, Marit Skjørestad

Table of Contents

List of Tables

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1.0 Document

1.1 Document History

Table 1: Document history

Revision	Description of change	Date
0.1	Created document	12.05.15
0.2	Proof reading	14.05.15
0.3	Updated 4.3, added comments to difference	17.05.15
1.0	**Final release**	**18.05.15**

1.2 Abbreviations

Table 2: Abbreviations

Abbreviation	Description
FO&GT	Freudenberg Oil & Gas Technologies
IIM	Iterative Incremental Model
J. B. B	Jørgen Bårnes Borgersen
L. E. A	Laila Egbocha Andersland
M. Sch	Mathilde Schinnes
M. Skj	Marit Skjørestad
ROV	Remotely Operated Vehicle
SW	SolidWorks
UP	Unified process

2.0 Scope

This document is a short summation of the entire bachelor project. We will go through how the project period has been and what we have learned during this time. A comparison is made between estimated hours and the actual hours spent on the different activities. In addition, a summation on how the project model and project plan has been followed. This After Analysis will provide confirmation of whether the project plan with its project goals and requirements has been satisfied or not. The total After Analysis represent the project group's evaluation of the project. At the end of this document, there will be an individual self-assessment from each of the group members.

3.0 Project Evaluation

When this project first started, the first document created was the Vision Document. This document gave a description of the assignment and an insight of the project's purpose and goals. In this chapter, we will compare the projects vision and end result.

3.1 Fulfilment of Goals

3.1.1 Assignment Goals

Our main goal for this project was to find a way to assemble the compact flange with the use of a ROV. It was never a goal to try to invent the compact flange all over again, but rather make a ROV compatible assembly system. Our goal was to make a system that provided a quick, safe and reliable make-up/splitting of the flange.

Based on requirement fulfilment and tests, we can state that we in our final design in all respect have achieved the project goals. Our final design is a well-functioning, effective, efficient system that provides a quick, safe and reliable make-up and splitting of the flange. The project group have emphasized to design the system in a way that makes it easy for the ROV operator to assemble the flange relatively quick and safe.

3.1.2 Project Group Goals

The goals from the group's point of view was to deliver a final product that meets customers' requirements and specifications. We wanted to get increased experience and expertise with general project work. We also wanted to challenge the knowledge we have gained throughout our courses and test it out in a more realistic work situation.

It has been important for the project group that the work and the result both satisfy the schools' and the customers' requirements and specifications. The school emphasize the project plan, the project way of working and the documentation. FO&GT on the other side, have a bigger interest in a good concept and a good solution of the problem. We have tried our best to satisfy both, in a good way. This have been a challenge seeing as time haven't been an extensive resource in this project. Even though the group are satisfied with the final design and documentation, we see that there are things that could have been further optimized and improved.

We do see that if we would have chosen the correct project model from the beginning, and started to make decisions in the concept phase earlier, we could have had several more hours to use in the design phase. Every good and bad incident have given us experience and knowledge that we will take with us in further development and project work.

3.2 Challenges during the Project Time

3.2.1 Challenges in the Assignment

When we analysed our given assignment at the beginning of the project, we thought our challenges was the design of all the mechanical and hydraulic components. Material selection and strength calculations were seen as challenging as well. We also thought the adaptation to the ROV would be a hard task.

During the concept study and design development, we saw clearly that things we thought would be very hard, was not that bad. Other parts we had not even thought about became a challenge and required a large amount of hours. The best example being the nut freedom system. It took some time before we even understood the extent of this problem and that if we didn't have a solution for this problem, the whole design and assembly would be close to worthless. We spent a lot of time trying to solve this with a large amount of ideas and models, and we are well pleased with our result.

3.2.2 Challenges in the General Project Work

On the basis that none of the group members have been through a project like this before, we did expect that the project work could be challenging. Especially in the beginning of the project, it was a challenging job to plan the whole project cycle, and estimate the needed hours. We had no idea how much time the different activities would require. We had to analyze our assignment closely and divide the assignment into different activities. We then tried to do an estimate of hours that would be spent doing said activities, and plot the timeline in a Gantt chart. The change of project model one month into the process did not make the planning any easier, because the focus changed when the model changed. It was revised with better plans and estimations, but it required a lot of time.

We spent some time to make a good plan and Gantt chart for the total project time. We were curious whether the plan would work or not, but this have not been a problem. The Gantt plan underwent an improvement during the change of model, and has been followed the rest of the time. Some changes have been made along the way, but these have been relatively small.

4.0 Iterative Incremental Model

In the Project Plan document, there is written about the choice of project model and the change of the project model during the project. This chapter will deal with how the project model have contributed to the project progress.

4.1 Project Model and Gantt chart

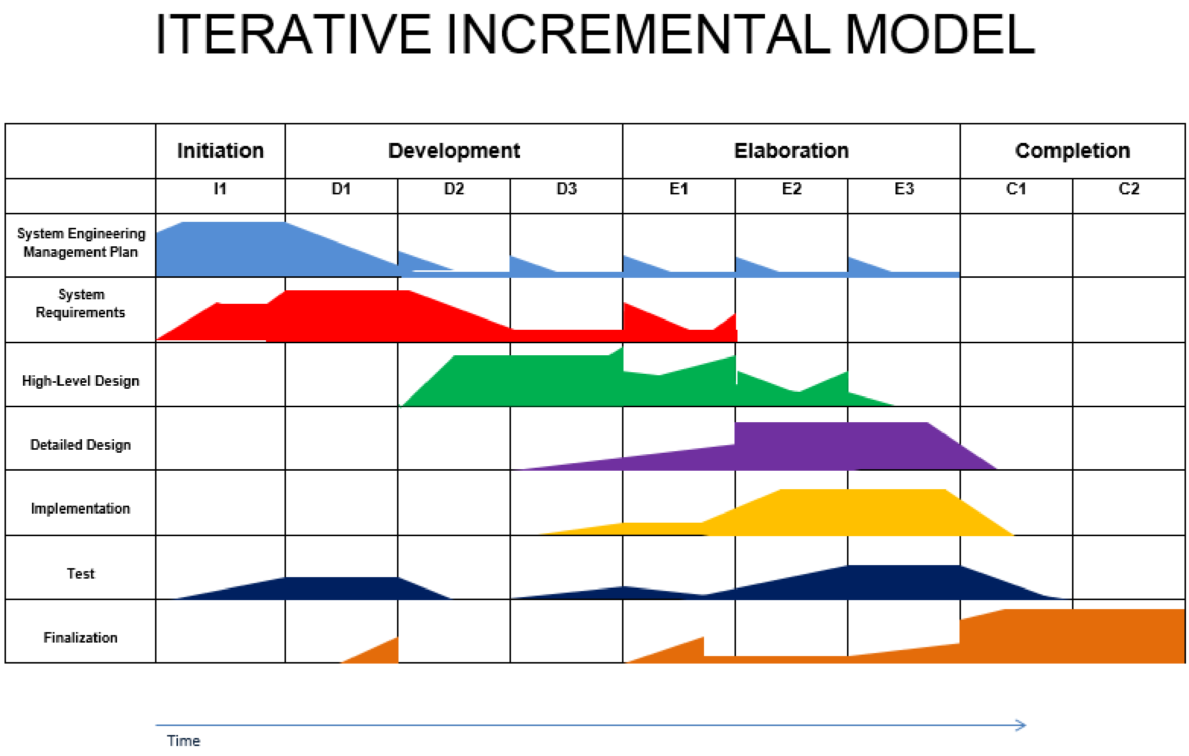

Figure 1: Iterative incremental model

The work that have been by far the most influenced by the IIM is how we have planned our work in the Gantt chart. The influence from the IIM is reflected in the Gantt chart. Since we have been following the Gantt chart consistent throughout the whole project time, we can state that we also have followed our project model. We have been through total nine iterations throughout the whole project time.

The Gantt chart have been very useful throughout the whole project time, as it has kept us on schedule and clearly showed whether we needed to pick up the pace or continue as is. The very first Chart we made had a very tight schedule compared to our final one.

This plan followed the Vee-model and the different activities was presented in steps. We saw relatively clear after the first presentation that this plan would be hard to follow. When the project model was changed, a new chart was made as well.

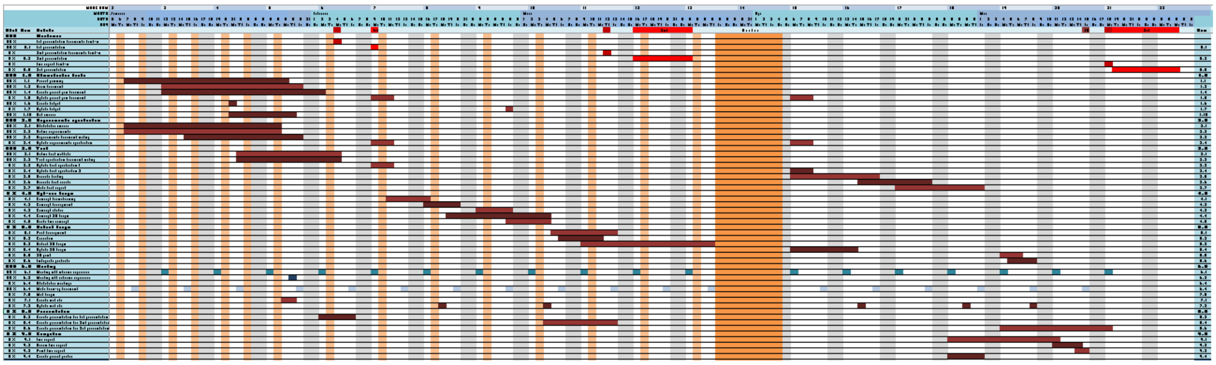

Figure 2: Gantt chart first release

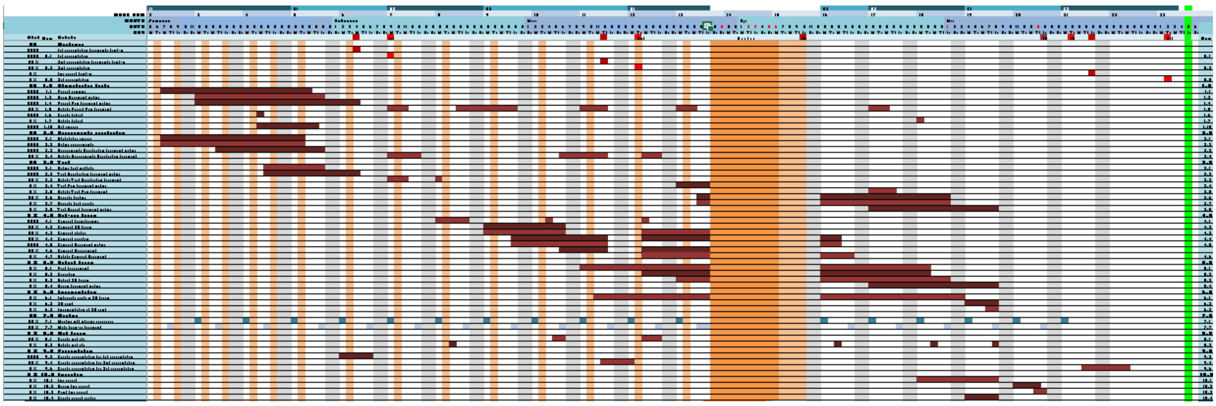

Figure 3: Gantt chart final version

As shown in the two figures above, we can see that there is a clear difference in how we planned to work. In the first chart, there was only one or two activities that were going to be worked at the same time. As seen in the final version of the chart, it is clear that it became much more parallel working throughout the whole project time. This plan, and this way of working did fit our project in a much better way. Several times, it suddenly appeared new requirements or other things that lead to changes in earlier documents or design.

Please note that our complete chart is attached in the end of the Project Plan document.

4.2 Time management

When the model was chosen and the activity list was made, we estimated the amount of hours we thought we would spend on each activity. This was a hard task to do because none of us had been in a project like this before, and we did not have a clue of how long time different things would take. The Bachelor project count 20 credits and it was expected that we used the number of hours according to this. These 20 credits implies around 550 hours per each member, total 2200 hours for the group. These numbers was used as a basis in the estimation of hours. The project model and the making of the Gantt chart helped us to spread the total 2200 hours in a good way throughout the whole project time. The model also helped us to know what to emphasis in the different phases and the making of the Gantt chart gave us a good overview over the total project period.

The table below shows estimated hours compared with actual hours spent on each activity. During the project time, new activities and new priorities appeared. These were given an amount of estimated hours and were added to the list. These numbers is written in parenthesis in the estimated hour's column.

Table 3: Time management

Activity Nr	Description	Estimated hours	Actual hours	Diff.
1.0	**Administrative tasks**			
1.1	Project Planning	100	118,5	+18,5
1.2				
1.3	Vision Document	30	18	- 12
1.4	Project Plan document	80	83	+3
1.5	Update Project Plan document	20	46	+26
1.6	Create Budget	4	2	- 2
1.7	Update Budget	4	1	- 3
1.8	Working hours	10	23,5	+13,5
1.9	Research	50	59	+9
1.10	Risk Analysis	30	15	-15
Total		**328**	**368**	**+40**
2.0	**Requirements Specification**			
2.1	Stakeholder Analysis	40	40,5	+0,5
2.2	Define Requirements	40	24	- 16
2.3	Requirements Specification document	90	26	- 64
2.4	Update Requirements Specification document	10	19,5	+9,5
Total		**180**	**110**	**- 70**
3.0	**Test**			
3.1	Define Test Methods	30	18,5	- 11,5
3.2	Test Specification document	40	21	- 19

3.3	Update Test Specification document	10	5,5	- 4,5
3.4	Test Plan document	50	12,5	- 37,5
3.5	Update Test Plan document	10	7,5	- 2,5
3.6	Execute Testing	90	79,5	- 10,5
3.7	Evaluate Test Results	40	18	- 22
3.8	Test Report Document	80	110	+30
Total		**350**	**272,5**	**- 77,5**
4.0	**High-level Design**			
4.1	Concept Brainstorming	90	80	- 10
4.2	Concept 3D Design	0 *(40)*	65	+65
4.3	Concept Studies	90	113,25	+23,25
4.4	Concept Selection	60 *(40)*	25	- 35
4.5	Concept Document	40 *(60)*	99	+59
4.6	Concept Development	90	68	- 22
4.7	Update Concept Document	0 *(20)*	5	+5
Total		**370 *(430)***	**455,25**	**+85,25**
5.0	**Detailed Design**			
5.1	Part Development	100	87,5	-12,5
5.2	Design Calculation	40	29,5	-10,5
5.3	Detailed 3D Design	130	129	- 1
5.4	Design Document writing	0 *(60)*	134	+134
5.5	Detailed Design Studies	0 *(40)*	61,5	+61,5
Total		**270 *(370)***	**441,5**	**+171,5**
6.0	**Implementation**			
6.1	Integrate Parts in 3D Design	50 *(70)*	52,5	+2,5
6.2	3D Print	5	1	- 4
6.3	Implementation of 3D Print	5	1	- 4
Total		**60 *(80)***	**54**	**- 6**
7.0	**Meetings**			
7.1	Meetings with Internal Supervisor	80	62,5	-17,5
7.2	Meetings with External Supervisor	40	70	+30
7.3	Internal Meetings with Group Members	30	30,5	+0,5
7.4	Stakeholder Meetings	40	8	-32
7.5	Follow-up document	40	23	-17
7.6	Write MoM’s	30	14	-16
7.7	Third Party Contact	30	6,5	-23,5
Total		**290**	**214,5**	**-75,5**
8.0	**Web Design**			
8.1	Create Web Site	20	7	-13
8.2	Update Web Site	20	7	-13
Total		**40**	**14**	**-26**

9.0	**Presentation**			
9.1	1st Presentation	6	6	+0
9.2	Create Power Point for 1st Presentation	50	64	+14
9.3	2nd Presentation	6	8	+2
9.4	Create Power Point for 2nd Presentation	60	66,5	+6,5
9.5	3rd Presentation	10	*10*	*+0*
9.6	Create Power Point for 3rd Presentation	90	*180*	*+90*
Total		**222**	**334,5**	**+112,5**
10.0	**Finalization**			
10.1	Final Report document	110	61,5	-38,5
10.2	Review Final Report document	50	45	- 5
10.3	Print and Hand In Final Report document	20	*20*	+0
10.4	Create Project Poster	10	8	- 2
10.5	Installation and Assembly Procedure	0 *(15)*	23,5	+23,5
10.6	After Analysis	0 *(20)*	19,5	+19,5
Total		**190 (225)**	**222,5**	**+ 32,5**

Table 4: Total hours

Activity Nr	Description	Estimated hours	Actual hours	Diff.
1.0	Administrative tasks	328	368	+40
2.0	Requirements Specification	180	110	- 70
3.0	Test	350	272,5	- 77,5
4.0	High-level Design	370 *(430)*	455,25	+85,25
5.0	Detailed Design	270 *(370)*	441,5	+171,5
6.0	Implementation	60 *(80)*	54	- 6
7.0	Meetings	290	214,5	-75,5
8.0	Web Design	40	14	-26
9.0	Presentation	222	334,5	+112,5
10.0	Finalization	190 (225)	222,5	+32,5
Total (excl hours for Final Presentation)		**2200**	**2224,25**	**+24,25**
TOTAL (incl hours for Final Presentation)		**2320**	**2434,25**	**+114,25**

4.2.1 Comment on Deviations

1.0 Administrative Tasks

The high difference in activity 1.4 (Project Plan document Update) is the result of the unexpected change of project model in week 8 of the project.

2.0 Requirement Specification

Defining requirements is always a very important part of a project. In our assignment from FO&GT we were given a specification that helped us a lot and did the requirement specification easier and quicker. This may be a reason why the difference is so high. Another reason could be that we have discussed the requirements a lot in fellowship, but have not written hours on this activity because we were working with parallel tasks at the same time.

3.0Test

The basis for the negative difference in the test activity is that after some time we changed our focus, to spend more time on concept study and design. This is to rather get a good concept than spend the time on test. The tests and analysis the group have knowledge to would never satisfy the contactors requirements of accuracy. FO&GT is using Ansys for their analysis, while the group only have knowledge of FEM-analysis in SolidWorks Simulation.

4.0 High-level Design

The reason why the actual hours is so much more than estimated hours is because the decreased focus on test, and the increased focus on concept development and design. This changed when the project model was changed.

5.0 Detailed Design

Same reason as 4.0.

6.0 Implementation

Ok estimation.

7.0 Meetings

Comment to 7.7: There have been more 3rd party contact then listed. There have not been that many meetings but a lot of mail contact.

8.0 Web Design

The web page have not gotten that much focus. We made a simple and explanatory web page. We have also spent a lot of time working at our contractors offices, and therefore we have not seen the reason for the web page to function as a channel of information towards them.

9.0 Presentation

Comment to 9.6: We have ambitions of making a good final presentation. Since the date for the 3rd and final presentation is late, we will get more time than estimated to make a good presentation.

10.0 Finalization

Two new activities 10.5 and 10.6 was added to the list. The final report contains documents that already was written, the estimated hours was therefore a bit high.

4.3 Iterations

4.3.1 Iteration 1 – Initiation I1

05.01.2015 – 25.01.2015

The very first phase of the project was the initiation phase. This is normally the smallest phase of the project, according to the ordinary UP. At this time of the project however, we used the Vee model as our project model. In the Vee Model there is no backlink feature to the Concept of Operation phase, where the Gantt-chart was made. Therefore, according to the model, we had to make a plan that should stand throughout the whole project time. We tried to make a good and detailed plan for the whole project, but of course, with no experience from a project like this, we expected that there would be changes.

The real startup for this first phase was the beginning of the 6th semester, when the project started running in the early January. The first step was to define and understand the assignment and to find a good project model for the project. From the subject "Systems Design and Engineering" we learned about mainly four different models: "Vee-model", "Spiral-model", "Waterfall-model" and "CAFCR". Each of these models was evaluated and assessed against the assignment size, scope, degree of difficulty and type. By doing advantages and disadvantages for each model, we found that the Vee-model would fit our project in the best way. We saw our assignment as very concise, well defined and relatively easy to carry through. All of this was criteria's that defended the use of the Vee-model as the project model. However, we saw that the original Vee-model was not perfect. In the original model, each phase has to be perfectly done before you can move to the next phase. We saw that this did not fit our project, so we decided to customize the model to our project. We inserted some backlink features, some iteration rounds in the design and test part. The modified version of the model was called "Vee-model^{+}".

In this phase the Project Plan document was established. This included a Gantt-Chart, an activity list, estimated hours, budget and a risk analysis. A vision document was also created where the project scope, the assignment, the contractor and project goals were presented. There were also spent much time on defining stakeholders and their requirements, together with the project and functional requirements. There were many functional requirements in our task description from FO&GT who was sorted and classified in our own Requirement

Specification document. These were classified in accordance to priority. We also started to define test methods and created Test Specification document in close relation to the Requirement Spec.

4.3.2 Iteration 2 – Development D1

26.01.2015 – 08.02.2015

At the time when the first development phase started, according to the IIM, we still used the Vee-model as our project model. Therefor there was not any clear distinction between the two phases nor any clear iteration. We continued to work with the documents started in the first iteration.

In this phase, a big focus was to write and define our requirements. All of the requirements should fulfill 10 characteristics. This demanded quite a lot of time. Another big focus and a goal for this first development phase was the first presentation. In front of the presentation, four documents should be handed in. This was the Project Plan document, the Vision document, the Requirement Specification document and the Test Specification document. This was fulfilled and released in front of the presentation, where the contents of these documents were presented. The first presentation represented the end of this iteration.

The first presentation went very well with good feedback. The work of the project this far was received as quite good and with high quality. There had to be done some more work with the requirements, as they were not specific enough and had to be more unambiguous. We also had to include iterations, not only in the project model, but also in the plan, the Gantt-chart and the activity list. There was feedback on our choice of project model, that this was maybe not the best model for our project type. The model had been modified in a good way, but it still did not give the freedom and possibility to make big mistakes. In a student project like this, with very little experience, there will be some failure. This was discussed internally in the group and with the internal supervisor, but the conclusion was for the time being to keep the Vee-model^{+} and follow the phases and project working as planned.

4.3.3 Iteration 3 – Development D2

09.02.2015 – 22.02.2015

The third iteration was the kick-off for the design and concept development. According to the first Gantt-chart, we should use the two/three first days of the iteration to update all of our documents according to the feedback from the presentation. The plan also said that we should start concept brainstorming the first week. Because of some unforeseen third party- and contractor meetings, the plan had to be changed. It was when we started to update the Project Plan and Gantt-chart; we realized that we were not allowed to do changes in the plan if we should have been following our project model precisely. We also realized that we thought the requirements was well defined and concise from the beginning, but it became clear that there would be more changes in the requirements during the development than expected. After the first presentation, we discussed our project model again and we saw that we were working more parallel through all the phases than the model allowed us to. It became clear that the project needed a more iterative and incremental project model who allowed us to do mistakes during the project work. It was then discussed some different project models and if there were some project models that would fit our project better. One of the models that were discussed was the Unified Process Model. This model was first introduced to us late in the first iteration. None of us had heard about this model before. UP is specifically based on iterations and parallel working. The UP is originally based on software development that requires use-cases, but this did not fit with our project, so we made a new project model inspired by the UP and named it "Iterative Incremental Model".

The first week of this phase went to update the four documents handed in before the presentation. We also had an important meeting with FO&GT and VASI. VASI is the Norwegian department of TenTec, a huge tooling company. These meeting helped us a lot and gave us good inputs to redefine and update the requirements. At the meeting with FO&GT our external supervisor tried to really open our minds before the concept brainstorming. In a brainstorming process like this, it is important to be creative and with no limitations. Even though the system we shall develop is a flange, and all other flanges use bolts, it is not necessarily the ultimate solution. Our external supervisor really pushed us to open up our eyes and see the big picture, not wear blinders. He also advised us to look into solutions that not included bolts.

The real brainstorming started in the middle of this iteration. The system was first divided into different functions. Then we used time boxes where we drew sketches and ideas for each function. This was done in several rounds and many good ideas was created. The discussion of each sketch internally in the group also led us to new ideas. The brainstorming marked the end of this iteration.

4.3.4 Iteration 4 – Development D3

23.02.2015 – 17.03. 2015

This iteration was originally intended to last two weeks. However due to the date of the second presentation being later than initially assumed, and because the presentations were a natural ending to this iteration, we chose to run this D3 iteration for an additional week.

As seen in the figures, we can see that the E1 iteration end before the Easter holidays. To maintain consistency, the E2 iteration only lasted one week.

The plan made in the first iteration worked perfectly in the beginning, but after some weeks, we saw that the plan would be hard to follow. It turned out that, among others, the concept development should have greater focus and took more time than planned.

The focus in this iteration was the concept development and selection. We started the iteration by drawing our best sketches and ideas in 3Dmodels in SolidWorks. This took a great amount of time because the most of us were re-learning SolidWorks as none of us had used it for a long time. We spent the whole week with SolidWorks drawings. In retrospect, we see that this was a bit wasted time. The focus should have been on concept selection and make the right preparations for further design, but we took a wrong turn where we started to detail design each concept. Both the internal and external supervisor commented on this issue and we decided we had to get a move on and catch up the lost time. Therefore, the focus in the second week of the iteration was to do a proper concept selection. Every selection and concept choice had to be documented properly defended. The rest of the iteration was the Concept document writing. This took a great amount of time.

The end of this last development iteration was the second presentation. Here we presented the change of new project model and new Gannt Chart, but most of all the concept study had the focus in this presentation. We presented lots of our concept sketches and drawings with different solutions for each function. At the very end of the presentation we presented our conclusion. This included conclusions like; there would be a bolted connection, tightened by a hydraulic nut. We also decided to expand the outer flange diameter and integrate the tool system in the swivel flange. The presentation went well and we got a lot of good feedback.

4.3.5 Iteration 5 – Elaboration E1

16.03.2015 – 23.03.2015

This iteration was kind of a kick-off for the detailed design part of the assignment. Following advice from our external supervisor, we divided our system in components we knew our system would include. This included flange, studs, nuts, threads and washers. Each of the group members got one or two components to gather general information about and elaborate. The basis of this was to understand the function of every component so that the solution could be adjusted to the function and not the component as we are used to see it. We worked with this for some days until our internal supervisor guided us not to spend time on that kind of work when there was much more of the concept selection work to do. We complied and decided to work further with the concept selection.

We used many Pugh Matrixes as a tool to help us to make educated selections. Choices that was made, among others, were that the hydraulic tool should be pre-installed in the flange and that the system should have all the “freedom” in one side. We also decided that there should be used studs, not bolts, and that the studs should be pre-installed in the tooling side of the flange. All choices that set the guidelines for further development and detailed design. The first draft of the Test Plan document was created.

At the end of the iteration we divided our system into different functions that each could work separate with. The functions were:

Table 5: Sub-system responsibilities

Sub-system	Responsible
Flange calculation and tool calculation	J. B. B
Turning mechanism of bolts and turning mechanism of lock	M. Sch
Nut retainment and bolt top design	L. E. A
Seal ring installation and retainment	M. Skj

4.3.6 Iteration 6 – Elaboration E2

13.04.2015 – 19.04.2015

After the Easter holidays and some days free from the project, practicing for our exam, it was time to make a real effort in the last project period. Because of the late date for the second presentation and the big break for the Easter and exam, this iteration only lasted one week. This week each of the group members worked with detailed design and solutions for their specific responsibilities. The goal for this week was to have a complete solution for each of the functions by the end of the week.

In the plan and Gantt Chart, testing was a big part of this iteration. This had not the right amount of focus as the plan required. No FEM analysis was executed at this stage, but there was done some testing, some inspections, by asking the external supervisor and examiner if the solution looks good and if it could be used in the design.

4.3.7 Iteration 7 – Elaboration E3

20.04.2015 – 03.05.2015

The last iteration of the elaboration phase started with a small presentation of each of the solutions for the different functions, internally in the group. The different solutions were then discussed and the group members gave both good and bad criticism. This was also presented for our internal supervisor in the follow-up meeting.

When the group members and internal supervisor approved the different solutions and ideas, we started the detail design of the components. In the detailed design process, we were mostly sitting at Freudenberg offices. We had a great collaboration with our external supervisor and examiner. Different designs was discussed with initiative changes from both the student group and the contractor. The close cooperation helped the design process to be relatively quick. It also contributed to a constantly improved design.

In this phase there was also executed a lot of sub-system testing. By testing, we mostly mean doing FEM analysis. This tests led to improved design and gave a feedback if the designed system could be working or not, if it was usable or not. Both the detailed design and the testing calculation documents were created. For the calculations documents we used the program “Mathcad” at recommendations from our external supervisor. We found this program very useful and it have been an important tool for the development and design. Implementation of the different parts was also started in this iteration. When the implementation was started it was challenging to keep a good review. We had some problems when two of the group members was doing changes in the same part at the same time. It also required focus when changes was done in one part which led to that other parts also needed to be changed. The interference problems was solved by selecting one person, who took control and had the greater overview. If anyone had to do changes in some parts, this had to be reported to said person, so that the following changes could be done in a correct way. Evaluation of the test result and writing of Test Report was also very time consuming. Every person wrote the Detail document and Test Report for their area of responsibility. The document responsible then gathered all the different reports into one document.

4.3.8 Iteration 8 – Completion C1

04.05.2015 – 19.05.2015

After hundreds of hours with project work, developing, designing and testing, it was the time to finalize the whole project. The biggest challenge in this iteration was to try to write the documents in a way that reflected the project group’s quantity and quality of work. Often several solutions and design development suggestion have been discussed, where the discussion have contributed to one or several design choice. In most cases this have not been reflected in the documents. It is very hard to write a good report, but we have tried our best to make this Final Report extensive, but at the same time, well arranged and understandable.

New documents created and finished in this iteration was the Installation and Assembly Procedure document and the After Analysis document. There was also made a project poster that represent the group and the project.

This iteration is completed when the Final Report is printed and handed in.

4.3.9 Iteration 9 – Completion C2

20.05.2015 – 02.06.2015

The very last iteration will occur after the Final Report has been released. Since the date for our final presentation is very late, we have a large amount of time to create this presentation. This presentation will include a sale part and a technical part. We will try to make this a very interesting presentation with lots of drawings, simulations and maybe a short movie. The group will also print a 3Dprint of our final product. The last iteration and the whole project will end with this final presentation.

5.0 Responsibilities

5.1 Document Responsibility

Table 6: Document responsibility

Document type:	Chapter:	Responsible:
1.0 Vision Document	Contractor	M. Skj
	Project	M. Skj
2.0 Project Plan	Objectives and Limitations	M. Skj
	Project Organization	M. Skj
	Meetings	M. Skj
	Project Model	M. Sch
	Activities	M. Sch
	Plan	M. Sch
	Risk Analysis	J. B. B
	Economy	M. Skj
	Web Site	L. E. A
3.0 Requirements Specification	Requirements	L. E. A/M. Skj
	Case Study Specifications	L. E.A
4.0 Test Specification	Test and Verifications Methods	L. E. A
	Test Specifications	L. E. A
5.0 Concept Study	General Design Choices	M. Skj/All
	Seal Ring Installation and Replacement	M. Skj
	Seal Ring Retainment	M. Skj
	Flange Alignment	M. Skj/All
	Flange Assembly	M. Skj/M.Sch
	Flange Preload	J. B. B
	Flange Lock	M. Skj/All
	Flange Un-lock and Dis-assembly	M. Skj
	Conclusion	M. Skj
6.0 Design Document	ROV Operated Assembly System	J. B. B
	Crude Alignment System	J. B. B
	HX Seal Ring for ROV Installation	M Skj
	Stud Turning System	M. Sch
	Nut Retainment System	L. E. A
	Hydraulic Tension Nuts	J. B. B
	Load Collar Locking System	M. Sch
	Flange Modifications	J. B. B
	Test Port	J. B. B
	Hydraulics	J. B. B
	Visual Indicators	J. B. B
	ROV interfaces	J. B. B

	Material	All
7.0 Calculation	Compact Flange	J. B. B.
	Seal Ring	M. Skj
	Nut Retainment System	L. E. A.
	Stud Turning System	M. Sch
8.0 Test Plan	Test Scope	L. E. A
	Resource Requirements	L. E. A
	Test Schedule	L. E. A
9.0 FEM Analysis Report	Seal Ring Retainment System	M. Skj
	Stud Turning Tool	M. Sch
	Nut Retainment System	L. E. A
	Hydraulic Tool	J. B. B
10.0 Test Report	Seal Ring System	M. Skj
	Stud Turning System	M. Sch
	Nut Retainment System	L. E. A
	Hydraulic Tension System	J. B. B
	Flange System	J. B. B
	Verification System	J. B. B
	Crude System	J. B. B
	Conclusion	L. E. A
11.0 Installation and Assembly Procedure	Responsibilities	M. Skj
	System Definition	M. Skj
	Equipment	M. Skj
	Preparatory Procedure Topside	M. Skj
	Assembly of the Flange Topside	M. Skj
	Assembly and Installation Procedure Subsea	M. Skj
	Dis-assembly Procedure Subsea	M. Skj
12.0 After Analysis	Project Evaluation	M. Sch
	Iterative Incremental Model	M. Sch
	Responsibilites	M. Sch
	Self-assesment	All

5.2 System Responsibility

Table 7: Sub-system responsibility

System:	Responsible:
Seal Ring Installation and Retainment	M. Skj
Nut Retainment System	L. E. A
Stud Runner System and Locking S	M. Sch
Flange	J. B. B

5.3 Design Responsibility

Table 8: Design responsibility

System:	Component:	Designer:
Stud Running System	Hydraulic Stud In	J. B. B
	Hydraulic Stud Out	J. B. B
	Stud Turning Tool	M. Sch
	STTH	M. Sch
	ROV handle	M. Sch
	Reaction Arm	M. Sch
	Reaction Link	M. Sch
	Stud	L. E. A/ M. Sch
	STT Guide Pin	M. Sch
Seal Ring	Seal Ring	M. Skj
	Rubber Ring	M. Skj
Crude Guide System	Guide Frame	J. B. B
	Guide Lid	J. B. B
	Guide Slider	J. B. B
	Guide Pole (1)	J. B. B
	Guide Pole (2)	J. B. B
	ROV Grabber Bar	M. Sch
	Hub	M. Skj
	Guide Pin (1)	J. B. B
	Guide Pin (2)	J. B. B
	Swivel Collar	J. B. B
	Swivel Collar Bolt	J. B. B
	Collar Bolt	J. B. B
	Collar	J. B. B
	Guide Clamp (1)	J. B. B
	Guide Clamp (2)	J. B. B
SPO Compact Flange	Weld Neck	J. B. B
	Swivel	J. B. B
	Pipe (1)	J. B. B
	Pipe (2)	J. B. B
Locking System	Counter Gear Clamp (1)	J. B. B
	Counter Gear Clamp (2)	J. B. B
	Hydraulic Stud In	J. B. B
	Hydraulic Stud Out	J. B. B
	Stem	M. Sch
	Counter gear	J. B. B
	Seat	M. Sch
	Clip RS 7811	Lesjofors

Hydraulic Nut	Tooling Bridge	J. B. B
	Tooling Retainment	J. B. B
	Tooling Clamp	J. B. B
	Hydraulic Stud In	J. B. B
	Hydraulic Stud Out	J. B. B
Nut Retainment	Nut Retainer Belt	L. E. A
	Nut	L. E. A
	Washer Bottom	L. E. A

6.0 Self-assessment

6.1 Jørgen B. Borgersen

How do you think the project have been?

The project might not always have been a pleasure, but it has been an exceptional experience from start until end.

What have you learned throughout this project?

Seeing as Freudenberg is such an international company all communication and documentation has been in English. This has been great practice for my career to come, as I have gained lots of confidence in speaking my second language. I have also learned the importance of good communication in such an intricate project, as I've realized that my decisions may greatly affect three other peoples work. More specifically, I've acquired knowledge regarding subsea flange connections, hydraulic tools and general procedures regarding system development.

How are you satisfied with your own performance?

One of the first things we discussed was what expectations we each had regarding the workload and decided as a group how extensive our project should be to satisfy it. We simply agreed that we wanted to do a job we could be proud of and decided specifically how many hours we wanted to put towards that goal. I have worked my hours and I feel satisfied with what I have produced. Some days have obviously been more efficient than others, but overall I feel confident saying I've pulled my weight. I don't have a single sick day, but I have however not worked more than a couple evenings, something I know the other members have done from time to time. I decided as early as the first week, that for me to function on a personal level I had to leave the workload at the door and relax when I left for the day.

In some areas, I've contributed knowledge and experience, while in others I've had to rely on my group. This balance have appeared naturally throughout the course of the project and I feel that as a group we all deserve both the praise and the criticism that may come.

What would you do differently if you could start the project all over again?

I would be more confident. We encountered a period during the concept development phase where we just weren't moving forward, only because we didn't have the balls to make decisions. The largest chip in our confidence came when we unexpectedly had to present our current work in front of several Freudenberg employees, who brutally shot down our ideas and concepts one by one. At least it felt that way. I did however realize a few things because of this particular incident. For one, the business world doesn't cuddle you and make exceptions or simplifications. They want results and they want them when they say they want them. Second, you can't get where you want to be without making choices that may prove to be wrong. I think our major issue have been indecisiveness brought forth by our fear of excluding good solutions or overlooking important details. Thankfully, our external supervisor noticed our hesitance rather quickly and gave us that much needed kick in the bum. It turned out that was exactly what we needed and we quickly picked up the pace again, but all agreed this was something we should be cautious about proceeding with our work.

What do you think about the cooperation between internal group members?

This has by far been the best experience I have had working as part of a compact team. There haven't been a single argument nor have there been any unpleasant incidents. We've enjoyed each other's company and discussed things in a civil matter, regardless of how strong our personal opinions have been. More importantly, everyone have been humble and recognized their mistakes, rather than being stubborn and waste time.

As the only male member in the group, I must admit I expected more intrigues, but my fellow project members did time and again impress me by how professional they have handled every situation. I will remember how easily they crushed all of my prejudices and preconceptions for a long time to come, and more importantly, I will be forever grateful for the great months they have given me.

What do you think about the cooperation with external and internal supervisor and examiner?

The cooperation from all parts have been beyond my expectations. As a textbook pessimist, I did however not expect much. I had an idea that the final project was about fending for ourselves and being tossed out the deep end, but I quickly realized this was in no way the case. Both our internal and external supervisors have given us plenty of elbowroom to play with, but kept a watchful eye, steering us in the right direction whenever we were moving of course. Their support have been a huge relief throughout the project. The external examiner have in many ways acted as a third supervisor, so what is previously stated does not exclude him. He has been a great resource throughout our project and I have really appreciated both his, and the others level of interest in our work.

We haven't had the opportunity to spend as much time with our internal examiner, but she did however help us greatly during the startup, making sure we planned our project as good as possible. She has also given us great pointers after each of our presentations, guiding us in the right direction.

Is there anything else you want to comment?

I would like to emphasize that Freudenberg have been a remarkable company to work for. Their team have provided us with great amounts of knowledge and experiences and have been excessively eager to help us. We also had the pleasure of working at their offices as much as we wanted which turned out to be a great resource in terms of communication and relevant information.

6.2 Marit Skjørestad

How do you think the project have been?

The bachelor project has been very educational. It has given me a small insight into how work life can be after graduation.I have worked together with people I have not worked much with prior to the project, and made three new very good friends.

What have you learned throughout this project?

Learning by doing. I think that the bachelor project have been a great way to put our theoretical knowledge into practice. It is also a good way to find out how you cooperate with other people. In total three presentations during the project, force us also to work with the oral presentation.

How are you satisfied with your own performance?

I have been eager to perform well since the start of the project, and think that I have worked steadily during the whole duration. I have followed up on my area of responsibility and my specific tasks, and have offered to help if needed.

What would you do differently if you could start the project all over again?

We spent too much time in the concept phase. I think that the system were a little bit bigger than first anticipated and unclear to us, and it was a little hard to systemize it in the beginning. We also started to draw models in SW before even taking any design choices, and wasted time there.

What do you think about the cooperation between internal group members?

The internal group dynamics have been great, from the beginning of the project and until the end five months later. We spent a little bit of time before the project started to go through how and how much we would like to work, and how we would handle potential conflicts. We have had discussions, but solved this in a constructive manner. We have divided the work between the group members, but there have always been room to ask for advice. Overall, we have had a good time together, with a lot of serious work, but also a little bit of fun.

What do you think about the cooperation with external and internal supervisor and examiner?

We have had weekly meetings with our internal supervisor at a set time. This have been very good and helpful. He has demanded a weekly review of the projects progress, and given us advice on how to plan and handle further work from the beginning. He has also asked us questions to make us think differently or on aspects, we did not consider important prior to the meetings.

When starting the design process we have also spent a lot of or time working at our contractor's office in Drammen. This have given us directly contact with our external supervisor and examiner, and have been a golden opportunity to ask for advice and discuss our solutions with qualified personnel. We have always felt welcome to ask about anything.

6.3 Mathilde Schinnes

How do you think the project have been?

The whole project have been a very educative experience. The project have been both demanding and challenging in many ways, this has not always been comfortable. After all, when I look back, it have been five fantastic moths and a very interesting time.

What have you learned throughout this project?

I have got new technical skills and have learned a lot of things about compact flanges, hydraulic tools, pre-load, 3D drawings etc. However, what I see as the most important experience is that I have learned a lot about product development and to create and design something together as a team. I have learned that it is important to make choices even though you don’t feel you have the complete overview. You always have to move forward.

I have never been confident by either speaking or writing English. When we wrote our project contract with FO&GT, I saw the communication language as the greatest challenge. I feel confident saying I have strengths in writing, communication and speak in front of people in meetings and presentations, when it is in Norwegian. I feel very limited by my weak English knowledge. I have felt several times that this have been a hindrance for me and have led to misunderstandings and confusion. On the other hand I feel that this have been improved to the better throughout the project time. I feel much more confident with both writing and speaking English now, but I am still not enjoying it.

How are you satisfied with your own performance?

I am very pleased with my own performance during this project. As the project leader, I have felt responsibility for the project the whole way through. I feel I have given real effort in the tasks I have had. On the other hand, I have also seen my weaknesses and shortcomings. However, I also feel that I always have been doing my best to improve myself in these areas. I have had a job on the evenings that have forced me to go earlier than the others a few times. To make this fair, I have several times had longer working days.

What would you do differently if you could start the project all over again?

If I could start the project all over again with the knowledge I have now, I would have done many things differently. Among others I would tried to have a good plan beforehand every new week, with a good and detailed distribution of tasks. I was good at this in the beginning, but after some time this was given less and less priority. I would also been more frank with the people at FO&GT.

What do you think about the cooperation between internal group members?

I will argue that the cooperation between the group members could not have been any better. It has been a good atmosphere and a good moral all the way. I feel that we have been good to make use of each other’s strengths and abilities and helped each other with our weaknesses. Normally, the biggest challenge by being a project leader is to lead the project group and to ensure everyone are doing a good job, and not only twiddle one’s thumbs. I also thought it would be a bit hard to have the authority like a leader because I am the youngest person in the group. I have not felt this like a problem at all. When I have gave tasks, everyone have done their task in a proper way with a good quality result. Each of the three group members have done an excellent job, and as the group leader, I feel very proud of what we have made together.

What do you think about the cooperation with external and internal supervisor and examiner?

I think the cooperation with both the internal and external contact have been very well. Especially our external supervisor have shown great interest in helping us throughout the project. It have been easy to ask both supervisor and examiner if something has been unclear or hard, and they gave good help and good answers. Our external contacts have been giving us much help in technical problems and issues. The weekly contact with our internal supervisor have also been very helpful. He have helped us to always stay on track and have given good guidance according to the project work, the whole way through.

6.4 Laila E. Andersland

How do you think the project have been?

Project has been a learning experience, where it has been acquired both technical skills as well as project working abilities.

What have you learned throughout this project?

Since the external supervisor is English speaking, the project has been carried out in English. Because of this it has become clear how important good communication is.

How are you satisfied with your own performance?

Since this project is so different from the other courses in the bachelor education, it has been easy to stay motivated to do a good job. Another motivation is that three other people are depending on me to do a good job. In my opinion, this motivation has resulted in satisfactory performance.

What would you do differently if you could start the project all over again?

Be more determined to make more choices without the approval of external supervisor. There would be a couple of specific documents that I would have started to work with much earlier.

What do you think about the cooperation between internal group members?

Since I have worked with all team members before, I knew it would be easy to work with them. All of the group members are mature individuals, so we have not encountered any major conflicts. The group worked together every day so that if there were any questions it could be answered immediately. In my opinion, this has worked very well.

What do you think about the cooperation with external and internal supervisor and examiner?

We had weekly meeting with the internal supervisor, to keep him updated about the development process. If we had any questions, it was easy to visit his office and ask questions, which has worked well. Internal examiner has contributed to good feedback to the group, and have been guiding us in the right direction. Without internal examiner, we would still use an unfit project model.

After the second presentation, the external supervisor wanted to have more contact with us. The group took this to heart and started to have much more of the workdays at the contractors' locations. After this, we had a much closer communication with external supervisor as well as the external examiner. External examiner have also contributed to the good feedback, but with a more technical approach.

Is there anything else you want to comment?

Earlier in the development process, it was difficult to feel that we had done a day's work for a day. This is because it requires a lot of thinking in a design development work. Eventually I realized that it is allowed to call it work, even if you do not write down anything.

7.0 Credit

Finally, we will say thank you to some of the people who have had a significant role in ensuring that this project became successful.

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