Hydraulic Retrieval of Plugs in Tubing Hanger

Anni Skåtun

Ingrid S. Mjaatvedt

Aurora B. Loftesnes

Bachelor's thesis in Ocean Technology

Bergen, Norway 2022

Høgskulen på Vestlandet

Hydraulic Retrieval of Plugs in Tubing Hanger

Anni Skåtun

Ingrid S. Mjaatvedt

Aurora B. Loftesnes

Department of Mechanical- and Marine Engineering

Western Norway University of Applied Sciences

NO-5063 Bergen, Norway

IMM 2022 - M94

Høgskulen på Vestlandet

Fakultet for Ingeniør- og Naturvitskap

Institutt for maskin- og marinfag

Inndalsveien 28

NO-5063 Bergen, Norge

Cover and backside images © Norbert Lümmen

Norsk tittel:	Hydraulisk Trekking av Plugger i Tubing Hanger

Author(s), student number:	Anni Skåtun, 585914
	Ingrid S. Mjaatvedt, 585925
	Aurora B. Loftesnes, 585909
Study program:	Ocean Technology
Date:	May 2022
Report number:	IMM 2022 - M94
Supervisor at HVL:	Svein Ole Opdahl
Assigned by:	TechnipFMC
Contact person:	Ivar Noremark
Antall filer levert digitalt:	4

Preface

This bachelor thesis has been written in collaboration with TechnipFMC. The thesis was completed during spring 2022 at the Department of Mechanical and Marine Engineering at Western University of Applied Science. The project was carried out as part of the bachelor's program Ocean Technology, and was written by Anni Skåtun, Aurora B. Loftesnes and Ingrid S. Mjaatvedt.

We would like to thank TechnipFMC for this opportunity, and a special thanks to Ivar Noremark and Jon Halsne at TechnipFMC for their great support. We would also like to thank our Supervisor Svein Ole Opdahl for his support and guidance during our bachelor thesis.

Finally, we would also like to express our gratitude for the Test technicians at TechnipFMC Ågotnes and their hospitality towards us, as well as SOCON and Bergen Maritime for their cooperation.

Anni Skåtun	Aurora B. Loftesnes	Ingrid S. Mjaatvedt

Abstract

This report presents the possibility of implementing hydraulic retrieval of plugs from Tubing Hangers in Xmas Trees in the test centre at TechnipFMC at Ågotnes, and whether this is advantageous in relation to the current retrieving method. An adapter that connects existing hydraulic tools and the plugs are designed and optimized using various calculations and analyses. The methods that have been used, and relevant theory, are presented.

By implementing hydraulic retrieval, the ergonomics during the operation will be improved. In addition, the extent of damage in the event of accidents involving unwanted residual pressure beneath the plugs will be reduced. Damage that occurs during the current uneven jarring of plugs in the Tubing Hanger will be reduced by even hydraulic retrieving. This will further lead to reduced polishing time of imperfections inside the Tubing Hanger. The risk of a possible accident is reduced from high to low, calculated in two separate risk matrices.

To justify the implementation of this project in TechnipFMC, a Business Case is prepared. In this Business Case, the problem with the current method of retrieving is highlighted, both regarding Health & Safety Executive and finances, as well as a solution to this problem. With a total investment cost of NOK 35 076 and an annual saving of up to NOK 695 110, this Business Case clarifies the advantage of replacing the current method with hydraulic retrieving and implementation of the designed adapter.

Sammendrag

Denne rapporten presenterer muligheten for å implementere hydraulisk trekking av plugger fra Tubing Hanger i ventiltre i testsenteret hos TechnipFMC på Ågotnes. I tillegg blir det diskutert om dette er fordelaktig i forhold til dagens metode. En adapter som kobler eksisterende hydraulisk verktøy og pluggene blir designet og optimalisert ved hjelp av ulike kalkuleringer og analyser. Metodene som er blitt tatt i bruk og relevant teori blir presentert.

Ved å implementere hydraulisk trekking vil ergonomien under operasjonen forbedres, samt redusere skadeomfanget ved ulykker vedrørende uønsket resttrykk under pluggene. Skader som oppstår ved dagens ujevne jarring av plugger i Tubing Hanger vil reduseres ved jevn hydraulisk trekking. Dette vil videre føre til redusert pussetid av Tubing Hanger. Risikoen ved en eventuell ulykke blir redusert fra høy til lav, kalkulert i to separate risikomatriser.

For å begrunne gjennomførelsen av dette prosjektet i TechnipFMC ble det utarbeidet en Business Case. Her blir problemet med den nåværende metoden for trekking belyst, både angående Helse, Miljø & Sikkerhet og økonomi, samt en løsning for dette problemet. Med en total investeringskostnad på 35 076 NOK, og en årlig besparelse på opp til 695 110 NOK, tydeliggjør denne Business Casen fordelen med å erstatte den nåværende metoden med hydraulisk trekking ved å implementere designet adapter.

Table of Contents

Abbreviations

CoF	Consequences of Failure
CP	Crown Plug
EHXT	Enhanced Horizontal Xmas Tree
FEA	Finite Element Analysis
FEM	Finite Element Method
HRT	Hydraulic Retrieval Tool
HSE	Health and Safety Executive
HXT	Horizontal Xmas Tree
IS	Isolation Sleeve
PoF	Probability of Failure
ROV	Remotely Operated Vehicle
RT	Running Tool
TH	Tubing Hanger
UNC	Unified Coarse Thread
UNF	Unified Fine Thread
UNS	Unified Special Thread
VXT	Vertical Xmas Tree
WP	Wireline Plug
XT	Xmas Tree

1. Introduction

This chapter provides an introduction to this bachelor thesis. There will be an introduction of TechnipFMC, the company this project is in collaboration with, as well as the background and aim of the thesis.

1.1 TechnipFMC

"TechnipFMC is a leading technology provider to the traditional and new energies industry" [1]. With approximately 20,000 employees around the world, they are a massive company that delivers fully integrated projects, products, and services to some of the largest energy companies worldwide. The company was founded in 2017 as a result of a merger between the two companies FMC Technology and Technip. Their ambition was to become world leaders in subsea technology. One of TechnipFMC's many workshops is located at Ågotnes, outside Bergen in Norway. In this mechanical workshop they conduct tests, services and repairs on equipment and products used in the subsea industry. This bachelor is written in collaboration with the workshop's test centre [1].

1.2 Background for Bachelor Thesis

In the test centre at Ågotnes plugs are installed and retrieved in the Tubing Hanger by downward and upward jarring. Jarring requires mechanical force, performed by the test technicians in the workshop at TechnipFMC, Ågotnes. This procedure of retrieving the equipment can be tough, and in the long run it can be a huge strain for their bodies as it is a bad method ergonomically. Sometimes the plugs are stuck inside the Tubing Hanger, which makes it even more exhausting and time consuming for the workers performing this job. In addition to this, it can be challenging balancing on top of the Xmas Tree, when performing this task.

Figure 1 and 2 visualize the retrieving of plugs by jarring while standing on a dummy tree, which simulates a Xmas Tree. This is usually done standing on the Xmas Tree, which is even more demanding as they have to perform the work while balancing on components on the Xmas Tree. The employees who perform this jarring procedure saw potential for improvement with this current method. Figure 1 shows one worker trying to retrieve the plug. After several failed attempts, help of a colleague was needed, as shown in Figure 2.

Figure 1 & 2: Test technicians retrieving crown plug in the test centre [2].

There is also a risk involved in the procedure. When the Xmas Tree has been pressure tested, the pressure beneath the plugs should be equalized. If the pressure is not equalized and the jarring carries out, there is a possibility that the plug launches out of the Tubing Hanger. At worst, the workers managing the equipment can get injured by the plug launching out of the Xmas Tree. Major damage on the plug or Tubing Hanger may also occur and has to be taken into consideration.

Irregular traction transferred from the jarr to the plug can cause scrapes and deformation inside the Tubing Hanger. These irregularities need to be manually polished. In case of minor damage this takes approximately 3-6 hours. When bigger damage has occurred, it can take up to 30 hours. Sometimes major damage occurs which goes beyond the outer tolerance of the Tubing Hanger, this cannot be repaired at the workshop at Ågotnes and the Tubing Hanger needs to be forwarded to the manufacturer for welding repairs. It takes months to get the Tubing Hanger back and delivered to the customer.

A hydraulic tool can do the job of retrieving the plugs with less risk. TechnipFMC already has a hydraulic tool for installing the Tubing Hanger in the Xmas Tree at the test centre. This tool could also retrieve the plugs from the Tubing Hanger with the correct extension. TechnipFMC is lacking this extension, which is the background for this thesis.

This report presents the work and results of the design of a Hydraulic Retrieval Tool, henceforth called HRT. The task was to design an extension between a hydraulic tool and the different running tools which connects to the plugs, to avoid the scenarios presented above.

1.3 Aim of Thesis

Will it be advantageous for TechnipFMC to implement a retrieving tool for retrieving plugs in Tubing Hanger hydraulically, compared to the current method where mechanical force is used?

1.4 Scope of Work

- Presenting methods applied in the thesis
- Relevant theory for understanding and developing the bachelor thesis
- Risk assessment of current retrieval method and optimized method
- Presenting the calculations computed
- The design and analysis of the Hydraulic Retrieval Tool
- Business Case regarding the economical perspective of the Hydraulic Retrieval Tool

2. Method

Oxford Language defines a method as "a particular procedure for accomplishing or approaching something" [3]. There are two types of methods, qualitative methods and quantitative methods. Quantitative methods usually give a good overview of the topic, while the qualitative methods are more detailed. This chapter will present some of the different methods used in this bachelor thesis, which is a combination of both qualitative and quantitative.

2.1 Literature Search

Literature search has the objective to provide a comprehensive knowledge within a specific matter or topic [4]. When the aim of a project is defined, the next step is to determine important keywords. These are advantageous when the search starts. It is important to use professional resources when researching. For engineering, Oria and Knovel are good online sources for information. Oria is based on Western Norway University of Applied Sciences library, where papers, articles and books are published. Knovel is a search engine for engineering and science textbooks, presenting formulas, tables, charts etc. When collecting information, it is important to be critical to the source credibility [5].

2.2 Qualitative Research Interviews

In the book "Kvalitativ forskningsintervju", Kvale and Brinkmann write about the method of qualitative research interview. The book narrates; Research interviews are based on everyday conversation, but it is a professional conversation. They define the qualitative research interview as an interview with the intention to collect the person's interpretation on the given topic [6].

The book states that interviews can either be exploratory or descriptive. There are several types of interviews [6]. The different types of interviews are used in different contexts and for different purposes. Commonly for every interview, the mission is to help maintain focus on the topic that is researched. While conducting these interviews, it is important to have necessary prior knowledge about the topic. Factual, concept and narrative interviews are used to gather information in this thesis.

2.3 Observation

Observation is known to be a useful research method. It is characterized by observation of behaviour to collect data and information, often in the form of photos, videos or audio recording. This way the material can be studied further [7].

2.4 Business Case

Oxford language defines a business case as *"A justification for a proposed project or undertaking on the basis of its expected commercial benefit."*[3] A business plan considers all different aspects around a new plan or project to determine the value of it being implemented. Benefit, cost, risk and time are parameters often taken into consideration in these cases. A business case shall give a precise answer to these questions; "Why should we carry out this new project?", "What are the benefits for the company?", "What is the cost?" and "What are the risks?". These answers make it easier to understand different perspectives and conclude the preferred solution. Business case can be a useful tool to base a decision on and have as justification when trying to convince people in charge to embark on a new project. A business plan can be the foundation for an approval or rejection of a project proposal [8].

2.5 3D - Modelling

In this project, 3D modelling program Creo Parametric has been used. Creo Parametric is an efficient tool in this field and is used by engineers all around the world. In Creo Parametric, all desired dimensions of the construction are placed, and the part can be further simulated in Ansys mechanical to achieve the desired effect.

2.5.1 Engineering Simulation

When it comes to the design-part of this HRT, there are several factors to consider, such as material choice, design, size and how much it must withstand loads. In order to get the most optimal result, both in terms of its properties and the financial part of it, the choice was made to use Ansys, which is an engineering simulation software.

The following is stated on Ansys' website: "Ansys Mechanical enables you to solve complex structural engineering problems and make better, faster design decisions" [9].

Ansys uses Finite Element Analysis (FEA). By using this type of analysis, each behaviour under all given and conceivable conditions can be analysed and simulated to then be assessed using the finite element method (FEM). In this way, the best and most optimal result based on the given assumptions and limitations for the given problem will be achieved [10].

Finite element method is based on partial differential equations. The method involves the construction to be divided into smaller and simpler elements with known properties. Then it is rebuilt with precisely those known elements to analyse how the construction will react in the simulation [11].

2.6 Risk Assessment

In order to improve the safety of workers, it is crucial to be able to predict the types of dangers that may arise and when. Performing a risk assessment is useful to figure out what may cause harm. This report will include a risk assessment of both today's method of retrieving the plugs as well as the improved hydraulic method. The risk assessment will be conducted by following the ISO31000 standard listed in the steps underneath.

According to ISO31000 Risk assessment is a part of an overall risk management process and consists of three different stages [12].

1. Risk identification
    - Identifying hazards
2. Risk analysis
    - Analyse the hazards
3. Risk evaluation
    - Deciding how to deal with the occurred hazards

2.6.1 Risk Identification

The first step is to identify all the possible dangers that can occur. This identification is useful to prevent any dangerous incidents that may occur, such that the safety of the workers increases. After identifying the sources of such events, it is also important to figure out why they occur. In this way, future hazards can be detected earlier and hopefully be prevented.

2.6.2 Risk Analysis

Risk analysis is a tool that is widely used to improve safety. This involves finding out what is causing various dangerous events so that it can be avoided. This includes determining the level of risk, the probability of this happening and its significance.

Probability of Failure (PoF) and Consequence of Failure (CoF) are important factors during a risk analysis. An understanding of what's to be further analysed is needed before using a qualitative risk matrix (Figure 3). To be able to decide the level of risk on each event, the factors that may have an impact on CoF and PoF needs to be identified.

To define the level of risk, a Risk Matrix is used. The PoF is located on the vertical column and the CoF is located on the horizontal column, presented in Figure 3. This figure shows a qualitative risk matrix presented with five stages of PoF and five stages of CoF. By combining the PoF with the CoF, it results in a risk level that is in the interval from low to extreme.

	Consequence				
Likelihood	**Insignificant**	**Minor**	**Moderate**	**Major**	**Severe**
Almost Certain	Medium	High	High	Extreme	Extreme
Likely	Medium	Medium	High	Extreme	Extreme
Possible	Medium	Medium	High	High	Extreme
Unlikely	Low	Medium	Medium	High	High
Rare	Low	Low	Medium	High	High

Figure 3: Qualitative Risk Matrix [13]

2.6.3 Risk Evaluation

Risk evaluation is a comparison between the different levels of the calculated risks. In this step, it is clarified whether the type of risk is tolerable, or if it is necessary to initiate preventive actions for similar future incidents. By performing a risk evaluation, it is easier to decide which risk treatment should be further performed.

2.7 Pugh Matrix

"The Pugh Matrix is a decision-making tool to compare multiple alternatives" [14]. This method was developed by Dr. Stuart Pugh, who is a scientist from Scotland. With various alternative solutions to a problem, a Pugh Matrix can be an important and effective tool in determining the best and most optimal solutions and/or improvement opportunities. There are several steps that must be performed in order to create a proper Pugh Matrix for the defined problem [14].

The first step is to define the evaluation criteria. The criteria selected shall be the characteristics that have the greatest significance for the possible outcome. Thus, it is important to emphasize each characteristic in relation to its importance. In this step it is important to look at which of the selected evaluation criteria are more preferred than the others, and to what extent. Defining various improvement options and also the baseline of the problem/product follows in this step.

Further on, the various options for each criteria should be rated as either worse, equal or better than the defined baseline. Based on these rates the sum can be added up for each option. In this step it is important to multiply the number of its emphasis stated to consider. The last step is to choose the option that shows the best results based on your given criteria and emphasis, and then explore if there exists an even further optimal solution, based on a combination of the results in the Pugh Matrix [14].

3. Theory

In this thesis the crown plugs and wireline plugs are essential. In order to explain its features, some basic information about the subsea well completion system and other relevant topics regarding the thesis will be presented.

3.1 Subsea Well Completion System

"A completion system is a group of components that is needed to complete the well i.e. make it ready for production or injection" [15]. Xmas tree (XT) and Tubing Hanger (TH) are essential equipment that are permanently installed in the completion system.

3.2 XT - Xmas Tree

XT is a construction merged by several valves and fittings who have their own different functions which are essential in oil completion. XT are located above the wellhead and use their valves to regulate the pressure and flow that arise from the well. In addition to this, TH are essential in pressure relief, and for using injection of chemicals into the well [16].

We distinguish between vertical and horizontal XT. Both the vertical- (VXT) and horizontal trees (HXT) have the same structure and are based on the same components, but the location of some of the components, such as TH and barrier valves, are different. In this report, only the HXT are relevant.

3.2.1 HXT - Horizontal Xmas Tree

Figure 4 displays the HXT, which only has valves located horizontally outside the main bore, none in the vertical direction in the production pipe. Based on this, two plugs, CP and WP, are used as barriers in the production pipe. TechnipFMC maintains HXT as well as Enhanced Horizontal Subsea Tree (EHXT), which is shown in Figure 5. EHXT contains a larger TH than the HXT.

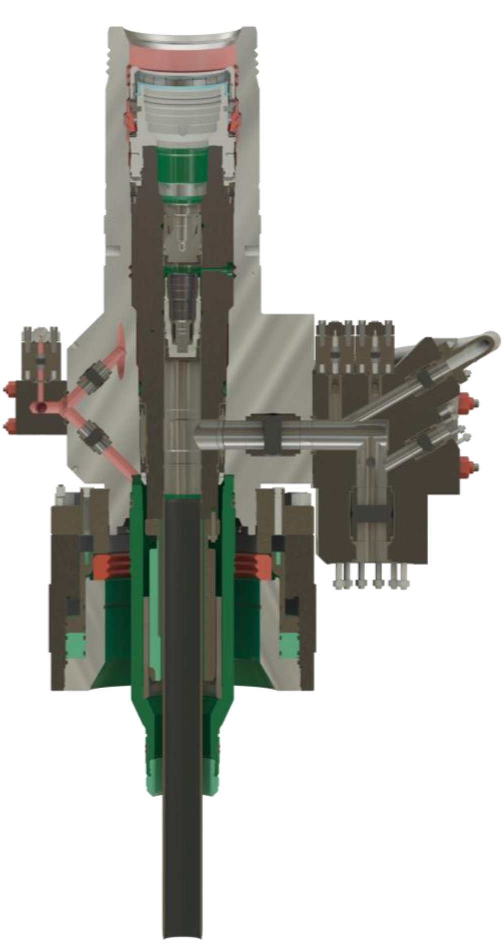


Figure 4: HXT [17]

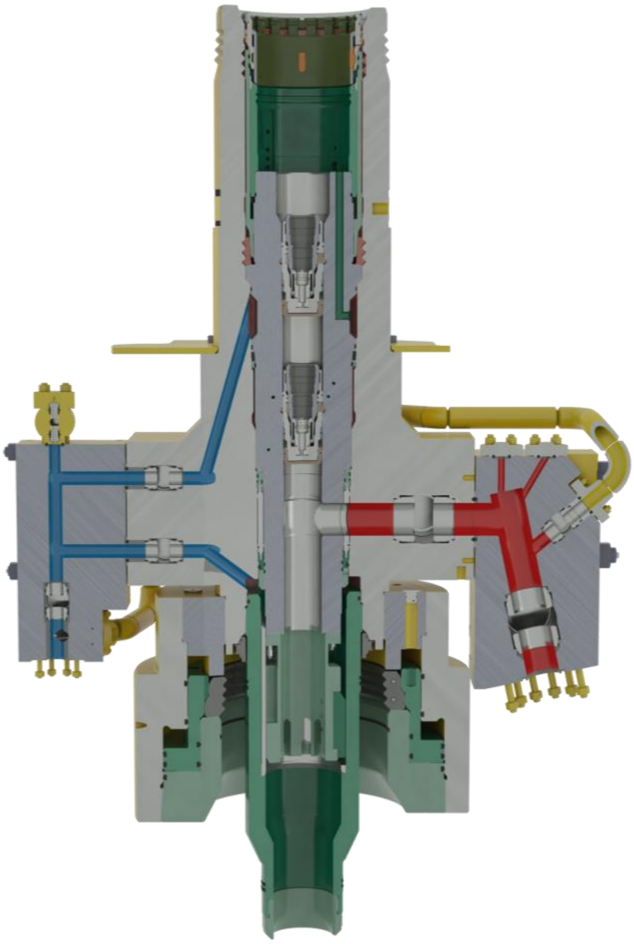


Figure 5: EHXT [17]

3.3 TH - Tubing Hanger

TH has different locations based on whether it is in VXT or HXT. According to TechnipFMC TH "Is a device attached to the topmost tubing joint in the wellhead, supporting the tubing string" [7]. For HXT the TH is located in the XT itself, while when using VXT the TH is located in the wellhead.

3.4 CP and WP - Crown Plugs and Wireline Plugs

As there are no vertical valves in the HXT there is a need for a different type of barrier. The requirement for barriers varies. The petroleum industry has a rule which states: "At least two tested independent barriers between hydrocarbons in the reservoir and the environment at all time" [18]. In HXT, two plugs are installed into the TH to secure the well. The plug's task is to hold the pressure from the well and be a barrier between the reservoir and the environment. There are two different types of plugs for this purpose, CP and WP. CP is always the first barrier between the well and the surroundings. This plug is referred to as a lower CP.

The second barrier distinguishes between a second CP or a WP, depending on the well and its characteristics. The CP has a higher strength than the WP and is used in both positions when needed. If the well allows it, a WP can be used. TechnipFMC uses SSP CP, which is a static set plug. The weight of the plugs varies from 23 kg to 54 kg, depending on the type [19]. Different types are used in different positions and it is also dependent on the size of the XT.

The plugs are installed into the TH with the help of running tools. While installing the plugs, the running tools are connected to the plugs with a fish neck connection. The tool is then connected to the fish necks, which drags and holds the dogs in an inner position. When the plug is in the right position, the running tool is disconnected, and the dogs in the plug go from the inner position to the outer position, locking the plug in the TH. The different components in the CP are shown in Figure 6. After the plugs are set, they hold pressure up to 900 bar (90 MPa, 13050 psi).

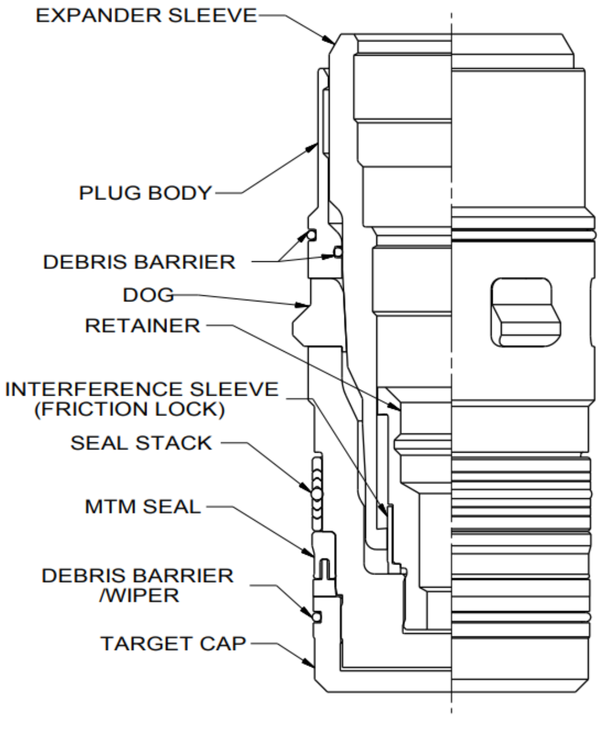


Figure 6: Drawing of Crown Plug [19].

3.5 IS - Isolation Sleeve

Isolation Sleeve (IS) is a device located in the TH to isolate the production outlet in the XT. IS is also installed and retrieved from the TH, with the same jarring as the plugs in the test centre. Isolating the production outlet allows the TH and production string to be pressure tested prior to the TH being set in the XT. There are two sets of sealing elements on the sleeve consisting of two pairs of O-rings. O-ring is a rubber gasket preventing leakage.

The IS has the same fish neck as the CP and WP. GS type running tool installs and retrieves the sleeve in the TH using conventional wireline technique. It is installed in the lower wellhead profile of the TH. A snap ring mechanism attached below the fish neck locks in place during installation by downward jarring. A No-Go ring forces the snap ring over an increased diameter on the fish neck when the share pin installed in the IS has been cut due to the jarring. A secondary interference hold-down mechanism will prevent the sleeve from accidentally unlocking. Then further downward jarring shears the shear pin in the running tool, which releases the running tool from the protector sleeve [20]. The different components of the IS are shown in Figure 7.

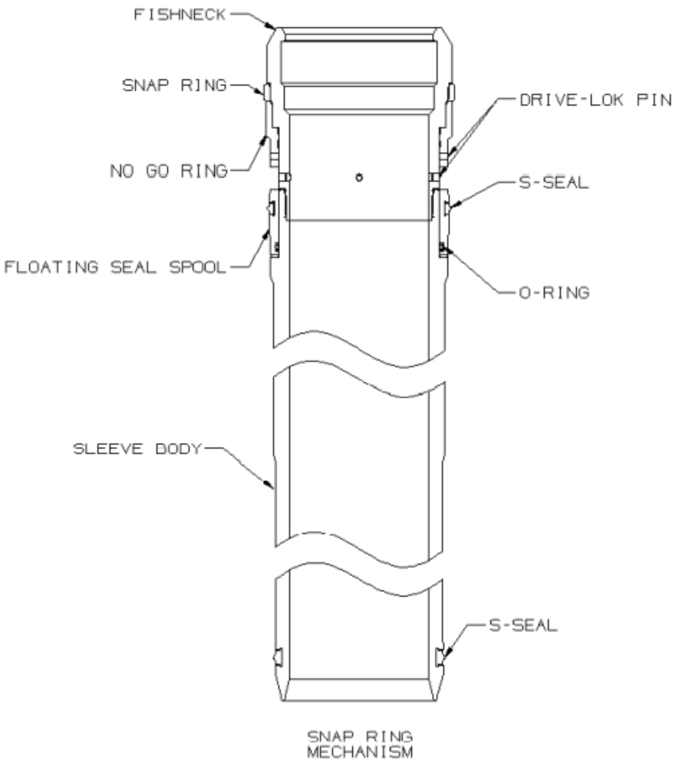


Figure 7: Isolation Sleeve [19].

3.6 Running Tool GS/GR

"Running tools are designed for retrieval and re-installation of equipment or modules larger than the handling capacity of the Remotely Operated Vehicle (ROV)" [21]. There are different types of running tools specified for different types of operation. Running tool for retrieving CP, WP and IS in TH is being used at the workshop at Ågotnes. A conventional tool string is connected to the pulling tools which runs it into the well or TH. When the pulling tool comes in contact with the plug expander sleeve on the fish neck, the weight of the tool-string causes the dogs on the plug to move up. The dogs retract and compress the spring. This forces the dogs down on an enlarged area of the core and the pulling tool is fastened in the plug/sleeve. Figure 8 illustrates the different stages of how the running tool is connected.

The GR Pulling tool consists of GS Pulling tool and GU Shear up adapter. This combination of tools converts the GS Pulling tool from a shear-down tool into a shear-up pulling tool. Shear-up refers to upward jarring, while shear-down refers to downward jarring. If the plug cannot be retrieved from the TH and operation needs to be aborted, jarring in the correct direction will shear an inertial shear pin releasing the tool from the plug. For retrieving the plug upward jarring pulls the expander sleeve from behind the keys and releases the plug from TH [20]. The running tool has a limit of 147 kN (25 tonnes).

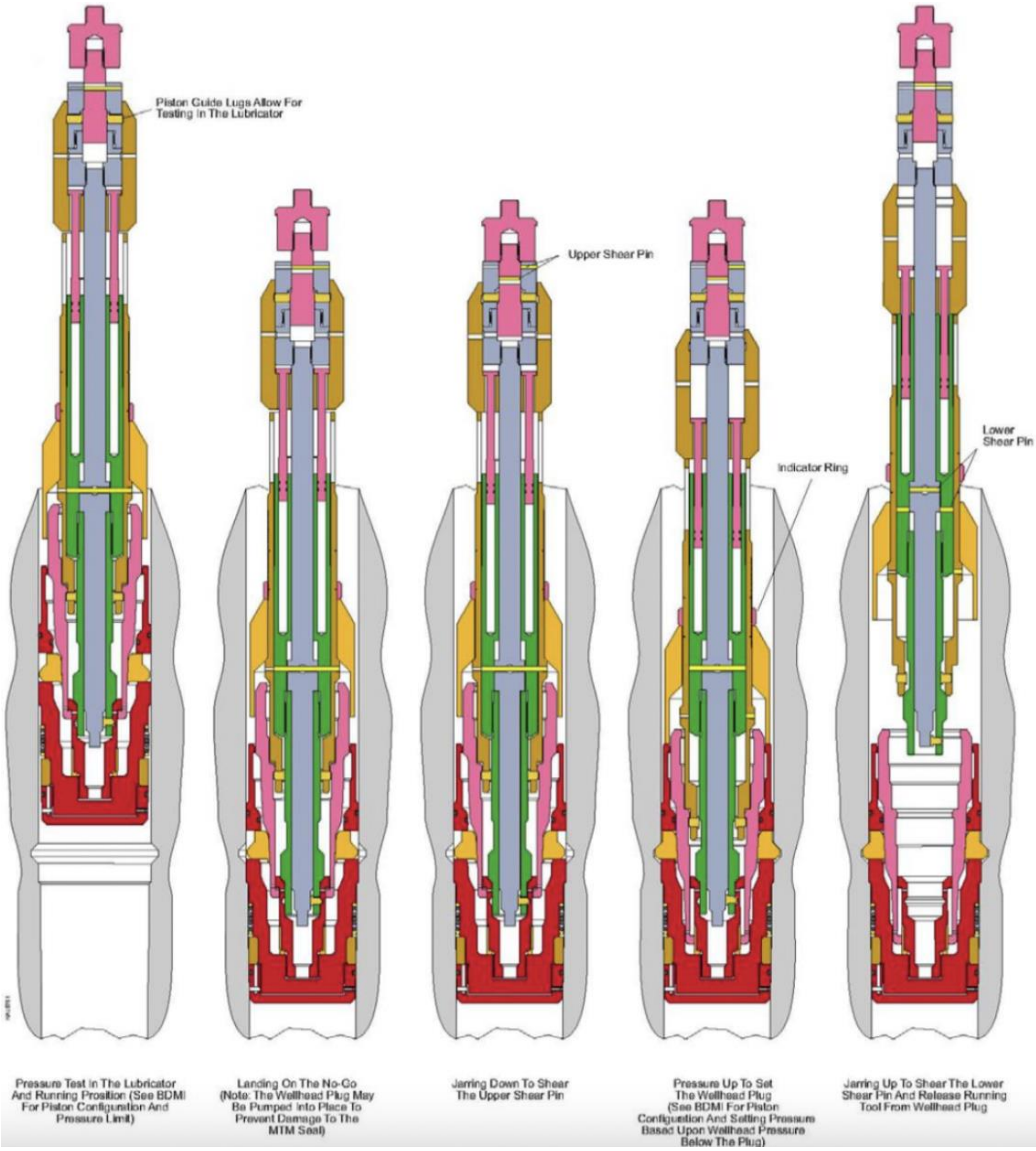


Figure 8: Wireline Tools attached in crown plug. The illustration shows the steps of how the wireline tool is attached to the crown plug [22].

3.7 Hydraulic Effects on Wellhead Plugs

Hydraulic is a major factor which is important to consider during installing and retrieving of CP and WP, as they are directly affected by hydraulic forces.

Merriam-Webster defines hydraulic as “operated by the resistance offered or the pressure transmitted when a quantity of liquid, such as water or oil, is forced through a comparatively small orifice or through a tube" [23]. This essentially means that hydraulics can perform very large work using relatively little force.

3.7.1 Hydrostatic Pressure

Hydrostatic pressure is defined as "The static pressure of a liquid equivalent to the pressure that would be exerted by a vertical column of the liquid under the influence of gravity" [24]. The hydrostatic pressure becomes greater at the bottom the heavier the liquid is and/or the taller the "column" containing the liquid is.

During work and operation of CP and WP in the wells on the seabed is it important to consider the hydrostatic pressure as large columns of liquid are present on deep water [20].

3.7.2 Pressure Differences

To achieve safe retrieval of the plugs in the wells, it is very important to have control over the pressures that are both beneath and above the plug. These pressures must be appropriately balanced for this work to proceed smoothly.

It can be difficult to get these two pressures to be the exact same because the pressure beneath the plug comes from the well. A small overbalance pressure will therefore be preferable to an underbalance pressure condition.

Overbalance pressure means that the pressure above the plug is greater than the pressure below, while an underbalance pressure ratio is the opposite, i.e. that the pressure under the plug is the greatest.

The reason why a greater pressure over the plug than below is preferable is to prevent the plug from accelerating up from the well when it is released from the nipple profile. A small pressure difference can cause very large forces on the plug due to its surface area. These forces have been calculated and will be presented in chapter 4.1.

With a greater pressure over the plug this will not happen, and it will also be possible to retrieve the plug as long as the pressure difference is small enough [20].

3.8 Tubing Hanger Retrieval Tool

Tubing Hanger Retrieval Tool is a hydraulic tool used to install and retrieve the TH in the XT. Figure 9 shows the installation process. This Tubing Hanger Retrieval Tool is referred to as Rioperk in the test centre, and further in this thesis. It is a double-acting, hollow plunger cylinder with maximum operating pressure at 690 bar (69 MPa, 10,000 psi), an advance stroke maximum capacity of 628 kN (64 tonnes) and a retract stroke maximum capacity of 412 kN (42 tonnes).

The cylinder can be adjusted to install and retrieve with desired force. Total height of the Rioperk can be adjusted because the steel frame has six different notches that are 200 mm apart. This is illustrated in figure 10. The piston located in the tool can move with a range of 10 3/25'' equivalent to 257 mm.

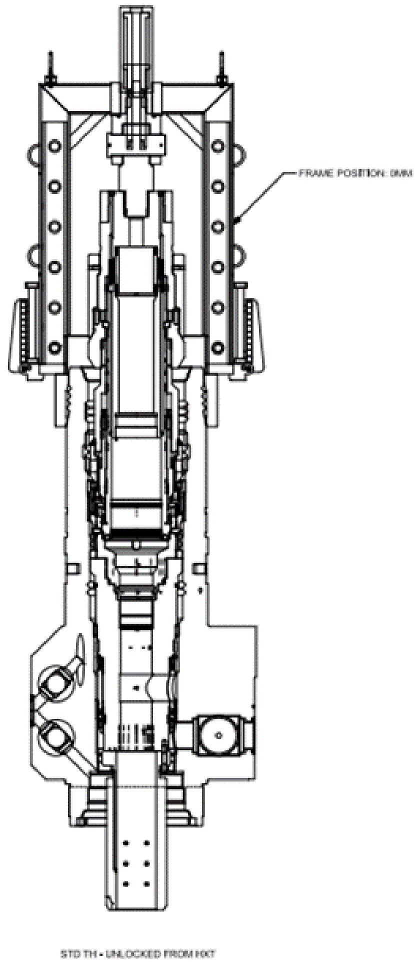


Figure 9 & 10: Rioperk installing TH on top of XT & drawing of installation process [25].

3.9 Threads and Tolerance

The most common threading is triangular thread profile. Unified threads measure in inches and distinguish from metric threads measured in millimetres. Unified threads are divided into two main types, both with flank angel 60°. UNC is the symbol for Unified Coarse Pitch threads, while UNF symbolizes Unified Fine Pitch threads. These categories are further divided into three different tolerance classes, based on requirement in accuracy for their purpose. External threads have tolerance designation A, while internal threads have tolerance designation B. Standard dimensions of these threads can be found in thread tables, also separated in external thread and internal thread [26].

Pitch is the distance between each tread peak and is often referred to as thread per inch (t.p.i). Figure 11 shows how terms of threads are defined.

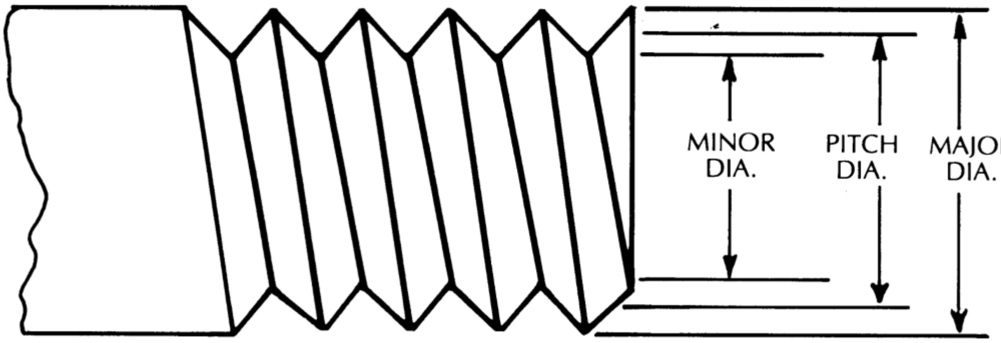


Figure 11: Tables distinguish between minor diameter, pitch diameter and major diameter. [27].

Due to unavoidable accuracy during manufacture, an upper and lower limit must be set within the stated measurements. The difference between these limits is tolerance. In the ISO-tolerance chart both shaft- and hole- tolerance is determined by preferred tolerance grade and nominal size [26].

3.10 Material Selection

In the process of designing new products, it is important to choose the right material. Materials have limitations and give opportunities. When choosing the material, it is essential to consider the material's different characteristics and properties. Material properties can be divided into chemical, physical, mechanical and dimensional properties shown in Table 1 [28].

Material Properties			
Chemical	**Physical**	**Mechanical**	**Dimensional**
Composition Acidity or alkalinity Weathering Corrosion	Density Conductivity Optical Combustibility	Strength Toughness Stiffness Hardness Ductility Malleability Brittleness Plasticity Elastasticity	Size Shape

Table 1: Material Properties [29].

In this thesis the material 520M will be utilized. This material was chosen due to the fact that it has a higher yield strength than Structural Steel S355, which is common to use on workshop equipment. Tensile yield strength of 520 MPa makes it suitable for high strength applications. 520M is weldable and also an easily accessible material, which is positive in terms of production costs. Table 2 and Table 3 presents 520M material specifications obtained from a Norwegian steel supplier [30]. Tensile yield strength is the maximum stress the material can have before permanent deformation occurs. Tensile ultimate strength is the maximum stress the material can have before failure occurred [31].

Tensile Yield Strength MPa	Tensile Ultimate Strength MPa
520	630

Table 2: Yield strength.

Density kg/m^3	**Young's Modulus** GPa	**Poisson's Ratio**	**Bulk Modulus** GPa	**Shear Modulus** GPa
7800	210	0,3	175	80,8

Table 3: Isotropic Elasticity.

3.11 Coating Applications

"A coating, from a surface engineering point of view, is a layer of material deposited onto a substrate to enhance the surface properties for corrosion and wear protection" [32].

Different coatings are used for different purposes. Factors like environment, material and its compatibility, lifetime, shape and size can affect the choice of coating. The goal is to protect the material from threats like corrosion, erosion, acids and other.

TechnipFMC uses Phenolic Based Thermosetting Resin Coating with PTFE Filler. This datasheet states requirements for application, surface preparation, quality control for low friction, load bearing, corrosion etc. Table 4 presents the acceptable coating provided from the datasheet. The HRT will be coated with Xylan 1424.

Manufacturer	Coating	Region Produced	Product Code	Color
Whitford	Xylan 1424	United States	D6580	RAL 3009 (Red #181)
		United Kingdom	F9459	RAL 3011 (Red Oxide)
Chemours (formerly Dupont)	857G	All	857G-508	RAL 3011 (Red Oxide)

Table 4: Coating Specification [33].

4. Risk assessment

The current method of retrieving plugs is bad ergonomically. In addition to retrieving the plugs by physical force which is straining on the test technicians' bodies, they also have to balance on top of the XT at the same time. The plugs can get jammed, and in some cases, accidents can occur.

The aim of this thesis is to optimize the current method both technically and financially, but also ergonomically. In this report, a simple but convenient risk analysis has been performed to map the risk associated with retrieval of the plugs. The risk analysis has been performed on the current method presented in this chapter. It has also been performed on the final and optimized hydraulic method which will be presented further on in the thesis. By doing this, both methods can be compared to each other to see the improvement of the new method that should be implemented.

4.1 Risk Identification

Today's method for retrieving plugs from the TH can be exhausting work and not ergonomic. In addition to this, more dangerous hazardous events can occur. When the plugs are tested, pressure is applied below and in between the plugs. This pressure is equalized before retrieval of the plug. However, there have been incidents where there has been a residual pressure beneath the plug while the plug was removed, without being conscious about it. Test technicians were retrieving the plug by jar while standing on top of the XT. When the plug was retrieved, it launched unexpectedly out of the XT, hitting a worker's arms with a force large enough to tear his whole arm off.

To give a visual presentation of the damage that may occur, the velocity of the plug with an imaginary residual pressure has been calculated. A 23 kg lower CP in EHXT has been computed, to show the potential force and velocity of the plug, the results are listed in Table 5.

$$A = \frac{\pi \cdot d^2}{4} \qquad (1)$$

$$F = P \cdot A \qquad (2)$$

$$a = \frac{F}{m} \qquad (3)$$

$$2as = V^2 - V_0^2 \rightarrow V = \sqrt{2as + V_0^2} \qquad (4)$$

Where A is cross section area and d is the diameter of the plug. F is potential force, P is pressure beneath the plug and m is the mass of the plug. In speed formula s is distance and V is the velocity.

			Velocity kph
Bar	**Psi**	**MPa**	**0,05m**
0,10	1,45	0,01	2,67
0,50	7,25	0,05	5,97
1,00	14,50	0,10	8,44
1,50	21,75	0,15	10,34
2,00	29,00	0,20	11,94
3,00	43,51	0,30	14,633
5,00	72,51	0,50	18,89
10,00	145,03	1,00	26,71
20,00	290,07	2,00	37,78
50,00	725,18	5,00	59,74

Table 5: Table of potential force and velocity of a 23 kg CP.

4.2 Risk Analysis

Pressure in the XT should be completely equalized before removing the plug. The probability of a residual pressure is minimal but cannot completely be neglected as there have been accidents earlier. Consequence of this event occurring can be huge. The plug can either hit someone when launching out of the TH or hit someone when falling back down. Given the plug's weight, both of these outcomes could be fatal. Besides injuries inflicted on persons, it can also cause huge damage to the TH, the building and different equipment, which again can result in economical loss. Based on these calculations, a risk matrix has calculated the risk of the current method of retrieving plugs, Figure 12.

	Consequence				
Likelihood	Insignificant	Minor	Moderate	Major	Severe
Almost Certain	Medium	High	High	Extreme	Extreme
Likely	Medium	Medium	High	Extreme	Extreme
Possible	Medium	Medium	High	High	Extreme
Unlikely	Low	Medium	Medium	High	High
Rare	Low	Low	Medium	High	High

Figure 12: Risk Matrix of current method of retrieving plugs.

4.3 Risk Evaluation

The total risk was calculated high. This is due to its high consequence and low likelihood. Based on the result, it would be recommended to find a better way to perform this task. By retrieving the plug hydraulic, this hazard will be eliminated because the heavy construction of Rioperk would withstand the force and prevent the plug launching out of the XT. The probability of any residual pressure remaining beneath the plug would still be the same.

5. Calculations

In this chapter all calculations required for designing the HRT will be presented.

5.1 Measurements

The total length of the HRT has been calculated from manufactured drawings and measurements manually measured in the workshop. The design requires the Rioperk to be in the lowest position, as this makes the design as short as possible. This is beneficial for the weight as well as ease of use.

The HRT shall retrieve upper and lower CP and WP, in both HXT and EHXT as well as IS. Therefore, the HRT must be versatile in all these positions. Table 6 shows calculations for the length required to reach the plugs in all positions. “TH depth” is the length from top of TH to top of the plug while inside the TH. “Rioperk height” is from the bottom of the Rioperk to the bottom of the piston. When the Rioperk sits on top of the TH there is an overlap that is deducted. The piston has a range of 250 mm, considering it has to be in an outer position 200 mm is excluded. The length of the lower plug and IS is roughly the same. Adjusting the Rioperk ensures the correct range.

<table>
<tr><th></th><th>TH depth</th><th>Rioperk height</th><th>Running tool</th><th>Overlap of Rioperk on TH</th><th>Length of piston</th><th>Total length</th></tr>
<tr><td>HXT Lower Plug</td><td>1114.5 mm</td><td rowspan="4">1470 mm</td><td rowspan="4">- 136 mm</td><td rowspan="4">- 210 mm</td><td rowspan="4">- 200 mm</td><td>2038.5 mm</td></tr>
<tr><td>HXT Upper Plug</td><td>783.6 mm</td><td>1707.6 mm</td></tr>
<tr><td>EHXT Lower Plug</td><td>1378.1 mm</td><td>2302.1 mm</td></tr>
<tr><td>EHXT Upper Plug</td><td>795.8 mm</td><td>1719.8 mm</td></tr>
</table>

Table 6: Calculated length of HRT.

5.2 Required Force Needed to Retrieve Plug

Before the design process started, determining the maximum force the HRT should withstand was essential. The hydraulic Rioperks maximum retract stroke of 412 kN (42 tonnes) was assessed, as well as the running tool limit of 235 kN (24 tonnes). Both of these forces were evaluated, with the conclusions that those numbers were much greater than the actual force needed for retrieving plugs. This conclusion is based on the fact that the current method of retrieving plugs is done by personnel working in the workshop. With respect to size and weight it was not desired to oversize the HRT.

Therefore, the exact force for retrieving plugs was needed. This was challenging because the current jarring procedure is done by mechanical force and momentum from the jarr. There were several unsuccessful attempts to obtain this force. In the end this information came from the manufacturer of the running tool. Normally the force needed to retrieve a CP is 98 kN (10 tonnes) and it was determined that the HRT should be designed for a traction of 147 kN (15 tonnes).

5.3 Safety Factor & Maximum Allowed Stress

"Safety factor is defined as the ratio of a material's strength to an expected strain" [3]. This factor is determined by the specification of usage of the product. There were some uncertainties about whether the HRT was categorized as a lifting tool or not. Øyvind Drage, Subject Matter Expert in Lifting and Handling at TechnipFMC, was contacted to determine this. According to Drage, the HRT will not be categorized as a lifting tool, but as an ordinary workshop tool. Based on this, the safety factor was set to 1.5.

From the safety factor and the maximum yield strength, the maximum allowed stress ($\sigma_{allowed}$) are determined by formula 5. Steel 520M, which is the material used on the HRT, has a yield strength of 520 MPa.

$$\sigma_{allowed} = \frac{Yield\ Strength}{Safety\ Factor} \quad (5)$$

$$\sigma_{allowed} = \frac{520\ MPa}{1.5}$$

$$\sigma_{allowed} = 346{,}7 \text{ MPa}$$

In order for the HRT to be approved, it must not exceed a stress of 347 MPa.

5.4 Analysis of Rioperk Adapter

The Rioperk is equipped with two different adapters for installing the TH. Each of them is equipped with its own pin to attach the Rioperk. The first thought for attaching the HRT to the Rioperk was to use these pins, but that would be problematic as it had to result in an unnecessarily complicated design considering the diameter of the pins. At the request of the workers who did not want to disassemble the adapter every time they were to use the HRT to retrieve plugs, the possibilities of making threads into the adapter were considered. This way, the HRT could be attached with threads instead.

The Rioperk is designed to withstand a force of 412 kN (42 tonnes) during retrieval, and a force of 628 kN (64 tonnes) during installation. To enable the threads to be made in the adapters, it was important to ensure that the strength of the adapters would not be weakened even if some material is removed and threads are made.

Based on drawings of the adapters provided by TechnipFMC, they were modelled in CREO both with and without the milled hole, and then further simulated in the ANSYS software. In Ansys, a force of 628 kN (64 tonnes) was applied in the downward direction to simulate the installation it is designed to perform. This was done on both sizes of the adapters with and without holes. By doing this, it was easy to see if the adapter was significantly weakened or not, and if the ratio between the adapters with and without the hole was too large. The results from the simulation are presented in Table 7 below.

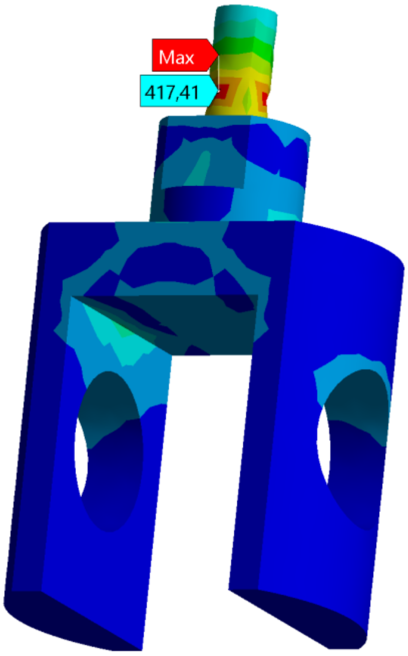
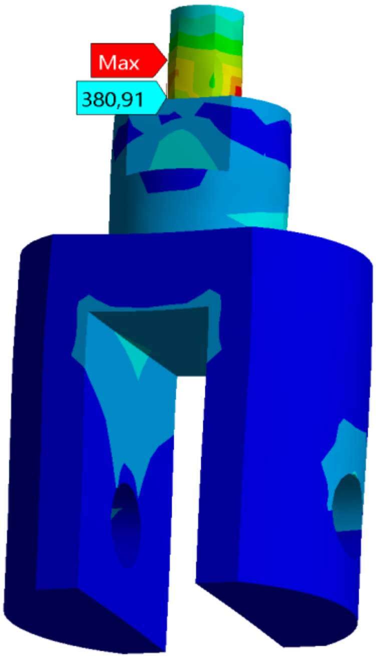
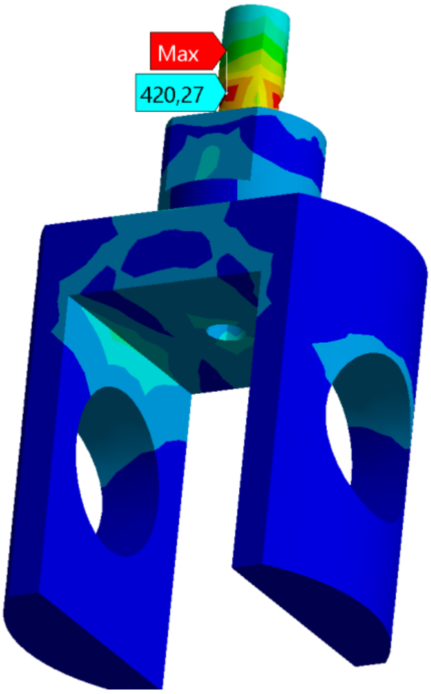
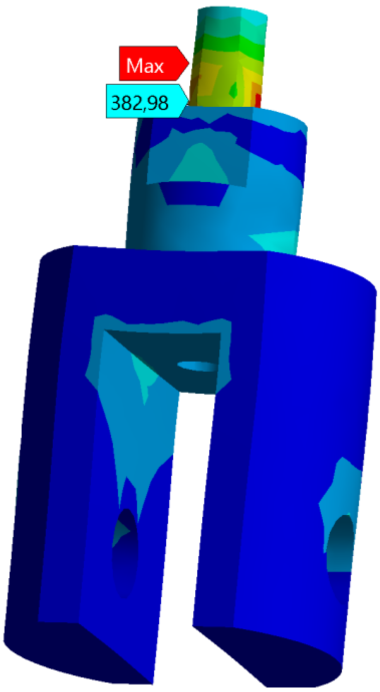
	Big adapter	Small adapter
Original adapter	 Max stress: 417.41 MPa	 Max stress: 380.91 MPa
Hollow adapter	 Max stress: 420.27 MPa	 Max stress: 382.98 MPa
% Difference in equivalent stress	0.69%	0.54%

Table 7: Strength simulation of adapters with and without hole

The results show a difference of 0.69% in stress for the big adapter, and a difference of 0.54% for the small adapter. Both adapters can still withstand the power of 628 kN (64 tonnes) even though they are hollowed out. It was also checked that it met the requirements of 412 kN (42 tonnes) during retrieval, and this resulted in an even smaller percentage change.

Making threads in both the adapters is therefore a feasible solution for attaching the HRT to the Rioperk.

5.5 Manufacturing of a Nut and Thread Testing

Thread pitch gauge was used to determine the threads on the running tool, to verify that the drawings were correct. 1 1/16" - 10 UNS, which is the same on all the different running tools that the HRT needs to be compatible with. This exact size of threading is not to be found in any normal thread pitch chart, but has been manufactured specifically for these tools. Hence UNS, which represents Unified Special Thread. Therefore, a prototype of these threads was made. This was a nut, where the specified minor diameter, pitch diameter and major diameter were stated, as well as the pitch.

When testing the nut on the running tool it turned out that the nut was a bit too small. The reason for this comes from the challenges of making UNS threads, not specified in charts. There are also narrow margins on threading caused by the tolerance stated.

5.5.1 Calculations of Threads

It was determined that the threads should be calculated manually. Considering the HRT only has axial forces, the stress (σ) was calculated using formula 6 and 7.

$$\sigma = \frac{F}{A} \tag{6}$$

Outer diameter (D): 26,99 mm

Inner diameter (d): 24,79 mm

Number of threads: 9

$$A = \pi \frac{D^2}{4} - \pi \frac{d^2}{4} \tag{7}$$

$$A = 89.469\ mm^2$$

$$A_{Total} = 89.469 \cdot 9 = 805.221\ \text{mm}^2$$

$$\sigma = \frac{F}{A_{Total}} = \frac{150\ 000\ \text{N}}{805.221 mm^2} = 186.28\ \text{MPa}$$

This calculation indicates that the threads, according to the safety factor and allowed stress of 347 MPa calculated in chapter 5.3, will restrain and be approved for the load it is subjected to.

6. Analysis

The analysis of the HRT was conducted in the 3D modelling program Creo and the 3D simulating program Ansys.

6.1 Design Process

While working on the design of this HRT, there were a lot of different aspects to consider, and there were several different alternatives of how the design should end up. Before the actual process started, some criteria were set for the HRT so that it got the best properties needed to be as beneficial as possible.

The most essential criteria were that the HRT should withstand the load of 147 kN (15 tonnes). Other important criteria were costs, weight, simplicity and space-efficiency during storage.

Both the price and the weight of the final HRT depends on the design and the choice of material. It is important to keep in mind that the material needs enough strength to withstand the necessary force of 147 kN (15 tonnes). It is also important that the HRT is light enough for one person to lift. According to the TechnipFMC own requirements, the maximum weight one person can lift is 23 kg, which is important to be taken into account.

Given it was initially one of the test technicians who saw potential of improvement in the current method of retrieval, it is important that the HRT is easy to use. The last criteria were space-efficiency for storage purposes.

6.2 Different design proposals

During the design process, several different design proposals were considered. Some of them were eliminated straight away, and some of them were further investigated. A design that was considered early on was using square beams on account of the fact that it is primarily stronger than pipes. Considering the smallest adapter only has a gap of 70 mm, the diagonal of the square beam limits the size of the sides when twisting into the adapter. The dimensions that were applicable would then not be strong enough.

Eventually there were three cylindrical design proposals left. Each proposal contains three parts for convenience. All of them were modelled and simulated to check if they met the requirements stated. The different designs proposals with their pros and cons will be analysed in a Pugh matrix to determine which is the most optimal design, and will then be presented later in this chapter.

6.2.1 Option A - Solid Shaft in Three Parts with Threads

First design proposals that were investigated was a solid shaft with threads in both ends (Figure 13). The end connecting to the running tool has internal threads and the end connecting to the Rioperk has external threads. The parts were connected with threads matching the running tools threads. Dividing the shaft makes the HRT easier to use due to weight and the fact that the parts would be more manageable.

Figure 13: Design option A.

The HRT would not have different depth levels, so the Rioperk would have to be adjusted to make the HRT fit the different depth of the plugs. This is not a problem, but it makes the process more time consuming.

This design would be easy to make. Using a shaft, the load will be distributed onto a larger cross section making it strong. This model would need to be in the material 520M, which refers to its yield strength of 520 MPa, to withstand the required force. The weight of each part is 9.2 kg, which is below the maximum allowed weight of 23 kg. Total weight would be approximately 28 kg. The weight of total material needed, and production cost gives the model an estimated cost of 15 000 NOK.

6.2.2 Option B – Pipes with Threads

The second design option was based on pipes, instead of using only solid shafts. Dimensions used on option B and C follows API Spec 5CT (American Petroleum Institute), table C.24 showcasing dimensions and masses for standard tubing and for tubing threaded [34]. Based on the standard, there are no pipe dimensions that would fit the threading of the running tool with a cross–section area strong enough to withstand the force of 147 kN (15 tonnes). Because of this, the lower part would need to be a solid shaft with a length of 300 mm. The two other parts has a length of 1000 mm.

The total weight of the pipes was 28 kg, and the heaviest part had a weight of 11 kg which would be manageable for one employee. On both ends of all the pipes, there are threads that fit into each other, on the running tool and into the adapter of the Rioperk, showcased in Figure 14. This design would need a material with tensile yield strength of 758 MPa to withstand the capacity needed within the bounds of the safety factor. The weakest spot of this design is the cross-section of the internal threads.

The cost of material and the complexity of production gives the model an estimated price of 16 800 NOK.

Figure 14: Design option B.

6.2.3 Option C - Telescope with Lock-pins

After a few different designs were tested, a telescopic design was proposed in a meeting with SOCON. A telescopic design had previously been used extensively and could be a useful solution in terms of strength, simplicity, and space-saving.

The two upper parts were pipes, while the lower part was solid. These three parts come in different diameter sizes so that the lower one fits into the pipe above. They are also equipped with two solid pins that fasten the parts together, presented in Figure 15. A typical telescopic solution with fish necks, without these pins, was first considered. Considering the running tool also has to be pushed into the plug with this tool, the fish necks had to be replaced with pins.

The bottom solid part comes in three different lengths, so it can be adjusted according to fit the different types of plugs and XTs. On top of this HRT there are external threads that are attached to the adapter connected to the Rioperk, while at the bottom there are internal threads that fit the running tool.

Figure 15: Design option C.

The upper part is the heaviest with 8.1 kg, while the other parts are lighter. The total material needed, and the complexity of the production gives the model an estimated cost of 17 500 NOK. When performing simulation of this model, it became clear that even with a material with a tensile yield strength of 758 MPa, it was not sufficient enough to withstand the applied force.

6.3 Pugh Matrix

The three presented designs were put into a Pugh matrix to find the most optimal solution based on different weighted criteria. If the criteria were met, but nothing further, the design scored neutral (0). If the design exceeded the criteria it scored positive (1), and if the design did not meet the criteria it scored negative (-1). Table 8 presents the Pugh Matrix.

Pugh Matrix							
Criteria	**Emphasis**	**Option A** *Solid shaft in three parts with threads*		**Option B** *Pipes with threads*		**Option C** *Telescope with lock-pins*	
Low price	0.15	1	0.15	0	0	0	0
Low weight	0.2	1	0.2	1	0.2	1	0.2
Easy to use	0.2	1	0.2	0	0	0	0
Strength	0.25	1	0.25	1	0.25	-1	-0.25
Storage - space	0.1	0	0	0	0	1	0.1
Availability	0.1	1	0.1	-1	-0.1	-1	-0.1
SUM	1		**0.9**		0.35		-0.05

Table 8: Pugh Matrix

An estimated price of the designs was found after consulting with SOCON. The price depended on the material weight, the amount of work that needed to be done, and the material quality. None of the designs had huge expenses, but A was the cheapest due to least work on the product.

All three different options weigh less than the maximum requirement for a single lift. Every option is easy to use, but because option A consists of three equal parts that can be mounted in a random order, option A will be even easier to use than B and C. All three alternatives are attached equally in the Rioperk.

Both option A and B can withstand the force required to retrieve the plugs. Option C did not meet the requirement of strength, but it is great when it comes to storage-space as it has a telescopic effect, where each part fits inside each other. A and B do not take up much space during storage either.

In conversation with SOCON, it was presented that some products and material were unavailable and hard to get a hand on. Shafts were more available than pipes and 520 quality material was more available than stronger types. The material with yield strength of 758 MPa, which is the one TechnipFMC used on the Rioperk, is outdated and difficult to find.

After each criteria was assessed, design A was chosen to be the most optimal solution for the task. It was decided that the HRT would be designed as a solid shaft in three similar parts with internal- and external threads in the ends.

6.4 Simulation in Ansys

After the model was designed in Creo, the geometry was imported to Ansys where the simulation was done. The model was assigned the correct material, and boundary conditions were set. The end connecting to the running tool was set as a fixed point, and a force was assigned at the bolt with an axial force of 147 kN (15 tonnes). Standard earth gravity was also assigned, as well as a fine mesh method and size. All values are shown in Table 9.

Boundary conditions	Value	Location
Material	Steel 520 M low alloy	All
Fixed support	-	Internal threads
Force	147 kN	External threads
Standard Earth Gravity	9.81 m/s^2	-

Table 9: Values from Ansys.

6.4.1 Problem Solving

When simulating threads in Ansys there are two options. Treads can be modelled to the right dimensions in the 3D modelling program and then be simulated in Ansys. Some problems appeared using this method. Ansys uses a finite element method when calculating, which divides the part into small pieces and calculates the stress in every piece. The threads had an even smaller surface area than the smallest mesh Ansys could solve, so the calculations could not be done correctly [35]. To solve this problem, Ansys has an option for connections between two parts with bolt thread, with default settings for designated pitch. This allows us to simulate the stress and strengths of the threads without modelling them. This method could be used to perform calculations on the threads. The provided student version of the simulation program cannot perform this feature correctly. It was therefore preferred to do the thread calculation manually using formula for threads presented in chapter 5.5.1.

7. Design Results

In this chapter the results from the simulation of the final design of the HRT is presented. Only simulation of one part will be presented, considering that the HRT consists of three identical parts, and will have the same result in terms of stress and deformation.

7.1 Dimensions of Final HRT

Figure 16 showcases 2D-drawing of the final design of the HRT and table 10 specifies the dimensions. The solid shaft is 1 ¾ " (44.45 mm). It would also be possible to use a 45 mm shaft, or even greater dimensions. Both the internal- and external threads have thread profile 1 1/16 '' 10 UNS with g6-H7 tolerances.

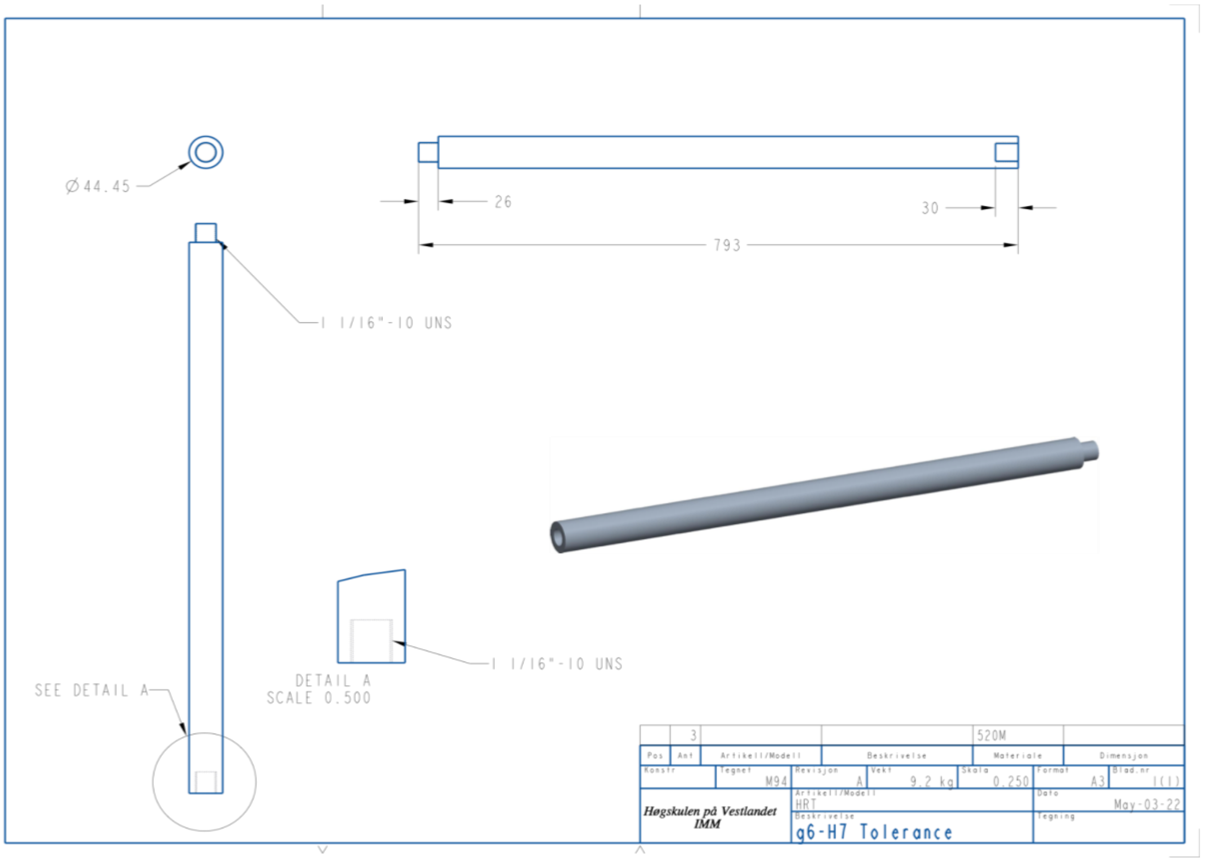


Figure 16: 2D-drawing of the HRT. Appendix A.

Dimensions HRT	**Measurements**
Solid shaft	1 ¾ ’’ (44.45 mm)
Threads	1 1/16 ’’ 10 UNS
Tolerance	g6-H7
Length / part	793 mm
Total length	2301 mm

Table 10: Specification of HRT.

Figure 17 illustrates how the three equal parts of HRT will be attached together and into the adapter of the Rioperk, as well as the running tool connected to the plug in the XT. The Rioperk is adjustable to ensure the range, which reaches both upper and lower plug in HXT and EHXT.

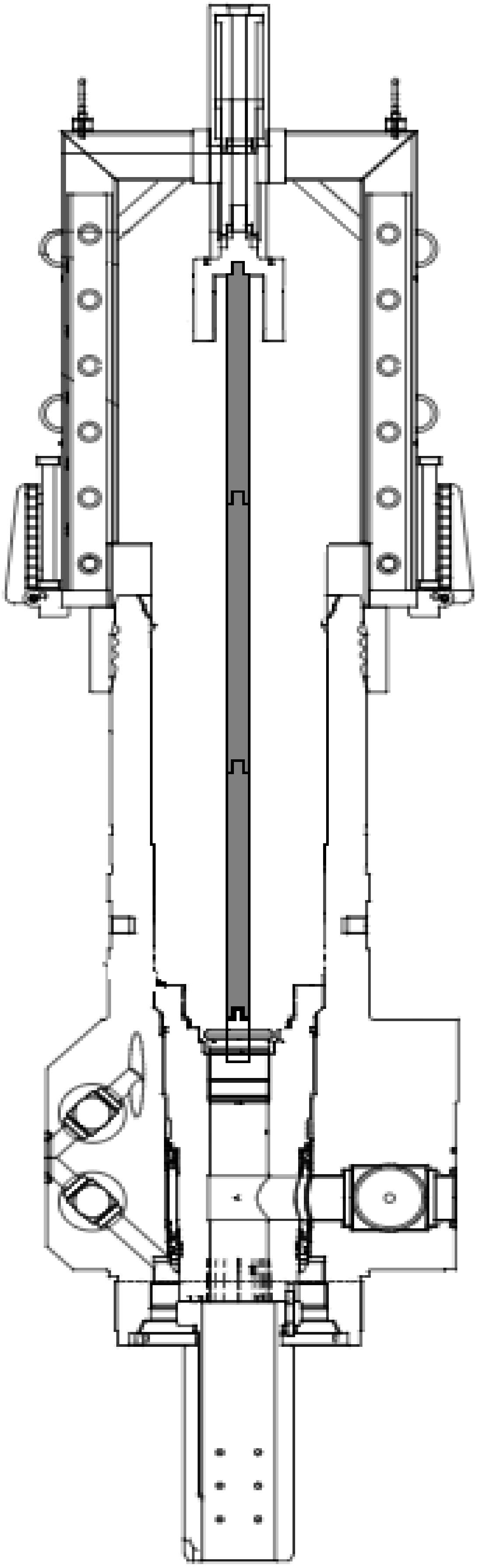


Figure 17: Illustration of HRT implemented in Rioperk on top of XT [36].

7.2 Engineering Simulation of HRT

The result of the simulation shows that HRT has a maximum stress of 346 MPa, presented in Figure 18. Based on calculations presented in chapter 5.3, the HRT is within the requirements for the maximum allowed stress. Figure 19 visualizes a close up of where the maximum stress is located. The maximum stress spreads over a small area, and it is shown that the stress is low elsewhere.

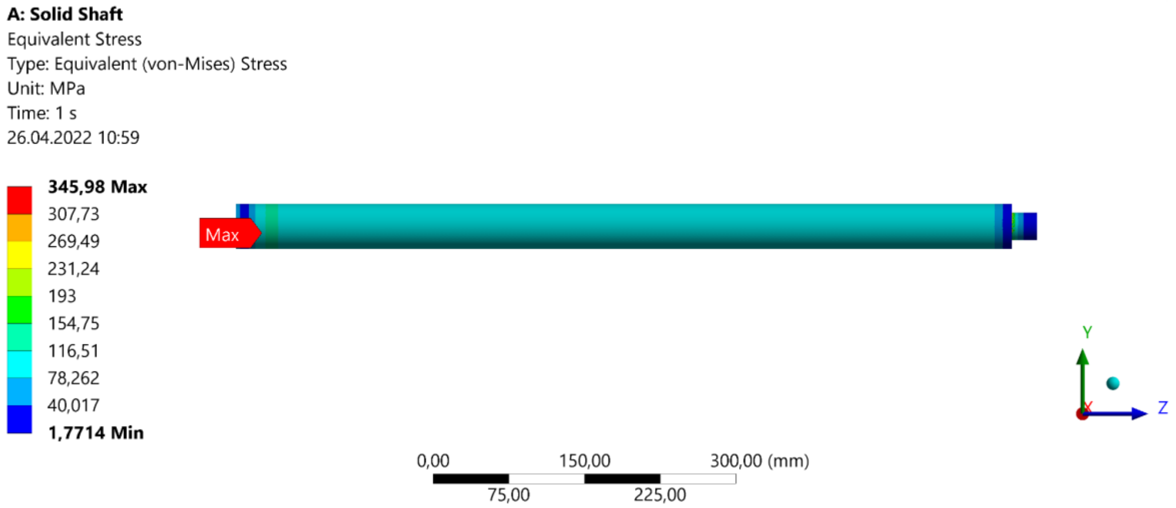


Figure 18: Different magnitudes of stress on the HRT.

Figure 19: Section Plane, maximum stress.

As mentioned in chapter 6.4.1, there were problems during the simulation of the threads in Ansys, as the surface area of the threads is smaller than each element in the fine mesh. The calculations for the threads were therefore done manually, so that it was carefully checked that the threads also withstood the force required. Presented in chapter 5.5.1, it is clear that the threads also can withstand the maximum allowable stress of 347 MPa, as it has a maximum stress of 186 MPa. Regardless, simulations were performed in Ansys, without the threads, but with the correct dimensions, Figure 20.

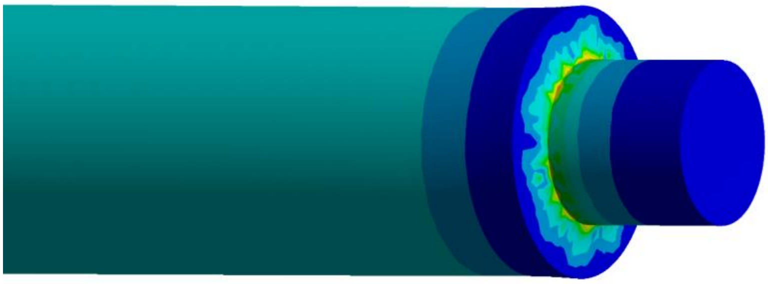


Figure 20: Simulation without threads.

From the simulation, deformation is also shown. The model will have a maximum total deformation of 0.36 mm per part. Figure 21 shows that the deformation is highest at the internal threads. The total deformation on the whole HRT will be 1.08 mm. This is a small deformation and it will not have an impact on its function.

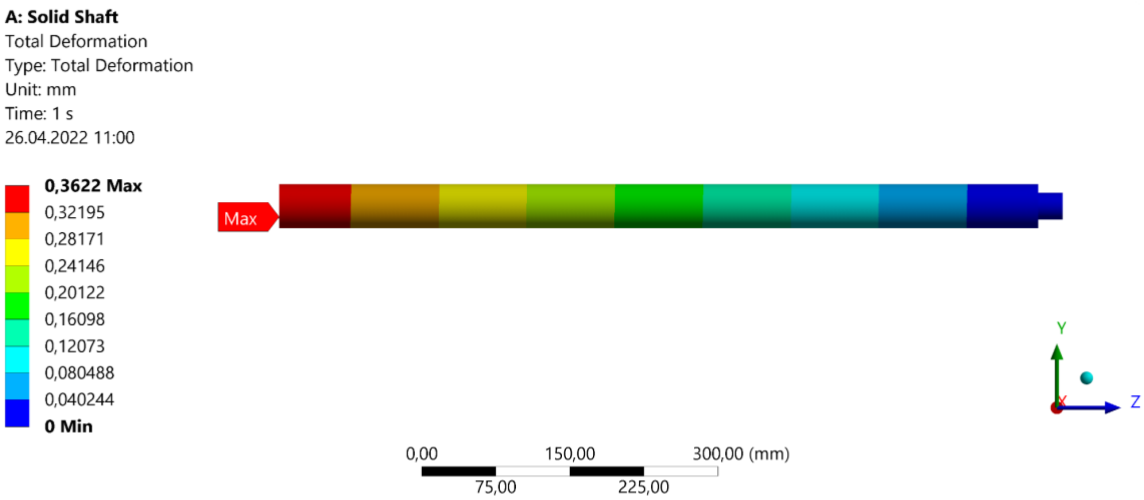


Figure 21: Deformation on HRT.

Table 11 shows a summary of the simulation result of the HRT, from Appendix B.

Results summary	Each part in HRT	Complete HRT
Material	Steel 520 M low alloy	Steel 520 M low alloy
Weight	9.1829 kg / part	$\approx 28\ kg$
Volum	$1{,}1773 \times 10^6\ mm^3$	$3{,}5319 \times 10^6\ mm^3$
Maximum stress	345.98 MPa	345.98 MPa
Maximum deformation	0.36 mm	1.08 mm

Table 11: Results summary of the HRT [37].

7.3 Production Costs

For the economy and production costs, SOCON was contacted for their expertise in this field. A 2D-drawing of the design was sent to get a cost estimation of the product. The material cost for 520 quality is nowadays at approximately 30 NOK/kg (1.4 USD/lb). After production, the finished product has a cost from 200 NOK/kg (9.4 USD/lb) up to 700 NOK/kg (32.7 USD/lb), depending on the amount of work that needs to be done. The HRT model consists of 3 shafts with standard dimensions and internal/external threads at the ends, and therefore SOCON estimated it to cost around 500 NOK/kg. The total weight for the HRT is at 28 kg, which results in a total cost of approximately 15 000 NOK. This cost includes local shipping and has a standard delivery time of four weeks.

7.4 Risk Assessment of HRT

After the HRT was simulated, the risk related to retrieving the plugs with this tool was calculated using a risk matrix. By implementing the HRT, the risk of retrieving the plugs would be reduced, because the heavy construction of Rioperk would withstand the force and prevent the plug from potentially launching out of the XT. This results in the CoF to be reduced from major to minor, while the PoF stays the same. Figure 22 exhibits that the risk is set as low for the method with HRT.

	Consequence				
Likelihood	**Insignificant**	**Minor**	**Moderate**	**Major**	**Severe**
Almost Certain	Medium	High	High	Extreme	Extreme
Likely	Medium	Medium	High	Extreme	Extreme
Possible	Medium	Medium	High	High	Extreme
Unlikely	Low	Medium	Medium	High	High
Rare	Low	Low	Medium	High	High

Figure 22: Risk Assessment of HRT.

8. Business case

In this chapter the results of the business case based on the HRT will be presented.

8.1 The Problem

The current method for retrieving CP and WP is by jarring the plugs out of the TH. TechnipFMC spends many hours polishing inside the TH after retrieving the plugs by conducting jarring. In addition, this method causes various ergonomic injuries.

8.1.1 Quality & Damage Rate

According to the estimated average of the last couple of years, approximately ten XT is tested yearly at Ågotnes. Lower and upper plug needs to be tested on both soft seal and metal seal, in addition to installing the IS. This results in five retrieving procedures on each XT, which potentially are damaging the TH.

The damage that occurs on the TH varies. Figure 23 below showcases an example from a Visual Testing Report made after inspection and testing. Each number defines an imperfection in the TH that must be repaired before forwarding it in the process and returning the TH to the customer.

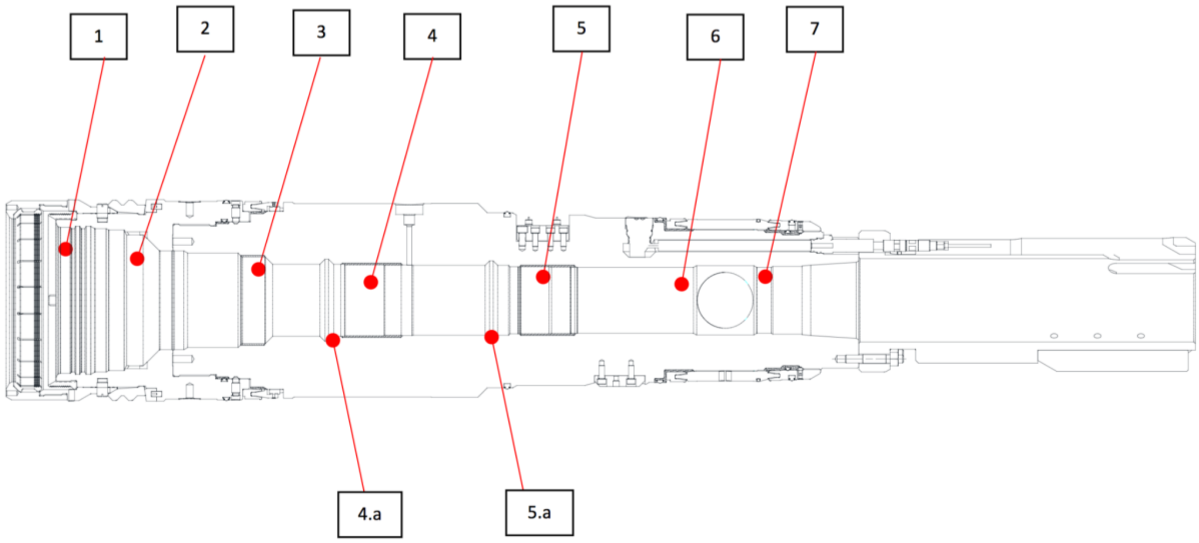


Figure 23: Visual Testing Report showcases damage in TH [38].

Damage and imperfection that occurs while retrieving plugs must be polished manually. Usually this procedure takes 3-6 hours, but at worst this can take 30 hours. Major damage that occurs, which needs welding repairs, takes 2-5 months and costs approximately 200 000 - 300 000 NOK.

8.1.2 Health and Safety Executive

The current method of retrieving CP and WP with the jar, is not very ergonomic. This is heavy work that strains the mechanics unnecessarily, which can lead to prolonged fatigue in their musculature. In addition, by using the current method, the worker is more prone to injury if there should be an unforeseen residual pressure left under the plugs while retrieving, as they are standing close to the TH during this procedure.

Figure 24 illustrates jarring on top of a dummy tree instead of a XT. Jarring on top of a XT is more challenging as the workers also have to keep their balance at the same time as the retrieval takes place. This can result in the workers ending up in a skewed position which in turn can lead to even more fatigue on their bodies.

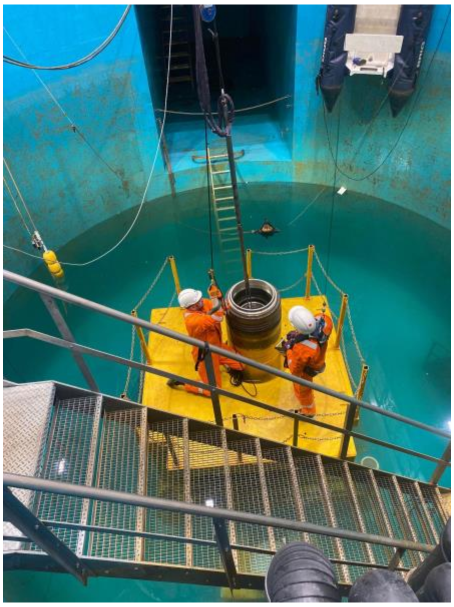


Figure 24: Test technicians retrieving crown plug. Picture taken in the test pit [2].

As mentioned, imperfections in the TH which occurred after the retrieval procedure, must be manually polished. This work is time consuming and tough due to inconvenient working positions while reaching inside the TH. Ultimately this can lead to tendonitis and sick leave. Polishing for several hours daily is not a motivating work either.

8.2 The Solution

The problem can be solved by implementing a new hydraulic retrieving tool, HRT.

8.2.1 Design

The HRT is an extension between the Rioperk and the running tool attached to the plug. This gives the opportunity to retrieve the plugs hydraulic, giving a much more even retrieval.

8.2.2 How to Reduce the Problem

Retrieving the plugs hydraulically will lead to a more even procedure. This will lead to reduced damage inside the TH and diminish total polishing hours. Cases where the TH has been damaged and the TH has been sent to the manufacturer for reparation, would be eliminated. Also, using hydraulic forces, the workers will spear their bodies by not retrieving the plugs manually.

8.3 Investment Cost and Yearly Savings

Costs from hours various employees spend on their jobs are based on an internal rate within TechnipFMC. In addition, hours spent on each task are estimated by relevant employees.

The new HRT has a production cost of approximately 15 000 NOK. A purchase cost of 10 % will come in addition to the production cost. Then the HRT needs to be registered in TechnipFMC systems. Threads need to be made on the adapters as well. This gives the HRT a total price of approximately 35 000 NOK. Numbers for one-time investment cost is presented in Table 12.

By retrieving the plugs more evenly and therefore reducing the damage inside the TH, hours spent polishing is estimated to be reduced by 50%. This means that instead of spending 3 - 6 hours polishing each time, it is reduced to 0-3 hours. This results in a yearly saving of 31 440 NOK - 62 880 NOK.

Once or twice a year, coarse and deep scratches occur inside the TH, which results in it being sent away for repair. Each time this happens it costs approximately 200 000 NOK - 300 000

NOK. In addition, this process takes 2-5 months, which may create delays in deliveries for customers. The potential yearly saving of implementing the HRT is presented in Table 13.

One-time Investments	
Expenses	**Costs**
Production- & shipping costs	15 000 NOK
Coating	6000 NOK
Produce threads in adapter	6288 NOK
Purchasing process	1 500 NOK
Registration in system	6288 NOK
SUM	**35 076 NOK (3552 USD)**

Table 12: Table presenting one-time investments by implementing the HRT.

Yearly savings		
Area	**Money**	**Time**
Polishing	31 440 NOK - 62 880 NOK	30 - 60 hours
Logistics	32 230 NOK	30 hours
TH sent for repair	200 000 NOK - 600 000 NOK	2 - 6 months
SUM	**63 670 NOK - 695 110 NOK**	**60 hours - 6 months**

Table 13: Table presenting yearly savings by implementing the HRT.

9. Discussion

The presented HRT reduces the risk of hazardous events due to residual pressure for test technicians while retrieving plugs from TH. It also improves the ergonomic working positions. Hydraulic retrieval provides safer and more stable working conditions that will not exhaust the test technicians as much as the current method using the jar. The probability of any residual pressure remaining beneath the plug would still be the same, but the heavy construction of the Rioperk would withstand the force and prevent the plug launching out of the XT. In addition to retrieving both the CP and WP, the HRT is also designed to retrieve the IS.

In conversation with several test technicians it was repeatedly stated the importance of making a tool that was easy to use. By replacing the current method with the HRT, it will not save working hours in the test centre considering that the jarring is usually a quite rapid method. It is therefore important to elucidate the other benefits that will be advantageous by using the HRT, such as improved HSE and saved polishing hours. It is also important to illuminate that there have been incidents where the jarring procedure has taken up to twelve hours due to complications, which could be eased with hydraulic retrieval.

By implementing the HRT which provides even pulling, and thus reducing damage and imperfection in the TH, the polishing hours of the TH in the workshop will be reduced considerably. The TH that previously would need welding repairs will presumably be eliminated, as well as TH with major damage where polishing for 30 hours was needed. This is advantageous considering it would shorten the time technicians are exposed to inconvenient working positions when polishing imperfections inside the TH.

HSE is a high priority at TechnipFMC. Because of this, it was important that the ergonomic improvement results were well promoted to them, to convince them to replace the previous method of retrieving plugs with implementing the HRT. The work, results and the business case were therefore presented for the management group at TechnipFMC. The presentation was a success, and they were pleased with the work and results.

One of the participants at this presentation reported some information regarding sick leave due to polishing. Two men were currently on sick leave due to injuries caused by repetitive movement and strain from polishing work. It was also confirmed that working with polishing was indeed not a motivating job.

Based on the business case, it is made clear that an implementation of HRT saves the company money, but even more importantly, the ergonomics of the work will be improved. It is more difficult to estimate a cost, but the benefits of ergonomics will outweigh other savings.

The test centre at TechnipFMC is also commissioned to maintain and test crown plugs. This is performed in a test cylinder that imitates an XT. These crown plugs are also retrieved with the same jarring method, but this procedure cannot be substituted with the HRT and hydraulic force because the Rioperk has no fastening options onto the cylinder. The possibility of designing an HRT that also could retrieve from this test cylinder was desirable but was abandoned in collaboration with the project's external supervisor considering the complexity of it. This results in the jar to still be used and current storage space will not be eliminated. In addition, test technicians would need to cope with two different methods of retrieving plugs.

It was desirable that the HRT would be the weakest link in the retrieval process. Based on this, and the estimated force required to retrieve the plugs, the HRT was designed to retain a force of 147 kN (15 tonnes), while the running tool withstand 235 kN (24 tonnes). This was desirable so that if something were to go wrong, the HRT, which is the least expensive tool, would fail first.

When implementing the HRT, the first step is to get a quality check of the product. The product should be ordered, and threads would need to be manufactured in the two adapters of the Rioperk, to make them compatible with the HRT. TechnipFMC has no standard routine for implementing new tools, but it would be recommended training the technicians for use of the tool according to HSE.

10. Conclusion

This bachelor thesis has investigated the possibility of retrieving CP, WP and IS hydraulically by designing the new tool "HRT", and the benefits of this. The background for the thesis was their current situation by retrieving the plugs by jarring with mechanical force. This method is exhausting as well as it causes unwanted damage inside the TH and therefore extra polishing work.

Several design proposals were looked at and simulated before the most optimal proposal was chosen. The HRT is a solid shaft in three parts with internal- and external threads in the ends. By implementing the HRT in the retrieval procedure, the workers spare their bodies against the exhaustion of jarring in addition to making the retrieval more even, resulting in less damage inside the TH. Less damage leads to less hours spent on polishing, which again leads to money saved. The yearly savings have been calculated to be anywhere from 63 670 - 695 110 NOK.

By implementing the HRT, the risk will be reduced from high to low and the HSE during retrieval procedures, and when polishing the TH, will improve.

According to results presented in this report, the conclusion is that it would be advantageous for TechnipFMC to implement a retrieving tool for retrieving CP, WP and IS in TH hydraulically, compared to the current method where mechanical force is used. After presenting the thesis to the management group, TechnipFMC was positive about the proposal and wanted to take the idea further for implementation.

12. References

[1] ‘About us - TechnipFMC plc’, *TechnipFMC.com*. https://www.technipfmc.com/en/about-us/ (accessed Mar. 18, 2022).

[2] Anni Skåtun, TechnipFMC - Ågotnes. *Picture of jarring in test center*, (Mar. 28, 2022).

[3] ‘Oxford Languages and Google - English | Oxford Languages’. https://languages.oup.com/google-dictionary-en/ (accessed Mar. 18, 2022).

[4] NTNU Undervisning, *Litteraturstudie som metode*, (Dec. 19, 2018). Accessed: Mar. 21, 2022. [Online Video]. Available: https://www.youtube.com/watch?v=KF3PtpaDsm8

[5] O. har fire bibliotek-tre i P. og et på K. S. mer her: U. : B. nettside, ‘OsloMet – storbyuniversitetet - Litteratursøk og kildekritikk’. https://student.oslomet.no/litteratursok-kildekritikk (accessed Mar. 21, 2022).

[6] Steinar Kvale and Sven Brinkmann, *Kvalitative forskningsintervju*. Oslo: Gyldendal, 1997.

[7] F. Svartdal, ‘observasjon – psykologi’, *Store norske leksikon*. Nov. 01, 2018. Accessed: Mar. 23, 2022. [Online]. Available: http://snl.no/observasjon_-_psykologi

[8] ‘What is a business case? - Knowledge Base’, *microTOOL*. https://www.microtool.de/en/knowledge-base/what-is-a-business-case/ (accessed Mar. 18, 2022).

[9] ‘Ansys Mechanical | Structural FEA Analysis Software’. https://www.ansys.com/products/structures/ansys-mechanical (accessed Mar. 21, 2022).

[10] ‘What is Finite Element Analysis (FEA)?’ https://www.twi-global.com/technical-knowledge/faqs/finite-element-analysis.aspx (accessed Mar. 21, 2022).

[11] K. Bell and R. W. Meyer, ‘elementmetoden’, *Store norske leksikon*. Nov. 07, 2021. Accessed: Mar. 21, 2022. [Online]. Available: http://snl.no/elementmetoden

[12] ‘Risikostyring – ISO 31000 | standard.no’. https://www.standard.no/fagomrader/kvalitet-og-/risikostyring/iso-31000-risikostyring--retningslinjer/?gclid=Cj0KCQjw-JyUBhCuARIsANUqQ_KEgVvDaoLQxW2emx3Vm3EBxyOi0XSMOr9qkowFGLMx0yJ5_Vh3kCUaAt6QEALw_wcB (accessed May 20, 2022).

[13] ‘Hazard and Operability Study (HazOp) – Jeferson Costa’. https://jefersoncosta.com/hazard-and-operability-study-hazop/ (accessed Apr. 19, 2022).

[14] ‘Pugh Matrix Definition’, *iSixSigma*. https://www.isixsigma.com/dictionary/pugh-matrix/ (accessed Apr. 04, 2022).

[15] ‘Subsea School - Well Completion System’. TechnipFMC.

[16] C. Schaschke, ‘CIP’, in *Dictionary of Chemical Engineering*, Oxford University Press, p. 67. [Online]. Available: https://app.knovel.com/hotlink/pdf/id:kt00TW58Z1/dictionary-chemical-engineering/cip

[17] Ivar Noremark, ‘Tegninger av ventiltre’, Apr. 04, 2022.

[18] J. Bellarby, ‘1.2.1 Well Control and Barriers’, in *Developments in Petroleum Science, Volume 56 - Well Completion Design*, Elsevier, pp. 3–4. [Online]. Available: https://app.knovel.com/hotlink/pdf/id:kt00C7Y9H9/developments-in-petroleum/well-control-barriers

[19] ‘Installation/Commissioning Procedure, Subsea - Completion & Workover, 7 Inch Nominal SSP Wireline Equipment’. TechnipFMC.
[20] TechnipFMC, ‘Wireline Tools’.
[21] ‘Subsea School - Intervention & Connection System’. TechnipFMC.
[22] FMC Technologies, ‘Wireline Tools’.
[23] ‘Definition of Hydraulic’. https://www.merriam-webster.com/dictionary/hydraulic (accessed Mar. 23, 2022).
[24] ‘hydrostatic pressure - Knovel’. https://app.knovel.com/web/view/khtml/show.v/rcid:kpDCE00021/cid:kt00TW5XJ1/viewerType:khtml//root_slug:dictionary-chemical-engineering/url_slug:hydrostatic-pressure?bq=Hydrostatic%20pressure&include_synonyms=no&sort_on=default&page=11&view=collapsed&zoom=1&q=Hydrostatic%20pressure (accessed Mar. 23, 2022).
[25] Ivar Noremark, ‘Workshop Tool’, Jan. 18, 2022.
[26] B. Lundkvist, *Maskintegning*, 4. utg. Oslo: Universitetsforlaget, 1993. Accessed: Mar. 23, 2022. [Online]. Available: https://urn.nb.no/URN:NBN:no-nb_digibok_2007112801013
[27] ‘Bolt Thread Sizing Guide | UNC & UNF Conversion Chart’. https://www.ostermfg.com/resources/bolt-sizes (accessed Mar. 22, 2022).
[28] P. H. Kenneth G. Budinski, *Engineering Materials, Properties and Selection*, International Edition. 1996.
[29] Maryam, ‘Mechanical Properties of Materials: Toughness, Hardness and Stiffness’, *Information Palace*, Oct. 18, 2020. https://www.informationpalace.com/mechanical-properties-of-materials/ (accessed May 02, 2022).
[30] ‘Datasheet: Skärbarhetsförbättrat, mikrolegerat stål 520M’. Tibnor AB.
[31] ‘Engineering Fundamentals Refresh: Strength vs. Stiffness vs. Hardness’, *Fictiv*. https://www.fictiv.com/articles/engineering-fundamentals-refresh-strength-vs-stiffness-vs-hardness (accessed May 20, 2022).
[32] ‘What is a coating?’ https://www.twi-global.com/technical-knowledge/faqs/faq-what-is-a-coating.aspx (accessed Mar. 24, 2022).
[33] M. Herst and M. Coles, ‘Phenolic Based Thermosetting Resin Coating with PTFE Filler’. TechnipFMC.
[34] ‘5CT 9th Edition Purch Guidelines R1 20120429.pdf’. Accessed: Apr. 25, 2022. [Online]. Available: https://www.api.org/~/media/Files/Certification/Monogram-APIQR/Purchasing%20Guidelines/5CT%209th%20Edition%20Purch%20Guidelines%20R1%2020120429.pdf?fbclid=IwAR3qXnnjfH-1R1rr3BycFp0__FAvMtbXh7jUdrVYZsIQ0xW0J9frmsX1KoA
[35] ‘Contact Technology Guide’. ANSYS Inc, Jan. 2022.
[36] Ingrid Skodvin Mjaatvedt, *Illustration of HRT*. 2022.
[37] ‘Ansys Project’. Ansys, Apr. 2022.
[38] Kenneth Trellevik, ‘VT - Visual Testing Report’. TechnipFMC, Feb. 14, 2020.

List of Figures

List of Tables

Appendix

Appendix A: 2D-drawing of HRT

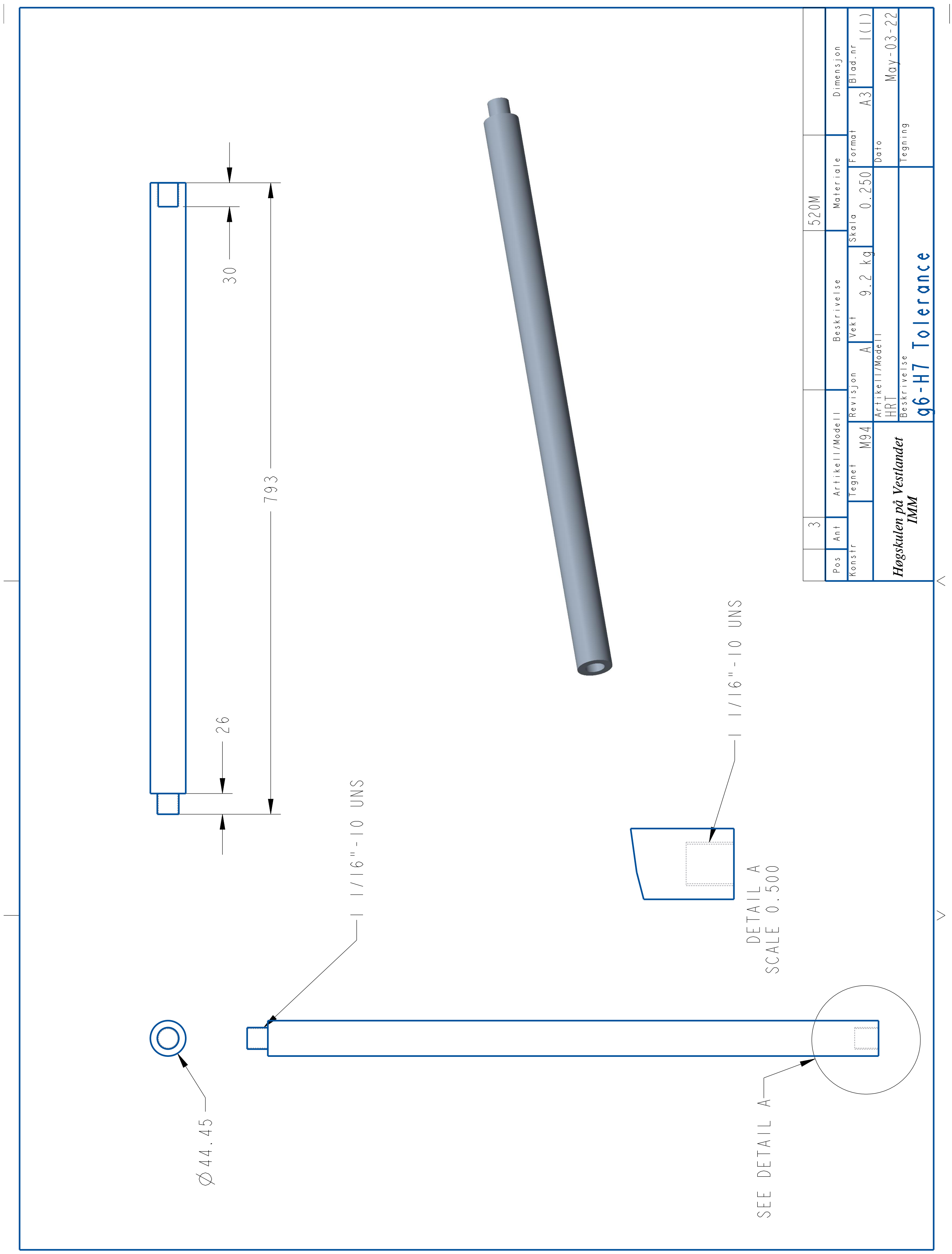
Appendix B: Mechanical Report

Appendix C: STEP-file of HRT (attached separately)

Appendix D: Ansys Workbench of HRT (attached separately)

Appendix E: EXPO-Poster (attached separately)

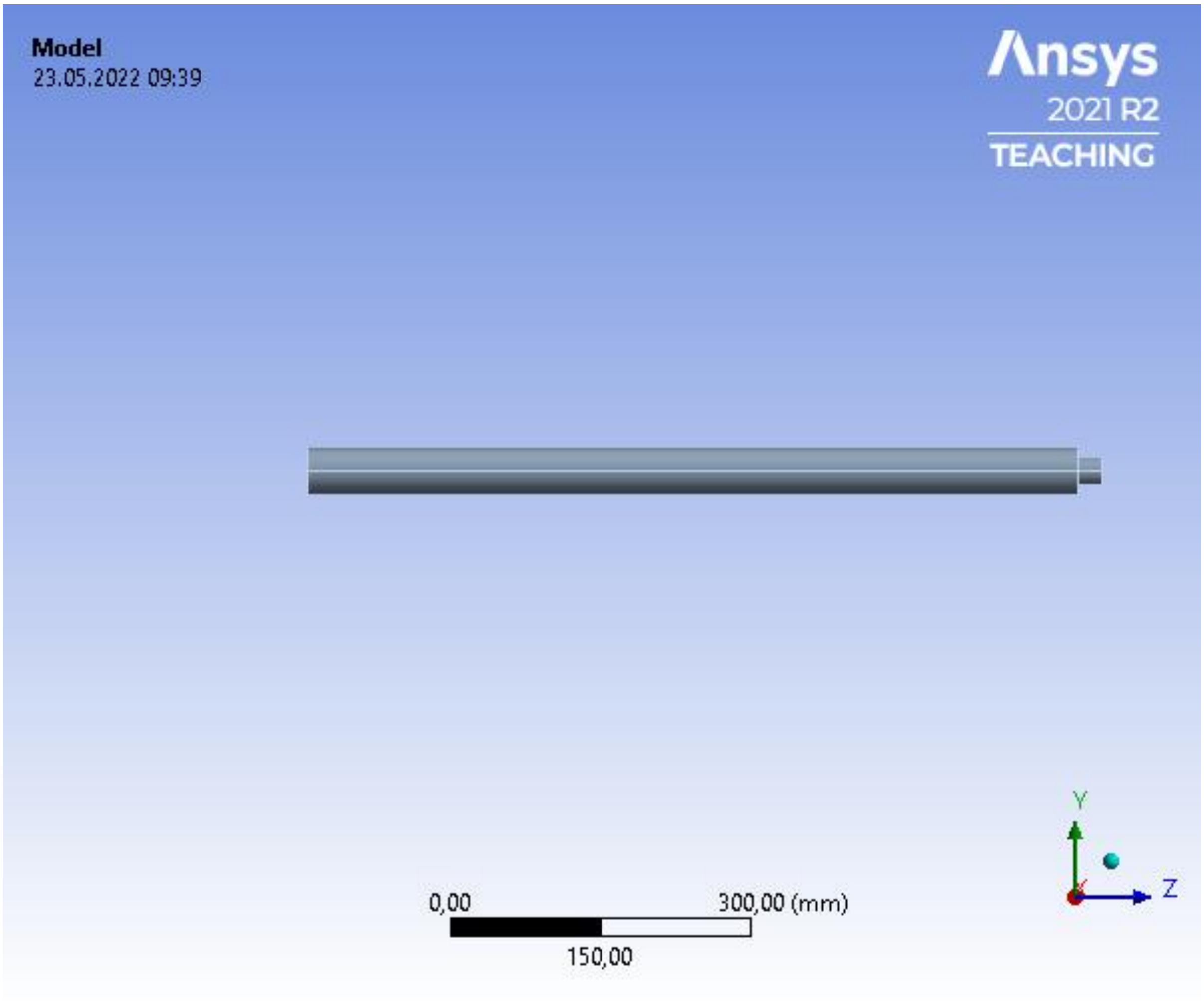
Appendix A – 2D-drawing of HRT



Appendix B – Mechanical Report

Project

First Saved	Wednesday, April 20, 2022
Last Saved	Thursday, April 28, 2022
Product Version	2021 R2
Save Project Before Solution	No
Save Project After Solution	No



Contents

Units

TABLE 1

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\ingri\OneDrive - Høgskulen på Vestlandet\Dokumenter\Bachelor tegning\del_til_simulering.stp
Type	Step
Length Unit	Millimeters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	44,45 mm
Length Y	44,45 mm
Length Z	793, mm
Properties	
Volume	1,1773e+006 mm³
Mass	9,1829 kg
Scale Factor Value	1,

Statistics	
Bodies	1
Active Bodies	1
Nodes	271418
Elements	159788
Mesh Metric	None
Update Options	
Assign Default Material	No
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Independent
Parameter Key	ANS;DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Analysis Type	3-D
Mixed Import Resolution	None
Import Facet Quality	Source
Clean Bodies On Import	No
Stitch Surfaces On Import	Program Tolerance
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*del_til_simulering-FreeParts|VERSTE_DEL0*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Treatment	None
Material	
Assignment	Steel 520M
Nonlinear Effects	Yes
Thermal Strain Effects	Yes

Bounding Box	
Length X	44,45 mm
Length Y	44,45 mm
Length Z	793, mm
Properties	
Volume	1,1773e+006 mm³
Mass	9,1829 kg
Centroid X	-2,6285e-016 mm
Centroid Y	3,9335e-017 mm
Centroid Z	393,64 mm
Moment of Inertia Ip1	4,5321e+005 kg·mm²
Moment of Inertia Ip2	4,5321e+005 kg·mm²
Moment of Inertia Ip3	2243,7 kg·mm²
Statistics	
Nodes	271418
Elements	159788
Mesh Metric	None

TABLE 4
Model (A4) > Materials

Object Name	*Materials*
State	Fully Defined
Statistics	
Materials	5
Material Assignments	0

Coordinate Systems

TABLE 5
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0,
Origin	
Origin X	0, mm
Origin Y	0, mm
Origin Z	0, mm
Directional Vectors	
X Axis Data	[1, 0, 0,]
Y Axis Data	[0, 1, 0,]
Z Axis Data	[0, 0, 1,]

Mesh

TABLE 6
Model (A4) > Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Use Geometry Setting

Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	2, mm
Sizing	
Use Adaptive Sizing	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Fast
Span Angle Center	Coarse
Initial Size Seed	Assembly
Bounding Box Diagonal	795,49 mm
Average Surface Area	11442 mm²
Minimum Edge Length	24,79 mm
Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Aggressive Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0,272
Maximum Layers	5
Growth Rate	1,2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	No
Rigid Body Behavior	Dimensionally Reduced
Triangle Surface Mesher	Program Controlled
Topology Checking	Yes
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Statistics	
Nodes	271418
Elements	159788

TABLE 7
Model (A4) > Mesh > Mesh Controls

Object Name	*Automatic Method*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Method	Automatic
Element Order	Use Global Setting

Static Structural (A5)

TABLE 8
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	22, °C
Generate Input Only	No

TABLE 9
Model (A4) > Static Structural (A5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1,
Current Step Number	1,
Step End Time	1, s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Off
Solver Pivot Checking	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Quasi-Static Solution	Off
Rotordynamics Controls	
Coriolis Effect	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Combine Restart Files	Program Controlled
Nonlinear Controls	
Newton-Raphson Option	Program Controlled
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Program Controlled
Advanced	
Inverse Option	No
Contact Split (DMP)	Off
Output Controls	
Stress	Yes
Surface Stress	No
Back Stress	No
Strain	Yes

Contact Data	Yes
Nonlinear Data	No
Nodal Forces	No
Volume and Energy	Yes
Euler Angles	Yes
General Miscellaneous	No
Contact Miscellaneous	No
Store Results At	All Time Points
Result File Compression	Program Controlled
Analysis Data Management	
Solver Files Directory	C:\Users\ingri\Simulering_HRT_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Contact Summary	Program Controlled
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	nmm

TABLE 10
Model (A4) > Static Structural (A5) > Accelerations

Object Name	*Standard Earth Gravity*
State	Fully Defined
Scope	
Geometry	All Bodies
Definition	
Coordinate System	Global Coordinate System
X Component	0, mm/s² (ramped)
Y Component	0, mm/s² (ramped)
Z Component	-9806,6 mm/s² (ramped)
Suppressed	No
Direction	-Z Direction

FIGURE 1
Model (A4) > Static Structural (A5) > Standard Earth Gravity

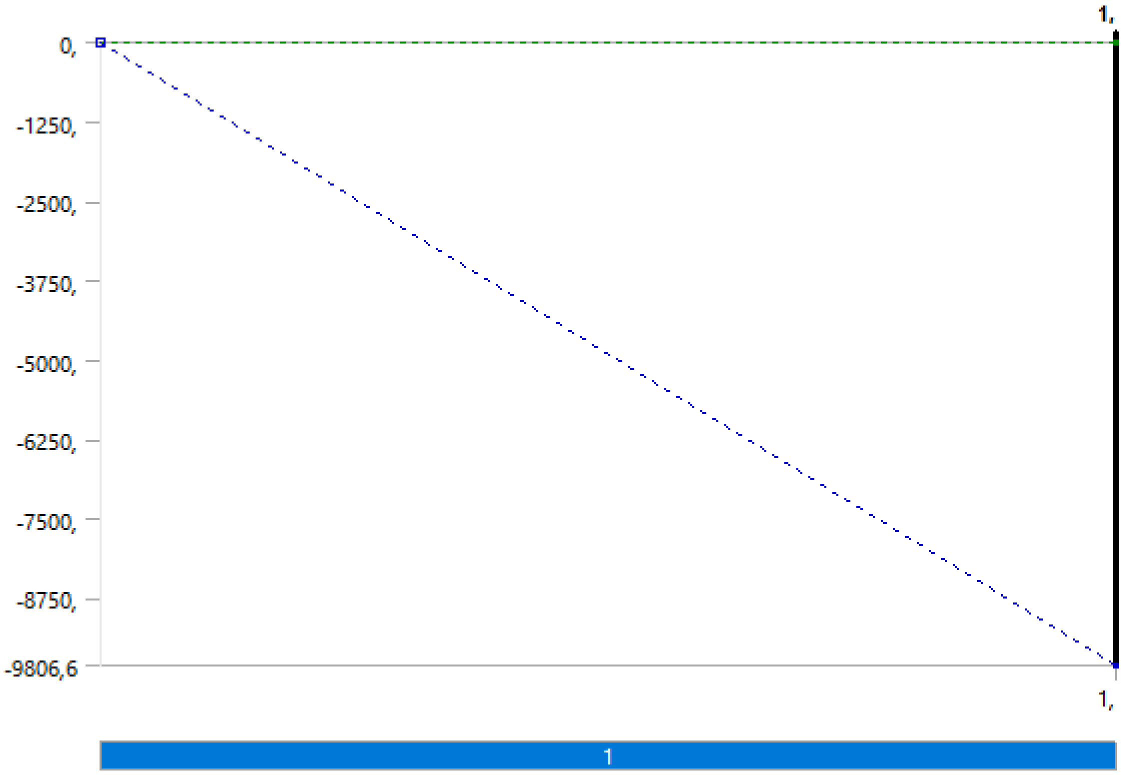
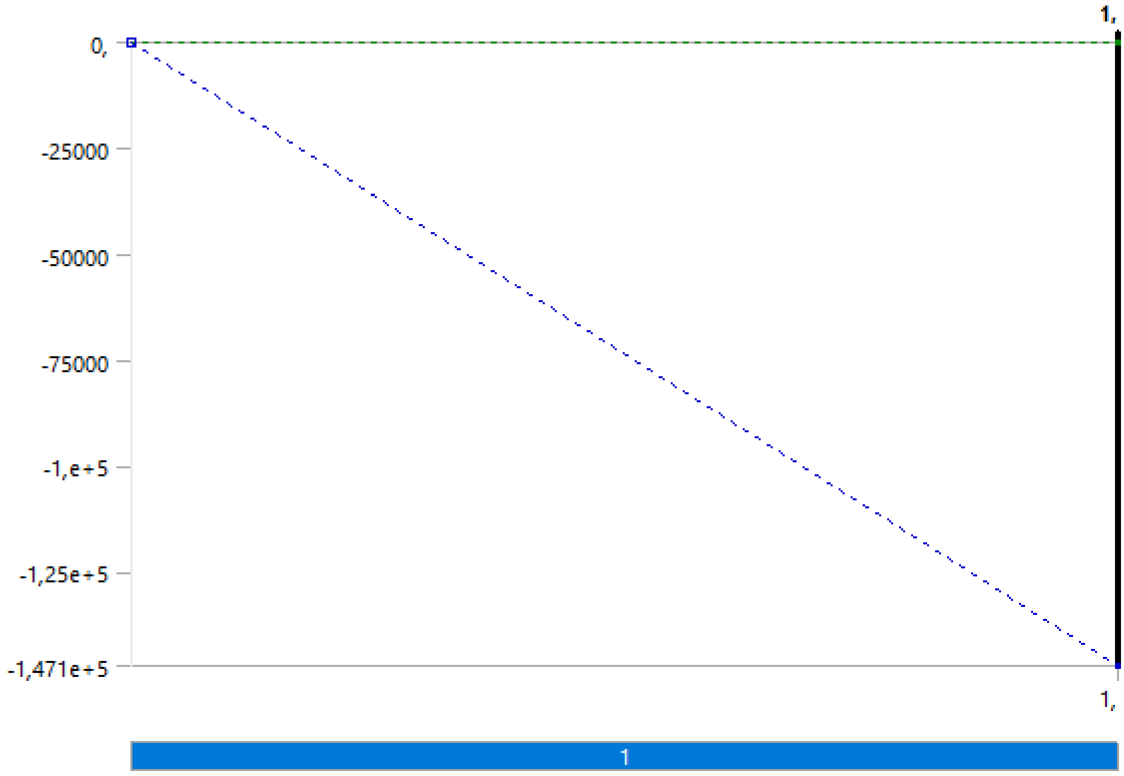


TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Applied By		Surface Effect
Coordinate System		Global Coordinate System
X Component		0, N (ramped)
Y Component		0, N (ramped)
Z Component		-1,471e+005 N (ramped)

FIGURE 2
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1,
Refinement Depth	2,
Information	
Status	Done
MAPDL Elapsed Time	37, s
MAPDL Memory Used	1,4678 GB
MAPDL Result File Size	101,13 MB
Post Processing	
Beam Section Results	No
On Demand Stress/Strain	No

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Identify Element Violations	0
Update Interval	2,5 s
Display Points	All
FE Connection Visibility	

Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Equivalent Stress*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Total Deformation	Equivalent (von-Mises) Stress
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Suppressed	No	
Results		
Minimum	0, mm	1,7714 MPa
Maximum	0,3622 mm	345,98 MPa
Average	0,18176 mm	94,492 MPa
Minimum Occurs On	del_til_simulering-FreeParts|VERSTE_DEL0	
Maximum Occurs On	del_til_simulering-FreeParts|VERSTE_DEL0	
Information		
Time	1, s	
Load Step	1	
Substep	1	
Iteration Number	1	
Integration Point Results		
Display Option		Averaged
Average Across Bodies		No

FIGURE 3
Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation

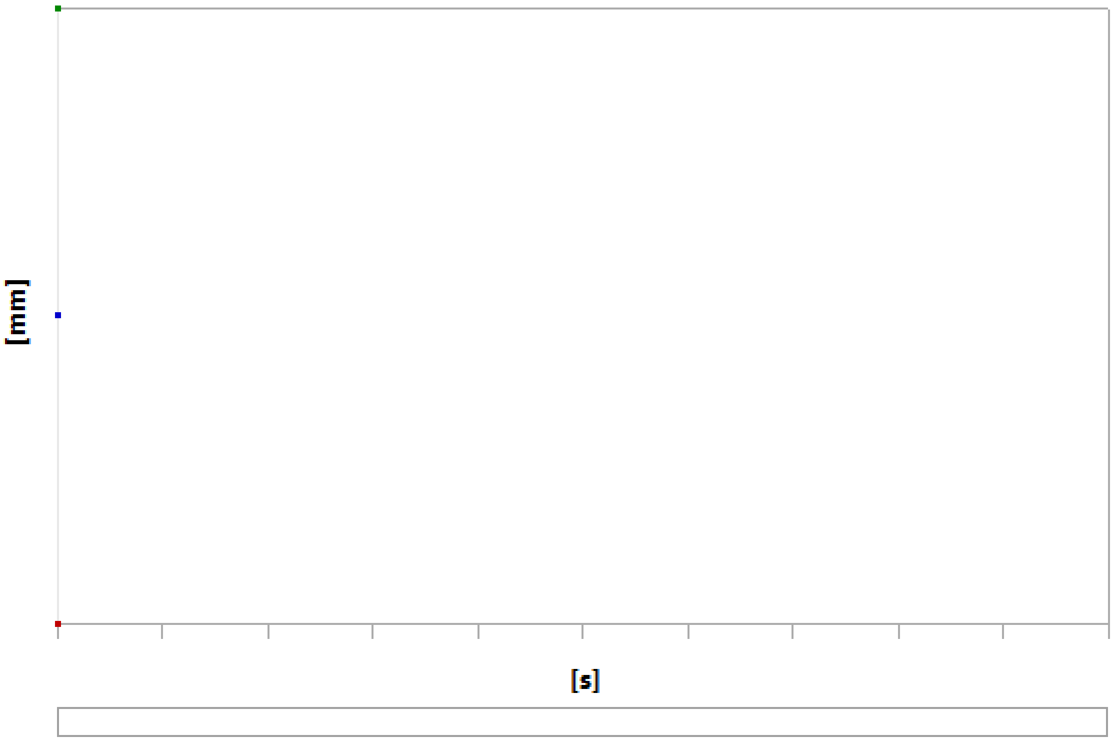


TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1,	0,	0,3622	0,18176

FIGURE 4
Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Stress

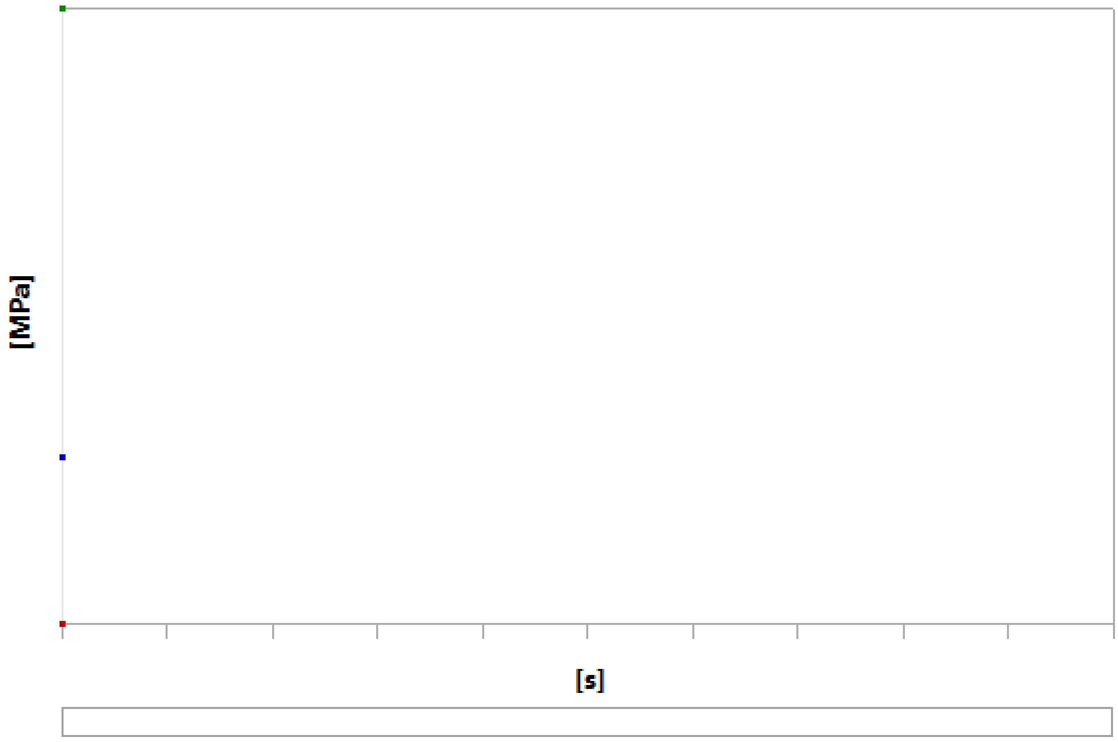


TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Stress

Time [s]	Minimum [MPa]	Maximum [MPa]	Average [MPa]
1,	1,7714	345,98	94,492

Material Data

Steel 520M

TABLE 17
Steel 520M > Constants

Density	7,8e-006 kg mm^-3

TABLE 18
Steel 520M > Color

Red	Green	Blue
109,	157,	209,

TABLE 19
Steel 520M > Tensile Yield Strength

Tensile Yield Strength MPa
520,

TABLE 20
Steel 520M > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
630,

TABLE 21
Steel 520M > Isotropic Elasticity

Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa	Temperature C
2,1e+005	0,3	1,75e+005	80769