Lock Down Verification System for Tubing Hanger

Verifikasjonssystem for låsing av rørhenger

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PREFACE

This is a master thesis written by Maren Charlotte Gregersen, student at Norwegian University of Life Sciences (UMB). It has been conducted as a part of a master program in Machinery, Process and Product Development at Department of Mathematical Sciences and Technology. The thesis was carried out in the period 7.Jan.2013 – 12.Mai.2013, and has a scope of 30 credits.

The task has been carried out in cooperation with Aker Solutions. I chose to conduct the task provided by Aker Subsea AS (part of Aker Solutions), since I would like to get a better insight to their products, before I start in a full time position in August 2013.

Thanks go to my supervisor at UMB Nils Bjugstad and my supervisors at Aker Solutions Robert Johansson and Magnus Fjørtoft Urke.

I would also like to thank employees at Aker Solutions that have provided guiding help with finding important information for the project and given valuable feedback to my work; Harald Martin Aarbogh, John A. Andersen, Tore Arntsen, John Barry, Anders Brekke, Vicens Breiz, Alexander Gillebo, Victor Grennberg, Emil Hafsteinsson, Jan Herland, Ole Kristian Holmen, Shelly Holmesland, Arto Kantojarvi, Vinayak Kulkarni, Rajeev Lehar, Lars Lundheim, Per-Olaf Queseth, Kenneth Sjøvold, Torgeir Skauen, Øyvind Skjold, Daniel Vik Skogen, Hogne Tvenning, Dag Twist, Joachim Villhelmsson and Dmitri Volkov.

Thanks also goes to Brendan Hyland from WFS, Wireless for Subsea and Martin Biehle from SEACON Advanced Products, that have provided valuable product information.

Ås in Norway, 13th of May 2013

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Maren Charlotte Gregersen

SUMMARY

This master thesis is a product development project, carried out in cooperation with Aker Subsea, which is a part of Aker Solutions.

The goal of the master thesis was to develop concepts for a new verification system, which can confirm landing and locking during installation of Tubing Hanger. Tubing Hanger (TH) is installed and locked into Xmas Tree`s spool body, after the Xmas Tree (XT) is landed and locked onto the wellhead. Production stream from well flows through the TH. Thus it is of high importance that TH is properly locked before production of oil or gas is started, in order to prevent the possibility of leakage to the environment.

Today`s verification methods do not provide any information about TH`s position relative to the XT, before it is locked. Therefore a new verification system needs to be developed, which can verify that:
1) TH has landed in the right position.
2) TH is sufficiently locked to the XT spool.

In order to come up with new verification methods I started off with an extensive analysis phase. I did a general study of subsea production systems (appendix A). In addition a more detailed study was carried out to get to know lock down sequence related to TH installation, and today`s verification methods (chapter 4). As part of the analysis phase reported incidents were studied (appendix B) and a hazard identification study was carried out (appendix C).

Before starting to develop the actual verification concepts, I carried out a technology analysis (appendix D). For the concept development work I chose to only focus on landing and locking of TH, and have not taken into account what kind of verification is needed for retrieval of TH. Retrieval of TH is needed for product maintenance, and when production system is disassembled.

In order to come up with as many verification concepts as possible, I started off with a creative concept phase, where "everything is possible". Further on positive and negative concept characteristics were evaluated in order to narrow down number of relevant concepts. The final concept selection process was an expert test carried out by employees at Aker Solutions.

The result of the concept development work are two verification concepts. Here is a short description of each solution:

- A proximity switch with two sensors is positioned in XT spool, and two target magnets with opposite poles (north/south) are positioned in TH`s activation sleeve. When TH lands in right position the north poled magnet will activate one of the sensors, and when TH is locked properly to the spool, the south poled magnet will activate the other sensor. Verification signal is sent through a wireless communication system to a ROV (Remotely Operated Vehicle) and then up to rig and operator.
- One proximity switch is positioned in XT spool to verify correct landing of TH, and another switch is positioned in Tubing Hanger Running Tool (THRT) to verify lock down. Land verification switch uses wireless communication and lock verification switch is connected to topside with an electric wire.

Either of these two concepts can be supplemented with additional verification methods in order to increase system safety.

I have managed to reach the goals that were set up for the project. I also learned a great amount about subsea engineering and got many new experiences. It has been an exciting project, and it has been very giving to have the opportunity to work with a project with focus on improving safety of the oil and gas production system. Lock down verification system for TH is a crucial part of the subsea system that can prevent damage of product components, project delays, huge extra costs and leakage to the environment.

SAMMENDRAG

Denne masteroppgaven er et produktutviklingsprosjekt, utført i samarbeid med Aker Subsea, som er en del av Aker Solutions.

Målet med masteroppgaven var å utvikle konsepter for et nytt verifikasjonssystem, som skal kunne bekrefte landing og låsing under installasjon av rørhenger. Rørhenger blir installert og låst i ventiltre, etter at ventiltre har landet og blitt låst til brønnhodet. Produksjonsstrøm fra brønn flyter gjennom rørhengeren. Derfor er det viktig at rørhenger er ordentlig låst før produksjon av olje eller gass blir startet, for å forhindre muligheten for lekkasje til omgivelsene.

Dagens verifikasjonsmetoder gir ingen informasjon om rørhengerens posisjon i forhold til ventiltreet, før den blir låst. Derfor må et nytt verifikasjonssystem utvikles, som kan verifisere at:
1) TH har landet i riktig posisjon.
2) TH er tilstrekkelig låst til ventiltre.

For å kunne komme frem til nye verifikasjonsmetoder, startet jeg med en omfattende analysefase. Jeg utførte en generell studie av undervanns produksjonssystem (vedlegg A). I tillegg utførte jeg en mer detaljert studie for å bli kjent med låse sekvensene relatert til installasjon av rørhenger, og dagens verifikasjonsmetoder (kapittel 4). Som den av analysefasen, ble rapporterte hendelser undersøkt (vedlegg B) og en kartlegging av potensielle farer ble utført (vedlegg C).

Før jeg startet med å utvikle konsepter, utførte jeg en teknologianalyse (vedlegg D). For konseptutviklingsarbeidet valgte jeg å kun fokusere på landing og låsing av rørhenger, og tok ikke hensyn til type verifikasjon som trengs ved henting av rørhenger. Henting av rørhenger kan være aktuelt ved vedlikeholdsarbeid, og når produksjonssystemet skal demonteres.

For å kunne finne på så mange verifikasjonskonsepter som mulig, startet jeg opp med en kreativ fase hvor "alt er mulig". Videre ble positive og negative konsept egenskaper vurdert, for å kunne snevre inn antall aktuelle konsepter. Endelig konseptutvelgelse ble gjort med en ekspert test, som ble utført av ansatte ved Aker Solutions.

Resultatet av konseptutviklingsarbeidet er to verifikasjons-konsepter. Her er en kort beskrivelse for hver av løsningene:

- En proximity bryter med to sensorer er plassert i ventiltreet, og to magneter med motsatte poler (nord/sør) er plassert i rørhengerens "activation sleeve". Når rørhengeren lander i riktig posisjon vil den ene magneten aktivere en av sensorene, og når rørhengeres låses riktig til ventiltreet, vil den andre magneten aktivere den andre sensoren. Verifikasjonssignal sendes gjennom et trådløst kommunikasjonssystem, til en ROV (Remotely Operated Vehicle), og deretter opp til operatøren på rigg.
- En proximity bryter er plassert i ventiltreet for å verifisere korrekt landing av rørhenger, og en annen bryter er plassert i rørhengerens installeringsverktøy for å verifisere låsing. Bryter for landeverifikasjon bruker trådløs kommunikasjon og bryter for låseverifikasjon er koblet til rigg med en elektrisk ledning.

Disse to konseptene kan suppleres med ekstra verifikasjons-metoder, for å oppnå økt systemsikkerhet.

Jeg har klart å nå målene som ble satt opp for prosjektet. I tillegg har jeg lært mye om undervanns prosjektering og fått mange nye erfaringer. Det har vært et spennende prosjekt, og det har vært givendes å få muligheten til jobbe med et prosjekt med fokus på økt sikkerhet for olje- og gassproduksjon. Verifikasjonssystem for rørhenger er en viktig del av undervannssystemet som kan hindre skading av produktkomponenter, prosjekt forsinkelser, store ekstrakostnader og lekkasje til miljøet.

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1. INTRODUCTION

1.2. Background Information

1.2.1. The Taskmaster

Aker Solutions is a global provider of offshore engineering and construction services, technology products and integrated solutions. The company has approximately 25.000 employees in more than 30 countries.

The Subsea Business stream is a section of Aker Solutions providing a complete range of surface and subsea solutions for the oil and gas industry. The wide range of products meets the requirements of the most demanding and hostile subsea environments, such as high pressure, high temperature and deep water solutions. One of the main products delivered by Aker Subsea is the tree stalk system, commonly known as Xmas Trees (XTs).

The Global Product Owner for XTs is located at Tranby, Lier. The first XT delivered from Tranby was in 1997, and today more than 350 XT`s have been delivered to different production fields. XTs are products within the subsea business area, and they are in constant development to meet future requirements for oil and gas extraction.

Figure 1: *Aker Solutions slogan and logo. [1]*

1.2.2. The Project

The project is a master thesis for a Master degree in Machinery, Process and Product Development, at Norwegian University of Life Sciences.

As mentioned in section 1.2.1. Aker Subsea delivers Xmas trees (XTs). There exist a few varieties of XTs, and the type of tree that will be studied in this project is horizontal XT. For a horizontal XT solution a Tubing Hanger (TH) is installed and locked into XT`s main spool body, after the XT is landed and locked onto the wellhead. The tree system is depended on the Tubing Hanger`s locking mechanism to hold the Tubing Hanger fixed in its position when the gas or oil production is started. As production stream from well is flowing through the Tubing Hanger, it is of high importance that the Tubing Hanger is properly verified in locked position before pressure is applied from below.

The verification methods used today are:

1. To apply a certain tonnage of over-pull; this ensures that the TH is locked to a certain degree, but it does not assure that it`s locked in the right position.
2. Flow through a hydraulic circuit in Tubing Hanger Running Tool. This should verify that the locking sleeves are fully stroked and that TH`s split lock ring is fully expanded, but there are some system weaknesses causing uncertainty around the verification.

These methods do not give any secure information about the TH`s physical position in comparison to the XT. Due to this the TH might be locked in the wrong position when the oil or gas production is started. A wrong TH position could be caused by e.g. debris that is trapped within the spool, and can lead to fatal incidents like leakage to the environment. This must be prevented.

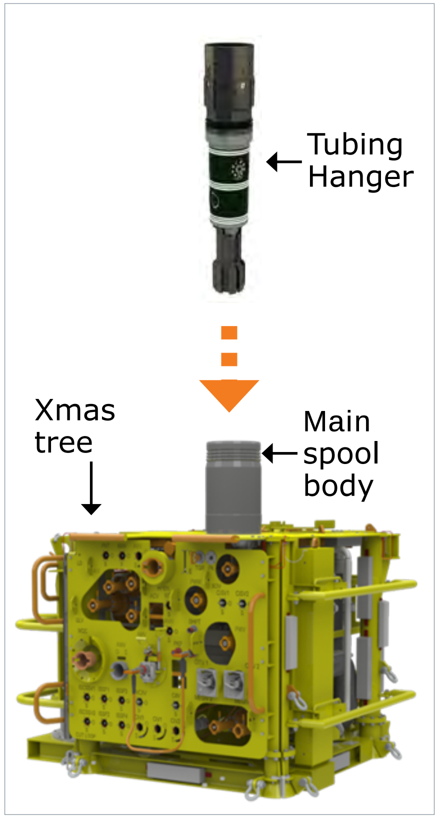


Figure 2: *Landing Tubing Hanger into XT spool body. Scale is about 1:80 [2]*

1.3. Task Description

The candidate shall in this project get an overview and understanding of the Tubing Hanger locking sequence, how this is verified by the installer today and how it can be improved by introducing a positive lock down verification. Main focus shall be the TH and its lockdown verification system. This shall be thoroughly described in this projects report. Candidate must prove that the physics, mechanical and/or electrical science is understood. Relevant theory on the topic shall be considered in the report. Based on this study, the candidate shall describe a plan of actions in order to implement a Positive Lock Down Verification system and describe alternative concept proposals.

The tasks associated with this project include:

- A general study on the TH system, with focus on the TH Lock Down system.
- A description of how TH lockdown sequences are and how the system is verified in locked position.
- A study and description of relevant theory.
- The thesis shall include a feasibility study covering a variety of available technology that can be implemented to achieve a positive verification system.
- Generate minimum 2 conceptual designs.
- Candidate shall describe a method to follow in order to develop and implement a Lock Down Verification System.

Figure 3: *Subsea installation. [2]*

1.4. Issues and Technological Difficulties

I am not to develop concepts for the positive lock down verification system all on my own. I will get some supervision form colleagues at Aker Solutions, carry out internal research and get in touch with persons that can provide valuable knowledge and information. They will typically help and guide me, in order to solve the issues and technological issues listed below.

Technical and functional issues

- The subsea system and in particular the XT system has to be investigated in order to get a good understanding of how today`s TH lockdown sequences work.
- There is a limited amount of technology and products that can be used in a subsea environment with high pressure and temperature varieties.
- New conceptual verfication methods shouldn`t result in demanding changes of curret design.

Construction

- The new verification method should not be too complex to produce/carry out, and product construction must be strong enough to take relevant stresses.
- The final concepts should have a durability of about 20 years (including maintendance). This is typical lifespan for XT tools.

Environmental

- Environmental aspects have to be taken into account, to make sure sealife is not harmed.

Design and ergonomics

- The new concepual verification methods have to be suitable for high pressure and hight temperature environment.
- The Lock Down Verification System should be easy to remote.

Economic aspects

- The verification system cannot be too expensive to implement.
- The verification method has to be reliant, so that system faults don`t lead to huge reinstallation and repairment costs.

2. PROJECT OBJECTIVES AND PROJECT PLAN

2.1. Project Objectives

2.1.1. Main Objectives

- Get an overview of the Tubing Hanger`s locking sequence and how this is verified by the installer today.
- Identify existing applicable technology or the lack of this.
- Come up with and present two verification system concepts that provide landing and lock verification for Tubing Hanger installation.

2.1.2. Secondary Objectives

- Create a project plan and a method description to follow in order to develop new conceptual solutions.
- Attend an introduction course for subsea tree technology, arranged by Aker Solutions.
- Investigate the Tubing Hanger`s locking system and today`s verification methods.
- Create a design basis.
- Perform a study of reported incidents related to the Tubing Hanger`s lock down process.
- Conduct a feasibility study covering a variety of available technology.
- Describe alternative concept proposals and generate minimum two conceptual designs.
- Write a design report that describe the product development process, and present the final concepts.

2.1.3. Project Constraints

- The focus will be on the Tubing Hanger and it`s locking and verification system, in addition to related products that are used in the Tubing Hanger`s landing and locking process.
- I will only study and develop concepts for landing and locking of Tubing Hanger, and not look into retrieval, maintenance and disassembly processes.
- The final result of this project will be conceptual solutions and not detailed product solutions ready for production.
- The study of reported incidents will be limited to the most serious incidents that I`m able to find information about during the project's analysis phase.
- I will attempt to come up with a good variety of different concept solutions in the start of the concept phase, in order to not overlook any smart solutions, but I will not have the time to look closely into each possible solution.
- The concepts I develop will not be modelled or tested.

2.2. Plan with Milestones

TABLE 1: *Overview of activities with specified period of time and week nr. The orange triangles represent milestones.*

ACTIVITY	WEEK																		
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Project preparations	■																		
Fixing contracts	△																		
Report layout	■																		
Introduction course		■																	
Define projcet objectives		■																	
Make a method description			■																
Product analysis		■	■	■															
Incident analysis				■	■														
Basis of design					△														
Concept generation						■	■	■											
Own screening									■										
Concept choices									△										
Concept development										■	■	■							
Expert testing													■						
Final concepts													△						
Detailing of concepts														■	■				
Maintenance evaluation																■			
Manufacturing & cost evaluation																■			
Market presentation																	■		
Process evaluation and conclusion																		■	
Writing master thesis report	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Finished report																		△	
Prepare for exam presentation																			■
The exam presentation																			△

Table 2: *Actual progress in blue marking and orange triangles represent completion of milestones. I have added HAZID study activity to the plan, which was not planned initially. In addition three more weeks are added to the time period, as presentation is in week 23.*

ACTIVITY	WEEK																					
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Project preparations	■	■																				
Fixing contracts		△																				
Report layout	■	■	■					■														
Introduction course		■																				
Define projcet objectives		■	■																			
Make a method description				■																		
Product analysis		■	■	■	■	■	■	■	■	■												
Incident analysis				■	■	■			■	■												
Hazard identity (HAZID) study										■												
Basis of design										△												
Concept generation						■	■	■	■	■	■	■										
Own screening													■									
Concept choices													△									
Concept development														■	■							
Concept selection														■	■							
Further concept development														■	■							
Expert testing																■						
Final concepts																△						
Detailing of concepts																	■					
Maintenance evaluation																	■					
Manufacturing & cost evaluation																	■					
Market presentation																		■				
Process evaluation and conclusion																		■				
Writing master thesis report	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
Finished report																		△				
Prepare for exam presentation																				■	■	■
The exam presentation																						△

3. METHOD DESCRIPTION

3.1. Methodology and Tools Used

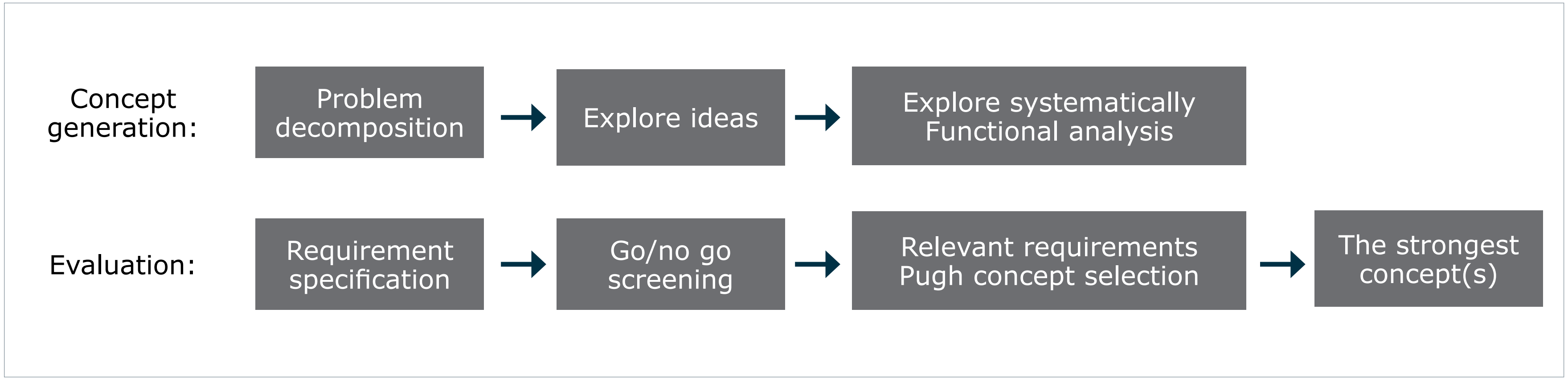
The focus for the project will in brief be:
- Function
- Design
- Process
- Verification techniques and equipment
- Cost evaluation
- Regulations and the environment

For the execution of this project I will mainly focus on the first two bullet points, but also consider and take economic, regulatory and environmental aspects into account.

Integrated Product Development (IPD) will be used for the project work. IPD is a product development methodology, and can be roughly characterised as a checklist of important elements one should include in the organisation of product development projects. The main elements that are included in an IPD process will vary for different projects. The process steps diagram on the next page shows the main elements that will be included in this project. A good assessment of these elements can lead to a product with high functionality, safety and simplicity.

Multiple concepts will be developed, and Pugh`s systematics for idea generation and concept choice will be used. The method is described in figure 4.

Figure 4: *Pugh`s method. [5]*



A concept evaluation will be performed on the basis of the requirement specifications given in chapter 5.6.

Internal expert concept testing will be performed at Aker Solutions in Tranby, with project supervisors and employees at Aker Solutions that are working in the subsea product development department.

For the analytical phase of the project I will use existing 3D models in order to investigate today`s locking mechanism and verification methods. In addition I will visit the workshop in order to see and study manufactured subsea products. My colleagues at Aker Solutions will of course also be an important source of information.

If applicable the 3D modelling software SolidWorks will be used for visualisation and presentation of the final verification concepts.

3.2. Process Steps

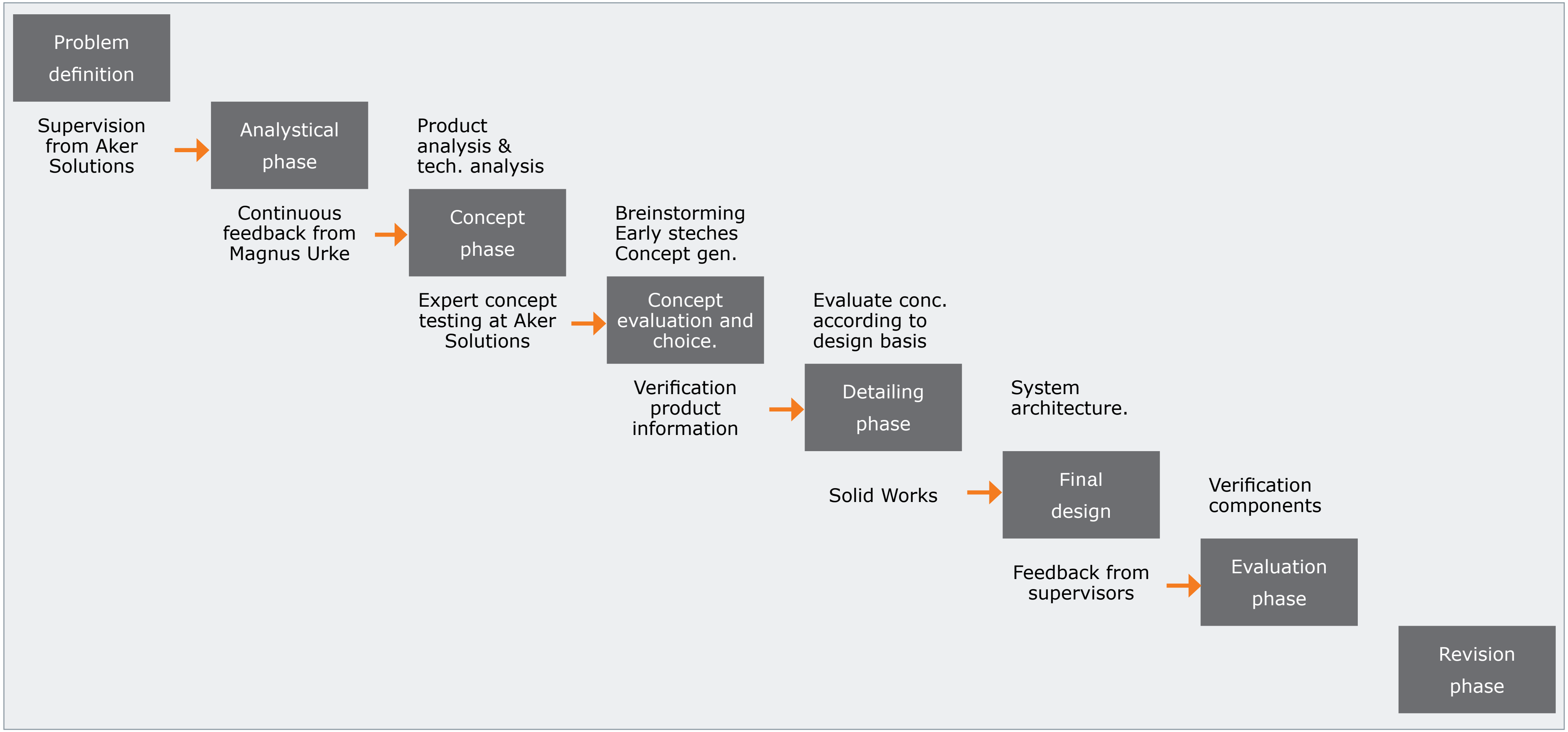


Figure 5: *Product development process for the project, with start of project up to the left.Gray boxes represent process steps, text behind the boxes describe what is to be done, while text in front specifies use of programs and supervision. [5]*

3.3. Abbreviations, Symbols and Terminology

3.3.1. Important Abbreviations

Table 3: *An alphabetical ordered list of important abbreviations with a description for each.*

Abbreviation	Description
BOP	Blow Out Preventer
BP	Bore Protector
CA	Casing Adapter
CM	Choke Module
CT	Computed Tomography
DGPS	Differential Global Positioning System
DNV	Det Norske Veritas
FCM	Flow Control Module
FM	Frequency Modulation
GPS	Global Positioning System
HDSDI	High Definition Serial Interface
HP	Hybrid Penetrator
HP	High Precision
HSCT	Horisontal Standard Configurable Tree
HSE	Health, Safety and Environment
HXT	Horizontal Xmas tree/Horizontal Subsea tree
IP code	Ingress Protection Rating
ISO	International Standard Organisation
MSM	Magnetic Shape Memory
PGB	Production Guide Base
PMV	Production Master Valve
PT	Production Tubing

Abbreviation	Description
RCU	Remote Control Unit
RDS	Radio Data System
ROV	Remote Operated Vehicle
RTK GPS	Real Time Kinematic Global Positioning System
SA	Selective Availability
SCM	Subsea Control Module
SCT	Standard Configurable Tree
SCM	Subsea Control Module
SLS	Simplified Landing String
SXT	Surface Xmas Tree
TH	Tubing Hanger
THRT	Tubing Hanger Running Tool
TRT	Tree Running Tool
VSCT	Vertical Standard Configurable Tree
VXT	Vertical Xmas Tree/Vertical Subsea Tree
WH	Wellhead
WHRT	Wellhead Running Tool
WOCS	Workover control system
XT	Xmas Tree
XTRT	Xmas Tree Running Tool

3.3.2. Terminology

Actuator
Mechanism for the remote or automatic operation of a valve or choke.
Adapter
Pressure-containing piece of equipment having end connections of different nominal sizes and/or pressure ratings, used to connect other pieces of equipment of different nominal sizes and/or pressure ratings.
Body
Any portion of wellhead and christmas tree equipment between end connections, with or without internal parts, which contains well-bore pressure.
Bore Protector
Device that protects internal bore surfaces during drilling or workover operations.
Casing
Pipe run from the surface and intended to line the walls of a drilled hole.
Choke
Equipment used to restrict and control the flow of fluids.
Christmas tree
Assembly of equipment, including tubing-head adapters, valves, tees, crosses, top connectors and chokes attached to the uppermost connection of the tubing head, used to control well production.
Completion / workover riser
Extension of the production and/or annulus bore(s) of a subsea well to a surface vessel.
Conductor housing
Top of the first casing string, which forms the basic foundation of the subsea wellhead and provides attachments for guidance structures.
Deep water
Water depth generally ranging from 610 m (2 000 ft) to 1 830 m (6 000 ft).
DHCIV
Down Hole Chemical Injection Valve.
Sensor / detector
A converter that measures a physical quantity and converts it into a signal which can be read by an observer or by an (today mostly electronic) instrument.
End connection
Outlet connection integral male or female thread; clamp hub end connector and flange, studded or through-bolted, or any other means used to join together equipment that contains or controls pressure.
Flowline
Production/injection line, service line or pipeline through which fluid flows.
Gallery area
Area in which the Hybrid Penetrator connects to the Tubing Hanger.
Hazard
Potential source of harm.
Horizontal tree
Tree that does not have a production master valve in the vertical bore but in the horizontal outlets to the side.
Jumper
Short segment of flexible pipe with a connector half at either end.
Negative verification.
Prove that bugs do not exist [4].
Machinery / machine
Assembly, fitted with or intended to be fitted with a drive system consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application.
Maintainability
Ability of a machine to be maintained in a state which enables it to fulfil its function under conditions of intended use, or to be restored to such a state, with the necessary actions (maintenance) being carried out according to specified practices and using specified means.

Master valve
Lowermost valve on the vertical bore of the christmas tree.
Positive verification
Prove that a design performs a necessary task [4].
Radiography
The use of X-rays to view a non-uniformly composed material such as the human body.
Reliability
Ability of a machine or its components or equipment to perform a required function under specified conditions and for a given period of time without failing.
Risk
Combination of the probability of occurrence of harm and the severity of that harm.
Risk analysis
Combination of the specification of the limits of the machine, hazard identification and risk estimation.
Risk assessment
Overall process comprising a risk analysis and a risk evaluation.
Risk evaluation
Judgment, on the basis of risk analysis, of whether the risk reduction objectives have been achieved.
Running tool
Tool used to run, retrieve, position or connect wellhead equipment remotely from the drill floor.
SCSSV
Surface Controlled Sub-Surface Safety Valve.
Sensor / detector
A converter that measures a physical quantity and converts it into a signal which can be read by an observer or by an (today mostly electronic) instrument.
Single pole, double throw
A simple change over switch.
Single pole, single throw
A simple on-off switch.
Specific weight
Weight per unit volume of a material.
Spool
Short segment of rigid pipe with a connector half at either end
Note: A spool is commonly used to connect flow lines and/or subsea facilities together, e.g. a subsea tree to a subsea manifold.
SSV actuator/Underwater safety valve actuator (USV actuator)
Device which causes the SSV/USV valve to open when power is supplied and to close automatically when power is lost or released.
SSV valve / USV valve
Portion of the SSV/USV that contains the well stream and shuts off flow when closed.
Subsea BOP
Blowout preventer designed for use on subsea wellheads, tubing heads or trees.
Subsea casing hanger
Device that supports a casing string in the wellhead at the mudline.
Subsea wellhead housing
Pressure-containing housing that provides a means for suspending and sealing the well casing strings.
Swab valve / crown valve
Uppermost valve on the vertical bore of the christmas tree above the flowline outlet.
Tee
Pressure-containing fitting with three openings
Note: Two openings opposite one another form the run portion of the tee, and one opening is at 90° to the line of the run. Tees may be equipped with threads, flanges, studs or other end connectors.
Topside
Above sea level, on a platform or a floating installation.
Tree cap
Pressure-containing environmental barrier installed above production swab valve in a vertical tree or tubing hanger in a horizontal tree.

Tubing
Retrievable pipe placed within a well to conduct fluid from the well's producing formation into the christmas tree or to conduct kill or treatment fluids in a well.
Note: Tubing is distinguished from casing as being retrievable during the life of the well.
Tubing-head adapter
Equipment that adapts the uppermost connection of a tubing head to the lowermost valve of the christmas tree.
Tubing-head spool
Piece of equipment attached to the uppermost casing head or smallest casing string which serves to suspend the tubing and to seal the annular space between the tubing and casing.
Umbilical
Hose, tubing, piping, and/or electrical conductor that directs fluids and/or electrical current or signals to or from subsea trees.
Valve
A device that regulates directs or controls the flow of a fluid by opening, closing, or partially obstructing various passageways.
Vertical tree
Tree with the master valve in the vertical bore of the tree below the side outlet.
Wellhead
All permanent equipment between the uppermost portion of the surface casing and the tubing-head adapter connection.

3.3.3. Symbols and Units

Table 4: *A list of symbols used in the report. Quantity name, unit name, SI-unit symbol and relevant non-SI units are specified for each unit of measurement.*

Quantity name	Unit name	SI-unit symbol	Non-SI symbols
length	metre	m	inch (in or ") foot (ft)
mass	kilogram	kg	ton
time	second	s	
electric current	ampere	A	
thermodynamic temperature	kelvin	K	
frequency	hertz	Hz	
force, weight	newton	N	
pressure	pascal	Pa	Bar, psi, amp
energy	watt	W	
voltage	volt	V	
temperature	degree Celsius	°C	
angle	radian	rad	degrees, °

4. ANALYSIS PHASE

- Getting to know the subsea system that I am going to develop a Lock Down Verification System for.

4.1. Preface

The surface and subsea systems Aker Solutions provide for the oil and gas industry, consist of a range of different system components. In order to get a good understanding of the subsea technology that will be in focus for this project, I have made an overview the subsea system`s main product components. The overview can be found in appendix A.

In addition to the study presented in appendix A, I have carried out a more detailed study of the Tubing Hanger (TH) and Tubing Hanger Running Tool (THRT), which is presented in this chapter. It includes relevant installation steps and verification methods.

Most of the illustrating figures in this part of the report are from the subsea projects named; Skuld and Kristin. Both projects are located in the North Sea. Kristin is located almost 5.000 meters below ground, and the reservoir ranks as the highest pressure and highest temperature field ever tapped on the Norwegian continental shelf, at 91 MPa (13,195 psi) and 170°C. The project was delivered in March 2005, and is operated by Statoil. The Skuld project was delivered 21. August 2012. It is located at a water depth of 360 meters.

The subsea products and system solutions presented in this report are not only produced by Aker Solutions. Other oil and gas companies like GE OIL & GAS, SUBSEA7 and FMC also deliver similar subsea production systems.

Thus there are not any specific designers that should be given credit for the products presented here. It is a result of many years of product development, and contributions from many people working in the oil and gas sector.

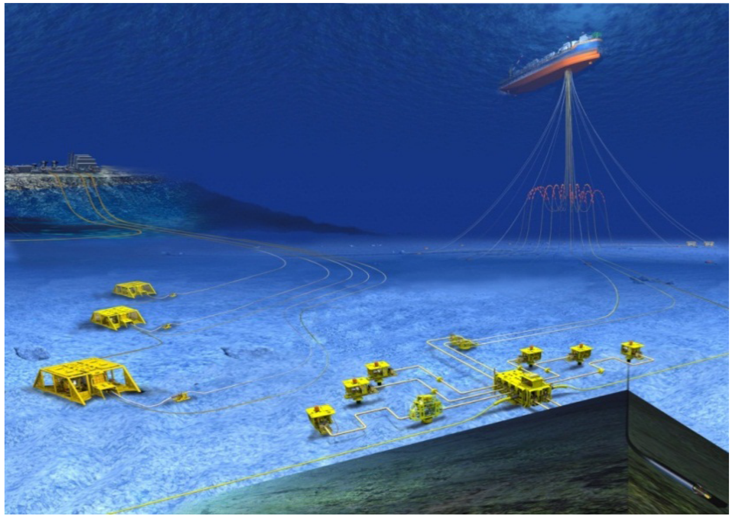


Figure 6: *Subsea installation. [2]*

4.2. The Tubing Hanger and Tubing Hanger Running Tool

4.2.1. Tubing Hanger (TH)

The TH is placed into the spool and sits inside the Xmas Tree, as illustrated in figure 7. The TH has a length of about 2500 mm and an outer diameter of about 500 mm.

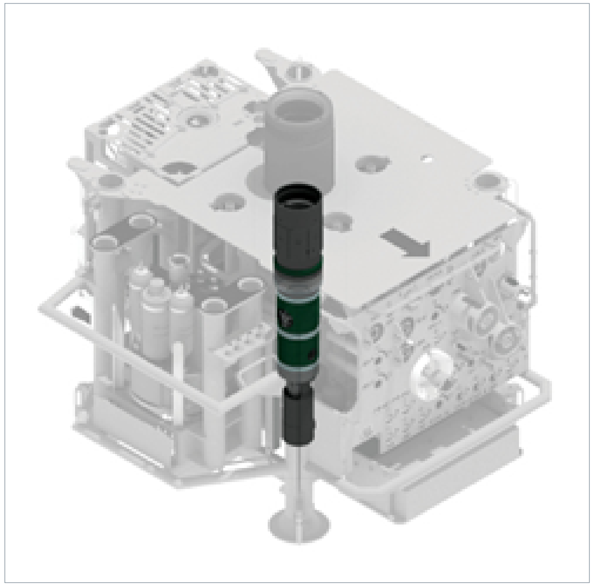


Figure 7: *Position of TH inside HXT. Scale of figure is about 1:80. [3]*

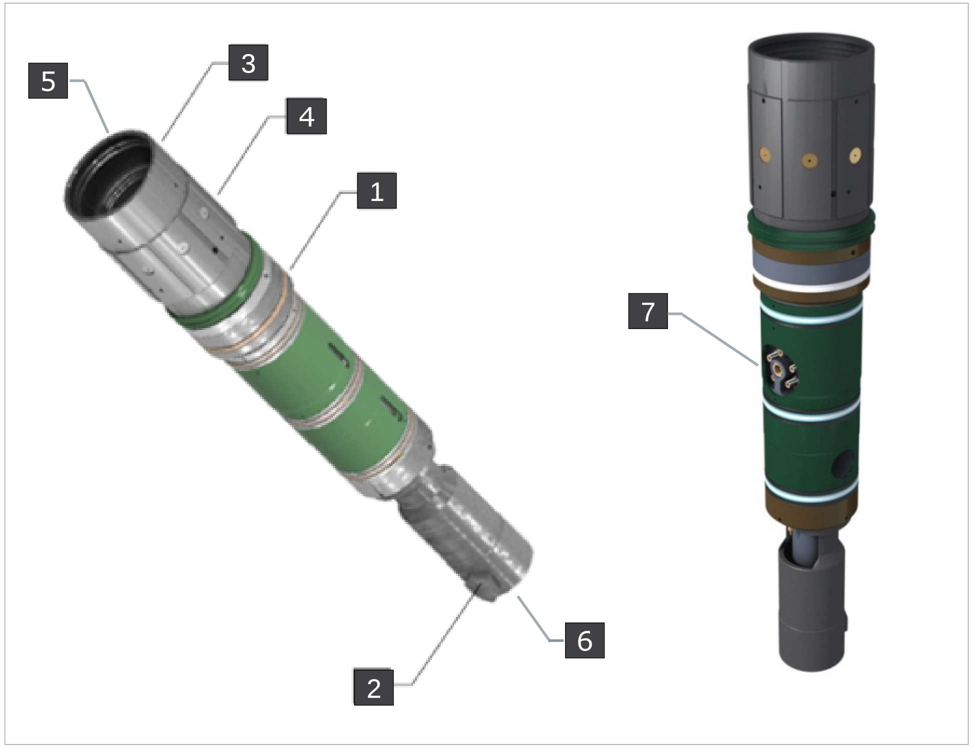


Figure 8: *Tubing Hanger. Scale of figure is about 1:30. [2], [3]*

Explanation to figure 8:

1. *Spilt Lock Ring; Locks the Tubing Hanger to the XT spool.*
2. *Orientation Key; Ensures correct orientation of the TH in the XT.*
3. *Bore; Contains the Crown Plugs.*
4. *Body; Routes the wellflow into the XT in addition to containing the Crown Plugs.*
5. *Internal profile to attach to THRT.*
6. *Internal tread interference for attaching to production tubing.*
7. *Connection interface for Hybrid Penetrator.*

The TH`s main functions are:
- To make a connection between the tubing in the well and the XT, so that the wellflow can be guided form the well, through the TH and over to the XT.
- The Crown Plugs works as a barrier for the wellflow.
- To provide an interface between the downhole instruments and the XT.

Figure 9 shows a cross section of the TH with labelling of important functions. Here one can see where the Crown Plugs are placed inside the TH. The diagram also shows electric and hydraulic lines, in addition to production flow in and out of the TH.

The Locking Ring and Orientation Key (tag 1 and 2 in figure 8) will be described more closely in section 4.3.

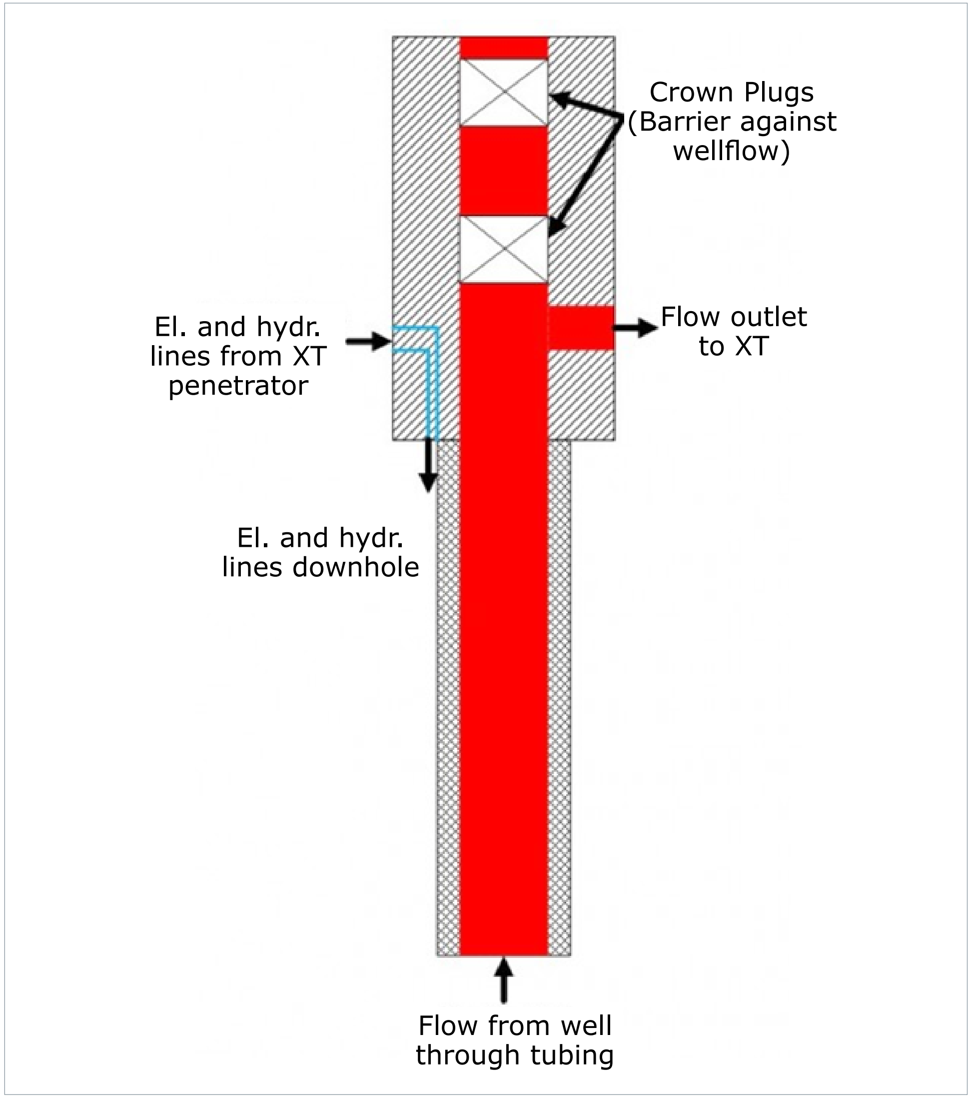


Figure 9: *Cross section of TH, showing key functions. [3]*

4.2.2. Tubing Hanger Running Tool (THRT)

As mentioned in appendix A, section A.12, the Tubing Hanger Running Tool is one of many XT tools that Aker Solutions provide, and it is used for installation of the Tubing Hanger. In figure 10 the THRT is connected to a landing string which is attached to the upper part of THRT when TH is run subsea.

There are two engage/disengage mechanisms for the Tubing Hanger system; lock and latch. It is important to notice the difference between these two terms. The latch mechanism engage/disengage the THRT to/from the TH, while the lock mechanism engage/disengage the TH to/from the Spool.

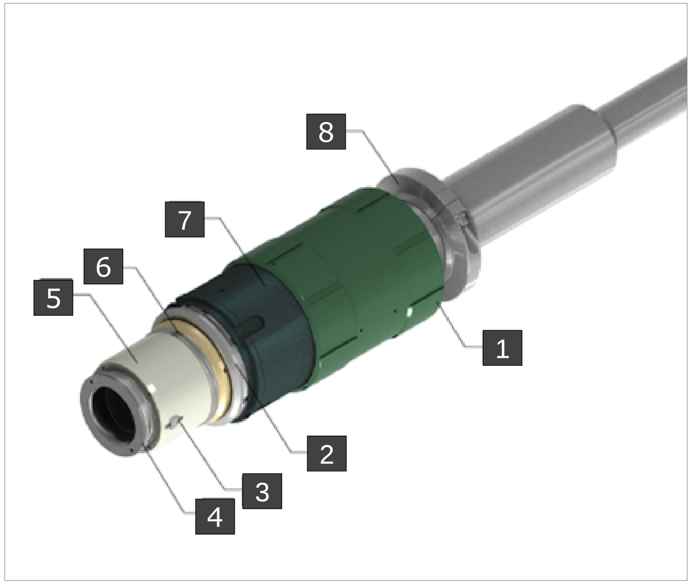


Figure 10: *Tubing Hanger Running Tool. [3]*

Explanation to figure 10:

1. *Upper Locking Sleeve; Engage/retracts the Lock Actuator Ring.*
2. *Lock Actuator Ring; Engage/disengage the lock ring on the TH*
3. *Anti-rotation Keys; Prevent rotation of TH during operations*
4. *Emergency Retainer Ring; Enable emergency interface to TH*
5. *Emergency Shoulder Ring; Enable emergency interface to TH*
6. *Latch Ring; Retracts/engage the tool to the TH.*
7. *Lower Locking Sleeve; Engage/retracts the Lock Actuator Ring.*
8. *THRT body*

The Upper Locking Sleeve and Lower locking Sleeve are attached together, and thus move in the same direction and pace.

The Latch Piston, which retracts/engange the Latch Ring is not shown in this diagram, since it is an internal component, but it is described in section 4.3.

The emergency components (tag 4 and 5), are parts of an emergency release feature on the THRT. If the THRT fails to unlatch form the TH, one can shear an emergency release by applying a large torque force.

The upper part of the THRT`s body where label 8 is positioned, is possible to modify for various tasks that are to be performed. Usually a NUT retainer is attached to the top of the THRT`s body. The NUT retainer can be seen in figure 12. If a tool like the Chasing Adapter (described in section A.12) is to be attached to the THRT, the THRT`s NUT retainer is usually dismantled, since the CA also contains a NUT retainer.

The THRT`s main functions and properties are:

- Used to run the TH down into the XT, and lock TH to XT spool.
- Used for retrieval of TH, when invention or maintenance is needed.
- Hyraulically operated, through five hydraulic connections.
- The THRT can latch/ unlatch itself to/from the TH.
- Can lock/unlock the TH to/from the Spool body.

The latch and lock features of the THRT are activated by pressurising the THRT`s hydraulic ports. Two of the hydraulic ports are linked to the latch mechanism, while two others are linked to the lock mechanism. The fifth hydraulic port is used for verification of complete lock-down.

Size of THRT with attached NUT retainer is a length of about 1600 mm and an outer diameter of about 500 mm.

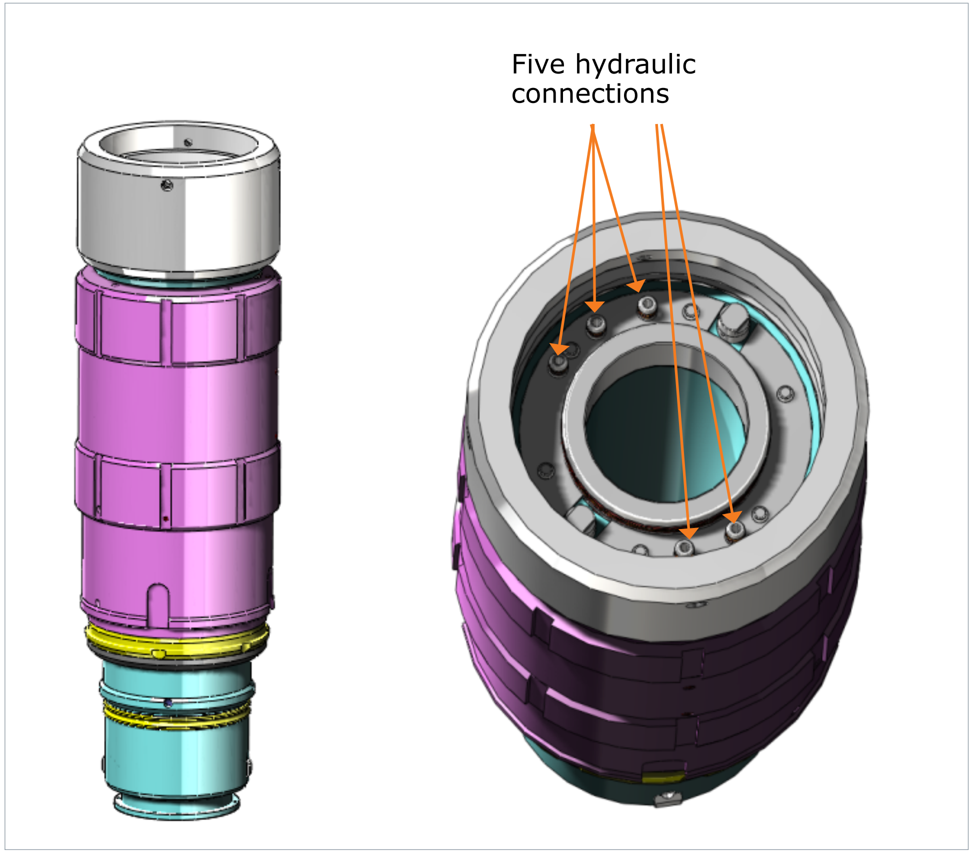


Figure 12: *The THRT, and its five hydraulic connections. Figure scale for THRT on left side is about 1:20. [6]*

The five hydraulic lines:
F1: Latch line
F2: Lock line
F3: Unlatch line
F4: Unlock line
F5: Test lock down

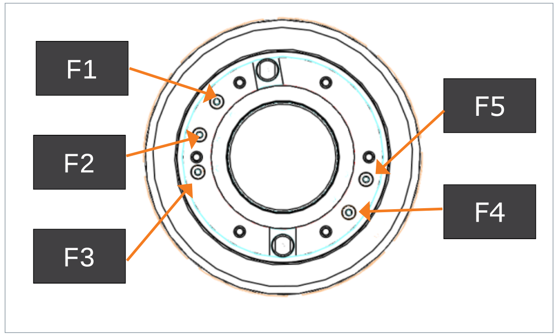


Figure 11: *THRT`s five hydraulic lines. [6]*

The figures below are pictures of 3D model illustrating how the five hydraulic lines are located in the THRT. The model shows a see through view of the THRT`s main body. On the next pages, a more detailed description with figures are given for each hydraulic line. The scale of figure 15 to 22 is about 1:10. The green/orange lines illustrates fluid (oil) sent through the hydraulic ports.

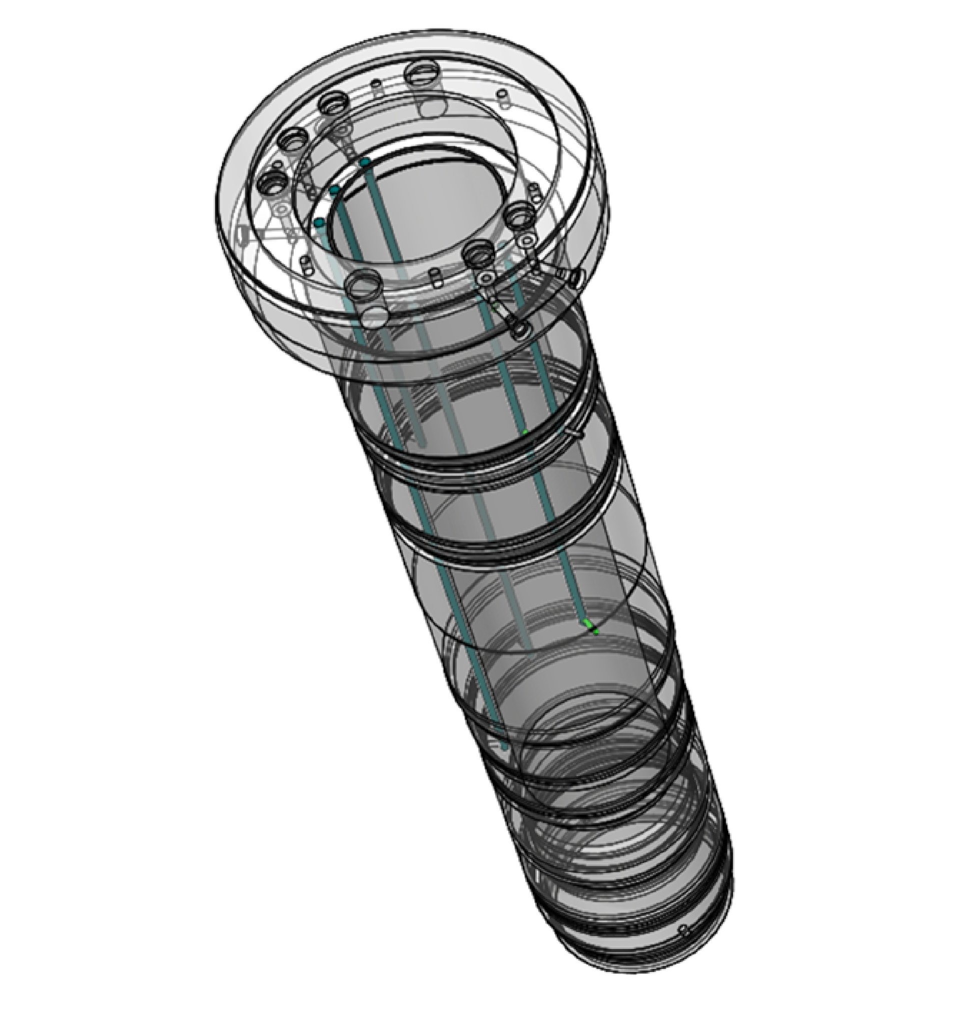


Figure 13: *See through view of THRT. [2]*

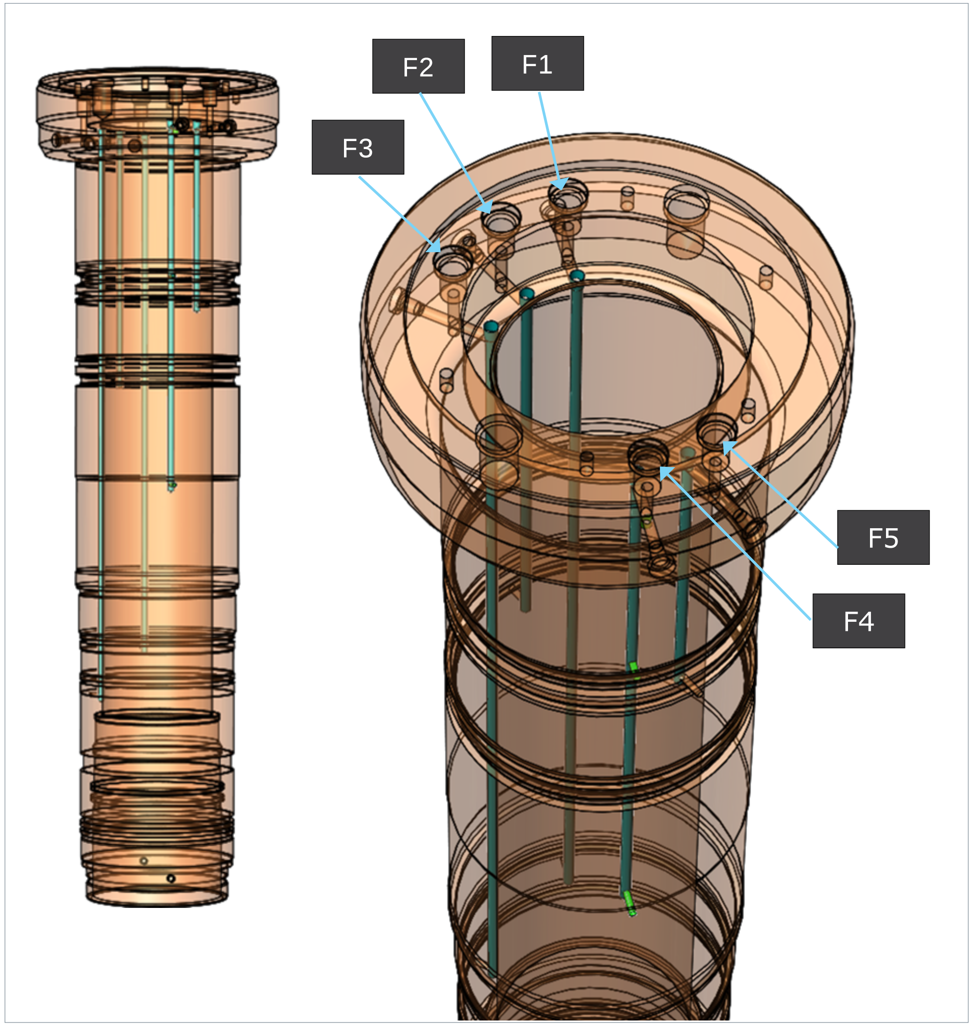


Figure 14*: THRT`s five hydraulic lines, in see though view. [2]*

F1: Latch line

The green/orange lines illustrates fluid (oil) sent through hydraulic line F1.

When F1 is pressurised it will push the latch piston so that it activates the latch ring.

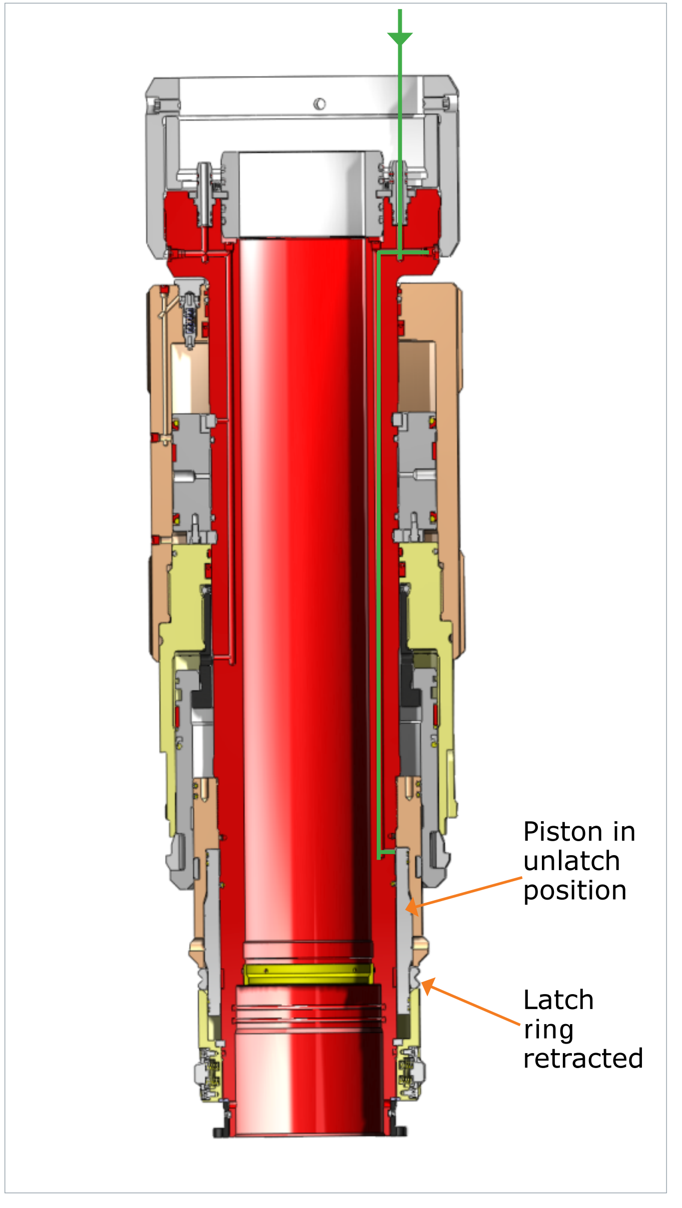


Figure 15: *THRT in unlatching position. [6]*

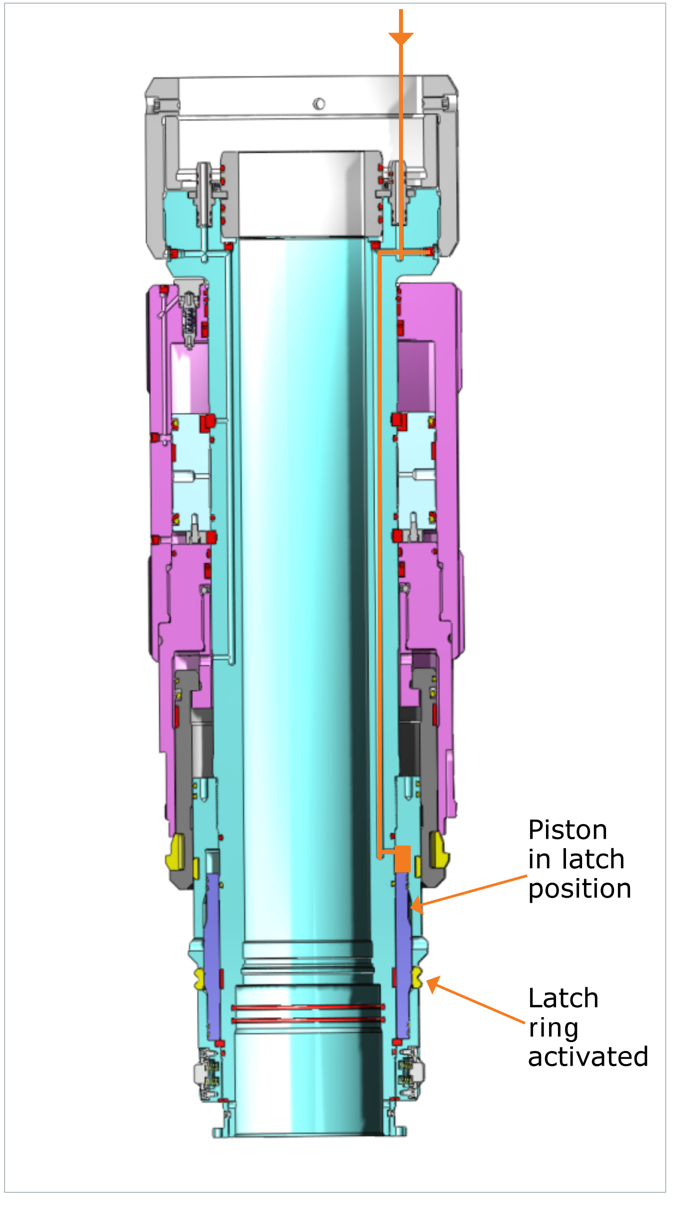


Figure 16: *THRT in latching position. [6]*

F2: Lock line

When F2 is pressurised the lower locking sleeve is pushed and will move, and since the upper locking sleeve is attached to it, it will follow its movement.

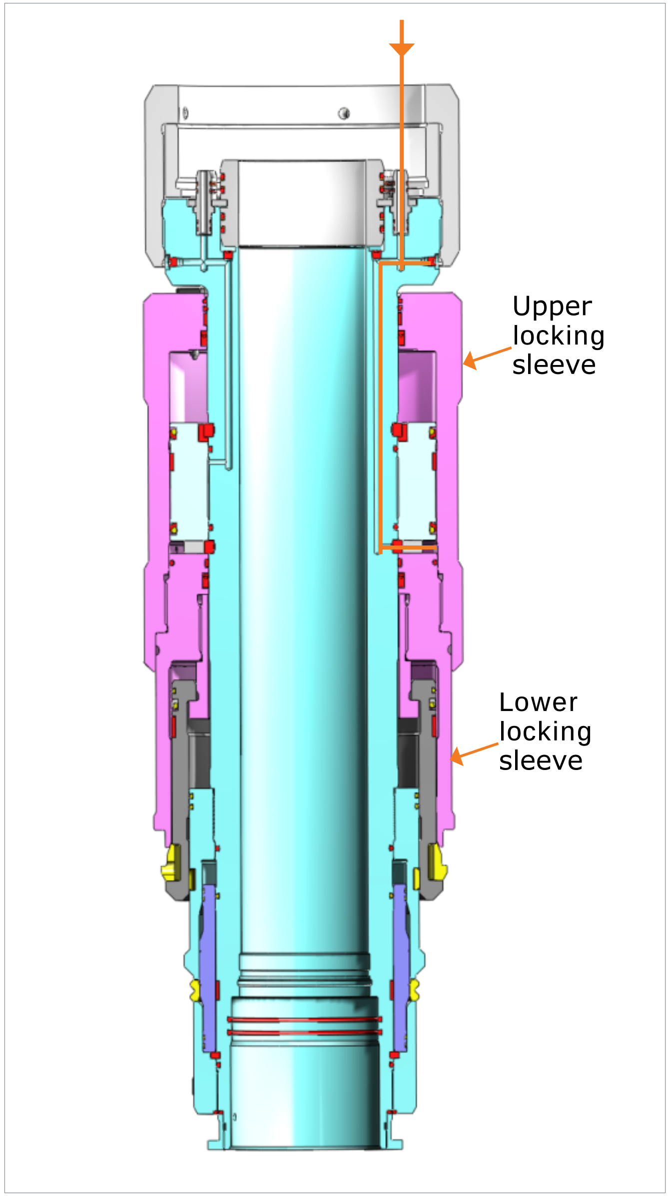


Figure 17: *THRT in unlocking position. [6]*

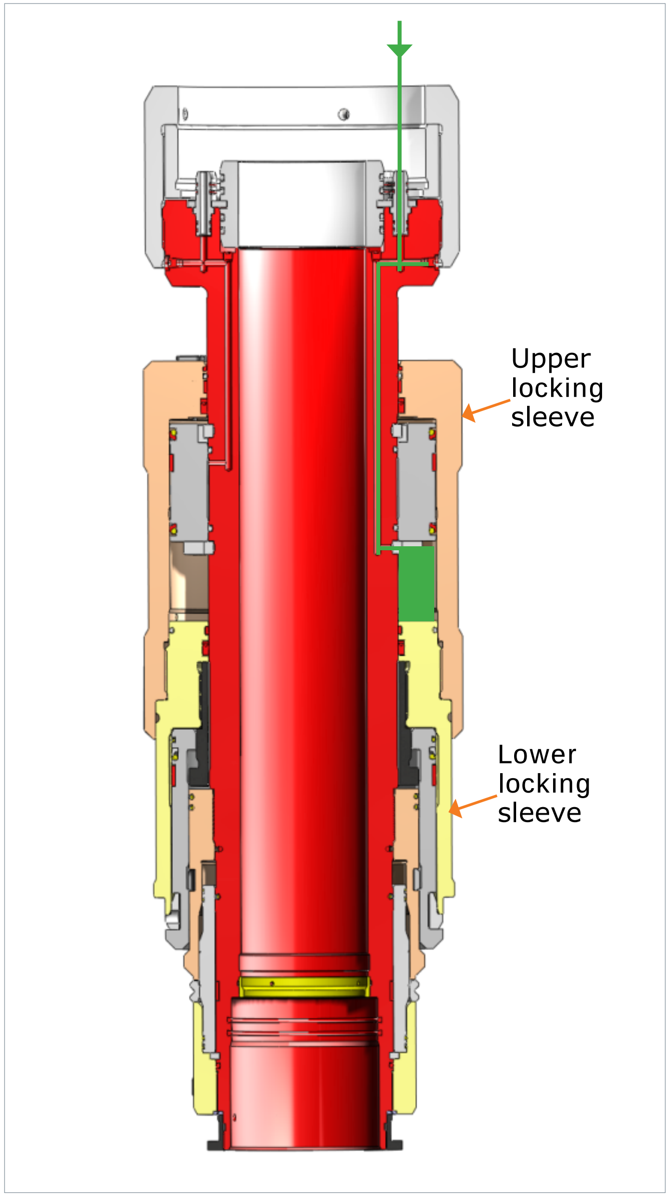


Figure 18: *THRT in locking position. [6]*

F3: Unlatch line

When F3 is pressurised it will push the latch piston up so that it deactivates the latch ring.

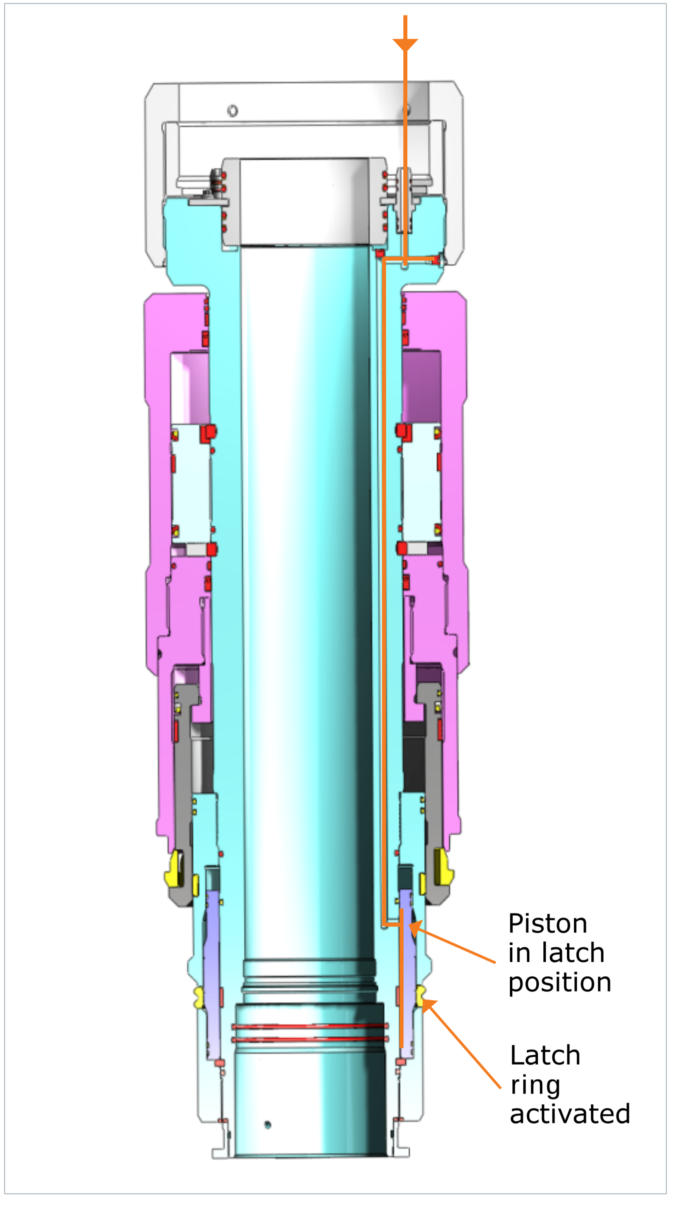


Figure 19: THRT in latching position. [6]

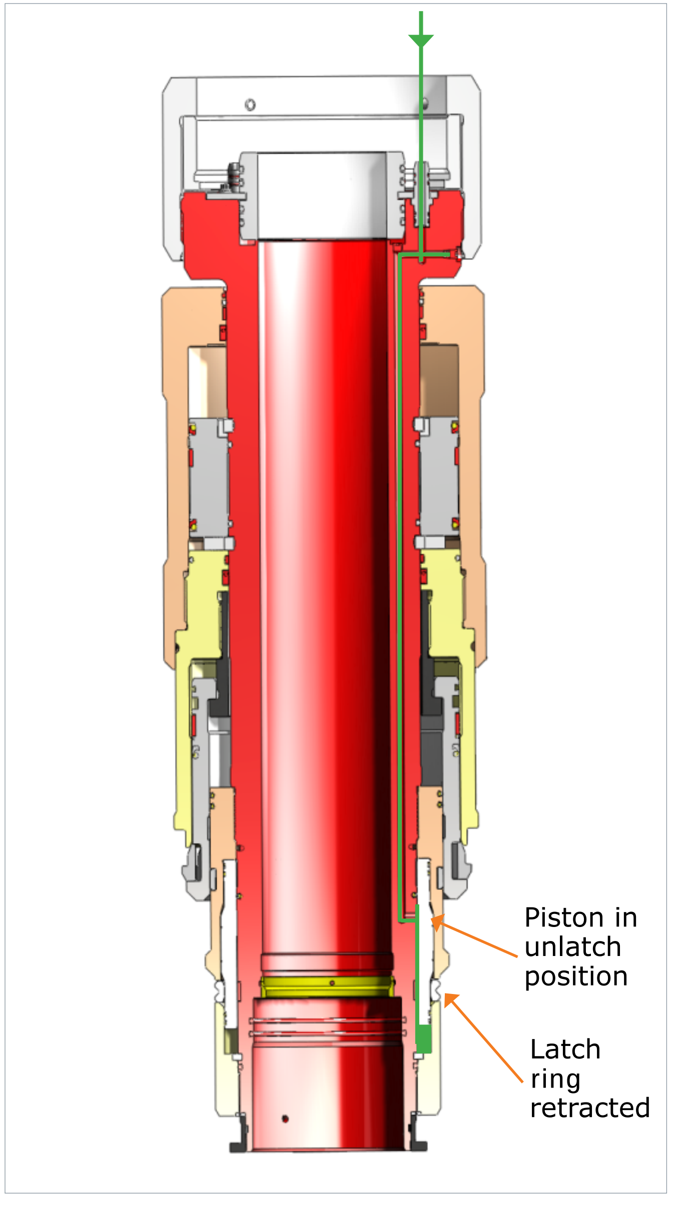


Figure 20: THRT in unlatching position. [6]

F4: Unlock line

When F4 is pressurised the lower locking sleeve is pushed and will move, and since the upper locking sleeve is attached to it, it will follow its movement.

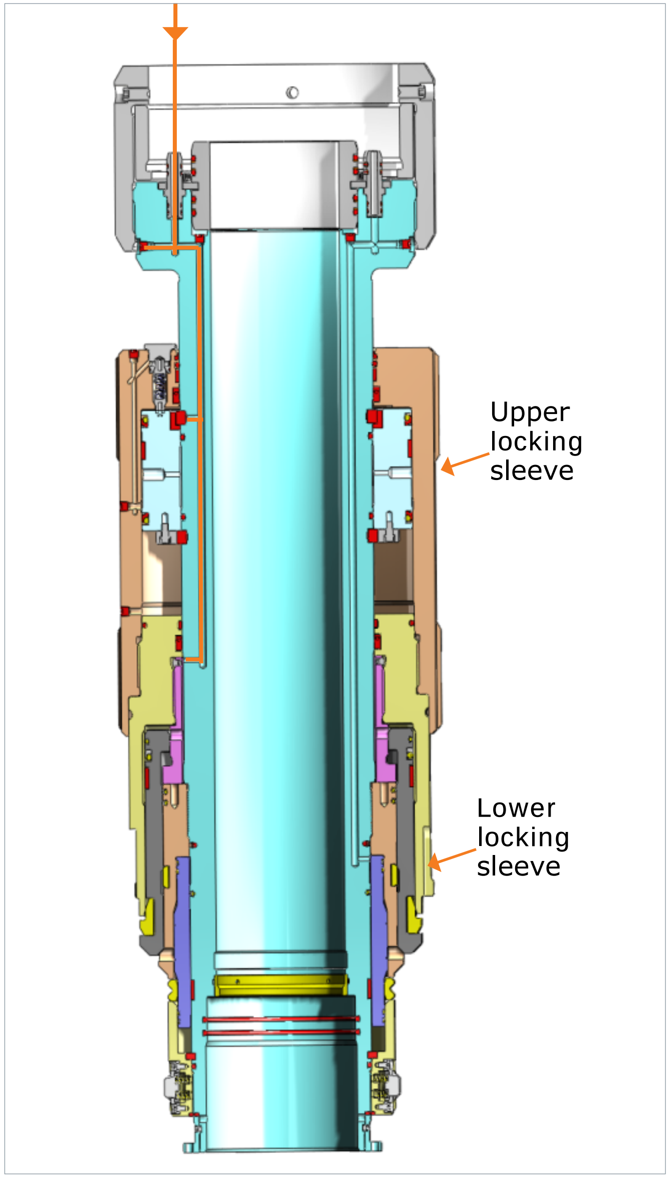


Figure 21: THRT in locking position. [6]

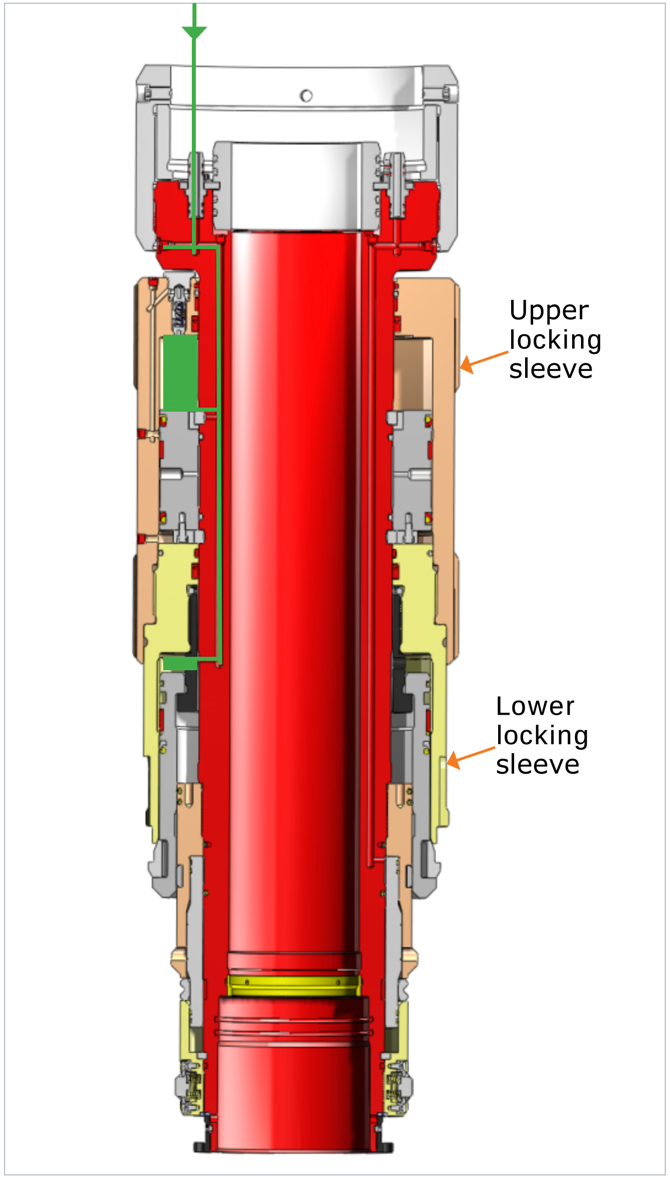


Figure 22: THRT in unlocking position. [6]

F5: Verification

If the TH is to be fully locked to the spool, the sleeves have to be fully stroked. In order to verify this, a hydraulic valve is used.

The valve which is called "poppet valve" will only be open if the sleeves are fully stroked. This happens when a piston mechanically push the poppet valve`s spring together.

When and only when the spring is compressed, fluid will be able to pass the valve. The valve is located in the THRT`s upper locking sleeve.

When poppet valve is closed the fluid will be able to push down the upper poppet retainer and flow past, but the fluid will be stopped by the lower poppet retainer.

When poppet valve is open fluid from F5 will be able to pass through the poppet valve, and out of port F4.

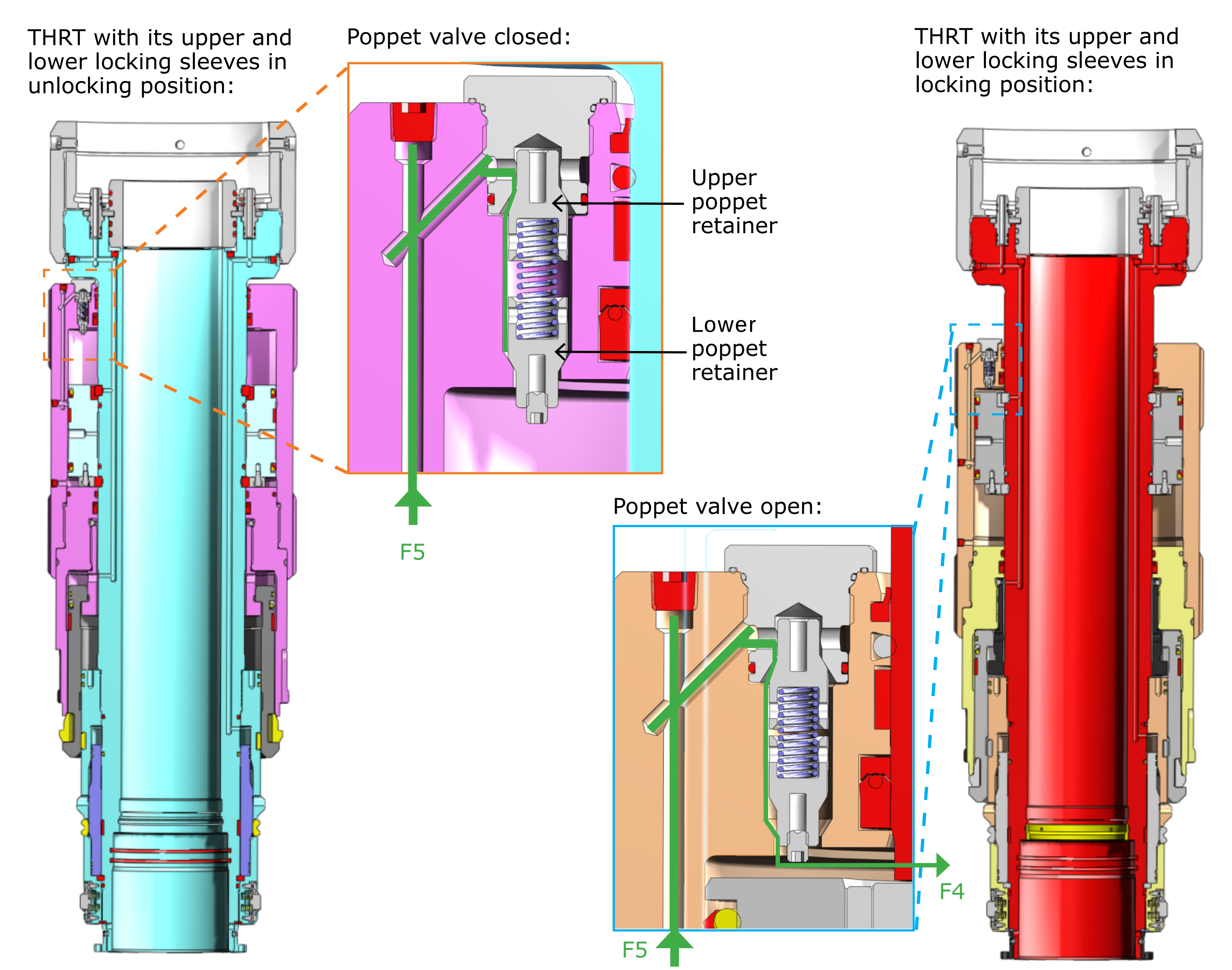


Figure 23: *Poppet valve located in THRT, in closed and open position. [6]*

To ensure complete lock-down, pressure is applied to the test lock-down function port F5. If successful, poppet valve in THRT is open, and fluid will be enable to return to the surface. At the surface the fluid exits through port F4, which provides proof of lock-down. Figure 24 and 25 illustrate how fluid flows in port 5 and to inner annulus, over to outer annulus, up and through poppet valve, and then towards and out of port F4.

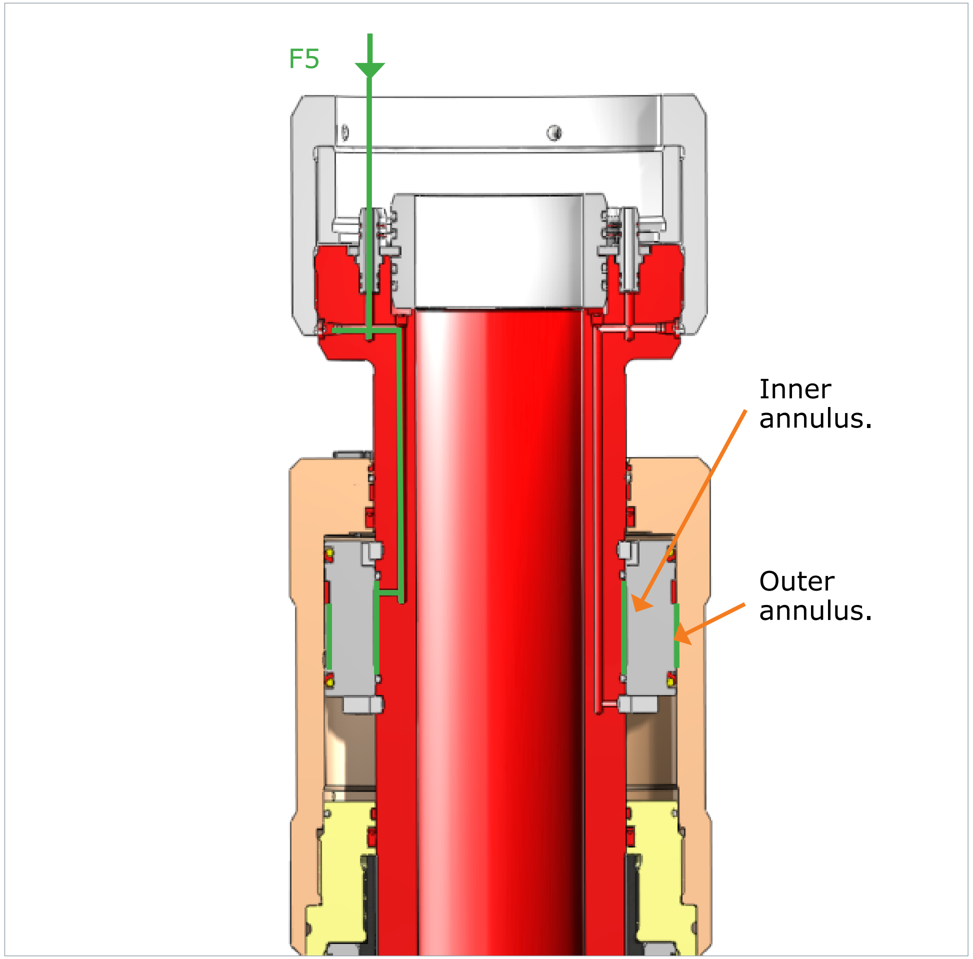


Figure 24: *Fluid sent through hydraulic port F5. [6]*

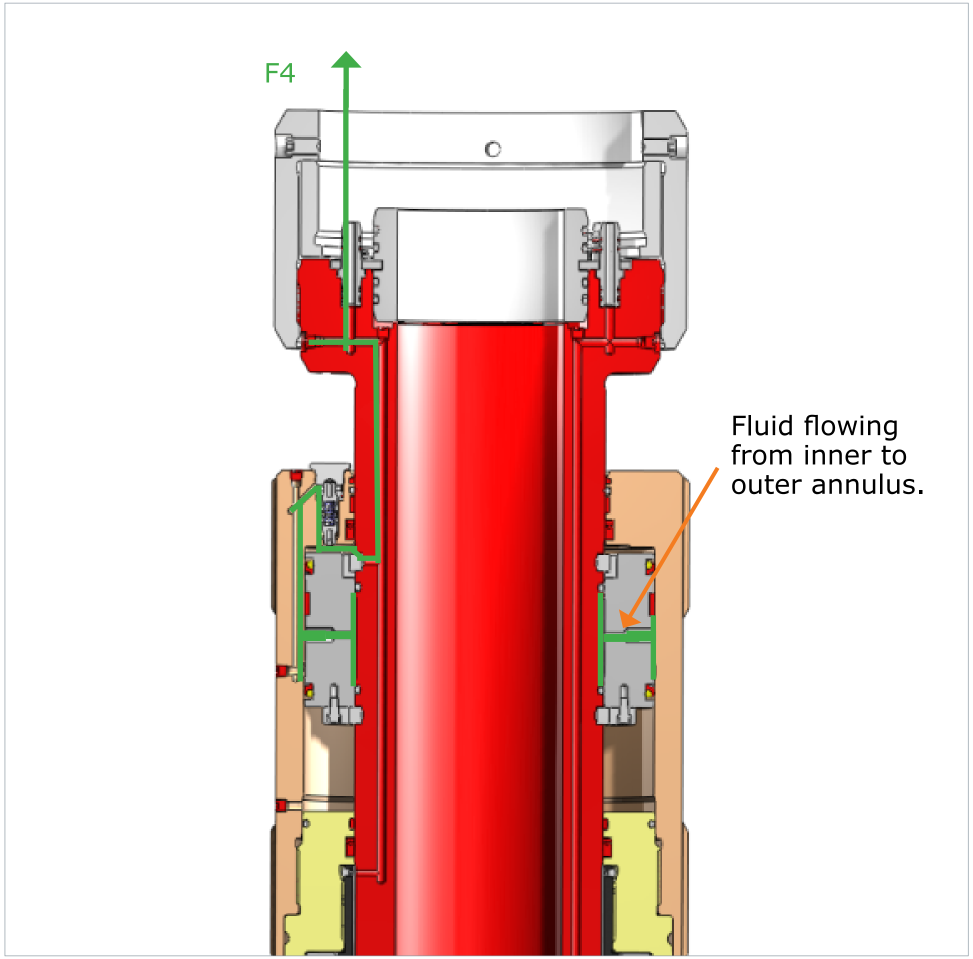


Figure 25: *Fluid flowing out of hydraulic port F4. [6]*

4.3. Installation of Tubing Hanger

4.3.1. The Installation System

The first preparations for TH, before installing it subsea are performed on topside by a Tubing Hanger Handling Tool (THHT), like the one shown in section A.12 in appendix A.

For the installation of the TH subsea, there are two usual procedures. Either one can connect a Casing Adapter (see appendix A, A.12) and typically a 4.5" (114 mm) tubing to the THRT and TH. The CA and tubing is a usual landing string system, which provides a link to the Drill Pipe/Bore string.

The other alternative is the completion system described in section A.7. Figure 26 shows the same type of Landing String connected to THRT and TH, on rig. For this type of installation system, the CA is not used, but replaced by another tubing system with bigger diameter, e.g. 7" (178 mm)

The main difference between these two alternatives is that the CA solution can only be used for the installation of TH and not for further installation of subsea XT tools, since the tubing is too narrow for the tools to be run through. The last mentioned alternative on the other hand can be applied for both. This makes the second alternative the most practical one, as it is time saving.

Earlier in this section and in section A.7, the installation system that is connected above the TH is described. There is also components connected below the TH, and that is Production Tubing (PT). Figure 26 shows PT attached to the bottom end of the TH. PT are tubes of about 30 m in length that are connected together. The production tubing will run all the way through the casing and down to the well. The PT component that is attached directly to the TH is called a Pup Joint.

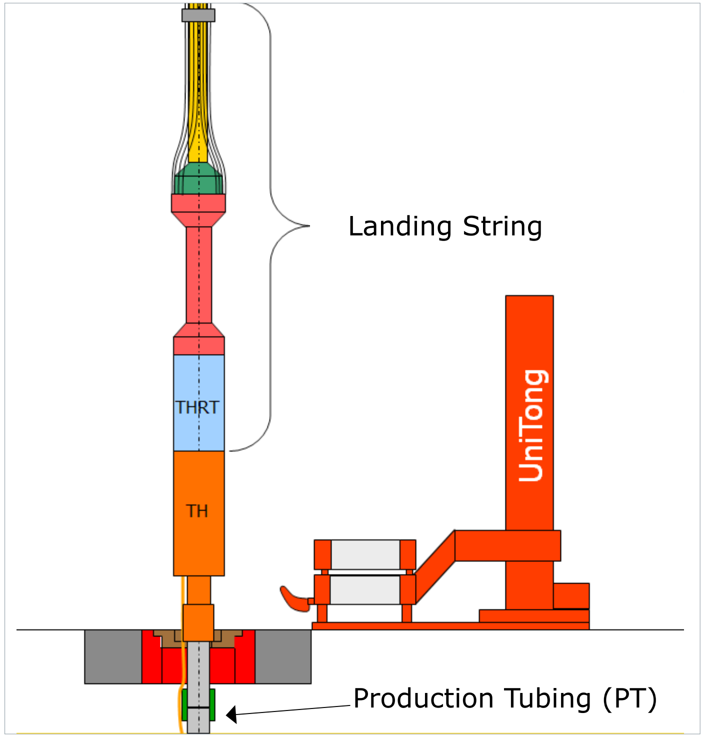


Figure 26: *Installation setup. [2]*

It is important to have an overview of the complete installation assembly described here, in order to fully understand the installation process. Now that this has been described I have chosen to simplify the further installation descriptions and figures by focusing on the THRT, TH (with connected Pup Joint PT) and Xmas Tree spool. These are the most central components for TH installation. TH only interact directly with attached Pup Joint, THRT and XT spool during TH installation. The next section is a step by step description of TH installation.

4.3.2. The Sequence of TH Installation

1) Running THRT down into TH (Unlatch-Unlock)

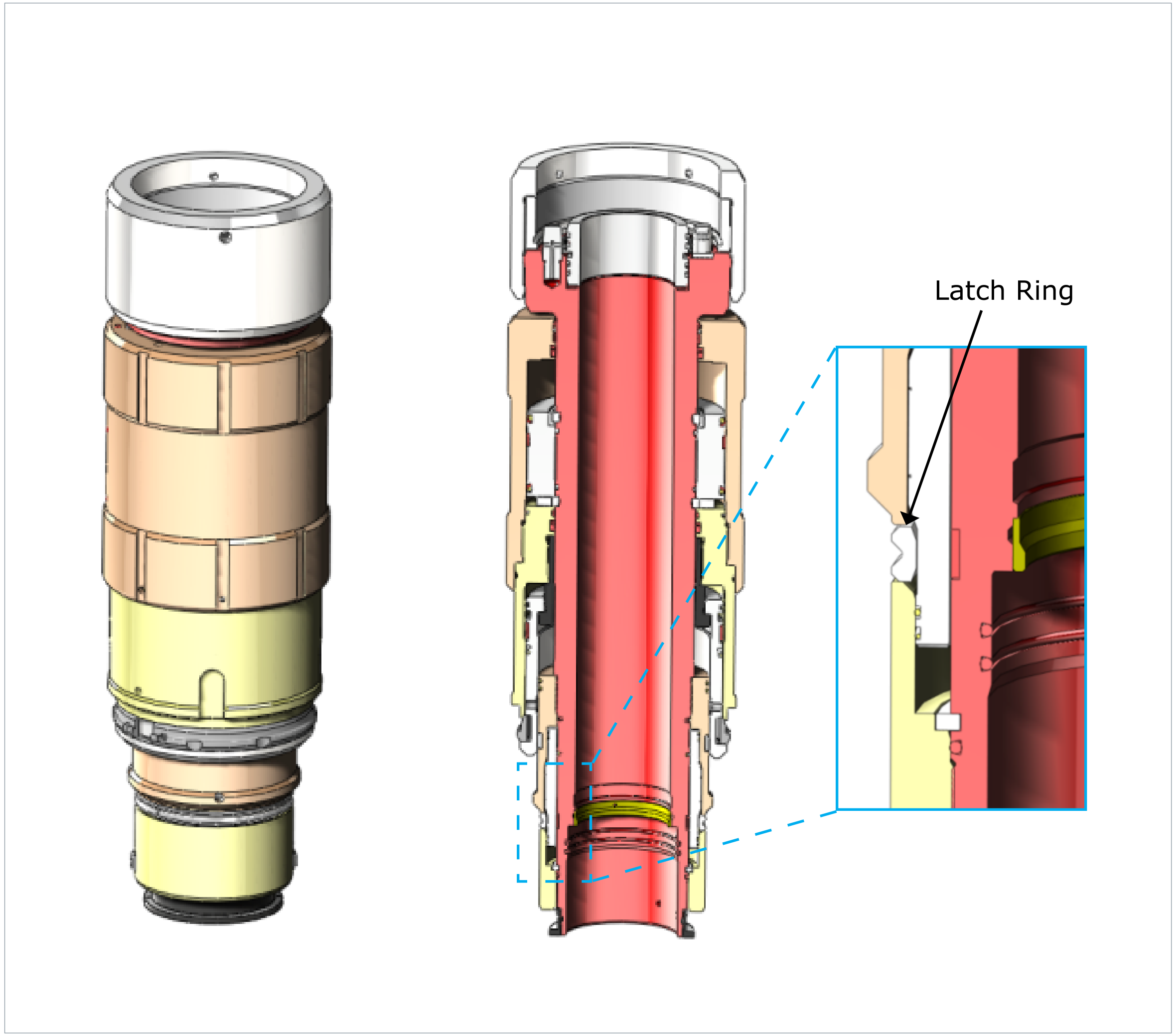


Figure 27: *First of, one pressurise unlatch line (F3) to 345 bar, so that the latch ring is retracted. Scale of figure is about 1:20. [6]*

Figure 28: *While the THRT is in Unlatch-Unlock position, the THRT is lowered down into the TH. Scale of figure is about 1:50. [6]*

2) Latching THRT to TH (Latch-Unlock)

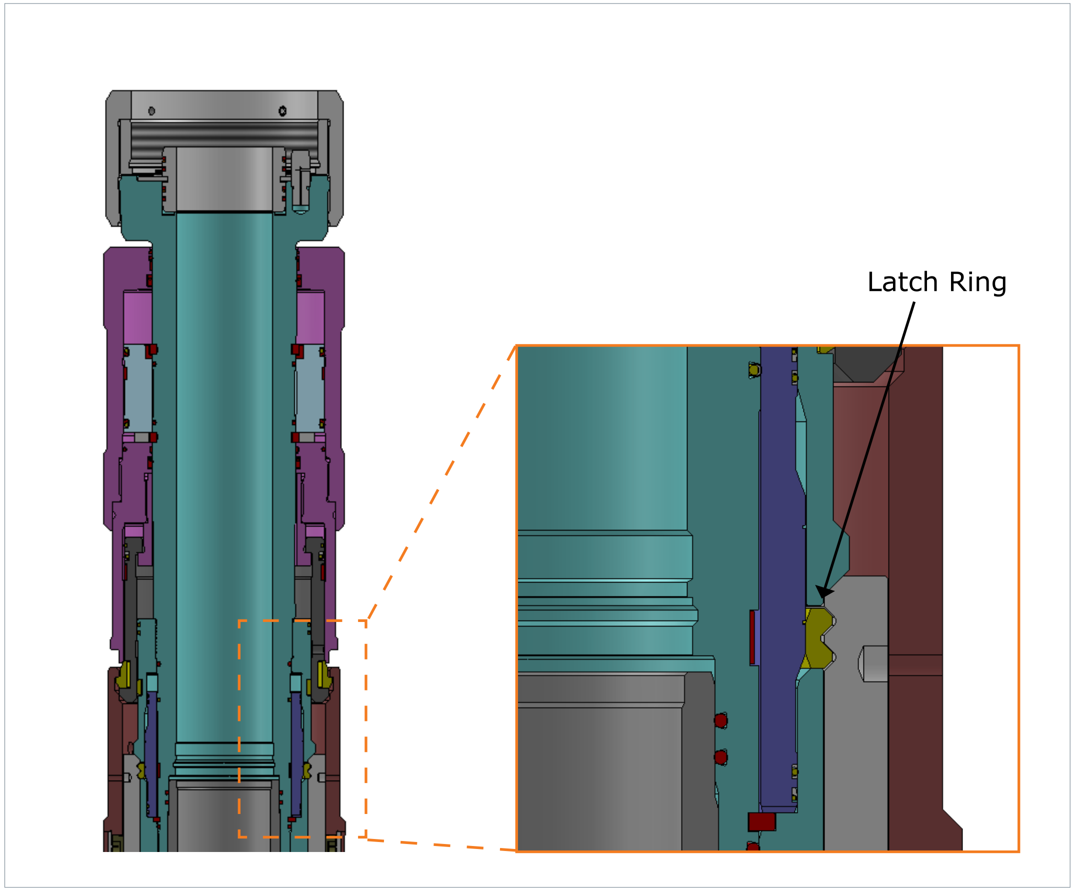


Figure 29: *Next the THRT is latched to the TH by pressurising tool latch line (F1) with 345 bar while venting unlatch line (F3). [6]*

Figure 30: *THRT is latched to TH. [6]*

3) Running TH down into spool (Latch-Unlock);

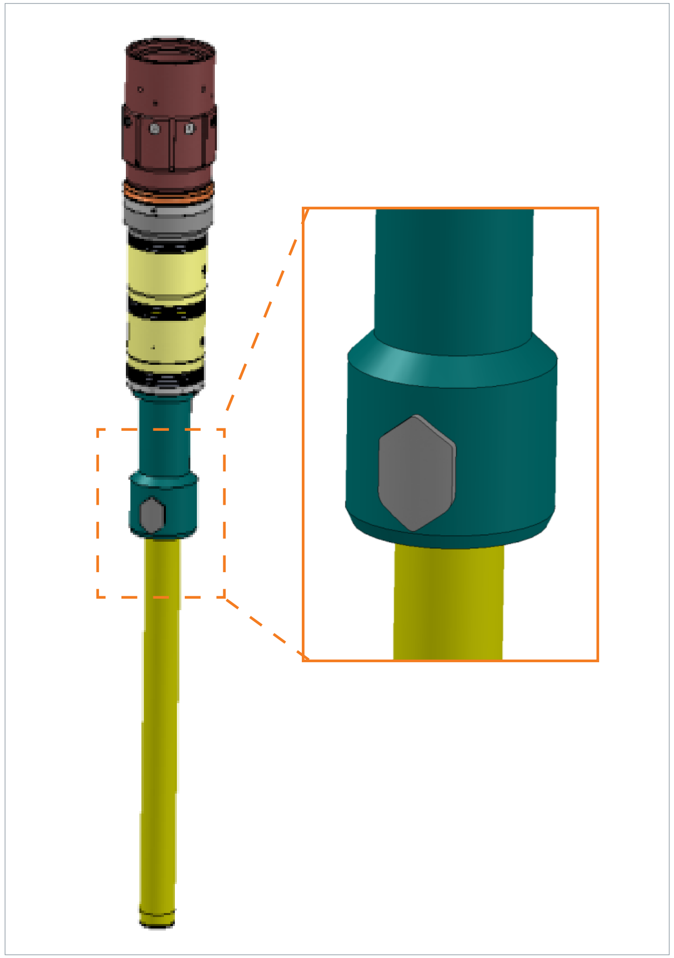


Figure 31: *Orientation key which ensures correct orientation of the TH in the XT. (Scale, 1:25) [6]*

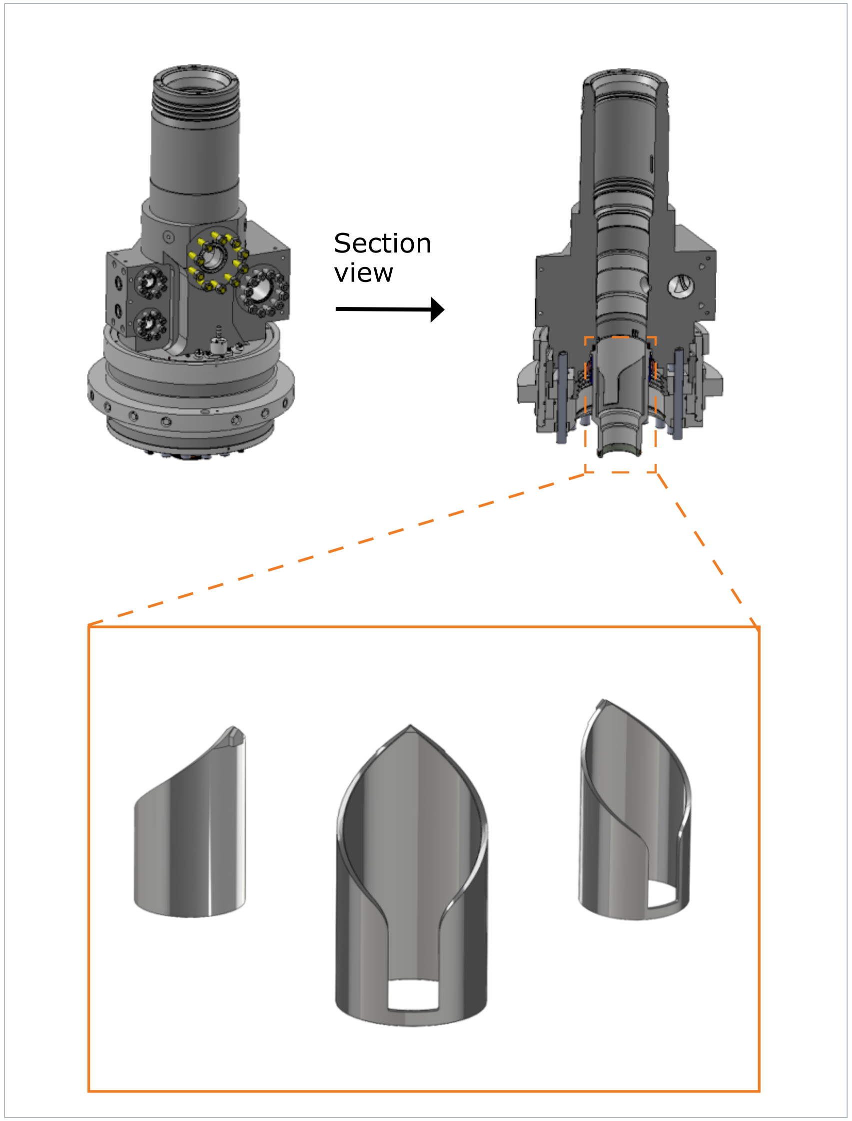


Figure 32: *Helix shape inside spool that guides orientation key into right position. Spool has a height of about 3100 mm and an outer diameter of about 1600 mm. [6]*

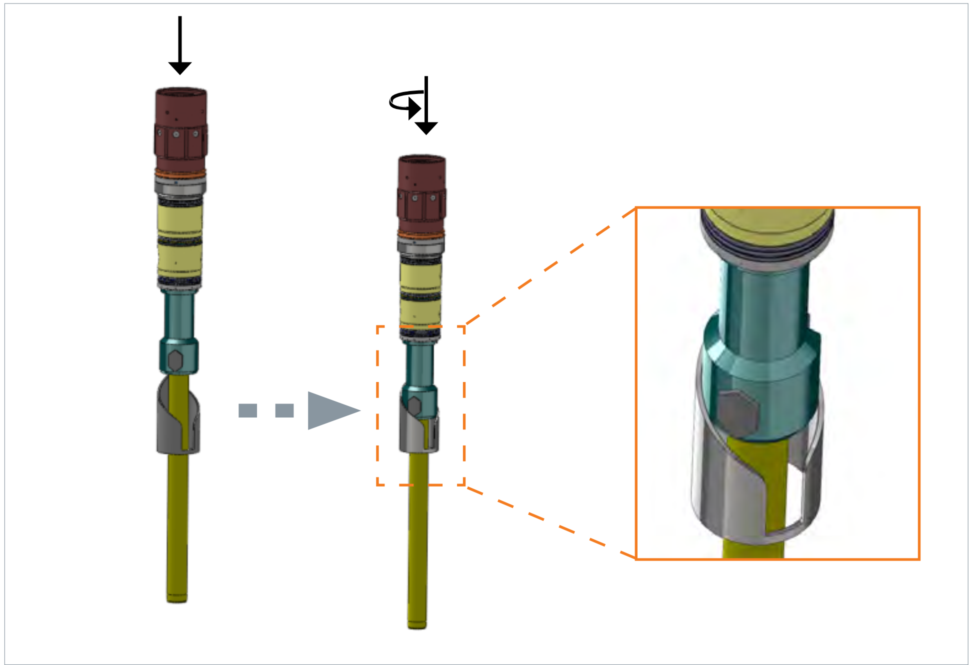


Figure 33: *The TH is lowered down vertically, until orientation key hits the helix shape in spool. Then TH has an axial and rotational movement down into spool [6].*

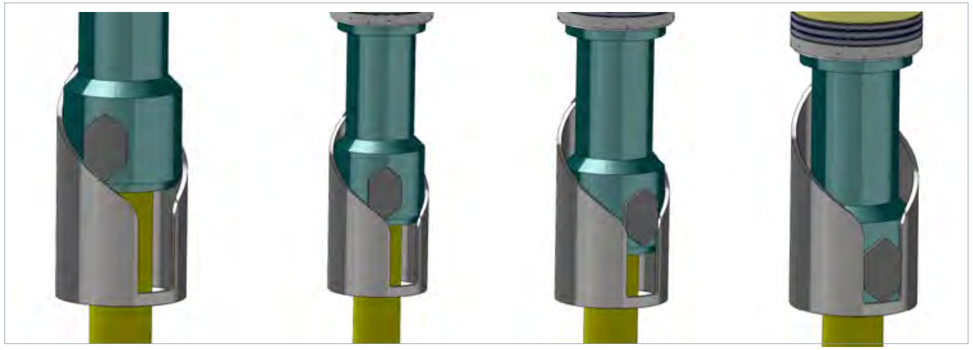


Figure 34: *After combined axial and rotational movement, TH has a pure downward axial movement of about 150 mm. [6]*

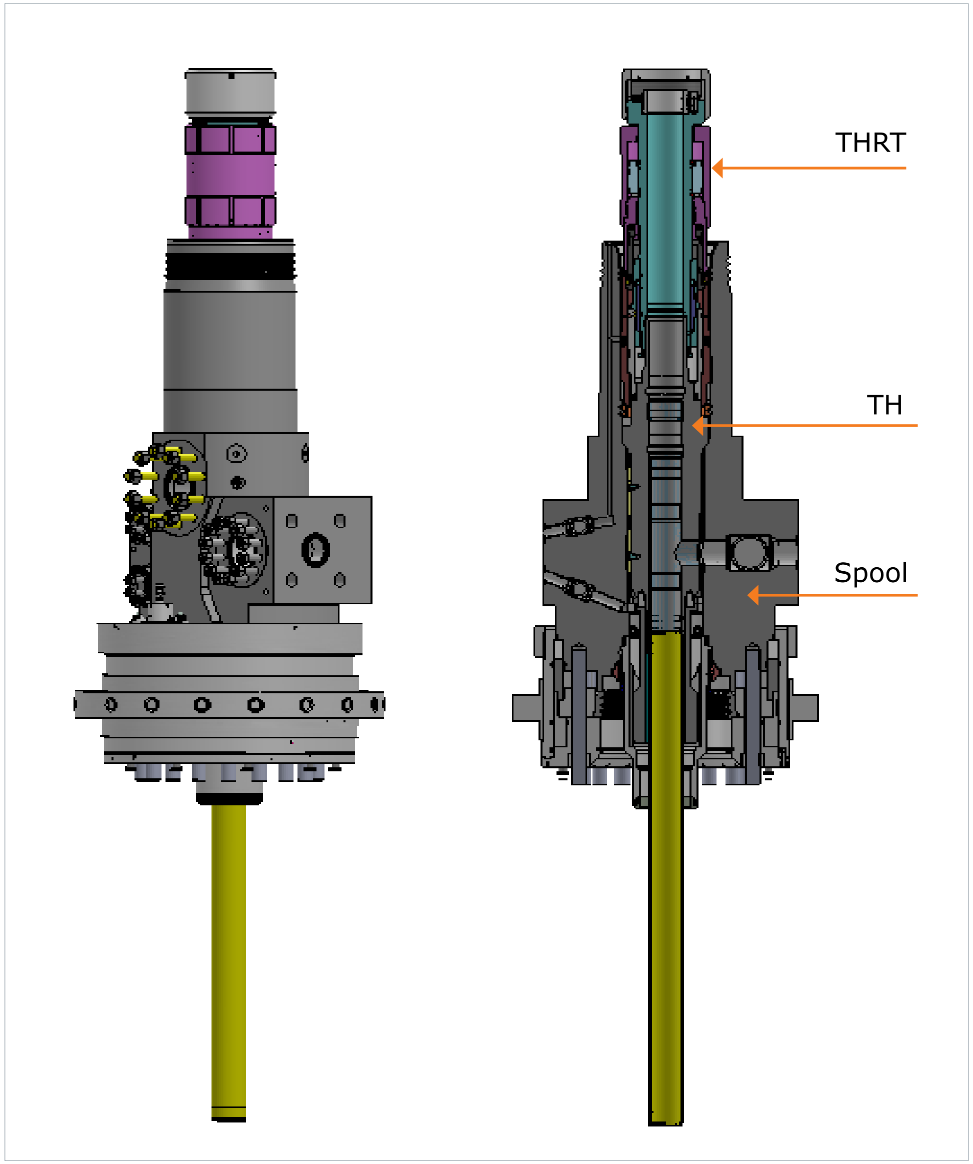


Figure 35: *Here the TH has been lowered all the way down, and is positioned in its dedicated place in the tree spool. (Scale, 1:40) [6]*

4) Locking the TH to the spool (Latch-Lockdown)

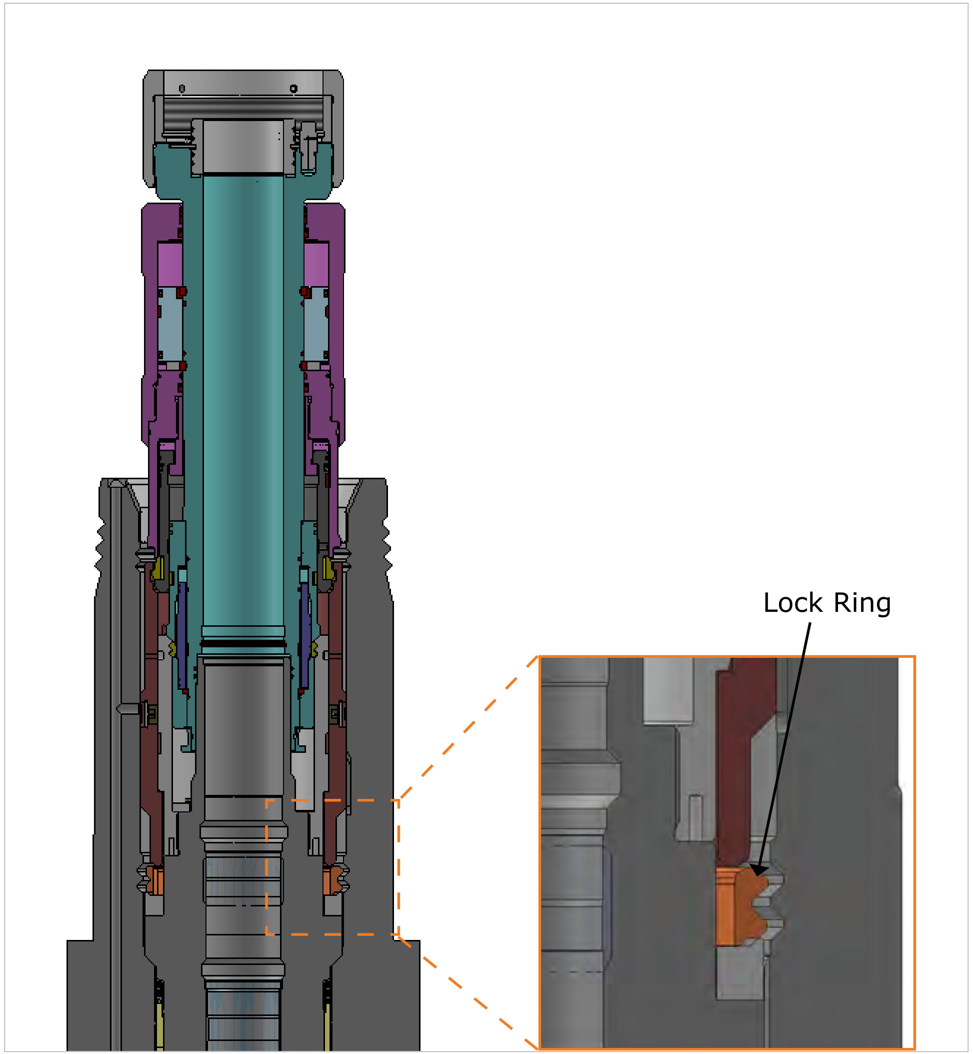


Figure 36: *TH positioned in spool but not locked to the spool. [6]*

How to lock TH to spool:

Maintain pressure on latch line (F1) and run THRT in lock position by pressurising hanger lock line (F2) to 345 bar and venting unlock line (F4).

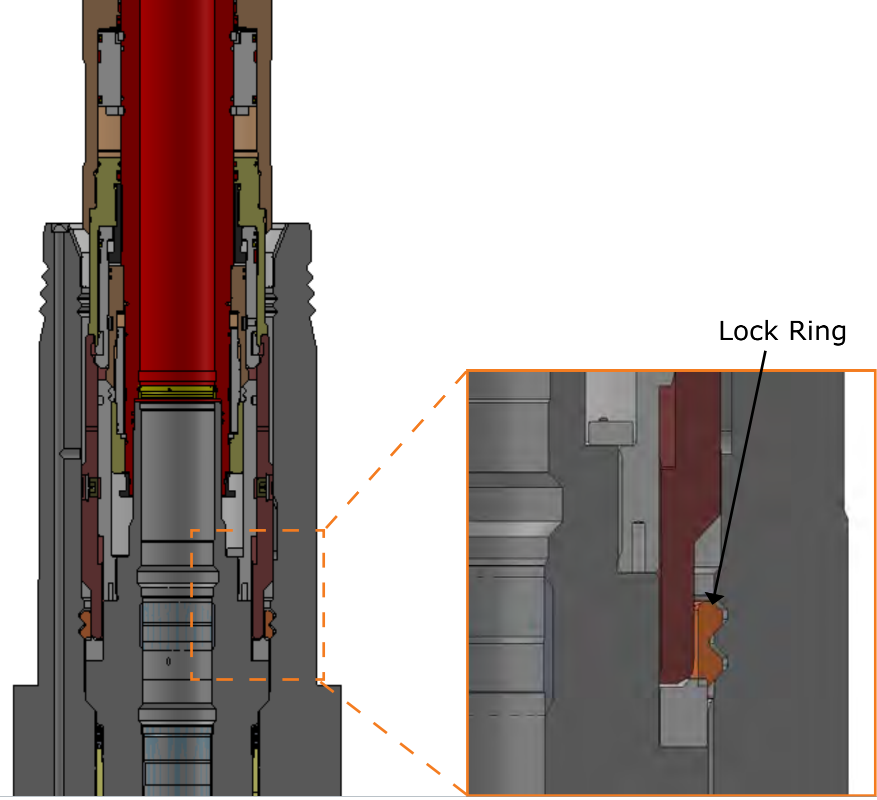


Figure 37: *TH locked to the spool. [6]*

5) Verification methods

When TH has been locked to the XT spoll body, two verification methods are used in order to verify that the TH is locked properly to the spool body.

Over pull
An over pull is to pull the THRT which is attached to the TH, with a force that exceeds combined weight of THRT, TH ans attached production tubing. A typical over pull is 50 ton. That means a force that is 50 ton greater than the weight of THRT, TH and attached production tubing. A THRT typically weights 1146 kg, and has a max pulling capacity of 450 ton.

When performing the over pull one wish to find out if the TH is locked properly to the spool. If it can take the over pull without loosing grip, one assume that it is locked sufficiently.

This method ensures that the TH is locked to a certain degree, but it does not assure that it`s locked in the right position.

Lock down verification with poppet valve
This is the verification method described on p.36 and 37. It is used to ensure complete lock down; this means that the locking sleeves are fully stroked and that the split lock ring is fully expanded. The operator performing the test first pressure port F5 which is the test lock-down function. If successful, the piston has opened the poppet valve, and fluid will be able to pass through the valve and exit through port F4. The flow out of port F4 provides positive proof of TH lockdown.

There are some weaknesses to these two verification methods. System weaknesses are presented in appendix B and appendix C which give and overview of reported incidents and hazard identification.

6) Retrieving the THRT (Unlatch-Lockdown)

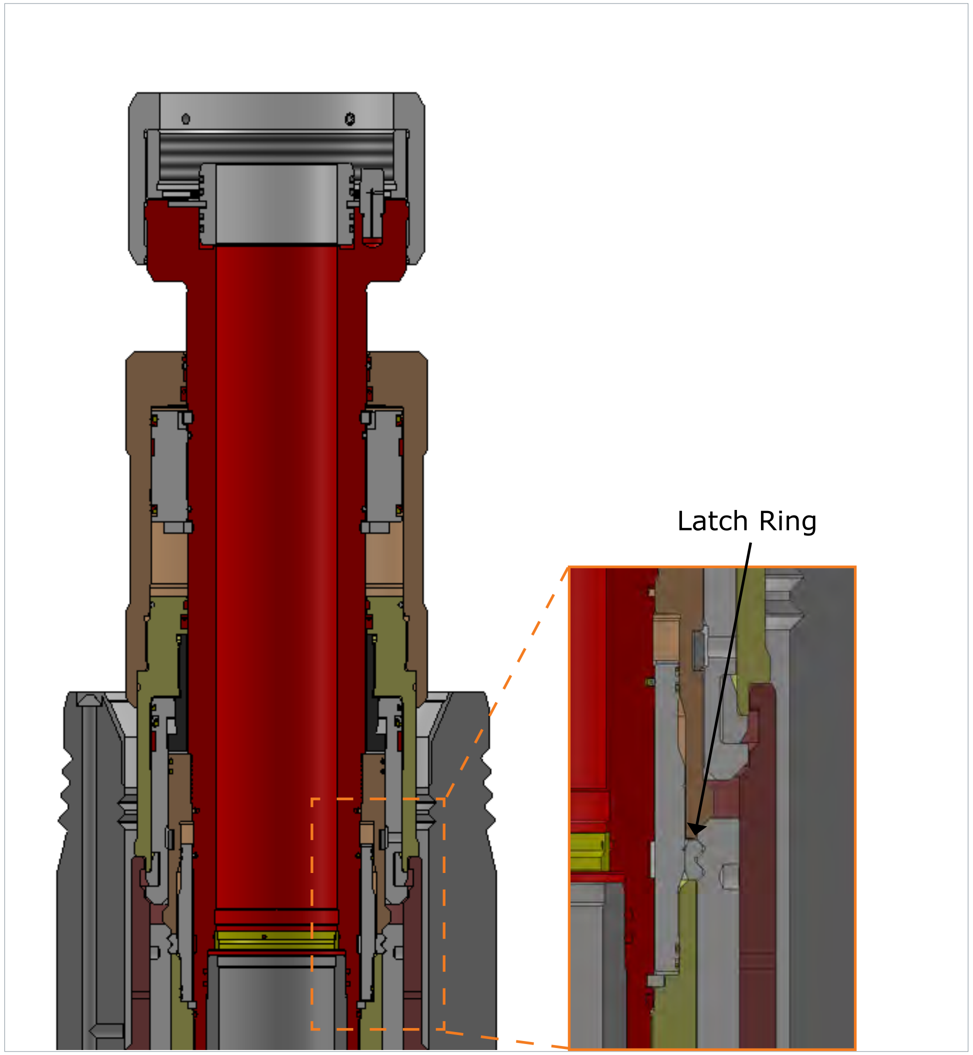


Figure 38: *THRT latched to TH. [6]*

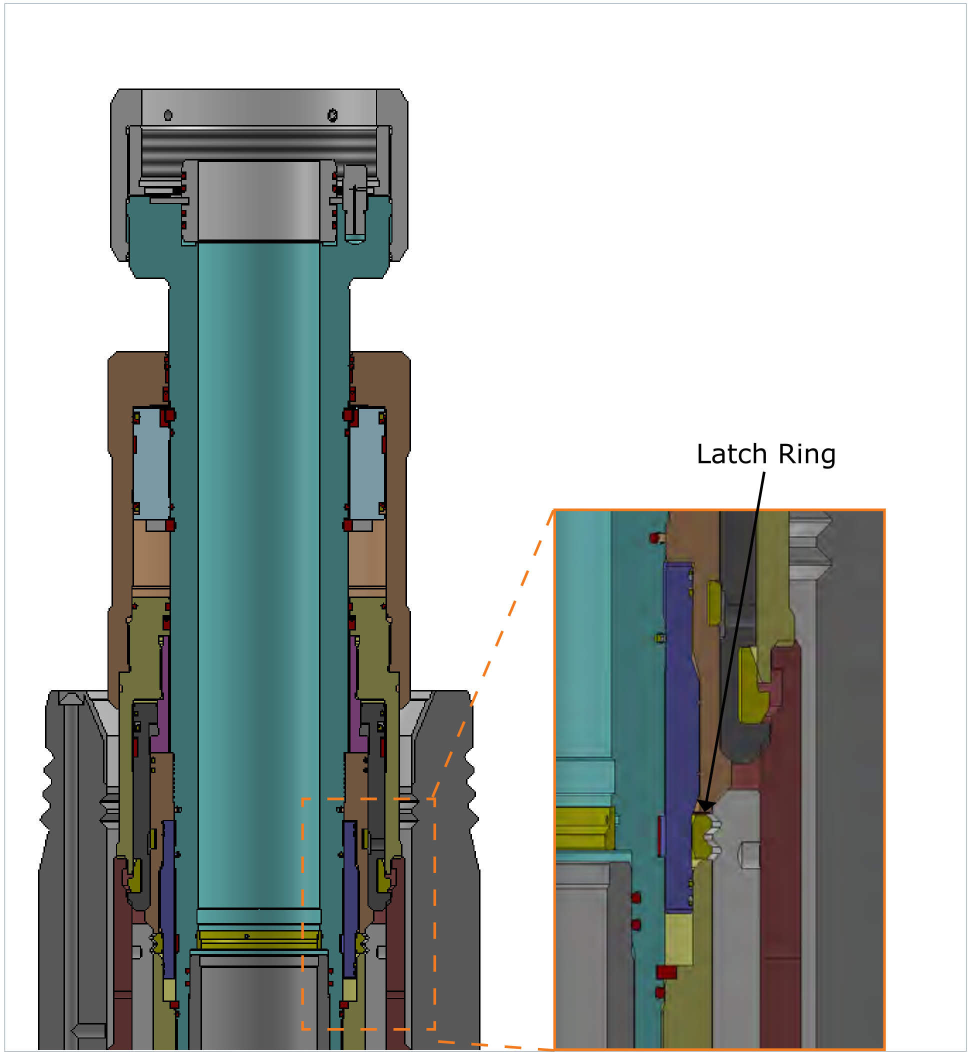


Figure 39: *THRT unlatched from TH. [6]*

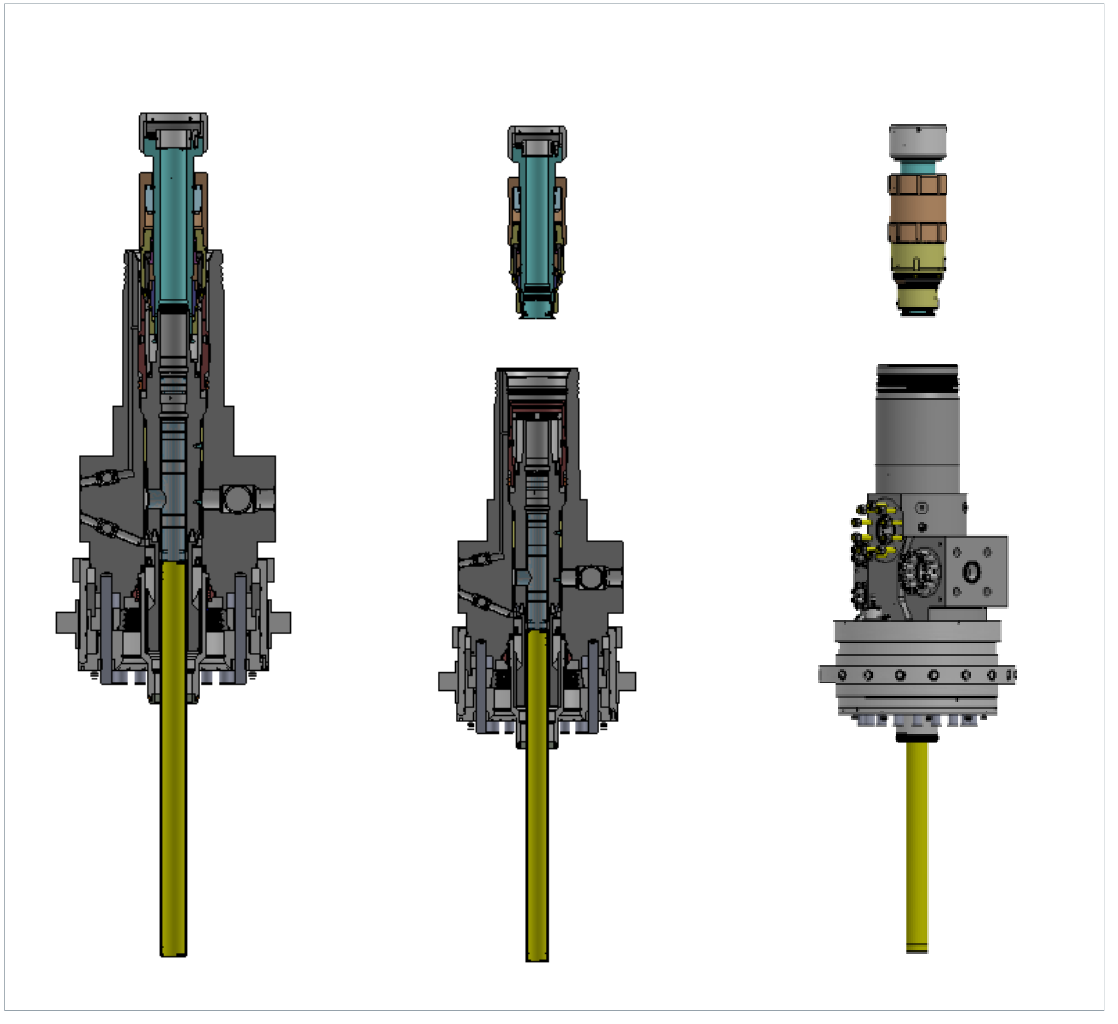


Figure 40: *After the THRT has been unlatched form the TH, it can be retrieved. [6]*

Emergency release:

If the THRT fails to unlatch, a second release can be activated by applying a large torque. This will shear a emergency release feature on the THRT and release the tool from the TH.

4.4. Operative System Information

Earlier in this report I gave an overview of the workover and completion system, and two lock down verification methods. The verification methods are mainly procedures performed by an operator, in order to find out if the TH is locked properly to the XT spool.

A central part of a verification system, is how information is sent from the subsea system and the operator on topside, during installation. Today, the operator gets feedback by:

- Measuring the amount of oil that is sent into and out of the cambers/annulus during latch and lock procedures. If there are any hydraulic leakages e.g. from umbilical's, these readings can be misleading.)
- Cameras on ROV. This only provides a view on the outside of the subsea system, and not internally.
- During over pull verification procedures, the tension is measured in order to know what force is applied.
- During verification with poppet valve, it can be observed that fluid is flowing into port F5 and out of F4, by using flow meters that provide information to the operator about speed and amount of flow.

These are all good information sources for the operator, but none of them give 100% positive feedback for installation of TH. They are just indicators telling the operator that the system is probably acting the way that it should.

Informationsending is a crucial part of the subsea system, in order for the operator to be able to know what in going on subsea. While running the TH subsea, the operator does not get any visual feedback for the TH`s position.

4.5. Reported Incidents and Hazard Identification

In order to get a better insight to today's installation procedure and its weaknesses, I have carried out a Hazard Identification (HAZID) study, which can be found in appendix C. As an introduction to this I made an overview of reported incidents, which can be found in appendix B.

4.6. Overview of Today's Verification Methods for TH Installation

On the next pages I have carried out an analysis to get an overview of today`s verification methods for TH installation. I have not only looked at the over pull method and lock down verification with poppet valve, but all other types of verification that operators at topside get during TH installation.

It includes both visual verification during preparations on topside, and different dypes of verification gained by operator while running TH subsea.

The overview has been made in order to find out which important installation information is already provided by verification methods included in today`s Tubing Hanger installation procedure, and which installation information that requires product development in order to be covered. Typical examples of important TH installation information are correct latching of TH to THRT and vertical position of TH inside XT spool prior lockdown.

Table 5: *I got to know about the over pull and poppet valve verification methods for lockdown at the very start of the project. Other verification methods for TH installation, I have discovered throughout this analysis phase. The table below provides an overview of all verification methods used today for the different TH installation steps. I have given an indication of its trustworthiness; high, medium or low. I studied Aker Solution`s general installation procedure [2] and installation procedure for Goliat project [2], in order to make sure all possible verification methods are included. A short description from installation procedure is given for each verification method.*

Installation step	Factor	Topside or subsea	Installation procedure	Verification method	Trustworthiness
Get THRT in right position relative to TH	Concentric orientation	Topside	• Pressurize THRT Unlatch line and TH Unlock line • Guide THRT onto TH with guide arm soft slings/rope around THRT body. • Mark the position of THRT alignment keys and TH alignment grooves with vertical white painted lines and align THRT/SLS as it enters TH. • Orient the actuator sleeve to line up the viewing-port. • Turn THRT to engage spring-loaded keys.	Visual by operator	High
	Right vertical position	Topside	• Stab THRT into TH.	Visual by operator	Medium
Activating latching	Latch piston fully run	Topside	• Vent THRT Unlatch and apply 345 Bar to THRT Latch	Hydraulic flow readings	Low
			• Verify latching through the viewing port in the side of the TH actuator ring. Verify the mark on the THRT latch piston is visible in the middle of the viewing port. This confirms that the THRT is fully latched.	Visual verification	High

Table 5 continued:

Installation step	Factor	Topside or subsea	Installation procedure	Verification method	Trustworthiness
Activating latching	Latch ring fully activated and in right position	Topside	• Perform a pick-up test of full sting weight to verify proper THRT/TH engagement. Then set down weight again onto the support plate.	Lift full weight of production tubing	Middle
			• Vent TH Unlock line and apply 345 Bar to TH Lock line until lock ring snaps into actuator sleeve. Obs! Do not activate/expand the TH split lock-ring! • Vent TH Lock line and apply 345 bar to TH Unlock line. • Lock in 345 bars pressure and close needle valves for TH Unlock and THRT Latch at reel. • Vent pressure from WOCS to THRT/SLS functions and disconnect jumper from WOCS to the reel.	Run locking sleeves	High
Running subsea	How far the TH has travelled	Subsea	• Lower TH until TH Lock Ring is flush with Rotary. (Ensure that minimum 45 degrees clockwise rotation is achieved when the TH enters the XT helix.) • TH Guide Bushing is used while lowering the TH down into marine riser. • Run TH and Upper Completion subsea until it is positioned directly above the Blow Out Preventer (BOP).	Tubing length connected on topside	Middle
Land TH into right position in spool	Running down into POB stack	Subsea	• With the TH 3-5 meters above flex joint, rig up landing stand and long bails. Top drive brake- and gear-lock have to be off to enable right-hand rotation of TH when landing. • Check flex joint angle with ROV and adjust rig position if required. • Check distance to landing point. • Keep compensators on. • Slowly lower TH through BOP stack (0.2 m/s or less). • Continue bleeding off compensator to slowly lower TH into XT. • Laser mark measurements to be performed	Laser beam	Middle
	TH rotating about 90° inside spool	Subsea	• Observe an anticipated right-hand rotation and then a straight vertical movement of approx. 150 mm before TH lands (may be difficult to detect). • Set down all tubing weight plus 5 ton weight of landing string.	Observe rotation	Low
				Calk pen and yardstick	Middle

Table 5 continued:

Installation step	Factor	Topside or subsea	Installation procedure	Verification method	Trustworthiness
Locking TH to XT spool	Locking sleeves fully run and split lock ring fully engaged in right position	Subsea	• Vent TH Unlock line and apply 345 bar to TH Lock line. Monitor fluid volume for these lines. (Expected values stated in procedure)	Hydraulic readings	Low
			• Open Lock Verification isolation valve on reel • Apply low pressure (150 bar) to Lock Verification line F5. Supply 5.0 L of fluid into line F5 to ensure that TH is properly locked. Monitor that fluid is coming out from line F4 (TH Unlock). Check same return flow as supply – then stop. • Close Lock Verification isolation valve on reel. • Vent TH Lock line.	Poppet valve	Low
			• Over pull test: Pull 50 ton above pre-landing pick-up weight. • After good over pull test, reduce to 5 ton pull on the Landing String	Over pull	Low

Comments to table 5:
As one can see in table 5, all the verification methods of high trustworthiness are those for orienting THRT and latching it to TH on topside. A high trustworthiness means that verification method is sufficient for relatively problemfree TH installation. The verification methods of low accuracy only give a weak indication of right TH installation step. Middle trustworthiness gives a relatively good indication, but e.g. not to required installation accuracy level for the subsea system. A good example of this is the laser beam verification method which gives an accuracy of ± 1-2 cm, while an accuracy of ± 1,5 mm is required for the TH`s vertical position. It does not matter if an installation factor has a verification method of low accuracy, if it also has other verification methods of higher accuracy. Thus verification method of highest accuracy is the one that counts.

What steps of the TH installation that should get improved verification methods does not only depend on the grading of trustworthiness in table 5, but also on seriousness and frequency of possible hazards related to each installation step. I have chosen to not go in detail on this, since I don`t have enough information basis to evaluate seriousness and frequency of the different hazards I made an overview of in appendix C.

Conclusion:
The verification aspects listed below are least covered by today`s TH installation procedures.

- Vertical position of TH while run down into BOP stack.
- Verification registering if TH is in right position in spool.
- Verification registering if split lock ring is fully engaged.

4.7. Final Evaluation of What Type of Verification is Needed

4.7.1. Result from HAZID Study

Conclusion from the HAZID study (appendix C) has a list of what a verification system for Tubing Hanger installation should include:

- Verification registering if THRT is in right position relative to TH, before latch.
- Verification activated when latch ring is fully engaged.
- Verification registering if TH is in right position in spool.
- Verification registering if lock ring is fully engaged.

The overview of today's verification methods for TH installation gave me a good insight to which of these bullet points are already covered by today`s installation procedures. The first two are covered. The first one by these procedures:

- Mark the position of THRT alignment keys and TH alignment grooves with vertical white painted lines and align THRT/SLS as it enters TH.
- Orient the actuator sleeve to line up the viewing-port.
- Turn THRT to engage spring-loaded keys.
- Stab THRT into TH. (THRT spring-load keys will lock into TH grooves.)

The second one by these procedures:

- Verify latching through the viewing port in the side of the TH actuator ring. Verify that the mark on the THRT latch piston is visible in the middle of the viewing port. This confirms that the THRT is fully latched (Figure 41).

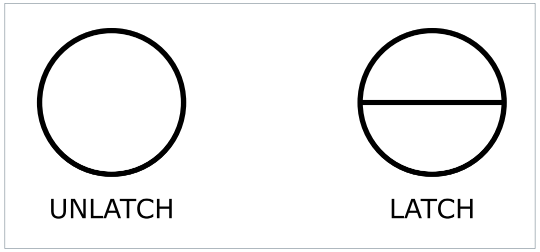


Figure 41: *Latch verification. [2]*

- Perform a pick-up test of full sting weight to verify proper THRT/TH engagement. Then set down weight again onto the support plate.
- Vent TH Unlock line and apply 345 Bar to TH Lock line until lock ring snaps into actuator sleeve.

The verification illustrated in figure 41 provides information about both position of THRT inside TH after latch, and if latch ring is fully engaged. The figure is from the TH installation procedure. On the next page I have shown how the figure is related to the THRT and TH.

Figure 42 shows section cut of the lower part of THRT. The blue/purple coloured component is the latch piston, and it is on the latch piston the line mark is (figure 43). Figure 44 also shows lower part of THRT but without section cut. In this figure a THRT viewing port can be seen. Figure 45 is a section cut of THRT and TH latched together, and one can see a TH viewing port. When THRT has been stabed into TH, the viewing ports on THRT and TH will line up if THRT is both positioned in correctly vertical height and aligned in right rotational position relative to the TH.

When latch piston is in latch position its line mark will be positioned right in the middle of the two viewing ports. Thus when the operator verify that mark on the THRT latch piston is visible in the middle of the viewing ports, one know that THRT is in right position relative to TH, and that latch ring is in latch position. This also means that latch ring is fully engaged, in right position. The pick-up test and lock line test with snapping of lock ring are safety procedures performed in order to have an even stronger verification of latch.

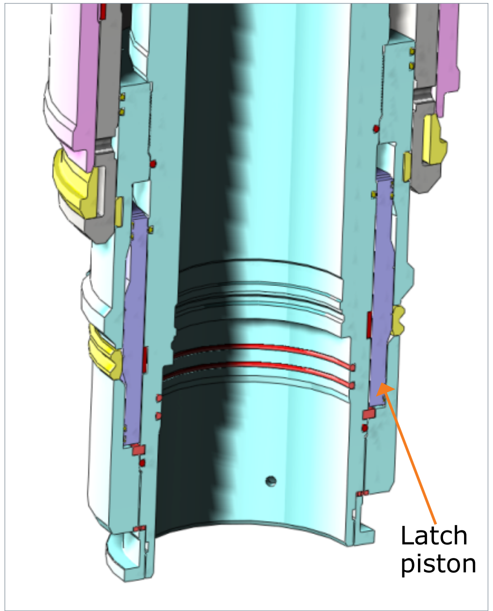


Figure 42: Section cut of *Lower part of THRT, showing location of latch piston inside THRT. [6]*

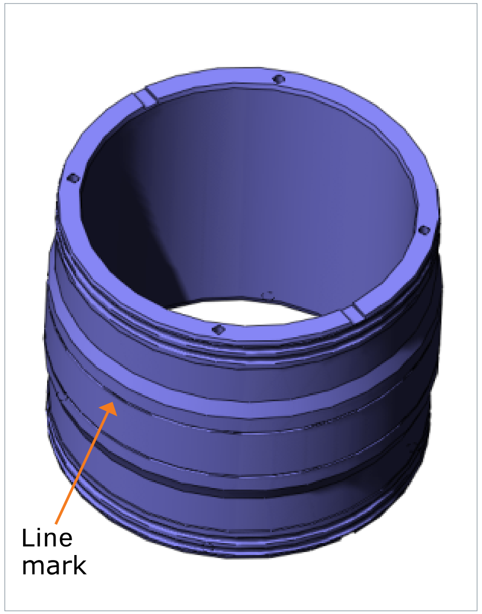


Figure 43: *Latch piston and location of line mark. [6]*

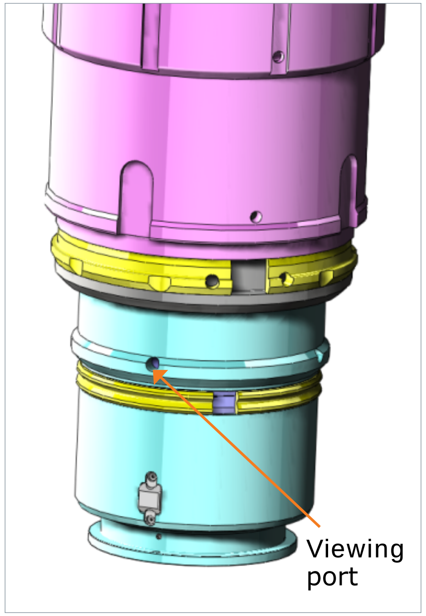


Figure 44: *Lower part of THRT, with viewing port. [6]*

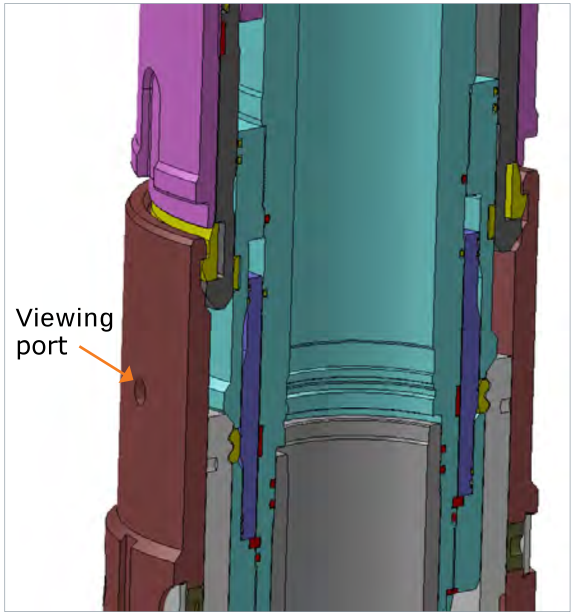


Figure 45: *THRT latched to TH, and location of TH`s viewing port. [6]*

The two last bullet points from HAZID conclusion are not as well covered as the first two.

4.7.2. Result from Overview of Today`s Verification Methods for TH Installation

One of the findings from the overview of today's verification methods was that the installation factor of lowest verification trustworthiness is; "Locking sleeves fully run and split lock ring fully engaged in right position". In addition I found out that there is not much verification given for vertical position of TH while it is lowered down into BOP stack.

Thus the conclusion from overview of today's verification methods was this: The verification aspects listed below are least covered by today`s TH installation procedures are;

- Vertical position of TH while run down into BOP stack.
- Verification registering if TH is in right position in spool.
- Verification registering if split lock ring is fully engaged.

4.7.3. Setting up System Function Requirements

When I started setting up key product requirements in Basis of Design (next chapter), I set up these system function requirements for the lock down verification system:

- Verify vertical position of TH while run down into BOP stack.
- Verify position of TH relative to XT spool before lock down.
- Verify when split lock ring is fully engaged.

Changes to system function requirements

I arranged a meeting for quality assurance of HAZID and first draft to Basis of Design. A "minute of meeting" can be found in appendix H, section H.2. The meeting resulted in some changes to the list of key product requirements.

Three new requirement have been added:

1) "Verify position of TH relative to XT spool after lock down."

   Reason: The position of TH can change during lock down as the split lock ring is partially guided into the grooves in XT spool. Thus the position of TH must also be checked after lock down.

2) "Verify when split lock ring is retracted."

   Reason: This is not central for the lock down of TH, but when TH is to be retrieved for e.g. maintenance, this is crucial verification information. Thus the verification system should be able to confirm when TH is unlocked from the XT spool.

3) "Provide continuous verification of TH`s position and locking until TH installation and pressure testing is complete. "

   Reason: If verification system is able to confirm that TH is locked properly to XT spool and that it is in correct vertical position, until pressure testing is complete, system safety is increased. It has happened earlier that system leakage has caused components to unlock during pressure test procedures. Continous position and lock verification for TH will give the possibility of alerting the operator, if TH unlock by fault.

Final system function requirements:

- Verify vertical position of TH while run down into BOP stack.
- Verify vertical position of TH relative to XT spool before lock down.
- Verify when TH is locked to the XT spool.
- Verify vertical position of TH relative to XT spool after lock down.
- Provide continuous verification of TH`s position until TH installation and pressure testing is complete.
- Provide continuous verification of TH lock down until TH installation and pressure testing is complete.
- Verify when TH is unlocked from the XT spool.

4.8. Evaluating Required Precision of Lock Down Verification System

The verification system is to provide information about:

1. Vertical position of TH while run down into BOP stack.
2. Vertical position of TH relative to XT spool before lock down.
3. When TH is locked to the XT spool.
4. Vertical position of TH relative to XT spool after lock down.
5. Continuous verification of TH`s position until TH installation and pressure testing is complete.
6. Continuous verification of TH lock down until TH installation and pressure testing is complete.
7. When TH is unlocked from the XT spool.

Of these seven requirements, the last six has to meet quite strict precision requirements. Bullet point one on the other hand does not need to provide installation information of high precision.

The first precision requirements I set up in the Basis of design, in which the last three are precisions Hybrid Penetrator requires in order to engage correctly into TH, were these:

- Alignment: All equipment assemblies should be balanced within 1°.
- Vertical alignment of TH with precision of ±1.5 mm (after lock down)
- Concentric alignment of TH and spool with precision of ±1mm
- Rotational alignment of TH and HP with precision of 1°.

During meeting (See appendix H.2) in which the Basis of Design was quality assured by some of my colleagues at Aker Solutions, I was informed that most of these precision requirements are already covered. This means that they do not need to be covered by the lock down verification system.

Rotational position verification is not necessary to include in new lock down verification system, as the helix shape in spool and orientation key on TH has a tolerance of ± 0,45°, which is smaller than the HP`s maximum slack of ± 1°.

Precision of concentric alignment is also covered by the XT spool. The requirement of assemblies being balanced within 1° is covered by installation of wellhead and XT. Thus the only precision requirement the lock down verification system needs to cover (of the four precison requirements that were set up) is the vertical alignment of TH inside XT spool.

The requirement of providing information about:

4. Vertical position of TH relative to XT spool after lock down,

demands a verification system which can confirm vertical position of TH with a precision of ±1.5 mm.

This precision requirement only specify needed precision for nr.4 in the verification information list. Thus some new presicion requirements needs to be included in the basis of design. As mentioned earlier nr.1 in the list does not require any strict precision requirement. It is only supposed to give an indication of correct TH installation while TH is run down into BOP stack. Nr.5 will require same precision as nr.4, as it is supposed to provide information of TH position after lock down.

On the next pages, I have evaluated needed precision for verification information nr.2, 3 and 7. Nr.6 will require same precision as nr.3.

In order to find an aproximated value for required precision for verification providing information about:

2. Veritical position of TH relative to XT spool before lock down,

I have studied the shape of the groove in which split lock ring engage into, shape of the split lock ring, and possible outcome of different TH positions. Figure 46 shows where groove in XT spool is.

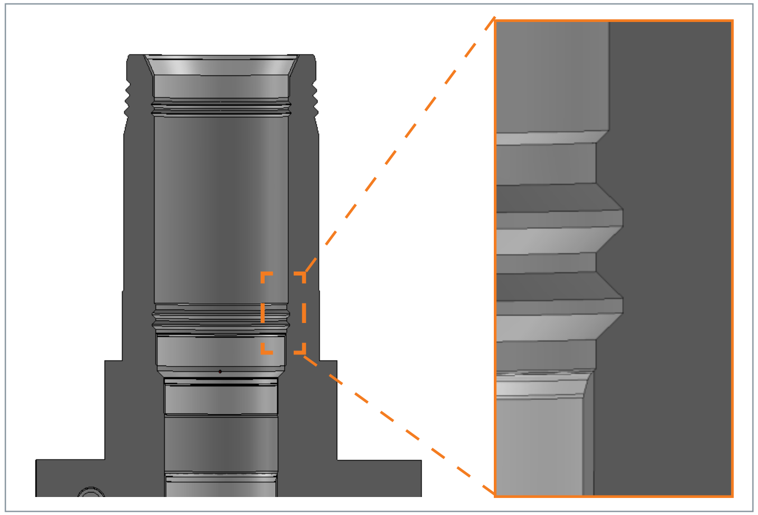


Figure 46: *Section cut of XT spool; showing location of grooves which split lock ring engage into. [6]*

Figure 47 shows how the split lock ring is supppoused to be positioned before and after lockdown. Figure 48 on the other hand shows a possible position of split lock ring that is not optimal, but that probably will result in a correct lockdown.

The TH is in this case in a vertical position higher up than optimal. If there is no obstacles like debris preventing TH from being lowered down in right position, the grooves will align the TH correctly relative to XT spool.

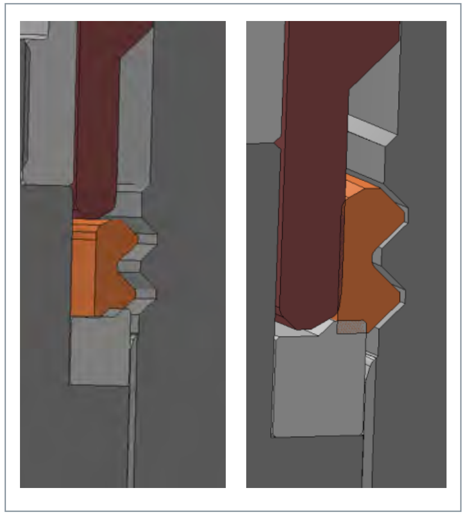


Figure 47: *How split lock ring is supposed to engage into grooves. [6]*

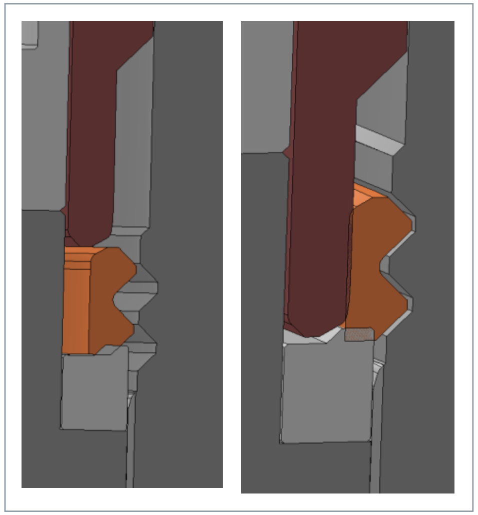


Figure 48: *Split lock ring in originally wrong position, being guided into right position in groove during lock down. [6]*

If the TH is positioned even higher up than in figure 48, there might be a problem. If split lock ring engage into spool with upper tap above the upper groove, the split lock ring will engage into wrong area of spool. This is illustrated on the next page. A too low vertical position of TH is not possible, as it will be physically stopped by the spool. Thus it is only a risk of TH landing too high up in XT.

For the two examples of split lock ring position before lock down shown in figure 49, the split lock ring will probably engage into the area of spool directly opposite the split lock ring. If that is the case one will find out about the lock down failure during over pull test, since the split lock ring has not been able to emerge into the spool.

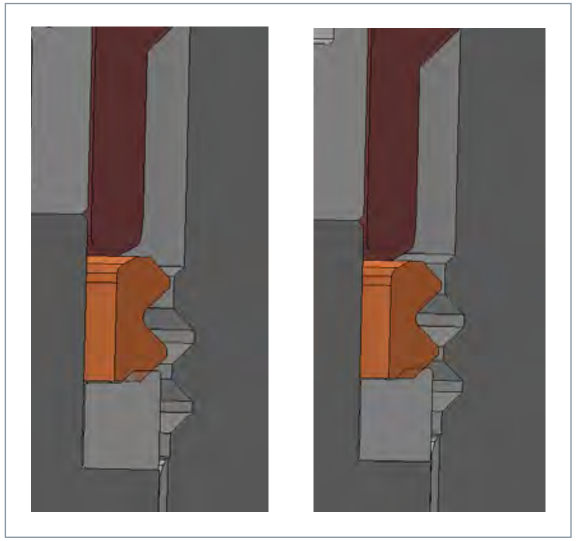


Figure 49: *Two examples of TH and split lock ring located too high up. [6]*

If the split lock ring is positioned even higher up, the lower tap will emerge into the upper groove. This has actually occurred during an installation earlier. Detailed description of that can be found in appendix B, section B.3. An illustration of how split lock ring will emerge into spool is given in figure 50.

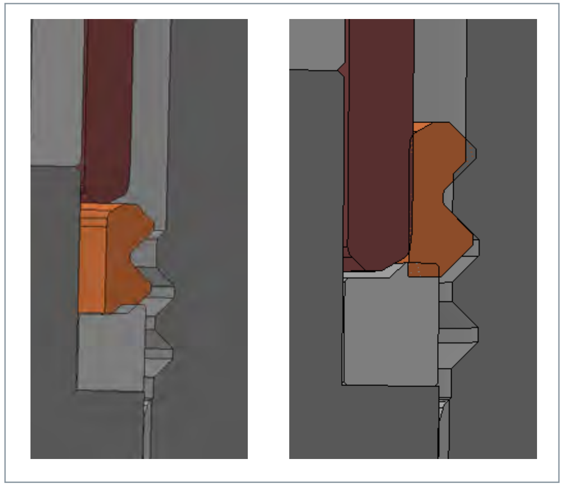


Figure 50: *Split lock ring locking into wrong area of spool, due to TH positioned to high up before lock down. [6]*

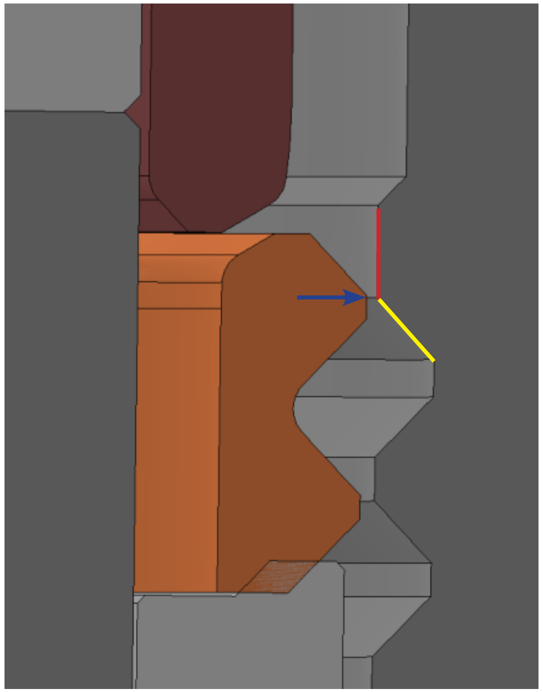
The result of split lock ring emerging into this position with lower tap emerged into upper groove can be quite bad. The split lock ring is actually locked to the spool, but in wrong position. This can result in a positive test result from over pull test.

The question I want to find the answer to now is:

- By how much can the TH be misaligned, without causing failure of lock down?

Figure 51 shows position of retracted split lock ring, for which it just might be in a low enough vertical position to engage correctly into spool.

In figure 52 I have found measurement from center of split lock ring and up to edge of split lock ring which has to engage into yellow area, and measurement from centre of groove and up to the point where the yellow line ends. The dfference of these two measuremets is the absolute maximum slack one can have for vertical position of TH and its split lock ring.



Comment:

Edge marked with blue arrow has to engage into area of groove which is marked with yellow line. If it hits area higher up marked with red line, it will engage into wrong area of spool.

Figure 51: *Highest point that split lock ring can engage into, without causing failure of lock down. [6]*

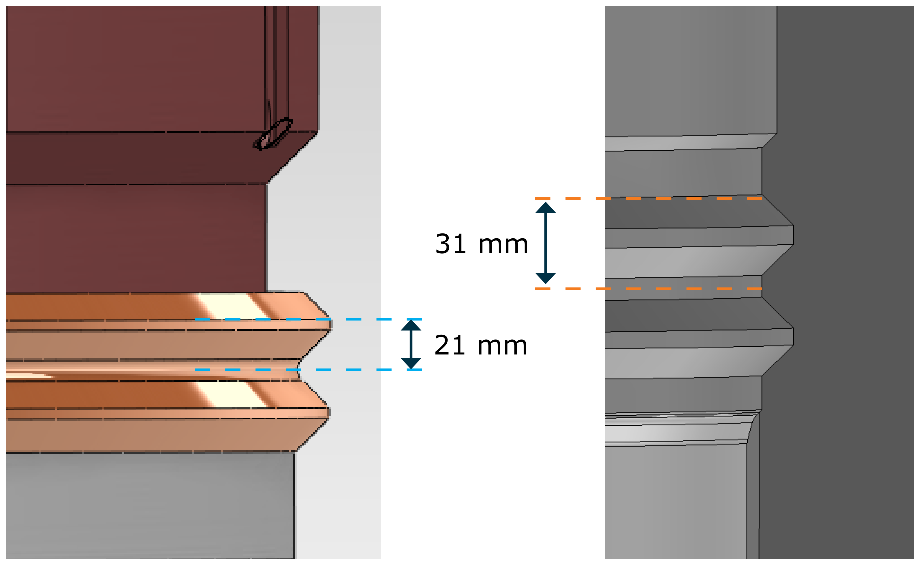


Figure 52: *Measurements for split lock ring and groove in XT spool, in order to calculate possible slack for vertical position of TH and split lock ring. [6]*

The absolute max slack is:
31 mm - 21 mm = 10 mm

If I choose a safety factor of about 2, allowed slack is:
(10 mm/2) = 5 mm

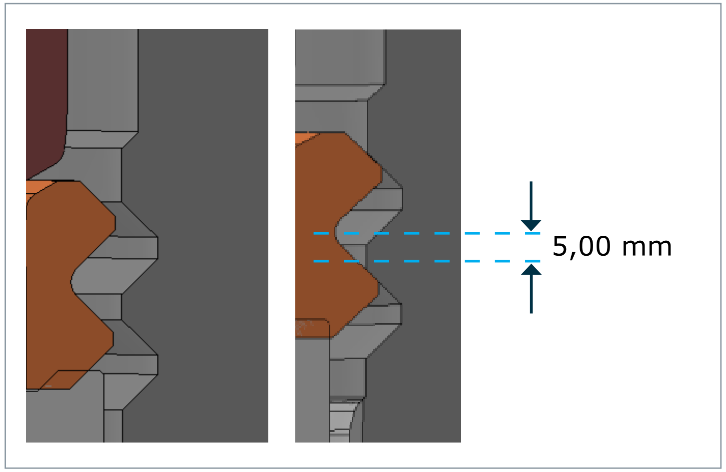


Figure 53: *Position of split lock ring relative to groove, when positioned 5mm out of vertical position. Picture to the left: split lock ring is retracted. Picture to the right: split lock ring is partially expanded. [6]*

Contact area between split lock ring and groove, as the surface of split lock ring meet the surface in groove is quite crucial. Thus I have made calculations to find out what the overlap length between split lock ring and groove is, when the ring is positioned 5mm up from its ideal position:
$\sqrt{(2 \cdot (5\ mm^2))} = 7{,}1\ mm$

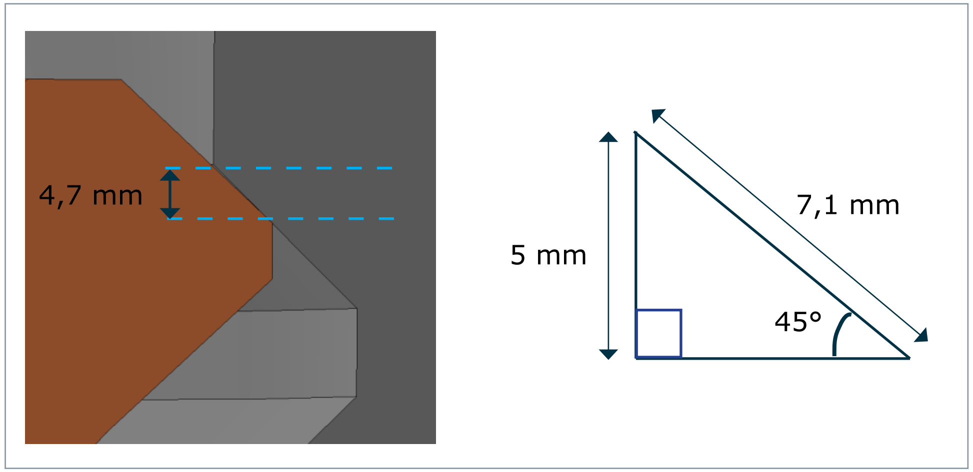


Figure 54: *Figures for calculating overlap length. [6]*

I would like to stress the fact that this is only a very brief aproximate of allowable slack. An overlap of 7,1 mm is not very much, and in my oppinion the split lock ring should not be allowed to be positioned any higher up during activation of lock down. It is preferred that is is positioned as close to ideal position as possible.

I will use as guidance that the verification system should have a slack for vertical alignment of maximum ± 5 mm. This value should only be used for concept development and evaluation, and not for construction of future lock down verification system.

Remaining precision requirements are for the verification systems providing information about:

3. When TH is locked to the XT spool.
7. When TH is unlocked from the XT spool.

The poppet valve should have a precision which secure that locking sleeves are run far enough down in order to activate the split lock ring to an acceptable locking position inside groove in spool. Thus the precision of poppet valve verification should give an indication of how precise a lock down verification must be for verification of when TH is locked to the XT spool.

As for the evaluation of required verification system precision of split lock ring`s position before lock down, I will make a brief estimation for how much slack the poppet valve allow for vertical position of locking sleeves.

The poppet valve is positioned in upper locking sleeve, which moves axially downward during lock down. The poppet valve is opened as the set screw meets THRT`s piston (see figure 55). Thus the allowed slack will be the remaining downward movement the locking sleeves have left, at the moment an upward force starts to act upon the set screw. This value can be found by subtracting distance a and c from distance b. See figure 55 for details.

Distance a = 94,0 mm, b = 104,8 mm, c = 6,8 mm
b - a - c = 104,8 mm - 94,0 mm - 6,8 mm = 4,0 mm

This means that the lock down verification used today; the poppet valve, is activated when the locking sleeves still have about 4 mm of axial downward movement left. This does not mean that the poppet valve is activated before the split lock ring is sufficiently engaged into groove in spool.

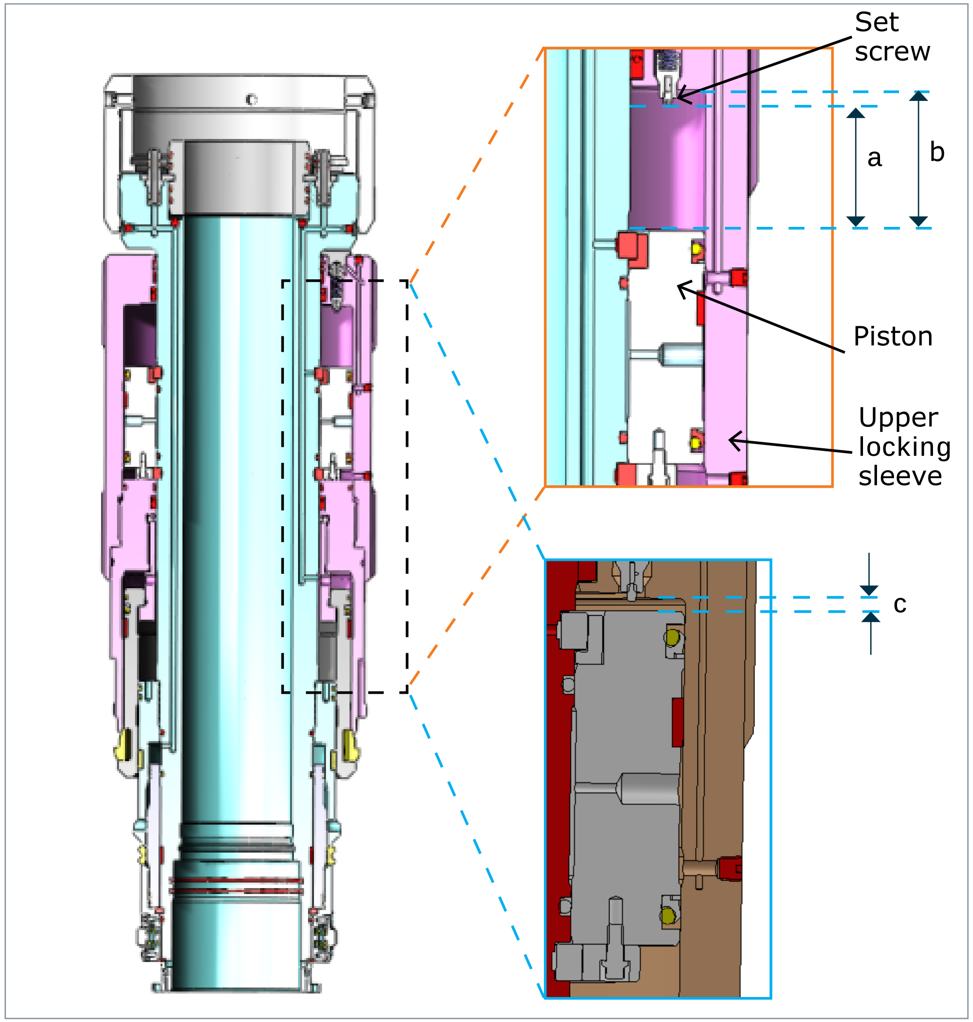


Figure 55: *Distance a is from lower tip of et screw to piston (which is in fixed vertical position relative to THRT body), b is distance between locking sleeve`s shoulder and piston before lock, while distance c is distance between upper locking sleeve shoulder and piston after lock down. [6]*

Due to the shape of the split lock ring and the actuation sleeve, the ring might be fully expanded before the actuator sleeve is fully run down in lock position. Height of the ring is 67,9 mm. Compared to the 4 mm remaining distance calculated above, the actuation sleeve has moved past:

(4,0 mm)/(67,9 mm)=0,127=5,9 %

100 % - 5,9 % = 94,1 % of the ring`s total height.

This is probably sufficient enough for the actuation sleeve to exert a radial force upon the ring and lock it into groove in spool.

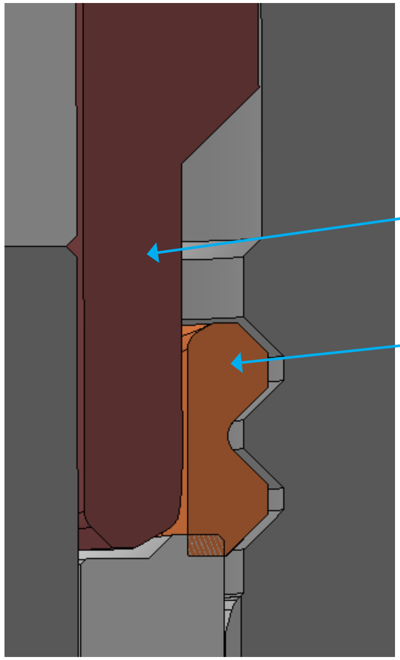


Figure 56: *Actuation sleeve and split lock ring in lock position. [6]*

Allowed slack for vertical position of locking sleeves and thus for which degree the split lock ring is engaged, will be related to how far the split lock ring needs to engage into groove in spool, for suffiecient lockdown. To find out exact measurements can be quite complicated. Allowable slack is also related to precision of component sizes within the XT system. It will require too much time to find exact values for allowable slack and thus required system precison for verification of lock down.

Thus I will not try to calculate exact values but use the poppet valve`s slack as a base, and make sure that verification systems for verifying when THRT`s locking sleeves are in lock position has a precision of at least ± 4,0 mm. Since locking sleeves push TH`s actuation sleeve in lock position, same precision will account for verification of Actuation Sleeve`s position. This value is only for use during my concept development, and concept evaluation. It is not to be used during construction of a final verification system.

Precision requirement for verification of:

4. When locking sleeves are in unlock position,

will be related to retrieval of TH due to e.g. required product maintenance of TH. One need to make sure that the verification is precise enough to prevent any damage on XT components during unlock and retrieval of TH.

For the split lock ring to retract into unlock position, the actuation sleeve has to move upwards by a distance greater than the ring`s height. This required movement is quite short compared to the total axial distance the actuation sleeve moves from lock to unlock position. As I have limited time to complete this project, I have decided to set requirement to precision for verification of when locking sleeves are in unlock position, to the same as that for verification of when locking sleeves are in lock position. Precision requirement for lock position should be more than sufficient enough, since lock position is more critical than unlock position.

Conclusion:

Table 6: *Overview of required system precision to verification system, for different types of verification information.*

Nr and type of verification information		Required precision to verification system
1	Vertical position of TH while run down into BOP stack.	Not specified
2	Vertical position of TH relative to XT spool before lock down.	± 5 mm
3	When TH is locked to the XT spool can be verified by position of THRT`s locking sleeves or TH`s actuation sleeve.	± 4 mm
4	Vertical position of TH relative to XT spool after lock down.	± 1.5 mm
5	Continuous verification of TH`s position until TH installation and tressure testing is complete.	± 1.5 mm
6	Continuous verification of TH lock down until TH installation and tressure testing is complete. This can be verified by position of THRT`s locking sleeves or TH`s actuation sleeve.	± 4 mm
7	When TH is unlocked from the XT spool can be verified by position of THRT`s locking sleeves or TH`s actuation sleeve.	± 4 mm

These values are only intended for use during concept development, since most of them are only vague approximations of actual required precision of future lock down verification system for TH installation. All content of table 6 will not be included in the basis of design, as some values are listed twice.

5. BASIS OF DESIGN

This Basis of Design is created in order to have clear goals for the concept development. The goals are set up as requirements that should be met, in order to end up with a verification method that function well, is safe and which meet the costumer`s and user`s expectations. Thus this section will handle the functional and technical requirements for a lock down verification system.

Since it was natural to include all installation steps related to TH installation to the HAZID analysis, I have also included some requirements for verification of the installation steps taking place in advance of the final locking of TH. As it was revealed through my analysis in the previous chapter that there already exist relatively good verification methods for the first TH installation steps, the requirements for verification of final installation steps related to the lock down have a higher level of priority.

5.1. Target Group

5.1.1. The Taskmaster

As explained in section 1.2.1, the task master for this project is Aker Solutions. This means that the concepts I develop have to meet their product requirements that typically apply for all their subsea production systems.

Aker Solution`s intension of giving me this task for my master thesis is that they want me to come up with innovative concept solutions that they haven’t though of themselves. Since I don`t have any experience from the subsea field from before, I will probably be able to think more freely than people who know the system well.

5.1.2. Customer/Client

The customers are the companies ordering projects from Aker Solutions. Their biggest customers are Statoil, Total and Eni.The positive lock down verification concepts I will develop are not ordered from any of Aker Solutions customers, but is a system improvement that Aker Solutions have decided that they would like to carry out. Thus I will only focus on Aker Solutions internal product requirements for subsea tools, and not on requirements and expectations that customers might have.

5.1.3. User

The once working offshore with installation of TH, are the users of the TH installation and verification system. I will make sure that offshore workers are included in the design process. They will have valuable product experiences that can help me on the way of developing strong concepts for TH lock down verification.

5.2. Product Aims

SAFETY
One of Aker Solutions main slogans is “safety first”. Safety will be in focus during my concept development. Aker Solutions would like to increase the safety of their system by developing a more reliant and secure verification system.

In order for the verification system to be safe, it also has to be:

Durable
Durability is an important aspect for a good verification method. The subsea system is stationed at the seabed for a long time period, and thus the verification system should have corresponding durability

Simple
Simple product solutions are often more reliant than more complex once, since less can go wrong. There is no need for creating a more complex solution than necessary, and thus I will try to develop concepts that are as simple as possible. Simple product solution will in most cases also lead to lower production costs.

5.3. List of Relevant Standards and Directives

All of Aker Solution`s product development is based on directives and standards. I have searched through standard and directive databases in order to find out which once are relevant for my project.

Table 7: *The most relevant standards and directives for subsea design and especially for concept development of a Lock Down Verification System for Tubing Hanger installation, are listed in this table with corresponding code, title and relevance for my master thesis. I have divided it into two standard themes; Design and HSE (Health, Safety and Environment).*

Type of std.	Code	Title		Relevance for my master thesis
DESIGN	ISO 13628-1	Petroleum and natural gas industries – Design and operation of subsea production systems.	Part 1: General requirements and recommendations.	Guidance for development of subsea production systems for gas and oil industries, and positive guidance for the selection of an optimum solution.
	ISO 13628-4		Part 4: Subsea wellhead and tree equipment.	Includes common system requirements and general design requirements for subsea trees and tubing hangers.
	ISO 13628-7		Part 7: Completion/workover riser systems.	Gives a description of the completion/workover riser systems and the tubing hanger orientation system.
	ISO 13628-8		Part 8: Remotely Operated Vehicle (ROV) interfaces on subsea production systems.	Provide recommended practices for the selection and use of ROV interfaces for installation, maintenance and inspection tasks on subsea equipment.

Table 7 continued:

Type of std.	Code	Title	Relevance for my master thesis
DESIGN	ISO 10423	Petroleum and natural gas industries – Drilling and production equipment - Wellhead and Christmas tree equipment.	Specifies requirements and gives recommendations for function, design, materials, testing, inspection, etc.
	2006/42/EC	Directive 2006/42/EC of the European parliament and the council of May 2006, on machinery, and amending Directive 95/16/EC.	The directive applies for all machinery, in addition to safety components and removable mechanical transmission devices.
	DNV-RP-O401	Safety and Reliability of Subsea Systems.	Guidelines that apply to the design, fabrication, transportation, installation, and maintenance of subsea production systems.
HSE	ISO 12100	Safety of machinery - General principles for design – Risk assessment and risk reduction.	Terminology, principles and a methodology for achieving safety in the design of machinery. Specifies principles of risk assessment and risk reduction.

I have looked and read through these standards in order to pick out the parts that are most applicable for this master thesis. The next sub-sections are primarily based upon those standards and directives. In addition I have used some internal information about earlier subsea projects and own experience from earlier product development projects. The requirements have been quality assured by my supervisor at Aker Solutions, Magnus F. Urke.

5.4. Relevant Environment

"All environmental phenomena which may impair the proper function of the system or cause a reduction of the system reliability should be considered." [7]

"Possibilities for electro-magnetic interference from external sources should be considered as well as vibrations, humidity, dust, saltmist and temperature that may influence sensitive instrumentation." [8]

Since it is quite challenging to come up with very specific environmental data for a conceptual verification system solutions that aim at future subsea projects that can vary a lot in characteristics, I have chosen a scope of the most central factors and given general/standard data to these.

The most relevant environmental data is given in table 8 on the next page.

Table 8: *This table gives an overview of the most important environmental factors that can have an effect upon a Positive Lock Down Verification System for Tubing Hanger Installation. I have listed different factors for three different key areas; topside, subsea, and inside Workover Riser System and TH.*

Relevant area	Environmental factor		Description		
Topside	Air temperature		Min: -25°C	Max: + 70°C	
Subsea	Seawater temperature		Min: -2°C	Normal: +4°C	Max: +12°C
	Water depth		Min range: 0-1.500 m	Max range: 0-3.000 m	
	Visibility	Inside TH and THRT	Mix of seawater and drilling mud/drilling fluid		
		Environment surrounding XT-installation	Normally good visibility but e.g. in the North Sea fishes like to stay around the XT, both since it is warm and since they get attracted to light beams from ROVs. This can reduce visibility a lot, since they block the ROV camera. In addition one can get reduced visibility of subsea installation if the ROV propels are run at too high speed. ROV propels are oriented downwards and the flow they induce can disturb the seabed and mix mud into the seawater.		
Inside Workover Riser System and TH	RWP (rated working pressure)		34,5 MPa (5 000 psi)/69 MPa (10 000 psi)/103,5 MPa (15 000 psi)		
	Temperature of production flow*		Min: -18°C	Max: +121°C	

NOTE: The max seawater temperature is mainly caused by the Golf stream, while the normal temperature is the temperature of water with highest specific weight. The rated working pressure is gauge pressure.

* *Temperature class u (ISO 10432)*

5.5. Operational Philosophy

The operational procedures for installing and testing of subsea products are to be as safe as possible.

In general:
"Subsea Production Systems should offer acceptable safety against loss of life or health, significant environmental pollution and major economic loss." [9]

"Whenever practical, Subsea Production Systems should be so designed that the effect of a single failure cannot develop into a situation that may cause loss of life or health, significant environmental pollution, and major economic loss." [10]

"The most probable failures, e.g. loss of power, failure in control systems, should result in the least critical of any possible new condition (fail to safety)." [11]

Control stand:
"There should be control from at least one stand. From this stand all normal control and production monitoring should be possible. The control stand should give the operator all required status information to allow for safe operation." [12]

"The control stand should indicate the expected system responses from operations executed. The feedback for this indication should be derived from a point appropriate to the criticality of the operation in question." [13]

5.6. Ranking of Key Product Requirements

***Table 9:** List of requirements for lock down verification system for Tubing Hanger installation. The requirements are measureable, so that it is possible to verify if they are met or not. I have given a specification on how important each requirement is, by grouping them into; can, should and must. For internal requirements that are also mentioned in ISO or DNV standard, I have made a reference with superscript, and the relevant information is given below the table.*

Type of requirement	ISO, DNV (std.) or internal (I)	Requirement	Degree of importance		
			Can	Should	Must
Function	I	Verify vertical position of TH while run down into BOP stack.	x		
		Verify position of TH relative to XT spool before lock down.[1, 2, 3]			x
		Verify when TH is locked to the XT spool. [4]			x
		Verify vertical position of TH relative to XT spool after lock down.[1, 2, 3]			x
		Provide continuous verification of TH`s position until TH installation and pressure testing is complete. [1, 2, 3, 4]		x	
		Provide continuous verification of TH lock down until TH installation and pressure testing is complete. [1, 2, 3, 4]		x	
		Verify when TH is unlocked from the XT spool. [4]		x	
	ISO 13628-1 5.5.2.3	The system should be designed for easy fault diagnosis without system retrieval.		x	
System safety	I	Low risk of damage on lock down system as well as adjacent components.			x
HSE/ Ergonomics	I	Easy interaction between operator and verification system; Verification information received by the operator is to be so clear that it is very low chances of misinterpretation.			x
		Verification method is to facilitate/enable the provision of "safe operation procedures" 5 for future TH installation procedures.			x

Table 9 continued:

<table>
<tr><th rowspan="2">Type of requirement</th><th rowspan="2">ISO, DNV (std.) or internal (I)</th><th rowspan="2" colspan="2">Requirement</th><th colspan="3">Degree of importance</th></tr>
<tr><th>Can</th><th>Should</th><th>Must</th></tr>
<tr><td rowspan="10">Technical</td><td rowspan="10">I</td><td colspan="2">Verification information is to be sent to the operator located topside.</td><td></td><td></td><td>x</td></tr>
<tr><td colspan="2">Clear verification information of TH installation (easy to interpret).</td><td></td><td>x</td><td></td></tr>
<tr><td colspan="2">Store TH installation data; e.g. time and vertical position.</td><td></td><td>x</td><td></td></tr>
<tr><td rowspan="4">Limit time period used on performing verification procedures</td><td>If verification system requires installation of e.g. umbilical that has to be clamped onto land string, the time consumed on required preparations should be limited, in order to limit the total time used on rig.</td><td></td><td>x</td><td></td></tr>
<tr><td>Each verification procedure performed is to provide information of significant value, either on its own or in combination with other verification systems, which increases safety of TH installation.</td><td></td><td></td><td>x</td></tr>
<tr><td>Compared to the increased safety of TH installation, future verification procedures should not be more time consuming compared to today`s procedures. Preferably less time consuming compared to today`s procedures. (Lock down verification takes about 2h.)</td><td></td><td>x</td><td></td></tr>
<tr><td>Low response time for verification feedback.</td><td></td><td>x</td><td></td></tr>
<tr><td colspan="2">Suited for subsea installations and subsea environment.</td><td></td><td></td><td>x</td></tr>
<tr><td colspan="2">Prioritise the use technology that has been approved from before, also preferably for subsea installations.</td><td>x</td><td></td><td></td></tr>
<tr><td colspan="2">Prioritise technical systems components with high reliability.</td><td></td><td></td><td>x</td></tr>
</table>

Table 9 continued:

Type of requirement	ISO, DNV (std.) or internal (I)	Requirement		Degree of importance		
				Can	Should	Must
Technical	ISO 13628-1	If an ROV is to be used, the capabilities and the type of ROV should be considered. Special ROV concerns include:	Access.		x	
			Docking/reaction points.		x	
			Required mechanical or hydraulic power.		x	
			Load carrying capacity of the ROV.		x	
			Design of special service tools.		x	
			Type of ROV deployment system (tether management system; cage deployment system or surface deployed).		x	
Precision	I	Vertical alignment of TH before lock down; precision of ±5 mm				x
		Imply when locking sleeves and/or activation sleeve are in lock position; precision of ±4 mm				x
		Vertical alignment of TH after lock down; precision of ±1.5 mm				x
		Imply when locking sleeves and/or activation sleeve are in unlock position; precision of ±4 mm				x
Reliability	I	Low risk of malfunction; Any possible malfunction is not to result in any severe impacts; For every hazard related to verification procedures there is to be a back-up procedure.			x	
Simplicity	I	The verification system is not to be more complex than necessary. Thus simpler solution is preferred if two verification concepts are equally precise and reliable.			x	

Table 9 continued:

Type of requirement	ISO, DNV (std.) or internal (I)	Requirement	Degree of importance		
			Can	Should	Must
Durability & serviceability	I	Low wear on subsea system during use.			x
		Bear max rated working pressure (RWP) 103,5 MPa (15 000 psi).			x
		Meet same temperature requirements as mating and surrounding components.			x
		Life span according to required life span of component(s) which the verification system is implemented in, for permanent installations.			x
		For verification system inserted in tool, the system should not require more frequent maintenance of tool, but adjust to the tool`s refurbishment cycle.		x	
		System is to be maintainable.			x
		Possibility of replacing wear parts in the verification system. (Not subsea)			x
		Good accessibility for inspection, testing and maintenance of system. [5]		x	
Environment	I	The system should not cause any leakage of environmental hazards.			x
		System solutions causing harmful radiation is to be avoided.			x

Table 9 continued:

Type of requirement	ISO, DNV (std.) or internal (I)	Requirement	Degree of importance		
			Can	Should	Must
Economics	I	Not result in comprehensive changes of today`s design.		x	
		Costs related to implementation of verification system to the product design are not to be too high, and should be reflected in the increased safety obtained by integrating the system. Thus cost level should be balanced with benefits the system provides. (A Benefit can be lower amounts of subsea products being damaged during TH installations.)		x	
		A high cost-low risk verification system is preferred over a low cost-high risk verification system, as safety is to be increased.		x	

References to the internal requirements:

(1) ISO 13628-1; Orientation, if required, relative to a given datum for corresponding interface with the tree

(2) ISO 13628-1, 5.5.2.17; The subsea production system should have position indicators for all subsea-operated connections.

(3) ISO 13628-1; Location of TH (in wellhead, in tubing spool or in XT).

(4) ISO 13628-1, 5.5.2.16; The subsea production system should include means of determining the fully open and closed positions for equipment, such as valves and connectors, etc., that may cause damage or be damaged due to wrong/unknown position when performing an operation.

(5) DNV-RP-O401, 2.1.2.1: The layout of the Subsea Production System should ensure accessibility for; (This may include space for access by divers, remote operated vehicles or special dedicated tools.) safe operation, maintenance, inspection and testing.

6. CONCEPT GENERATION

6.1. Brainstorming, Alternative Verification Technology

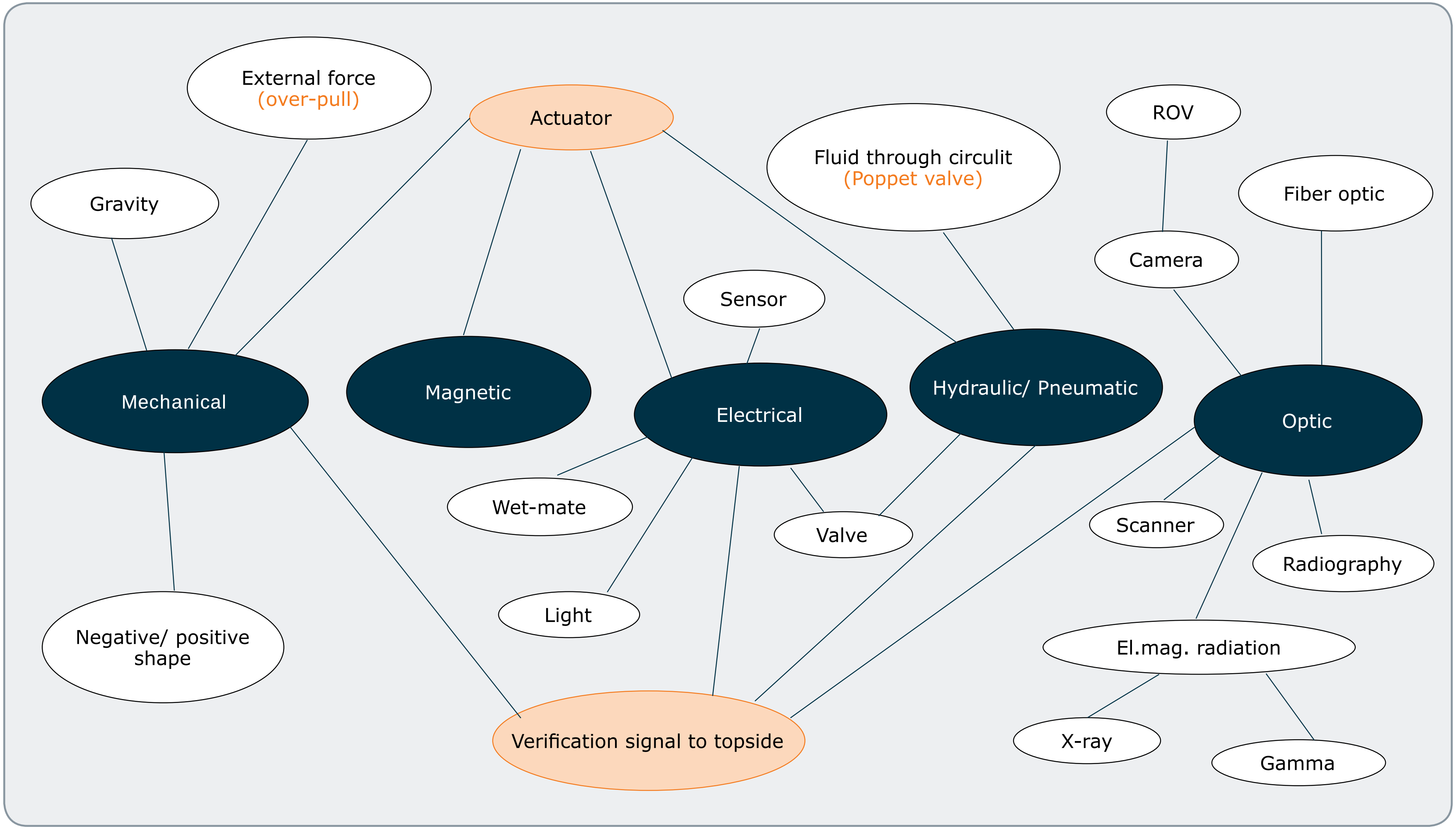


Figure 57: *This is a brainstorming I carried out in order to get a quick overview of alternative technology to be used in a verification system. [5]*

6.2. Systematic Representation of Brainstorming with Verification Sequence and System Alternatives

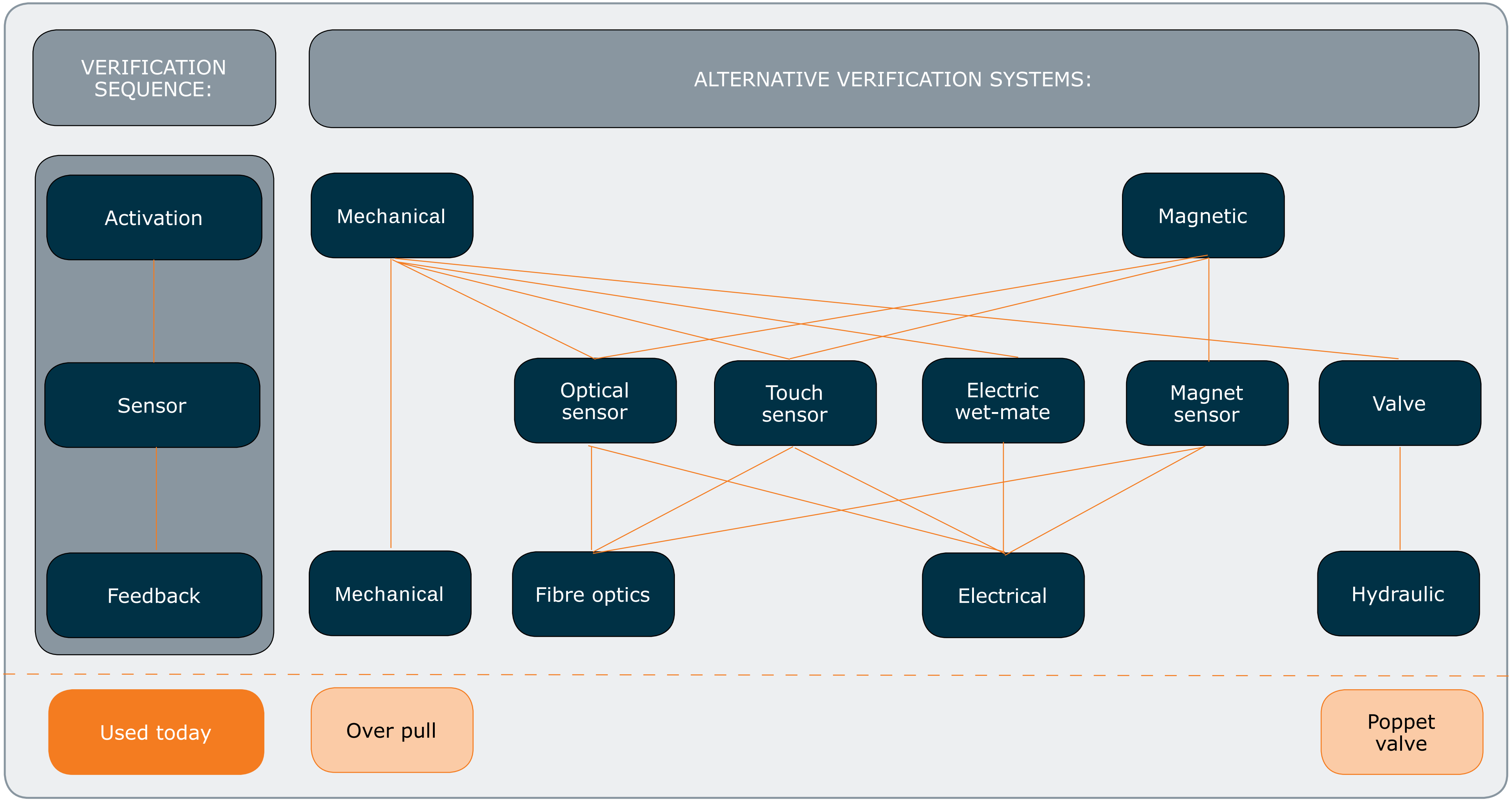


Figure 58: *A systematic presentation of different technology (dark blue boxes) that can be used in a verification system, and how these can be combined (orange lines) in order to form a complete verification system. The orange boxes position today`s verification methods in the overview of alternative verification systems. [5]*

6.2.1 Comments to figure 58

As mentioned earlier in this report the verification methods used today are over pull and poppet valve. The two verification systems are marked with orange boxes in the figure, and above the orange boxes, the activation-sensor-feedback sequences are illustrated with dark blue boxes and orange lines.

The over pull is a mechanical test procedure where one pull the TH up with a certain force, to see if it is fixed to the XT. Thus one applies a mechanical test activation force and gets a mechanical feedback. Either the TH is fixed and does not move, or it is actually loose and gets pulled upwards.

Today's lock down verification system consists of two hydraulic lines and a poppet valve, thus a pure hydraulic verification system. As illustrated in figure 58, the verification system is activated hydraulically, the poppet valve is used as a sensor, and the feedback is given hydraulically.

The remaining part of the diagram, consisting of dark blue boxes naming possible technology to be used in a verification system and orange lines connecting these together to form an activation-sensor-feedback sequence, provides an overview of alternative verification systems that can be applied for TH installation.

A few examples of verification systems from the figure:
One can create a verification system that is activated mechanically by e.g. a pin being pushed up as the TH has landed in right vertical height. An optical sensor can be used in order to detect the pin`s movement, e.g. with an optical laser sensor for which a laser beam gets cut when TH is in right vertical position. The sensor can be connected to electric line and fibre optics line which sends feedback to topside.

An optical sensor can also consist of e.g. mirrors and/or optical lenses which reflect a laser beam in a specific way. Another option is to use a small camera as an optical sensor. It`s also possible to use a touch sensor instead of an optical sensor.

A different verification system example is to use magnets as activation and either magnet senor, touch sensor or optical sensor connected to optic fibre line and electrical line. The electric line will provide power, while the optical line will send verification information to topside.

One can also have an electric verification system, with mechanical activation; electric wet mate as sensor, and electric circuit line for feedback. E.g. when TH is in right vertical position, the wet mate obtain connection by connectors being pushed mechanically into each other, and an electric signal will be able to pass through an electric circuit. This will in many ways be similar to the hydraulic verification circuit and poppet valve used today. After circuit is mechanically connected/opened, electricity/fluid flow will be able to travel through the circuit.

Figure weaknesses:
It is important to keep in mind that actual verification systems in some cases will be a bit more complex than the simple overview represented in figure 58. There might be an activation sequence and/or sensor sequence and/or feedback sequence related to the verification system, and not a single technology covering all of the activation, sensor or feedback part of the system.

An example for this is the optical system described above with the use of mirrors and/or optical lenses in addition to optical laser beam sensor. For this kind of system the sensor system will consist of at least 2-3 sub-sequences of verification steps. Another example is a magnetic activation system which will typically be related to either mechanical lowering of TH or hydraulic activation of lock/ latch. Thus in this case the activation part of the system should have had orange line connections to mechanical and hydraulic activation, and those boxed should have been positioned above the magnetic activation box.

Another weakness of the diagram overview is that a fibre optic line requires an electric power line as well, and that is not well illustrated by the figure, since it looks like one either use fibre optic or electric feedback technology.

If I would have tried to implement all of this into the figure, it would have become too complex. Thus I chose to focus on the main technology used for activation, sensoring and feedback.

6.3. Keywords

Below are some keywords that should be associated with the final verification concepts. I will put this diagram up on by board, to remind myself of these important characteristics through the project`s concept phase. It will help me to stay in focus, and to end up with strong concepts.

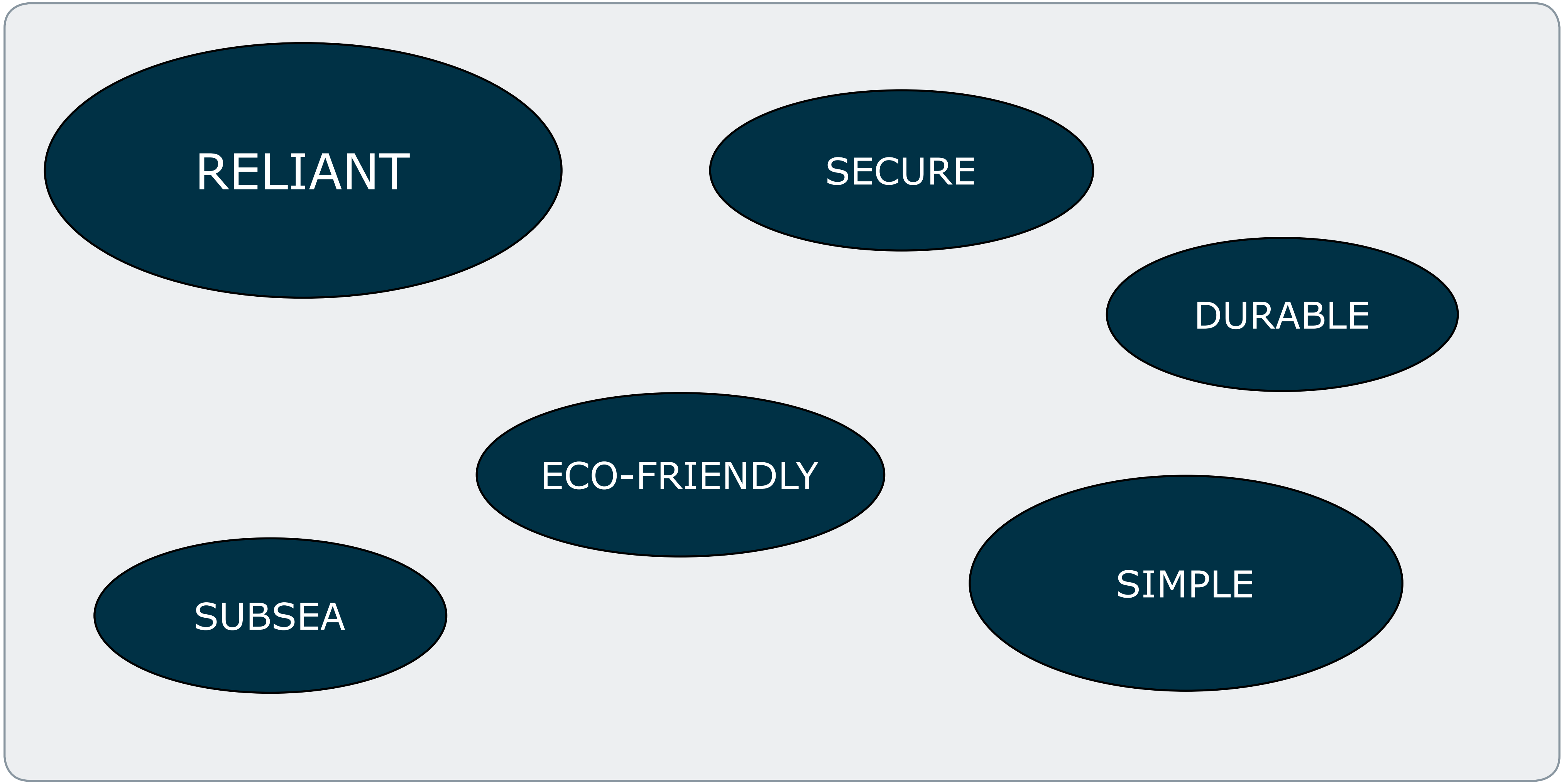


Figure 59: *Key words for lock down verification system. [5]*

6.4. Feed Through Technology on Today`s XT System

Hydraulic, electric and optic XT Feed Through systems will be a central part for my concept development of new verification systems for Lock Down verification. The only case in which a feed through system is not required is pure mechanical verification methods, e.g. the over pull test.

The XT system is monitored from topside through umbilical which provides electrical, hydraulic and chemical service lines. Tie-in system is used in order to connect Umbilical to different parts of a subsea production system. In addition to monitoring subsea equipment directly through umbilical connections, a ROV can be operated from topside, in order to carry out different system installations, maintenance and adjustments.

Since the lock down of TH take place subsea, while the operator is positioned on a rig, information needs to be sent form subsea to topside. The umbilical system which transfers electric signals and hydraulic control pressure during TH installation is connected to both the XT and THRT.

6.4.1. XT Assembly’s Feed Through System

The XT is connected to topside through Subsea Control Module (SCM). The umbilical connected to the SCM contains hydraulic and electric lines. The hydraulic lines are used to pressure test the XT production system prior production start.

The XT contains actuators which are connected to XT spool. These actuators transform electric input signal from topside into mechanical motion, which either can be used directly or to monitor hydraulic valves.

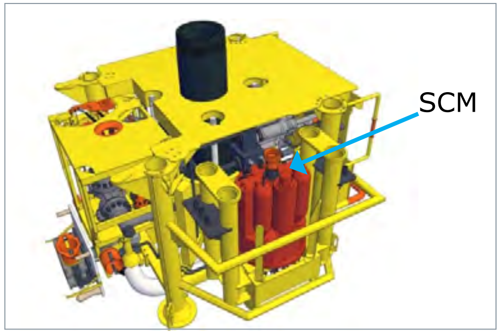


Figure 60: *XT with SCM. [2]*

6.4.2. THRT`s Feed Through System

As described in detail under chapter 4, the THRT contains five hydraulic lines. The lines are utilized in order to latch/unlatch THRT to TH, to lock/unlock THRT to XT spool and to run lockdown verification with poppet valve. The five hydraulic lines are the only feed through system connected to the THRT.

Figure 61 shows how the THRT is connected to WOCS (Workover/ Completion System), through a reel. Hydraulic power is controlled in WOCS, and is sent through reel unit and forwarded to the THRT`s hydraulic lines.

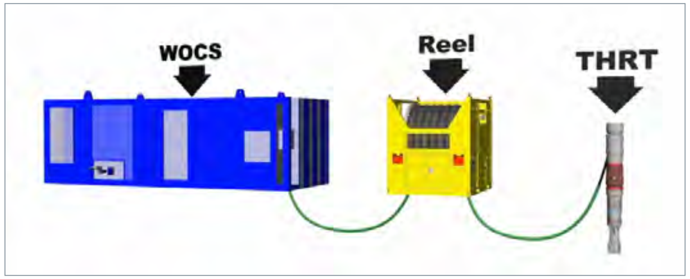


Figure 61: *Hydraulic connection from WOCS to THRT. [2]*

6.4.3. Hybrid Penetrator Feed Through System

The Hybrid Penetrator provides a feed through connection between the XT, TH and the in-well environment. This connection includes a electric line and hydraulic lines. Today there is no optical fibre line connected to the HP, but some optical fibre technology like e.g. pressure, temperature and flow sensors are connected to the electrical line.

There exist some vertical XT solutions delivered by other companies than Aker Solution, which include feed through with optical fibre lines in addition to regular electrical lines and hydraulic lines. For future XT solutions and VXT in particular, Aker Solutions are implementing optical fibre lines as well.

The HP is activated after installation of TH, when Hybrid Penetrator is engaged into the TH. This means that the feed through technology linked to the Hybrid Penetrator can`t be used directly for TH installation. If a new lock down verification system requires optical fibre technology, another connection than to the HP has to be implemented in the XT system, either through THRT or SCM.

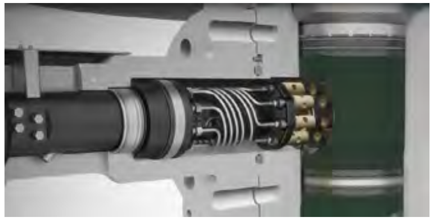


Figure 62: *Before HP engage into TH. [2]*

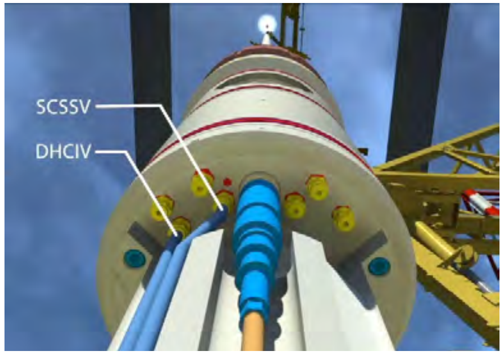


Figure 63: *The TH`s 7 hydraulic Down Hole (DH) lines and 1 optical fibre line for in-well sensor systems. SCSSV = Surface Controlled Sub-Surface Safety Valve, DHCIV = Down Hole Chemical Injection Valve. [2]*

6.4.4. ROV Feed Through System

The umbilical connecting ROV to vessel can contain electric, hydraulic and optical lines. Thus ROV can transmit video and data signals to topside. ROV is mainly used for operation of XT`s ROV panel, which allows it to e.g. open and close valves. ROV is also used in order to engage Hybrid Penetrator into Tubing Hanger.

For a new lock down verification system it might be relevant to use a ROV for communication to topside. If wireless feedback technology is installed inside the XT system, its signal can be received by a ROV positioned nearby, in order to limit distance for signal sending. Then the ROV can forward the signal to topside through its umbilical connection.

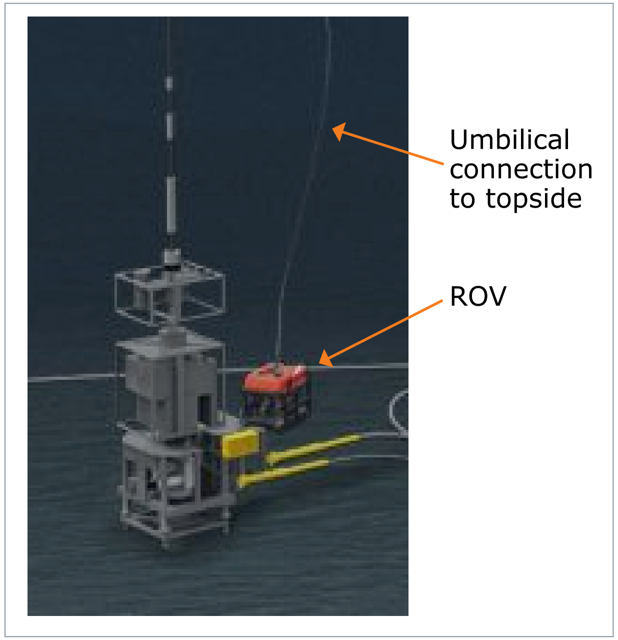


Figure 64: *ROV connected to topside with an umbilical. [3]*

6.5. New Feed Through and Verification Technology that can be Implemented into XT System

Today`s TH system is quite old, and has existed for about 20 years. At the time it was designed and produced, there was not an option to include electrical or optic fibre lines through the THRT, because there was no qualified technology for it. Thus today`s THRT only contains hydraulic lines, and no electric or optic system.

During the last 10-20 years, electronic and optic technology has developed a lot, especially optic fibre and sensor systems. The ROV utilize some optic technology in order to send video and data signals. The HP, SCM and THRT on the other hand does only contain hydraulic and electric lines, even though today`s technology opens for a lot of new product solutions.

Only minor design changes have been carried out for the THRT and TH system, during the last years. Seals have been improved to withstand environments of high pressure and temperature, and coatings have been improved.

In order to implement a new lock down verification system, it can be relevant to introduce some new technology to the subsea installation system. This will typically be optical fibre line connections between topside and THRT or topside and SCM. Sensor technology can also be of high relevance.

As mentioned earlier it might also be applicable to implement a wireless communication system. If meeting system requirements, a wireless communication system can lower the need for wire connections that might be difficult to implement in the XT system.

6.6. Early Concept Ideas

Before starting to develop concepts I carried out a technology analysis of existing technology, that can be used in a verification system. It can be found in appendix D.

This part of the concept phase is a pure creative process where "nothing" is impossible. I am thus open to all types of concept solutions, and do not include any critical assessment. The critical part of the concept phase will be included under the next chapter; "Own concept screening", where I will evaluate and compare all concepts, before choosing which once to develop further.

To start off I made some quick sketches. I tried to come up with as many concepts as possible and used figure 58 with schematic overview of alternative verification systems, the key words in figure 59 and the technology analysis as inspiration. Some of the illustrations are shown in figure 65, 66 and 67.

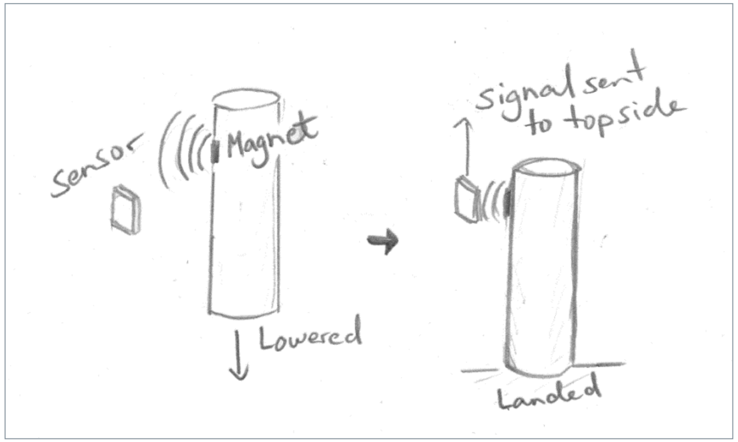


Figure 65: *Install magnet on one component and magnet sensor on another component. Signal sent when magnet gets close to sensor. [5]*

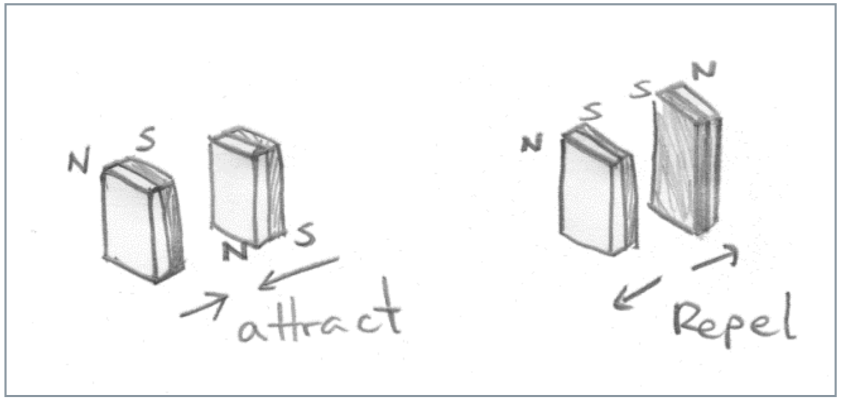


Figure 66: *Use magnets that attract or repel each other to activate verification signal. N= North pole of magnet, S = south pole of magnet. [5]*

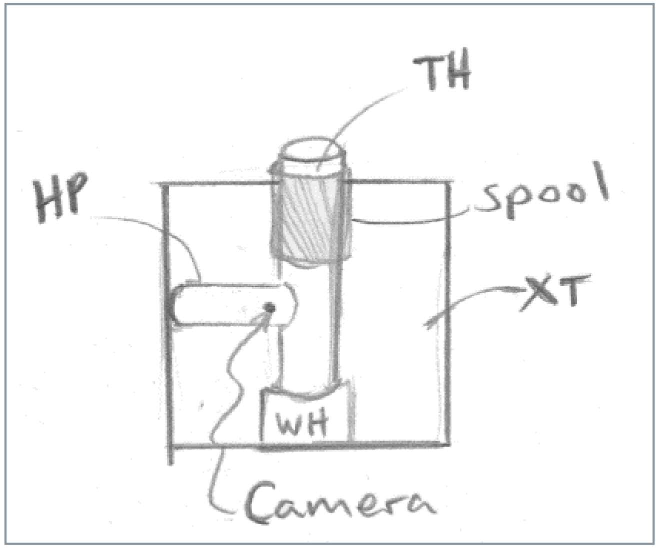


Figure 67: *Insert a camera in HP, that can check if TH is installed correctly. [5]*

The concepts on the following pages are both suggestions to amendments for today`s XT verification system, and examples of new technology that can be added to today`s XT system. The concept descriptions are quite general. The main reason for this is that I want to limit the time used on defining concepts that have obvious weaknesses when being compared to other concepts, in oder to have more time to develop the most promising concepts.

I have tried to make concept descriptions which are at an equal level of precision/detail, to prevent more defined concepts from having an advantage during the concept screening.

One factor I have chosen to not go in detail on is the exact position of technical components, within the XT assembly, TH or THRT. I wish to keep the concepts as general as possible, in order to not lock in on one specific system solution. Each verification concept might be possible to use in many alternative ways.

6.6.1. Concept 1, Improve Poppet Valve Design

It should be possible to improve today`s hydraulic lock down verification system; the poppet valve. If one manages to find the root of cause for its weaknesses and eliminate these, the poppet valve can become a reliable system for verification of fully stroked locking sleeves.

Apart from the poppet valve`s weaknesses of failure, it is a quite smart verification device:

- It utilizes a simple hydraulic line system.
- No expensive technology.
- Positioned at the highest point possible for verification of fully stroked locking sleeves (and fully activated split lock ring).

Thus it can be an option to keep the poppet valve, even though it has many hazards related to it today, if it is possible to increase its reliability.

Some design modifications are already being considered for the poppet valve. I was informed about this during an information meeting at Fornebu with Øyvind Skjold, 31.jan.2013. The agenda of the meeting was for me to get to know the TH installation process better and to find out about typical hazards related to TH installation.

The modifications being evaluated are:

- New coating, Xylan 1424 which can withstand more friction compared to the coating used today.
- Use flexible elastomer O-ring as seal instead of metal to metal seal.

After some further research I was informed that product development for improved poppet valve design is being carried out by some employees at Tranby. This is for another tool; ITC, Intervention Tool Carrier, for installation of subsea control module. The poppet valve in ITC and THRT are the same.

The improved poppet valve design has been modelled in SolidWorks, new components have been machined, and a new design solution is going to be tested in the workshop.

Figure 68 presents the weaknesses of today`s poppet valve design, that the new design for ITC poppet valve is supposed to resolve.

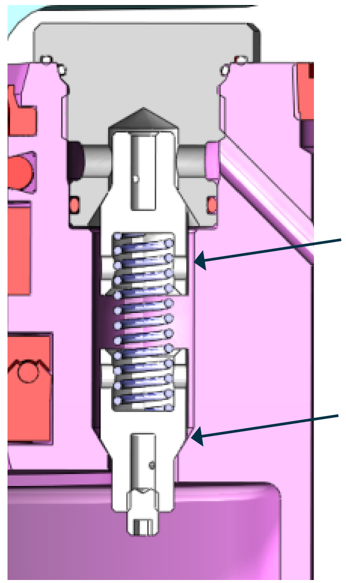


Figure 68: *Weaknesses of today`s poppet valve design. [6]*

6.6.2. Concept 2, Electric Wet-Mate

Electric wet-mate verification system which obtains electric connection at the moment an installation step is completed. This can be when TH lands in right position, or when locking sleeves are fully stroked. This type of system will require two electrical wet-mate lines installed within the XT assembly or THRT.

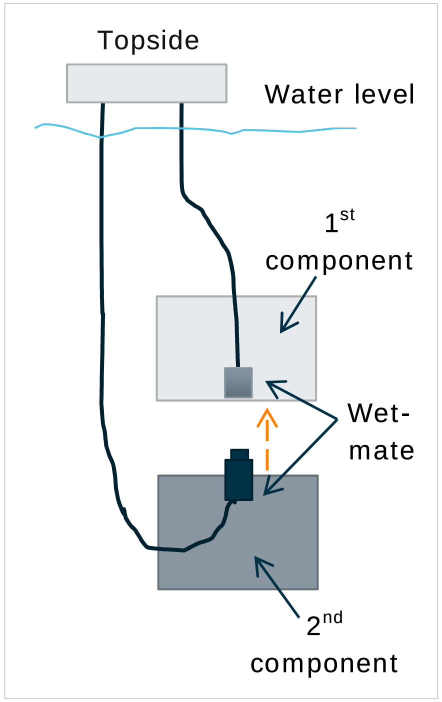


Figure 69: *Before installation step, the wet-mate is disconnected. [5]*

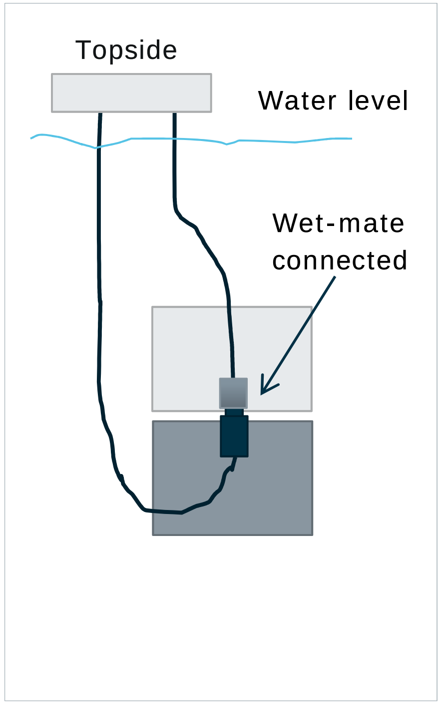


Figure 70: *After installation step is complete the wet-mate is connected. [5]*

As shown in figure 69 and 70, one of the electric connectors can be placed in one product component, while the other is placed in another product component which approaches the first one during an installation step. When the two product components meet, the connectors will mate, and an electrical circuit will be created. An electric signal sent from topside will then be able to travel subsea, through the electric connection, and back up to topside.

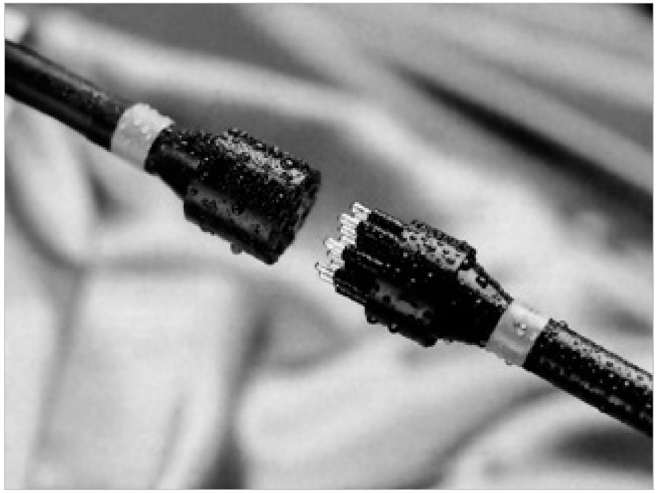


Figure 71*: Wet-mate [14]*

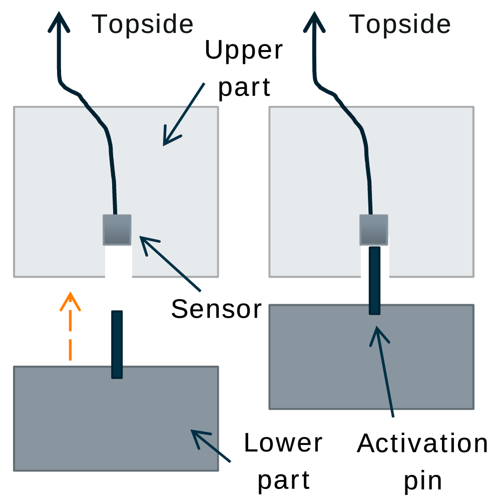
6.6.3. Concept 3, Touch Sensor

Encase sensors in XT system and/or THRT, which register complete installation step, and send a signal to topside. From the technology analysis, I have picked out two types of touch sensors I think are best suited for a verification of TH installation:

a) Mechanically based sensor
b) Piezo Touch Switch

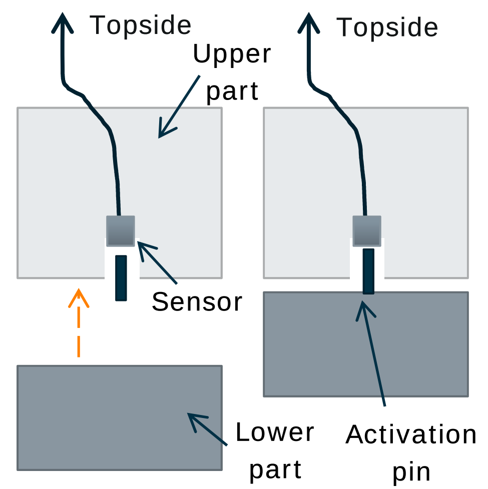
The main reason I see these sensor alternatives as the best once is that they can interact easily with metallic product components. In addition I do not think it is relevant to insert a sensor which registers the applied force, and these two touch sensor systems are on/off switches.

One possibility is to position the micro-switch or Piezo switch in the THRT at a location similar to that of today`s poppet valve, but there are probably other alternative locations as well. In figure 72 and 73, I have illustrated two alternative ways of setting up the system, with an explanation for each. The two system examples have different activation methods. The orange arrow indicates direction of movement.



Upper part contains touch sensor and lower part contains a pin which works as an activator. The lower part approaches the upper one during an installation step, and by completion of the step, pin will hit sensor as shown in left hand illustration.

Figure 72: *Left picture before, right picture after. [5]*



In this case the pin is positioned in the upper part. Just like the retainer in poppet valve is pushed up, the pin is pushed up by the lower part, and hits the sensor at completion of installation step, as shown in left hand illustration.

Figure 73: *Left picture before, right picture after. [5]*

6.6.4. Concept 4, Induce Current with Magnet

This concept is a verification system consisting of a coil with connection to topside, and a magnet that will move when a force acts upon it. The concept is best suited for verification of movement of latch piston and locking sleeves. If a magnet positioned inside a coil of conductive material moves, a current will be induced in the coil, due to changing magnetic flux. When magnet is at rest, there will be no current.

As illustrated by figure 74 and 75, a magnetic rod can either be placed in the same component as the coil and move when subjected to a force by an adjacent component, or it can be attached to and move together with an adjacent component This is in many ways similar to the two alternative positions of the pin in concept 3.

The technical solution of this concept consists of the same components as a solenoid actuator but it works in the opposite way. Instead of sending an electric current to apply a force on the magnet and make it move, a force is applied on the magnet in order to induce a current.

The magnetic rod is the activator, while the coiled motor wire works as a sensor. When the magnetic rod moves inside the coiled wire, an electric current will be induced in the coil, and this current will be registered by an operator on topside.

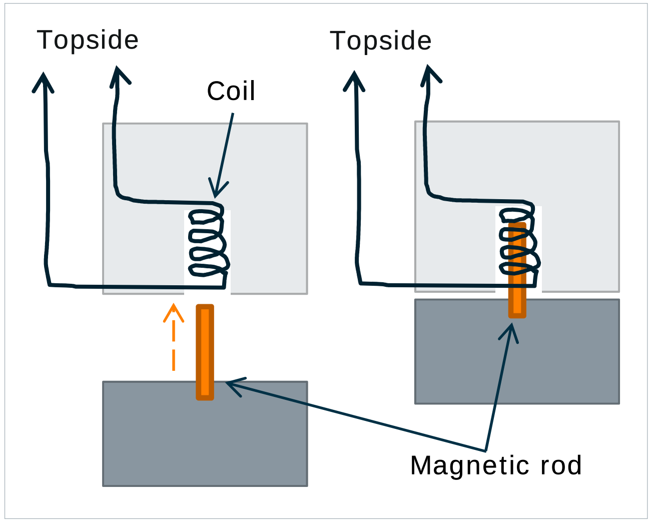


Figure 74: *Left side deactivated, right side activated. [5]*

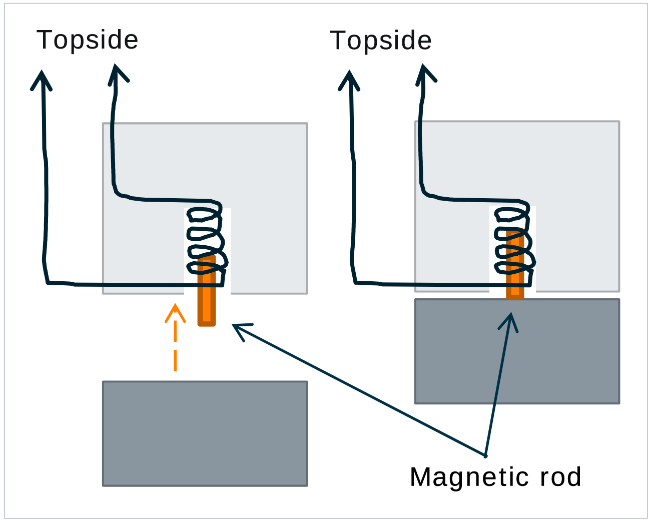


Figure 75: *Left side deactivated, right side activated. [5]*

6.6.5. Concept 5, Electro-Optical Sensor

For this concept the verification system consists of a laser light emitter, a reflector, a laser light detector, optic lines, electric lines and an object blocking/unblocking the laser light beam.

In deactivated position the emitter emits a laser beam, next it is reflected by the reflector before it hits the detector. In activated position an object will move due to an installation step being carried out and end up blocking the laser beam. Thus the laser beam never hits the reflector, and the detector will not receive any light beam. The detector will react to the change in light, and send an electronic signal to topside.

This verification concept can both be applied for verification of an objects position as it is gradually run subsea and for verification of installation step completion. When a signal is received at topside, the operator will know that the laser light beam has been blocked.

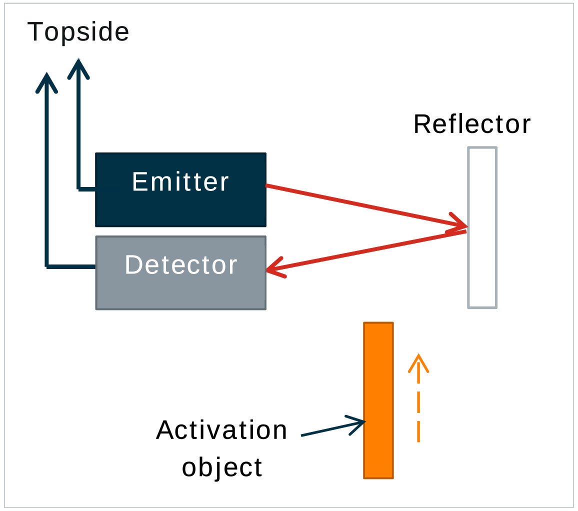


Figure 76: *Not activated. [5]*

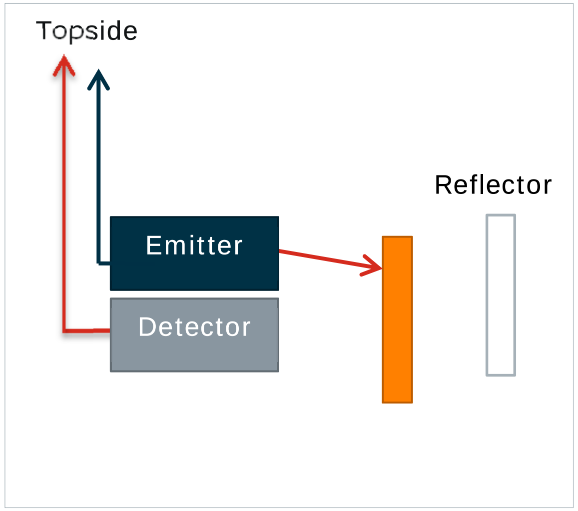


Figure 77: *Activated, verification signal sent to topside. [5]*

6.6.6. Concept 6, Proximity Sensor and Proximity Switch

Proximity switch or proximity sensor will be inserted into a product component in e.g. XT spool, THRT or TH. The sensor/switch will detect movement of another product component within the XT/THRT system.

There exists proximity switches/sensors suited for installation subsea. Thus as long as it is enough space for switch/sensor and connection lines for electrical circuit, it should be possible to insert this type of verification system for TH installation.

a) Proximity Switch

A proximity switch uses magnets, either in attraction or repulsion, to open or close an electrical circuit. This means that the object which is to be detected needs to contain a magnet or be magnetic. See figure 78.

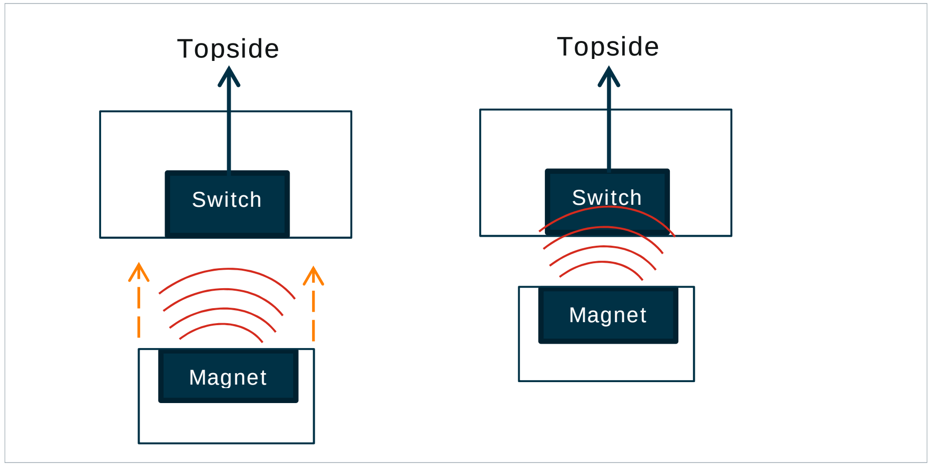


Figure 78: *Proximity switch. To the left the switch is deactivated. To the right an object containing magnet has approached the switch, which will detect the magnet and open or close electrical circuit connected to topside. [5]*

b) Proximity Sensor

A proximity sensor will emit an electromagnetic field or a beam of electromagnetic radiation, and look for change/ disturbance in field or return signal. The object being sensed can be referred to as the proximity sensor's target.

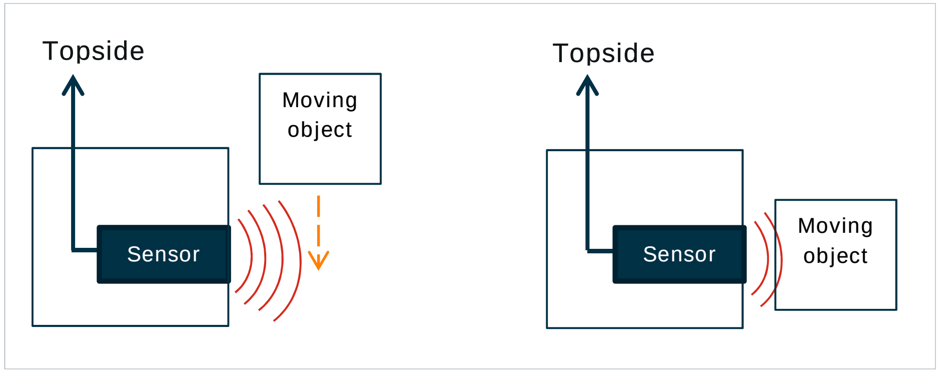


Figure 79: *Proximity sensor. To the left the target is out of the sensors reach. To the right the target will be detected by sensor since it is disturbing its magnetic field. Signal is then sent by sensor through electrical line to topside. [5]*

6.6.7. Concept 7, Wireless Communication

In some cases it can be difficult to implement electrical lines inside XT-assembly, TH or THRT. There is limited space available in the product components and in the TH and THRT, the components are also moving relative to each other during TH installation.

The solution for this can be to include a wireless communication unit to the verification system. Instead of having an electrical wire connection to topside, a battery will provide needed energy to technical verification components. The verification components positioned inside XT-assembly, TH or THRT can send verification signal to e.g. a unit like the one shown in figure 80, or a ROV which will forward the verification signal to topside.

I did some search on wireless subsea communication system, and found out that the firm Sonardyne has a product called BLUESOMM, which is a through-water wireless optical communication system. It can transfer high bandwidth sensor data and real-time video imagery. The product is shown in figure 80 and 81. Figure 82 and 83 are two alternative wireless systems. The one in figure 82 only provide wireless communication between verification components in XT and ROV, while system in figure 83 has wireless communication also between subsea unit and topside.

Figure 80: *BLUESOMM subsea unit. [15]*

Figure 81: *BLUESOMM unit on topside. [15]*

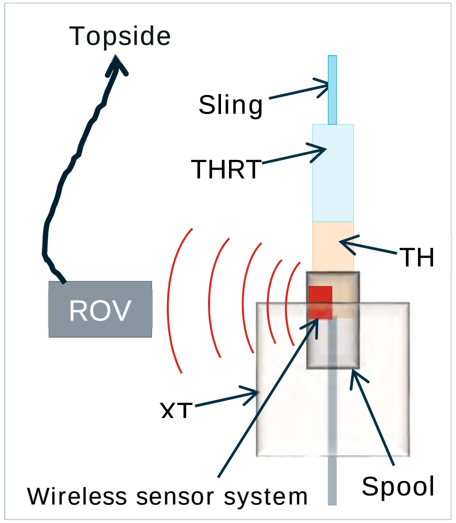


Figure 82: *Wireless signal to ROV unit. [5]*

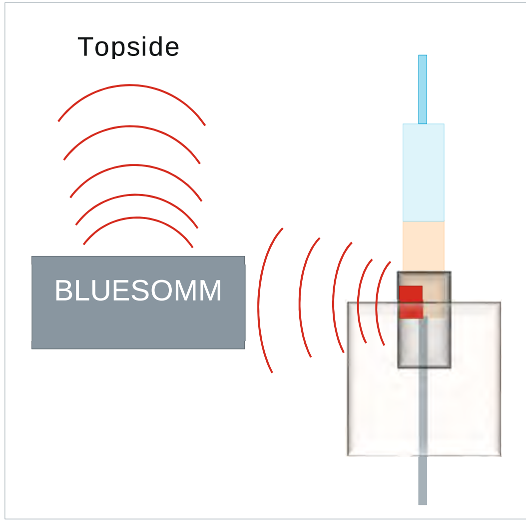


Figure 83: *Wireless signal to BLUESOMM & topside. [5]*

6.6.8. Concept 8, Radiography

The principle of this concept is to use a ROV with integrated optical e.g. x-ray (radioisotope) image system that can scan through subsea components and see if TH is in right position.

I did some research to find out if a product like this already exists. What I found out is that it exists a product solution for computed radiography deployed by a subsea remotely operated vehicle (ROV).

Figure 85 shows an X-ray picture of copper cables, while figure 84 shows the ROV with attached equipment. The ROV is scanning an umbilical, and the box that encases the umbilical creates a gas filled volume.

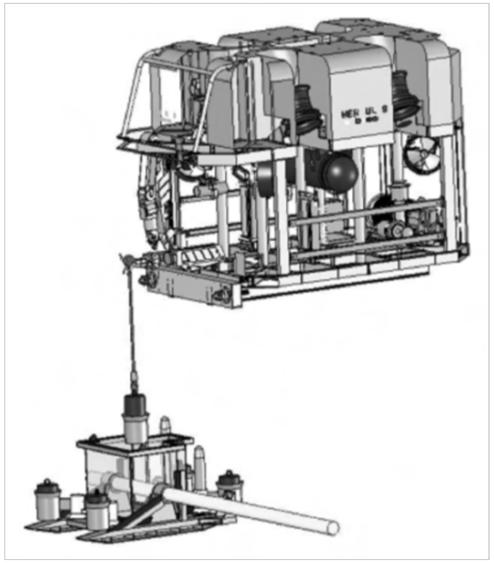


Figure 84: *ROV performing x-ray scan of umbilical. [16]*

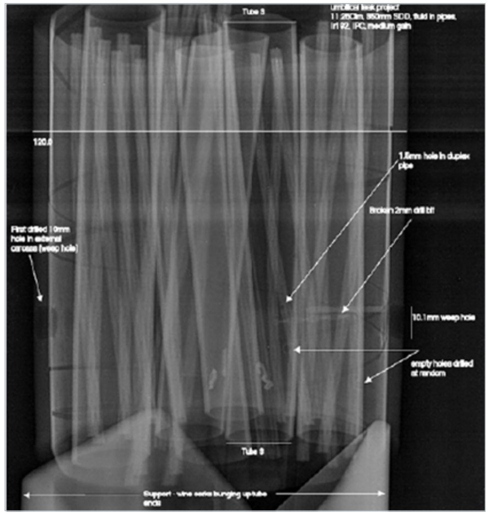


Figure 85: *X-ray picture of copper cables. [16]*

6.6.9. Concept 9, Verification System for Hybrid Penetrator

The main idea of this concept is to insert a verification system on the Hybrid Penetrator (HP) or in the gallery area where HP connects to the TH. In this way one can check if "the coast is clear" for the HP, before the HP is engaged into the TH. In this way one will prevent potential damage of HP and TH.

I am considering two different types of solutions:

a) Mechanical system
b) Small camera

a) Mechanical Verification System:

Mechanical systems are often more reliable compared to electrical or hydraulic once. A hydraulic line can leak and an electric line can lose power flow. A verification method that can be used is to insert an object which is positioned closer to the gallery area compared to the HP, which will stop HP from engaging if the TH is in wrong position. A possible design for this type of system is shown in figure 86.

The verification object here consists of a hollow disc with three pins. If TH is in right position, pins will slide into opposite cavity holes in TH connection area, as the HP is pushed towards the TH. In opposite case, the pins will not be able to engage into the holes. Instead they will hit a solid material surface, and prevent the HP from being engaged into wrong area of TH. The marginal size difference of the pins and cavity holes can be adjusted to meet the precision requirements of XT system installation.

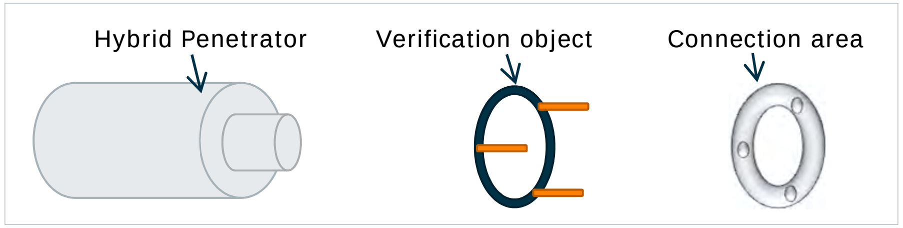


Figure 86: The main components related to the verification system. [5]

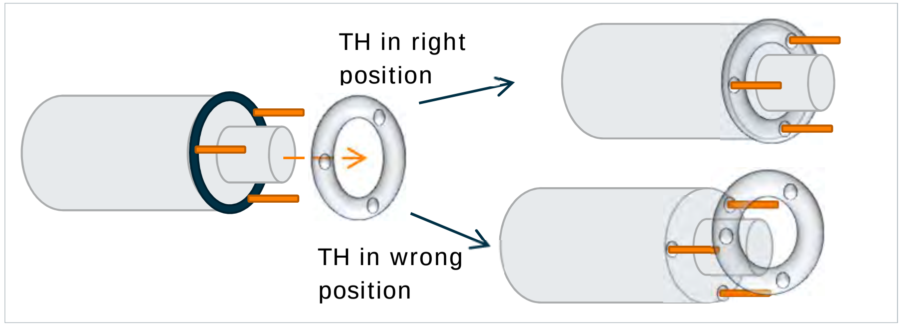


Figure 87: *The two possible verification results. [5]*

b) Verification System with Camera

Attach a small subsea camera to the Hybrid Penetrator that can verify if TH is in right position. The camera will be connected to fibre optic line, which can be connected to Subsea Control Module (SCM) or ROV with umbilical connection to topside or wireless feed through system.

For the operator to verify if TH is in right position or not, some marks will be made on both XT spool/HP and TH. These marks will combine to form a specific pattern/shape when TH is in correct position inside XT. If the marks do not form the required shape, the operator will know that the TH is in wrong position.

In figure 90 I have made a couple of alternatives to different types of marking that can be applied, and how these markings can form a specific pattern for verification of TH installation.

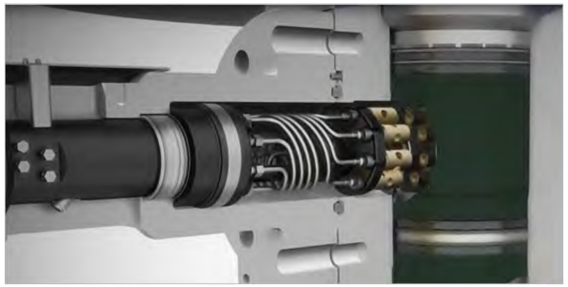


Figure 88: *HP before engaged into TH. [2]*

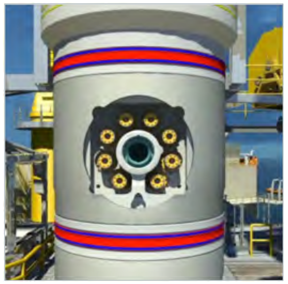


Figure 89: *Connection area for HP on TH. [2]*

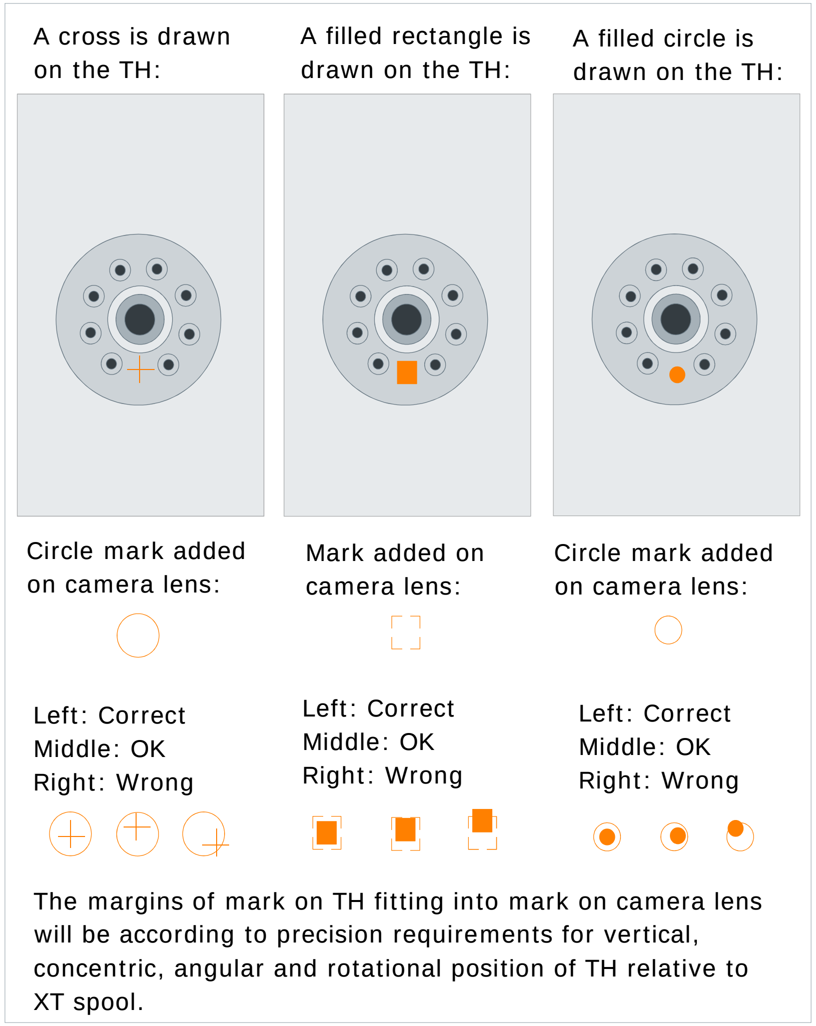


Figure 90: *Examples of geometric figures that can be used for verification. [5]*

6.6.10. Concept 10, GPS Device

While creating table 5 with overview of today`s verification methods for TH installation, I got to know from an employee at Aker Solution working offshore that they sometimes use a chalk crayon and yard stick to measure the last vertical movement of TH down into spool, which should be about 150 mm.

I think this should be put up as a standard procedure, since it is difficult to evaluate the rotation and vertical movement of the TH by only observing with the naked eye.

The calk pen method has an accuracy of ±1-5 cm. The inaccuracy is due to the long landing string system, accuracy of yard stick, and possible human error. One can improve the accuracy of this procedure, by applying a system which is less primitive.

The main idea of this concept is to place/stick a GPS device on the tubing on topside that measure/register rotation and translation movement of the landing string which moves relative to the TH`s movement inside XT spool.

Figure 91: *TH lowered down into spool`s helix. [6]*

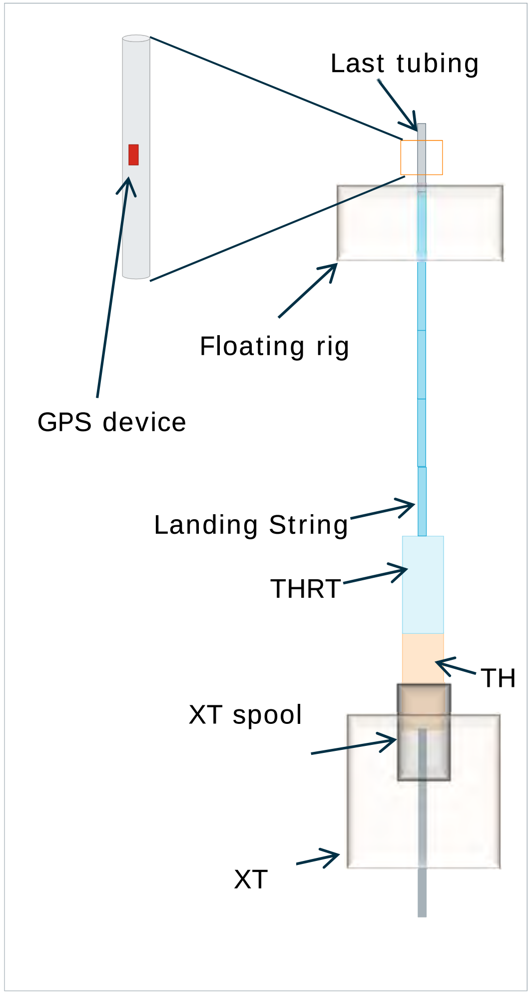


Figure 92: *Positioning of GPS device. [5]*

7. OWN CONCEPT SCREENING

7.1. Critical Assessment of Positive and Negative Concept Characteristics

Concept 1, Improve Poppet Valve Design

Since there are already some employees at Aker Solutions working with improvement of poppet valve design, I will not look in detail on this myself. But I will make sure I am informed about modifications taken to action, and possible test results. This kind of product development process can take some time, and might not be finished before I am done with my master. When the new poppet valve verification system design is ready, one can evaluate which verification systems should be a part of the future TH installation system.

Concept 2, Electric Wet-Mate

Positive:

- Only require one electrical circuit for the system to be complete
- Not expensive
- Suited for use in subsea installations

Negative:

- Can be difficult to assure that the two wet mate connectors are correctly aligned before merging into each other.
- One connector line must be installed in a moving part.

Concept 3, Touch Sensor

Positive:

- Micro-switch or Piezo switch can be positioned at a location similar to that of today`s poppet valve.
- No advanced technology.

Negative:

- Debris can get in between sensor and activation pin.
- Not sure if suited for subsea installation.
- Potential wear of electric switch when activated.

Concept 4, Induce Current with Magnet

Positive:

- Well known technology.
- Complete verification system for an installation step by just installing a solenoid actuator.

Negative:

- Not activated at a specific point, but as two components gradually move towards each other. Thus difficult to know the exact position of relevant TH components.
- Not sure if suited for installation subsea.

Concept 5, Electro-Optical Sensor

Positive:

- Can be used for verification of a component having passed/reached a specific location.

Negative:

- Problematic with laser beam due to mud mixed in the water.
- Difficult to adjust it in a way that the laser beam is blocked at the exact right moment as an installation step is complete.
- Might not be suited for subsea installations.

Concept 6, Proximity Sensor and Proximity Switch

Positive:

- Gives the opportunity of getting verification when two components are at a specific distance from each other, or within a specific range.
- No wear of verification components as they do not get in contact with each other.
- Suited for installation subsea.

Negative:

- Require more space compared to a touch switch.
- Proximity switch requires magnetizing of a component or insertion of a magnet in component.

Concept 7, Wireless Communication

Positive:

- This concept can be used for many different types of verification systems.
- No need for long electrical lines inside XT-assembly, TH or THRT.

Negative:

- Might have some reach limits for distance between sensor system and e.g. ROV unit.
- Might be a challenge to send signal through XT-assembly, TH or THRT.

Concept 8, Radiography

Negative:

- It will not be possible to carry x-ray scan on a XT system, since the XT and TH are both surrounded by and contain water.
- The x-ray system that exists today would not be able to scan through thick walls of steel.
- When taking into account the environmental aspect of x-ray scanning, it is not an option for Aker Solutions to use this type of subsea technology because it exposes the subsea environment for a lot of harmful radiation.

Concept 9a, Mechanical Verification System on HP

Positive:

- o A mechanical verification solution has few potential hazards compared the other verification concepts.
- o Ensures that HP does not get destroyed if TH is placed in wrong position.
- o Can verify vertical, rotational and angular alignment of TH inside XT spool.

Negative:

- Cannot verify concentric alignment of TH and spool.

Concept 9b, HP Verification System with Camera

Positive:

- o Can easily be designed according to precision requirements.
- o Can verify vertical, rotational, angular and concentric alignment of TH inside XT spool.

Negative:

- Camera must meet same system requirements as the rest of the HP.
- Must meet requirements for more permanent product component, than for tool equipment with shorter lifetime.
- Very limited space in gallery area.

Concept 10, GPS System Device

Positive:

- o Provide the operators with a new verification procedure that is easy to use, and which can spare them some time.
- o More exact measurements compared to today`s methods of observing with the naked eye or using chalk crayon and yard stick.

Negative:

- Do not know how yet how accurate readings one will be able to obtain out on offshore base.

7.2. Criteria Basis for Concept Screening

I have made two evaluation tables for own concept screening, to find out which concepts are the most promising once. This is done in order to narrow down the range of 10 concepts.

The first evaluation table is based on three of the keywords from figure 59; simple, eco-friendly and subsea. The verification concepts should not be more complex than necessary, they have to be suited for subsea installation and they should not cause harm upon subsea environment while being used. I have not included the other keywords in this screening since I think it is a bit too early to compare how reliant, secure and durable the verification concepts are. In order to do so I need technical product information from firms designing and manufacturing the different types of verification systems.

The second evaluation table is for evaluation of what kind of verification information each verification concept can provide. The different concepts will typically be suited for verification of different parts of the TH installation.

The four main criteria the two evaluation tables are based upon are:

- Simplicity
- Eco friendliness
- Suitability for installation subsea
- What kind of verification information each verification concept have the potential of providing.

The most important verification information the verification system should provide is:

- Vertical position of TH while run down into BOP stack.
- Position of TH relative to XT spool before lock down.
- When TH is locked to the XT spool.
- Vertical position of TH relative to XT spool after lock down.
- Continuous verification of TH`s position until TH installation and pressure testing is complete.
- Continuous verification of TH lock down until TH installation and pressure testing is complete.
- When TH is unlocked from the XT spool.

The verification information listed above is taken from the list of function requirements in Basis of Design. I have not included any other requirements from that table, since they are too specific for the very general concepts that are to be evaluated here. The more specific requirements will be included for evaluation of the further developed concepts.

7.3. Evaluation Tables

***Table 10**: An evaluation of how simple, eco-friendly and suited for subsea installation the early concept ideas are.*

All 10 concepts are listed in the first column. Ranking of simplicity: 1=complex, 2=slightly complex, 3=simple. Ranking of eco friendliness: 1=harmful to environment, 2=slightly harmful for environmentn3=no severe harm upon environment. Ranking of suitability for installation subsea: 1=Not very suited, 2=Not known or less suited, 3=well suited. Thus high score means a concept is strong, while low score means concept idea is relatively weak. In the last column I have calculated the sum of points for the three criteria. I have chosen to weight the three criterion equally.

Concept nr.	Simplicity	Eco friendliness	Suited for subsea	SUM
1	2	3	3	8
2	1	3	3	7
3	2	3	2	7
4	2	3	2	7
5	1	3	2	6
6	2	3	3	8
7	2	3	3	8
8	1	1	3	5
9a	3	3	3	9
9b	2	3	2	7
10	3	3	3	9

Comments to Table 10: Concept 5 got low score on simplicity. The reason for this is that it is more complex compared to e.g. concept 3 and 4, since it contains more electrical components and involves reflection of laser light. Concept 1 also got low score on simplicity as it requires integration of electrical line in two components, compared to concept 3 and 4 which only require integration of electrical line in one component. Concept 9a got full score on simplicity since it is a pure mechanical verification method, while concept 10 got full score on the same criteria since it requires no new design for XT-system or THRT. Concept 8 is the only concept with low score on eco friendliness. This concept did also get low score on simplicity since x-ray scanning is a quite complex technology.

When it comes to suitability for installation subsea, none got 1 as score. Most of the concepts with a score of 2 got its ranking since I do not know if they are suited or not. The concepts that got a high score for this criteria are the once with technology that I know have been used subsea before and pure mechanical solutions. Concept 10 got full score on "suited for subsea" since it does not need to meet this criteria, as it will be installed on topside.

The concepts with highest sum score are 9a and 10. They got full score on all three criteria.

***Table 11**: An evaluation of what kind of verification information each verification concept have the potential of providing. Type of verification information is listed as letters A-G, with reference to a description of each below the table. Points given for each type of verification information is according to priority/degree of importance in key product requirements table; can=1, should=2, must=3.*

Concept nr.	TH installation information in which the verification concept can provide							SUM points	How many verifications in total
	A*	B*	C*	D*	E*	F*	G*		
1			3			2		5	2
2		3	3	3	2	2	2	15	6
3a, 3b		3	3	3	2	2	2	15	6
4		3	3				2	8	3
5	1	3	3	3	2	2	2	16	7
6a, 6b	1	3	3	3	2	2	2	16	7
7	-	-	-	-	-	-	-	-	-
8								0	0
9a				3				3	1
9b		3		3	3			9	3
10	1	3		3	3			10	4
Nr of concepts	3	7	6	6	5	5	5	Average: 8,6	Average: 3,5

*Each type of installation information type with priority ranking in parentheses;

A) Vertical position of TH while run down into BOP stack. (1)
B) Position of TH relative to XT spool before lock down. (3)
C) When TH is locked to the XT spool. (3)
D) Position of TH relative to XT spool after lock down. (3)
E) Continuous verification of TH`s position until TH installation and pressure testing is complete. (2)
F) Continuous verification of TH lock down until TH installation and pressure testing is complete. (2)
G) When locking sleeves are in unlock position. (2)

7.4. The Actual Concept Screening

On the basis of the critical assessment of positive and negative concept characteristics and the two evaluation tables, I am going to decide which concepts to develop further and which once to set aside for now. The strongest concepts are the once that will be taken further into the concept development phase. The other concepts will be put aside. This does not mean that they are excluded, only that they will not be in focus for the further concept development work. I start of eliminating the weakest concepts.

Concept 8: Use of radiography is not applicable. As mentioned in the critical assessment of positive and negative concept characteristics, this concept is not possible to use for verification of TH installation, since it will not be possible to carry out x-ray scan on a XT system which is both surrounded by and contain water. In addition this type of technology is not an option to use for Aker Solutions as it exposes the subsea environment for a lot of harmful radiation. Concept 8 got the lowest score in the first selection matrix and no score in the second selection matrixes due to these facts.

Concept 5: Got the next lowest score in table 10, since it is a quite complex verification system. In table 11, concept 5 has a high score for both total sum and number of verifications, but there is a negative concept characteristic that does not appear in the table:

- Difficult to adjust system so that laser beam is blocked at exact same moment as complete installation step.

This result in that concept 5 probably will not give a verification that is according to system precision requirements for installation information type A, B, E, F and G. Thus it`s high score in table 11 is a bit misleading. The installation information type the concept is suited best for is D; Vertical position of TH while run down into BOP stack. As this is also covered by concept 6, which has a higher score in both of the tables, I chose to eliminate concept 5 as it is relatively weak.

Concept 4: This concept also has an underserved high score in table 11. As mentioned under critical assessment of positive and negative concept characteristics, the system is not activated at a specific moment but as two components gradually move towards each other. Thus it is difficult to know the exact position of relevant TH components, and the verification will not meet system precision requirements of TH installation. This means that concept 4 is not accurate enough to verify any of the important installation steps. Therefore it will be eliminated on much of the same basis as concept 5.

Concept 2: Got low score on simplicity. The six installation information types the concept covers are the once covered by highest number of verification concepts. Thus it does not provide any special verification information, that other even stronger concept solutions cannot provide. In addition it has an important system weakness:

- It is difficult to assure that the two wet mate connectors are correctly aligned before merging into each other.

Mainly due to the very low score on simplicity and the fact that the concept does not contribute with any important system characteristics that is crucial for good TH verification, it will be put aside.

The remaining concepts are:

- Concept 1, Improved poppet valve design.
- Concept 3, Touch sensor.
- Concept 6, Proximity sensor and proximity switch.
- Concept 7, Wireless communication.
- Concept 9, Verification system for Hybrid Penetrator.
- Concept 10, GPS System Device.

Concept 1: As mentioned earlier I will not develop this concept further myself, since there are already some employees at Aker Solutions working with improvement of poppet valve design. I will on the other hand implement any new information I get, since it is a highly relevant concept for the future lock down verification system for TH installation. By including it for my further work, I make sure that it is not excluded from the collection of relevant verification concepts by fault.

Concept 3: This concept got an average score in table 10. In table 11, concept 3 has a high score of 15 points. It is only one installation information type this verification concept does not cover. As it is a relatively strong concept with high potential I will include it in my further work, but I have to find suppliers of this type of verification system and reveal if the technical system is suited for subsea installation or not.

Concept 6: This verification concept got one of the highest scores in table 10 and the highest possible score in table 11. It has a potential of covering all types of important installation information linked to TH installation. There is thus no doubt that it should be included in my further work, but as for concept 3, I also need to find out how suited this verification system is for use subsea.

Concept 7: As one can see in table 11, I chose to not give this verification concept any evaluation at all. The reason for this is that it is not a complete verification system in itself, but can be a part of a verification system. Thus it cannot itself verify any of the TH installation steps, but provides means of sending verification information in an easy and effective way. Concept 7 got one of the highest scores in table 10. Thus it is a relatively strong concept. I will not develop it further as an independent verification system, but evaluate if it is applicable to implement it into some of the other verification concepts, like e.g. concept 3 and 6 that is to be further developed.

Concept 9a: Got the highest possible score in table 10, with full score on all criteria. In table 11 it was revealed that it only covers one type of TH installation information, but this is also one of the most important once; position of TH relative to XT spool before lock. Concept 9a is the only verification system concept which is a pure mechanical system. This concept will be included in the concept development phase, as it has a high potential.

Concept 9b: In table 10, it got a bit lower result compared to concept 9a, while in evaluation table 11 it got a higher score. It is more complex compared to a pure mechanical solution, and I do not know for sure if it will be suited for installation subsea. As it is a quite innovative solution to implement a camera onto the Hybrid Penetrator, I will include this concept in the concept development phase. The main focus will be to find out more about existing product solutions, if they are suited for use subsea and also typical product size as it is very limited space available in the gallery area.

Concept 10: This concept got full score in table 10, and in table 11, it got a score above the average. The verification concept does not give an indication to required system precision level, but can give a good indication of correct TH installation. Thus this concept can work as a verification method carried out in advance of other more precise verification procedures. It is good for the operator to get some verification during the installation process, before a final lock down verification test is run. Therefore I choose to include this concept in the collection of relevant verification concepts that are to be further developed.

Result of Own Concept Screening:

Disqualified concepts:

- Concept 2, Electric wet-mate.
- Concept 4, Induce current with magnet.
- Concept 5, Electro-optical sensor.
- Concept 8, Radiography.

Qualified concepts:

- Concept 1, Improved poppet valve design.
- Concept 3, Touch sensor.
- Concept 6, Proximity sensor and proximity switch.
- Concept 7, Wireless communication.
- Concept 9, Verification system for Hybrid Penetrator.
- Concept 10, GPS System Device.

Concepts I will develop further:

- Concept 3, Touch sensor.
- Concept 6, Proximity sensor and proximity switch.
- Concept 9, Verification system for Hybrid Penetrator.
- Concept 10, GPS System Device.

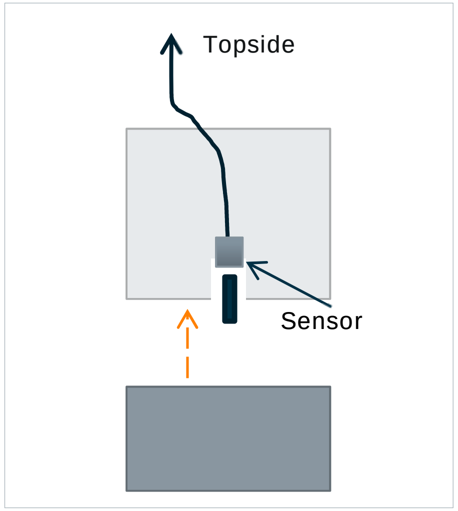


Figure 93: *Concept 4. [5]*

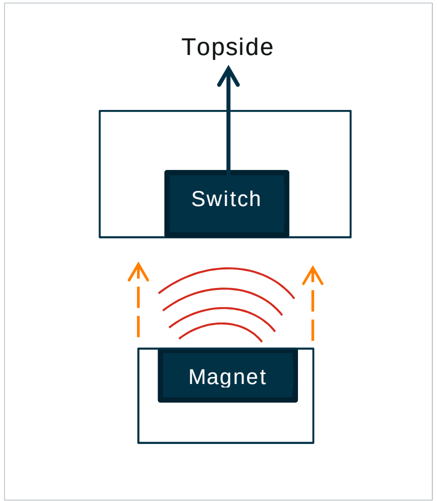


Figure 94: *Concept 6. [5]*

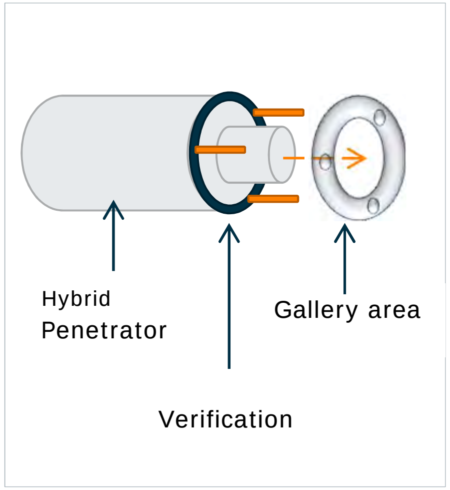


Figure 95: *Concept 9a. [5]*

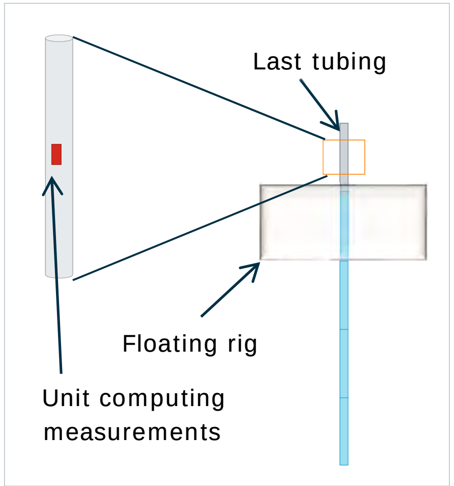


Figure 96: Concept 10. [5]

7.5. Overview of Installation Information Requirements Covered by the Relevant Concepts

***Table 12**: This table`s content is similar to that of table 11. It gives an overview of what type of installation information each concept can provide. It is set up in order to find out if the chosen concepts have the potential of covering all the function requirements for TH installation information listed in Basis of Design.*

Concept nr.	TH installation information in which the verification concept can provide						
	A*	B*	C*	D*	E*	F*	G*
1			x			x	x
3		x	x	x	x	x	x
6	x	x	x	x	x	x	x
9		x		x			
10	x	x		x	x		
Nr of concepts providing verification	2	4	3	4			3

*Each type of installation information type with priority ranking in parentheses;

A) Vertical position of TH while run down into BOP stack. (1)
B) Position of TH relative to XT spool before lock down. (3)
C) When TH is locked to the XT spool. (3)
D) When locking sleeves are in unlock position. (2)
E) Continuous verification of TH`s position until TH installation and pressure testing is complete. (2)
F) Continuous verification of TH lock down until TH installation and pressure testing is complete. (2)
G) Position of TH relative to XT spool after lock down. (3)

Conclusion: As one can see, all of the specified TH installation information is covered by the relevant concepts.

8. CONCEPT DEVELOPMENT

8.1. Introduction to Concept Development Phase

In the very start of this phase I searched for patents relevant for subsea verification system. The work can be found in appendix E.

For further development of the concepts I will search for more technical information and find suppliers of the relevant types of verification systems. The most crucial information to find is if the verification concepts are suited for subsea installation or not, in addition to size of different technical components. When I know more about how much space each verification system requires, I will study 3D models of XT assembly, TH and THRT in order to find out where it is most practical to place the verification systems.

I will also try to find other technical information for each verification concept according to the key product requirements in Basis of Design, e.g. system precision, durability, required maintenance and costs.

The goal of this concept development process is to end up with more detailed verification concepts which will be presented to an expert group consisting of employees from Aker Solutions. I will arrange a Concept Design Review meeting where the expert group can come with questions, comments and feedback.

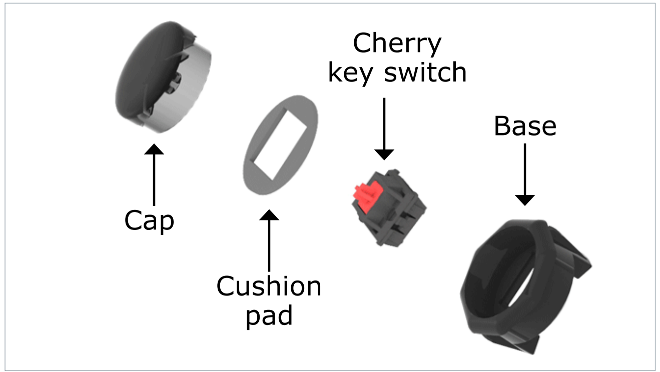


Figure 97: *Mechanical switch components [17]*

8.2. Further Technical Research

8.2.1. Concept 3, Touch Sensor

Mechanically Based Sensor
"The simplest form of touch sensor is one where the applied force is applied to a conventional mechanical micro-switch to form a binary touch sensor. The force required to operate the switch will be determined by its actuating characteristics and any external constraints." [18]

I have found a variety of mechanical micro switches available on the market. Figure 97 shows the different component parts to one type of mechanical touch switch.

There exists a huge variety of mechanical micro switches. A mechanical switch can be e.g. a directional switch, push switch, or rotary switch or slide switch.

The waterproof micro switches on the market are typically sealed with protection up to IP67. "The IP67 rated switches provide full dust protection and protection against the effects of immersion in water to depths between 15 cm and 1 meter." [19]

Products with an IP Code (Ingress Protection Rating) of IP67 are not suited for installation subsea. I have not been able to find any mechanical micro switches suited for subsea installations.

Figure 98: *Micro switch with protection up to IP67. [19]*

Piezo Switch
Most of today`s piezo switches are "based on mechanical bending of Piezoceramic, typically constructed directly behind a surface. This solution enables touch interfaces with any kind of material. Current commercial solutions construct the Piezo in such way that touching with approximately 1.5 N is enough, even for stiff materials like stainless steel." [20]

"A force applied to the switch surface transfers to the piezo disk creating an electrical pulse. This electrical signal is converted to an expected electrical output through a customisable electronic circuit. The duration of the electrical signal depends on the speed, force and duration of actuation." [21]

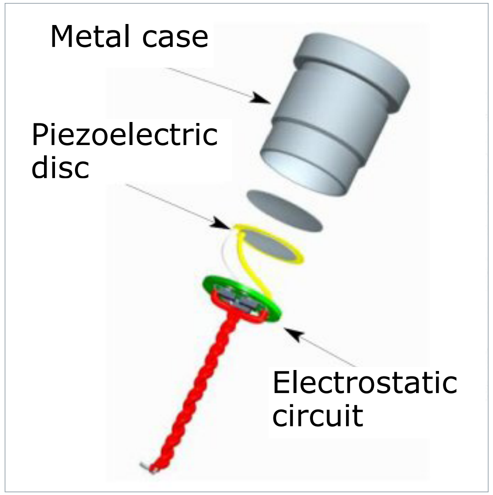


Figure 99: *Main components of a Piezo switch. [21]*

Piezo switches can be very robust, and switches from manufacturer APEM are "based on solid-state output allowing for a very long life expectancy (more than 50 million cycles), ideal for demanding applications where reliability is most important." [21]

Figure 100: *Electrical Piezo switch with connected wire leads and connectors. [22]*

Actuation surface can be completely closed, "preventing intrusion of liquids or other contaminants. High performance sealing (IP68 and IP69K) is achieved due to the one-piece construction of the switch." [21]

An IP code of IP68 means that the "equipment is suitable for continuous immersion in water under conditions which shall be specified by the manufacturer. Normally, this will mean that the equipment is hermetically sealed. However, with certain types of equipment, it can mean that water can enter but only in such a manner that it produces no harmful effects. German standard DIN 40050-9 extends the IEC 60529 rating system with an IP69K rating for high-pressure, high-temperature wash-down applications. Such enclosures must not only be dust tight (IP6X), but also be able to withstand high-pressure and steam cleaning." [23]

Piezo switches are not construced for use in subsea environments. Thus I have chosen to look more into swiches that are actually constructed for use in subsea environments.

A company which provides a range of different switches suited for underwater systems is SEACON. “In the 45 years since the company was established, the SEACON Group have become manufacturers of probably the largest range of underwater electrical and fibre optic connectors in the world. Today the company has manufacturing facilities in California, Texas and Rhode Island, USA, Mexico, Norway and the United Kingdom, and exports its range of products through a worldwide network of agencies and representatives.” [24] The manufacturer located in Norway (Notodden near Kongsberg) is Precision Subsea AS.

The types of underwater switches the company produces are:

- Limit Switches
- Plastic Limit Switches
- Positive Actions Switches
- Proximity Switches
- Modular Proximity Switches

The proximity switches will be studied in the next section, 8.2.2, while the limit, plastic limit and positive action switches will be described here.

Figure 101: *SEACON underwater switches. [24]*

“All switches are qualified for successful deployment on Submarines, ROV's, AUV's, UUV's, hulls, submersibles of all types, buoys, underwater communication systems, surveillance devices, oceanographic equipment, on deck and wherever equipment is exposed to severe marine and other hostile environments. These switches are also used in oil well logging, wellhead controls, dredging, fishery gates, and underwater Christmas Trees.” [24]

Limit Switches from SEACON

“Limit switches are designed to give a signal to a control system when a moving component like an overhead door or piece of machinery has reached the end point (or limit) of its travel or just a specific point of its journey.” [24]

“A limit switch uses a mechanism moving against a spring to move a magnet which is then placed either in attraction or repulsion, to open or close an electrical circuit. All switches are single pole double throw.” [24]

Key features:

- Hermetically sealed
- Pressure rated up to 41,4 MPa (6.000 psi, 4.000 msubsea).
- Rated for > 50.000 cycles.
- Load capacities; 1 & 7 amps.
- Single pole, double throw.
- Stainless Steel or Titanium.
- Non-metal options available.

Figure 102: *SEACON`s limit switch. [24]*

A limit switch can be very well suited for verification of lock down. It is designed for this type of application and is in addition pressure rated up to 41,4 MPa (6.000 psi).

Plastic Limit Switches from SEACON

"This limit switch is ideally suited for diver applications. Rated to 152,4 m (500 feet), this durable switch fits nicely into a gloved hand. Originally designed as a push to talk button, this switch has a wide variety of uses." [24]

Key features:

- Rated for > 50,000 cycles.
- Pressure rated up to 152,4 m (500 ft).
- Load capacities: 1 and 7 amps.
- Single pole, double throw.

Figure 103: *SEACON`s plastic limit switch. [24]*

This type of limit switch is not suited for verification of TH installation, as it is only pressure rated up to 152,4 m below sea level.

Positive Action Switches from SEACON

"Positive action switches are designed to give a continuous signal when the switch is activated. Various configurations are available including Rotary and Push and Pull (Kill Switches)." [24]

"A positive action switch uses a mechanism (rotary or linear) to move a magnet which is then placed either in attraction or repulsion, to open or close an electrical circuit. All switches are single pole double throw." [24] This is similar to the limit switch.

Key features:

- Hermetically sealed.
- Pressure rated up to 41,4 MPa (6000 psi, 4000 m subsea.)
- Rated for > 50,000 cycles.
- Load capacities: 1 and 7 amps.
- Single pole, double throw.
- Stainless Steel or Titanium.

Figure 104: *Positive action switches. [24]*

As the lock down verification system I develop concepts for do not require verification of rotary or pull movement, this type of switch is more advanced than necessary. The simpler limit switch technology will be sufficient enough, for verifications related to lock down of TH.

Conclusion:

When it comes to touch switch technology, none of the product solutions I had as alternatives in the start of this concept development phase, are suited for use in subsea installations.

But I have found three other alternatives for touch switch that are suited for subsea environment. Of those, the most suited type of touch switch proved to be the limit switch. Thus this is the touch switch product type I will base further concept development on.

8.2.2 Concept 6, Proximity Sensors and Switches

Proximity Switches from SEACON
As mentioned earlier SEACON also manufacture proximity switches. "The proximity switches uses magnets, either in attraction or repulsion, to open or close an electrical circuit. Several types are available to meet customer's needs." [24]

Key features:
- Hermetically sealed.
- Pressure rated up to 41,4 MPa (6,000 psi, 4000 m subsea).
- Rated for > 50,000 cycles.
- Load capacities; 1 and 7 amps
- Standard proximity and hall effect.
- Stainless Steel or Titanium.

Figure 105: *Proximity switch. [24]*

Possible configurations:
- Standard Proximity
  The switch can be normally open or closed. When a magnet is presented the switch will either open or close the circuit.
- Sinking Hall Effect
  The sensor is normally closed. When a magnet is present the sensor opens at a very high rate of speed.
- Sinking/Sourcing Hall Effect
  The switch is normally open and will gradually close as the magnet is brought closer to the switch. This is ideal for lining up two objects.
- Latching Hall Effect
  The circuit is closed when a South magnet is present and opens when a North magnet is presented.

For lock down verification for TH installation, I think the standard proximity and the sinking/sourcing hall effect configuration will be best suited.

Modular Proximity Switches from SEACON
In addition to the ordinary proximity switches SEACON offers a Modular Proximity Switch that has been integrated with a Micro WET-CON electrical wet-mate (underwater pluggable) connector. "Once the switch is mounted the cable can easily be added. Because a wet pluggable connector is used, this can be done in any conditions, even submerged. As a result of this modular design, switches become interchangeable. Simply replace the cable and the switch can be used elsewhere." [24]

Key features:
- Hermetically sealed.
- No o-rings or gaskets.
- Pressure rated up to 41,4 MPa (6.000 psi, 4000 m subsea).
- Rated for > 50.000 cycles.
- Load capacities; 1 and 7 amps.
- Standard proximity and hall effect
- Reinforced Neoprene mold.

Figure 106: *Modular proximity switch. [24]*

The additional features to the modular proximity switch are most likely not applicable for lock down verification system. The lock down verification system will probably be installed on the XT, TH or THRT prior to TH installation. Thus the ordinary proximity switches that SEA CON produce will be best suited for my verification concept development, compared to SEACON`s modular proximity switch.

Proximity Switches from Emerson Process Management

The company Emerson also produces proximity switches, which are suited for subsea installations. They call their switches “leverless limit switches” [25], but they are not touch switches like SEACON`s limit switches. Thus they will all be referred to as proximity switches in this report.

All of Emerson`s switches are “submersible to depths of 7.010 m (23.000 ft) and offer position sensing in applications such as offshore oil platforms, pin placement detection and subsea valve position monitoring.” [25]

Emerson has six different submersible proximity switch models, which are called GO Switches. Two of them are presented below.

- SubSea Model 73 GO Switch: performance at up to 7010 m. With no external moving parts, no springs or cams, and no reed element, there is nothing to wear or fail.
- SubSea Model 81 GO Switch: stainless steel enclosure.

***Figure 107:** Right: SubSea Model 73 GO Switch, Left: SubSea Model 81 GO Switch. [25]*

Subsea Proximity Switch from Hydracon

Another company which produces proximity switches is Hydracon subsea. “Hydracon California engineering and manufacture its own designs of submersible electric switches.” [26]

Hydracon manufactures proximity switches that are molded onto underwater cable. It is activated with an accompanying magnet actuator. This is show in figure 108.

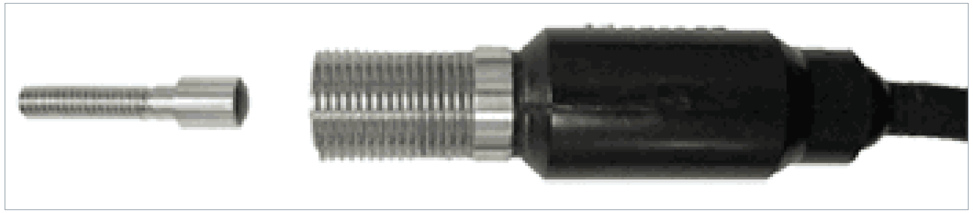


***Figure 108:** Proximity Switch molded onto underwater cable with magnet actuator [26]*

Key features:
- Hermetically Sealed.
- Submersible to 69 MPa (10,000 psi).
- Zero power consumption.
- 2-Wire System.
- No transmitter needed.
- Robust & dependable.

“Switch actuates 6,35 mm (¼ inch) to 12,7 mm (½ inch) and even higher distances depending on the magnet actuator. Distance between the switches "on" and "off" is tight. The switch hysteresis (distance between “on” and “off”) is a low distance of 0,51 mm to 1,02 mm (0.020 to 0.040 inch).” [26]

This proximity switch can also be used as a proximity sensor to provide accurate positioning.

Subsea Proximity Sensor from Hydracon
As mentioned on previous page, Hydracon`s proximity switch can also be used as a proximity sensor. The proximity switch in conjunction with the actuating magnet can be used to detect the proximity of two objects.

Conclusion:
When it comes to proximity switch and sensor technology, there are a variety of different product solutions to choose between. The most relevant product solutions are delivered by SEACON, Emerson and Hydracon.

From SEACON`s product range, the proximity switch type shown in figure 109 is the most relevant one. It can be configured in different ways. E.g. one can have a standard solution in which the switch can be normally open or closed. When a magnet is presented the switch will either open or close the circuit. Or one can use Sinking/Sourcing Hall Effect in which the switch is normally open and will gradually close as the magnet is brought closer to the switch. Last mentioned is ideal for lining up two objects. This proximity switch type is pressure rated up to 4.000 m below sea level. Dimensions of switch and relevant detection distances are not specified in the product information.

Figure 109: *Proximity switch. [24]*

Emerson`s proximity switches are pressure rated up to 7.010 m below sea level. Thus they are qualified for taking more pressure compared to SEACON`s proximity switches. Which of Emerson`s switches that are most relevant will depend on e.g. which length one need. Sensing ranges are of typically 2,5 mm, 1,8 mm or 1,5 mm. Component size of switch is not specified.

Figure 110: *Emerson`s switches [25]*

Hydracon provide a proximity switch which can also function as a proximity sensor. It is submersible to 6.000m in ocean depth. The switch actuates at 6,35 mm to 12,7 mm and even higher distances depending on the magnet actuator. The switch hysteresis 0,51 mm 1,02 mm (0.040 in). Outer dimensions are 103x19x19 mm

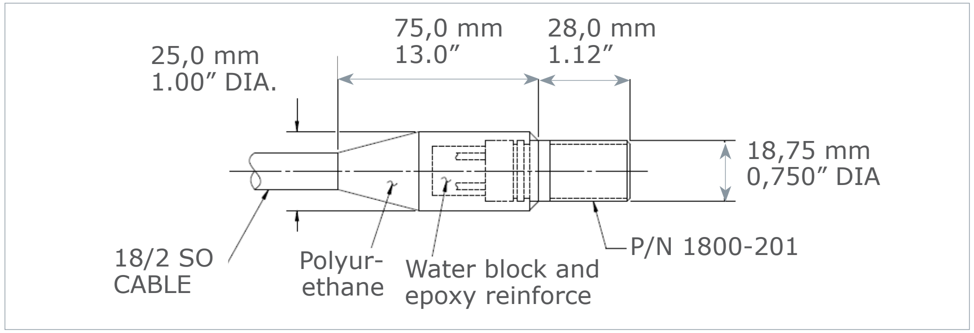


Figure 111: *Dimensions of the Hydracon proximity sensor/switch. [26]*

8.2.3. Concept 9, Verification System for Hybrid Penetrator

Mechanical Verification System

As this concept is a pure mechanical verification system, a technology analysis is not needed. I will look closer into this verification concept later on in the concept development phase.

Micro Camera Technology

Figure 112 shows picture of a Naneye camera, which has dimensions of 1 by 1 mm. "It is used for medical endoscopy, dental imaging and surgical robots." [27] The camera runs off 1.8 volts and can be used on a cable up to 2 meters long.

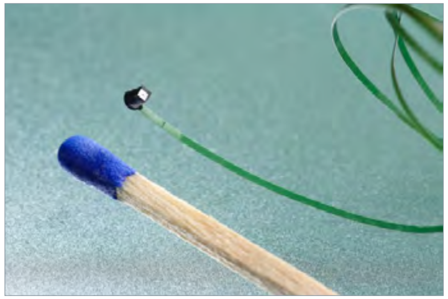


Figure 112: *Naneye camera next to a match. [27]*

Subsea Camera

Naneye camera technology is quite impressive due to the extremely small size of the camera, but it is not designed for used in high pressure environment. The companies Hadal, Imenco and Bowtech offer subsea camera designs for the oil and gas industries.

Hadal has a camera called Oculus. Some of its key features are [28]:

- Designed for ROV integration.
- Transmit HDSDI over fiber directly from the camera, so there's no external conversion required.
- Just under four inches (ca 100 mm) in diameter and eight inches (ca 200 mm) long.
- Pressure rated to 6.000 meters.

Figure 113: *Oculus camera. [28]*

Imeco also offer camera models that are pressure rated to 6.000 m. One of their models is called Greytip. It is a "popular small size color camera often chosen by ROV and diving operators. A high resolution color camera module is built into the small duplex steel housing, enabling the Greytip to withstand pressures up to 6.000m." [29]

Product specifications:

- Diameter: 36 mm
- Length: 110 mm
- Weight: 0.5/0.4 Kg
- Power: 24V/1.2W

Figure 114: *Imeco`s camera model Greytip. [29]*

Bowtech also has a ROV underwater video camera. As for the two earlier mentioned subsea cameras, it is pressure rated to 6.000 m. "The camera is no smaller than a standard underwater colour zoom camera and therefore ideal for mounting on all ROV's." [30]

Product specifications:

- Diameter: 82 mm
- Length: 176 mm
- Weight in air: 1,4 Kg
- Weight is water: 0,5 Kg

Figure 115: *Bowtech camera in titanium housing. [30]*

Conclusion

The most compact camera I have found on the market which is pressure rated up to 6.000 m, is Imeco`s Greytip camera.

8.2.4. Concept 10, GPS Device

"GPS is an acronym that stands for 'Global Positioning System'. The system was devised by the US Department of Defense and is open for use to anyone who wishes to use it. Basically, it uses satellites that were sent into space, determining their current location based on the signals the satellites continually send to the GPS device. At the moment, there are over 30 GPS satellites in service; however, to determine the location of any one GPS device, taking into account the signals of four of those satellites is enough." [31]

As illustrated by figure 117, the GPS consists of three main components; space component, control segment and a GPS user component. The GPS "provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. (Figure 116)

Although four satellites are required for normal operation, fewer apply in special cases. If one variable is already known, a receiver can determine its position using only three satellites. For example, a ship or aircraft may have known elevation." [32]

A GPS receiver calculates its position by precisely timing the signals sent by GPS satellites. Each satellite continually transmits messages that include

- the time the message was transmitted
- satellite position at time of message transmission" [32]

"Many GPS units show derived information such as direction and speed, calculated from position changes." [31] Thus it will most likely be possible to create a GPS unit that can display rotational and axial movement of landing string during TH installation.

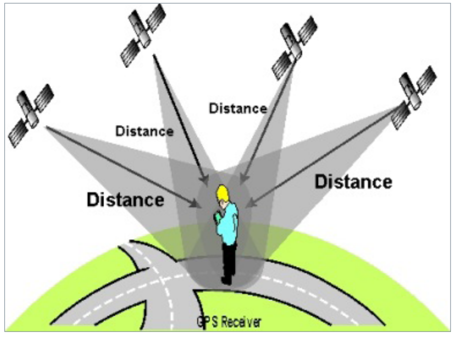


Figure 116: *GPS device calculate its position typically by communicating with four satellites. [33]*

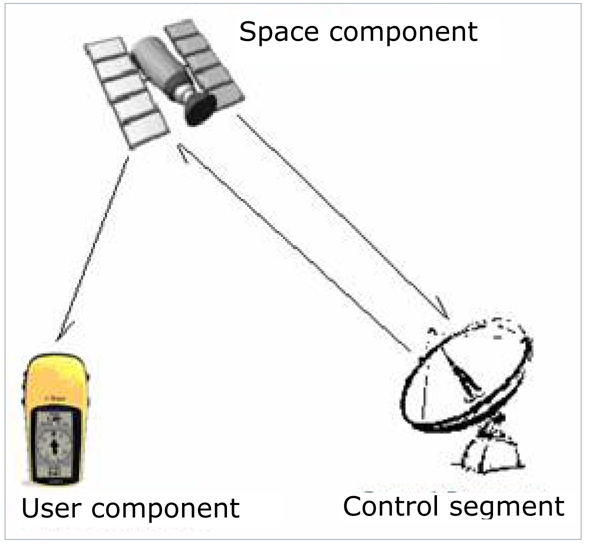


Figure 117: *GPS communication system. [31]*

The position information received by the GPS is latitude, longitude altitude. Thus three dimensional position information. A GPS unit to be used for TH installation verification has to calculate and register movement of the GPS unit while attached to the lading string.

The relevant movement of TH is related to the helix shape in XT spool and the alignment key on TH. First off one has rotational and axial downward movement at the same time, before one has a pure axial downward movement.

The movement of a GPS unit attached to the installation sling will be slightly different from that of the string and TH, since the GPS will not rotate around its own axis.

Movement of the GPS unit is illustrated below in figure 119 and 120.

Figure 118: *Helix guiting orientation key into right position. [6]*

The GPS can let the operator know by how much the landing string has rotated and moved downward, by displaying latitude, longitude and altitude movement during a specific time period.

In order to find out if this type of GPS already exist, that can inform a person about three dimensional movements that GPS unit has experienced during a specific time period, I have done some research online.

The PGS in figure 121 is a standard GPS unit showing location with the means of a map. One can also display current geographical position in addition to or instead of the map. For this kind of GPS it is possible to insert map coordinates for a specific geographical location one would like to get to. As one moves towards that location, the GPS will indicate in which direction to head onto. The GPS unit is also able to track the actual route/path that it has traveled to get to the final destination. Thus the GPS register geographical starting point, the path it has moved, and geographical coordinates for final destination.

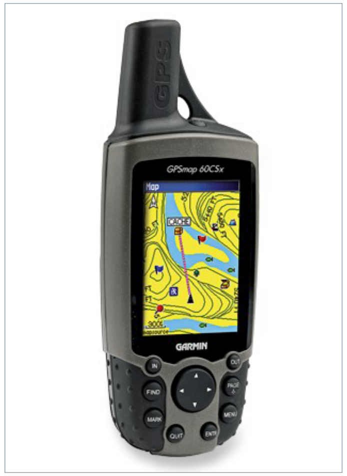


Figure 121: *GPS device [34]*

Figure 119: *Top view, Rotational movement. [5]*

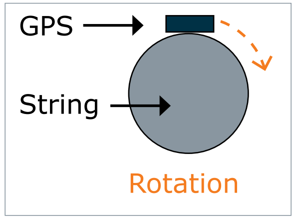
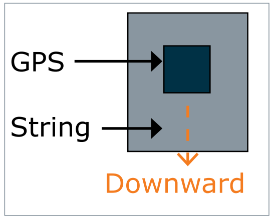


Figure 120: *Side view, Downward movement. [5]*



There already exist GPS units that can provide information about exact three dimensional movements for latitude, longitude and altitude. Figure 122 shows a GPS device which displays speed and altitude movement.

Thus it should be possible to verify approximate movement of TH inside XT spool, by measuring movement of landing string on topside, by the use of a GPS unit that is to be fixed to the string. But this requires a GPS device that can calculate its position in a precision of about ±1 cm, in order to get an approximation of the movement.

Figure 122: *GPS unit displaying altitude movement in addition to speed. [35]*

“The two elements of GPS accuracy is the precision to which the coordinates are written, and the accuracy to which the receiver works. The more decimal places one use in the coordinates, the more precise they are.” [36]

“On May 2, 2000 the so-called selective availability (SA) was turned off. Selective availability is an artificial falsification of the time signal transmitted by the satellite. For civil GPS receivers this leads to a less accurate position determination.” [37]

“The reasons for SA were safety concerns. For example terrorists should not be provided with the possibility of locating important buildings with homemade remote control weapons. Today SA is permanently deactivated due to the broad distribution and worldwide use of the GPS system.

With the SA still activated, the error was in the range of ± 100 Meter. Today the overall error is reduced to approximately ± 3 - 5 meters.” [37] GPS will not be able to give measurements of required accuracy for TH installation. An accuracy of ± 3 - 5 m is far from sufficient enough.

This concept will be presented in a concept design review meeting, together with other relevant verification concepts. I will then try to find out if there exists an alternative positioning system with higher accuracy.

8.3. Possible Locations for the Different Verification Systems and Connection to Topside.

The verification information set up with the highest priority in the key product requirements table is:

1. Position of TH relative to XT spool before lock down.
2. When TH is locked to the XT spool
3. Position of TH relative to XT spool after lock down.

For verification of position of the TH relative to the spool before lock down, one can register position of any TH product part, relative to the spool. Some alternatives are:

- Register when TH lands on the landing shoulder in XT spool.
- Register position of the lock piston relative to the spool.
- Position of TH connection area relative to the spool.

For verification of when TH is locked to the spool, one can verify the position/movement of The TH and THRT product parts that change position during lock down. These are:

- The split lock ring on TH; goes form retracted to engaged position.
- Actuation sleeve on TH; pushed down during lock down in order to activate the split lock ring.
- Locking sleeves on THRT; move axially downward during lock down, in order to apply a downward force upon the actuation sleeve.

For verification of position of the TH relative to the spool after lock down, one can register position of a TH product part (preferably in fixed position), relative to the spool. Some alternatives are:

- Register distance between TH and landing shoulder in XT spool.
- Position of TH connection area relative to the spool.

The three bullet point lists to the left indicate what a verification sensor should register and where it ought to be positioned. For concept 9, it is already decided that the mechanical verification system or camera device will be positioned in the gallery area. Also for concept 10, position is already specified. GPS device will be attached to the landing string. For concept 3 and 6 on the other hand, there are multiple possible positioning alternatives.

One the next pages I have shown possible positions for switch, sensor and magnets. I have also studied the possibilities of a mechanical verification system, in addition to finding out where it can be possible to integrate a subsea camera. In addition I have studied how sensor/switch or camera can be connected to topside. I have focused on the XT spool, TH and THRT.

Concept 10 is not included here, as the concept already is defined enough to be presented in a concept design review.

8.3.1. Concept 3 and 6, Possible Locations of Sensor/Switch

This is a very simplified figure of the TH installation system components, that I have made in order to only focus on the components that are directly related to the lock down of TH.

The figure illustrates the system after lock down. I have not added any drawings of subsea system before landing or before lockdown, as relevant movement of product components during landing and lock down have been described in detail earlier (chapter 4).

THRT in purple, TH in blue and XT spool in light grey colour. I have given a slightly darker purple and blue colour to the vital product components involved in lock down. Sensor/switch is marked with orange colour, while magnets are marked in red. All specified measurements are to the nearest whole mm with precision of ± 0,5 mm. Figure 123 to 129 has a scaling of about 1:40.

P1

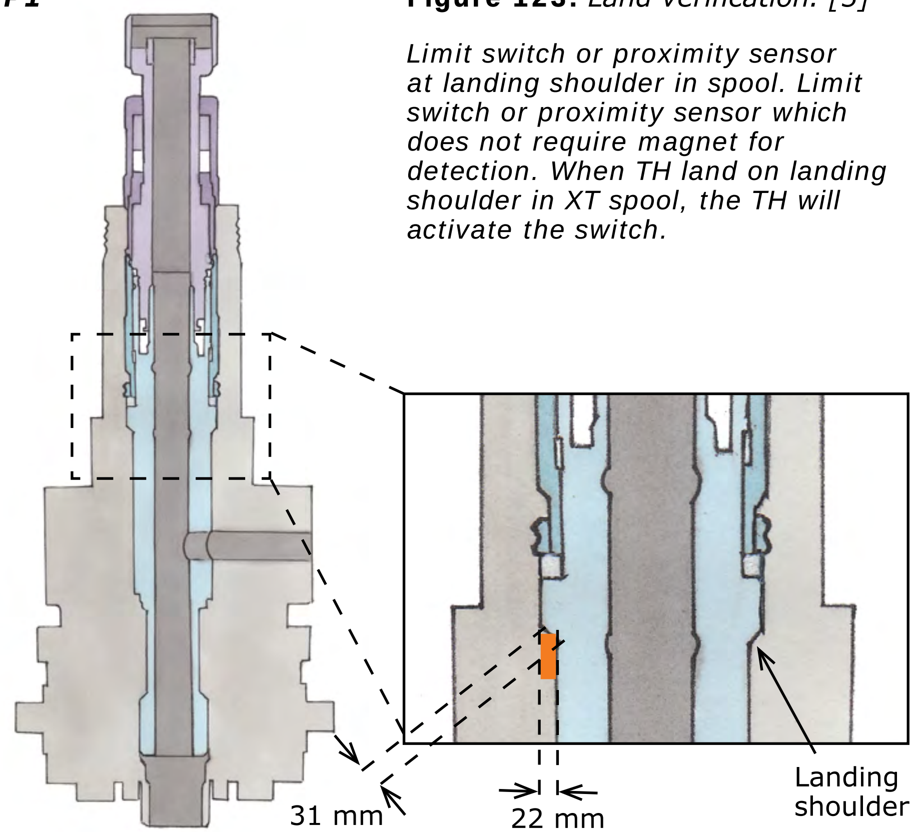


Figure 123: *Land verification. [5]*

Limit switch or proximity sensor at landing shoulder in spool. Limit switch or proximity sensor which does not require magnet for detection. When TH land on landing shoulder in XT spool, the TH will activate the switch.

P2

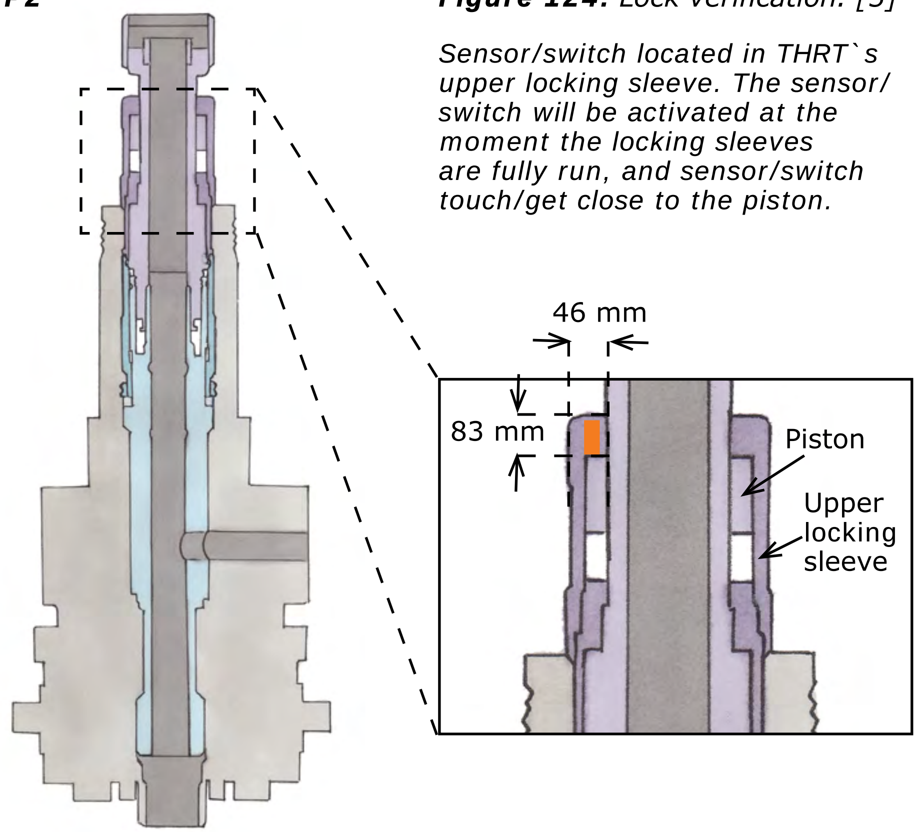


Figure 124: *Lock verification. [5]*

Sensor/switch located in THRT`s upper locking sleeve. The sensor/switch will be activated at the moment the locking sleeves are fully run, and sensor/switch touch/get close to the piston.

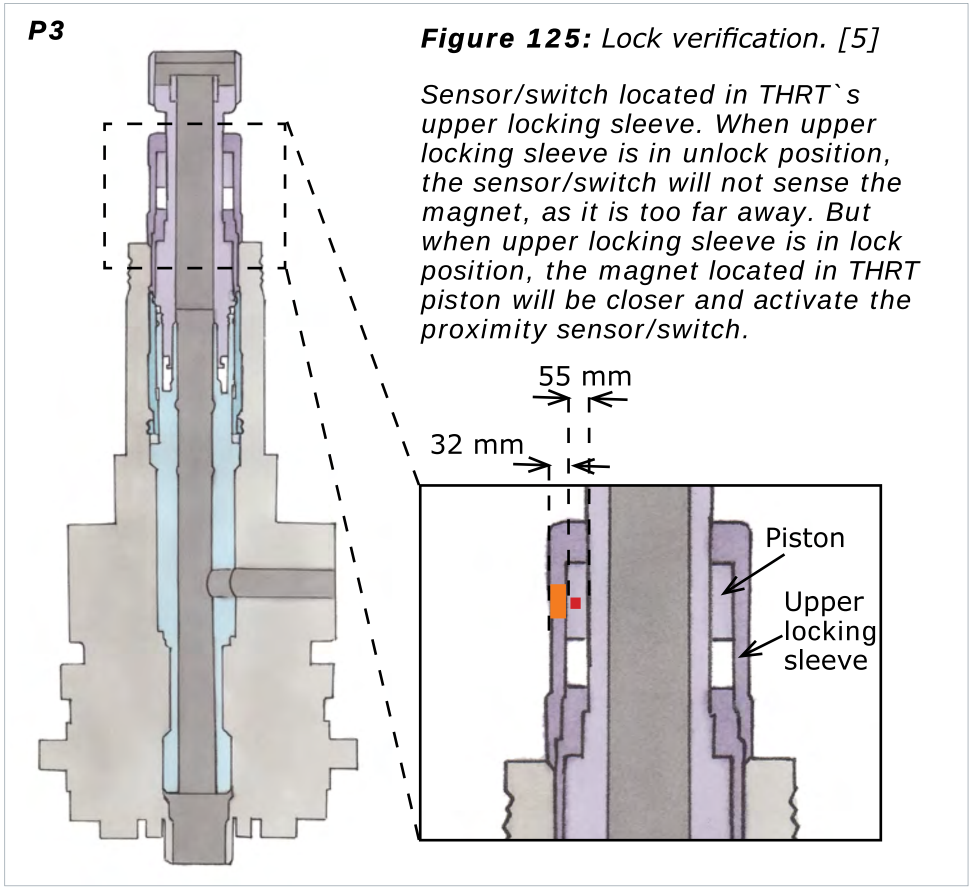


***Figure 125:** Lock verification. [5]*

Sensor/switch located in THRT`s upper locking sleeve. When upper locking sleeve is in unlock position, the sensor/switch will not sense the magnet, as it is too far away. But when upper locking sleeve is in lock position, the magnet located in THRT piston will be closer and activate the proximity sensor/switch.

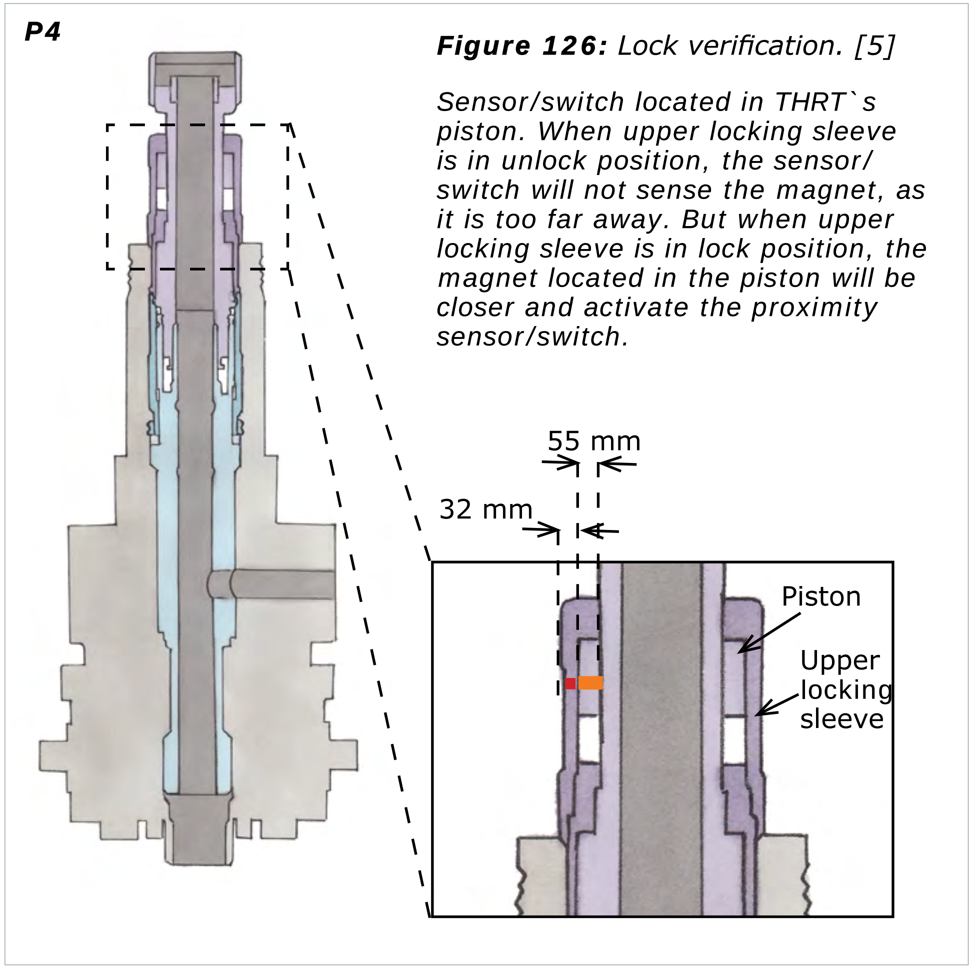


***Figure 126:** Lock verification. [5]*

Sensor/switch located in THRT`s piston. When upper locking sleeve is in unlock position, the sensor/switch will not sense the magnet, as it is too far away. But when upper locking sleeve is in lock position, the magnet located in the piston will be closer and activate the proximity sensor/switch.

P5

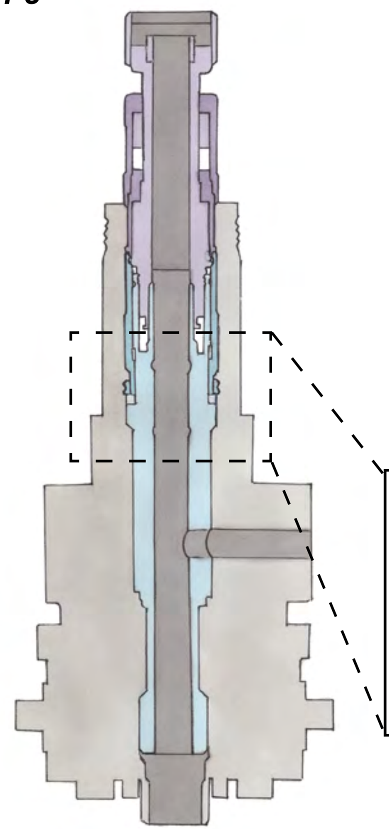
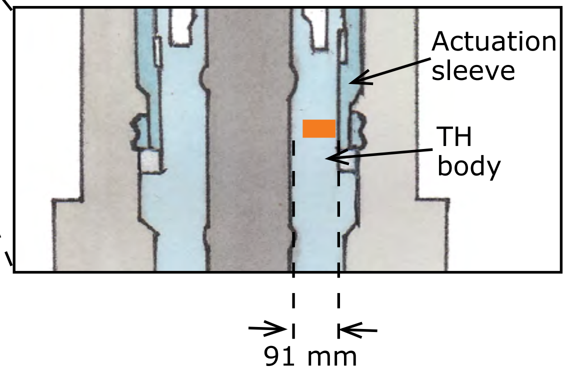


Figure 127: *Lock verification. [5]*

Limit switch or proximity sensor located in TH body, at the lower end of actuation sleeve. Limit switch or proximity sensor which does not require magnet for detection.

Sensor is deactivated when actuation sleeve is in unlock position. As the actuation sleeve moves over to lock position, it will activate the switch/sensor at the moment the split lock ring has emerged sufficiently into XT spool.



P6

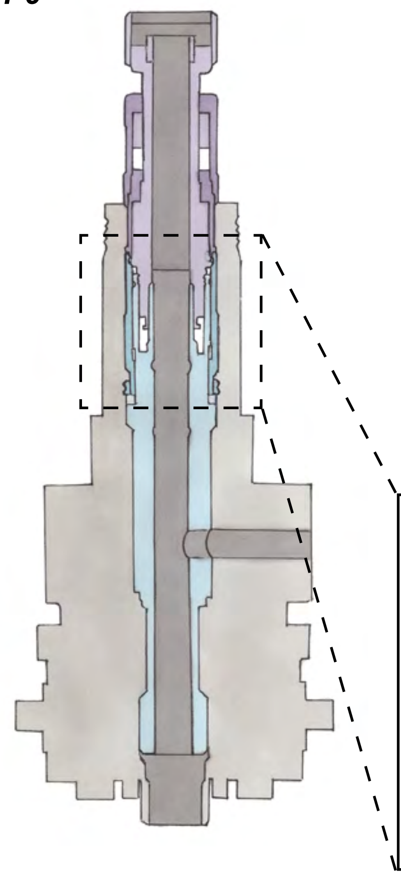
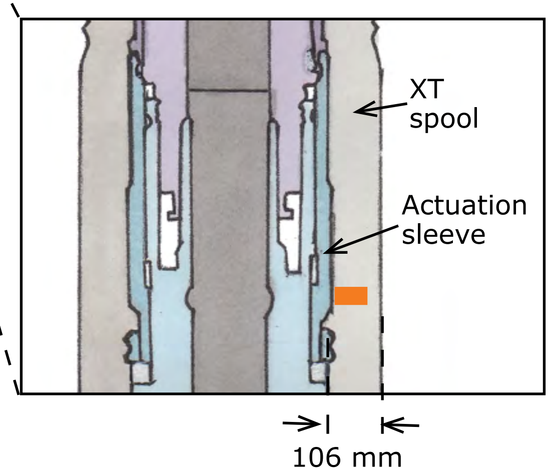


Figure 128: *Lock verification. [5]*

Limit switch or proximity sensor which does not require magnet for detection, positioned in XT spool.

Sensor is deactivated when actuation sleeve is in unlock position. As the actuation sleeve moves over to lock position, it will activate the switch/sensor at the moment the split lock ring has emerged sufficiently into XT spool.



P7

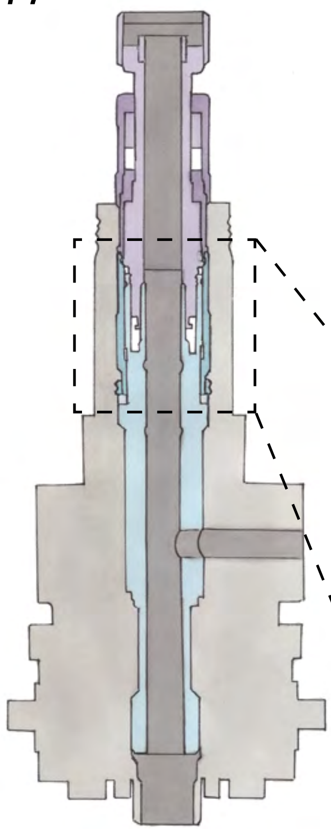
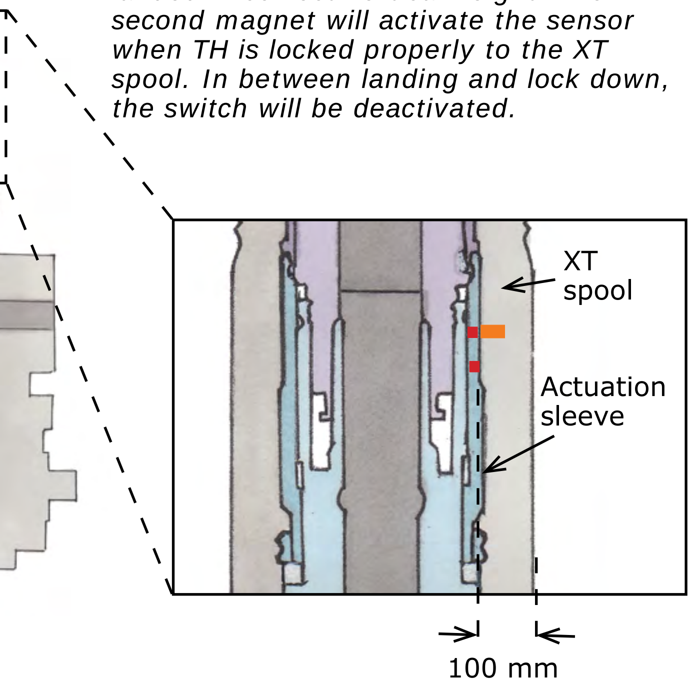


Figure 129: *Land and lock verification [5]*

Proximity switch located in XT spool, registering movement of TH`s actuation sleeve. Proximity switch that requires magnets for detection. The lower magnet will activate sensor/switch when TH has landed in correct vertical height. The second magnet will activate the sensor when TH is locked properly to the XT spool. In between landing and lock down, the switch will be deactivated.



If it is possible to have sensor/switch in the positions illustrated in the figures above, both depend in the available space in component in which switch/sensor is to be integrated into, the size of switch/sensor, and possibility of linking the sensor/switch to topside. I will start off evaluating the size of relevant switch/ sensor components, and find out if it is enough space for them in the relevant locations.

Table 13: *Size spesifications for relevant switch models to the nearest whole mm.*

Product			Length [mm]	Diameter or square area [mm]
	SEA CON limit switch		86	32
	SEA CON proximity switch	Smallest	37	19
		Thickest	51	32x32
		Longest	99	25
	Emerson proximity switch	Model 81	111	38x38
		Model 73	92	16
	Hydracon proximity switch		103	19

The shortest proximity switch is 37 mm long and has a diameter of 19 mm. The most narrow proximity switch is 70 mm long and has a diameter of 16 mm. The limit switch has a relatively long length of 86 mm and a diameter of 32 mm.

P1: For the switch positioning providing landing verification, the landing shoulder that TH lands on has a width of 22 mm, and a length of 31 mm. Thus the limit switch`s diameter of 32 mm is too large. If one is to use a limit switch, a new limit switch product needs to be found or be developed by the producer.

P2: For positioning of sensor/switch similar to that of poppet valve today, the total space is 83mm x 46mm. Today`s poppet valve has a height of 73 mm and a diameter of 21 mm. The limit switch is too long to be positioned here, but three of the switch models are short enough.

P3 and P4: The other possible positioning examples in THRT provide wall thicknesses of 32 mm (upper locking sleeve) and 55 mm (piston). Position in 32 mm thick wall of upper locking sleeve in not an alternative, as it is very problematic to machine a suitable groove for the switch. Thus positioning example P4 is more promising. The THRT piston is thicker than length of two of SEACON`s proximity switches. Thus switch can be orientated horizontally.

P5, P6 and P7: For these positioning examples there is more than enough space for switch/sensor component since they are positioned in the spool, which has large wall thickness compared to other parts of the XT system.

Conclusion:
From evaluation of space available and size of sensor/switch components, positioning alternative P3 can be eliminated, due to too little space available. For the remaining 6 concepts, I will evaluate alternatives of how to connect switch/sensor to topside.

8.3.2. Concept 3 and 6, Connection to Topside

The subsea XT system is mainly controlled through the Subsea Control Module, which is connected to topside with an umbilical. All hydraulic and electrical lines go through the SCM. Some of the lines are also linked to the ROV panel, and can thus be monitored by a ROV unit. If a Casing Adapter (CA) is used, the THRT is connected to topside through CA, during TH installation.

P1
As the switch/sensor is positioned by the landing shoulder, it will be most natural to connect the switch/sensor with an electrical line out of the spool and to the SCM and/or ROV panel. An alternative can be wireless connection.

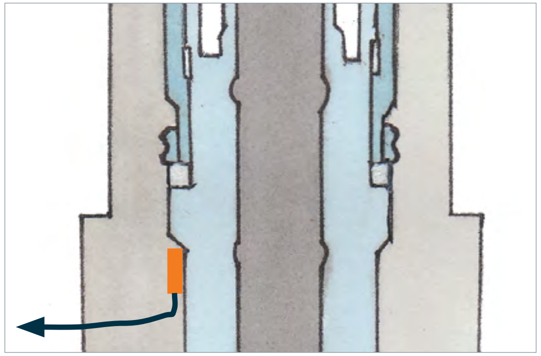


Figure 130: *Position alternative P1. [5]*

P2
Since the switch/ sensor is positioned similar to the poppet valve, it might be possible to let an electric line go though the already existing hydraulic line. F4 is the line that is directly linked to the poppet valve.

There is a major issue: there is not possible to connect a fixed electrical line to the upper locking sleeve, as it is moving relative to the THRT body. In addition it is not possible to integrate a wet mate for the line, as it will take up too much space.

The last alternative is to use a wireless connection, but it is probably too little space available in the upper locking sleeve, as the switch/sensor takes up most of the space already.

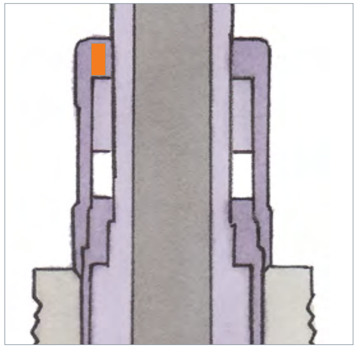


Figure 131: *P2 [5]*

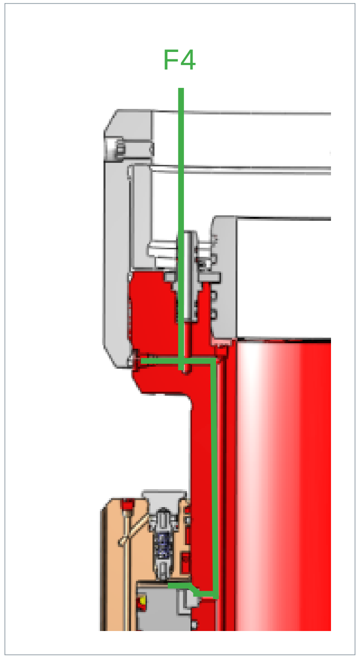


Figure 132: *Connection to topside for P2 [6]*

P4
For this positioning alternative, the switch is located in THRT piston.

Line F5 is linked directly to the piston. Thus it should be possible to insert an electrical line through the hydraulic line. One has to evaluate how this will affect assembly of the THRT, and find out if it is physically possible to take a line which is connected to switch/sensor inside the piston, and run it through line F5.

This will also have affect upon how THRT in connected to Casing Adapter and landing string.

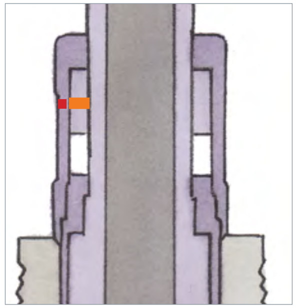


Figure 133: *P4 [5]*

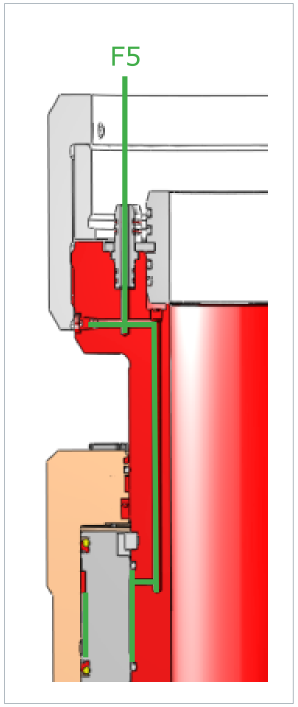


Figure 134: *[6] Connection to topside*

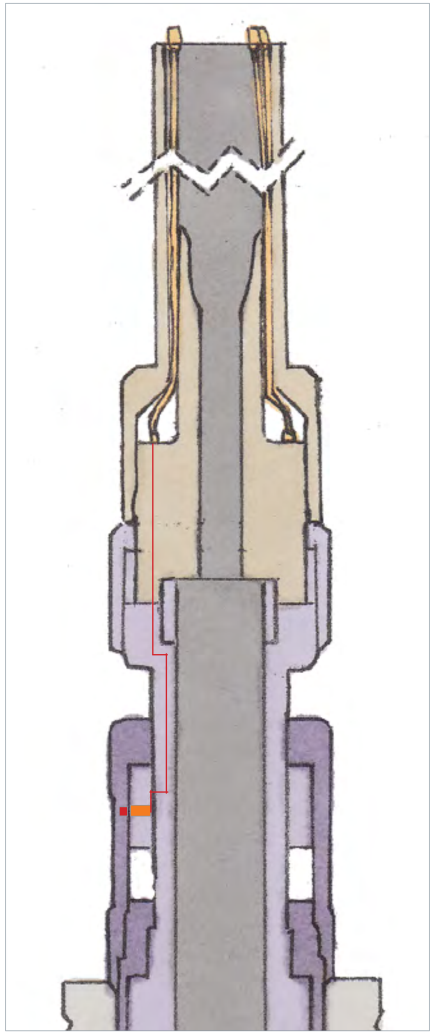


***Figure 135:** How the electric line can be installed. Electric line from switch is in red colour, and it travels through main body of THRT, and up through CA with the hydraulic lines. [5]*

P5:
This positioning example has a switch/sensor located in TH`s main body. The best way to connect to topside, is by having an electric line going all the way up to the top of TH`s main body, over THRT`s body and then all the way up THRT`s main body.

This will require a wet-mate connection in the transition between TH and THRT. As shown in figure 136, the relevant wall thickness for this is only 11 mm.

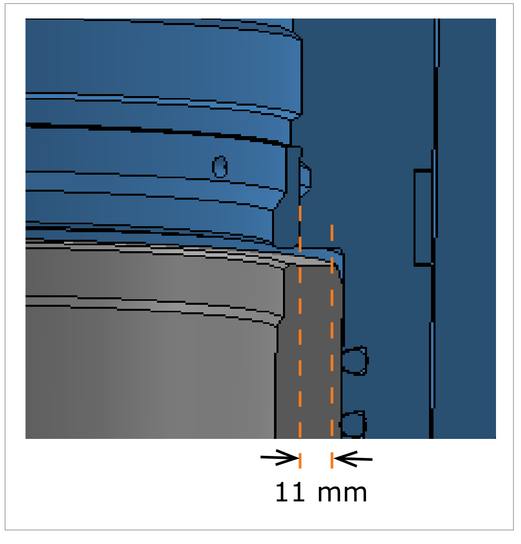


Figure 136: *Transition area between TH and THRT. [6]*

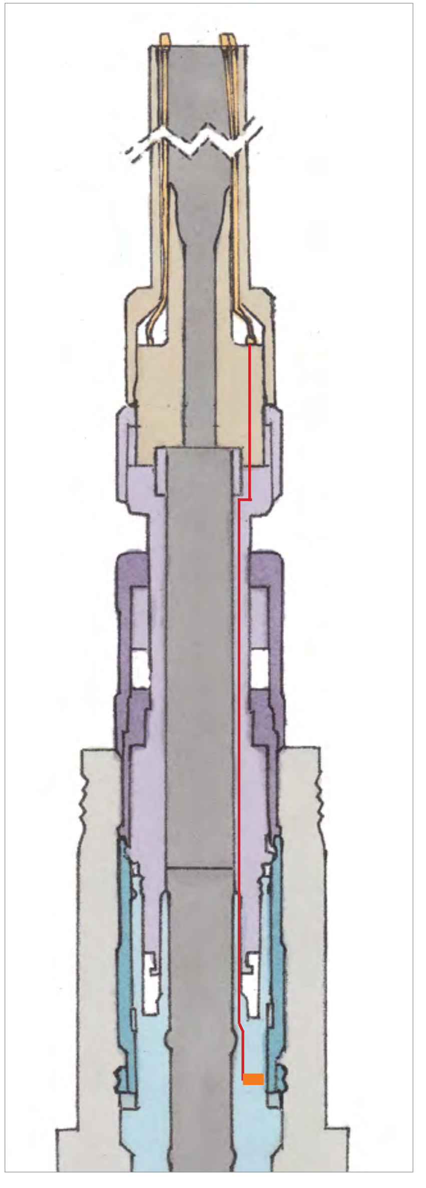


Figure 137: *connection to topside for P5. [5]*

P6:
Switch/sensor is located next to the actuation sleeve, inside the spool. Since it is located inside the spool, it is most natural to let electric line run further down inside the spool, before it goes out of the spool and is connected to SCM and/or ROV panel. Alternatively one can try to integrate a wireless communication system.

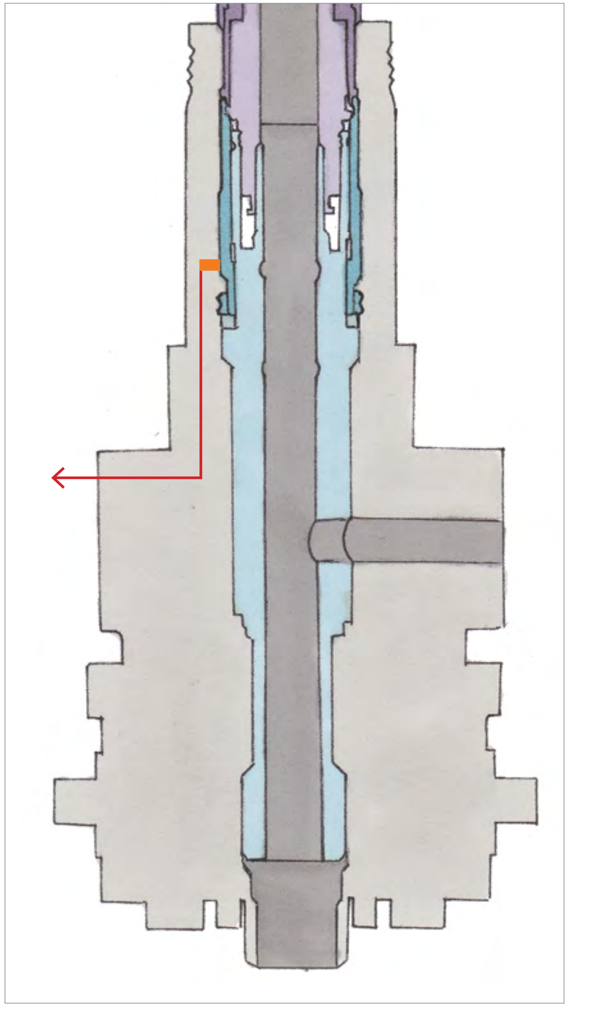


Figure 138: *Connection to XT control units. [5]*

P7:
As for positioning alternative P1 and P6, it is also here most natural to let the electric line run down and out of the XT spool, and connect it to SCM and/or ROV panel.

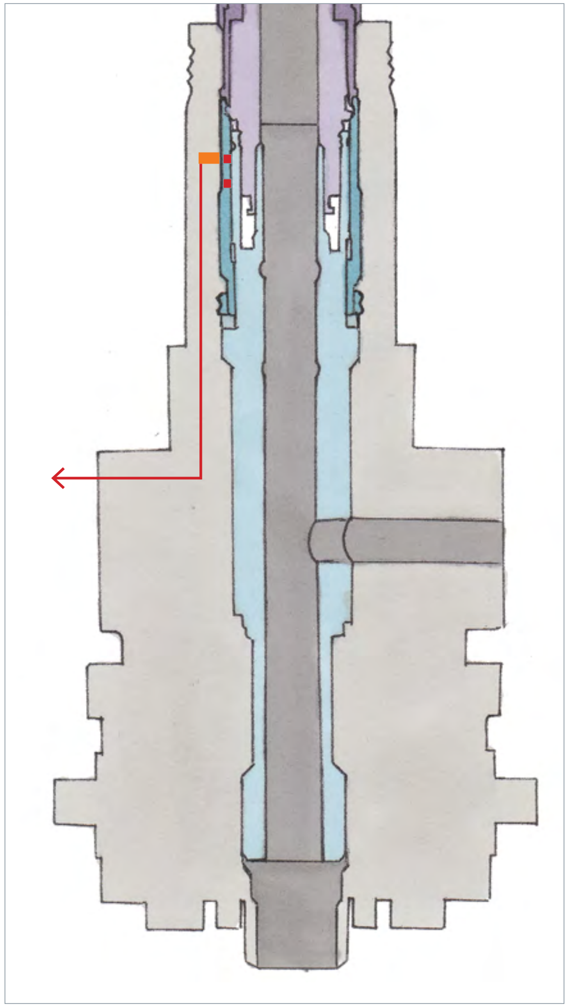


Figure 139: *Connection to XT control units. [5]*

Comments
From evaluation of possibility of connection to topside, I have found out that position alternative P2 is not applicable, as it is not possible to connect to topside with either fixed electric line, wet mate or wireless communication.

In addition I think there will be a problem connecting to topside for positioning alternative P5, due to the very narrow area in the transition between TH and THRT. Since I am not certain of how small an electric wet mate can be, I will ask for advice from a technical specialist at Aker Solutions before making any conclusion.

The remaining positioning examples are thus: P1, P4, P5, P6 and P7, which will be presented in a concept design review (See section 8.4).

8.3.3. Concept 9a, Possible Design and Location of Mechanical Verification System for Hybrid Penetrator

The Hybrid Penetrator has 8 hydraulic connectors and one electric connection that is to be connected to the TH. The hydraulic connectors are positioned closer to the TH than the rest of the Hybrid Penetrator. Thus when one is to prevent HP from engaging into wrong area of TH, one has to make sure mechanical verification solution, stop the HP from engaging, before the hydraulic connectors meet any area of the TH.

In order to use a mechanical verification method with pin(s), the pin(s) has to emerge into an area of TH that is closer to the pin than the hydraulic connectors on HP are to the TH.

When HP engaged into wrong area of TH earlier (appendix B, section B.3), it engaged into part of TH in yellow colour (figure 140), and into the area the electric connector is supposed to connect. Of these two areas of the TH, the yellow coloured part is closest the HP as it engages.

In cases of TH being positioned in wrong height: As long as one makes sure that the HP will be stopped before reaching any component of TH that is at a distance equal to or greater than the yellow areain figure 140, the hybrid penetrators will not be damaged.

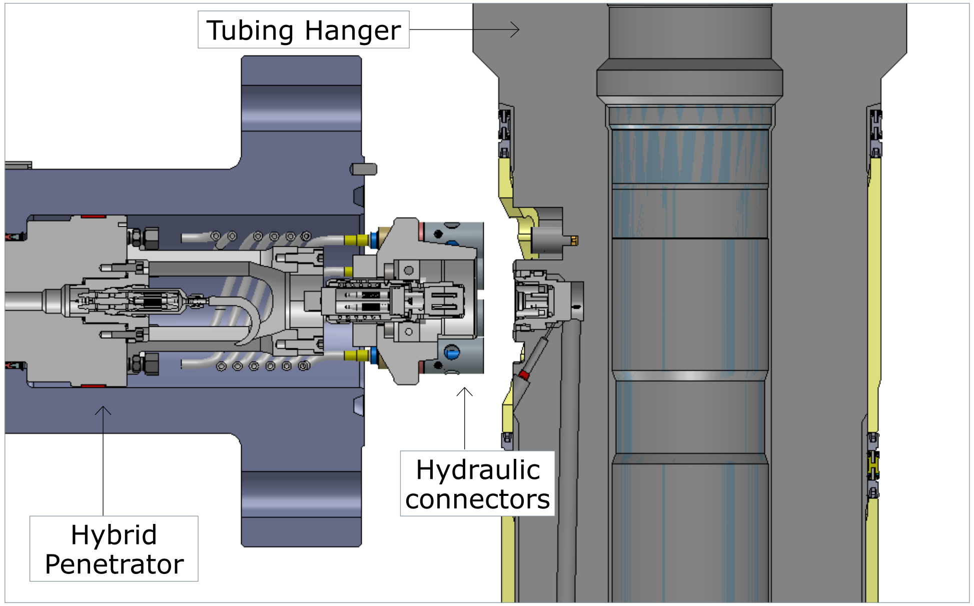


Figure 140: *Section cut of Hybrid Penetrator and Tubing Hanger. [6]*

Figure 141: *Red circles indicating where Hybrid Penetrator got engaged into TH. [2]*

The TH can be in wrong position by a few millimetres, or as much as e.g. 38 mm, which was the case in incident described earlier (appendix B). The challenge is to make sure that the HP is stopped whenever TH is in wrong vertical position, independent of by how much, in addition to making sure that the TH do not get damaged.

If one include a pin on HP that is to engage into a hole in the TH, this can cause harm to the TH connection area, if it hits one of the electric or hydraulic connecting points. In addition there is no space on the TH where a long pin can engage into. It will conflict with other components.

In order to get a better overview of the situation, I have added the XT spool to the model:

One solution could be to add an obstacle component on spool that will engage if TH is in wrong position and stop HP from engaging. The disadvantage for that kind of verification system is that if the obstacle component fails to retract, the HP will not be able to engage even though TH is in the right position. To implement a verification system that can result in installation failure if it fails itself is off course not an option.

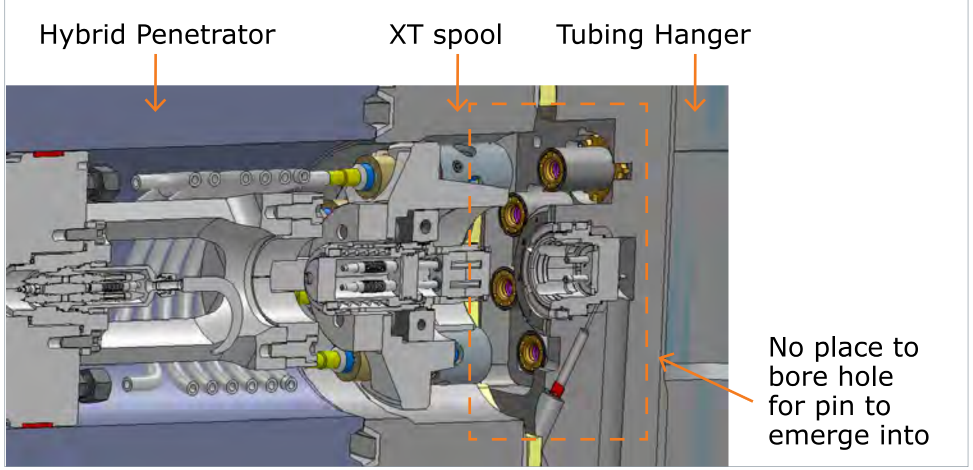


Figure 142: *Section cut showing close up picture of TH, XT spool and TH, before HP has engaged into TH. [6]*

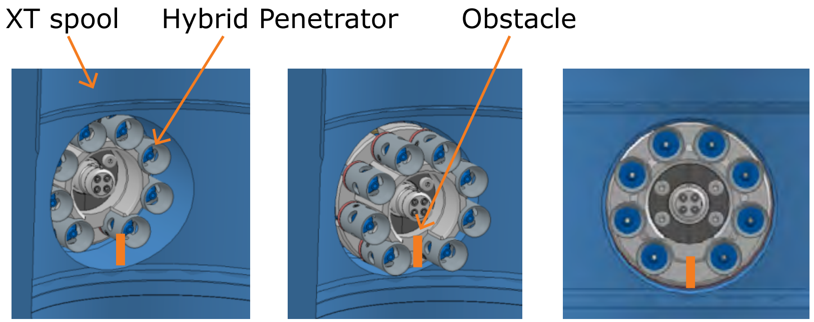


Figure 143: *The orange pin is the obstacle preventing HP from emerging when TH is in wrong vertical position relative to the spool. [5], [6]*

Comments
After having studied SW 3D model for a while and evaluating different solutions that all will cause more problems to the system as a whole than it solves, this is my conclusion: Gallery area where HP engage into TH is so full packed of hydraulic and electric connectors, and related components that there is no space for mechanical verification component(s) there.

Since this mechanical verification concept for HP turned out to be very difficult to work out, I have tried to come up with an alternative concept for mechanical verification system. The new concept, will be refered to as concept 11, and a description is given below.

8.3.4. Concept 11, Possible Design and Location of New Mechanical Verification System.

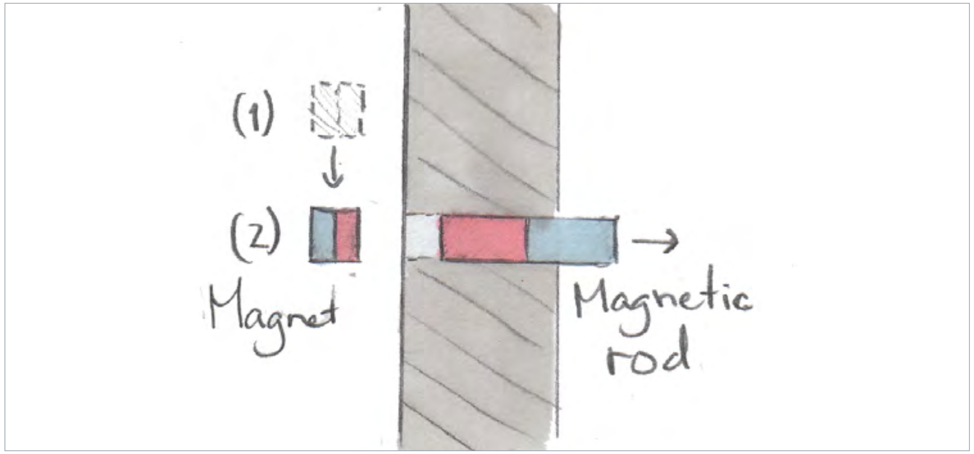


Figure 144: *When magnet is in position 1, the magnetic rod will be inside grey component, when the magnet move to position 2, a repulsive magnetic force between magnet and magnetic rod will cause magnetic rod to move partially out of the grey component. [5]*

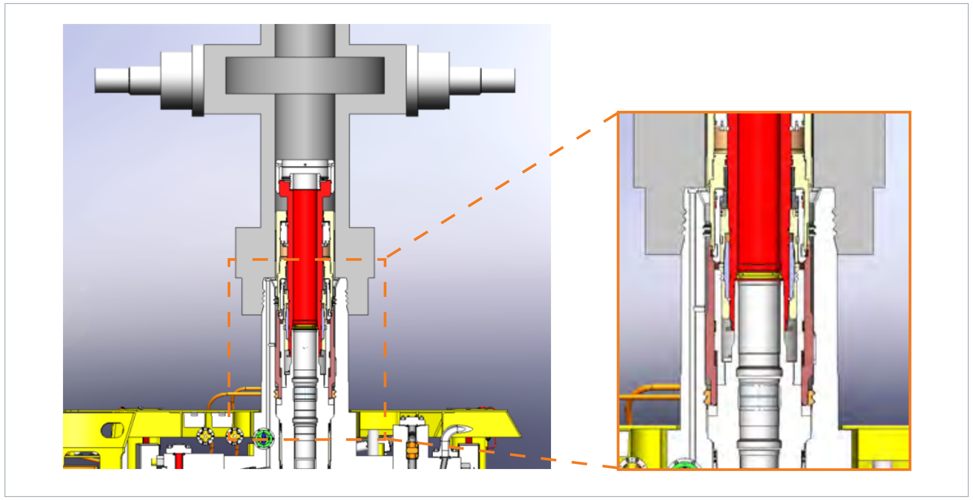


Figure 145: *Area of spool suited for integration of new mechanical verification concept. [6]*

The main thought of concept 11, which is illustrated in figure 144, is that the magnetic rod is to be visual for inspection by a ROV unit with camera. The upper part of the XT spool body which is below attachment area for BOP, is the only section of the XT spool that is not closed within XT or BOP. Thus it is the only area that can be suited for this concept. For ROV to be able to inspect magnetic rod, it has to be located in the spool body.

On the next page, I have illustrated how the verification concept can be integrated to this area, in order to provide verification of landing and locking of TH.

Figure 146:
A magnet is inserted in the actuation sleeve. When the TH lands in right vertical height, a magnetic rod located in the spool will be pushed out by repulsive magnetic forces. As the activation sleeve goes into lock position, a second rod will emerge from the spool.

A weakness of this concept is that it will only work once. [5], [6]

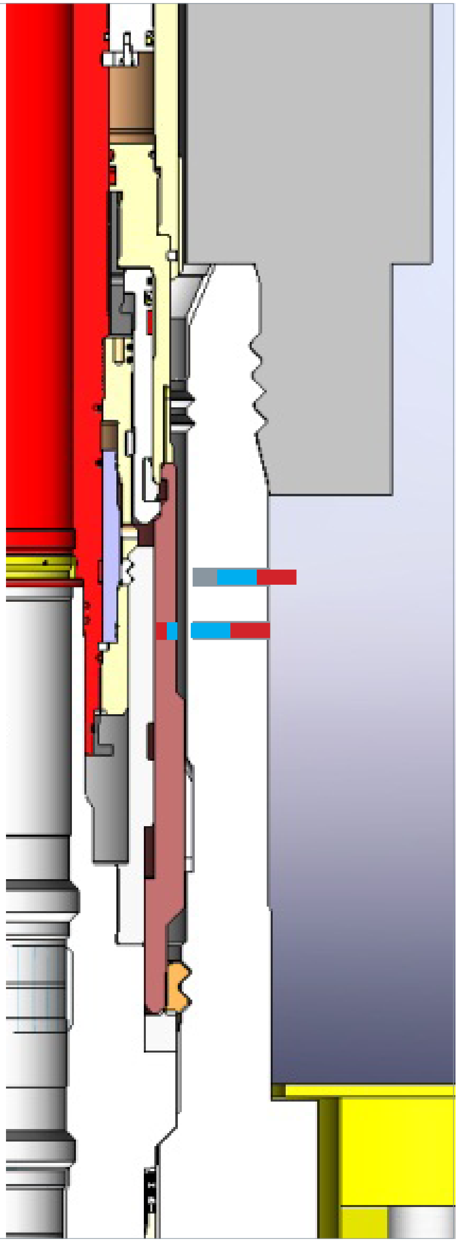
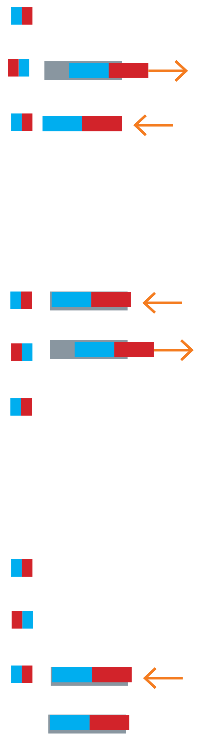


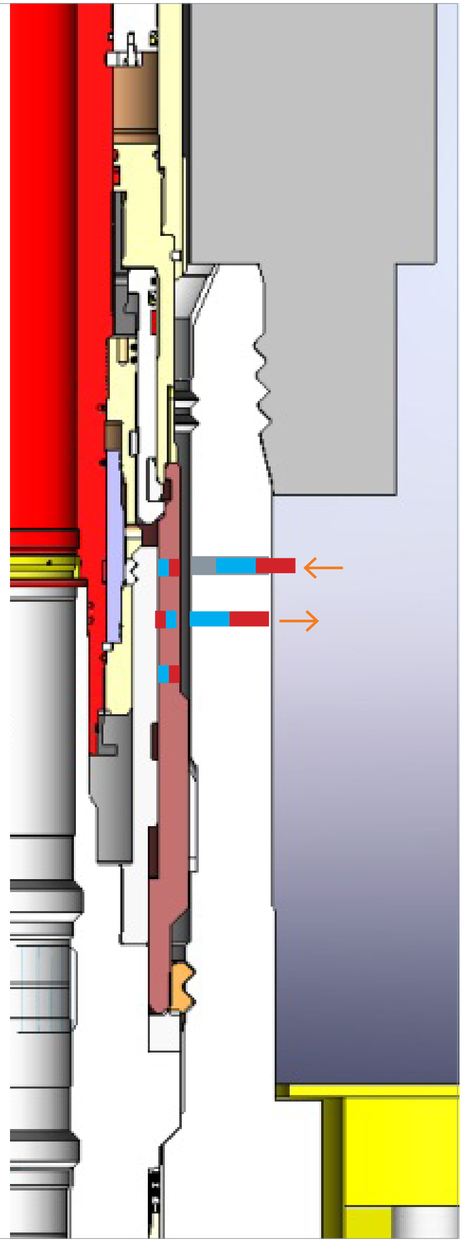
Figure 147:
Here I have tried to improve the weakness of solution shown in figure 146. The system has three magnets in actuation sleeve instead of one. [5], [6]



1) When TH lands in correct position, a repulsive force will act upon the upper magnetic rod, while an attractive force acts upon the lower.

2) When TH lands is properly locked to the spool, the opposite will be the case.

3) If one unlock TH the lower rod will glide back into spool body, while upper rod goes out. If TH is to be retrieved, the lower magnet will make sure the upper rod glide back into spool body.



Comments:
The new mechanical verification concept has some weaknesses. A magnet do not send out a line of magnetic force, but a whole magnetic field around itself, thus the magnetic force of one magnet in the lock piston will apply a force upon both rods at all times (when close enough).

In addition, if the rods are to be loose enough to be able to move when a magnetic force acts upon them, they will probably also move by fault due to pressure difference on the outside and inside of the XT spool.

8.3.5. Concept 9b, Possible Location of Subsea Camera

The most compact subsea camera I have been able to find is Imeco`s Greytip camera. I have made a simplified 3D model of the camera in SolidWorks, and given it a yellow colour, so that it will be visible when inserted into original model of XT system.

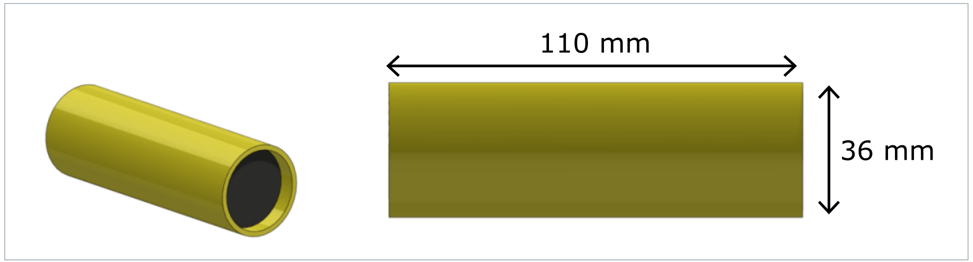


Figure 148: *SolidWorks 3D model of camera, with length and diameter dimensions. [5]*

Figure 149: *Hybrid Penetrator. (scale 1:15) [6]*

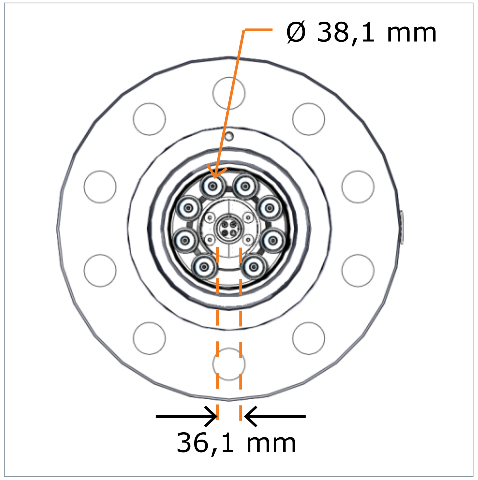


Figure 150: *Front view of HP, with indication of available space for camera. (scale 1:10) [6]*

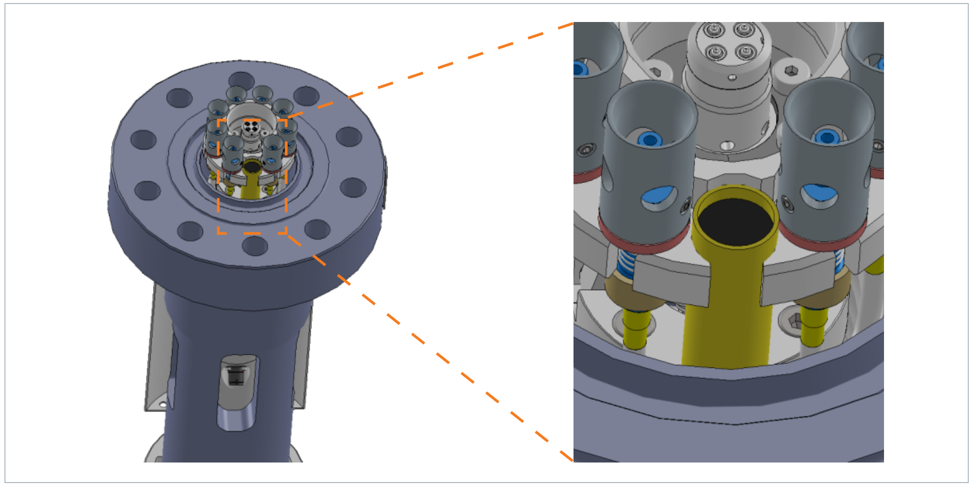


Figure 151: *This is the only possible way to position a camera with diameter of 36 mm, on the Hybrid Penetrator, if it is to inspect vertical position of TH relative to the spool. [5], [6]*

In order to impement the camera to the Hybrid Penetrator, the original design of HP component which holds the electric and hydraulic connections has to be altered.

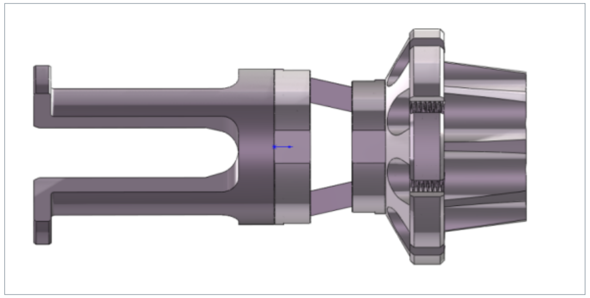


Figure 152: *Pedestal misalignment system, which holds the electric and hydraulic connectors. (scale 1:4) [6]*

For the new design I have bored a new hole in the pedestal misalignment component, and cutted away area between the hole and the outer edge, similar to design of holes for hydraulic connections. In addition I have made sure that there are no sharp edges.

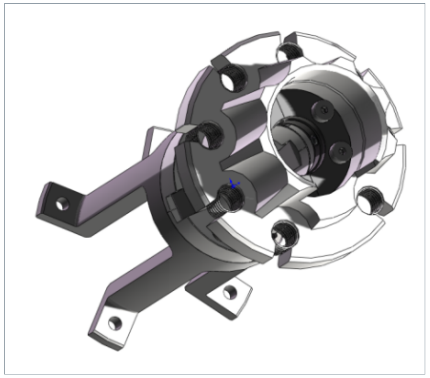


Figure 153: *Original design. [6]*

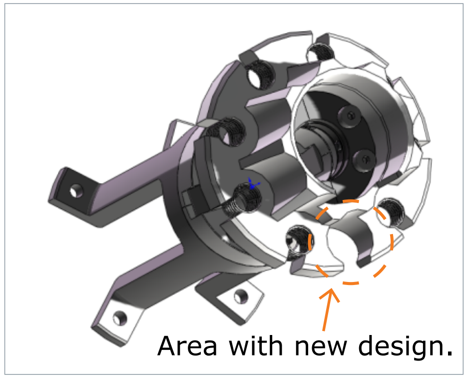


Figure 154: *New design. [5], [6]*

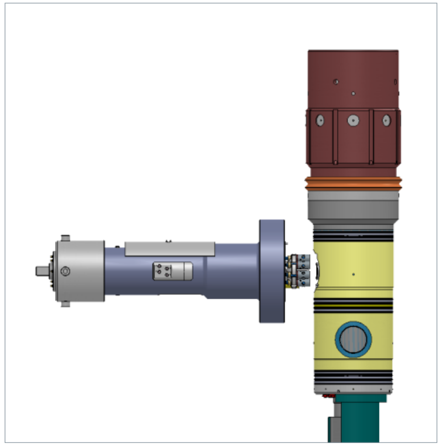


Figure 155: *Before HP emerge into TH. [5], [6]*

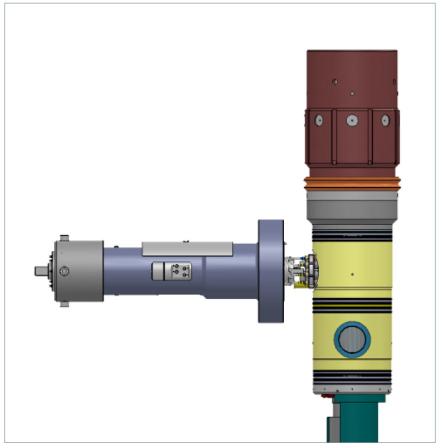


Figure 156: *HP connected to TH. [5], [6]*

The is a problem when HP emerge into TH, since the camera is so long that it hits into the TH (figure 155, 156, 157 and 158). It is not possible to locate camera further into the HP component, as it is only 2 mm from conflicting with component inside HP.

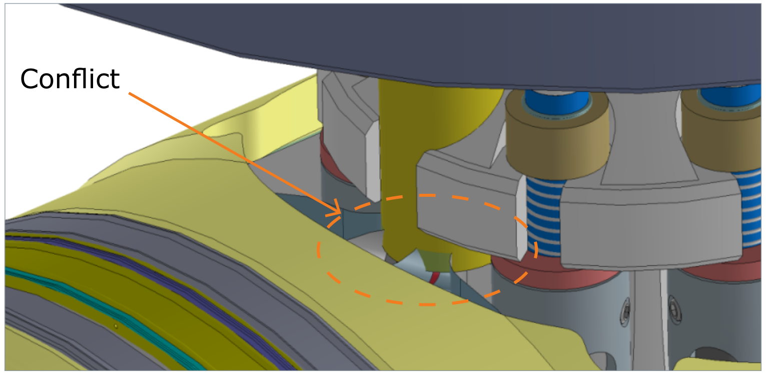


Figure 157: *Conflict between camera and TH. [5], [6]*

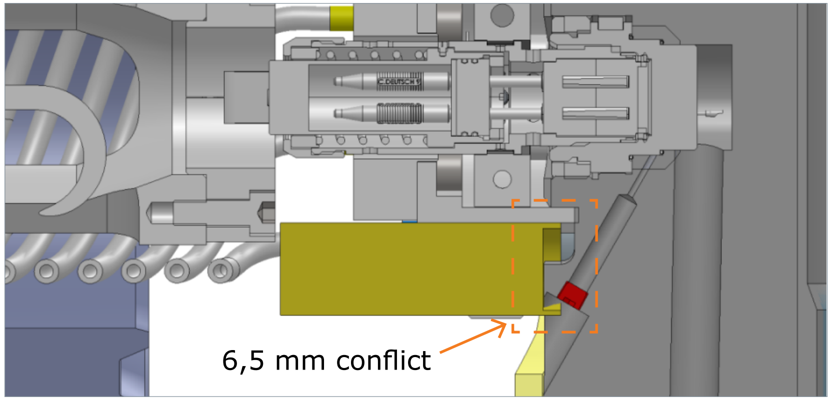


Figure 158: *Side view in order to visualise the conflict more clearly. [5], [6]*

This means that if camera is not to conflict with TH, the length of the camera has to be smaller. If it already exists or is possible to develop a camera that is 10 mm shorter, there will be no conflict between camera and TH:

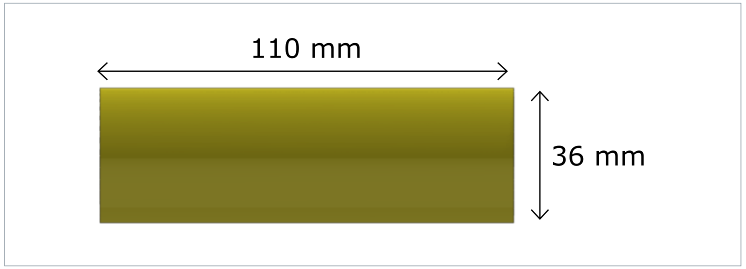


Figure 159: *New measures for shorter camera. [5]*

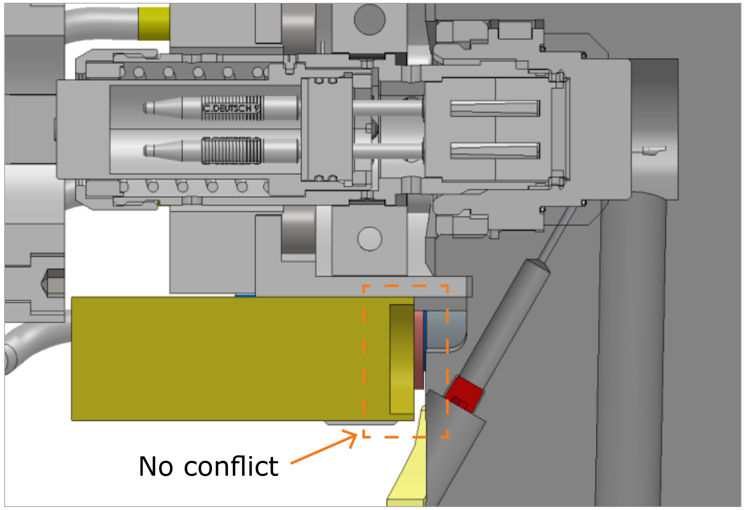


Figure 160: *No conflit between camera and TH. [5], [6]*

Next I have looked into how the camera should verify correct height of TH:

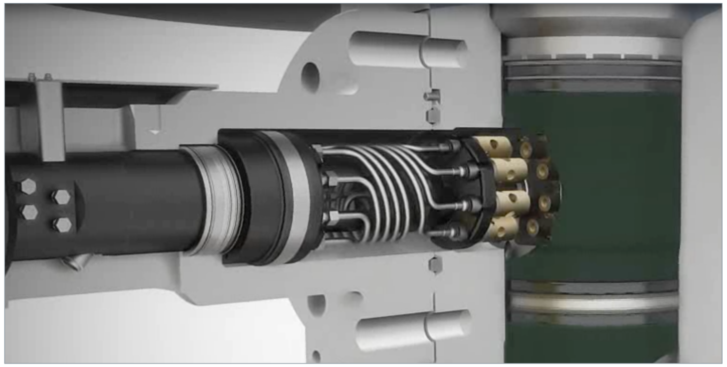


Figure 161: *Before HP engage into TH. [2]*

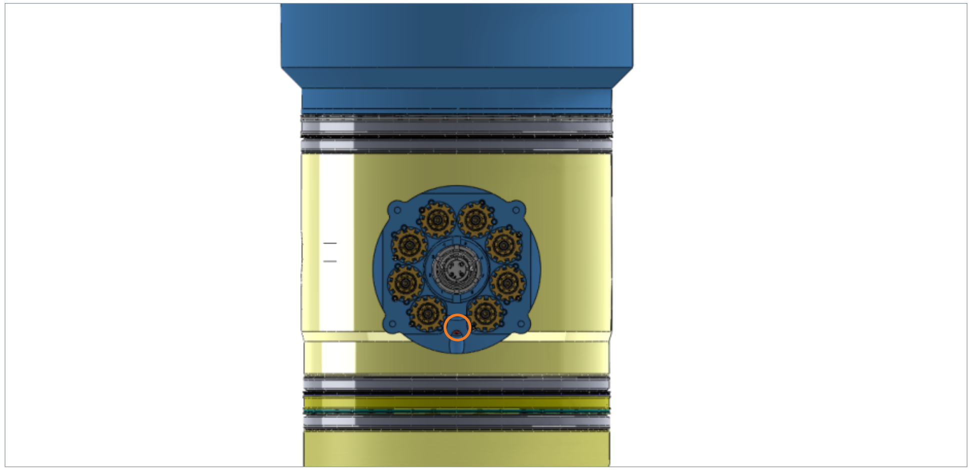


Figure 162: *The orange circle indicates which area of TH that the camera looks directly into. The blue coloured area is usually grey, but in order to get a good contrast to the orange marking, I have given it a blue colour. [6]*

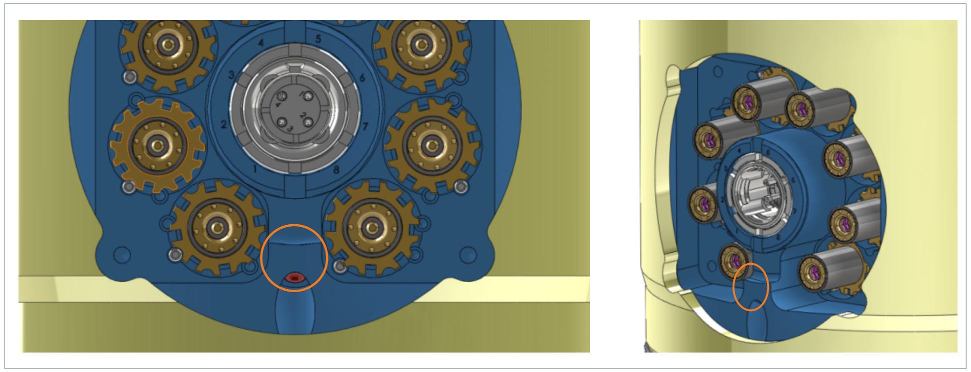


Figure 163: *Closer view of area in which camera loooks directly into. [6]*

A rectangular frame will be drawn onto the class cover in front of camera lens, as shown in figure 164. The illustration to the left in the figure shows what the camera sees when looking at a white surface.

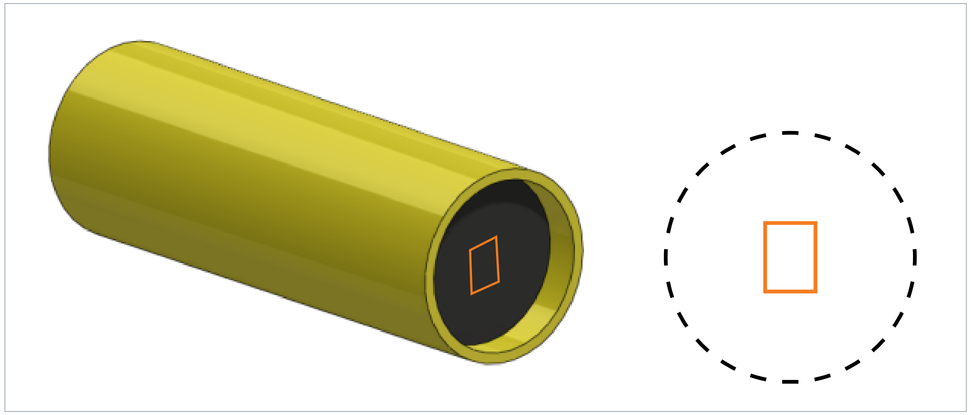


Figure 164: *Rectangular frame drawn onto class cover of camera lens. Illustration to the right is what camera will see when looking at a white surface. [5]*

A similar rectangular shape, shat is slightly smaller will be painted onto the TH. That shape can either be a frame, or a filled rectangle as shown in figure 165.

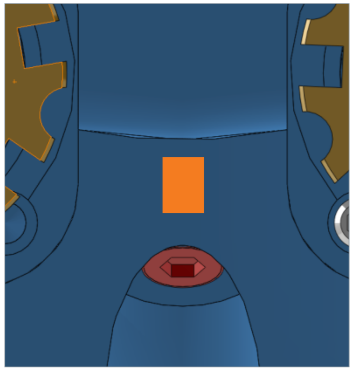


Figure 165: *Mark painted onto TH. [5], [6]*

Figure 166 illustrates how the frame on camera should line up with the painted mark on TH, when TH is in right position. If the rectangular shape on TH is outside the frame, TH is in wrong position.

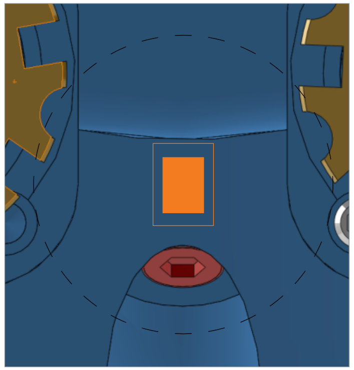


Figure 166: *What camera should see when TH is in correct position. [5], [6]*

8.3.6. Concept 9b, Connection to Topside

As the camera is connected to the Hybrid Penetrator, it is probably easiest to connect in in a way similar to that of the electric connector, or the hydraulic lines.

The hydraulic lines are connected to the remaining XT system on the sides in the HP. There are 4x2 connecting points on opposite sides of the HP.

Each hydraulic line has its own path inside the core of HP, before they all exit and form a spiral shape. At the end of the spiral, they are aligned in a circle for connection to TH.

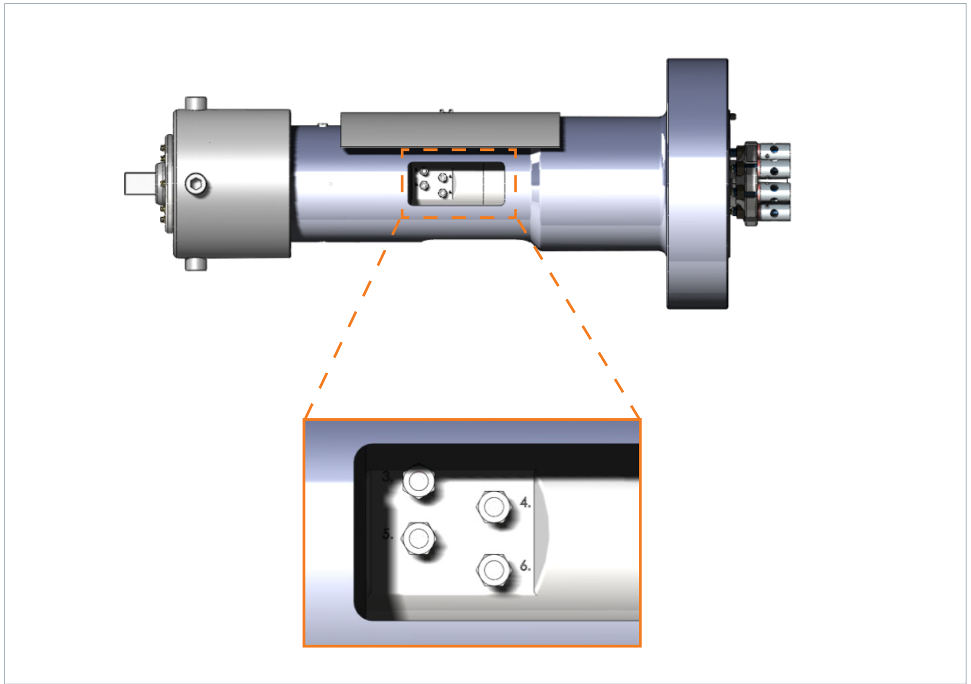


Figure 167: *Connection to hydraulic lines on Hybrid Penetrator. (scale 1:10) [6]*

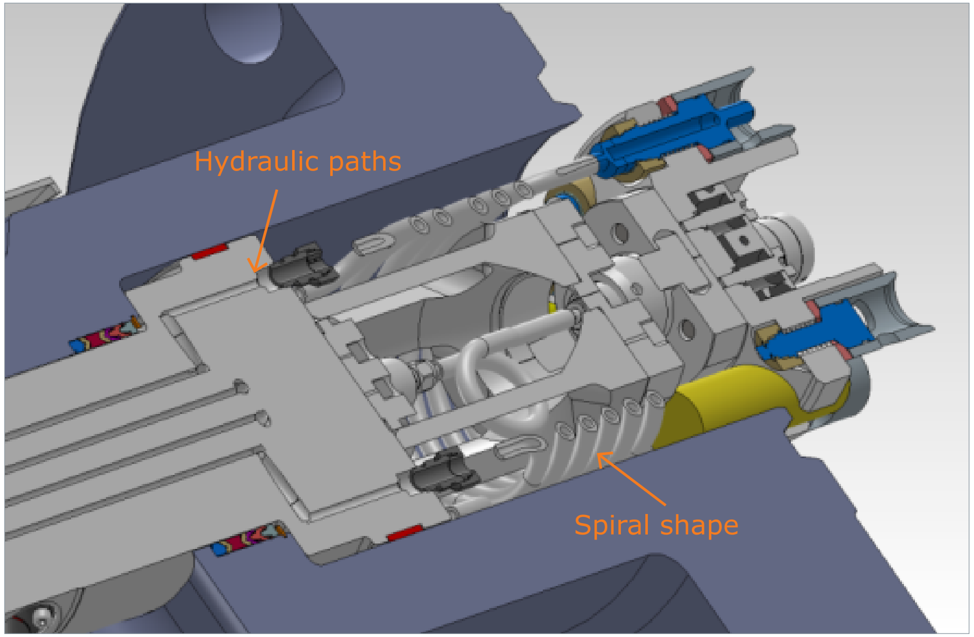


Figure 168: *Section cut of Hybrid Penetrator showing hydraulic lines. [5], [6]*

The electric line is connected on the underside of the HP:

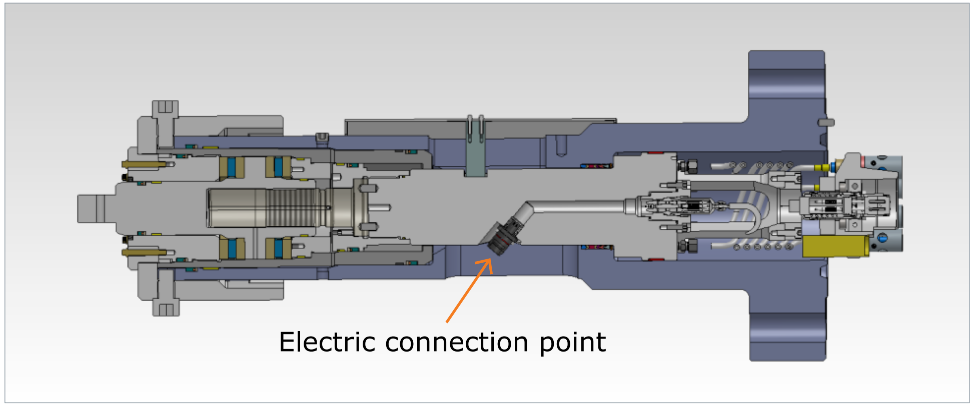


Figure 169 *Cross section view, to show location of electric connection point. (scale 1:20) [5], [6]*

The electric line goes through the core of HP, and then it forms a loop, before one reach the other end of the electric HP line. The loop is created so that the line will be a bit flexible.

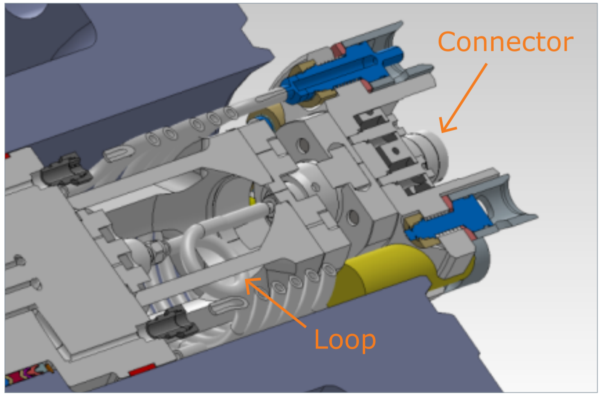


Figure 170: *Section cut showing HP`s electric line. [5], [6]*

Comments:
As I am unsure about how connection line for camera should be integrated to the Hybrid Penetrator, I will ask for advice during a concept design review meeting, where I also will present my other verification concepts. Information about the concept design review meeting is presented in the next section.

8.4. Concept Design Review

8.4.1. Short About the Meeting

I arranged a Concept Design Review meeting for supervisors and colleagues at Aker Solutions. The aim of the meeting was to get some feedback on the work I have done so far.

In order for the attendants of the meeting to understand how I ended up with my latest concepts, I first explained the design process I have had which includes: getting to know the subsea system, research on reported incidents, hazard identification, basis of design, technology analysis and creative concept development phase. I also gave an explanation of how TH is installed for those who did not know the system in detail from before.

The ten early concept ideas I started off with were presented, and I explained which four concept I ended up with after own concept screening. In addition these concepts were presented in more detail with a subsequent discussion:

- Concept 3 and 6 with positioning alternatives P1, P4, P5, P6 and P7.
- Concept 9a, mechanical verification system for HP.
- Concept 9b, subsea camera attached to Hybrid Penetrator.
- Concept 10, GPS device attached to landing string.
- Concept 11, new mechanical verification system.

8.4.2. Most Important Feedback

Concept 3 and 6

P1:

- If there is debris on the landing shoulder, the switch/sensor can be activated, even though TH is not in right position. Thus the position of switch/sensor should be changed.
- Smart to do the verification by the TH`s main body, as it is not free to rotate relative to the rest of the XT system.

P4:

- Instead of using existing hydraulic line, one should make a new line for electric connection.
- It will probably be difficult to assemble the TH with the relevant sensor position.
- THRT piston can rotate relative to the TH`s main body, and thus it can be critical to have an electric line between main body and piston.

P5:

- As I assumed earlier the transition area between TH and THRT is too narrow for integration of electric wet mate.
- A suggestion was made to have the connection in hollow area in between TH and THRT.

P6:

- The actuation sleeve can rotate relative to the TH`s main body.
- Will probably be difficult to insert the electric line, sice it is not a straight path.

P7:

- Not possible to penetrate wall of spool fully, so the proximity switch must be able to sense magnet through some wall thickness.

NEW: positioning alternatives for concept 3 and 6

P8:
- Position sensor by locking dogs (also called shear dogs, spring lock and secondary lock).
- Must be aware of that the locking dogs are positioned in the actuation sleeve, which can rotate relative to the TH`s main body.

P9:
- Position sensor in the spool, close to the lower part of split lock ring.
- This requires that it is possible to make material of split lock ring permanent magnetic.

P10:
- Position sensor in the upper part of spool body.
- This can give both verification of landing and lock by registering position of lower locking sleeve.
- Keep in mind that the locking sleeves can rotate relative to the THRT`s main body.

P10:
- Position magnet in TH component which is of inconel material.

Concept 10, GPS
- Can use a local positioning system at rig, that will be more precise than the global positioning system (GPS)

Concept 11, new mechanical verification solution
- This kind of system will not be visible for ROV, due to a guiding funnel covering the upper part of the XT spool. I was not aware of this from before. Thus this concept is not applicable.

Concept 9a, mechanical verification system for HP.
- No suggerstions were made for how to solve the space issue.

Concept 9b, subsea camera
- Not necessary to have a camera, it is enough with a simpler verification that is not visual. On/off switch system of any type can provide necessary verification for vertical position of TH.
- Important to be aware of that there is bore slam in the gallery area, thus there is not any good visibility. In addition the drilling fluid is filled with magnetic materials, so that a magnet sensor will probably not be an ideal solution.
- Keep in mind that there will be a distance of about 96 mm between sensor and TH.
- Strength of this concept is that it does not require any new penetration into XT system for feed through, it can be linked the Hybrid Penetrator`s feed through system.
- It has been discussed to change one of the Hybrid Penetrator`s 8 hydraulic lines with an optic connection that is to go down hole. This cannot be used for verification of TH position.
- Verification sensor can be located in the same way as I positioned the camera.
- One has to insert a new line from sensor, which is connected to the rest of the XT system in the same way as the hydraulic lines are today. It is uncertain how easily that can be done.
- Must be combined with a lock down verification, as it only gives verification of the TH`s vertical position.

NEW: Concept 12, laser measurer
- Can use laser mark measurement for TH`s last veritical movement of 150 mm.

NEW: Concept 13, torque resistance tool
- I was informed that it exists a measuring device for torque resistance, that can be used when engaging Hybrid Penetrator.

General comment: One cannot penetrate the spool body fully, but partially is possible, as long as the spool as a whole can still perform its task as a safety barrier.

8.4.3. Result from Concept Design Review Meeting

It appeared some new concepts during the concept design review. Here is an overview of all the relevant concepts:

- Concept 3 and 6 with their relevant positioning alternatives P1, P4, P5, P6, P7 in addition to the new positioning alternatives P8, P9, P10 and P11.
- Concept 9a
- Concept 9b
- Concept 10
- Concept 11
- Concept 12
- Concept 13

In the next section, comments from the concept design review meeting has been used as a base for concept selection.

8.5. Concept Selection

After the concept design review meeting, a concept test was carried out together with my supervisor Magus F. Urke, in order to narrow down the scope of concepts. This was done on basis of the feedback that was given during the concept design review meeting.

Table 14: *Results from the concept selection process are shown below. The criteria is a selected scope of relevant requirements from basis of design. Points given are +1, 0, and -1. A ranking has been done from 1-5 where 1 is the strongest alternative. There is also an indication of if concept is to be further developed or not.*

Type of criteria	Criteria	Concept nr. and title							
		3	6	9a	9b	10	11	12	13
		Limit switch	Proximity switch	Mechanical system for HP	Subsea camera in HP	Local positioning system	Magnetic rods in spool body.	Laser measuring device	Register torque resistance
Technical	Provide valuable verification info	+1	+1	-	-1	0	+1	0	-1
	Integrability to XT system	+1	+1	-	+1	0	0	+1	+1
	Possibility of connecting to topside	+1	+1	-	+1	+1	-1	+1	+1
	Low risk of malfunction	0	+1	-	0	0	-1	+1	+1
Durability	Low wear on verification system	-1	+1	-	0	+1	-1	+1	+1
	Limited need of maintenance	-1	+1	-	0	+1	-1	+1	+1
Simplicity	Low system complexity	-1	-1	-	-1	-1	+1	0	0
SUM		0	5	-	0	1	-2	5	4
Ranking		4	1	-	4	3	5	1	2
Relevant/ Continue development?		No	Yes	No	Maybe	Yes	No	Yes	Yes

Comments to table 14:

As stated in the concept selection table, I will continue developing concept 6. Concept 3 will not be developed further, because:

1. It got a low score, since it does not have low wear, and require inspection and cleaning.
2. A limit switch can be easily substituded by a proximity switch, and concept 6 got a much higher score.

Concept 9a did not get any score in the table, because there is no space available for connecting a mecanical verification system to the Hybrid Penetrator. Concept 13 on the other hand is able to privide the type of verification that concept 9a was suppoused to.

Concept 9b might be relevant for further development. Due to the fact that there is not good enough visibility for the camera to give the intended verification, use of subsea camera is not a good solution and the concept got a negative score on "providing valuable verification information". But the concept has got a high score on most of the remaining criteria. Thus if one is able to find a suited sensoring system, and position it at the same location as the camera was positioned, one has a potentially strong concept.

None of the sensoring system concepts that were developed earlier in this project, are able to substitute the camera`s function. As I do not have time to start developing completely new sensoring system concepts, further development of concept 9a can be a back up solution if concept 6 prove to not be feasible after all.

Concept 10 got zero as score on the criteria "providing valuable verification info". The reason for this is that it can give a good indication of TH`s movement down into the XT-spool, but not to required precision level for TH installation. Thus this verification method can be carried out in advance of e.g. verification method used for concept 6. Concept 10 got a realtaively high score for the rest of the criterias, and thus it is relevant for further deveopment.

Concept 11 will not be further developed, as it is a very weak concept, that is not possible to integrate in the XT system.

Concept 12 got a low score on first criteria, because it does not provide verification to required accuracy of TH position. For the rest of the criterias it got high scores, and ended up as 3rd strongest concept. As stated in the table, this concept will be further developed.

Similar to concept 10 and 12, concept 13 also got low score on the first criteria, but relative good score on remaining criterias. Concept 13 does not provide any verification of TH landing or lock, but it can ensure that HP is not destroyed if TH is in wrong position. Thus this concept can work as a fail safe solution. If landing and lock verification fails, the registration og torque resistance will ensure that the HP is not damaged. Concept 13 got one of the highest scores, and will therefore be developed further.

Conclusion:

- Concept 6 will be further developed, and now counts as the most relevant verification concept.
- Concept 9b will be further developed, if concept 6 prove to not be feasible.
- Concept 3, 9a and 11 are not relevant anymore.
- Concept 10 and/or 12 can be used in combination with concept 6, and will provide the first indication of correct installation.
- Concept 11 can be used in combination with concept 6, 10 and/or 12 as a fail safe solution.

Which type of verification information each concept provide was not included in the concept selection table 14, but this was evaluated earlier in table 12, where concept 6 proved to have the potential of providing all relevant verification information that is listed in basis of design.

8.6. Further Concept Development

8.6.1. Concept 6, Proximity Switch

Integration of verification system in spool

I will start off by studying the spool body more closely in order to get a better understanding of relevant restrictions.

Today there are 6 bore lines in the spool. One of them is for Hybrid Penetrator to be able to connect to TH, another is for the production stream from well and the other four are used for pressure testing of TH after landing and lockdown.

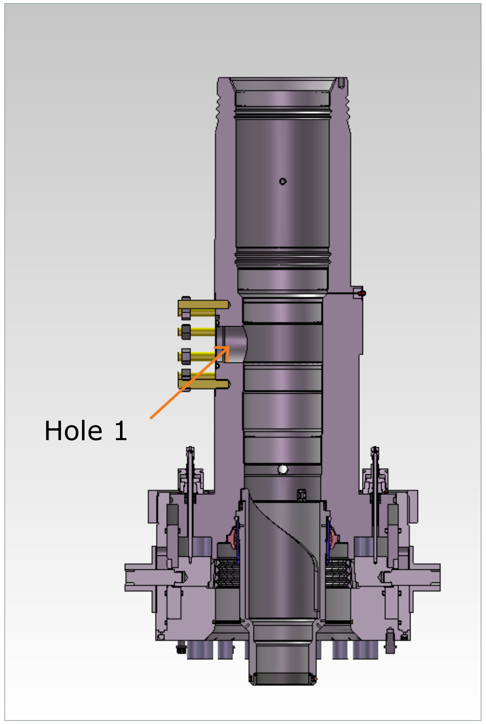


Figure 171: *Hole in spool body for Hybrid Penetrator. (scale 1:25) [6]*

All of these 6 holes are straight lines that have been drilled into the spool body. Holes 1-5 have been drilled from the outside of the spool, while hole 6 have been drilled from the inside.

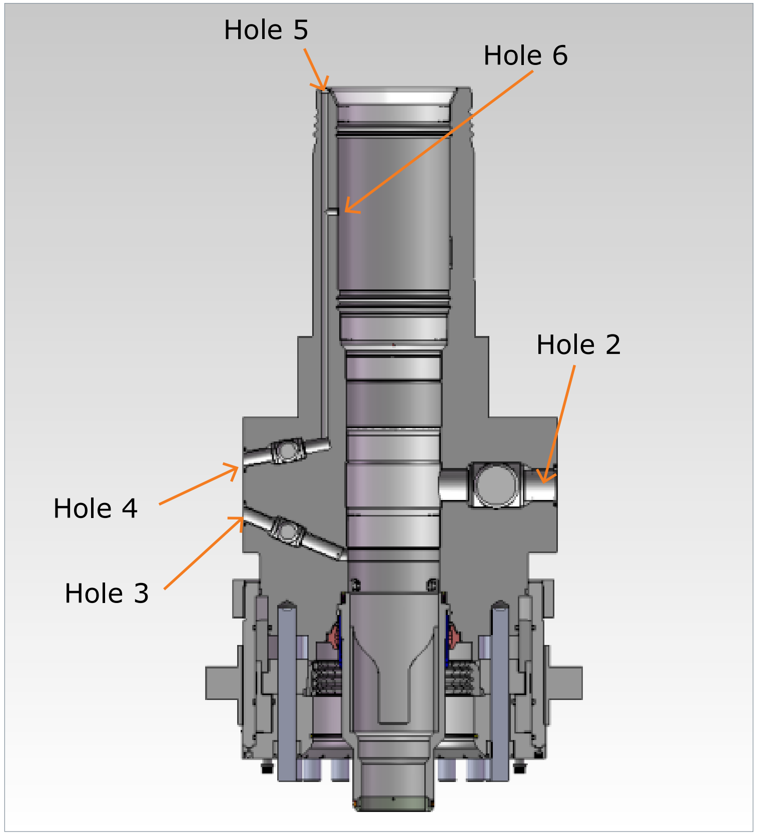


Figure 172: *Internal lines in spool body. [6]*

Seven of the Hybrid Penetrator`s hydraulic lines goes downhole. The last one provides means of pressure testing, and has a hydraulic path inside the wall of the spool.

Hole 2 (figure 172) is connected to Flow Control Module , and hole 4 and 3 are connected to Subsea Control Module. Hole 5 and 6 provide a path for hydraulic fluid during pressure tests. Holes 1-4 are connected to the XT assembly. Due to this they are located at about the same height.

If a future TH verification system is to be connected to subsea controll module or ROV panel, holes drilled for electric connection line has be located around the same heigth as holes 1-4.

Thus if one would like to drill a new hole for electric/optic line that is to be connected to a switch/sensor, one has to start within the area shown in figure 173. In addition it is only possible to drill straight paths.

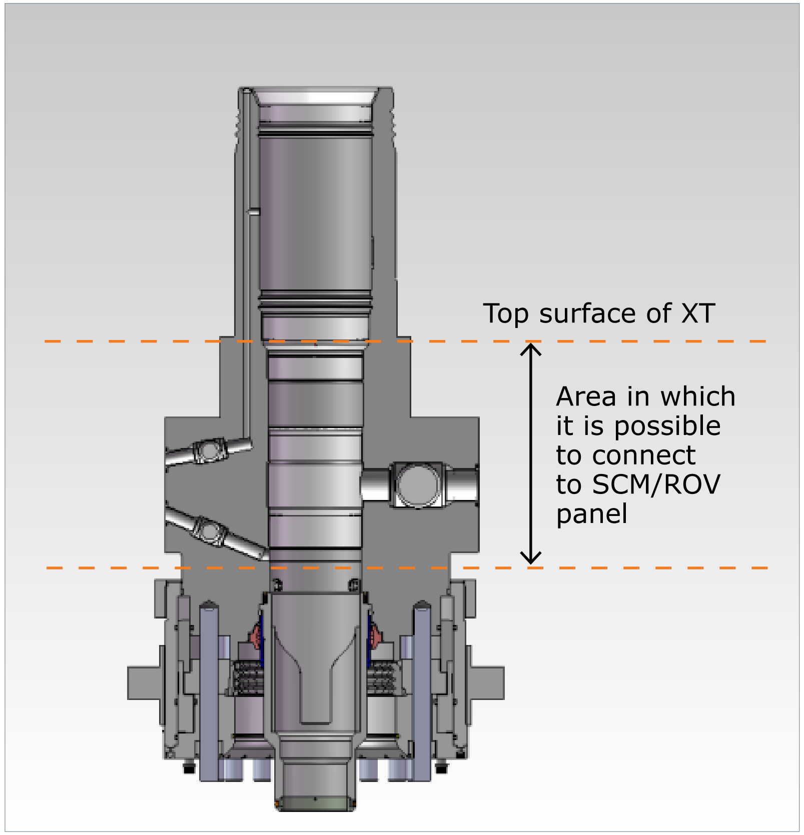


Figure 173: *Area for connection to Subsea Control Module (SCM) or ROV panel. [6]*

The blue lines in figure 174 are drilled lines that probably will be possible to make. For the upper part of the spool body, I have only given indication in one specific cross section and only on one side, but it applies for both sides of all possible cross sections that do not intersect with hole 5 or 6.

If one is to have switch higher up in the spool body with direct electric connection to XT, one need to drill three holes, as shown in figure 175. One is for the switch, while the two other are paths for electric wire. This kind of drilling process is much more expensive and complicated compared to the drill hole examples in figure 174. In addition it can be a challenge to run an electric line through the drilled lines. Therefore a wireless communication system might be preferred, for location of switch relatively high up in the XT spool body.

As mentioned earlier one cannot drill through the whole thickness of the spool`s wall, thus the blue lines are only partial drilling penetrations.

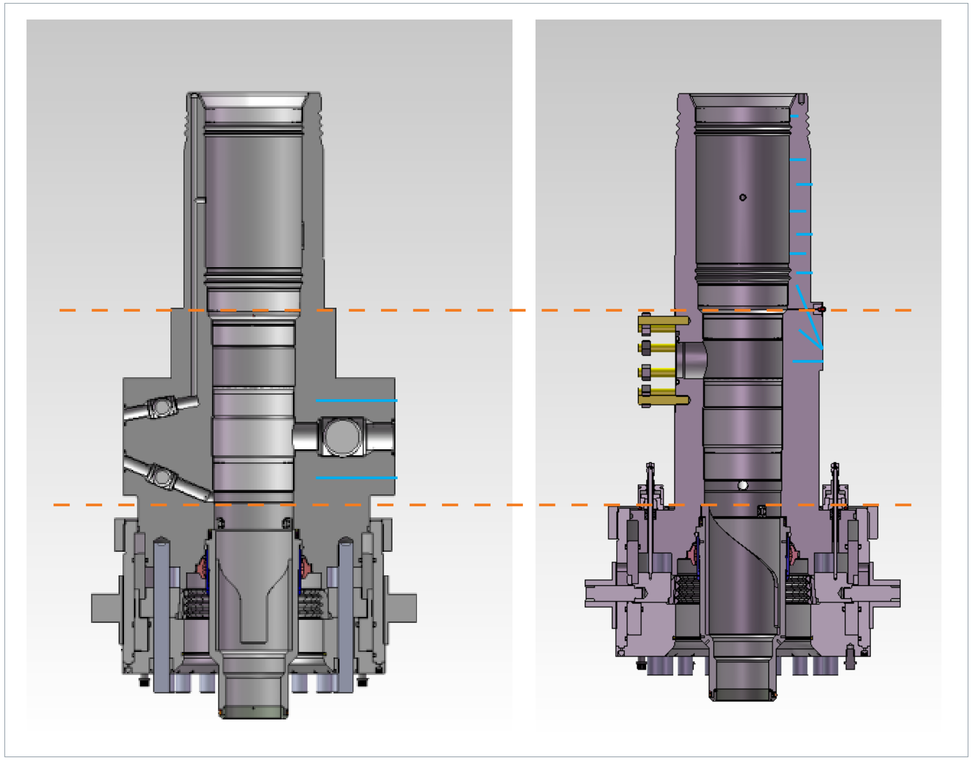


Figure 174: *Possible holes that can be drilled into spool body. [6]*

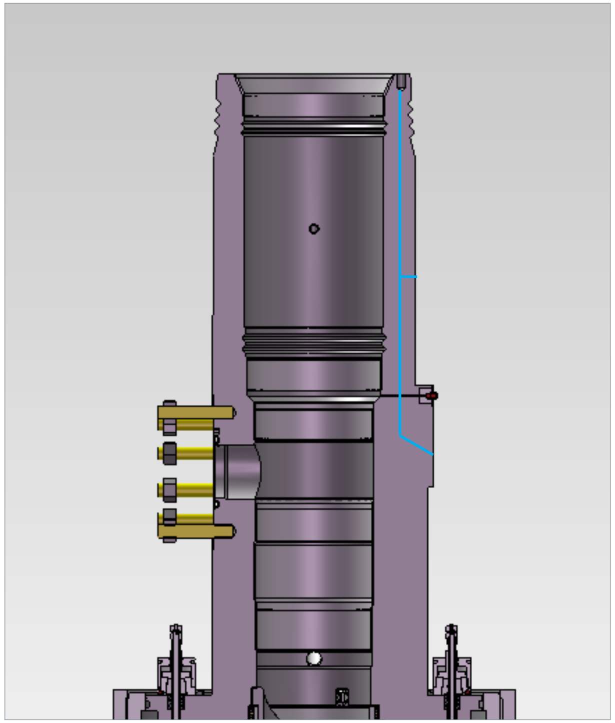


Figure 175: *Possible electric line path for switch positioned high up in the spool body. [6]*

Restrictions of proximity switch technology

In order to get a better overview of how a proximity switch verification system should be integrated into the XT system, I contacted SEACON for some more product information. Some of the information I got was this:

- Size of target magnets are typically 12,7 mm x 5,1 mm (0,5" x 0,2") and 19,1 mm x 9,7 mm (0,75" x 0,38")
- A proximity switch can in general not detect magnet through wall of ferrous material. If possible it will require a very strong magnet and the verification will be unreliable.
- Ferrous material surrounding magnet target will affect the accuracy and actuation distance.
- Mounting in non-ferrous material is best, or one should as a minimum allow a space around the magnet.
- SEACON has proximity switches that are able to sense from the side as well. (Side sensing switch).

P1, Landing verification, verify vertical position of TH`s main body with sensor located in spool body:

- Position of switch has been changed so that debris won`t be an issue.
- The verification is still registering vertical position of TH`s main body.

Figure explanation:
- Proximity switch in orange
- Magnet in red
- Dark grey area is cavity and potential space for wireless communication components.

- Before getting additional product information from SEACON, I thought of drilling hole for sensor from the outside of the spool, and to attach electric wire directly to XT control system. (Figure 176)
- Sensor has to use wireless communication, since one cannot penetrate spool wall fully, and the switch cannot be separated from the magnet by a wall of ferrous material. Dark grey area is potential space for wireless technology components. (Figure 177)
- Cavity will be made from inside of the spool.
- Magnet will be inserted in TH. (Figure 178)

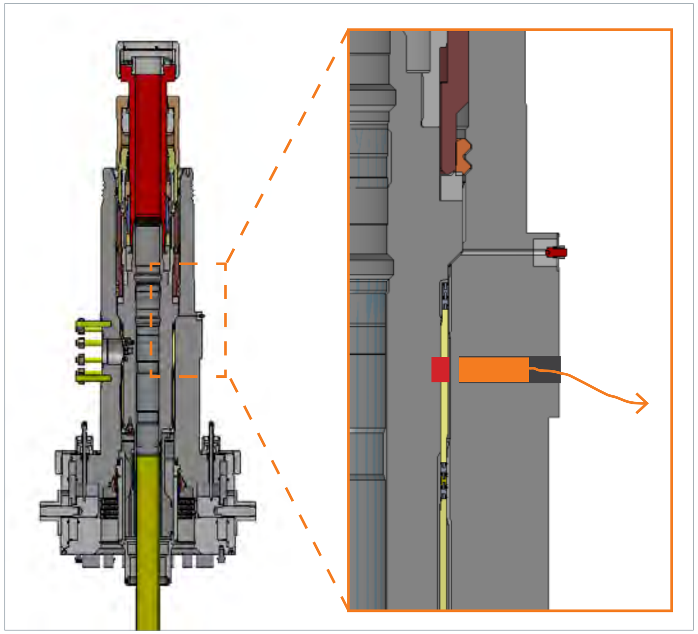


Figure 176: *Proximity switch verifying position of TH`s main body, with electric line connection. [5], [6]*

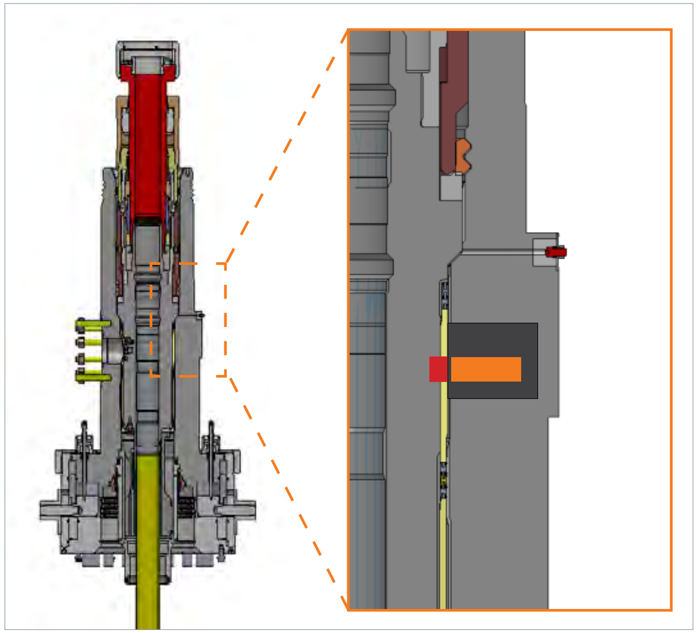


Figure 177: *Proximity switch verifying position of TH`s main body, with wireless connection. [5], [6]*

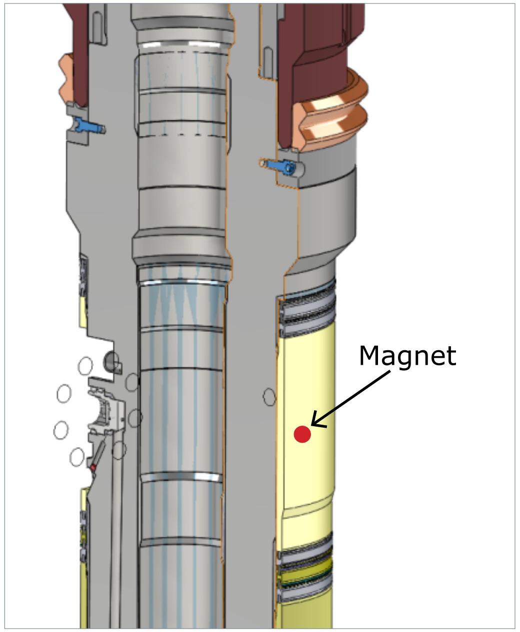


Figure 178: *Filled red circles indicate magnet position. [5], [6]*

P4, Lock verification, verify position of locking sleeve with switch located in piston:

- New position of proximity switch (figure 179), that was discussed during meeting is not feasible since switch cannot sense magnet through wall of ferrous material.
- Thus switch is now in same possition as earlier, as shown in figure 180
- New path for electric connection line, which will be drilled in same way as hydraulic lines.
- Uncertain how easy/difficult is it to insert electric line.
- Magnet will be positioned in upper locking sleeve.
- One significant weakness of this concept is that piston is able to rotate around axis of THRT`s main body.
- It is not enough space for integrating wireless communication system.

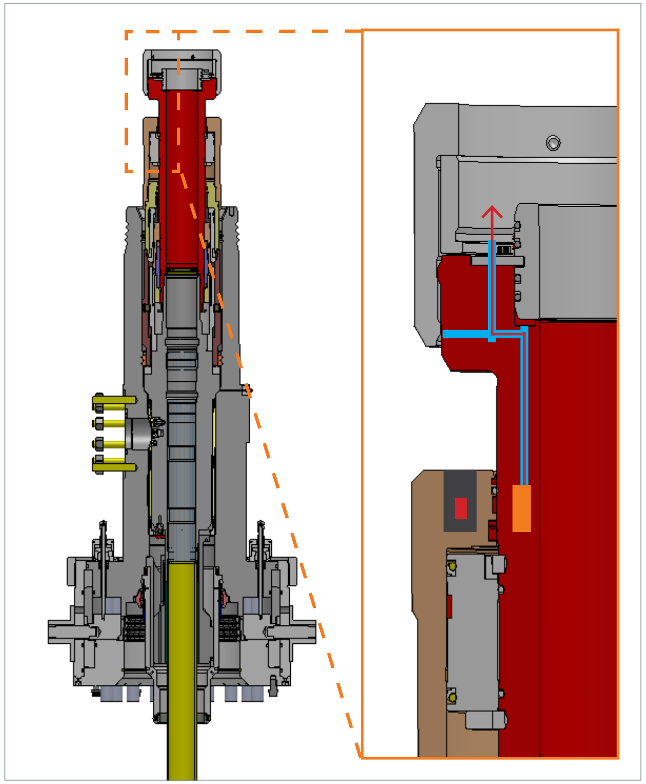


Figure 179: *New position of switch in THRT, that will not work in practice. [5], [6]*

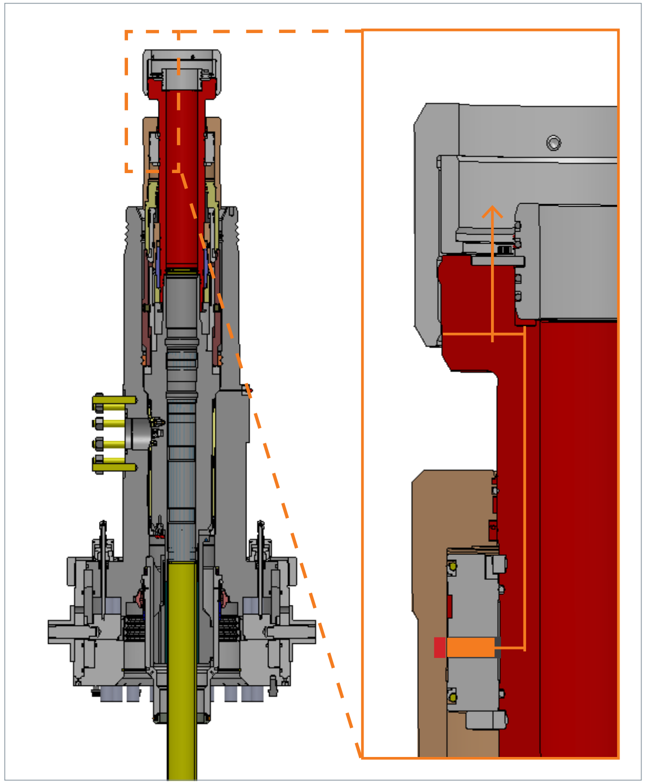


Figure 180: *Switch positioned in piston. [5], [6]*

Figure explanation:
- Proximity switch in orange
- Magnet in red colour.
- Drilled holes/lines in turquoise.
- Electric line is red.

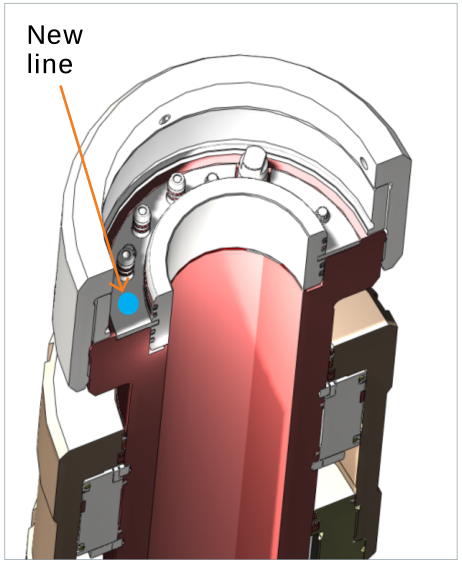


Figure 181: *New line for electric connection. [5], [6]*

P5, Lock verification, verify activation sleeve position with switch in TH`s main body:

- A suggestion was made to have the connection in annulus in between TH and THRT. The connection should be between TH`s and THRT`s main body, and as one can see in figure 182, available area that could be suitable for integration of a wet mate is even narrower than for the first path I evaluated.

Figure explanation:
- Proximity switch in orange.
- Magnet in red colour.
- Dark grey area is cavity with space for wireless communication components.

- This position alternative will require wireless communication.
- The proximity switch will require a magnet inserted into actuation sleeve as shown with red marking in figure 183.
- In addition to switch component and magnet, components for wireless communication must be integrated into area around the switch. Potential space for this is in dark grey colour.
- One weakness of this concept is that the actuation sleeve is free to rotate around TH`s main body where switch is located.

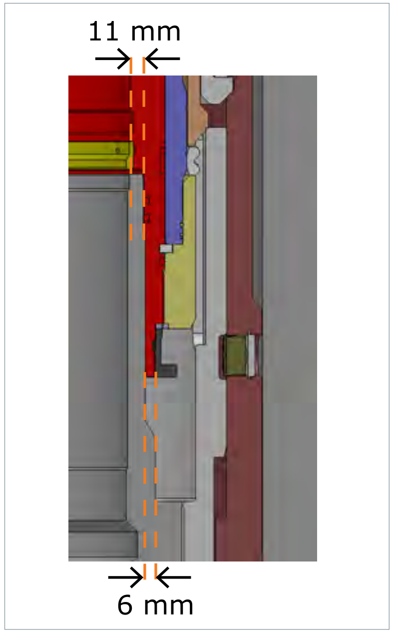


Figure 182: *Transition area between TH and THRT. [5], [6]*

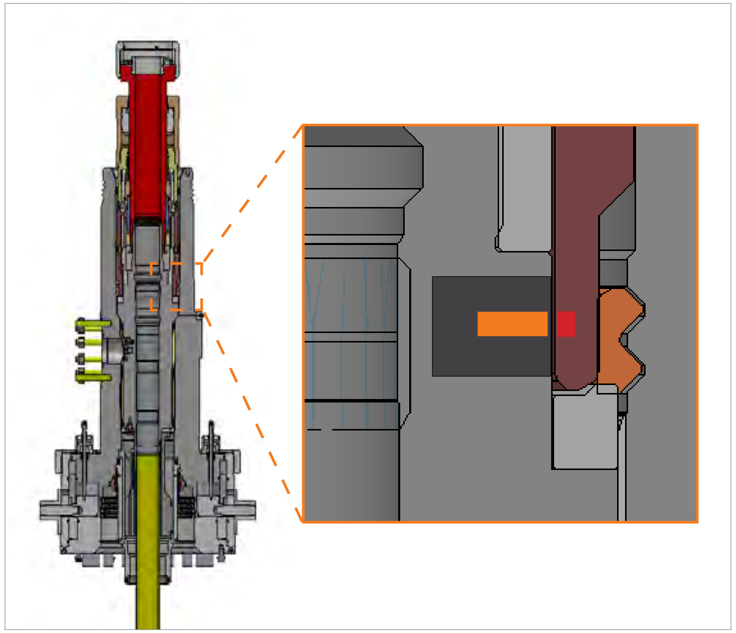


Figure 183: *Proximity switch positioned in TH`s main body. The wall thickness is about 47 mm where switch is located. [5], [6]*

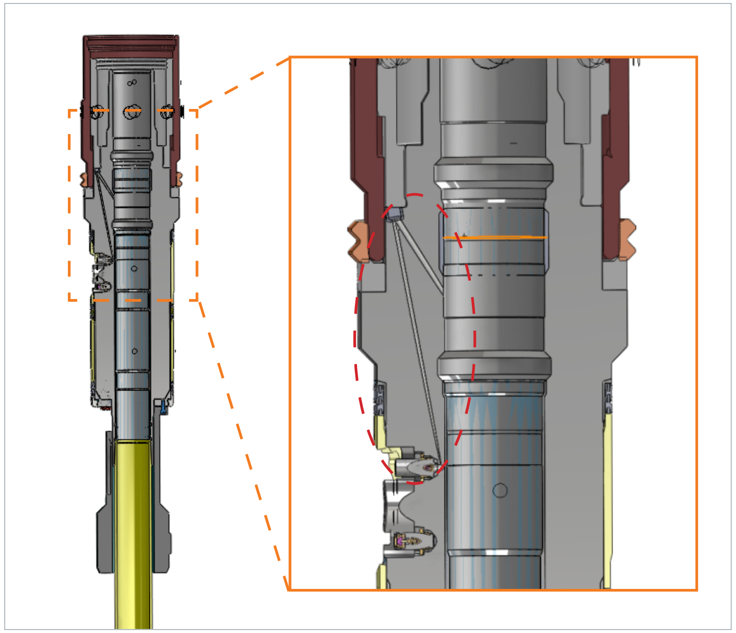


Figure 184: *There is a hydraulic line going from the gallery area and up inside spool. This is only place sensor cannot be located. [5], [6]*

P6, Lock verification, verify vertical position of activation sleeve with switch located in spool body:

- New line that is possible to drill has been created for electrical wire, in figure 185. But this solution will not work due to the fact that proximity switch cannot detect magnet through wall of ferrous material.
- Thus wireless communication must be used, in order to connect proximity switch to topside.
- Figure 186 shows relevant verification system, with wireless communication. Space for verification components will be drilled from inside of spool.
- One weakness of this concept is that the actuation sleeve is free to rotate relative to spool body where switch is located.

Figure explanation:

- Proximity switches in orange.
- Magnets in red.
- Light grey area is space for wireless communication components.

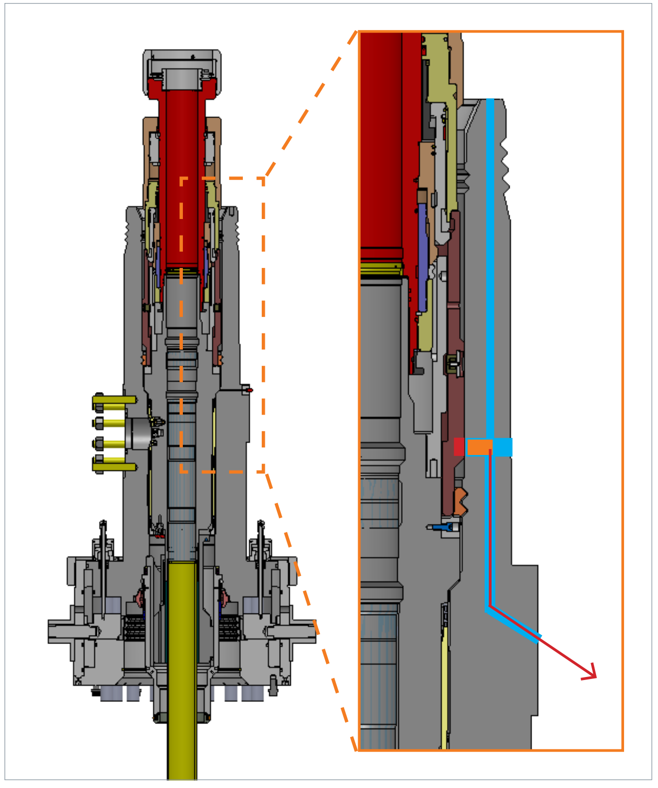


Figure 185: *Switch position which will require detection of magnet through wall of ferrous material. [5], [6]*

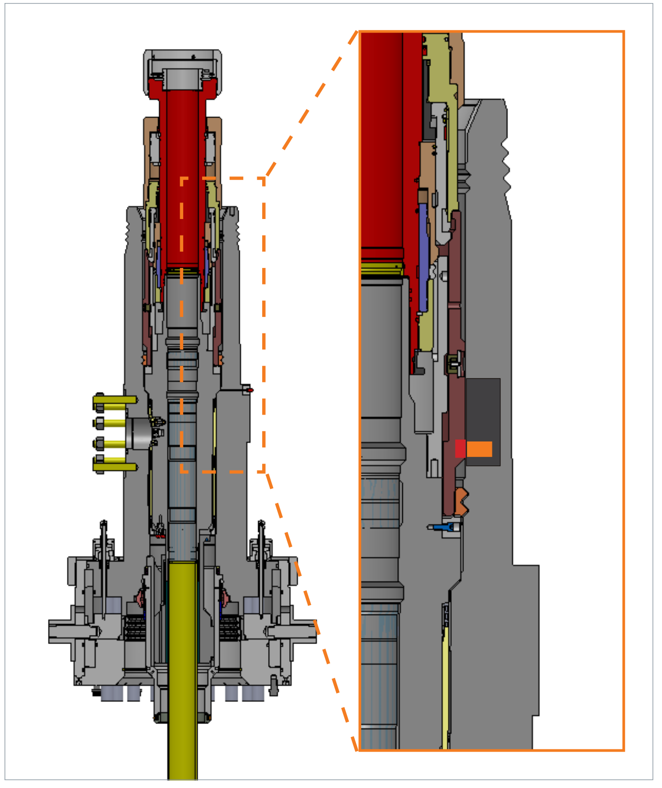


Figure 186: *Switch positioned directly next to magnet that is to be detected. [5], [6]*

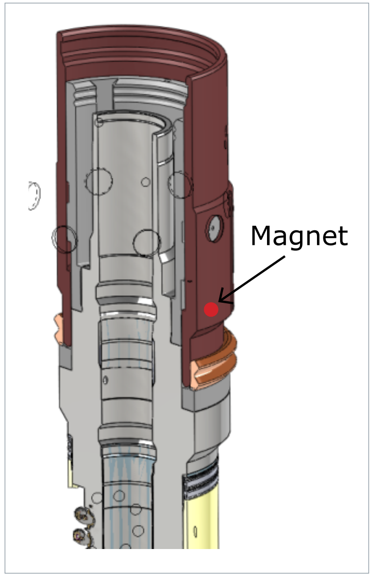


Figure 187: *Magnet`s position. [5], [6]*

P7, Landing and lock verification, verify vertical position of activation sleeve with switch located in spool body:

- Due to the fact that proximity switch cannot sense magnet through ferrous material, this concept has been amended in same way as positioning alternative P6, with use of wireless communication system.
- Disadvantage that actuation sleeve can rotate relative to TH`s main body and thus also relative to spool where switch is.
- Lower magnet will be close to switch at the moment TH lands in right position.
- Upper magnet will be close to proximity at the moment TH is locked properly to XT spool.

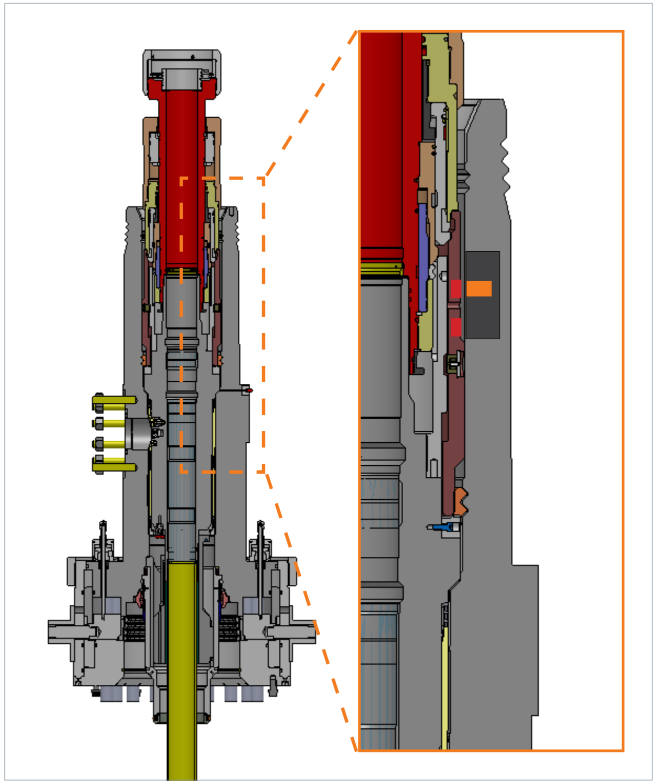


Figure 188: *Proximity switch located next to target magnets, with wireless connection to topside. [5], [6]*

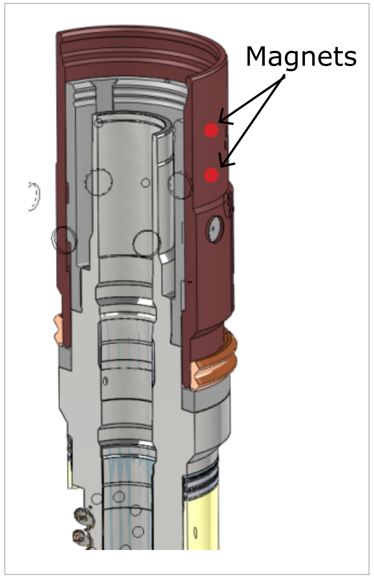


Figure 189: *Magnets located on TH`s actuation sleeve. [5], [6]*

Figure explanation:
- Proximity switches in orange.
- Magnets in red.
- Dark grey area is space for wireless communication components.

P8, Lock verification, verify vertical position of activation sleeve with switch located in spool body:

- Sensor positioned by/in locking dogs (also called shear dogs, spring lock and secondary lock).
- Shear dog`s task is to hold activation sleeve down after lock down.
- It has a spring, which makes the shear dog pop into TH`s main body during lockdown.
- One can insert a target magnet into the shear dog, and use a proximity switch to register the movement of shear dog as it first approaches switch from above, and then move slightly further away from switch and into TH`s main body.
- Must be aware of that the locking dogs are positioned in the actuation sleeve, which can rotate relative to the spool body.

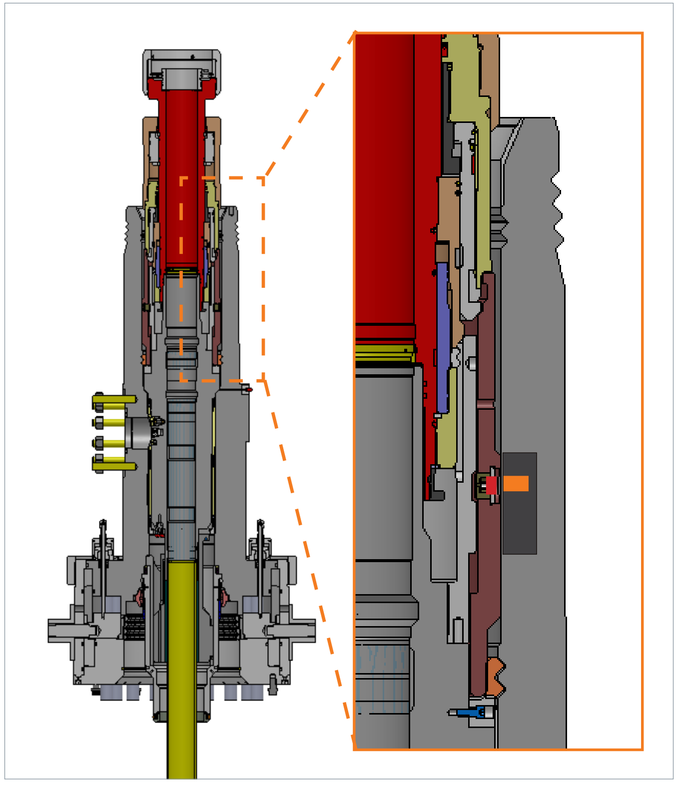


Figure 190: *Proximity switch located next to shear dogs. [5], [6]*

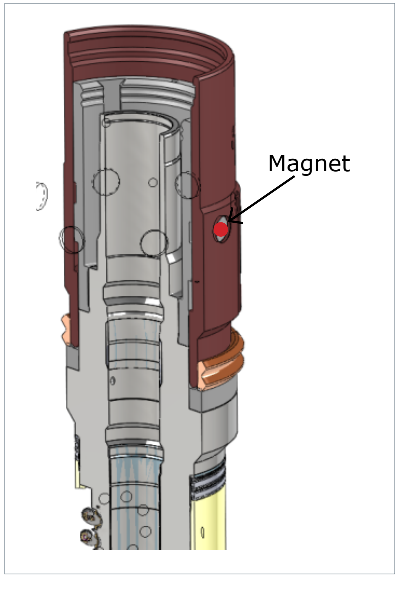


Figure 191: *Magnet located in shear dog. [5], [6]*

Figure explanation:
- Proximity switch in orange.
- Magnet in red.
- Dark grey area is space for wireless communication components.

P9, Lock verification, verify when split lock ring is in engaged position:

- Sensor positioned in the spool, close to the lower part of split lock ring.
- This requires that it is possible to make material of split lock ring permanent magnetic, or one has to insert a magnet in split lock ring.
- One disadvantage is that split lock ring can rotate relative to the TH and spool body. (If one choose to insert a magnet into split lock ring).
- Another disadvantage is that the ring will tend to change shape dependent of how many times that ring has been engaged. Thus distance to switch will vary.

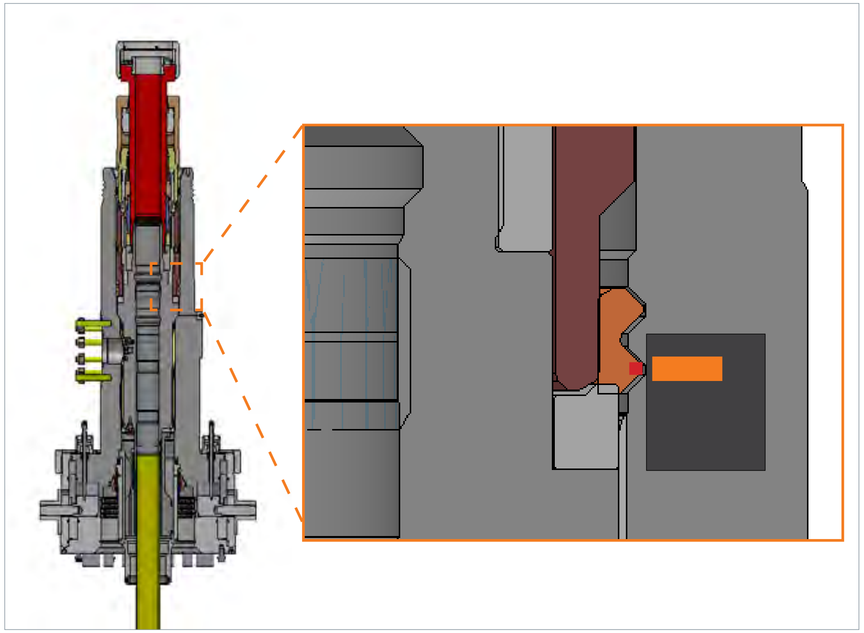


Figure 192: *Proximity switch verifying height of TH`s main body. The wall thickness is about 50 mm where switch is located. [5], [6]*

Figure explanation:
- Proximity switch in orange.
- Magnet in red.
- Dark grey area is cavity with space for wireless communication components.

P10, Landing and lock verification, register position of lower locking sleeve with proximity switch located in spool:

- Position sensor in the upper part of spool body.
- This can give both verification of landing and lock by registering position of lower locking sleeve.
- Keep in mind that the locking sleeve can rotate relative to the THRT`s main body.
- A disadvantage is that there is limited with space this high up in the spool.
- In addition one will weaken the design of spool where BOP is to be attached.
- Switch position might be in conflict with other components that will be attacted to spool body before/after TH installation.

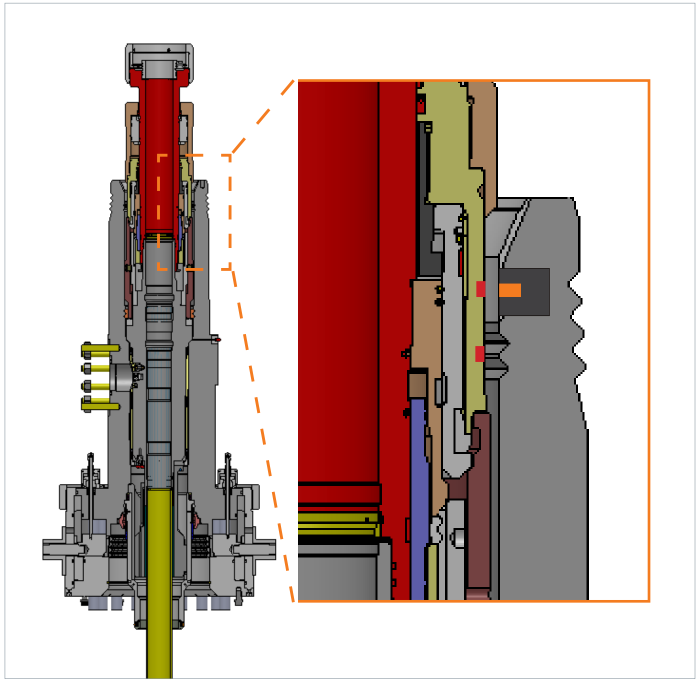


Figure 193: *Proximity switchlocated in upper part of XT spool body. [5], [6]*

Figure explanation:

- Proximity switch in orange.
- Magnets in red.
- Dark grey area is space for wireless communication components.

P11, Landing verification, verify vertical position of TH`s main body with sensor located in spool body

- The proximity switch is registering vertical position of TH`s main body.
- Sensor has to use wireless communication, since one cannot penetrate spool wall fully, and the switch cannot be separated from the magnet by a wall of ferrous material. Dark grey area is potential space for wireless technology components.
- Drilled holes will be made from inside of the spool.

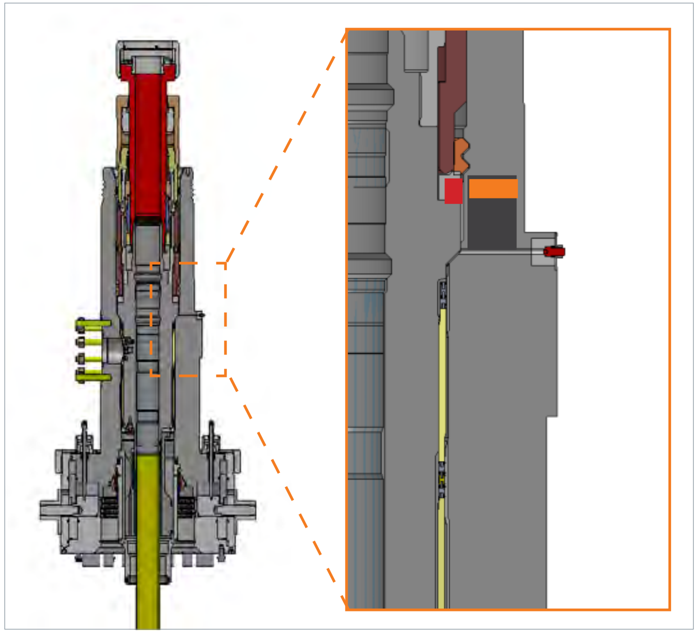


Figure 195: *Proximity switch positioned next to ring of inconel material. [5], [6]*

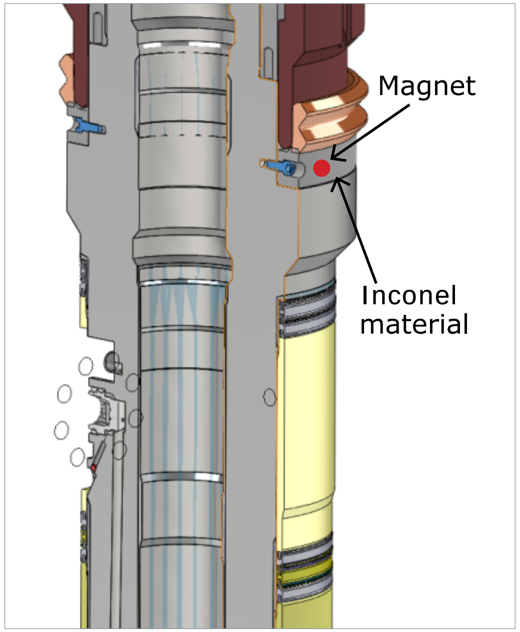


Figure 195: *Magnet positioned in inconell material. [5], [6]*

Figure explanation:
- Proximity switch in orange.
- Magnet in red.
- Dark grey area is cavity with space for wireless communication components.

Wireless communication system

Since eigth of the nine relevant positioning alternatives require wireless communication, some more research on wireless technology has been carried out. Verification system with wireless communication to topside, was among my ten first concepts.

Aker Solutions use an emergency control system today, that is developed by KONGSBERG (Kongsberg Gruppen). The system provides acoustic communication technology.

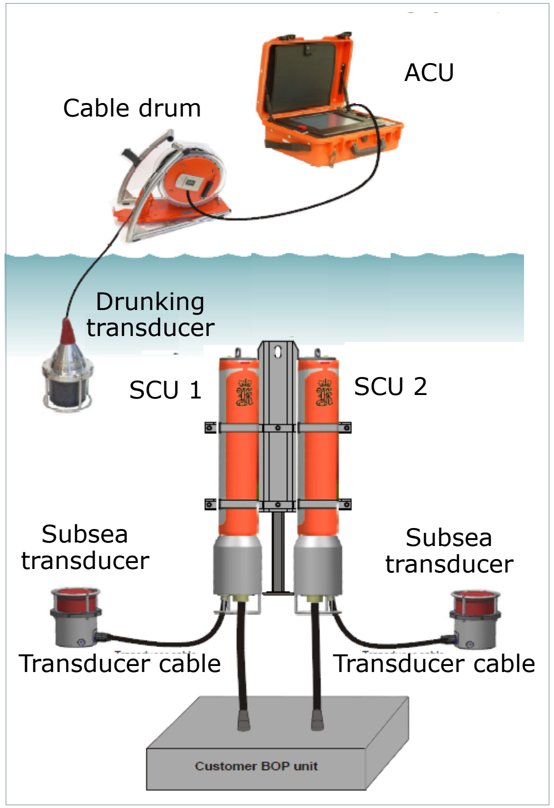


Figure 196: *Acoustic control system [38]*

Here is a short description of the acoustic control system: The system is divided into two main areas, suface equipment and subsea equipment. "Both system parts have transceivers that are connected to transducers". "The Subsea Control units (SCUs) are mounted on the BOP and receives acoustic command signals from the Acoustic Cummand Unit (ACU). It translates the signals into operational commands, then acts on those commands sending control signals to solenoids which in turn open or close hydraulic control valves on the BOP. Once the command signal has been biven (by the operator), a confirmation signal is transmitted by the SCU to the ACU." The ACM sends signal through the Drunking transducer which is sent subsea, and it`s sinal is rechieved by the subsea transducers. For a more product information, see appendix F.

Another company that provides wireless communication systems is WFS Technologies. It is "the world's leading supplier of subsea wireless technology for communication, control, navigation and power transfer.

Combining radio, acoustic and wireless power transfer technologies, their field proven expertise in wireless connectivity is delivering cost savings and new capabilities to the subsea, oil & gas, environmental and consumer industries worldwide." [39]

Figure 197: *WFS`s wireless communication system for subsea. [39]*

WFS also offers wireless harvest of data from subsea sensors. Therefore I chose to contact WFS in order to find out if their technology can be combined with proximity switch technology from e.g. SEACON. I got a positive answer, but WFS will have to carry out research and product development, in order to make a customised system that is suited for TH landing and lockdown verification.

Some of WFS`s wireless technology systems provide a black box /logger for registering data and a ROV for wireless retrieval of stored data. Verification information from switch can be stored in a unit positioned by the switch, which will send information to a ROV. In addition to a storing unit, power supply for the black box will be required. "The ROV unit can have its own loading station with a battery that can last for a period of about 10 years." [40] For additional product information, see appendix F.

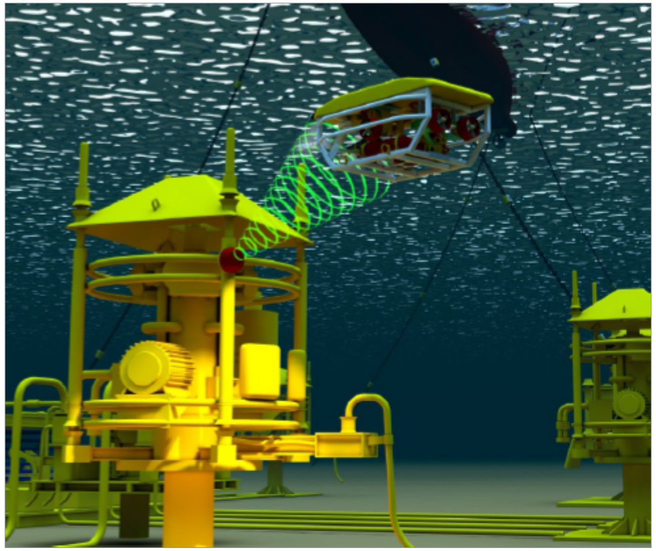


Figure 198: *Stored data can be extracted by ROV unit. [39]*

Wireless communication system attached to proximity switch will require integration of these components:

- Black box/instrumentation/rechiever for storage of verification information
- Battery/power supply
- Antenna
- Card with relevant electronics

8.6.2. Concept 10, Local Positioning System

As mentioned earlier in section 8.2.4. the Global Positioning System (GPS) han an accuracy of about ± 3 - 5 m. For use on a verification system for TH installation, this is far from sufficient enough. Thus an alternative system has to be evaluated.

Table 15: *Overview of accuracy for different positioning systems, in addition to approximated costs. [41]*

Type of GPS reciever	Accuracy	Costs/price
GPS	± 5 m	€100 - €1000
DGPS	± 1 m	€300 - €1500 plus a fee of €0 - €750 per year.
HP - DGPS	± 0,1 m	€4500 - €8500 plus a fee of €1000 - €3000 per year.
RTK - DGPS	± 0.01 m	€10.000 - €30.000

The "normal" GPS system is described earlier in this report, and uses signal from four satellites to calculate position of a mobile GPS unit.

The DGPS uses a fixed GPS unit and FM-transmitter Radio Data System (RDS) to create a RDS correction signal that is sent to a FM radio positioned by the mobile GPS unit. This system is used in combination with the "normal" GPS system, in order to obtain positioning data of higher accuracy.

A HP-DGPS uses two fixed GPS units in order to increase the accuracy of "normal" GPS. The two fixed GPS units communicate with a fifth satellite in addition to the four satellites used for "normal" GPS. Communication between the two fixed GPS units and the fifth satellite provides the mobile GPS unit with a correction signal, and higher position accuracy is obtained.

The only GPS system type that has a sufficient level of accuracy is the RTK GPS. It has an accuracy of ± 10 mm, which can give a good intication for TH landing in XT spool.

RTK stands for Real Time kinematic. The RTK GPS system consists of "normal" GPS system with four satellites and a mobile GPS unit in combination with a fixed GPS unit that communicate with the four satellites and a FM radio positioned by the fixed GPS unit that sends RTK correction signal to a FM radio positioned by the mobile GPS unit. For this type of system, the fixed GPS can be at a maximum distance of 10 km from the mobile GPS unit.

One can see in table 14, that increase in accuracy means an increase in costs/price. Since the RTK-DGPS system is the most accurate one of the once listed in table 14, it is also the most expensive positioning system, with a cost of about €10.000 - €30.000. With an exchange rate of 7.88, this is about 78.800 NOK - 236.400 NOK.

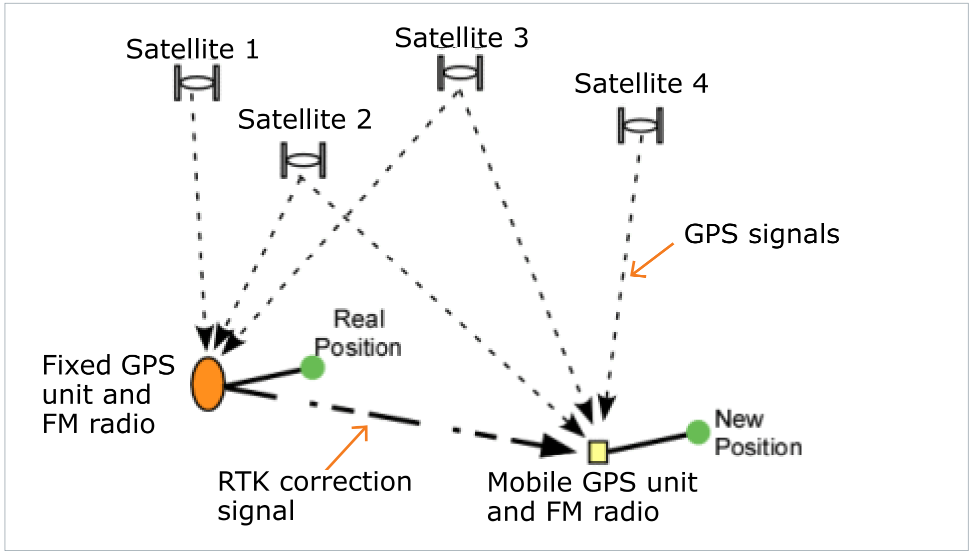


Figure 199: *Increased accuracy by the use of RTK GPS [42]*

8.6.3. Concept 12, Laser Measuring Device

There is a laser measuring device positioned on rig today, on the drillfloor, and it is used to measure movement of drillpipe as the TH is lowered down.

I have not been able to find out how precise the laser measuring device used today is, but since they use a chalk crayon and a yardstick to measure the last vertical movement of TH into XT spool, the laser system is most likely not precise enough for measuring of the last vertical movement of about 150 mm. If the laser measuring device gave a precision of a few cm, it would not be necessary to perform the chalk crayon and yard stick measuring method.

I have tried to find a picture of the laser measure device positioned on the drillfloor, but with no sucess.

8.6.4. Concept 13, Torque Resistance Measuring Device

Below is a picture of torque tool and ROV from OCEANEERING.

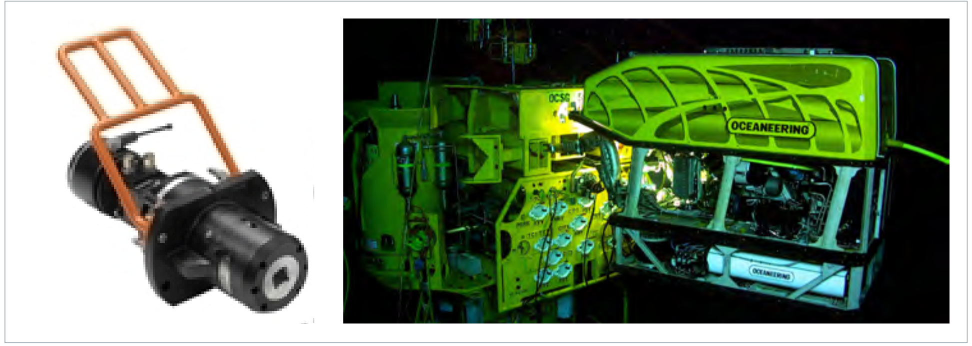


Figure 200: *Standard torque tool and ROV unit hadling torque tool. [43], [44]*

In addition to standard torque tools, OCEANEERING delivers a product called Smart Torque Tool System. It is a standard torque tool combined with a Remote Control Unit (RCU), which can provide real-time torque feedback and direct control over output torque. Torque output can be monitored and adjusted via a surface control unit.

These are the system`s main components:

- Remote Control Unit (RCU)
- Manifold Unit
- Topside Control Unit
- Standard Torque Tool
- Intellegent Test Jig

This system can be used to make sure that Hybrid Penerator (HP) is not engaged into wrong area of the Tubing Hanger (TH). If HP is about to engage into wrong area, it will hit outer surface of TH instead of angaging into gallery area in which electric and hydraulic connectors are suppoused to connect. When HP hit outer surface of TH, it will resist to engage. This resistace can be measured by the RCU. For more product information, see appendix G.

8.7. Concepts Relevant for Expert Testing

In order to narrow down the scope of relevant concept solutions, an expert test will be carried out by employees at Aker Solutions.

During the concept selection, concept 6 proved to be the strongest one, and was chosen for further development. Concepts 10, 11 and 12 does not provide any landing or lock verification of required precision level, and are therefore only additional verification methods that can be performed in addition to concept 6.

For the expert test, concept 6 will be in focus, and it`s positioning alternatives will be tested. In the previous section, nine positioning alternatives were described, but one of them, P6, will not be included in the expert test. The reason for this is that it has become very similar to P7, during the concept development work. Both confirm position of actuation sleeve, with switch located in spool body. Only difference is that P6 only provide landing verification, while P7 provide both landing and lock verification. Since P7 is one of only two positioning concepts that are able to provide both landing and lock verification, it will be included in the test, while P6 will be left out.

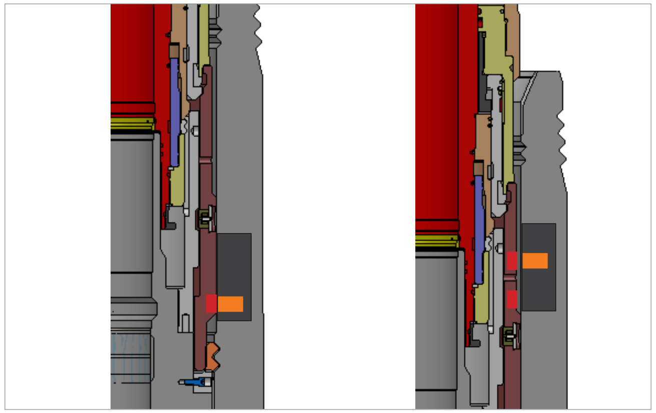


Figure 201: *P6 to the left and P7 to the right. [5], [6]*

Other relevant positioning alternatives relevant for expert testing, in addition to P7 are these:

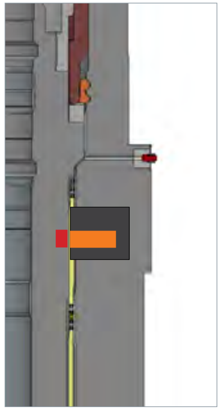


Figure 202: *P1 [5], [6]*

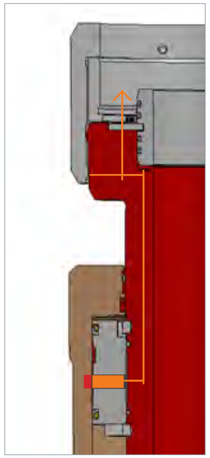


Figure 203: *P4 [5], [6]*

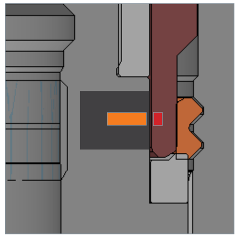


Figure 204: *P5 [5], [6]*

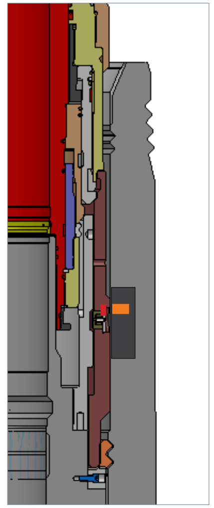


Figure 205: *P8 [5], [6]*

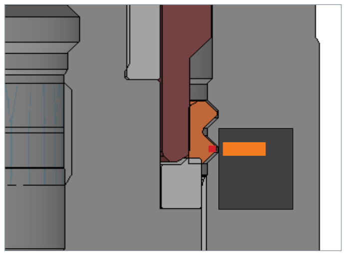


Figure 206: *P9 [5], [6]*

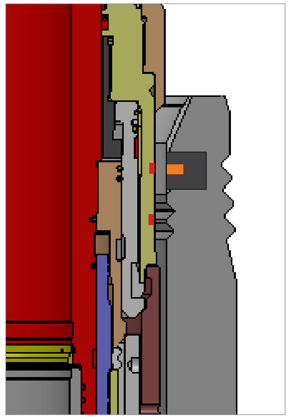


Figure 207: *P10 [5], [6]*

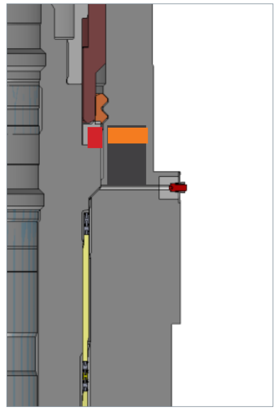


Figure 208: *P11 [5], [6]*

9. CONCEPT TESTING BY EXPERTS

9.1. Testing Objectives

The test is carried out in order to narrow down the scope of relevant concepts. A systematic concept selection method will be used. Since I have only been studying subsea technology for about five months, I have picked out a group of employees from Aker Solutions to perform the expert test. This is done in order to get an objective concept selection process, that is performed by persons that know the subsea products well.

9.2. Choice of Expert Group

The test have been performed by four people, that also attended the the concept design review meeting. These are the participants:

- Magnus Fjørtoft Urke, supervisor from Aker Solutions
- Jan Herland, First Chief Engineer
- John Andre Andersen, Engineer from Tooling group
- Vicens Breiz, Engineer from Tooling group

9.3. Development of Concept Evaluation Matrix

The selection matrix in table 16, lists key product requirements, from the basis of design. The most relevant once for expert testing have been included.

Each production requirement have got its own weighing, occording to ranking of importance in basis of design. In the basis of design, all requirements are ranked after importance with "can", "should" or "must". "Can" gives a weighing of 1, "should" a weighing of 2, while "should" has the highest weighing of 3.

Each of the persons in the expert group has given each concept a score, according to how well they meet each requirement.

1= Does not satisfy requirement.
2= Uncertain.
3= Satisfy requirement.

The S1 score in table 16 is the average of score given by the four test participants. Only cases where value is not average is when e.g. three persons gave a score of 1, while one gave 3. If 1 seemed most likely, 1 is set as the average.

In order to get a correct point distribution, each S1 score is multiplied with relevant requirement weighing. The products of this multiplication (S2 score) is then added together, so that each positioning alternative concept get their own sum of points, that can be compared to the other concept scores.

9.4. Test Procedure

The four test participants got an overview of the eight relevant positioning alternative concepts, which included description of verification method and illustrating figures. In addition they got a form to fill inn. The form was similar to table 16, but without the weighing columns. With the rating table, I attached a sheet for additional comments.

The participants were instructed to give the concepts a score from 1 to 3. They were also informed that if there were any concept(s) they thought was not feasible/not possible to implement to the XT system/THRT, they could leave the score coloumn of the concept blank, but then a comment should be added on the additional commets page.

The test results have been used as basis for filling in table 16. The average score for each concept has been inserted in the S1 colums. Scores and feedback from expert testing can be found in appendix I.

9.5. Concept Evaluation Matrix

Table 16: *The requirements are from the list of key product requirements. I have included the most relevant once for this selection process. Each concept has got a score (S1), which is the average score from expert test. In addition there is a point rating/weighing according to ranking of importance in basis of design. Score and point weighing are multiplied together to get a correct/most fair point level (S2), and point sum is found for each concept in order to compare their scores.*

Type of requirement	Point rating/ weighing	Requirement	Concept nr							
			P1		P4		P5		P7	
			S1	S2	S1	S2	S1	S2	S1	S2
Function	3	Verify position of TH relative to XT spool before lock down.	2,5	7,5	1	3	1	3	2,75	8,25
	3	Verify when TH is locked to the XT spool.	1	3	2,5	7,5	1,75	5,25	2,5	7,5
	3	Verify position of TH relative to XT spool after lock down.	2,75	8,25	1	3	1,25	3,75	2,75	8,25
	2	Continuous verification of TH`s position and locking until TH installation and pressure testing is complete.	1,75	3,5	1,25	2,5	1,25	2,5	3	6
	2	Verify when TH is unlocked from the XT spool.	1	2	2,25	4,5	2,25	4,5	3	6
System safety	3	Low risk of damage on lock down system as well as adjacent components.	2,5	7,5	3	9	2,5	7,5	2,75	8,25
Technical	3	Verification information is to be sent to the operator located topside.	2,75	8,25	2,25	6,75	2,25	6,75	2,25	6,75
Reliability	2	Low risk of malfunction[1]	2,25	4,5	2	4	2,25	4,5	2	4
Simplicity	2	The verification system is not to be more complex than necessary.[2]	2,25	4,5	2,5	5	2	4	2,25	4,5
Durability	3	Low wear on subsea system during use.	2,75	8,25	3	9	2,75	8,25	2,75	8,25
Serviceability	2	Good accessibility for inspection, testing and maintenance of system.	1,5	3	2	4	2,25	4,5	2,25	4,5
Economics	2	Not result in comprehensive changes of today`s design.	1,75	3,5	2,25	4,5	2	4	1,75	3,5
SUM:				59,25		62,75		58,50		96,00

Table 16 continued:

Type of requirement	Point rating/ weighing	Requirement	Concept nr							
			P8		P9		P10		P11	
			S1	S2	S1	S2	S1	S2	S1	S2
Function	3	Verify position of TH relative to XT spool before lock down.	1	3	1,75	5,25	2,5	7,5	2,5	7,5
	3	Verify when TH is locked to the XT spool.	2,25	6,75	2,5	7,5	2,75	8,25	1	3
	3	Verify position of TH relative to XT spool after lock down.	2,5	7,5	2,75	8,25	2,75	8,25	2,75	8,25
	2	Continuous verification of TH`s position and locking until TH installation and pressure testing is complete.	2,5	5	2,75	5,5	2,75	5,5	1,75	3,5
	2	Verify when TH is unlocked from the XT spool.	2,5	5	2,75	5,5	2,75	5,5	1	2
System safety	3	Low risk of damage on lock down system as well as adjacent components.	2,5	7,5	2	6	2,5	7,5	2,75	8,25
Technical	3	Verification information is to be sent to the operator located topside.	2,25	6,75	2,5	7,5	2,5	7,5	2,25	6,75
Reliability	2	Low risk of malfunction[1]	2	4	2	4	2	4	2,25	4,5
Simplicity	2	The verification system is not to be more complex than necessary.[2]	1,75	3,5	2	4	2	4	2,5	5
Durability	3	Low wear on subsea system during use.	2,75	8,25	2,25	6,75	2,5	7,5	2,75	8,25
Serviceability	2	Good accessibility for inspection, testing and maintenance of system.	2,25	4,5	2	4	2	4	2	4
Economics	2	Not result in comprehensive changes of today`s design.	1,75	3,5	1,75	3,5	2	4	2	4
SUM:				65,25		67,75		73,50		65,00

1) Components containing proximity switch or magnet should be in fixed position/not able to move relative to each other. It is preferred that magnet is either placed in non-ferrous material, or with air around it.

2) Simpler solution is preferred if two verification concepts are equally precise and reliable.

9.6. Results and Result Interpretation

Table 17: *Ranking of the concepts after score sum, with highest score on top.*

Postion concept	Score SUM
P7	96,00
P10	73,50
P9	67,75
P8	65,25
P11	65,00
P4	62,75
P1	59,25
P5	58,50

The two concepts with highest score are the once providing both landing and lock verification. Their score is significatly higher than the rest. The concepts only providing either landing or lock verification only has a maximum score difference of 9. This is not a big difference, because the sum adds up numbers from 1 to 3 that are multiplied together.

In order to put it in a perspective: a S1 score of 3 multiplied together with a weighing of 3, gives a S2 score of 9. Thus a score difference of 9 is very little, compared to all the requirements being evaluated.

The reason for this small difference in SUM, is probably the narrow score distribution from 1 to 3. I chose a small range, so that it wouldn`t bee too difficult to evaluate how high score each concept should get. Since the concepts not are specified technical solutions, but only positioning concepts for switches and magnets, with indication of possible connection to topside, it wil be wrong to have a very wide specter of points to distribute.

In order to get clearer results from the expert testing, a wider score range of 1-6 or maybe even 1-10 would probably be better suited. As I have very limited with time left, it will not be possible to carry out a new expert test in order to obtain clearer test results.

Thus I will use the test results I already got as a basis for narrowing down the scope of relevant concepts, but I will keep in mind that the test results are not very precise. During the expert testing I also got some additional comments to each concept. This will be very usefull for evaluation of the concepts.

The most important additional comments from expert test are listed below:

- It is possible to penetrate the XT spool`s wall, but a suited sealing solution has to be qualified.
- Concept P5 is less suited for wireless communication, and it is very problematic to run an electric line between TH and THRT.
- Little benefit of locating magnet in shear dog. Thus probably better to locate it somewhere else.
- P9 can give a good verification, but there is a risk of split lock ring hitting the switch, which can lead to failure of verification system.
- P10 has a bigger distance between sensor and magnet. Since proximity switches work best for short ranges, this can be a problem.
- P10 is in same area as sealing surfaces for Internal Tree Cap (ITC), which is an important barrier preventing possibility of production leakage to the environment.
- For P7, two sensors combined with a magnet might work better than two magnes and one sensor.

(List continues on next page)

- Spools are often submitted to extreme loads and tensions coming from the riser. Any structural weakness could be critical.
- Concept P9 is aiming at the most important target, as it gives direct verification of TH lock down as the split lock ring is engaging.

I also got a new concept suggestion from Vicens. It is based upon concept P9, but there will only be mechanical components inserted in the XT spool. A drawing and description of system is included in appendix I. The concept will imply integration of verification system in lower part of POB.

This is a concept that can have a good potential, but I do not have time to start developing a new concept this late in the mater thesis project. Therfore the concept should instead be part of the further work that is to be carried out on basis of my master thesis.

In order to get a better overview of the relevant concepts, I have set up three groups below.

Concepts providing both landing and lock verification:

- P7
- P10

Concepts providing landing verification:

- P1
- P11

Concepts providing lock verification:

- P4
- P5
- P8
- P9

9.7. Elimination Process

Positioning concept P7 and P10 provide both landing and lock verification. Of these two, concept 10 is the strongest one, because:

- It got a higher score compared to P7 in the expert test.
- Concept P7 will conflict with Internal Tree Cap`s sealing surface.
- Bore Protector is also sealing on the same surface.
- Concept 10 require a proximity switch and magnet system with longer sensing range

Thus I have chosen to eliminate P7 from group of relevant concepts.

The two concepts providing landing verification is P1 and P11. During the expert testing, concept P11 got a slightly higher score than P1. These two concepts are quite similar. Both have switch positioned in spool body, and magnet located in TH. P1 has more space available for integration of wireless communication system, but P11 provide the opportunety of interating magnet in non-ferrous material.

Martin Biehle from SEACON have stated that magnet should either be located in non-ferrous material our with some air filled space around. I also sent a description of concept P7 to Brendan Hyland from WFS earlier, and he did not think that there would be a space issue. Concept P7 is positioned in spool with same wall thickness as concept 11. Thus it should also be enough space to integrate wireless communication components for concept P11.

Since concept P11 have stronger concept characteristics compared to P1, concept P1 will be eliminated from group of relevant concepts.

Four concepts provde only lock verification: P4, P5, P8 and P9. Concept P5 will require a more complex wireless communication system, compared to other concepts using wireless communication. (See section 10.3.1, page 174 for further details). Due to this concept P5 is eliminated. Concept P5 got lowest score during the expert testing.

Concept P4 is the only position concept that does not imply wireless communication. Thus it will be kept in the group of relevant concepts, in case XT spool in not suited for integration of wireless communication system

Concept 8 is quite similar to concept P7, but it does not provide landing verification. During the exert testing, this additional comment was given: "Unsure about the benefit of placing magnet in shear dog." As the actuation sleeve is free to rotate, it can be problematic to secure that magnet positioned in shear dog is lined up with switch position during landing and lockdown. In addition shear lock is of ferrous material, which will disturb magnetic field.

As concept P8 does not add anny additional verification value, that concept P7 with the highest expert test score, cannot provide, Concept P8 will be eliminated.

Concept P9 provide direct lock verification when split lock ring engage. That is very beneficial, but the concept has quite a few weaknesses. A proximity switch verification system require specific distances for when switch is to be activated, but since the split lock ring`s shape can change as it is enganged and retracted multiple times, distance between engaged split lock ring and switch will varry. In addition there will be problematic to insert magnet in the split lock ring. On basis of this evaluation, I choose to eliminate concept 9b.

Instead of trying to solve all implications related to concept 9b, it is much more relevant to develop the new concept proposal from Visenc. But as mentioned earlier, this will have to be done in a later product development stage, as I have too limited time to do so.

Result from elimination process

After the elimination process, these are the remaining concepts:

- P7, landing and lock verification
- P11, landing verification
- P4, lock verification

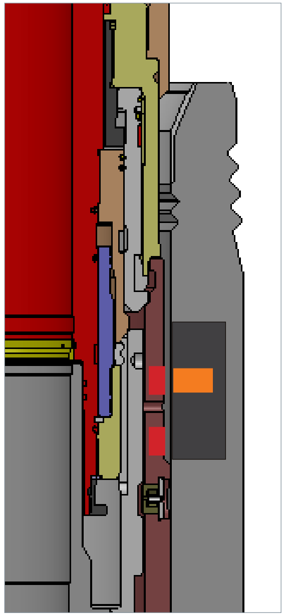


Figure 209: *P7, [5], [6]*

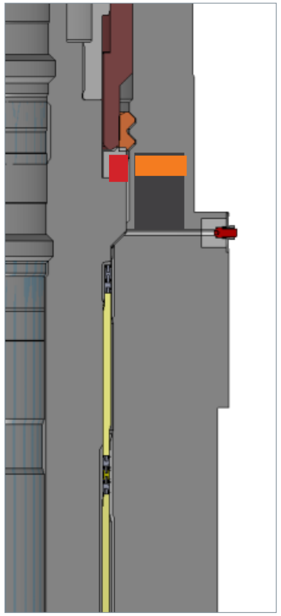


Figure 210: *P11 [5], [6]*

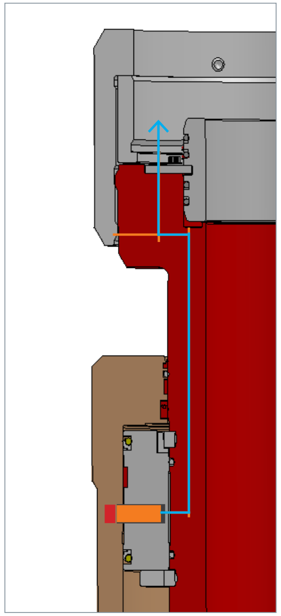


Figure 211: *P4 [5], [6]*

10. DETAILING OF CONCEPTS

10.1. Two Lock Down Verification Systems

One of the objectives for this master thesis project was to:

- Come up with and present two verification system concepts that provide landing and lock verification for Tubing Hanger installation.

Postioning concept P7 will be one of these two concepts, as it provides both landing and lock verification. The second concept will be a combination of position concept P11 and P4. P11 provide landing verification, while P4 gives lock verification.

These two verification system concepts can be supplemented with additional verification methods. Additional verification can be provided by concept 10, concept 13 and/or some of today`s verification methods.

10.2. First Indication of Correct TH Landing

During the further concept development (section 8.6) I found out that it can be relevant to use a RTK GPS (Real Time Kinematic, Global Positioning System), in order to get a first indication of correct landing of TH. It has an apropriate precision level of ± 10 mm.

To only use the laser measuring device that is already installed on rig today, will probably not give a precise enough indication of correct landing. The once installing TH today usually carry out an additional verification method with chalk crayon and yard stick to confirm correct movement during the last meter of TH landing.

Thus for a first indication of correct TH landing one can either continue carrying out the same verification methods that are used today with laser measuring device, chalk crayon and yard stick, or one can consider to replace that system with a RTK GPS.

10.3. Fail Safe System

Other verification concept that can be relevant to use in addition to the concepts providing landing and lock verification is concept 13. The Smart Torque Tool System can be a fail safe system that prevents Hybrid Penetrator from engaging into wrong area of Tubing Hanger, if the other verification systems have failed or given false verfication information.

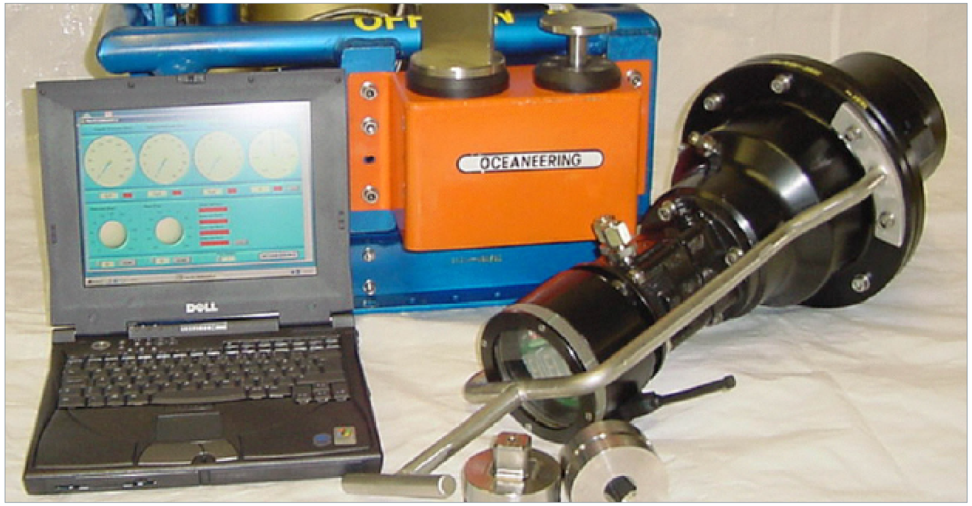


Figure 212: *OCEANEERING`S Smart Torque Tool System. [45]*

10.4. Possible Combinations of Additional Verification Methods, Providing First Indcation and Fail Safe System

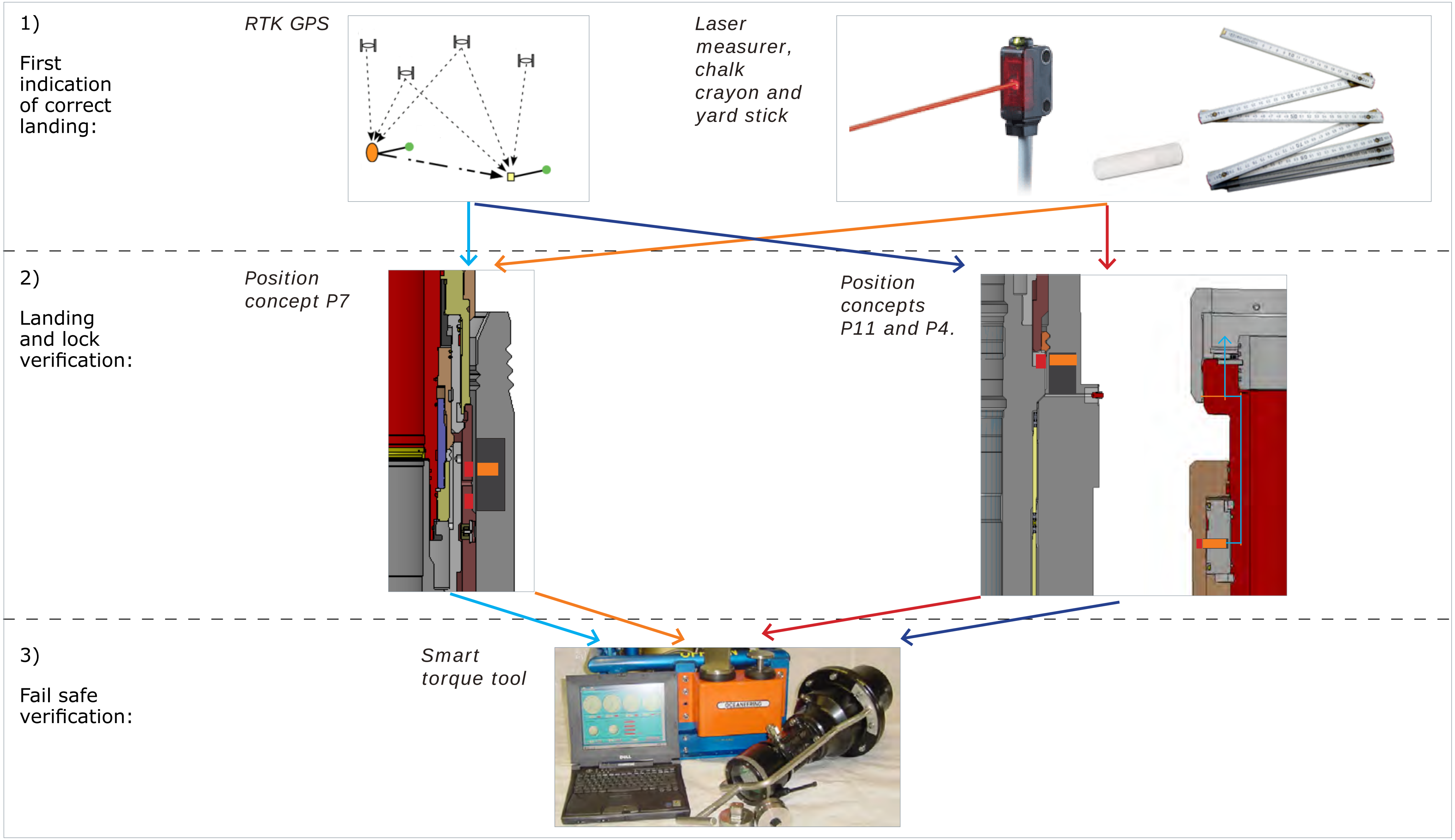


Figure 213: *Four possible combinations of verification methods marked with arrows of four different colours; turquoise, marine blue, orange and red. [42], [46], [47], [48], [5], [6], [45].*

10.5. Detailing of Concepts Providing Landing and Lock Verification; Concept A and B

Postioning concept P7 will from now on be referred to as concept A, and concept P11 in combination with concept P4 will be reffered to as concept B.

Verification systems providing first indication of correct TH landing and fail safe system will not be developed to any higher level of detail. For the remaining part of this report, I will focus on concepts A and B.

10.5.1. Detailing of Concept A

Concept A provides landing and lock verification by the use of switch, target magnets and wireless communication system. In order to find out what type of switch is best suited for the concept, I have been in contact with SEACON.

In section 8.2.2, a list of possible proximity switch configurations was set up. The configuration that will be best suited for provision of landing and lock verification is Sinking/Sourcing Hall Effect. Switch is normally open and will gradually close as magnet is brought closer to the switch.

Typical sizes for one of SEACON`s Sinking Hall Effect switches can be seen in figure 214. This is just to give an indication of switch size. Martin Biehle from SEACON has stated that shape and size of the proximity switch is reasonable flexible. Target magnets are supplied separately based on application requirements. They typically have diameter of 12,7 mm and a thickness of 5,1 mm, or a diameter of 19,1 mm and a thickness of 9,7 mm.

Magnet size depends on required sensing range. Sensing range with smallest magnet is about 3,8 mm to 12,7 mm, while for largest magnet it is about 7,62 mm to 16,51 mm.

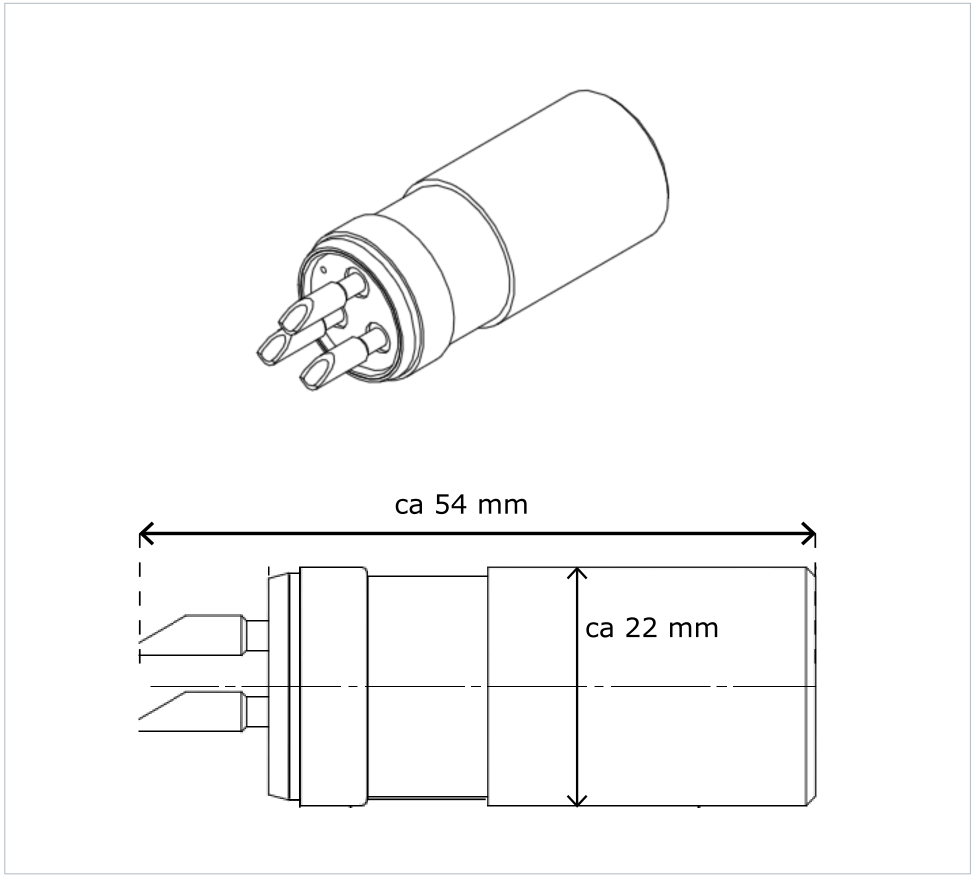


Figure 214: *Proximity switch with Sinking Hall Effect. [49]*

After it was found out that a wireless system could be relevant for sending of verification signal to topside, I have communicated with Brendan Hyland from WFS by e-mail, through out the product development process.

WFS have suggested two different options to how a wireless communication system can be attached to proximity switch and send verification information to topside:

1. **"Wireless communications through the metal wall**

   We'll need to know the thickness of the metal and the metal type then prepare a model to determine a system configuration that provides a reliable link.

   Pros

- o Simple solution
- o Off-the-shelf modelling tools to determine critical design parameters
- o Off-the shelf products that support through-pipe-wall communications that could be customised to deliver a proof-of-concept

Cons

- o Technical challenge to design a system to meet the size and power constraints of the target location

Next steps

- o Build model and run simulations to determine critical design parameters
- o Build and test proof-of-concept system based on Seatooth S200 platform operating at <300Hz

Cost & timescales

- o Modelling: approx. £15k; 4 weeks
- o Proof-of-concept: approx. £30k; 6 weeks

2. **Wireless communications along the pipe**

   We could use a relatively low power transmitter to use the pipe as a propagating medium and transmit the signal to a convenient location several metres away where a second transceiver can pick up the signal.

   Pros

- o Lower power solution than (1)
- o Greater bandwidth than (1)
- o Off-the-shelf modelling tools to determine critical design parameters
- o Off-the shelf products that support through-pipe-wall communications that could be customised to deliver a proof-of-concept

Cons

- o Greater complexity – 2 radio systems
- o Greater technical risk as reliable propagation along the pipe will be more challenging to model

Next steps

- o Build model and run simulations to determine critical design parameters
- o Build and test proof-of-concept system based on Seatooth S200 platform

Cost & timescales

- o Modelling: approx. £20k; 6 weeks
- o Proof-of-concept: approx. £40k; 8 weeks" [50]

These two suggestions for wireless communication system, were set up before the expert test was carried out. The first solution was aimed at these position alternatives: P1, P7, P8, P9, P10 and P11. The second solution was aimed at position concept P5. As solution nr. 1 is less complex and easier to model, I chose to use that as a base for further development of concepts.

Here is some additional product information from WFS:

- "Attached is a datasheet for a subsea wireless modem/ datalogger (See Appendix F). A proximity sensor can be connected to this device either via the digital input or 4-20mA. The logger can be used to provide time-stamped data on when the proximity switch moved and the data retrieved wirelessly by ROV or via a network back to the umbilical.
- Our goal is to build a custom device of dimensions similar to the unit below (figure 215). We will connect to an external antenna and to the switch. The electronics will be housed in a compact enclosure such as oil-filled enclosure. The electronics components include ICs, capacitors, resistors etc. these will need to be selected to match the requirements for oil-filled.
- It is difficult to give a precise size form the components until we have completed an analysis of the required link budget. But the transmit circuit will be compact and the antenna can be integrated tightly with the structure. To this end I am confident we will be able to find a practical solution." [50]

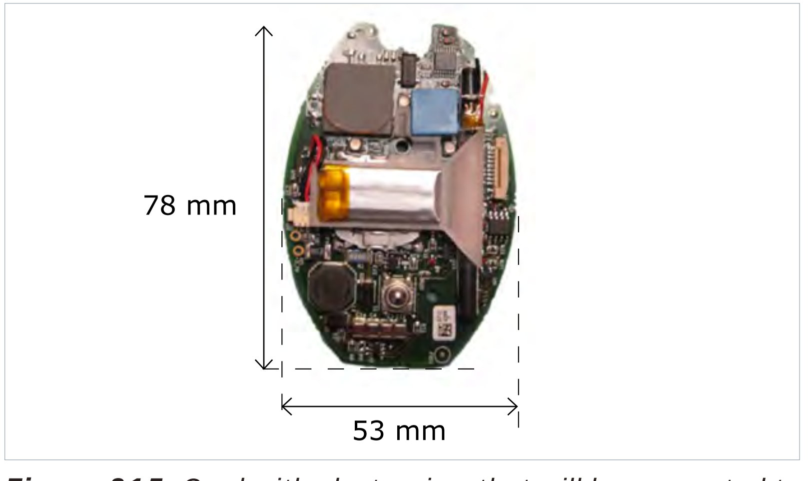


Figure 215: *Card with electronics, that will be connected to switch and register and store verification information. [51]*

I have tried to map out all required product componets that should be part of the verification system, how they should be linked together, and how they can be integrated into the XT system.

I set up and sent figure 216 to WFS, in order to find out if it is the type of system setup they will model and run test on. The answer I got was that they cannot give me any details before they have had the opportunity to model and test the system.

Therefore the system setup in figure 216 is only a suggestion to how I think the components might be linked and positioned. I have assumed that card with electronic components will have attached battery for power supply to both the logger and switch.

In order to be able to define a final concept solution, I will use system solution shown in figure 216 as a base. It is impotant to keep in mind that this is only a suggested solution that probably will transform as modelling and testing of switch technology and communication system is carried out.

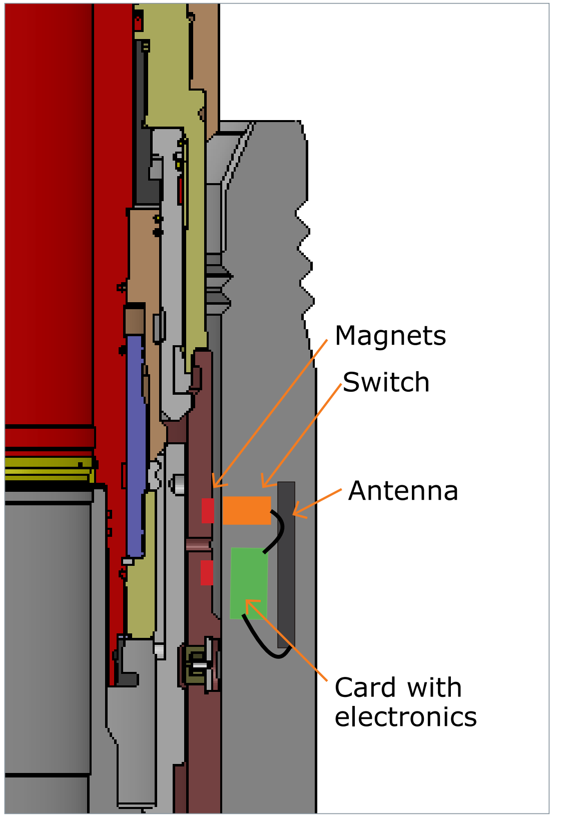


Figure 216: Suggestion to *verification system setup, with magnets, switch, card with electronics and antenna. [5], [6]*

The first idea for concept A was to insert one proximity switch in XT spool, and two magnets in the TH`s actuation sleeve. One of the magnets would provide landing verification on the other lock verification (figure 217). I have also evaluated the alternative of having two switches and one magnet, as illustrated in figure 218.

Both of these system alternatives were sent to SEACON in order to find out which was the best solution. The answer was that both could work well, but that it also is possible to develop a switch with two sensors, which allows detection of two different poled magnets. The system solution is illustrated in figure 219.

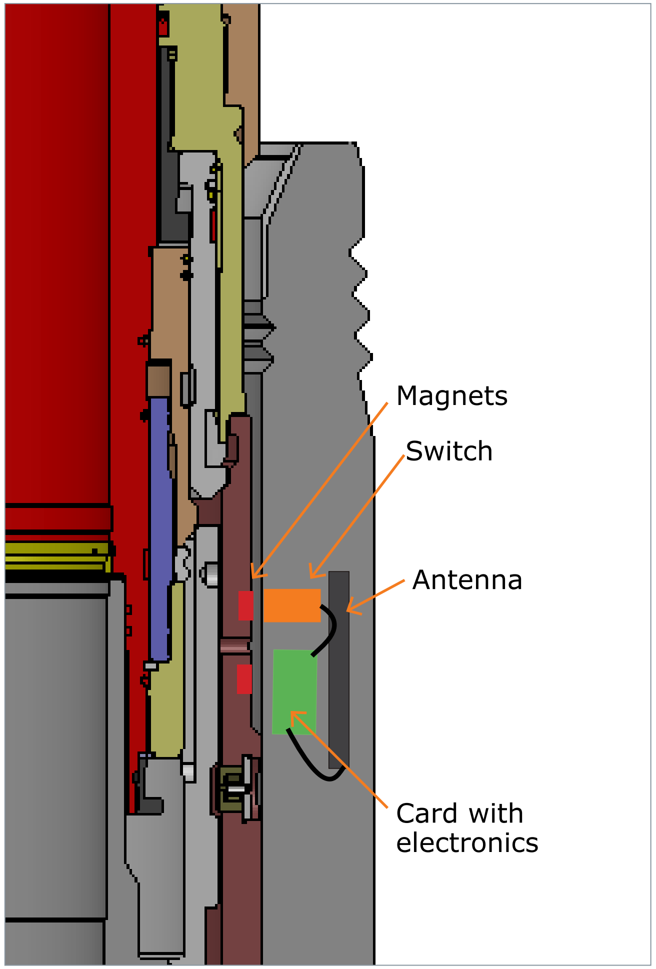


Figure 217: *Verification system with one ordinary switch and two equally poled magnets. [5], [6]*

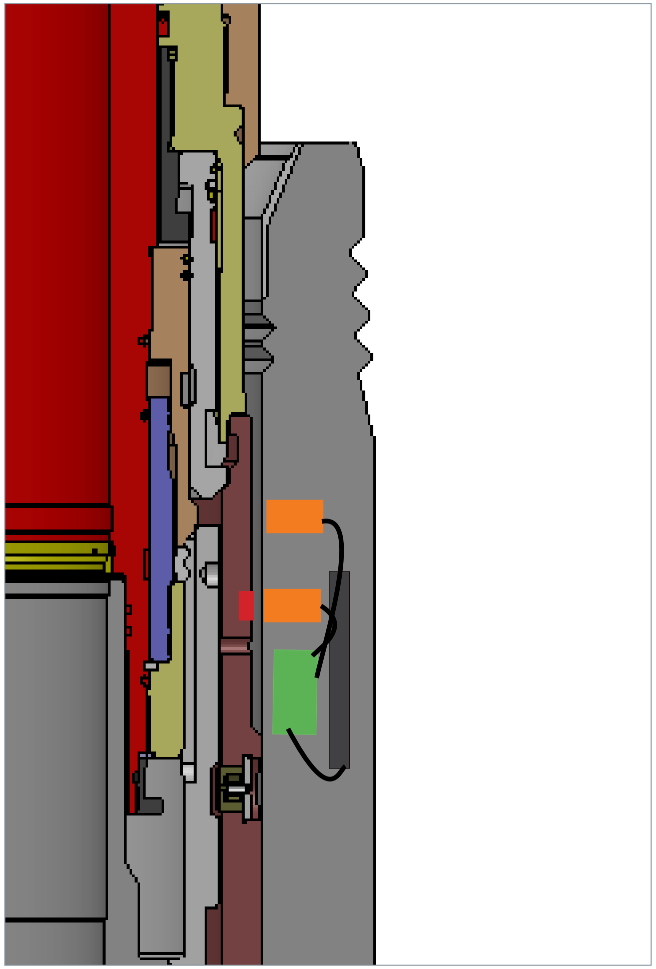


Figure 218: *Verification system using two switches and one magnet. [5], [6]*

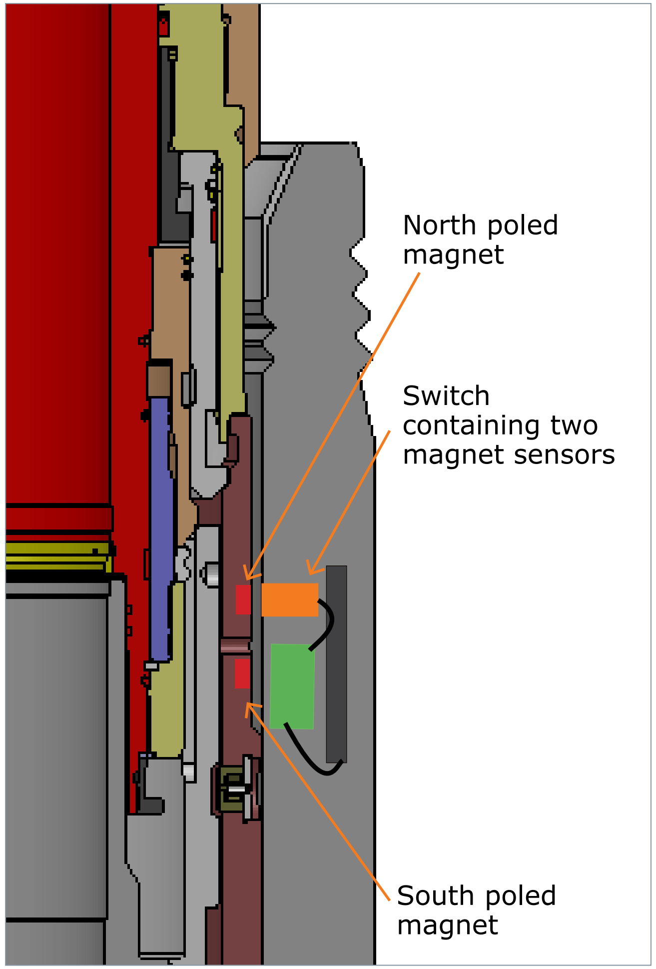


Figure 219: *Verification system that has one switch which contains two sensors. Two differently poled target magnets are used. [5], [6]*

Of the tree system alternatives in figure 217-219, I think the last alternative shown in figure 219 will be the best. The reasons for this are:

- When taking structural strenght of spool into account, it is not very optimal to position two switches in the spool, as it will require more space as thus weaken spool structure more compared to space required for one switch.

- Alternative in figure 217 where one standard switch is used, the magnetic fields of the two magnets might interfere with each other and cause false verification. For alternative in figure 219 on the other hand the two magnets will be opposite poled, so that the two sensors that are positioned in the switch will not be activated by wrong magnet.

I also got some other important product information from SEACON:

- Ideally a Hall effect switch would be best for this application, but the actuation distance (11,0 mm) is at the outer limits, which is affected by magnet size and strength.

- The greater the distance, the less accurate or less sensitive the switch will be.

This made me think of another alternative location for switch and magnets, further down in the spool body. As shown in figure 220 and 221, the required sensing range will be sorter further down in the spool, as gap between actuation sleeve and spool wall is narrower. In addition wall thickness of spool and actuation sleeve is greater, meaning more space for integration of verification system.

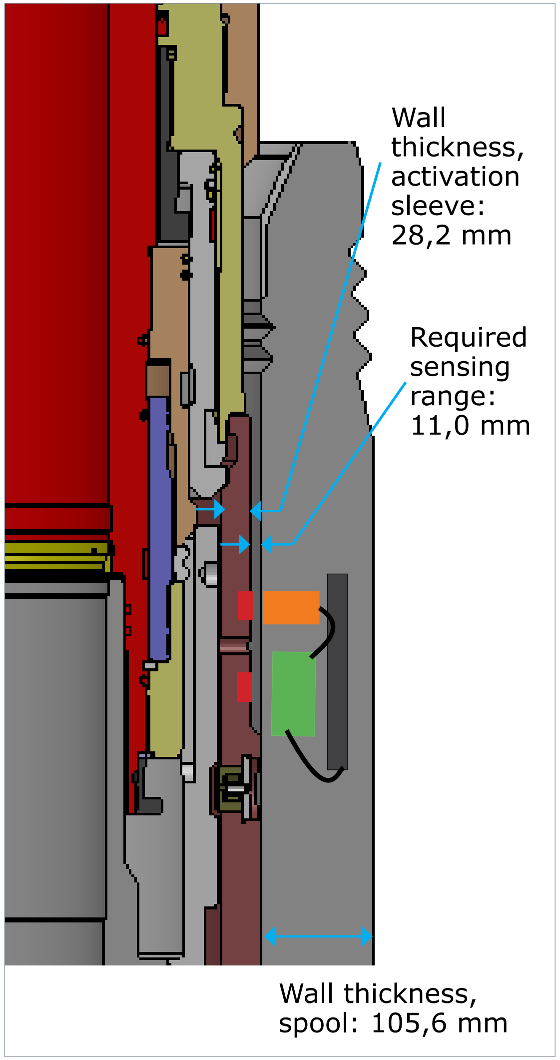


Figure 220: *Required sensing range of 11,0 mm. [5], [6]*

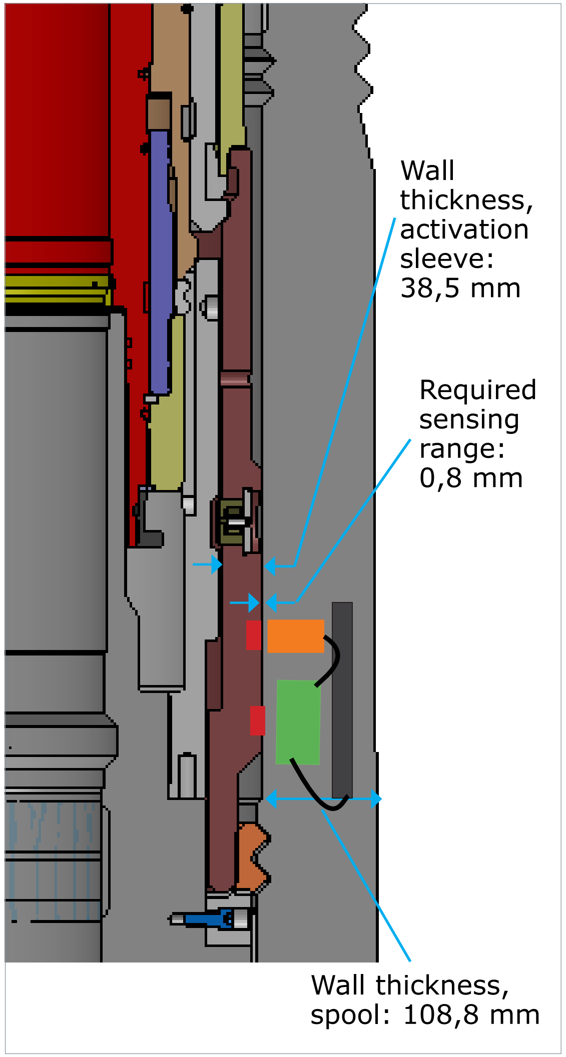


Figure 221: *Required sensing range of 0,8 mm. [5], [6]*

One of the weaknesses of concept A, that also have been mentioned earlier in section 8.6, page 153, is that actuation sleeve is free to rotate relative to the XT spool body. This means that even though TH has landed in correct position, sensor will not be activated by the south poled magnet, if sleeve is in wrong rotational position.

To solve this problem, a magnetic ring or a circle of magnets can be integrated in the actuation sleeve, instead of one single target magnet. During lock down the actuation sleeve moves a distance of 65,5 mm. Thus distance between magnet(s) for landing verification and magnet(s) for lock verification should be positioned 65,5 mm from each other. (Centre to centre distance)

Figure 222 shows upper part of TH where target magnets are to be integrated. If a magnet circle or circle of magnets is to be attached to the activation sleeve, the upper part of the sleeve is best suited as it has a smooth surface. It will be problematic to insert a magnetic circle or circular path of magnets at the middle part of the activation sleeve. Switch has to be calibrated for detecting of magnet at a specific sensing range, thus distance to magnet cannot vary.

Therefore it is probably best to position magnets in upper part of activation sleeve. Figure 223 shows two magnetic circles assemled onto actuation sleeve. The target magnets are made of an alloy of samarium and cobalt. "They are brittle, and prone to cracking and chipping" [52]. Due to this material characteristic it is most likely better suited for creating multiple magnet components that can form a circle, than trying to manufacture e.g. two half circles.

To find final position and shape of magnets will be part of further work, since development, modelling and testing of the verification system is required in order to know what size magnets should have, and where it is possible to integrate them.

Evnen thought it is not realistic to manufacture and assemble a 100% continuous circle of magnetic material onto the TH, I will use it to describe the final verification concept, as a continous magnetic path is the most ideal solution for the verification system.

It is impotant that target magnets do not block viewing ports that are used for verification of THRT latching to TH. In figure 223, lower magnet ring is positioned below viewing ports, while upper magnet ring is located above.

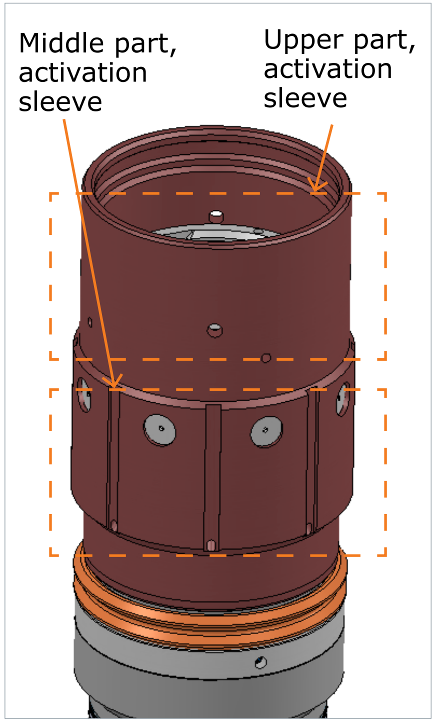


Figure 222: *Upper part of TH. [5], [6]*

Figure 223: *Two magnet circles located on smooth surface of actuation sleeve. [5], [6]*

A small groove in the outer surface of actuation sleeve can be made, for the magnets to sit in. To decide how they should be fixed to the sleeve, and shape of groove will be part of further work.

I have looked a bit into restrictions for magnet dimensions. The magnet rings should not stick further out than the actuation sleeve`s outer diameter. I have constructed a magnet circle in SolidWorks with a thickness of 5,1 mm (outside groove) and a height of 12,7 mm. It is shown i figure 224. The measurements are taken from typical size of SEACON`s target magnets.

The upper part of actuation sleeve has a smaller outer diameter, compared to middle section. Restriction to magnet thickness is linked to the difference in outer diameter of upper part and middle part of actuation sleeve. The difference in outer radius of sleeve, and thus maximum magnet thickness is 10,2 mm, as illustrated by figure 225.

Therefore one can without problem, double the magnet thickness from 5,1 mm to 10,2 mm, but I will keep the thickness of 5,1 mm to define the final concept solution.

An advantage of having thicker magnet is that required sensing range will be lower, so that switch will provide more accurate verification.

As mentioned earlier, center to center distance between upper and lower magnet will be 65,5 mm, as this is the downward movement actuation sleeve has during lockdown.

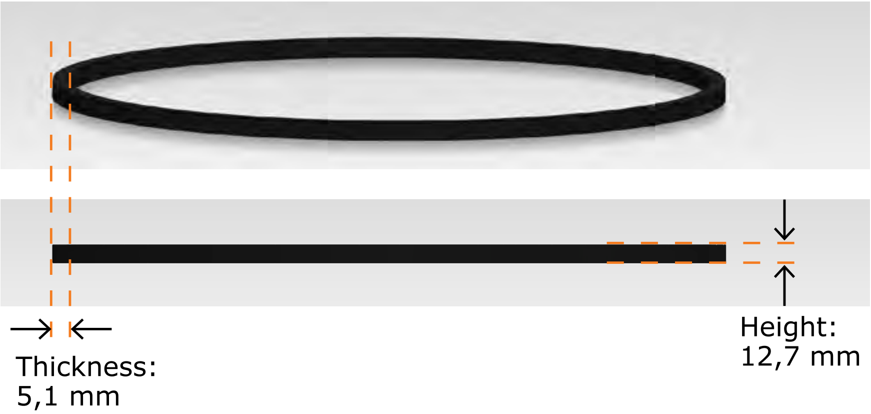


Figure 224: *Magnet ring. [5]*

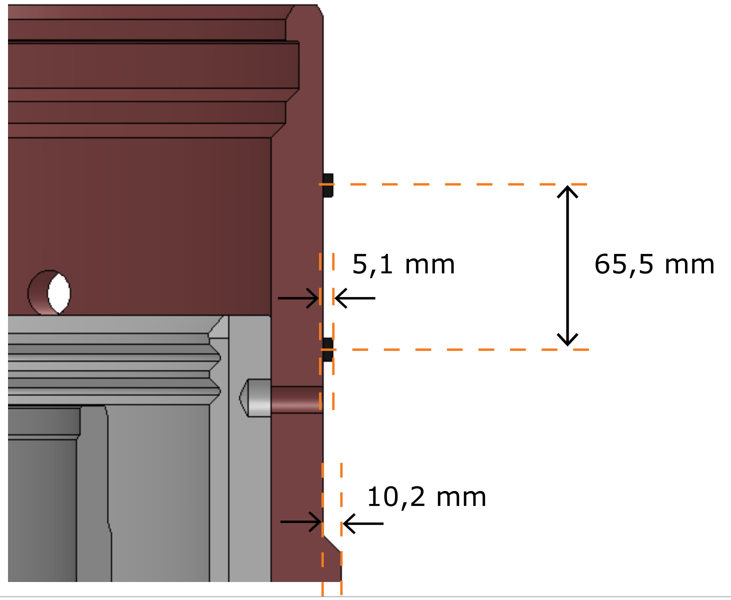


Figure 225: Restrictions to *magnet size and required distance between upper and lower magnet. [5], [6]*

10.5.2. Detailing of Concept B

Landing and lock verification in concept B is like for concept A, verified by the use of proximity switch and target magnet. Landing verification for concept B uses wireless communication, while the lock verification is sent through an electric wire connected to topside. I will first provide more detailed information for the lading verification system, and then have a look at the lock verification system.

TH landing verification system
Figure 226 shows a possible way to set up the verification system. Magnet is inserted into component of inconel material. The required sensing range will be 4,9 mm. Thus a magnet height of 12,7 mm and a thickness of 5,1 mm will be suited, as it provides a sensing range of about 3,8 mm to 12,7 mm.

The ring of inconel material (figure 227) that magnet is insertet into is not free to move. Therefore one do not need a ring of magnetic material, as for concept A. For concept B, a standard target magnet can be used.

A standard Sinking/Sourcing Hall Effect Switch can be used, with one integrated magnet sensor. Dimensions of card with electronics will be similar to the one shown earlier in figure 215.

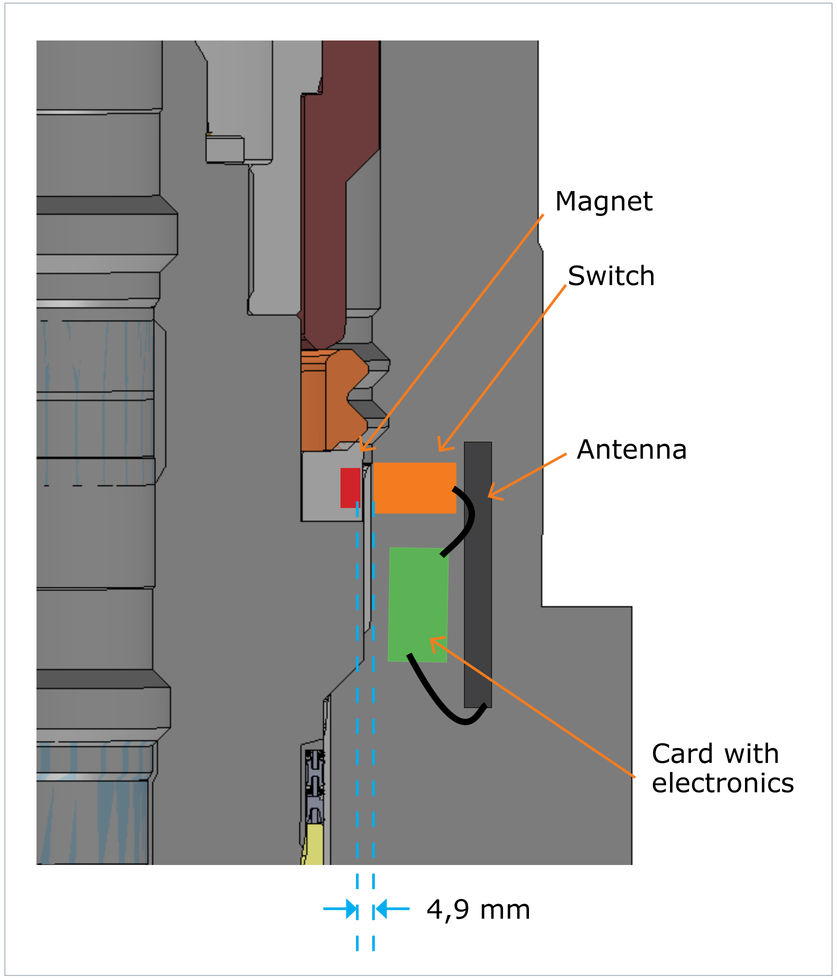


Figure 226: Suggestion to *verification system setup, with magnet, switch, card with electronics and antenna. [5], [6]*

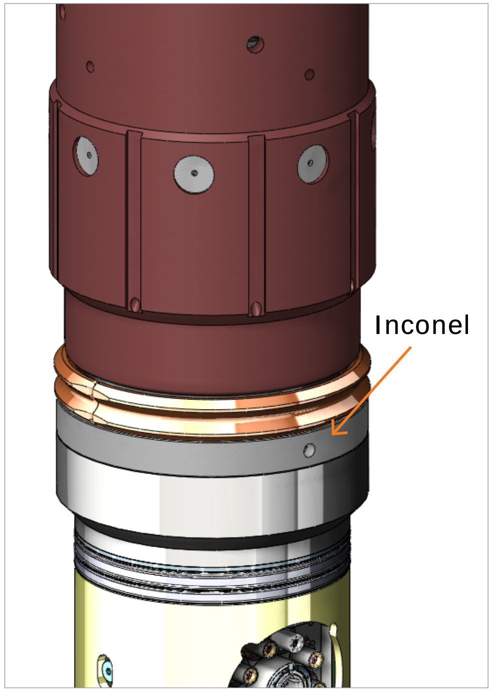


Figure 227: Ring of inconel material *[5], [6]*

TH lock verification system
This part of the verification system will require a path for the electrical line inside THRT`s body. It should not be a problem to drill lines for the path, as I have suggested that it should be done in the same way as paths are made for hydraulic fluid in today`s TH design.

What can be problematic on the other hand is to insert the electrical line, into the narrow lines that are to be drilled (THRT`s hydraulic lines have diameter of about 9,5 mm). It can also be problematic to assemble the THRT with integrated electrcal line that is to be connected to switch which is located inside piston.

An additional complication is that today`s THRT design allows the piston component to rotate feely around the THRT body. If a fixed electric line is to be integrated and connected to proximity switch positioned inside piston, the piston cannot be free to rotate.

When it comes to type of target magnet that should be used, gap between piston and inner wall of upper sleeve is only about 1,4 mm. (Figure 229) This is smaller than the lower limit of normal sensing range, which is 3,8 mm. In order to obtain a greater distance than this between magnet and switch, one can make a groove in upper sleeve for the magnet, that is deeper than the magnet`s thickness. In this way one can make sure that actual distance between magnet and switch is e.g. 4 mm, as indicated in figure 228.

If this lock verification system turns out to not be feasible, but new poppet valve design give good results, it should be considered to use new poppet valve design instead, for providing lock verification.

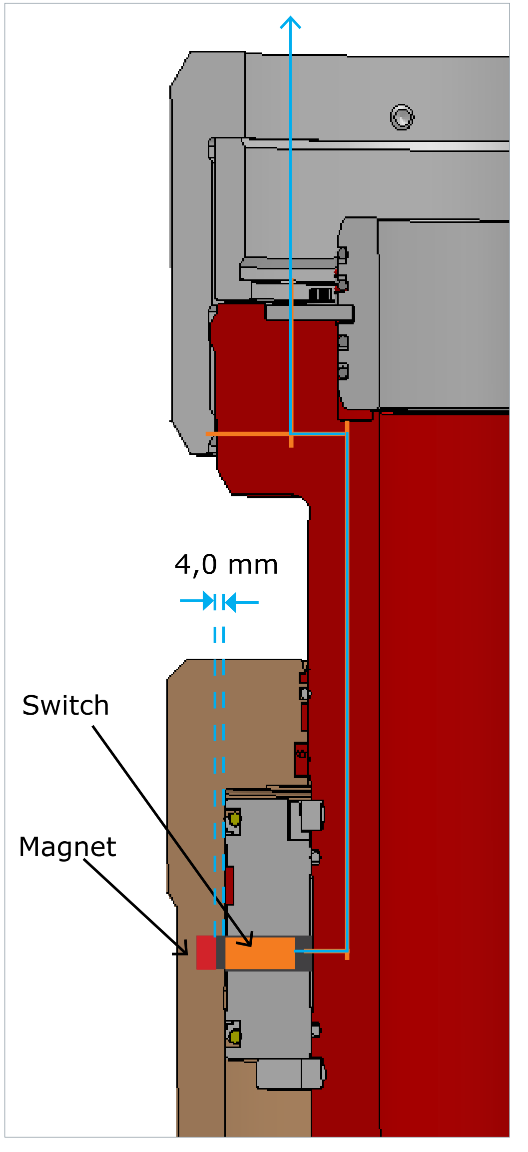


Figure 228: Lock verification system. *[5], [6]*

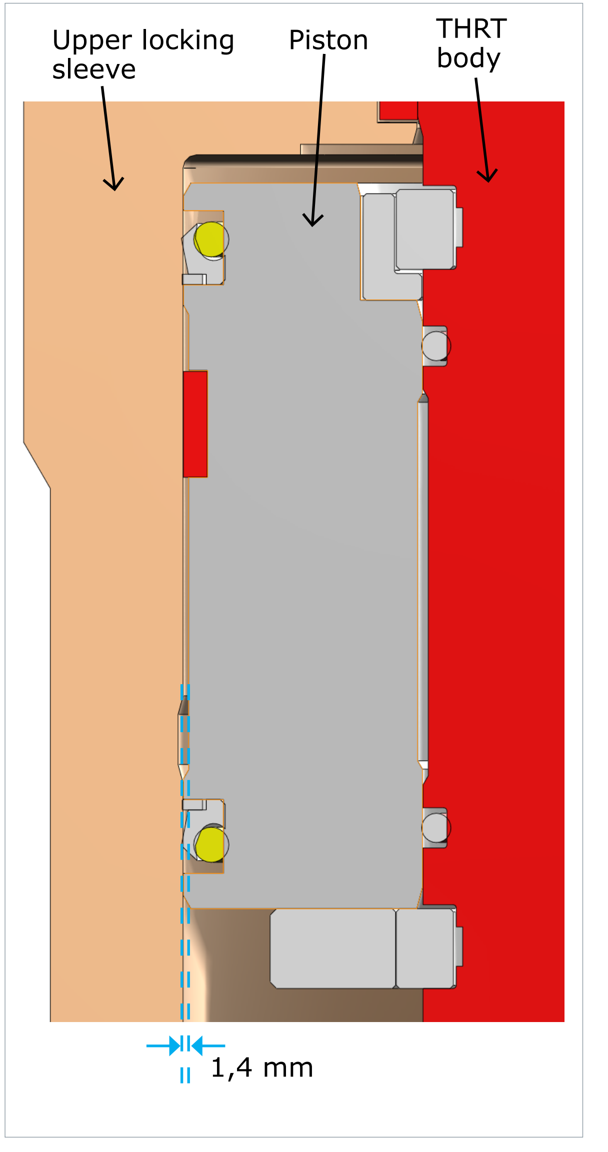


Figure 229: Too short sensing distance. *[5], [6]*

11. TWO FINAL CONCEPTS

For description of subsea production system, please see appendix A and chapter 4. In the two following concept descriptions, I have focused on integration of verification system components in XT spool, TH and THRT. In addition a short description is given for how verification information can be received by operator on topside.

11.1. Concept A

The verification system provides landing and lock verification for TH installation. This is what the system consists of:

- Two opposite poled magnet circles, assebled onto TH`s actuation sleeve. The north poled magnet is positoned above south pole magnet in a center to center distance of 65,5 mm.
- One proximity switch containing two magnet sensors. One of the sensors respond to south poled magnets, while the other respond to north poled magnets. Switch is positioned in wall of XT spool.
- A card with electronic components, positioned in spool wall.
- An antenna, located by the switch and electronics card inside wall of XT spool.

During installation of TH, TH is first latched to THRT on rig. Then they are lowered subsea trough a marine riser with landing string attached on top, and production tubing attaced below. As TH is lowered down into XT spool, it will be oriented in right position with the help of orientation key on TH and helix shape in spool. TH will first make a rotational movement, before it makes a final movement axially downward by 150 mm. (See section 4.3.2. for detailed description). During this last vertical movement, south poled magnet circle will get gradually closer to proximity switch.

The switch is a Sinking/Sourcing Hall Effect Switch. It has an electric circuit that is normally open. As magnet is brought closer to the switch, the electric circuit will gradually close. When TH is in right vertical position relative to XT spool, electric circuit will be closed. This is registered by a logging unit which stores the verification data for landing of TH. Next, the landing verification information will be transmitted with a wireless signal through wall of spool. The wireless verification signal will be recieved by a ROV unit, which will forward the information to operator on topside.

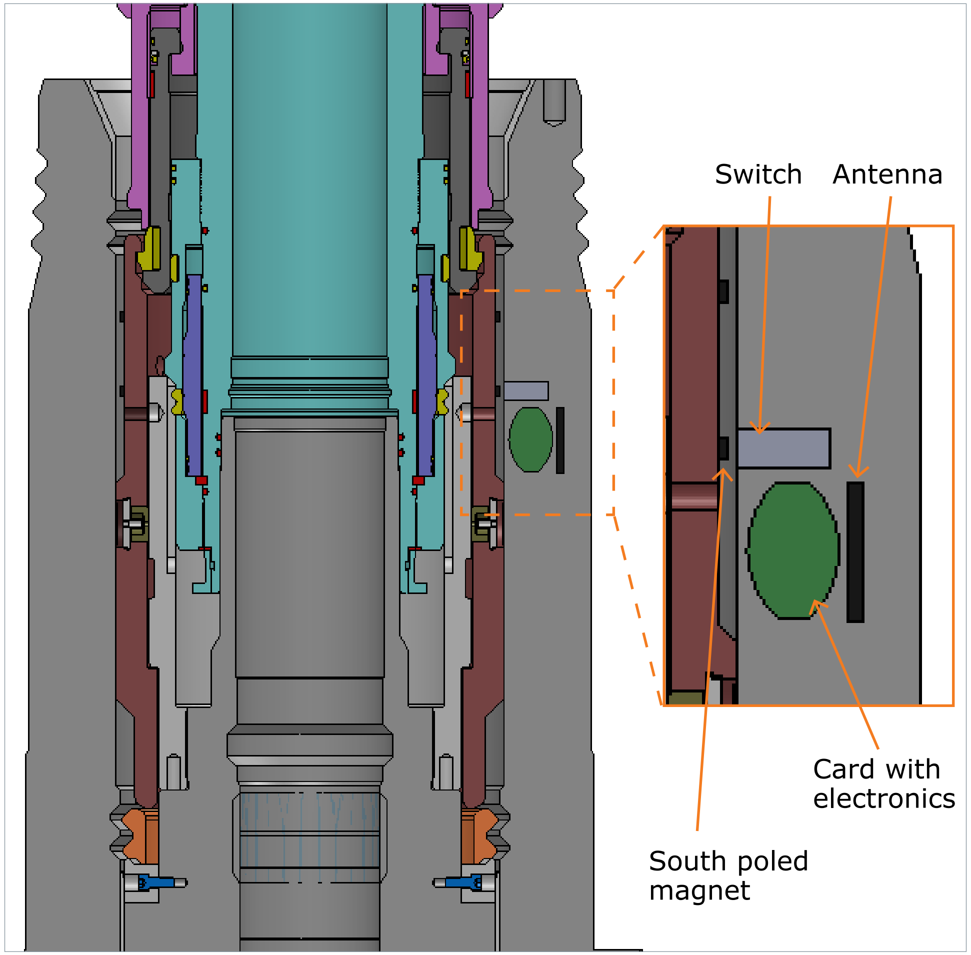


Figure 230: TH landed in right position, with south poled magnet positioned next to proximity switch. *[5], [6]*

Next step of TH installation, after TH has landed in right position in spool, is to lock TH to the spool. During this proceedure the actuation sleeve is being pushed downwards, causing south poled magnet to move away from switch, and north poled magnet to move towards switch. As south poled magnet move away from switch, electric circuit will gradually open. As actuation sleeve is pushed down it will expand the split lock ring, and lock TH to XT spool.

When north poled magned gets so close to switch that it can be sensed by sensor in switch, electric circuit will gradually close again. When actuation sleeve has been pushed all the way down, north poled magnet is positioned next to switch and electric circuit will be closed. Logger vil register that electric circuit has closed, and store the lock verification information.

Lockdown verification information will be sent wirelessly through wall of spool and be recieved by a ROV which forward signal to operator on topside.

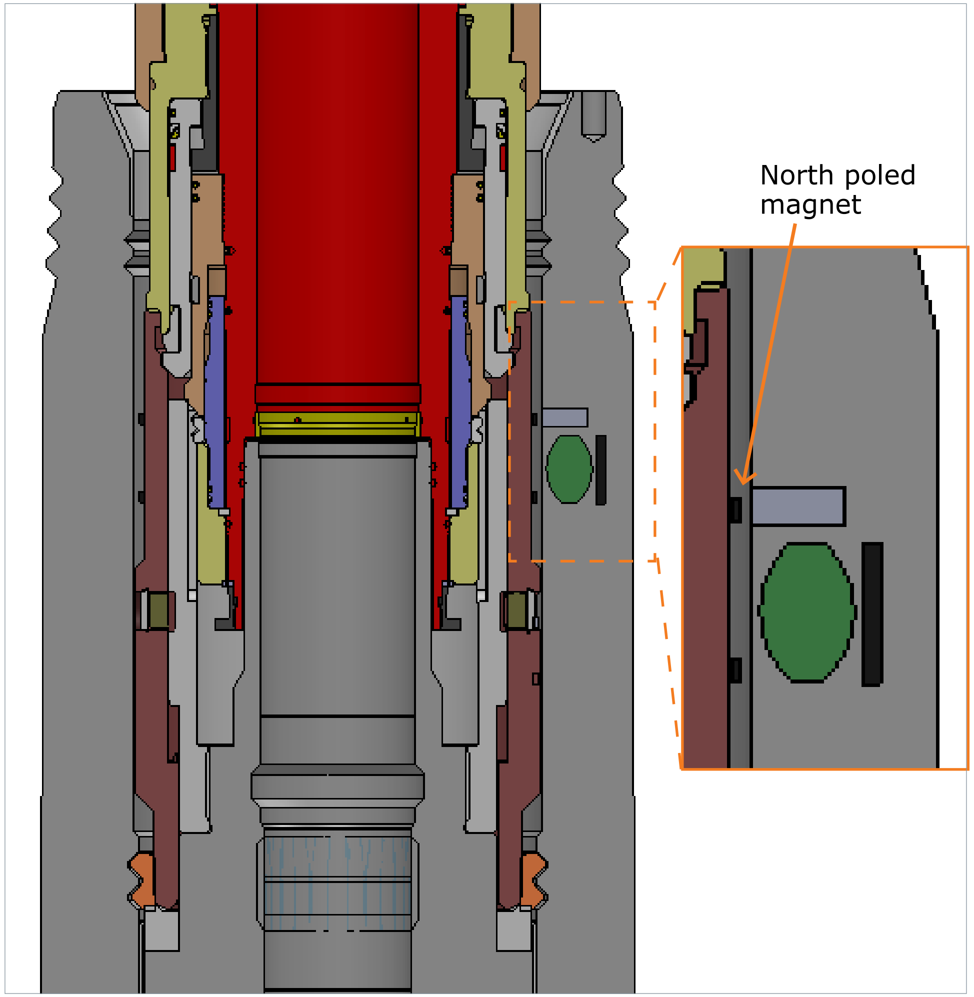


Figure 231: *TH locked to XT spool, with north poled magnet positioned next to proximity switch. [5], [6]*

11.1.1. Technical Details

Switch with two integrated sensors is not among SEACON`s product range, therefore deveopment of new switch solution will be required.

SEACON`s proximity switch sensors are qualified for pressure up to 10.000 psi. Aker Solutions XT system is qualified for 15.000 psi. If switch is required to withstand pressure of up to 15.000, new switch design will have to be developed by SEACON or another manufacturer of proximity switches that can deliver a qualified product.

Indication is given for size of switch (diameter of 22 mm and length of 54 mm), but shape and size of the proximity switch is quite flexible. Some research will also be required in order to find optimal size and shape of target magnets, as standard target magnet is not suited for the verification system.

In addtion the wireless communication system has to be modelled and tested. WFS has offered to build a model and run simulations to determine critical design parametres. They can also build a test proof-of-concept system. WFS has given an indication of dimensions for card that holds the electric componends (78 mm x 53mm). Dimensions for antenna is not known.

There are no standard componens in this verification system.

11.1.2. Manufacturing

In order to make space for switch, card holding electronic components and antenna, a groove has to be drilled from the inside of the XT spool.

This should not be a problem, as a similar drilling consists in the spool today. This drilled line is a path for hydraulic fluid to flow though during pressure testing of XT system.

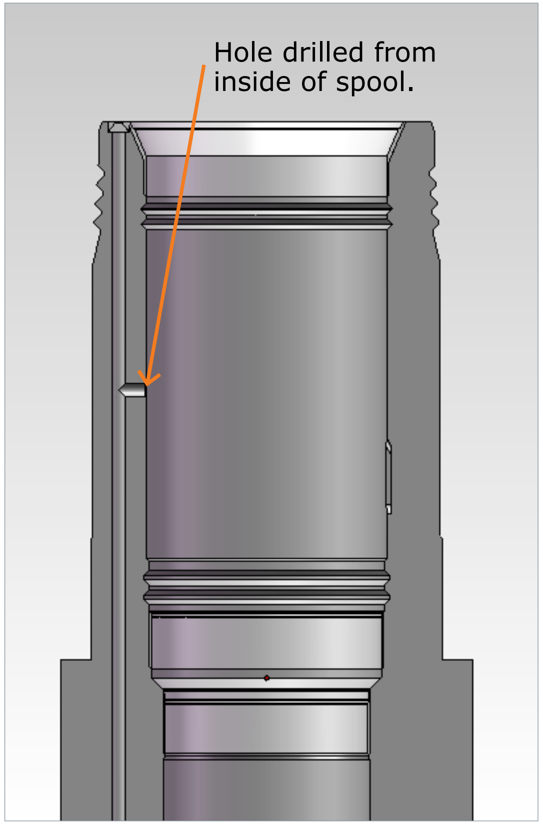


Figure 232: *Hydraulic line drilled from inside of spool. [5], [6]*

11.1.3. Costs for modelling, testing and research

Relevant costs for further development of the final concepts will be related to modelling and testing of the verification system. I have got some approximation of costs and time scale from SEACON and WFS.

SEACON has set up timescale for development:

- In general, it would be 10-12 weeks for design and development, if the 15,000 psi (103,5 MPa) is required additional development is necessary. Then allow 16-18 weeks for development.
- Production for max 10,000 psi (69 MPa), 12-16 weeks after approval of design, for 15,000 psi (103,5 MPa) 20-24 weeks.

This is cost & timescales provided by WFS:

- Modelling: approx. £15k (ca. 140.000 NOK); 4 weeks
- Proof-of-concept: approx. £30k (ca. 280.000 NOK); 6 weeks

11.2. Concept B

This concept consists of two independent verification systems, one provide TH landing verification while the other confirm TH lockdown.

The verification system that provides landing verification, consists of these components:

- One target magnet, located in ring of inconel material, which is part of TH.
- One proximity switch containing a magnet sensor, is located in wall of spool.
- A card with electronic components, also positioned in spool wall.
- An antenna, located by the switch and electronics card inside wall of XT spool.

As for concept A, the switch is a Sinking/Sourcing Hall Effect Switch. It has an electric circuit that is normally open. As TH makes its last vertical movement down into XT spool, target magnet is brought closer to the switch, and the electric circuit will gradually close.

When TH is in right vertical position relative to XT spool, electric circuit will be closed. This is registered by a logging unit which stores the verification data for landing of TH. Next, the landing verification information will be transmitted with a wireless signal through wall of spool. The wireless verification signal will be recieved by a ROV unit, which will forward the information to operator on topside.

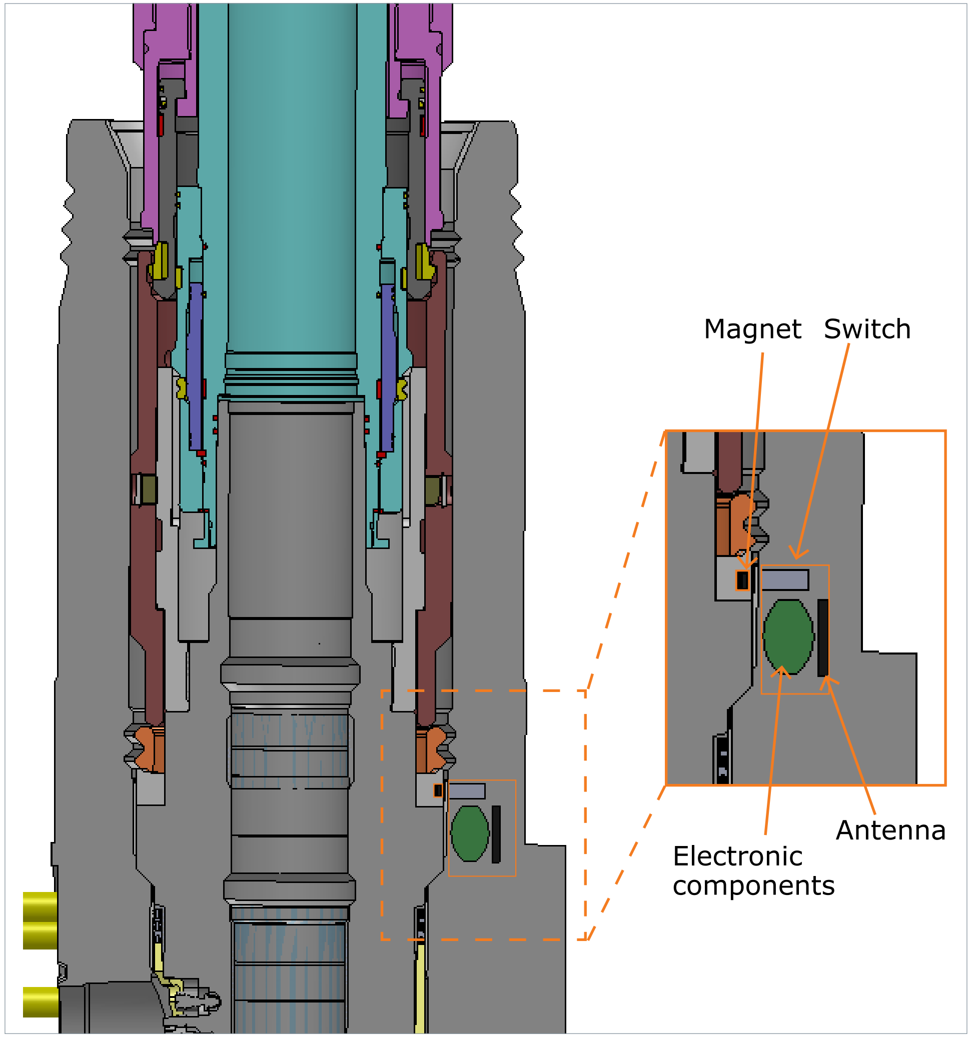


Figure 233: *TH locked to XT spool, with north poled magnet positioned next to proximity switch. [5], [6]*

The other verification system provides lock verification, and it consists of these components:

- Magnet circle, located in upper locking sleeve.
- Proximity switch containing a magnet sensor, located in THRT piston.
- Fixed electric line that is used to send verification signal from switch and all the way up to operator on topside.

After TH has landed in correct position in spool and a verification signal has been recieved by operator on topside, the TH is ready for lockdown.

During lockdown, upper sleeve where magnet is located will move axially downwards, and magnet will move towards the switch located in THRT piston. Same switch type is used as for landing verification.

When magnet gets close enough to be sensed by magnet sensor in switch, electric circuit will gradually close. When upper locking sleeve is in lock position, magnet will be positioned directly next to switch and electric circuit will be closed.

Since direct electric line is connected to topside, operator will be able to see on a registration unit on topside, when electric circuit is closed. When electric circuit is closed, operator will know that upper locing sleeve is in lock position, which means that TH is locked to XT spool.

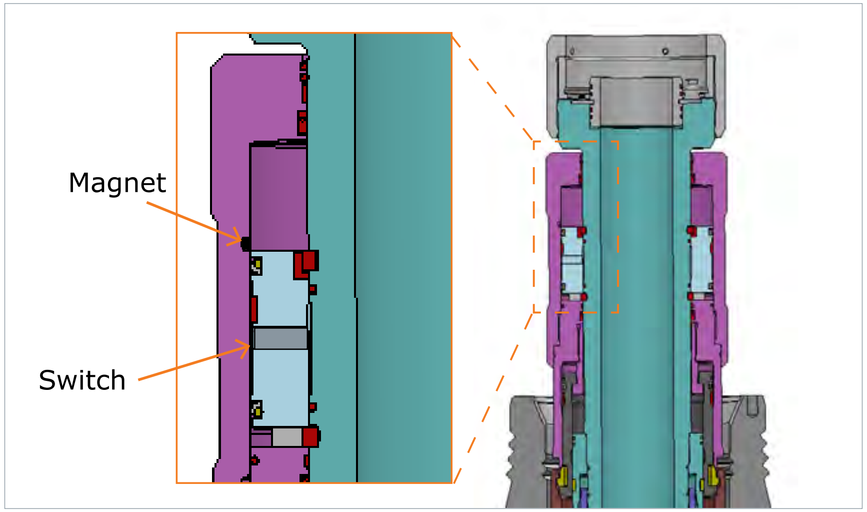


Figure 234: Lock verification system integrated in THRT. Here THRT is in *unlock position. [5], [6]*

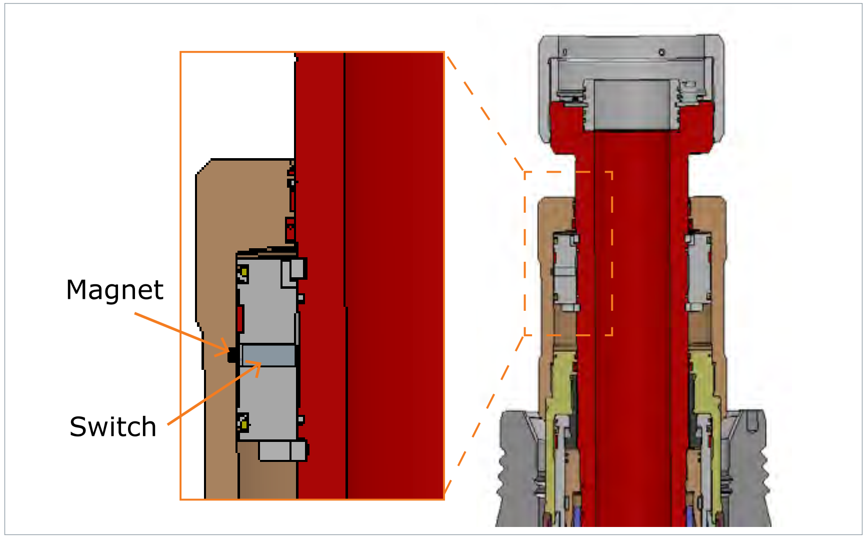


Figure 235: *THRT with integrated lock verification system. Here in lock position, with magnet positioned next to magnet sensor. [5], [6]*

11.2.1. Technical Details

TH lading verifiaction system
Verification system for TH landing has many similarities with concept A. Biggest difference is that concept B uses standard proximity switch with one integrated sensor. This means that new switch design is only required if switch has to be qualified for pressure above 10.00 psi. Land verification system also use standard target magnet.

When it comes to the wireless communication system, this concept require same modelling and testing of system as concept A.

TH lock verifiaction system
The lock verification system require little modelling and testing, compared to the landing verification system which uses wireless communication. But is will require some design modifications of THRT. Today THRT piston is free to rotate around THRT body. If fixed electric wire is to be integrated and connected to proximity switch located in the piston, the piston cannot be free to rotate.

Magnet ring will be required as upper locing sleeve is free to rotate, relative to THRT body, and thus also relative to the proximity switch.

As mentioned in previous chapter, it can be problematic to insert electric wire into THRT. In addition further concept development and research has to be carried out, in order to find out how electric wire should be connected to topside. Today there are only hydraulic lines connected to the THRT.

11.2.2. Standard Components

These are the standard components:

- Target magnet for land verification, with diameter of 12,7 mm and thicknes of 5,1 mm.
- Sinking/Sourcing Hall Effect Switch for both landing and lock verification. Typical dimensions are diameter of 22 mm and length of 54 mm, but shape and size of the proximity switch is quite flexible.

11.2.3. Manufacturing

The landing verification system requires that a groove is made in the spool body, for integration of switch, antenna and card that holds electronic components. Groove has to be made from the inside of spool. As for concept A, this should not be a problem, as a similar drilling consists in the spool today. (See figure 232)

Lock verification system require that some lines are drilled in the THRT, for integration of electric wire connection. It can be done in the same was as the hydraulic the, F5 is made today. In addition space has to be made for switch in the THRT piston, and for magnet in the upper locking sleeve.

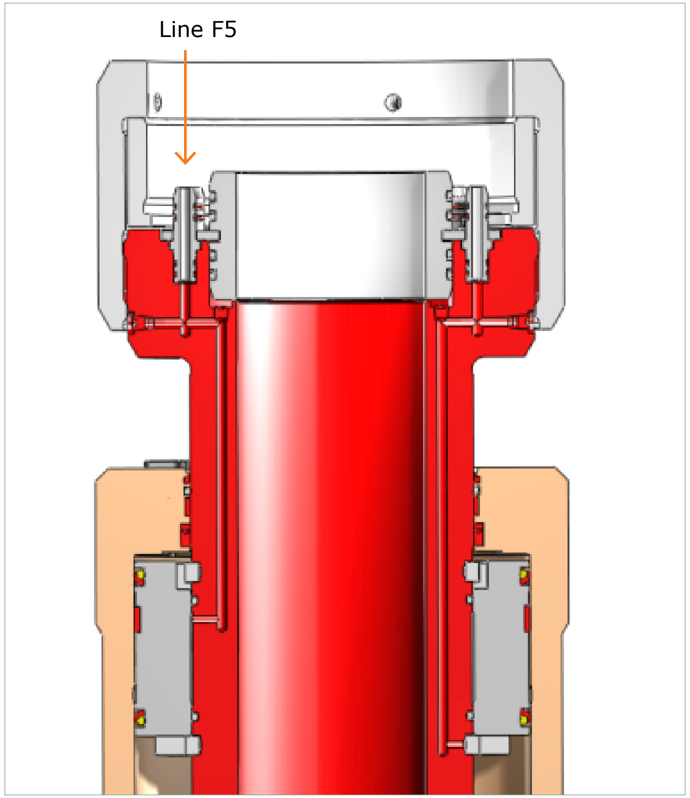


Figure 236: *Hydraulic line F5. [6]*

11.2.4. Costs

Costs related to modelling, testing and new design, will be similar to that of concept A. It is difficult to say which of concept A and B will be least expensive to develop and manufacture. Landing and lock verification system for concept B are less complex than A, when it comes to proximity switch, since switch do not need to contain two sensors. But if one look at the whole picture, concept B require two verification systems, while concept A only require one.

If standard proximity switch with pressure rating of 10.000 can be used, rough estimated price from SEACON is 4600 - 8700 NOK ($800-$1500)

12. PROCESS EVALUATION AND DISCUSSION

12.1. Concept Development Activities and Improvement Potentials

I have had a comprehensive concept development process. In the start of the master thesis project it was a lot to learn about the subsea system as a whole, and also about the Tubing Hanger`s installation process. Thus I had a quite long analysis phase.

This was done in order to get to know the subsea system:

- I attended an introduction course to XT production systems.
- I wrote appendix A, which is an introduction to subsea.
- Incident analysis was carried out (appendix B).
- A Hazard Identity study has been conducted (appendix C).

I do not have any suggestions to improvement potentials for the analysis phase. Incident analysis and HAZID was quality assured by employees at Aker Solutions.

On basis of the analysis phase, a Basis of Design was written, and concepts were developed. As part of the basis of design I calculated approximated precision requirement values for the verification system. The purpose of the calculated values was for me to get an indication of how precise the verification should be. The evaluation process I carried out probably has a great improvement potential, and new precision requirement values should be found for further work carried out on basis of my thesis.

In the first part of the concept development process, a technical analysis was carried out in order to get an overview of existing verification technology (appendix D). I started off with ten different concept solutions that were evaluated and developed further. Three concept selection processes were conducted in order map out concept weaknesses and strengths, and to narrow down number of concepts.

The final concept selection process was the expert testing. After results had been collected and evaluated, I found out that the test should have been set up a bit differently. Four employees at Aker Solutions carried out the test where different concepts were rated according to how well they covered the product requirements.

The score range was from 1 to 3, which proved to be a too narrow spectre of values. The result was that the concepts ended with very similar scores, and it was difficult to carry out the selection process on basis of the point distributions. As there was no time to carry out a new improved test setup, concept selection had to be carried out on basis of additional comments that some of the test participants gave during the expert testing.

12.2. Revision of System Design and Costs

System design
The two final concept solutions are not as defined as I hoped they would be. The reason for this is that there do not exist a similar system from before, and modelling and testing of technical components will be required in order to find a final design for the verification system.

The manufacturers of switch and wireless communication technology believe that the final verification system concepts are possible to make and integrate to the XT system. Results from modelling and testing of the verification systems might give negative results, but at least then one knows that another solutions have to be evaluated. This report has multiple concept proposals that can be further investigated, if some concepts are not suited for TH landing and lock down verification.

Costs
For further development of the final concepts, the highest costs will be related to modelling and testing of new lock down verification system. In order to keep the costs as low as possible, it is important find exact system requirements, (e.g. how high pressure the system should take.), before modelling and testing is started.

If one come up with new system requirements after the modelling and testing has started, one might have to do the work twice, and the product development work will have unnecessary high costs.

13. CONCLUSION

Three main objectives were set up for this master thesis:

- Get an overview of the Tubing Hanger`s locking sequence and how this is verified by the installer today.
- Identify existing applicable technology or the lack of this.
- Come up with and present two verification system concepts that provide landing and lock verification for Tubing Hanger installation.

I spent a good amount of time to reach the first of these three goals, which formed the basis for the rest of my work. Even though it demanded much time and work, it was crucial for me to get a good understanding of the system, before starting to develop concepts.

The second goal has also been reached. First research I did on identifying existing technology can be found in appendix D. In addition continuous research has been carried out along with the development and detailing of verification concepts.

The result of this master thesis are two verification system concepts, that can provide landing and lock verification for installation of Tubing Hanger. Thus the third project objective has also been reached.

I am satisfied with the work i have carried out, most of all because I have learned a lot during the product development process. Throughout the project work, I have contacted different people in order to find relevant information and guidance. That has been a new experience for me, as I have not been so dependent on gathering information in order to carry out a product development process before.

It has been a good experience to write master thesis for Aker Solutions. I got an own office space at their location in Tranby, and have thus had the opportunity to work with my master thesis project in short distance from helpful colleagues and work shop where subsea products are manufactured.

13.1. Recommendations

From the experiences I have got during the master thesis project, these are my recommendations:

- For a similar master thesis projects that are carried out in cooperation with a company, I will recommend that student(s) work at the company`s location, and not from university. It will be much easier to find information and to get help and guidance.
- For students that consider writing master thesis for a company, I will without doubt recommend Aker Subsea at Tranby. During my project work, people have been more than willing to help, and the work environment is really good.
- When it comes to project planning, I will advise that a project plan with milestones is not only set up, but also used actively during the project development work. I got a good insight to how my process has been by keeping record of my actual progress. It proved to be very different from the plan I first set up. The original plan was used in order to keep track of time and to know where in the product development process I should be.
- A concept test should have a wider score rage than the one I used for expert testing. A score of 1 to 3 proved to be too narrow in order to obtain significant differences between the different concepts.
- For further product development work that is carried out on basis of this master thesis, new and more accurate values should be found for required system precision. The values provided in this thesis are only rough estimations.
- One should contact producers of relevant technical components as early as possible during a product development process. They will be able to provide valuable product information. For further work on this project, product specifications will influence the final construction of components and reveal if components have dimensions outside the limitations of the TH.

13.2. Further Work

Before further work is carried out, the persons that are going to carry out further product development work on basis of this thesis should get an overview of the work that is presented in this report, and contact me if anything is unclear.

In addition it is important that basis of design and especially list of key product requirements are revised in detail. This should be done not only to ensure that requirements are updated and quality assured, but primarily to make sure that everyone are familiar with the product requirements. If not, one will not have a clear and common goal to work towards.

Below is a list of further work that should be carried out:

- Contact SEACON and WFS in order to agree upon what type of research, modelling and testing that is to be carried out, and what requirements the verification system should meet.
- New and more accurate values should be found for precision requirements. The values provided in this thesis are only rough estimations.
- Safety Integrity Level (SIL) study should be carried out, in order to evaluate the system`s reliability. For this Anders Holm can be contacted. He is SIL expert at Aker Subsea.
- During my work I have only focused on installation of Tubing Hanger. For further concept development work one should also evaluate the need for verification during retrieval of Tubing Hanger. E.g. latching of THRT to TH is easily verified on rig, before TH is run subsea, but when THRT is to be latched or unlatched from TH subsea, there is no verification.
- New concept proposal from Vicens Breiz should be studied and if applicable be further developed (page 168).

APPENDIX A

Introduction to Subsea

The different parts of the subsea system are described shortly and highlighted in yellow in a figure below each system description. A learning portal called SUBSEA1, has been used as a resource.

A.1. Umbilical System

This system provides electrical, hydraulic and chemical service lines between subsea equipment and to the host facility.

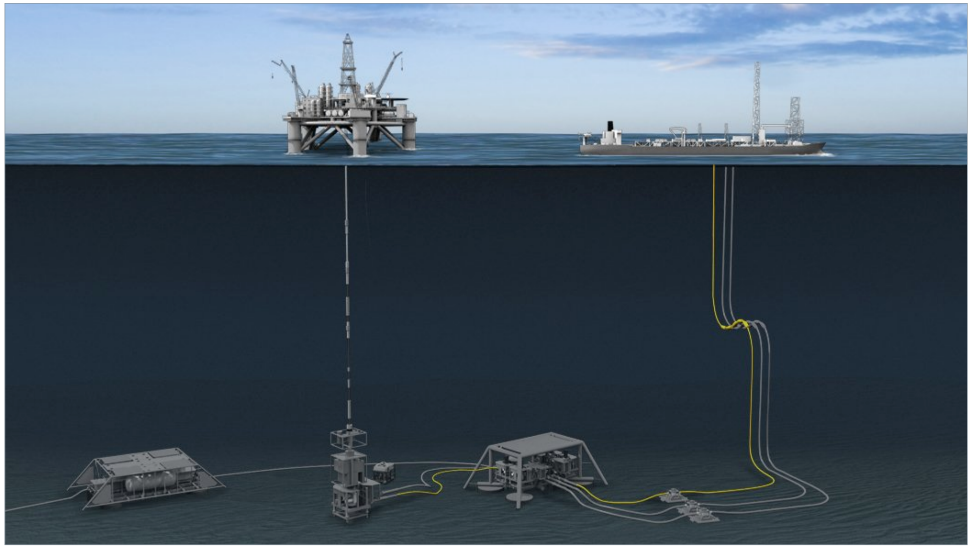


Figure 237: *Umbilical System. [3]*

A.2. Tie-in System

The Tie-in system is used to install and connect flowlines and umbilicals to different parts of the subsea production systems.

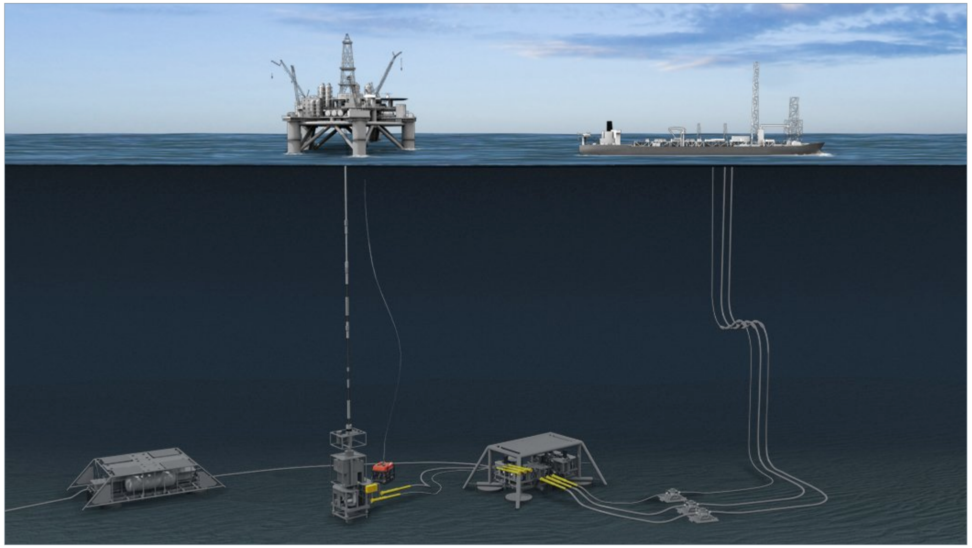


Figure 238: *Tie-in System. [3]*

A.3. Remotely Operating Vehicle (ROV)

A ROV is an underwater robot, that can be manoeuvred by a person positioned on topside (eg. on board of a vessel). An umbilical cable carrying electrical power, connetcts the ROV to the topside. This cable can also transmit video and data signals. In figure 238 the ROV is marked in red color.

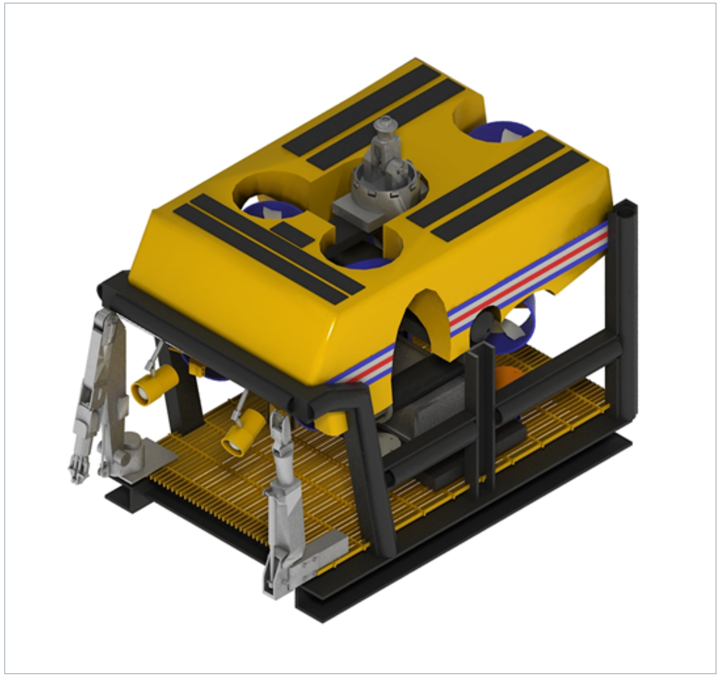


Figure 239: *Remotely Operating Vehicle (ROV). [3]*

For intallation and retrieval processes the ROV is eqipped with a range of ROV tools, in order to carry out different tasks. Some of these tools also enables opening and closing of valves.

Operations for the Tie-in system described on the previous page and intervention operations, are diver assisted for water depths down to about 100m. For corresponding operations on deeper waters, ROV and ROV tools are used.

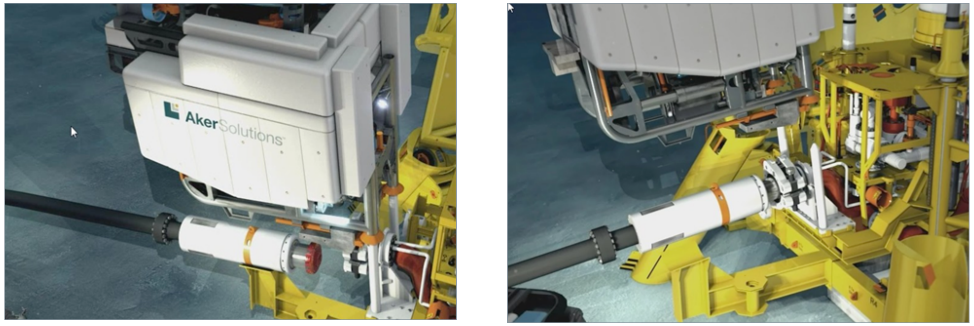


Figure 240: *ROV used for Tie-in and intervention operations at deep water. [3]*

A.4. Flowlines

Flowlines transport oil/gas production and injection fluids between subsea wells and host facilities. It is usually laid upon the seabed.

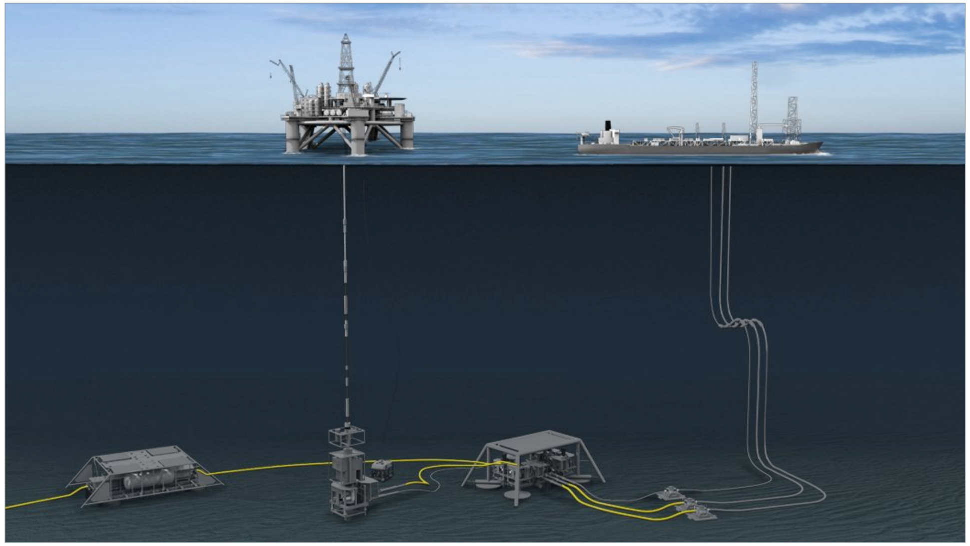


Figure 241: *Flowline System. [3]*

A.5. Subsea Processing Systems

The Subsea Processing Systems process the production fluids (typically a mixture of oil, gas and water) from the well, and separates out the vital components before they are exported further.

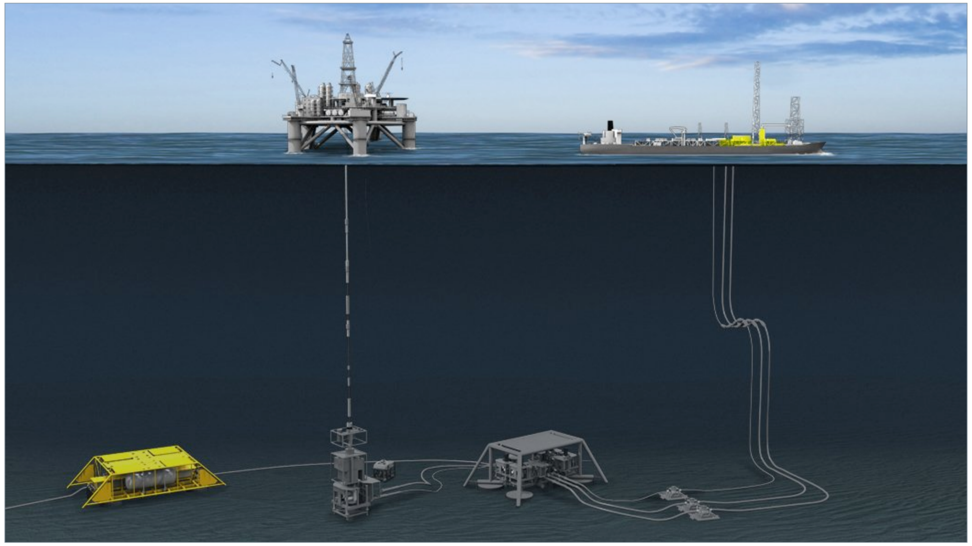


Figure 242: *Subsea Processing System. [3]*

A.6. Wellhead System

This is the part of the subsea system that gives a fixed foundation structure and pressure containment system for the well on the seabed.

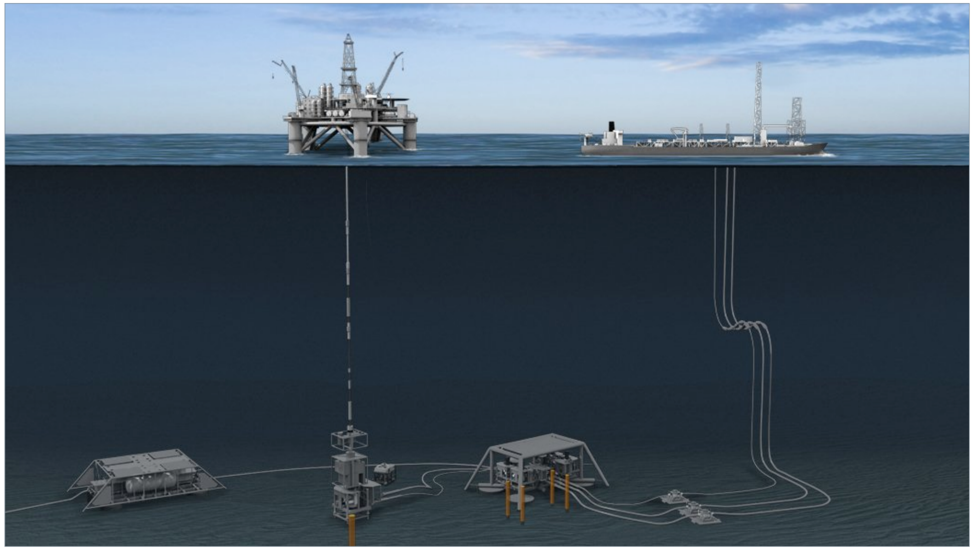


Figure 243: *Wellhead System. [3]*

The Wellhead system consists of a range of components, which are used for the installation of the wellhead.

Figure 244 gives an overview of Wellhead system components, with possible tube size.

1. Guide Base; to guide elements being installed
2. Seal Assembly; to seal the Casing Hanger against Wellhead
3. Casing Hanger 10 3/4"; to suspend a well casing string down the well
4. Also a Casing Hanger but with size 14"
5. Wellhead Bore Protector; to protect the Wellhead main bore for wear and tear during drilling operations.
6. Wellhead; to provide the suspension point and pressure seals for the casing strings.
7. Conductor; to support the surface formations and prevent the siders from the hole from caving into the borehole.

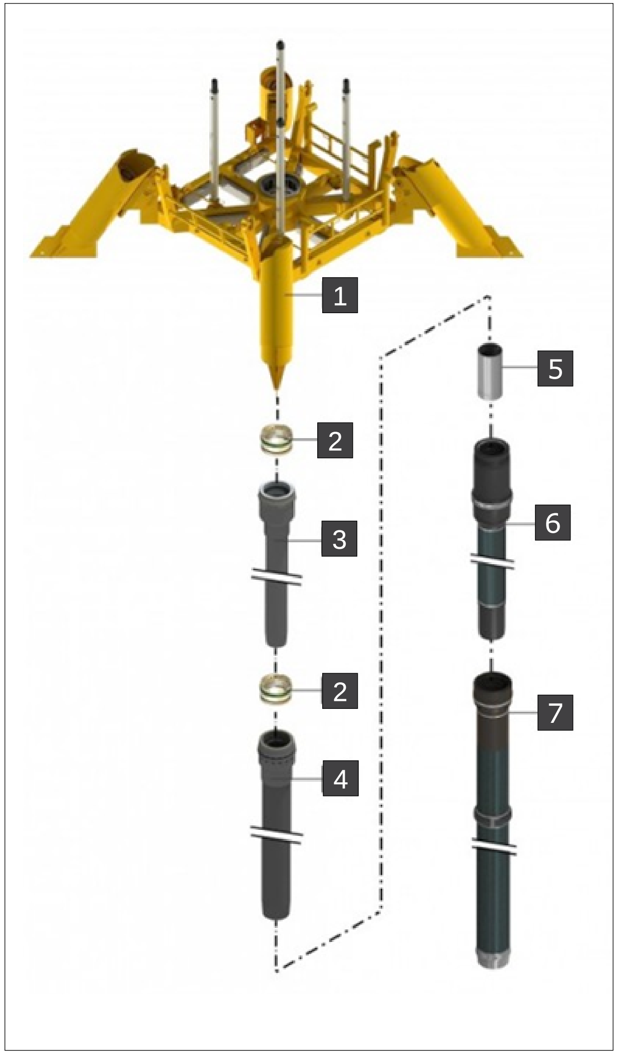


Figure 244: *Wellhead components. [3]*

The installation of the wellhead is a central part of the subsea system, and I have therefore made a quite detailed description for its process on the following pages.

Installation process:

1. Drilling an eg. 42” big hole for a eg. 30” Conductor Housing,and then retrive sling.

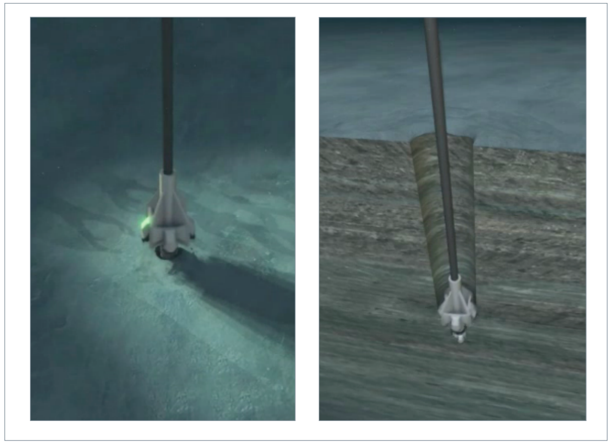


Figure 245: *Drilling down towards the well. [3]*

2. Running the Conductor Housing with a Conductor Housing Running Tool.

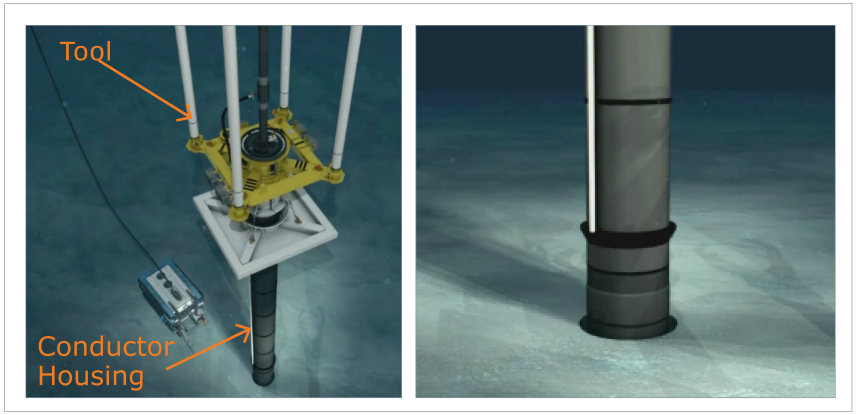


Figure 246: *Running of Conductor Housing. [3]*

3. Cement the Conductor casing. Cement is sent down to the bottom point of the Conductor Housing, and up on its outside to fill up the empty space between the Conductor and the drilled hole.

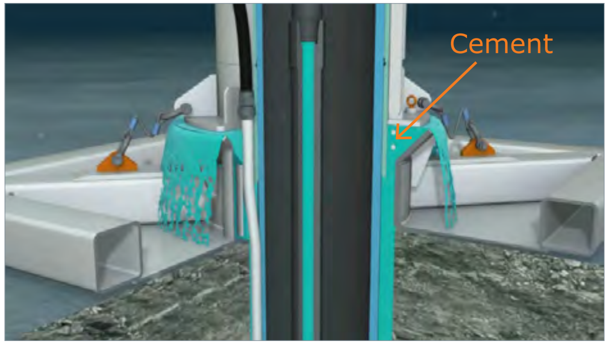


Figure 247: *Adding cement. [3]*

4. Drilling through 36” Conductor Housing. The hole is now made even deeper, past the bottom end of the Conductor.

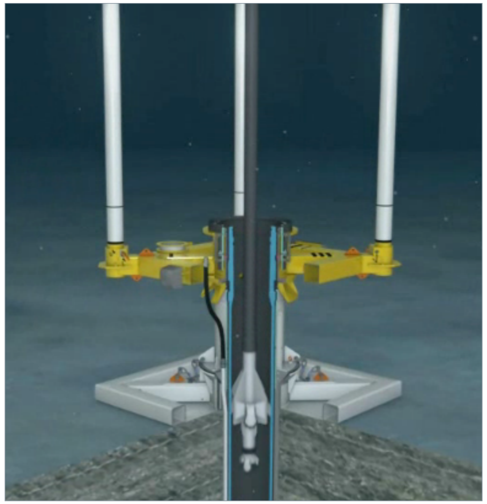


Figure 248: *2nd drilling. [3]*

5. Running the Wellhead Housing, with a size of eg. 18 ¾", and locking it into the Conductor Housing. It is run down with a Wellhead Running Tool (WHRT)

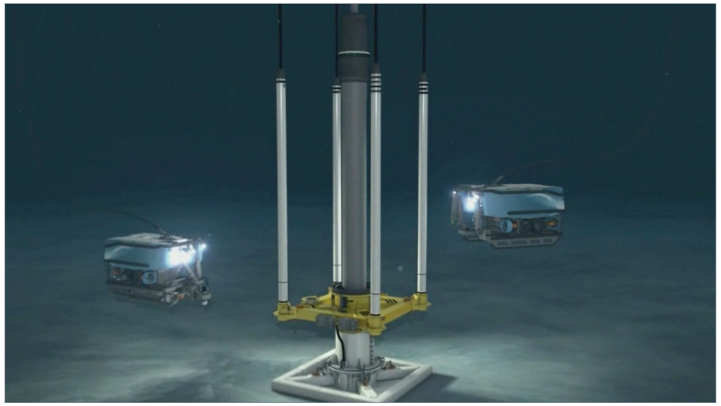


Figure 249: *Running Wellhead Housing. [3]*

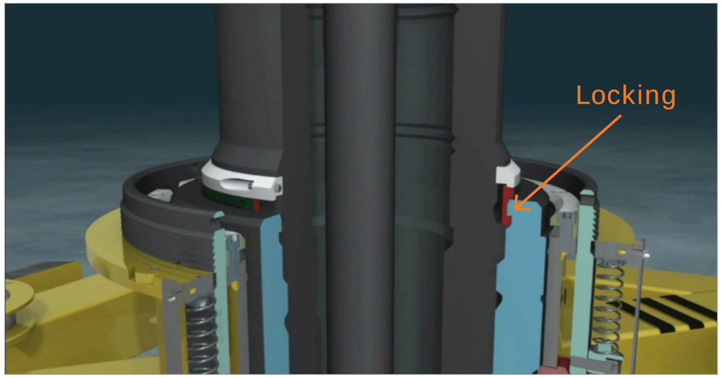


Figure 250: *Locking Wellhead Housing to Conductor Housing. [3]*

6. Adding cement again, this time into empty space in between the Conductor and Wellhead Housing.

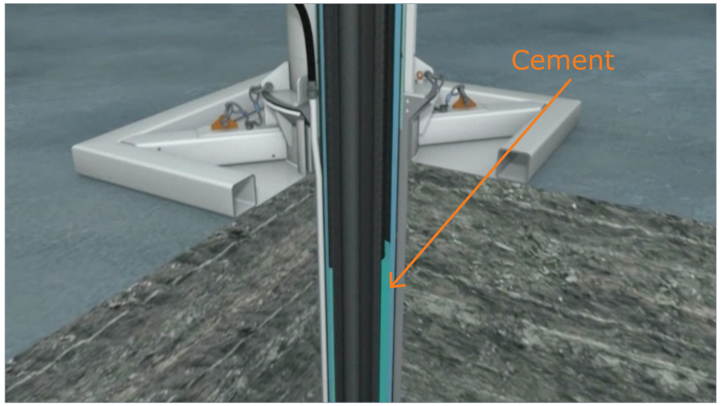


Figure 251: *Adding cement for 2nd time. [3]*

7. Rotation to the right in order to retrieve the Wellhead Running Tool (WH RT)

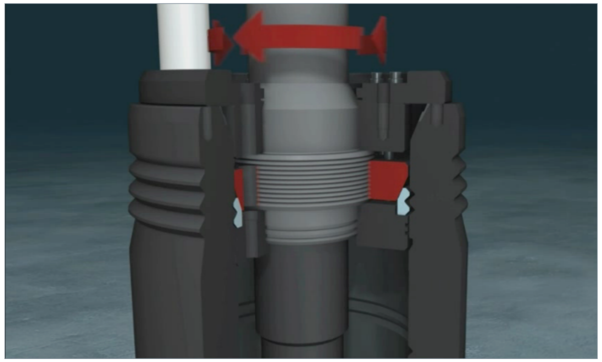


Figure 252: *Retrieving Wellhead Running Tool. [3]*

8. Blow Out Preventer (BOP) is placed on top of the Wellhead. Its purpose is to prevent uncontrolled blowout. (See figure 253)

9. Running Bore Protector (BP) into WH, with a Multi Utility Tool (MUT). The BP is landed in the Wellhead, and shear pins will engane to lock the BP. Next the MUT is retrieved by pulling it up. (See figure 254 and 255)

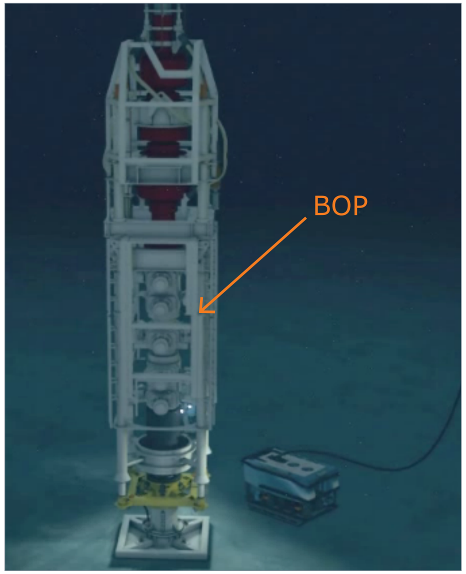


Figure 253: *BOP. [3]*

10. Drilling an even deeper hole through the Wellhead, and retrieve bore.

11. Retrieving the Bore Protector (BP) with the MUT

12. Running a Casing Hanger of eg. 14", with the drillpipe casing hanger running tool. Then apply cement to fill space out to the Wellead Housing. Then the running tool is rotated 3-4 times to the right, to loose grip of the Chasing Hanger, before being pulled up. (See figure 256)

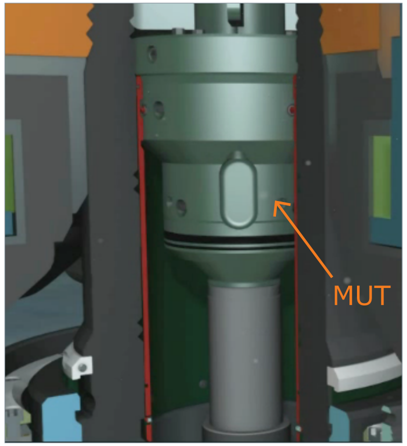


Figure 254: *Running BP with MUT. [3]*

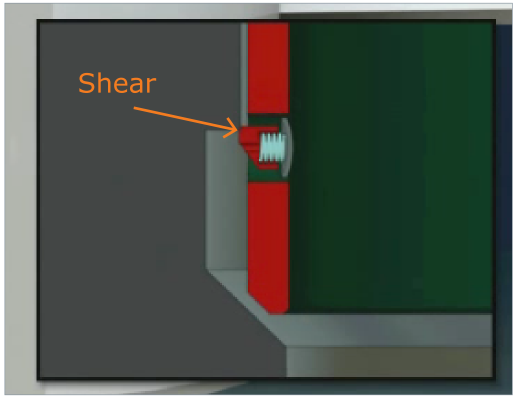


Figure 255: *Engaging shear pin. [3]*

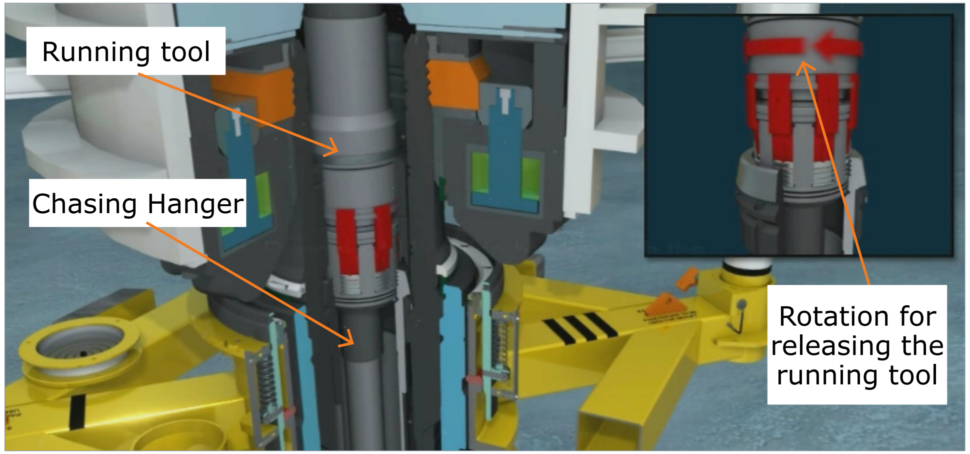


Figure 256: *Running the 1st Casing Hanger. [3]*

As one can see there is a pattern for the WH inst. process:
i) Bore a hole
ii) Run a tubing down the hole
iii) Add cement
iv) Add bore protection
v) Bore an even deeper, but more narrow hole
vi) Remove bore protection
vii) Repeat (ii)-(vi)

13. Thus after the 14" Casing Hanger is installed, cement is added, bore protection is added and a new deeper hole is made before the bore protection is removed.

14. Running a more narrow Casing Hanger of eg. 10 ¾"

15. Retrieve Bolw Out Preventer (BOP)

Down under the seabed the installation now looks like this:

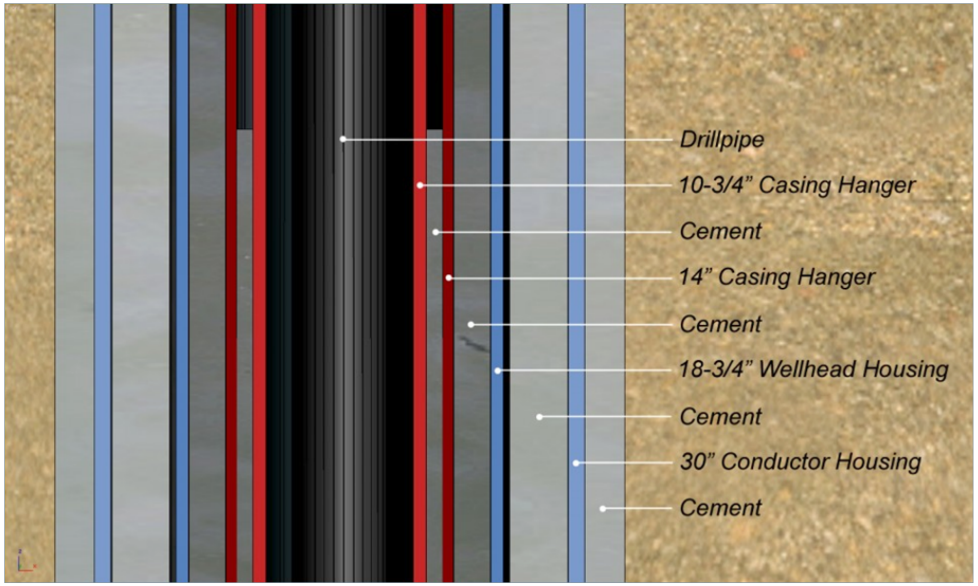


Figure 257: *Wellhead system under the seabed. [3]*

16. Retrieval of drilling/retrievable guide base

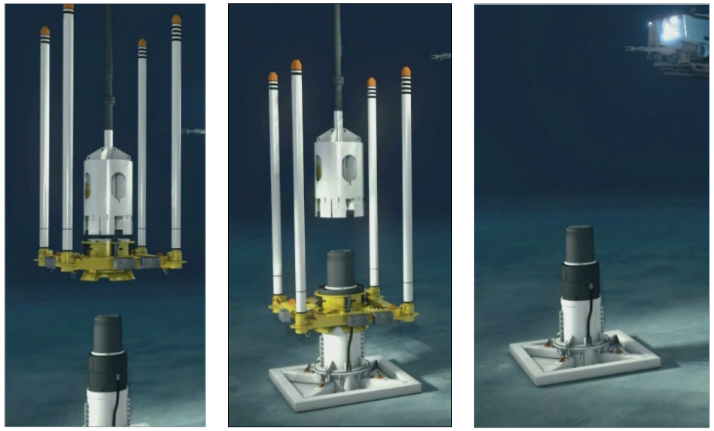


Figure 258: *Retrieving drilling guide bas. [3]*

Levelling is verified by observing Bulls Eye on PGB. The Bulls Eye is a multi directional levelling device, which consist of a slightly bowl shaped surface, and a freely rolling sphere.

Next, the running tool is released form the PGB by rotating the drill string six turns to the right. For the next procedures ROV`s are used, for releasing and fixing the PGB`s legs to the ground.

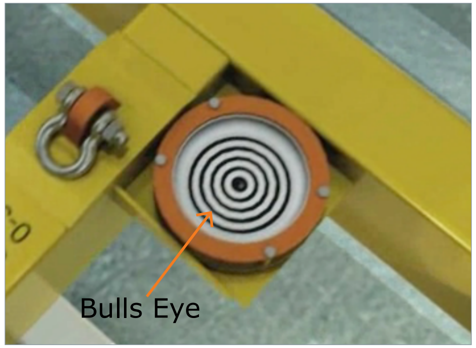


Figure 260: *Bulls Eye. [3]*

17. Installation of production guide base (PGB).

The guidecone on the PGB guides the PGB down onto the conductor housing. Next ROV monitors alignment of the paintmark on the PGB guide funnel with the "Master Slots" on the 30" Housing.

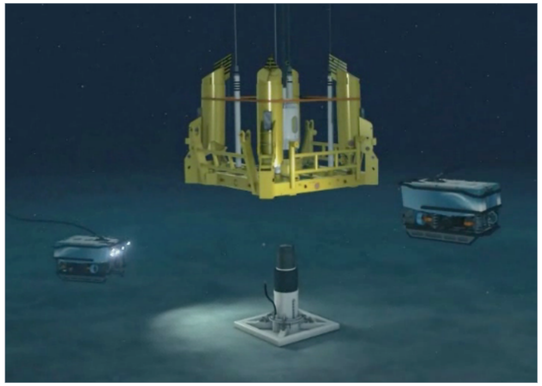


Figure 259: *Installing PGB. [3]*

First of the ratchet strap around the PGB legs is cut of and removed.

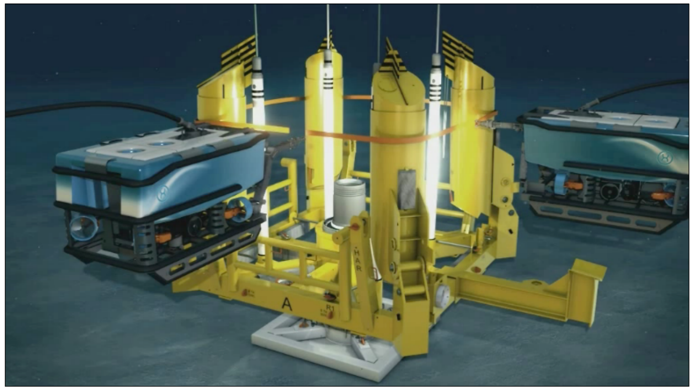


Figure 261: *Cutting strap with a ROV. [3]*

Each leg is lowered down with help from the ROV and a soft sling.

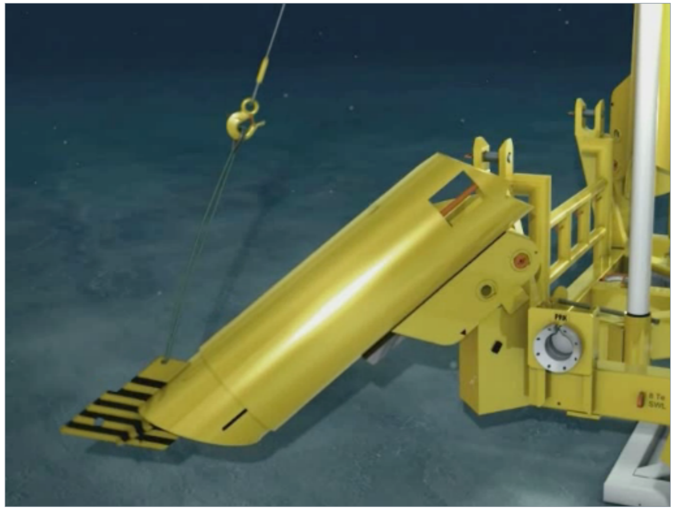


Figure 262: *Lowering legs down onto seabed. [3]*

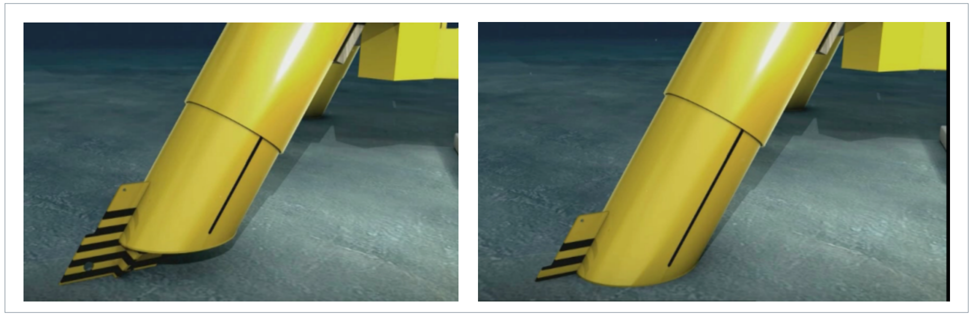


Figure 264: *Part of the leg that is pushed down into the seabed. [3]*

Next the telescopic legs are pushed down into the seabed. This is done by using a Land Class 4 torque tool at the top of each telescopic leg

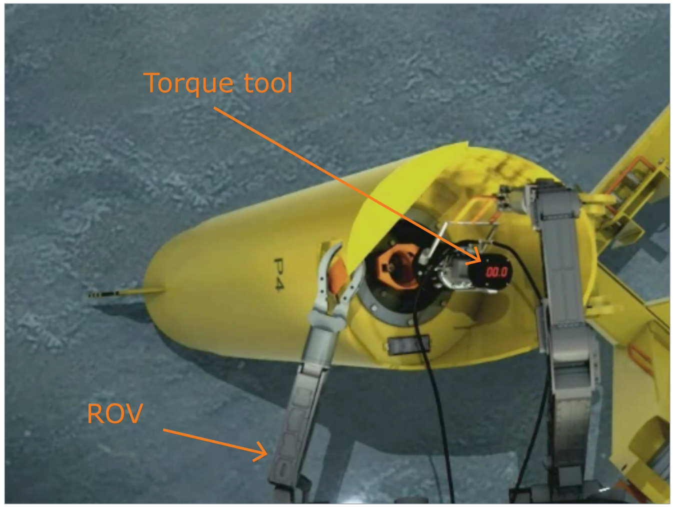


Figure 263: *Using torque tool. [3]*

Wellhead installation complete:

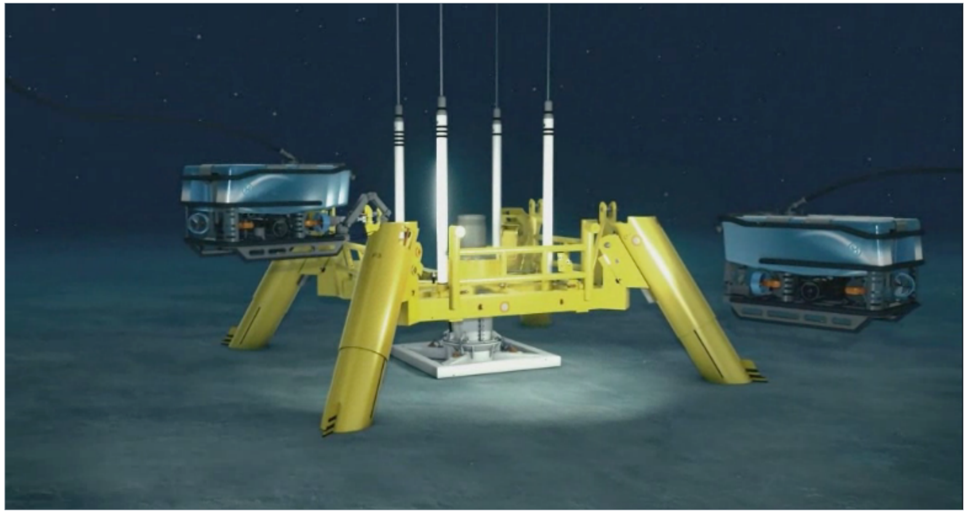


Figure 265: *Complete Wellhead installation. [3]*

A.7. Workover/Completion System

This is a temporary system that is used during the two following scenarios:

- Completion: to install all well equipment for a subsea well, before operation start-up.
- Workover: to perform maintenance or interventions on subsea wells.

The system consists of three sub-systems:

- Workover Control System
- Workover Umbilical Reels
- Workover Riser System

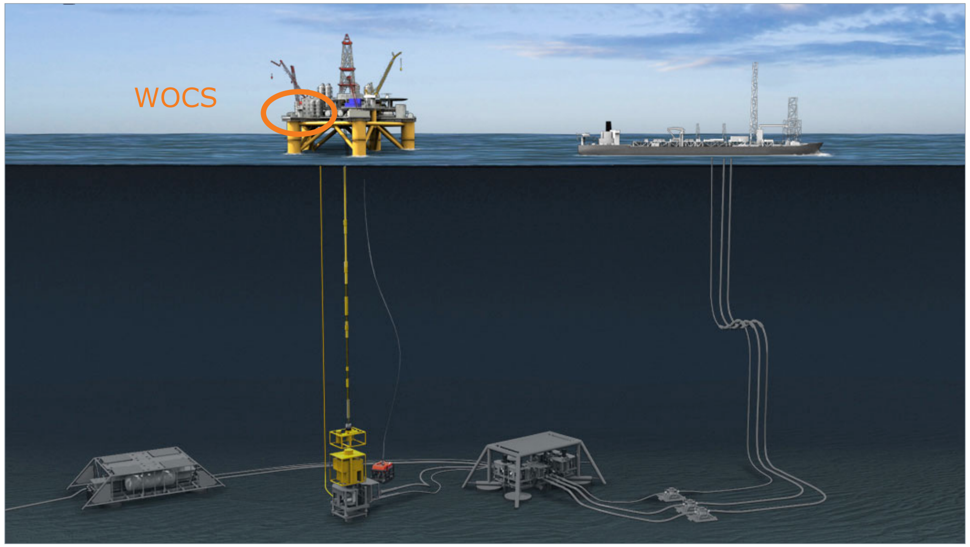


Figure 266: *Workover / Completion System. [3]*

Explanation to figure 267:

1. Umbilical and reel for transfer of electric signals and hydraulic control pressure form the Control Container to the Landing String and THRT.
2. Similar as (1) but for XT and XTRT.
3. Workover Control System Container which is centre for hydraulic and electric controls.

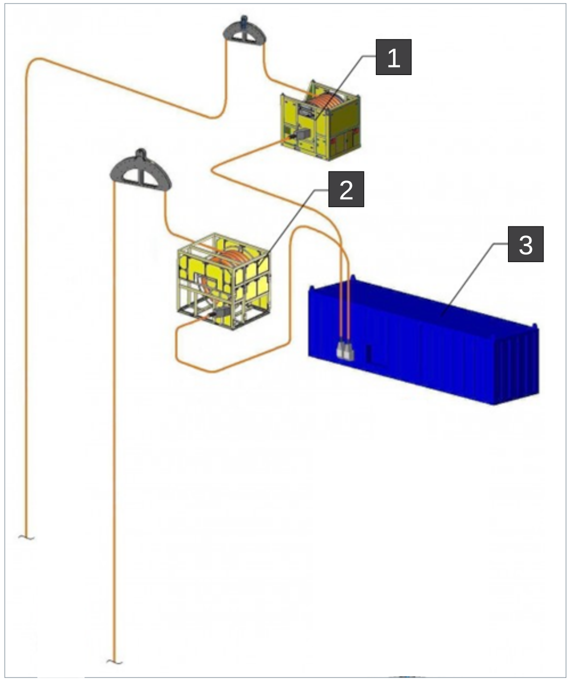


Figure 267: *Workover Control system (WOCS) and Workover Umbilical Reels. [3]*

The WOCS provides the means to remotely control all of the required functions on the Completion/Workover equipment, subsea tree and downhole equipment during the various phases of the C/WO operation.

All signals, controls and hydraulic supply is distributed and controlled from the WOCS Container, shown in figure 268.

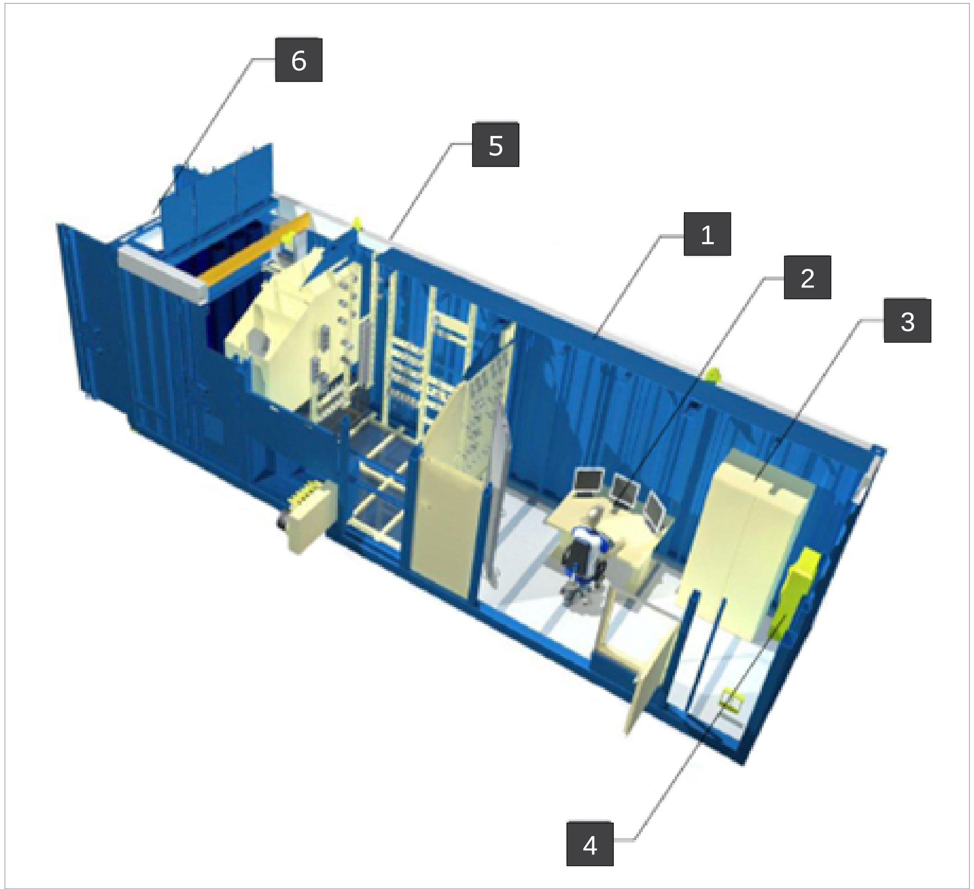


Figure 268: *WOCS Container. [3]*

Explanation to figure 268:

1. Control Room Compartment; control room for the operators
2. Control Station; operator station
3. Subsea Power and Control Unit; Electronic power signal interface and communication with subsea tools and equipment
4. HVAC Unit; provide stable temperature and pressure in the container
5. Accumulators; provide a pressurised hydraulic reservoir for hydraulic control lines.
6. Hydraulic Power Unit Compartment; provide hydraulic supply and distribution for the workover control system.

The last mentioned sub-system; the Workover Riser System, is shown in figure 269, in relation to rig, THRT, TH, XT, WH and the well. There exist almost an infinite amount of variations, but this system which is called Landing String System inside Marine Risers, is of the most common once for horizontal XT.

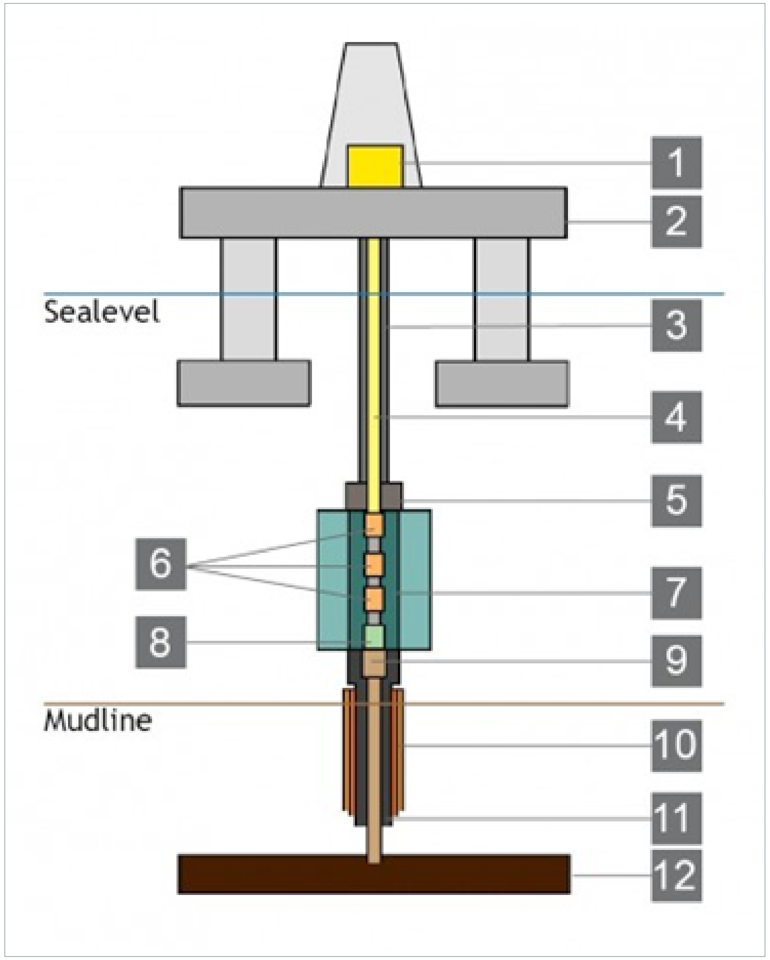


Figure 269: *Workover Riser System. [3]*

Explanation to figure 269:

1. Surface Flow Tree; provide facilities to flow, kill and control the well during workover and completion operations. (Not to be confused with surface tree on land, shown on p. 220).
2. Rig; to facilitate deployment of equipment subsea.
3. Marine Riser; used to establish a physical connection between the rig and the BOP.
4. Workover Riser; used to establish a physical connection between the rig and the Landing String deployed inside the marine riser.
5. Lower Marine Riser Package (LMRP); enables quick disconnect of the marine riser from the BOP in emergency scenarios.
6. Landing String; facilitates well control during operations.
7. Blow Out Preventer (BOP); enables well control in emergency scenarios.
8. Tubing Hanger Running Tool (THRT); tool for installation/retrieval of TH
9. Tubing Hanger (TH) and Xmas Tree (XT); installed on the well and subject to workover and completion operations using the Workover System.
10. Wellhead; Interface between the XT/TH and the well.
11. Completion/Tubing; connection between the wellhead and the well.
12. Well; reservoir to be explored.

A.8. Gathering and Distribution System

The network and process facilities that transport and control the flow of oil or gas from the sunsea wells to either a main storage facility, processing plant or shipping point topside.

The main components that the Gathering and Distribution System consists of are described on the following pages, with illustrating pictures.

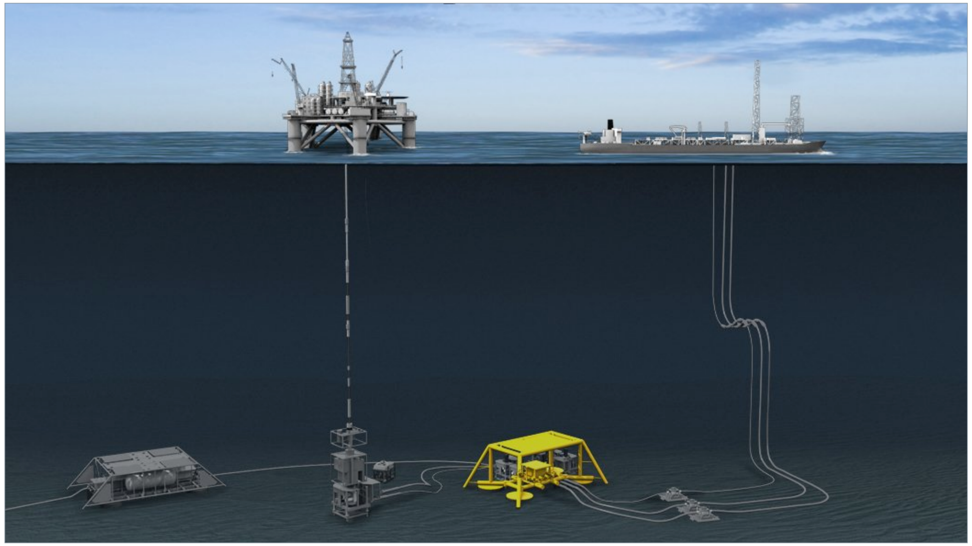


Figure 270: *Gathering & Distribution System. [3]*

A.8.1. Foundation

The foundation is an anchor and level platform, that the subsea products can rest on. It can either be a separate unit, or it can be integrated as a part of the Template.

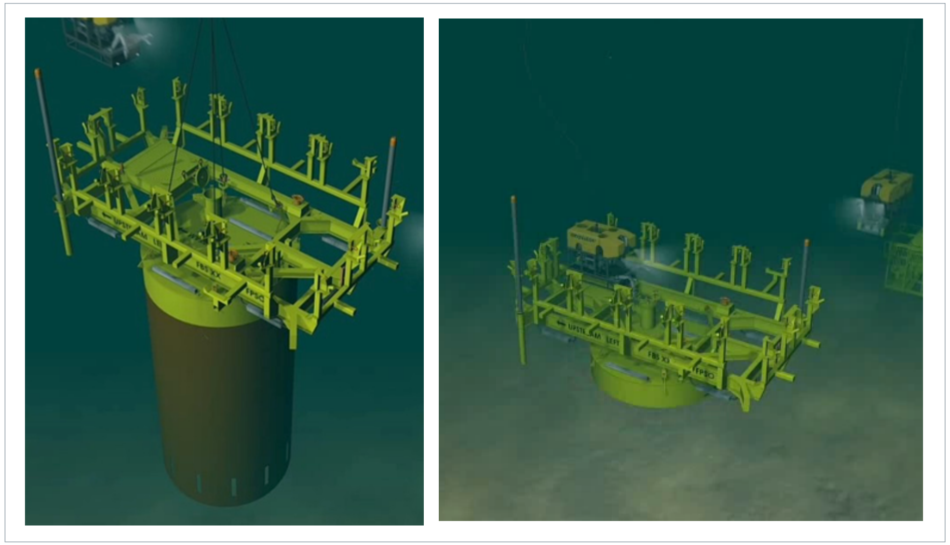


Figure 271: *Foundation structure. [3]*

A.8.2. Template

There are two main solutions for Gatering and Distribution systems; cluster template and multiwell template.

Cluster template:
For this system there are a multiple number of wells possitioned around an area. They are clusterd around and connected to a common manifold. The template supports this manifold by gathering production from the well, and by distributing injection fluids and gasses.

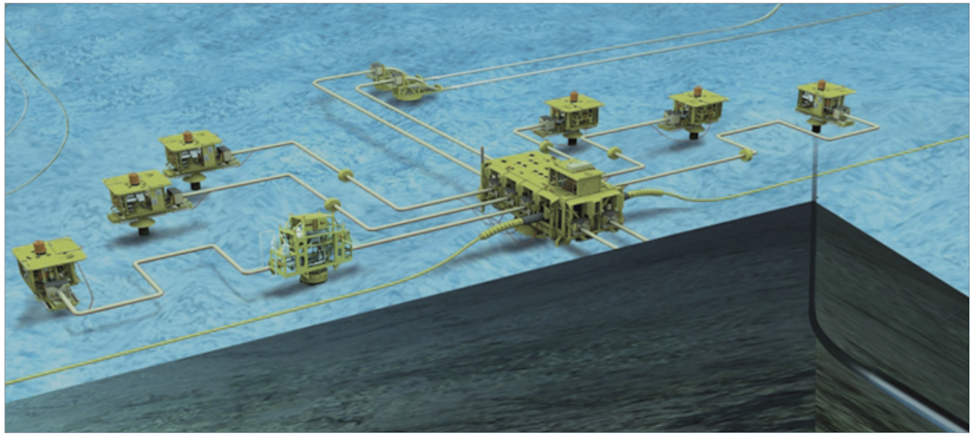


Figure 272: *Example of a cluster template. [3]*

Multiwell template:

This type of template can also be reffered to as a drilling and production template. Like for the cluster template this system also have a multiple number of wells, but they are drilled and completed through the template. Instead of having well positions spread around a manifold, these well installations are typically arranged in groups of four, with a manifold centered in between.

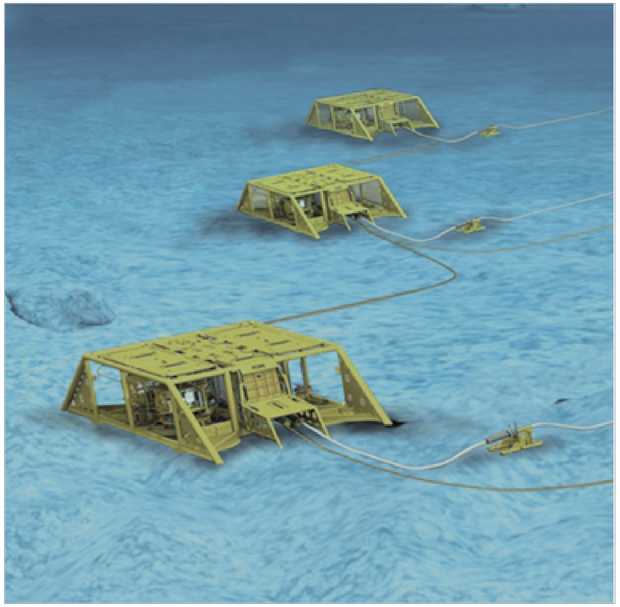


Figure 273: *Multiwell template. [3]*

The Multiwell template thus works as a structural base that Xmas trees and a Manifold are placed into. As for the cluster template, the template`s task is to gather production from the well and to distribute injection fluids and gasses.In addition it works as a protection for the Xmas trees and Manifold, against falling objects and trawling activities

The two main solutions for Gatering and Distribution systems, decribed here are just two examples for a template. An actual template can be a combination of these two system`s features.

Multiwell template:

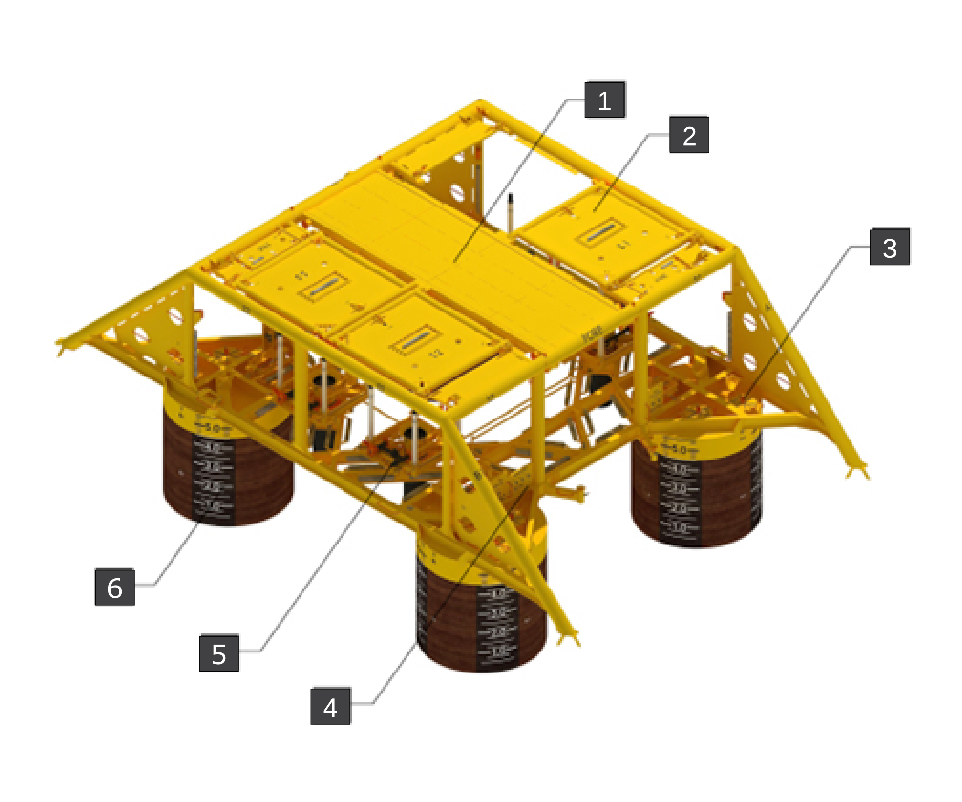


Figure 274: *A Multiwell manifold template with integrated foundation system. [3]*

Explanation to figure 274:

1. Temporary Protection Cover; To protect the Template temporariy against impacts from trawling activity and dropped objects prior to installation of the manifold.
2. Welbay Hatches; To protect XT`s against impacts form trawling activity and dropped objects.
3. Ventilation Hatches; To decrease added mass and washout during seabed penetrations.
4. Suction and Grout System; Contingency support for the foundation system.
5. Welbay Incerts (also called Permanent Guide Base) incl. Guide Posts; To support/guide Xmas Tree
6. Foundation System; Provides an anchor as well as a stable platform for the subsea equipment to rest on.

A.8.3. Manifold

A manifold gathers produced fluids from the Xmas Trees, and distributes the production through flowlines, and sends it to a processing facility. It can also distribute injected fluids into different wells. A Manifold is typically placed in the centre of a Multiwell manifold Template.

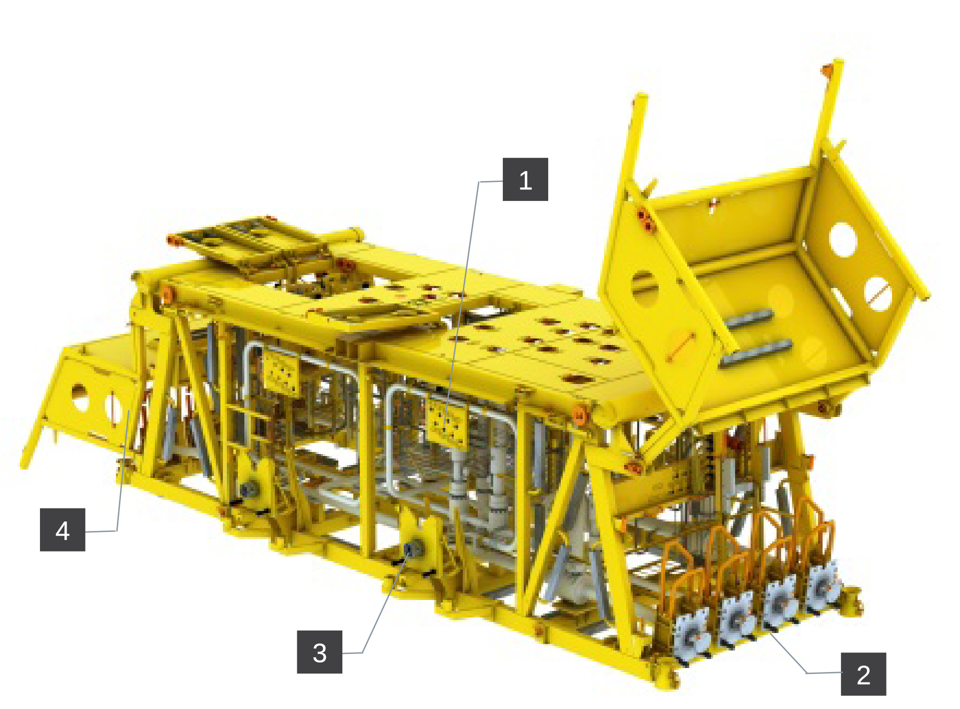


Figure 275: *A Manifold that can be installed in a Multiwell Manifold Template. [3]*

Explanation to figure 275:

1. ROV Panel; To operate the Manifold valves
2. Cable Bridges; To simplify the routing of cables between Umbilical Termination Head and Manifold
3. Horizontal Connection Module; To connect the Xmas Tree to the Manifold.
4. Sealine Protection Cover; To protect the Remote Tie-in System, tie-in porch and pipeline and terminations from potential dropped objects and impact loads from trawl activities.

A.8.4. Termination Structures and Tees

This part of the system gathers, distrbutes and terminates all the different flowlines, umbilicals and pipelines.

Figure 276 and 277 show typical termaination structures and tees connected together with Manifolds and Xmas Trees.

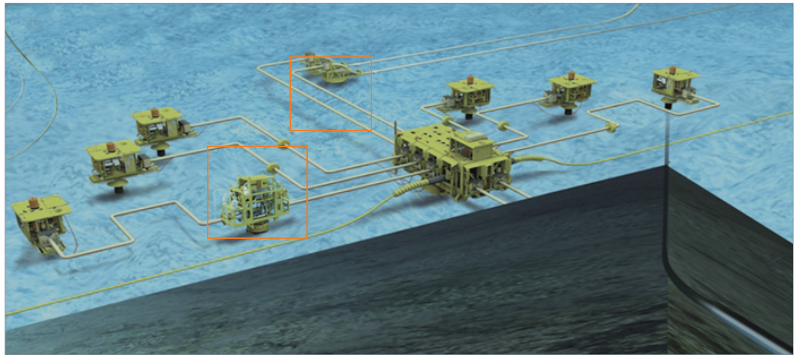


Figure 276: *Termination Structures and Tees for a Cluster template. [3]*

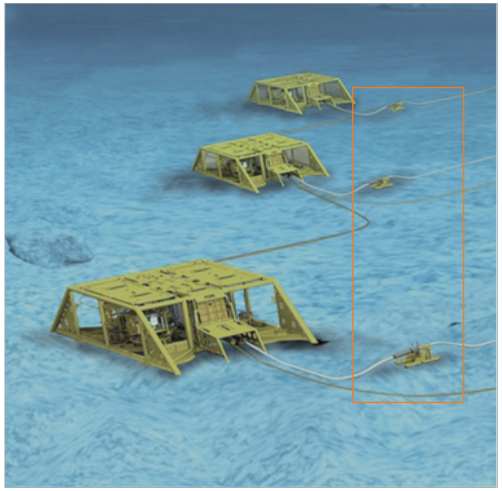


Figure 277: *Termination Structures and Tees for a Multiwell Template. [3]*

A.9. Xmas Tree System

This is the part of the subsea system that control and monitor the wellflow, and it consists of the Xmas tree itself in addition to related subsea equipment. The equipment is used for installation and operation of the X-mas tree.

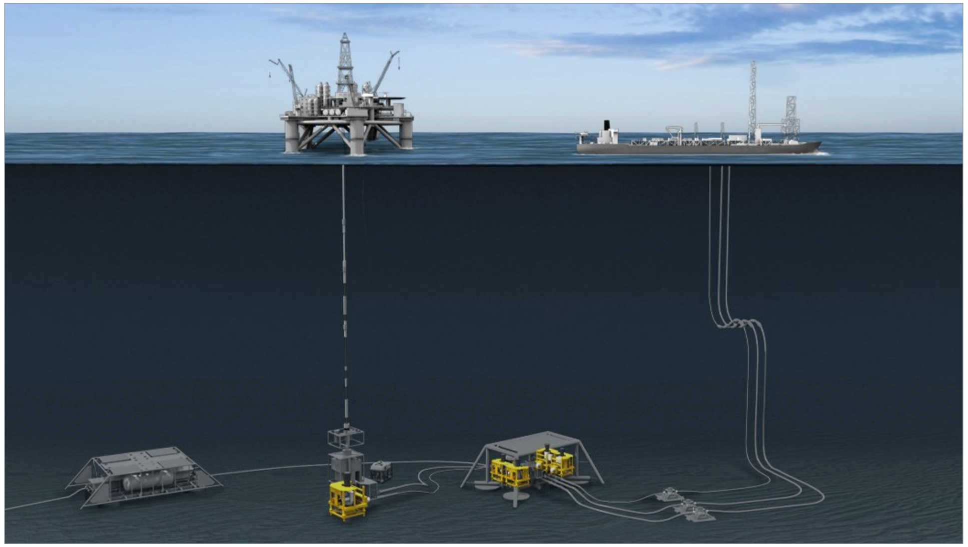


Figure 278: *Xmas Tree System. [3]*

For a cluster template different standalone Xmas trees (XTs) are connected together by the template, while for a multiwell template the template typically contain four XTs with a manifold placed in the middle, connecting them together. For a Cluster template, the standalone XT`s are lowered down and installed upon a production guide bases (PGB).

For a multiwell template the XTs are lowered down into a template with the use of guiding risers, and to run the XTs a Tree Running Tool (TRT) is used.

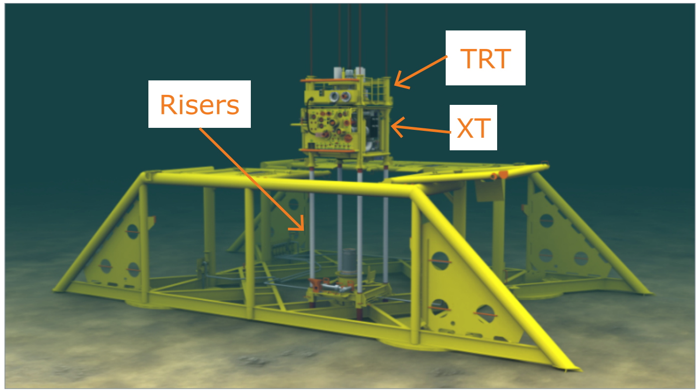


Figure 279: *Running XT down into template. [3]*

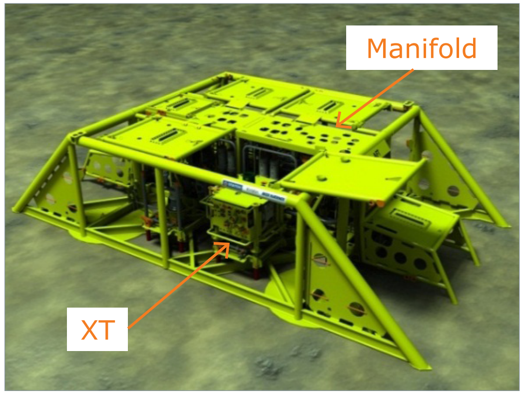


Figure 280: *XT and Manifold installed in template. [3]*

The Wellhead installation is described earlier in section A.6., and the complete installation with PGB on top is shown in figure 265 on page 208.

In figure 281, the XT is lowered town upon the PGB with the help of a XT Running Tool (XTRT), while in figure 282 the tool is retrieved

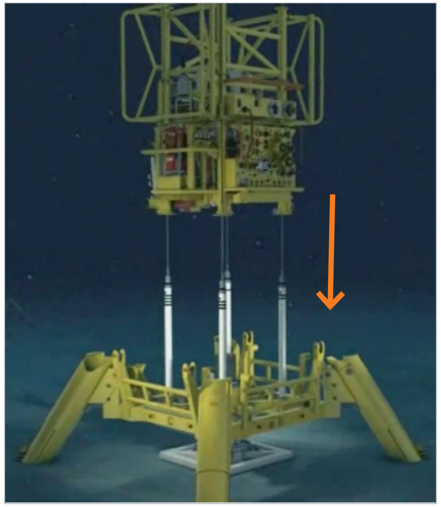


Figure 281: *XT being placed on top of PGB. [3]*

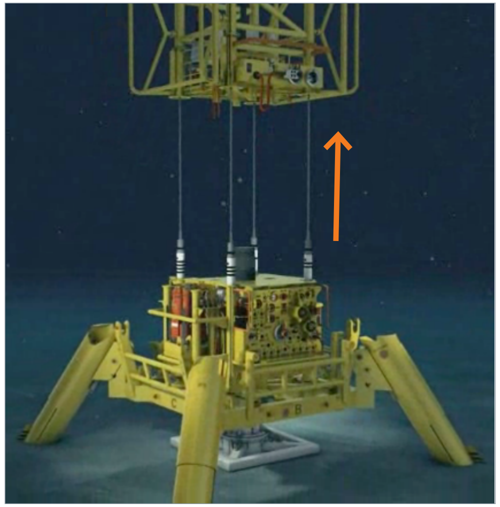


Figure 282: *Retrieving XTRT. [3]*

The X-mas Tree got its name from the shape of the old surface trees in Mexico. The trees consisted of tubing with many different branches and valves. This construction made it look like a decorated tree, and thus it was called Xmas tree. Subsea trees however look quite different, but it has kept its name.

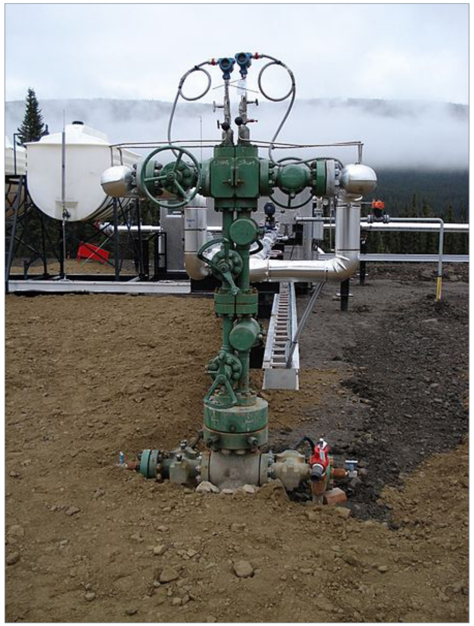


Figure 283: *Surface tree. [53]*

Figure 284: *Surface tree. [53]*

A XT works as a faucet for the oil and gas. The Xmas tree`s main functions are:

- Safety barrier
- Safely stop produced or injected fluid
- Injection of chemicals to well or flowline
- Allow for control of downhole valves
- Allow for electrical signals to downhole gauges
- To bleed of excessive pressure form annulus
- Regulate fluid flow through a choke (not mandatory)
- Allow for well intervention

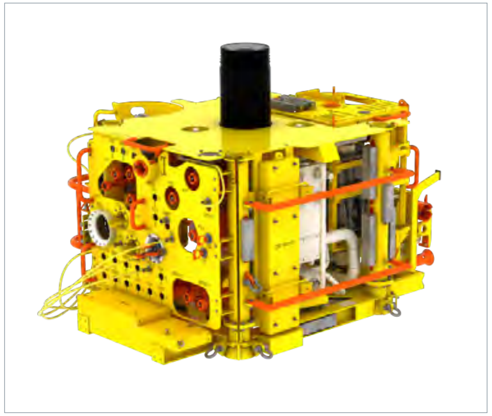


Figure 285: *Subsea tree, project SKULD. (scale 1:70) [2]*

Figure 286: *Subsea tree, project KRISTIN. (scale 1:70) [2]*

The Tubing Hanger (TH) which will be in main focus for this Master thesis, is one of the Xmas Tree`s product componenets. An overview of the Xmas Tree`s components is shown in figure 287.

The Xmas Tree System components in figure 287:

1. Tree Cap; acts as a barrier element against the bores(s) in the Tree.
2. Tubing Hanger Isolation Sleeve; a hollow cylinder used to lift over shafts or into holes.
3. Xmas Tree Bore Protector; a wear bushing that is run into and set in Xmas Tree to protect the inside wall against wear form the drill bit and drill pipe during drilling operations.
4. The Tubing Hanger; acts as an interface between the tubing from the well and the Xmas Tree. The TH directs the flow from the well to the Xmas Tree, in addition to provide interface possibilites for downhole electrical and hydraulic lines from the Xmas Tree.
5. Xmas Tree Isolation Sleeve; to protect the seal surfaces during drilling operations. Remains in the Xmas Tree bore during production.
6. Flow Control Module; installed on the Xmas Tree to act as a bridging module between the Xmas Tree and the Manifold/Flowline. The Flow Controll Module includes means to regulate and minitor the wellflow.
7. Xmas Tree Assembly; provide means to regulate the flow from and to the well. It also includes facilities to inject fluids into the wellstream and instrumentation to monitor the wellstream.
8. Protection Structure; is part of Satelite Xmas Tree Systems, i.e. Xmas Trees not installed in Template but as separate standalone units.

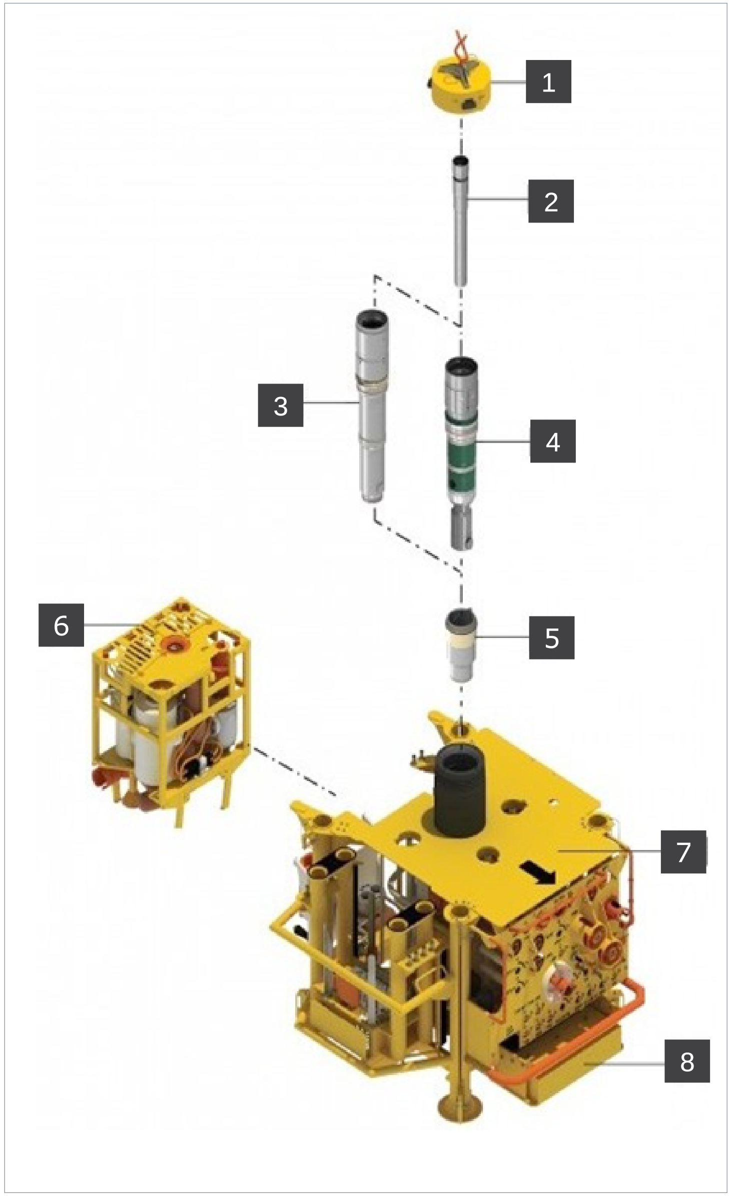


Figure 287: *The XT`s product components. [3]*

Aker solutions provide a range of different subsea tree solutions. The design of each subsea tree is usually customised for each subsea project. The two main types of subsea trees are Horizontal XT (H-XT) and Vertical XT (V-XT).

Figure 288: *HSCT. (scale 1:60) [2]*

Figure 289: *VSCT. (scale 1:60) [2]*

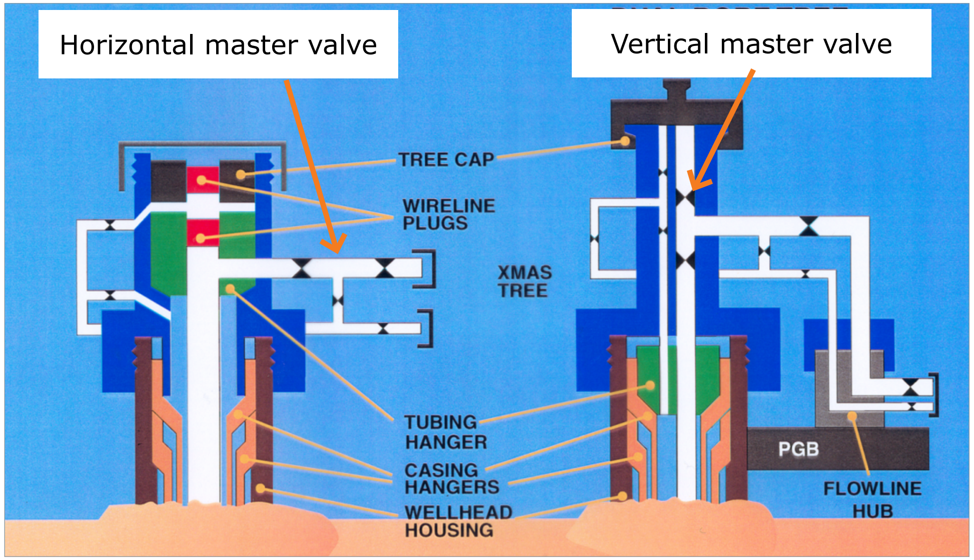


Figure 290: *Comparing HSCT and HSCT. [2]*

The naming of the H-XT and V-XT correspond to the orientation of the production master valve. For a H-XT it is horizontal, while for a V-XT it is vertical. The main differences between these two types of trees are the sequence in which the different parts of the subsea system are installed. For a H-XT the Tubing Hanger sits in the XT`s tree spool, and is thus installed after the XT. For a V-XT the Tubing Hanger is placed directly onto the Wellhead, before the XT is placed on top of the Tubing Hanger.

These two different ways of installing procedure, result in different situations when a subsea tree needs to be liftet up from the sea for maintenance. For a H-XT the Tubing Hanger needs no be retrieved before the XT can be liftet up, but for a V-XT the XT can be liftet up while the Tubing Hanger still sits in the Wellhead. This means lower maintenance costs for V-XT installation when XT needs to be fixed. On the other hand maintenance costs will be lower for H-XT if the Tubing Hanger needs maintenance.

The choice between a H-XT and V-XT will therefore depend on what part of the subsea system one expect will need maintenance most often.

Aker Subsea at Tranby has most experience with H-XT`s, but has also started to develop V-XT`s. I will be working with the H-XT solution in this project, but it might be applicable to implement the concepts I come up with in this project for future V-XT systems as well.

Together with the wellhead system, the subsea tree and the tubing hanger provide barriers between the reservoir and the environment in production mode.

In the installation/workover mode, the barrier functions are transferred to the Blow Out Preventer (BOP) and landing string for Horizontal Xmas Tree systems.

Just like the Xmas Tree System consists of different product components as shown in figure 287, the Xmas Tree Assembly which is a part of the Xmas Tree System, also consist of different sub-products. This is illustrated on the next two pages.

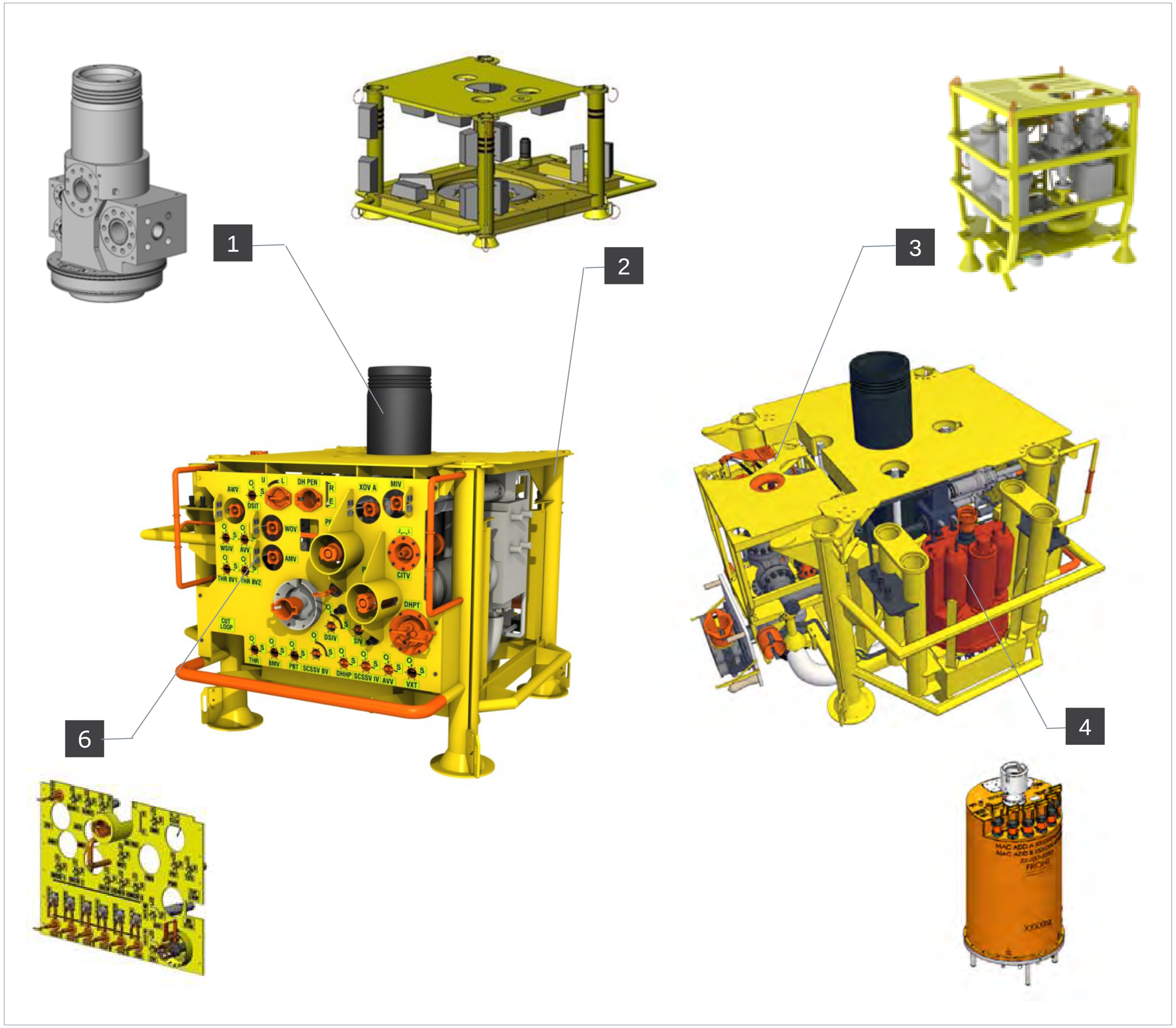
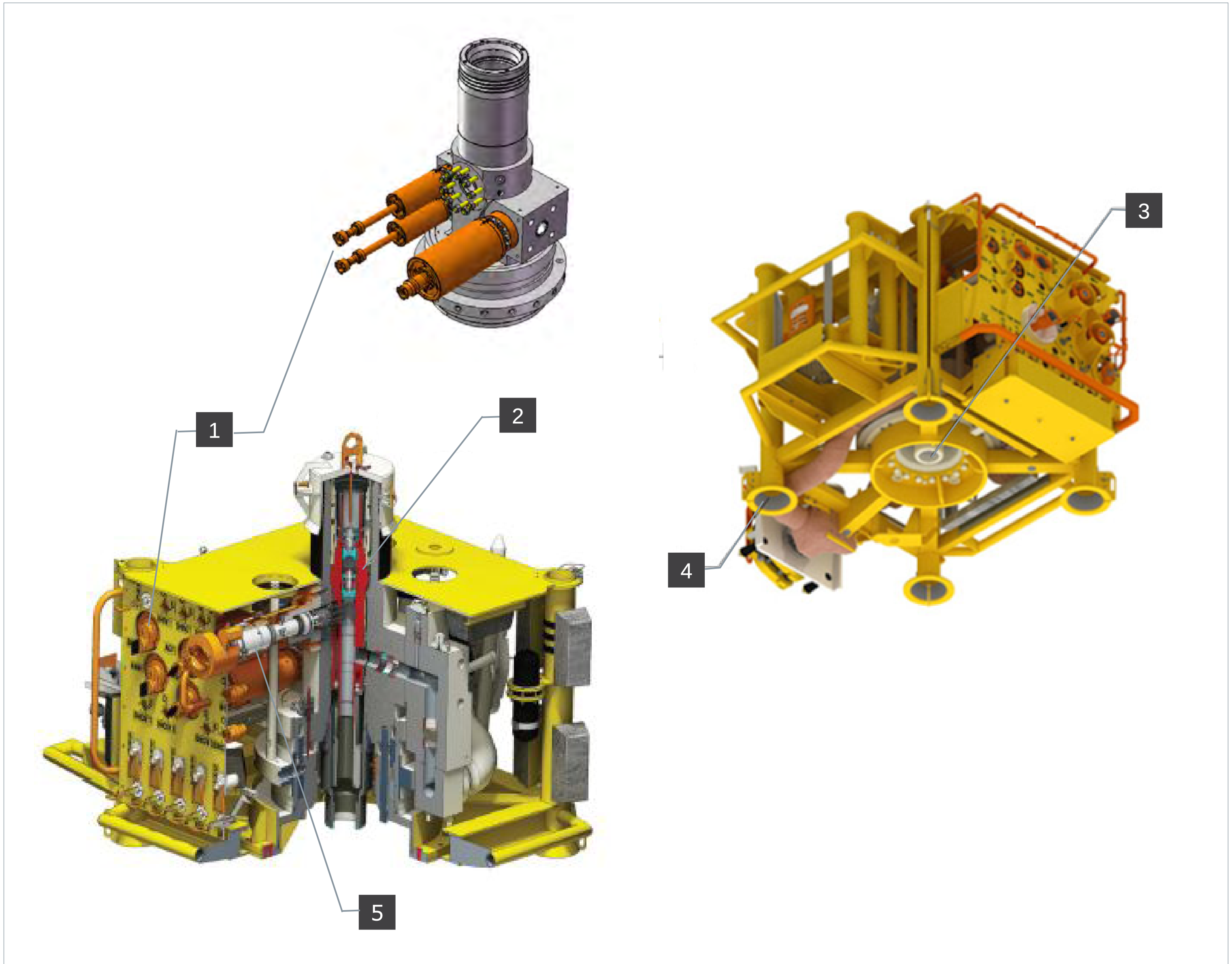


Figure 291: *The Subsea tree assembly`s main components, external. [3]*

Product components in figure 291:

1. Tree Spool
2. Xmas Tree Frame; Protection of components and mounting base
3. Flow Control Module (FCM); Includes choke for well flow regulation, instruments for monitoring the well flow and connection to the manifold.
4. Subsea Control Module (SCM); Provides an interface between the Xmas Tree instruments, hydraulic system and the Control System. Thereby allowing the XT to be monitored and controlled form the production control room. Hydraulic and electric connections go through the SCM, and are e.g. used for opening/closing valves.
5. Manifold Connector
6. ROV panel; ROV Interface for operation of valves



Product components in figure 292:
1. Actuators
2. Tubing Hanger (TH)
3. WH connector interface
4. Guide systems
5. Hybrid Penetrator

Figure 292: *Subsea tree main components, internal. [2], [3]*

When a XT with its corresponding tubing is attached to an oil or gas well, there is a pressure in the well that will push the gas/oil up from the well and through the production tubing. The pressure in the well is created from the sea bed that in pushing down on the well, and this is a result of a long development. When the oil or gas is being transported out of the well, the pressure in the well will gradually decrease.

A XT can either be a production tree for oil or gas, or it can be an injection tree for water or gas. Injections trees are used to extend the oil or gas production by adding pressure above and/or below the oil or gas. For this process, the principle of relative density is used. Figure 293 illustrates the relative densities of gas, oil and water. If oil is to be extracted out form a well, gas and water can be injected in order to increase the pressure in the oil.

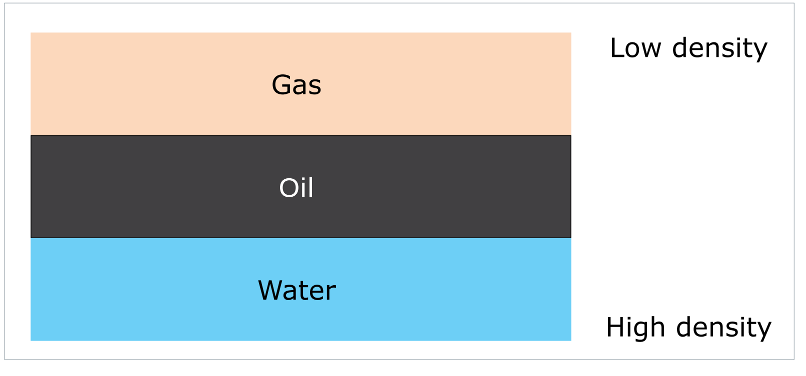


***Figure 293:** Relative densities of gas, oil and water. [5]*

Hybrid Penetrator:
The Hybrid Penetrator is an electric, optic and hydraulic XT/TH feed through system.

The main properties of a Hybrid Penetrator:
- It is flagged onto the tree spool.
- It includes 8 hydraulic lines, 7 hydraulic downhole lines
- It has a 4-pin/3-function wet-mateable electrical connector.
- It has a flexibility of about ± 3mm, which is taken up in spring suspension.
- Has a dedicated line for pressure testing and venting between wireline plugs.
- It has a ROV-operated drive mechanism.

Its two primary functions:
- "First and foremost, it is part of the wellhead pressure controlling barrier envelope where its system components straddle or penetrate XT/TH envelope boundaries." [2]
- "Secondly, the feed through system shall ensure that an electrical, optical or hydraulic transmission line can be reliably established and maintained through the XMT and TH system." [2]

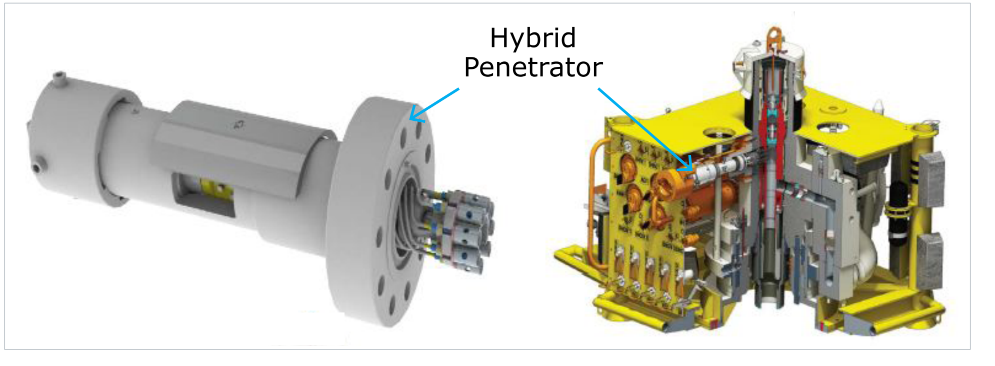


***Figure 294:** Hybrid Penetrator and position in XT. [2]*

A.10. Risers

Connect the subsea flowlines and umbilicals to the host facility.

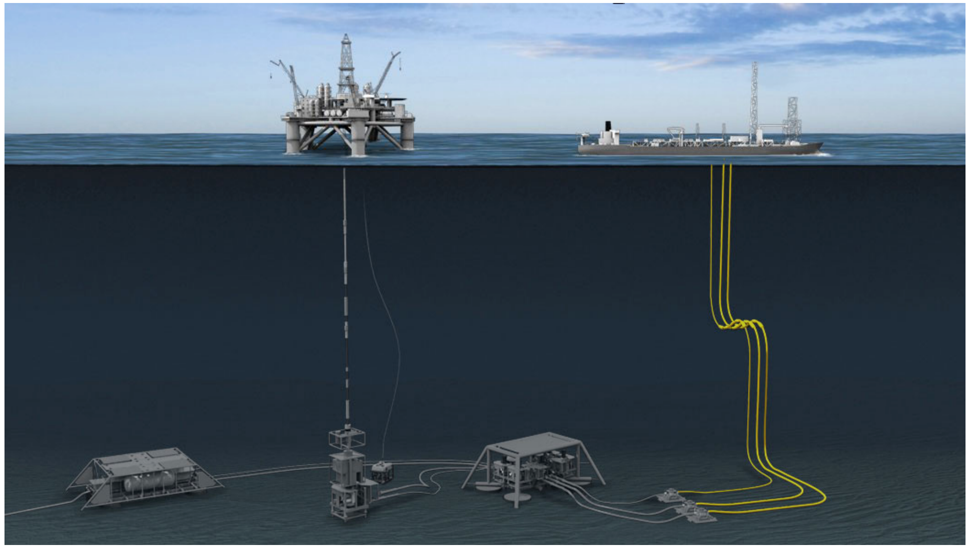


Figure 295: *Riser System. [3]*

A.11. Control System

Monitor and operate the subsea production system.

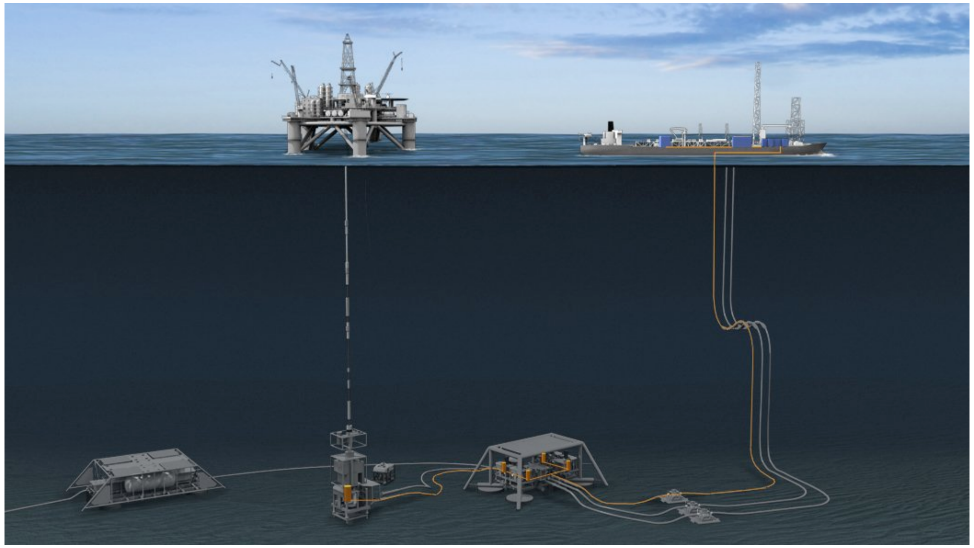


Figure 296: *Control System [3].*

A.12. Invention and Tooling System

Aker Solutions have a range of different tooling products which are used to install, connect, operate and retrieve different parts of the subsea production systems.

There are three main groupings for the tools; ROV tools, Remotely Operated Tools and Completion and Workover Tools. For this thesis a Completion and Workover Tool called Tubing Hanger Running Tool (THRT) will be the most central tool. This is the tool used to run and install the Tubing Hanger down into the Xmas Tree.

Figure 297: *Tubing Hanger Running Tool (THRT). [3]*

In addition to the THRT there are some more XT tubing hanger running/retrieval tools, that are involved in installing and retrieving the TH.

One of these is the Tubing Hanger Handeling Tool (THHT). It is used for retrieving the TH from the tubing hanger shipping skid, and preparing it to be run subsea.

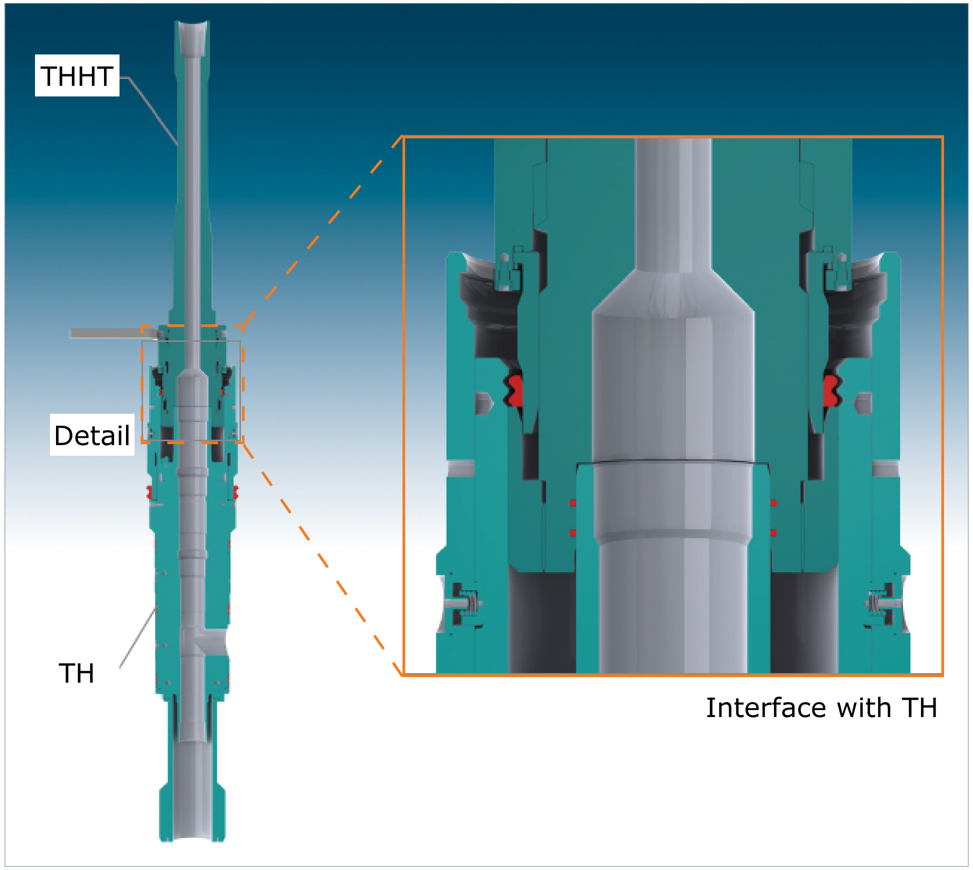


Figure 298: *Section cut of aTHHT holding a TH. [2]*

Another important tool is the THRT Chasing Adapter (CA), which can be used to run the TH and THRT subsea. The CA "is designed to provide a crossover from the customer furnished Drill Pipe (DP) running string to the THRT. There are five hydraulic passages through the spanner slick joint for interfacing of the hydraulic control umbilical to the THRT. There are two alignment pins in the top of the THRT that mate with two holes in the bottom of the CA." A CA weights about 1090 kg.

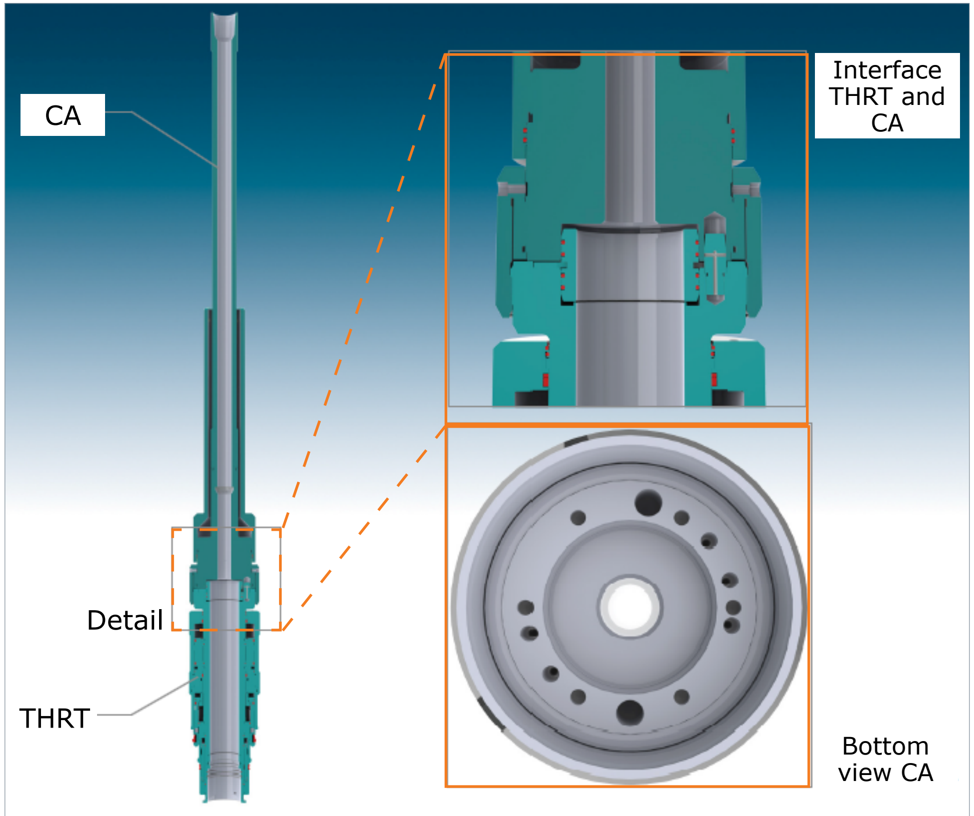


Figure 299: *Section cut of a CA connected to THRT. [2]*

APPENDIX B

Reported Incidents

B.1. Preface

In order to develop strong concepts for a Positive Lock Down Verification System, it is important to know what can go wrong during the TH installation. The verification methods have to ensure the operator that the TH is in the right position, and this can be done by making sure that typical installation failures do not occur.

B.2. Typical Incidents

In order to get an insight to what can go wrong during installation of TH, I have talked with colleagues at Aker Subsea who work with different areas within XT technology, and asked them about incidents where something went wrong during installation procedures.

The cases below were the once mentioned:

- Debris is the system, typically trapped within the spool
- Too high friction in seal
- Too high friction in download
- Leaking poppet valve
- Leakage over seals/packing's i.e. poor maintenance
- Procedure not followed
- Unwanted unlatch due to ambient pressure
- Flaw in design causing conflict between components
- Flaw in assembling THRT causing poppet valve to leak
- Problem retrieving TH due to corrosion issues

During installation procedures there is a mixture of seawater and drilling mud inside the riser system. Before the TH is installed the system is to be cleaned with a Washout Tool Assembly. This is done to make sure there is not too much debris in the system. Incidents were TH installation failure occur due to debris in the system, is usually caused by inadequate cleaning or lack of cleaning.

This is a typical example of procedures not being followed. If procedures are followed the system should be cleaned sufficiently, but in some cases the operator might choose to skip the cleaning procedure and jump right over to TH installation due to heavy time pressure. This is very unfortunate, as they can end up destroying crucial parts of the XT system, which again lead to high costs and project delay.

For these kinds of case`s it is important to stress the importance of following procedures closely, and as one of Aker Solutions promotive slogans says; "Do it right the first time".

For incidents where there is too high friction between components, the source of failure mainly has root in component production and transportation. There are often small margins used, since the system has to be 100% sealed during production form well. If the components are damaged by scratches or similar during production/ transportation/ installation, the component dimensions might change too much.

A leaking poppet valve can be caused by either:

- Coating that has fallen/ been peeled of and is clomped together.
- Metal to metal seals that are not properly sealed

Due to the mechanism of the poppet valve were fluid is only to be able to flow through the valve, if the TH is properly locked to the spool, a leaking poppet valve is very unfortunate. If the poppet valve is leaking, it will seem like the TH is installed properly even though the locking sleeves is not fully stroked.

In addition to the cases of failure mentioned above, there was an incident earlier at project Reliance positioned by the coast of India, where a tool/equipment accidentally was dropped down the riser system. Due to this TH failed to seal, and the pressure tests showed wrong readings. The people installing the subsea system reported that something was wrong, but not that they had dropped equipment into the riser system. Lot of work was done in order to find out what was wrong, and in the end they had to pull the subsea components up to topside, which is a very expensive act. The TH had got scratches, and they eventually found out what had happened.

This is a good example of how a smaller accident can fast become much more comprehensive by not keeping an open dialog. If the installer had told about the first incident of dropping the tool, less damage would be made, and less time and money would be used on trying to find the cause of installation failure, when someone already knew what went wrong. This type of incident probably don`t happen very often, but it is important to take all type of possible events it into account when analysing the installation procedures.

Below I have studied five reported incidents more closely.

1. Tubing Hanger landing issue, debris in XT spool
2. Leaking poppet valve
3. Flaw in design causing conflict between components
4. Flaw in assembling THRT causing poppet valve to leak
5. Problem retrieving TH due to corrosion issues

B.3. Tubing Hanger Landing Issue due to Debris in Spool

This is the case described earlier were the riser system hadn`t been cleaned with a Washout Tool, in order to save time. The TH is from the Kikeh Accelerated project located at the coast of India.

The result was quite fatal, as many parts of the XT system got destroyed. What happened in short during the installation was this:

- TH was run down and locked to the spool
- Lock volume and pressure was according to procedure
- An over pull test was performed (100 000 lbs), with good result
- The poppet valve lock down verification was removed from the THRT used for this installation, since the poppet was leaking, and caused problems for unlock. (More detailed description to the left.) Therefore no other verification except over pull was possible.
- Next they tried to engage the Hybrid Penetrator, and they understood something was wrong.

If the poppet valve is leaking, there will be problems when trying to unlock, since the liquid will travel past the valve and out port F5, instead of pressure being built up inside THRT in order to push the sleeves up and make the split lock ring retract. Due to this the Poppet valve and line F5 was removed form a THRT, for one subsea project.

Figure 300: *THRT that has been pulled back up. [2]*

Cause and result:
Since there was debris trapped in the system, the TH landed 1 ½" (ca. 38mm) too high up in the XT spool. This resulted in a partially locked split lock ring. The lower tooth locked inside the cavity the upper tooth should have been locked into, meaning that the upper part wasn`t locked at all.

Figure 301: *Cause of failure: lots of debris trapped between spool landing shoulder and TH. [2]*

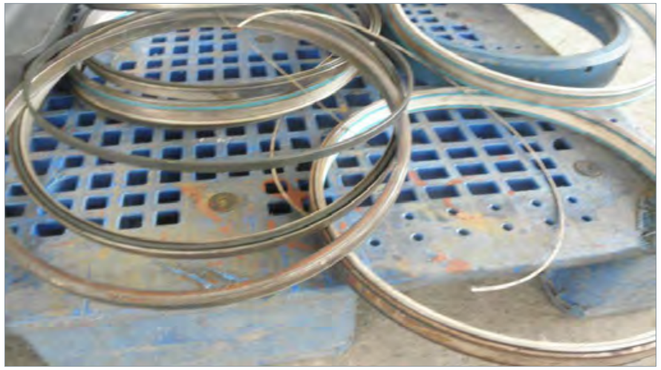


Figure 302: *Damaged seals after installation failure. [2]*

Damage of subsea equipment:

- Connections on Hybrid Penetrator got crouched.
- Indentation marks where the XMT Hybrid Penetrator tried to engage.
- The Lock Ring was wrapped and bend after a second installation attempt with an over pull of 98,000 lbs.

Figure 303: *Original Split Lock Ring. [2]*

Figure 304: *Deformed Split Lock Ring. [2]*

The figures below show the damges on both Hybrid Penetrator and TH from the incident, in addition to where the Hybrid Penetrator tried to connect to the TH.

Figure 305: *Crouched Hybrid Penetrator connectors. [2]*

Figure 306: *Marks on TH from Hybrid Penetrator. [2]*

Figure 307: *Red circles indicating where the Hybrid Penetrator got engaged into the TH. [2]*

B.4. Leaking Poppet Valve

For this incident a THRT was sent to the workshop located at Ågotnes from offshore (Visund project), because they had a problem with the lock verification. TH was not locked even though lock verification was achieved.

During test in workshop the tool was locked half way, before testing the lock verification line F5. As explainer earlier this involves sending hydraulic fluid (oil) into port F5 and to see if the fluid manages to flow through the poppet valve and out of port F4. When the THRT is positioned only half way to lock, and not in lock position, the fluid should NOT be able to pass the poppet valve.

The result was that fluid leaked out of F4, meaning that the poppet valve was leaking. Due to this the poppet was disassembled from the THRT. Next the upper poppet retainer was sanded/ honed before placed back into the THRT. After this the poppet valve proved to be tight.

Additional note:
A leaking poppet valve does not only result in false lock down verification, but can also cause problems for the unlock function of the THRT. The lock down verification is a hydraulic circuit which connects line F4 and F5 together. Thus hydraulic fluid that is sent through unlock line F4 in order to build up pressure in the annular cavity and induce a force to push the upper and lower locking sleeve up, will instead leak out of line F5 and result in unlock failure.

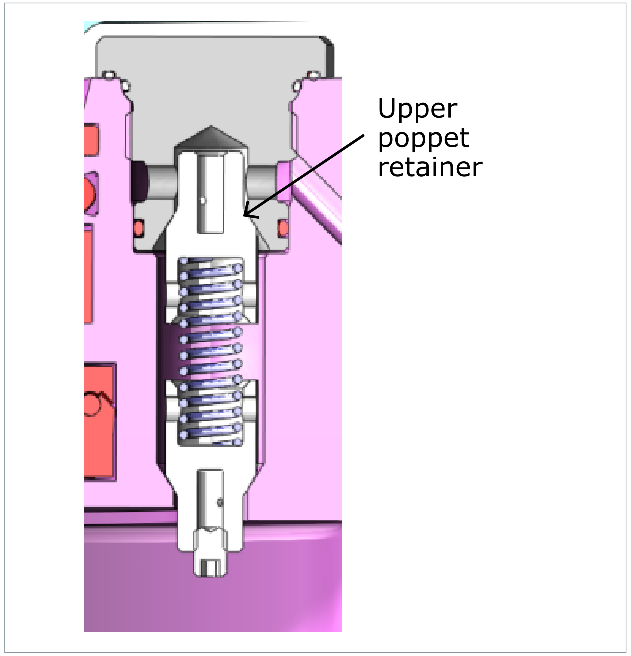


Figure 308: *Poppet valve; showing location of upper poppet retainer. [6]*

B.5. Design Weakness

In this case THRT for Skuld project was tested in a workshop to the company AdvanTec Aberdeen LTD. The failure status for this incident was this: "After stroking through port F2 and F4 there were score marks on the polished surface of the THRT." [2] Thus the THRT`s main body got scratch marks when they run the lock/ unlock function of the THRT. The component causing these scratch marks was the Poppet Keeper, which is the poppet valve`s top cover.

This is an example of weak design that causes conflict between components. The poppet valve cover has been designed too big, and to solve the problem, people at the workshop sanded/ honed the corner of the lid, that were in conflict with the THRT`s main body.

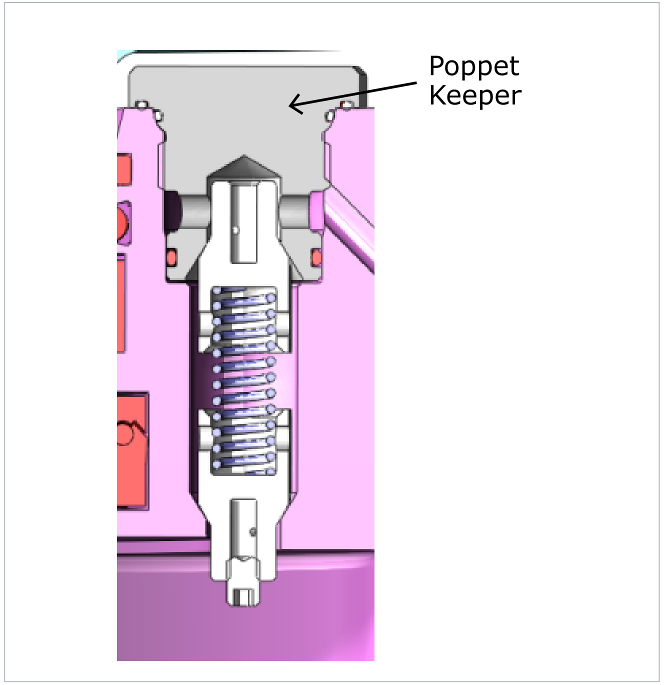


Figure 309: *Poppet valve; showing location of Poppet Keeper. [6]*

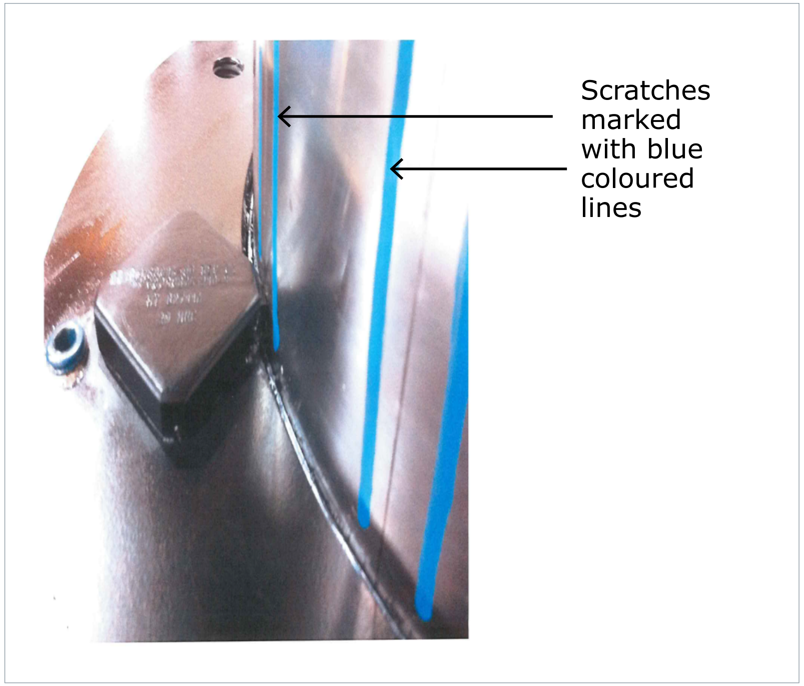


Figure 310: *Conflict between THRT Poppet Keeper and THRT main body causing scratch marks on main body. [54]*

B.6. Flaw in Assembling THRT Causing Poppet Valve to Leak

An example product assembling failure for the poppet valve, is one were the distance between the poppet retainers (B) was shorter than the distance between shoulder line that the Set Screw is pushed up to and the lower end of the Set Screw (A). (See figure 311 for position of components.)

For activation of the verification valve, the set screw gets pushed up the distance A. This happens when sleeves are fully stroked. When distance B is shorter than A, the lower popper retainer will end up pushing up on the upper popper retainer and thus close the upper part of the poppet valve.

The cause of the failure was that a too long Set Crew was inserted, causing distance A to be longer than originally planned. To solve this issue the Set Screw would have be replaced.

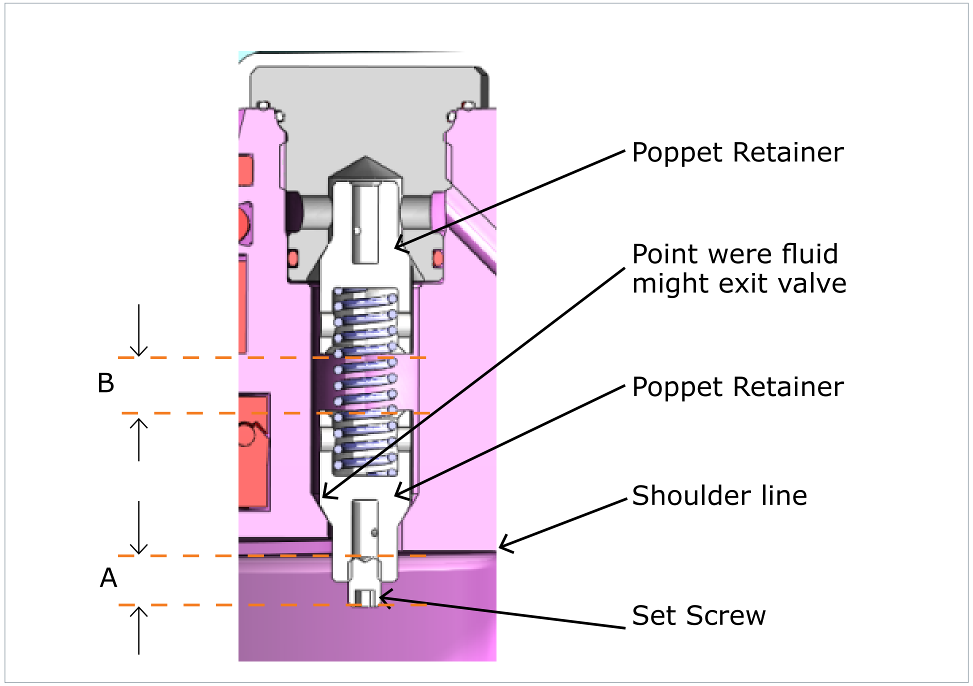


Figure 311: *Illustrating cause of poppet valve leakage. [6]*

B.7. Problem Retrieving TH due to Corrosion Issues

A TH at project Visund was going to be retrieved, but the operator offshore had huge difficulties with the retrieval. The problem proved to be huge amounts of corrosion on the TH. This means that the product needs a lot of maintenance before it can be installed offshore again, or there will arise problems while trying to install it.

This issue is not directly linked to the installation procedures of TH, but an important event to keep in mind, since the retrieval process also is a part of the same hydraulic system used for installation of TH subsea. This event might affect the installation procedures after maintenance, when the TH probably will be installed into the XT spool again. Then one have to take into account that the TH product might not be as good as a new one, after having huge corrosion damages.

Figure 312: *TH form Visund project stored in work shop. [2]*

Figure 313: *Corrosion issue on TH. [2]*

B.8. Comments to Reported Incidents

The reported incidents described above are related to the TH installation in different ways. Some of the incidents are closely linked to the TH installation procedures, and could have been prevented by an improved lock down verification system, while other incidents demand other measures to be carried out.

The problem of debris in the system will typically be solved by making sure that the written procedures are followed, so that the system gets cleaned before TH is installed. But one can`t assume that this wish will be understood and accepted by the installer/ operator. Thus one needs at least one safety procedure that can make sure that the system is fail-safe. That meaning; if cleaning of the system for debris fails, a followed safety procedure will make sure that possible debris problem is detected, so that the debris in the spool and wrong TH position cause as little harm as possible.

An action one can take in order to make sure that other Hybrid Penetrators don`t get destroyed like the one in figure 305, is to assure that the TH is in the right position, before the Hybrid Penetrator is engaged.

The example of flaw in design can typically not be prevented by a verification system, but a verification system can on the other hand let the installer know that something is wrong. They will then find out about the issue, preferably as soon as possible so they can prevent further hazards and improve the design.

Also flaws in assembling of poppet valve components can be discovered by a verification system. For the example described above, the failure will typically be revealed during test procedure of the verification valve in the workshop, and fixed before the THRT is sent offshore.

Both causes and consequences of a hazard can be many, and it is difficult to get an overview and reveal possible system weaknesses and potential system improvements, without carrying out a systematically structured analysis. Thus I have chosen to carry out a Hazard Identification (HAZID) study, that can be found in appendix C.

APPENDIX C

Hazard Identification (HAZID)

C.1. Background

"Poor reliability can have a major financial impact for all organizations involved in designing, manufacturing, installing and operating subsea equipment." [55] In addition to this Aker Solutions wants their products to have as low environmental impact as possible.

The complexity of technical and organizational challenges in subsea projects requires continual attention to detail to achieve high reliability performance." [55] In order to improve the reliability of subsea products and installations, one needs to find the weaknesses of the relevant subsea system.

In order to get an overview of what types of incidents that can be prevented or reduced in occurrence by an improved TH installation verification system, and to get some new ideas for what functions the Positive Lock Down Verification System should have, I have carried out a Hazard Identification (HAZID) study. A Hazard is a potential source of harm. Thus HAZID is identification and analysis of factors affecting safety and associated system reliability.

C.2. Methodology

Hazard Identification (HAZID) is a systematic approach technique used in order to reveal weaknesses in the product design, and I will use it to study the TH installation system in detail, and to identify all significant hazards associated with it.

C.3. Purpose and Objectives

When a hazard, and its cause and direct effects have been found, it is easier to identify design and procedures that can prevent or reduce the probability and/or the consequence of the hazard. When measures are made to this, the system will become more reliable.

C.4. Technology Environment and Analysis Boundaries

This HAZID will analyse the TH installation procedure at a system level. The product components THRT, TH and XT spool will be in focus. The Completion System will not be in focus for this analysis, since it is part of the operation from topside, while I will focus on the function of components closely related to TH installation (THRT and spool).

Analysis of the operational part of the system will not be included in this master thesis, but will be part of other analysis procedures at a later stage, when a final verification system is chosen. I will focus on the verification part of the TH installation, but also look some at the design elements that can make the installation fail.

I have chosen to only focus on identifying hazards for the primary installation procedures for the TH, in order to narrow the scope a bit, so that I will be able to obtain a study on a sufficient level of detail. If the system gets too extensive, the study will become too superficial. By primary installation I mean all the installation steps required in order to get the TH into the right position in the spool and to run relevant verification tests. Thus I have not included hazards associated with pressure testing of the system, retrieval of TH and potential maintenance work.

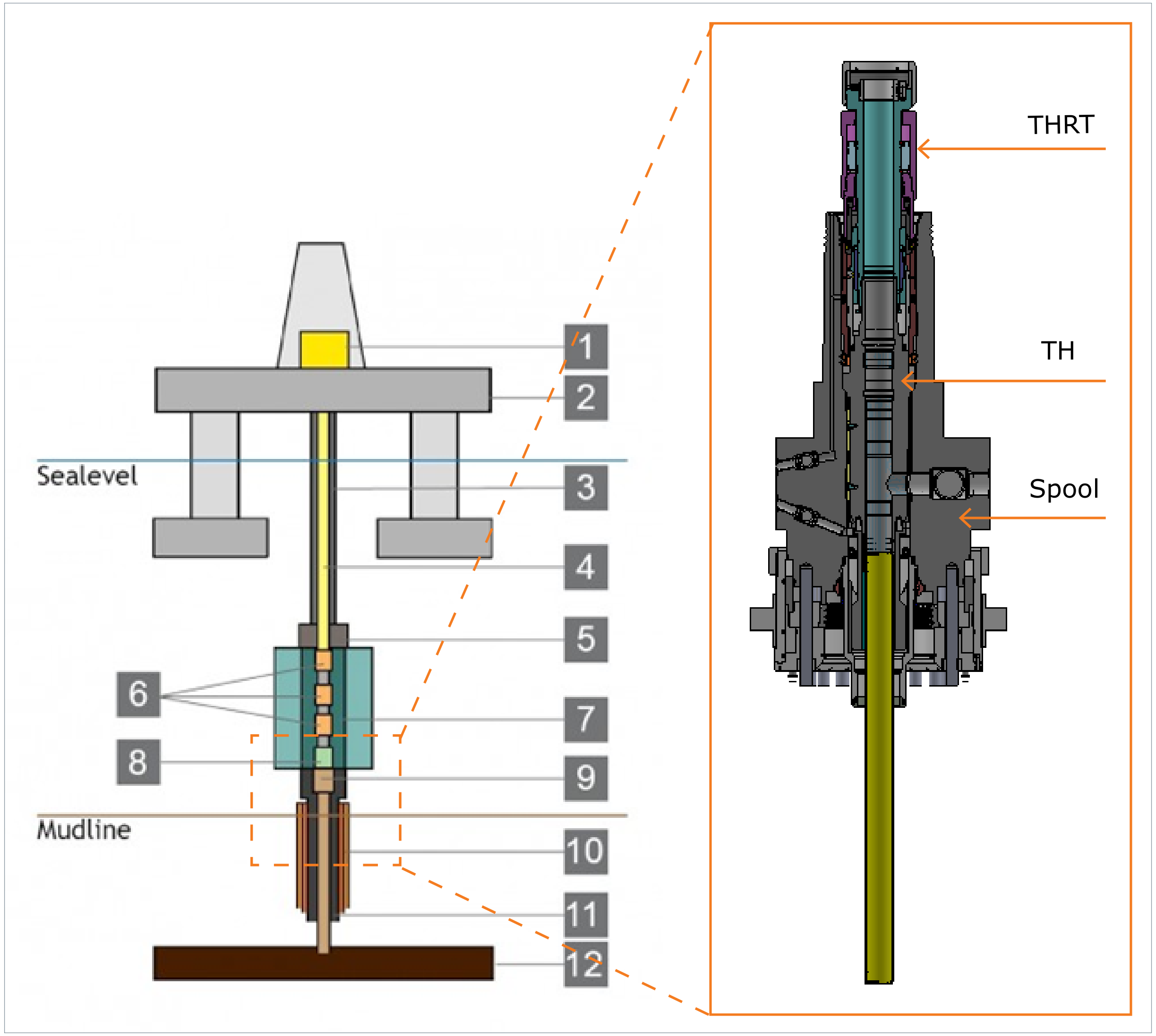


Figure 314: *Sub-system in focus, and it`s surrounding subsea system. The products that I will conduct a HAZID for are THRT, TH and Spool. (see figure 314, page 210 for labelling description.) [6], [3]*

C.5. System Breakdown Structure

Application of any HAZID within Aker Solutions is preceded by a hierarchical decomposition of the procedure into more basic steps. In addition of breaking down the installation procedure into different sub-steps, I will study the specific parts of each sub-system that is involved in each step of the installation. E.g. the Split Lock Ring is a part of the TH that will be involved in the possible hazards related to the locking procedures.

Figure 315 illustrates the process I plan to go through while carrying out the HAZID. This is not a standard HAZID procedure, but one I have created myself in order to carry out a HAZID study that is as customised as possible for the particular installation procedure and subsea system that I am studying. While creating the diagram I added study components according to recommendations in Aker Solutions Global Procedure for HAZID.

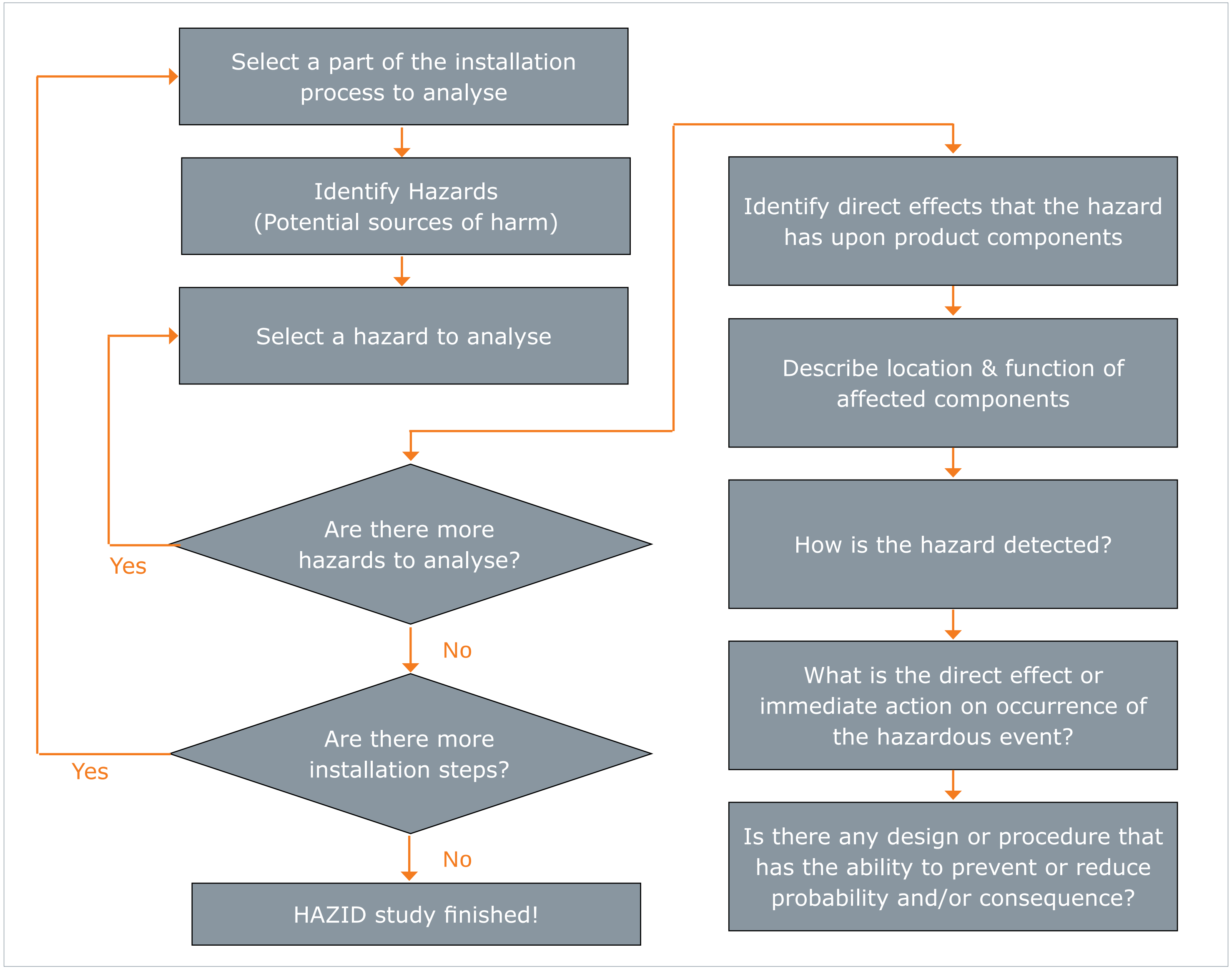


Figure 315: *Process diagram for HAZID. [5]*

C.6. HAZID Worksheet

Table 18: *The worksheet contains a hazard analysis for installation of TH. The installation is divided into installing steps in the same way as the installation description in chapter 4.3.2, so one can look at the figures there in order to get a good understanding of what parts of the installation process I am analysing in the table below. I have marked the key parts of the study in light orange colour; Identifying potential hazards and its causes and suggest improvements. The installation involves position and aid alignment of the TH, and the failure mode for the system is miss-alignment.* (HP = Hybrid Penetrator, TH = Tubing Hanger, THRT = Tubing Hanger Running Tool, XT = Xmas Tree).

Part of installation process	Activity	HAZARDS		Effects upon product components	Description of component		How hazard is detected	Direct effect and/or immediate actions	Design and/ or procedure preventing hazard
		Potential cause	Consequence		Location	Function			
Running THRT down into TH.	Unlatch-unlock activated on THRT.	THRT not run far enough down into TH.	Latch ring will engage in wrong position.	THRT latch ring deformed, and seals destroyed.	THRT, Topside.	Latch THRT to TH.	When one test run the sleeves up and down, or by pick-up test.	Unlatch and inspect, (repair) then try again.	Verification registering if THRT is in right position relative to TH.
Latching THRT to TH and running them subsea.	Activating latching.	Scratched seal surface. Leakage over seals, poor maintenance.	Hydraulic activating lines leaking.	Latch ring fail to engage.	THRT, Topside.	Latch THRT to TH.	During deck test of tool before attaching to TH.	Repair THRT & re-attempt.	Good product maintenance.
		Latch ring not properly engaged e.g. due to leaking seals.	Seems to be latched but is not.	Crunching latch ring.	THRT Topside.	Latch THRT to TH.	When test running the locking sleeves.	Unlatch and inspect, (repair) then re-attempt.	Verification activated when ring fully engaged.
	Running subsea.	Ambient pressure, and latch line not locked.	Unwanted deactivation of latch.	Latch ring deactivated.	THRT, subsea.	Latch THRT to TH.	THRT lose grip of TH.	Products get damaged. Delays.	Clear procedures.

Table 18 continued:

Part of installation process	Activity	HAZARDS		Effects upon product components	Description of component		How hazard is detected	Direct effect and/or immediate actions	Design and/ or procedure preventing hazard
		Potential cause	Consequence		Location	Function			
Running TH down into spool and locking.	Rotating TH into right position with THRT in latch-unlock position.	Spool contains too much debris, wash out tool not run. Fail to follow Aker procedure.	TH can land too high up in the XT.	Split lock ring forced into wrong place and damaged.	TH, subsea.	Locks TH to spool.	Hydraulic quantity readings / Verification tests / HP fail to engage.	Retrieve, repair, clean system and re-attempt. Delay on operation.	Run washout 3 cycles prior to landing TH. Verification registering if ring is fully engaged.
				HP emerges into wrong area & gets damaged.	Inside spool, subsea.	Hydraulic and electric feed through.			
		TH and spool angle outside operational range.	HP can fail to connect.	HP get damaged.	Inside spool, subsea.	Hydraulic and electric feed through.	HP fail to engage.	Retrieve whole XT , repair and re-attempt.	Verification system registering HP position.
		Too high friction.	Snagging of TH inside XT spool, in wrong position.	Split Lock Ring engage into wrong area, crunch damaged.	TH, subsea.	Locks TH to spool.	Hydraulic quantity readings.	Retrieve, repair and re-attempt.	Verification system registering if HP is in right position.
	Then activate lockdown on THRT.	Flaw in design, (e.g. poppet keeper).	Components conflicting & scratching against each other.	Keeper making scratches on THRT body.	THRT, subsea.	Part of lock mechanism.	Testing in workshop before sent offshore.	Keeper gets honed so it fits to the rest of the THRT.	Improve design.
		TH rotation key hit too hard down on the guiding shape inside spool.	TH get stuck in wrong position.	Spool and/ or TH helix crunch damaged.	XT/TH, subsea.	Guides TH into right position.	String not rotating.	Retrieve and re-attempt.	Not to run the TH too fast.
		Leaking sealing.	Split Lock ring not fully engaged.	Split Lock ring not able to activate	THRT, subsea	Lock TH to XT spool	Hydraulic quantity readings	Maintenance	Improved design/ good maintenance

Table 18 continued:

Part of installation process	Activity	HAZARDS		Effects upon product components	Description of component		How hazard is detected	Direct effect and/or immediate actions	Design and/ or procedure preventing hazard
		Potential cause	Consequence		Location	Function			
Lock down verification	Over pull test	TH fixed but in wrong position	False feedback on test	HP engage into wrong area	Inside XT spool, subsea	Provide hydraulic and electric feed through	Poppet valve verification	None	Verification system that registering if HP is in right position
	Poppet valve test/ Lock down verification	Flaw in assembling Poppet valve	Leaking poppet valve	Poppet valve not functioning	THRT	Verification of lock down	Testing in workshop or over pull test	False verification feedback	Testing in workshop or over pull test
			Poppet valve constantly closed						
		Coating clomped together	Leaking poppet valve, giving false verification	HP engage into wrong area	Inside XT spool, subsea	Hydraulic and electric feed through	Difficult to detect	HP destroyed and whole XT must be retrieved for maintenance	Use another coating, and/or plastic composite sealing. Design new verification to prove/disprove the test result
		Metal to metal seal not sealed							
		Seals on poppet keeper not holding tight (Dalia)							
Retrieving THRT	Unlatch THRT from TH and pull up THRT	Deformed latch ring with increased cap that won`t retract sufficiently	Latch ring not able to retract properly	THRT has to be emergency released	Subsea	-	Not able to retrieve THRT	Emergency release activated	Emergency release (New latch ring design)
		Fail to seal	Unlatch pressure not obtained						

C.7. New Information About TH Installation and Verification

While carrying out the HAZID, I tried to gather as much valuable information about TH installation and today's verification methods as possible. During this process I got some information about the installation process that I wasn`t aware of from before, mainly by talking to people with experience from offshore installation of TH and watching movies simulating offshore installations. I got to know about other verification methods used offshore, and how well the system works during installation procedures.

“While running the TH subsea a laser beam can be used in order to measure amount of tubing that is sent subsea, and in that way know how far subsea the TH is. From this reading the operator can know if the TH is in about the right place with an accuracy of 5-10 cm. The laser beam is positioned topside, and the readings are quite accurate since the tubing and string connected to the TH are rigid.” [56]

In addition one can verify that the TH rotates in the right way when entering the guiding in the spool, by observing the string on topside; The TH is lowered with 90 degree offset from final position. The rotation is verified by a 90 degree clockwise rotation of string.

These two verification methods of TH travel distance from topside and rotation inside spool are not accurate enough to be used as a positive verification, but they give a good indication of correct/incorrect installation of TH.

In addition I got to know about a test performed in order to verify if latch ring is activated correctly. “The sleeves are run up and down, before sending the TH subsea. If the Latch ring is in the wrong position, one will not be able to lower the sleeves.” [56]

Thus one will discover if the latch ring has failed to emerge into the right position, but if it is not, it is a possibility of damaging the ring while running the test. Therefore I think it will work best as fail-safe procedure, meaning that it will be run after a positive verification on the latch ring`s position, in order to justify that the first positive verification isn`t false.

If one manage to implement a reliable verification system that is not too expensive and time consuming to run/develop, it is worth to do so in order to ovoid project delays and huge extra expenses on maintenance and repair work.

C.8. Conclusions and Comments to HAZID Study

Comments
Development of a verification system for the Lock Down (fixing TH to XT spool) is the task for this Master Thesis, but in the HAZID analysis I have included all the installation steps required in order to get the TH into right position in XT spool and to run relevant verification tests. This was done in order to see the whole picture, and to ensure that the whole installation procedure for TH has sufficient verification methods.

Positive Lock Down verification will be in focus, but it is also crucial to avoid hazards that can occur while latching THRT to TH and running the TH down into the spool. If this is not ensured, the TH might not be guided into the right position in XT and installation failure can occur at an earlier installation stage, before Lock Down.

As one can see in the column listing "How hazard is detected" in table 18, hydraulic quantity readings is a central part of the system which let the operator know if installation is going as planned. Unfortunately this is not a reliable verification method. The method used is to measure amount of hydraulic liquid that exit the hydraulic line during venting/bleed of pressure. This takes long time since the umbilical connecting

THRT to topside is long, and the amount of detected fluid is seldom as specified in the installation procedures.

The root of failure for wrong hydraulic quantity readings is mainly leaking seals. Seals can leak due to scratched seal surfaces, coating or Inconel that is applied on seal surface where it should not be added, cladded coating by seals or use of groove and seal design that is not fitted for its use. I will not include possible improvement of seal design in this thesis, but come up with verification methods that can detect failure.

Nor will measures related to following the installation procedures and to carry out good maintenance be further discussed in this thesis. Even though I don't focus on these aspects, the parts of the HAZID related to seal design, installation procedures and good maintenance can be of good use to persons working with those areas.

Improvement of poppet valve design will is on the other hand directly related to Lock Down verification, and will therefore be included in the further work of this task.

Today there are two verification methods. If one fails there is no way to know which one is not giving false verification information. This is a huge dilemma and has resulted in the Poppet valve being named "confusion valve" by the offshore TH installation operators. If one run over pull test on the TH, one will know if it is fixed inside the spool or not. On the other hand if one runs a verification test with poppet valve, one can get a false verification if the valve is leaking, and one never know for sure if the verification is correct when it gives positive feedback. If the poppet valve gives a negative feedback, one knows for sure that the sleeves are not fully stroked, and that the TH sits to high up in the spool.

One possible way to solve the dilemma of having two verification methods giving opposite results, one could implement a third one, in order to be able to eliminate the wrong verification result.

This means that negative feedback from tests let the operator know for sure that installation went wrong, but any positive feedback don`t give any secure information about the TH`s position relative to the spool. The poppet valve should have been able to give a positive verification, but it has too many possible incidents of failure. Thus it only gives an indication and not a positive verification of the TH`s position.

Table 19: *An overview of possible status, after running over pull and poppet valve verification tests.*

Over pull test result	Poppet valve test result	Status from tests
Positive	Positive	The TH is fixed, and locking sleeves fully run. (If the poppet is working).
Positive	Negative	The TH is fixed in wrong position.
Negative	-	The TH is not locked properly in spool.

A Positive Lock Down Verification System for Tubing Hanger Installation is needed both to prove/disprove the results form over pull test and poppet valve test (or other suitable verification methods), and to give positive verification of the TH`s actual position relative to the spool. Detection of hazard by Hybrid Penetrator failing to engage is very bad, and should not happen. Thus if the poppet valve fail to work, one should have a fail-safe system to make sure the Hybrid Penetrator is not engaged, before the TH is in right position. Installation should be based upon secure events, and not weak indications.

Conclusion
The HAZID study has given me a nice overview of what a verification system for Tubing Hanger installation should include (from "Design and/or procedure preventing hazard" column in table 17):

- Verification registering if THRT is in right position relative to TH, before latch.
- Verification activated when latch ring fully engaged.
- Verification registering if TH is in right position in spool.
- Verification registering if lock ring is fully engaged.

Thus if only focusing on developing concepts for Positive Lock Down Verification System, and not on the latching sequence, the last two bullet points are of highest importance. In order to obtain a complete verification system for TH installation, verification for latching THRT to TH and verification related to running TH subsea, should also be included.

APPENDIX D

Technology Analysis

D.1. Fibre-Optic Wet-Mate Connectors

“As a very brief introduction to fibre optical communications, the principle of operation exploits the ability of light to travel efficiently within a very fine glass fibre. The glass fibre is essentially an optical wave-guide in which light stays trapped within the core by near total internal reflection between the core and its outer cladding. The core consists of a 9μm diameter high refractive index glass material covered by a 125 μm diameter lower refractive index cladding. For comparison of size a human hair is 90μm diameter.

Underwater optical connectors enable subsea system designers to build modular subsea components and systems utilizing optical communication systems.

The main advantages of such systems are for example:
- Significant increase in communication bandwidth.
- Significant increase in speed of data transfer.
- Significant increase in communication distances.
- Immunity to electrical noise.
- Potential cost reduction in subsea umbilical construction and installation by enabling the manufacture of smaller diameter umbilicals.
- Well-known temperature dependant properties of optical fibre.

The Challenge of Wet-Mate Fibre Optic Connectors:
- The alignment and coupling of these very fine 9 μm diameter glass fibres underwater without;
- Any contamination across the optical faces.
- High optical losses.
- The ability to operate underwater for long periods of time without discernible degradation.

Optical wet-mate connectors have been qualified for use to 23,000 feet (7,000 m). Underwater optical fibre and communication systems have been in use in the offshore and subsea oil and gas environs for many years now.” [57]

Figure 316: *Wet-mate connectors. [57]*

D.2. Hydraulic Actuators

Hydraulic actuators are used in subsea installations, since pneumatic actuators typically will not provide the large amount of force that is required for operation of the valves. The design of hydraulic actuators can vary, but the most common once have a piston. Figure 317 shows a hydraulic actuator with piston.

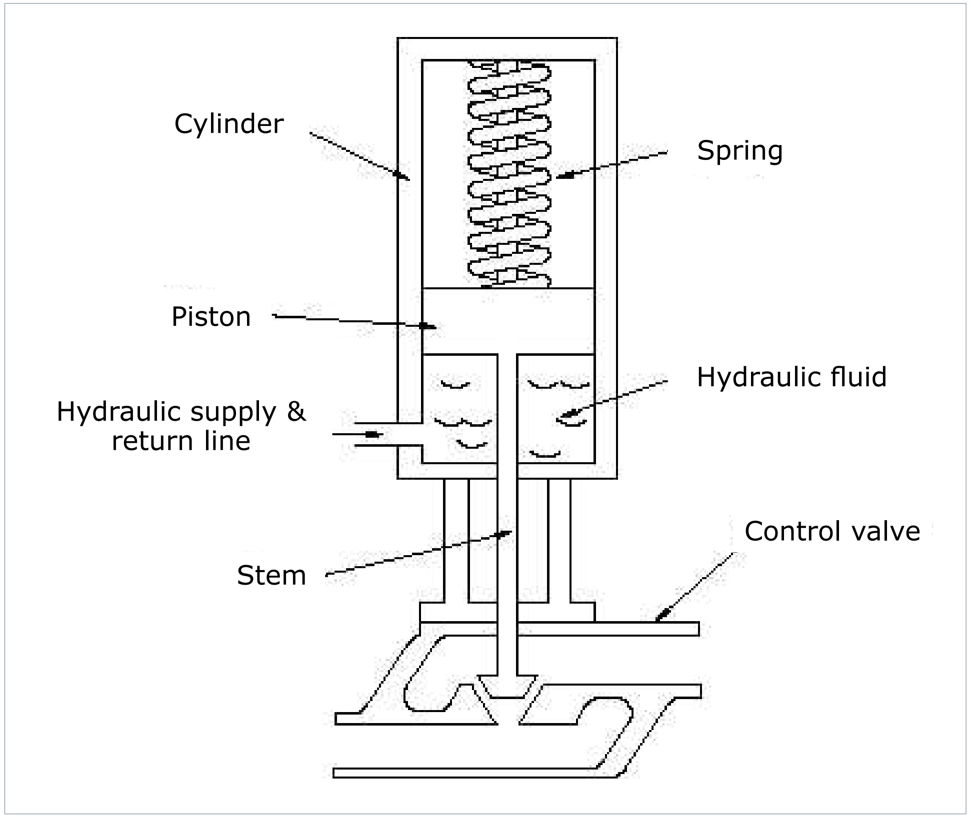


Figure 317: *A typical piston-type hydraulic actuator [58]*

Figure 317:
"Typical piston-type hydraulic actuators consist of a cylinder, piston, spring, hydraulic supply & return line and stem. The piston slides vertically inside the cylinder and separates the cylinder into two chambers. The upper chamber contains the spring and the lower chamber contains hydraulic oil. The hydraulic supply and return line is connected to the lower chamber and allows hydraulic fluid to flow to and from the lower chamber of the actuator. The stem transmits the motion of the piston to a valve.

Initially, with no hydraulic fluid pressure, the spring force holds the valve in the closed position. As fluid enters the lower chamber, pressure in the chamber increases. This pressure results in a force on the bottom of the piston opposite to the force caused by the spring. When the hydraulic force is greater than the spring force, the piston begins to move upward, the spring compresses, and the valve begins to open. As the hydraulic pressure increases, the valve continues to open. Conversely, as hydraulic oil is drained from the cylinder, the hydraulic force becomes less than the spring force, the piston moves downward, and the valve closes. By regulating amount of oil supplied or drained from the actuator, the valve can be positioned between fully open and fully closed" [58]

D.3. Solenoid Actuators

“Soleniods are actuators capable of linear motion. They can be eletromechanical, hydraulic or pneumatic driven. Give it energy and it will produce linear force.” [59]

Figure 318: *Solenoid actuator [59]*

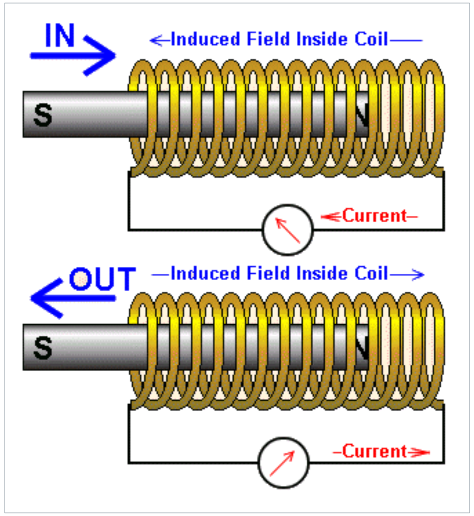


Figure 319: *Technical figure of Solenoid [59]*

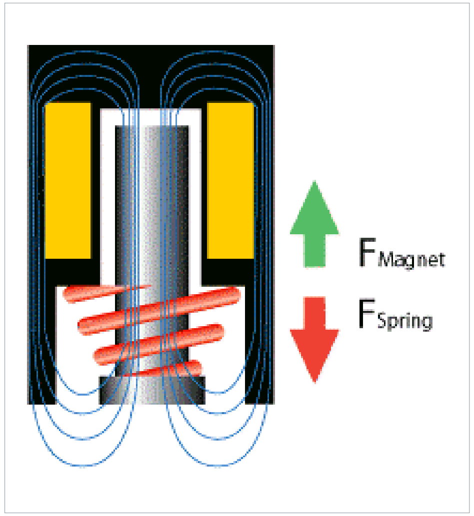


Figure 320: *Pull type solenoid [59]*

D.3.1. How Solenoids Work

“Inside a solenoid is wire coiled in a special way, as shown in figure 319. When you send an electric current through this wire (energized), a magnetic field is created. The inner shaft of a solenoid is a piston like cylinder made of iron or steel, called the plunger. The magnetic field then applies a force to this plunger, either attracting or repelling it. When the magnetic field is turned off, a spring then returns the plunger to its original state (see figure 319).” [59]

D.3.2. Push and Pull Type Solenoids

There are two main types of solenoids. The type directly refers to the solenoid start and energized positions, and is very important to understand. In pull type solenoids (figure 320), the plunger is normally outside the solenoid because the spring naturally forces the plunger out. Yet when energized, the force 'pulls' the plunger into the solenoid. Push type solenoids are the opposite, in that the spring forces the plunger into the solenoid, but when energized the plunger is 'pushed' out.” [59]

D.4. Micromechanical Components

"Magnetic shape memory (MSM) materials, in particular Ni-Mn-Ga alloys, have been suggested to have several potential applications including;

- valves, pumps
- mechanical couplers
- positioning devices
- vibrators, loudspeakers
- force and position sensors, generators

In most of these devices, the MSM materials are part of an actuator. The principle of an MSM actuator is shown in figure X. Typically, the MSM element is aligned with its short a axis along the direction of pre-stress in zero magnetic field. When the magnetic field is switched on, the twin variants reorient themselves and, as a result, the short axis turns parallel to the field. This leads to the elongation of the whole sample.

Devices based on MSM materials have some advantages.
The most obvious of them are;

- small size - large stroke, strain up to 100 mm/mm
- response time to the applied force < 1 ms
- accurate positioning (< 1 mm)
- low power consumption
- maximum operating frequency 10 kHz" [60]

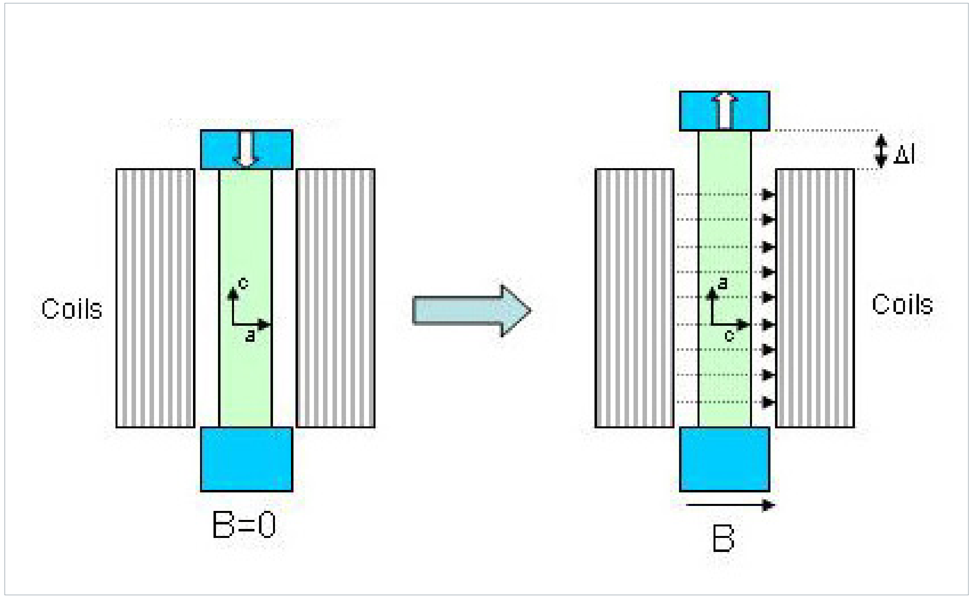


Figure 321: *Magnetic shape memory (MSM) actuator. [60]*

D.5. Touch Sensors

A touch sensor is "a device that detects objects through physical contact with them." Touch sensors can be used for determining position and orientation of TH inside XT-assembly. [61]

Touch sensor characteristics:

- "A touch sensor should ideally be a single-point contact, tough the sensory area can be of any size. In practice, an area of 1-2 mm2 is considered a satisfactory compromise between the difficulty of fabricating a sub-miniature sensing element and the coarseness of a large sensing element.
- The sensitivity of the touch sensor is dependent on a number of variables determined by the sensor's basic physical characteristic.
- A minimum sensor bandwidth of 100 Hz.
- The sensor's characteristics must be stable and repeatable with low hysteresis.
- As the touch sensor will be used in an industrial application, it will need to be robust and protected from environmental damage." [62]

There exist a huge variety of touch sensors. Below is a description of the types I think will be most applicable for a lock down verification system for TH installation. They are all suited for interaction with rigid objects.

D.5.1. Mechanically Based Sensors

"The simplest form of touch sensor is one where the applied force is applied to a conventional mechanical micro-switch to form a binary touch sensor. The force required to operate the switch will be determined by its actuating characteristics and any external constraints." [62]

D.5.2. Resistive Based Sensors

"The basic principle of this type of sensor is the measurement of the resistance of a conductive elastomer or foam between two points. The majority of the sensors use an elastomer that consists of a carbon doped rubber." [62]

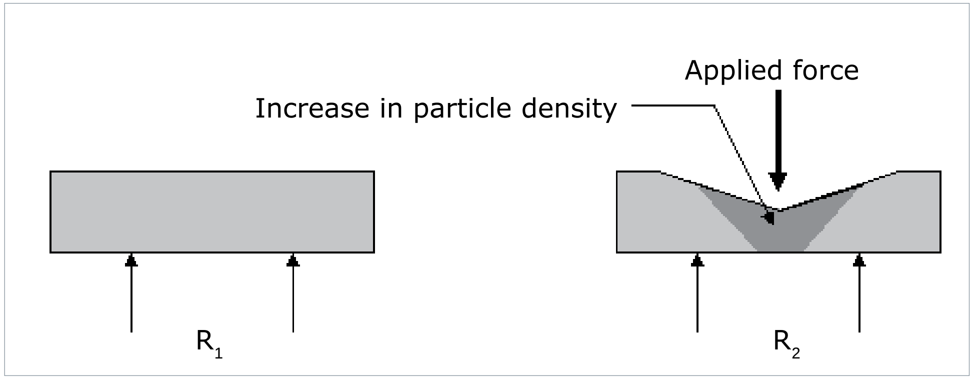


Figure 322: *This figure illustrates a sensor with an elastomer that has a resistance which increase with applied force, due to deformation and thus increased particle density. [62]*

The resistive based sensor has one main disadvantage for use in subsea installation; the elastomer material can permanently deform after repeated use due do fatigue, resulting in lower reliability. This will require replacement of sensor.

D.5.3. Capacitive Based Sensors

"The capacitance between two parallel plates is given by:

$$C = (\varepsilon \cdot A)/d$$

A is the plate area, d the distance between the plates, and ε the permittivity of the dielectric medium. A capacitive touch sensor relies on the applied force either changing the distance between the plates or the effective surface area of the capacitor. In such a sensor the two conductive plates of the sensor are separated by a dielectric medium, which is also used as the elastomer to give the sensor its force-to-capacitance characteristics.

The figure shows the cross section of the capacitive touch transducer in which the movement of a one set of the capacitors' plates is used to resolve the displacement and hence applied force." [62]

Capacitance touch switch is typically used in lamps, which can be regulated by a person by tapping it. "When a person touches it, it increases the capacitance and triggers the switch. Capacitance touch switch and resistance touch switch needs to be touched by an electrically-conductive object.
"A capacitance touch switch requires only one electrode to function, while a resistance touch switch needs two electrodes to be in physical contact with something electrically conductive to operate." [63]

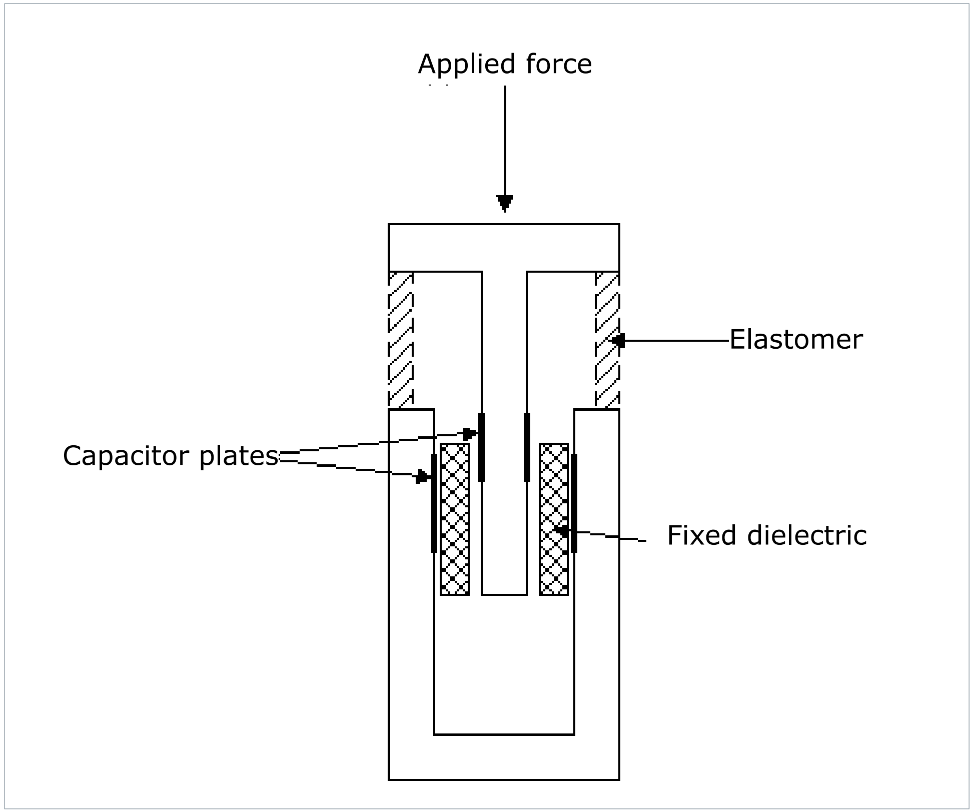


Figure 323: *Capacitive based sensor [62]*

D.5.4. Piezo Touch Switches

Piezo switched originate from piezoelectric crystals. “When mechanical pressure is applied to a crystal unit, electricity is generated on the surface (piezoelectric effect). Conversely, when electricity (voltage) is applied to the surface, mechanical strain is generated. (Inverse piezoelectric effect)”. [64]

“Many of today’s applications of piezoelectricity use polycrystalline ceramics instead of natural piezoelectric crystals. Piezoelectric ceramics are more versatile in that their physical, chemical, and piezoelectric characteristics can be tailored to specific applications. Piezoceramic materials can be manufactured in almost any shape or size, and the mechanical and electrical axes of the material can be oriented in relation to the shape of the material. These axes are set during poling (the process that induces piezoelectric properties in the material). The orientation of the DC poling field determines the orientation of the mechanical and electrical axes“. [65]

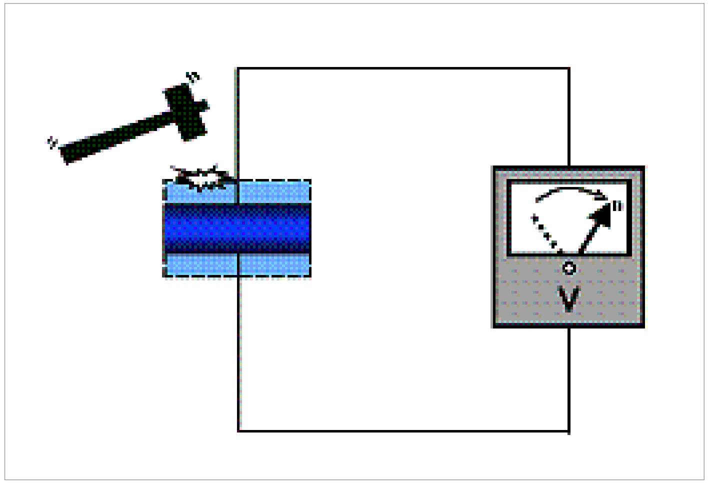


Figure 324: *Piezoelectric effect. [64]*

D.5.5. Magnetic Touch Based Sensor

1. “The movement of a small magnet by an applied force will cause the flux density at the point of measurement to change. The flux measurement can be made by either a Hall effect or a magnetoresistive device.” [62]
2. “The core of a transformer or inductor can be manufactured from a magnetoelastic material that will deform under pressure and cause the magnetic coupling between transformer windings, or a coil’s inductance to change. A magnetoresistive or magnetoelastic material is a material whose magnetic characteristics are modified when the material is subjected to changes in externally applied physical forces.” [62]

D.5.6. Optical Touch Sensors

1. “Modulating the intensity of light by moving an obstruction into the light path. The force sensitivity is determined by a spring or elastomer. To prevent cross talk from external sources, the sensor can be constructed around a deformable tube, resulting in a highly compact sensor; shown in figure 325.” [62]

2. Photoelasticity: “the phenomena where stress or strain causes birefringence in an optically transparent material. Light is passed through the photoelastic medium. As the medium is stressed, the photoelastic medium effectively rotates the plane of polarization and hence the intensity of the light at the detector changes as a function of the applied force”. [62]

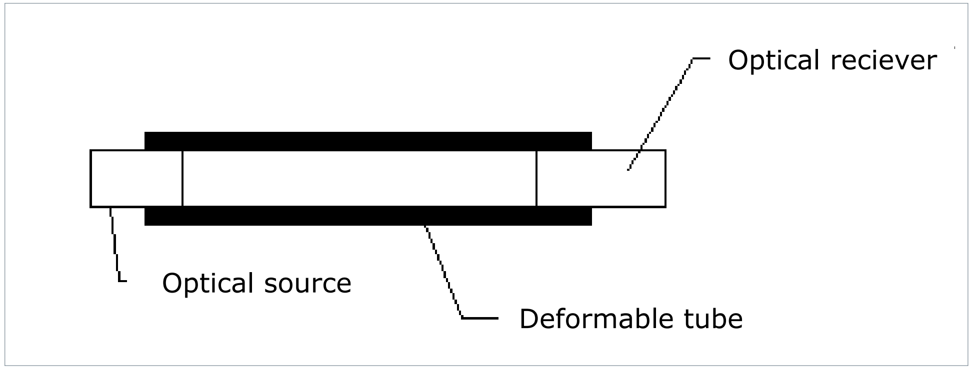


Figure 325: *Optical touch sensor. [62]*

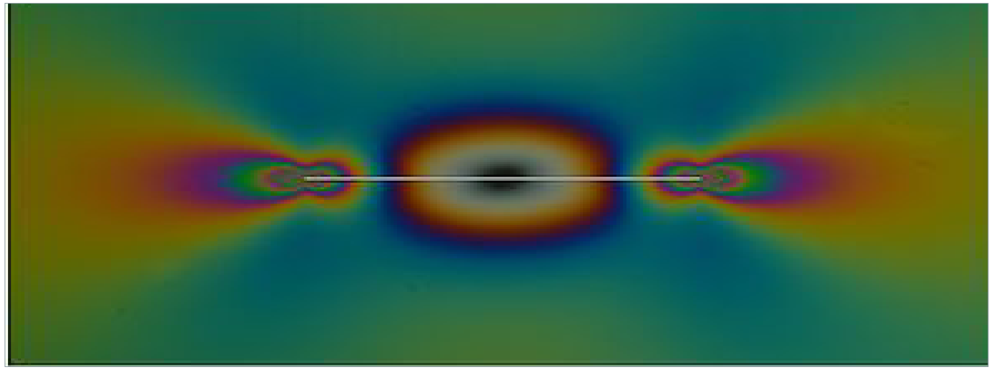


Figure 326: *Photoelasticity. [66]*

D.6. Proximity Sensor and Proximity Switch

D.6.1. Proximity Sensor

Proximity sensors are the most common and affordable solution for no-touch object detection. [67] Proximity Sensors are available in models using high-frequency oscillation to detect ferrous and non-ferrous metal objects and in capacitive models to detect non-metal objects. Models are available with environment resistance, heat resistance, resistance to chemicals, and resistance to water. [68]

The most commonly used proximity sensors are the inductive type which generate an electromagnetic field to sense metal objects passing close to the face. This is usually the easiest sensing technology to apply in applications where the metal target is within an inch or two from the sensor face. [67]

Figure 327: *Inductive sensor. [69]*

“An inductive sensor consists of an induction loop; a detection system which uses a moving magnet to induce an electrical current in a nearby wire. The inductance of the loop changes according to the material inside it and since metals are much more effective inductors than other materials the presence of metal increases the current flowing through the loop. This change can be detected by sensing circuitry, which can signal to some other device whenever metal is detected.” [69]

“Common applications of inductive sensors include metal detectors, traffic lights, car washes, and a host of automated industrial processes. Because the sensor does not require physical contact it is particularly useful for applications where access presents challenges or where dirt is prevalent.” [69]

Advantages of inductive proximity sensors include:

- Ignores water, oil, dirt, and non-metallic particles
- Insensitive to target color or target surface finish
- Short-circuit resistant
- Withstands high shock and vibration environments

D.6.2. Proximity Switch

“A proximity switch uses magnets, either in attraction or repulsion, to open or close an electrical circuit. The switch can be normally open or closed. When a magnet is presented the switch will either open or close the circuit.” [70] This means that the object that is to be detected has to contain a magnet, since the switch only respond to magnets.

Proximity switch systems have a switch-on point. This means that the system can be set up to switch when a magnet is at a specific distance from the proximity switch.

As mentioned in the description of proximity sensors, it is the most common and affordable solution for no-touch object detection. Proximity switch sensors on the other hand are often used in cases where inductive sensors reach their limits.

Since magnetic fields penetrate all non-magnetisable materials, the sensors can detect magnets through walls made of non-ferrous metal; e.g. stainless steel and aluminium, in addition to plastic and wood.

Advantages of proximity switches include:

- Detection even through non-magnetisable metals
- Small housings with very long sensing ranges up to 100 mm
- Cylinder and rectangular designs for demanding applications
- High mechanical stability in case of shock or vibration

Another usual name used for proximity switch is magnetic sensor. The picture below shows magnet sensors from ifm, one of many manufacturer of sensor technology.

Figure 328: *Magnetic sensors. [70]*

D.7. Ferrous Materials

For magnetic sensor/proximity switch technology it is important to distinguish between ferrous and non-ferrous materials. A proximity switch is used to detect magnets, and thus the object one wants to detect has to be a permanent magnet, or it has to contain one. "Permanent magnets are materials that can be magnetized by an external magnetic field and remain magnetized after the external field is removed." [71]

Pure iron tends to form magnets easily, and ferrous metals typically contain significant amounts of iron, which can make the material strongly magnetic. Iron and steel types have magnetic character, which vary with its constituents. Stainless steel has nearly no magnetic character.

In addition to ferrous magnetic materials, there also exist non-ferrous magnetic materials. "In fact, some of the strongest permanent magnets you can get are based on rare-earth elements, such as neodymium, rather than on iron." [72]

The figure below is a picture of different metals. Some of them are ferrous while others are non-ferrous. Some examples of ferrous and non-ferrous metals:

- Ferrous metals: Steel and Cast Iron
- Non-ferrous metals: Copper, aluminium, brass and stainless steel.

Figure 329: *Different types of metal [71]*

D.8. Electro-Optical Sensor

"Electro-optical sensors are electronic detectors that convert light, or a change in light, into an electronic signal. They are used in many industrial and consumer applications, for example:
- Lamps that turn on automatically in response to darkness
- Position sensors that activate when an object interrupts a light beam" [73]

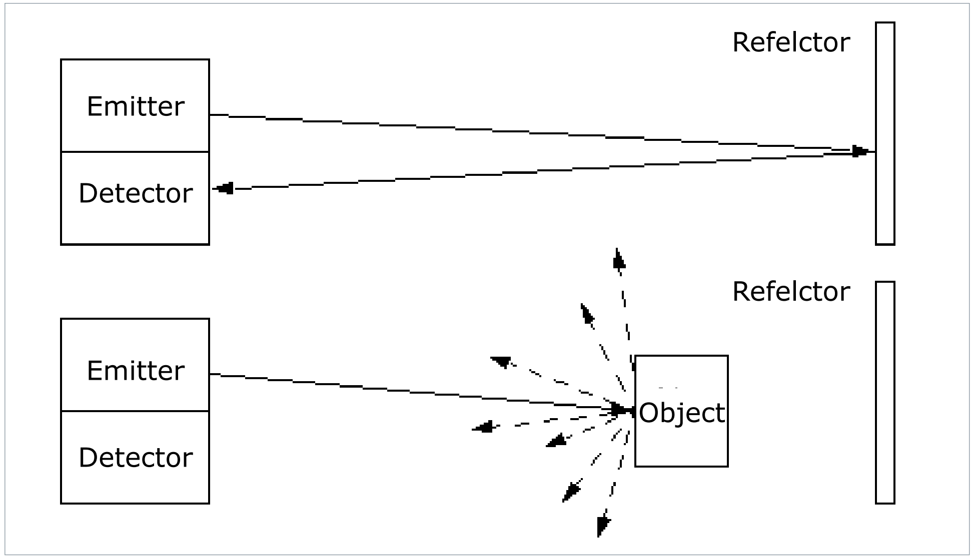


Figure 330: *Electro-optical sensor. [74]*

D.9. Laser Sensor

"Laser sensors are used where small objects or precise positions are to be detected. Laser light consists of light waves of the same wave length with a fixed phase ratio. This results in an important feature of laser systems, which is the almost parallel light beam." [75]

Figure 331: *Laser sensor. [48]*

D.10. Radiography

"Radiography is the use of X-rays to view a non-uniformly composed material such as the human body. By using the physical properties of the ray, an image can be developed which displays areas of different density and composition.

A heterogeneous beam of X-rays is produced by an X-ray generator and is projected toward an object. According to the density and composition of the different areas of the object a proportion of X-rays are absorbed by the object. The X-rays that pass through are then captured behind the object by a detector (film sensitive to X-rays or a digital detector) which gives a 2D representation of all the structures superimposed on each other. In tomography, the X-ray source and detector move to blur out structures not in the focal plane. Computed tomography (CT scanning) is different to plain film tomography in that computer assisted reconstruction is used to generate a 3D representation of the scanned object.

The types of electromagnetic radiation of most interest to radiography are X-ray and gamma radiation. This radiation is much more energetic than the more familiar types such as radio waves and visible light. It is this relatively high energy which makes gamma rays useful in radiography but potentially hazardous to living organisms." [76]

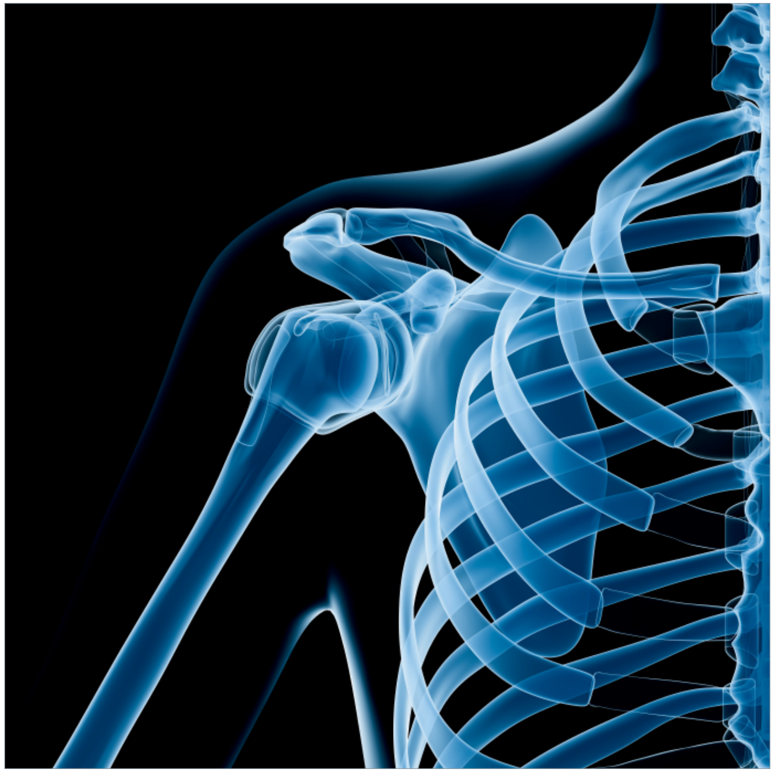


Figure 332: *A radiography picture example of human body. [77]*

APPENDIX E

Patents

E.1. Portable Dynamic Riser

This is a system solution that can be connected to ROV. I found an article about this product solution online. The article states that it is a patented system solution, but I have not been able to find the patent document.

“The Ocean Specialists, Inc. (OSI) patented Portable Dynamic Riser (PDR) system provides a step change in the communications capability of any mobile asset that is working on existing subsea oil & gas fields. No longer are these valuable assets and the work that they are employed to perform limited to high cost, low bandwidth satellite, or microwave communication. The PDR provides the capability of direct fibre-optic communication at data rates up to full gigabit.” [P1]

PDR System Description
“The PDR is made up of three main components, the Surface Launch and Recovery System (LARS), the Flying Lead Management System (FLMS) and the project specific wet-mate connector patch lead.

The LARS is a proven unit used for small ROV operations and comprises the power supply, control unit with video monitor, the main winch, A-Frame and the 3000m umbilical. The LARS provides control of the Flying Lead Management System, and a means of deploying it to a set distance above sea floor and for its subsequent recovery.

The FLMS operates on the same well-established principles of an ROV tether management system. It includes a deployment frame, the flying lead cable reel with its motor, control and level wind, 1500m of neutrally buoyant light-weight cable and a cable termination with dry-mate connector.

The function of the FLMS is to allow an ROV to pull out the Flying lead cable in a controlled manner. The FLMS also recovers the Flying lead cable after use, properly storing the cable on the cable reel using a precision level wind.

Finally, to provide a project specific interface to any available wet-mate connector, a short project specific patch lead is needed. The patch lead will typically include a standard dry-mate connector to mate with the flying lead, a short length of cable or pressure balanced oil filled hose and a project specific wet-mate connector, configured to interface with the available mating connector.” [78]

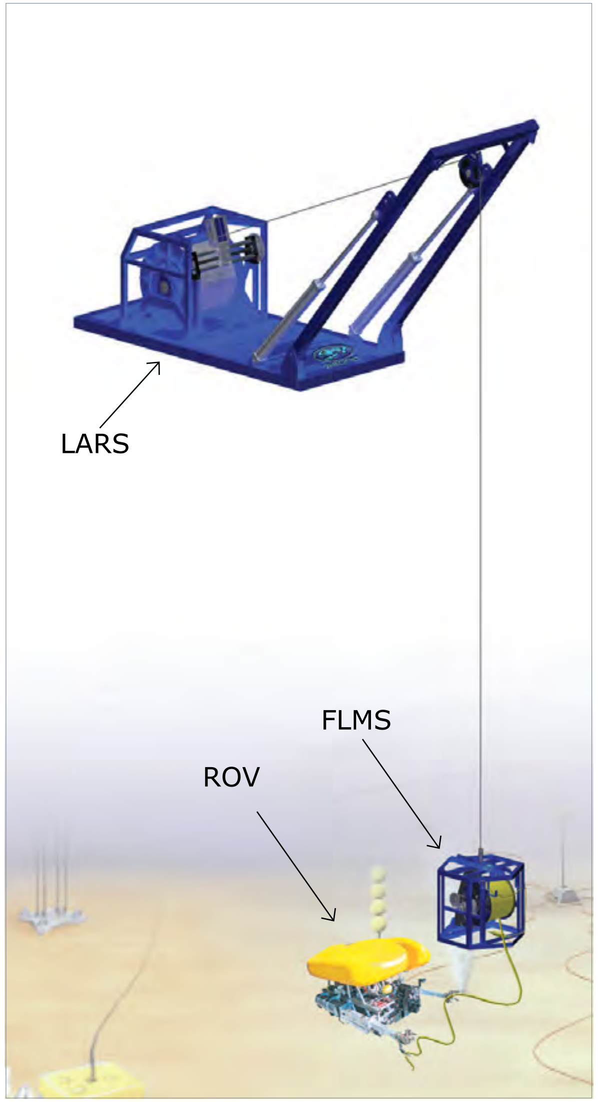


Figure 333: *Portable dynamic riser system. [78]*

E.2. Tubing Hanger Setting Confirmation System

This is the only patent I have found which addresses a verification/ confirmation system solution for TH installation. I have not found any other verification system patens related to other subsea product components either, except from this one.

The patented system provides both a tubing hanger landing confirmation and a tubing hanger locking confirmation. The patent has the title "Tubing Hanger Setting Confirmation System" and has patent publication nr: US 2012/0292035 A1, and it was publicised Nov. 22, 2012.

"The indicator assembly has an indicator stem that is adapted to move relative to the wellhead member when a specified function in the wellhead member occurs. A communication line connects to the running tool and extends alongside the running string to the platform. An indication of movement of the indicator assembly is transmitted through the communication line to the platform." [79]

The system consists of two indicator assemblies, one for landing verification and one for lock verification. They are both located in the TH. They have each their communication line connected to topside. Figure 334 provides an example of how the indicator assemblies can be located.

Most central labelings in figure 334:

37: Land confirmation assembly.
39: Locking confirmation assembly.
41: locking dogs
45: Landing soulder

Remaining labeling references can be found in the patent document.

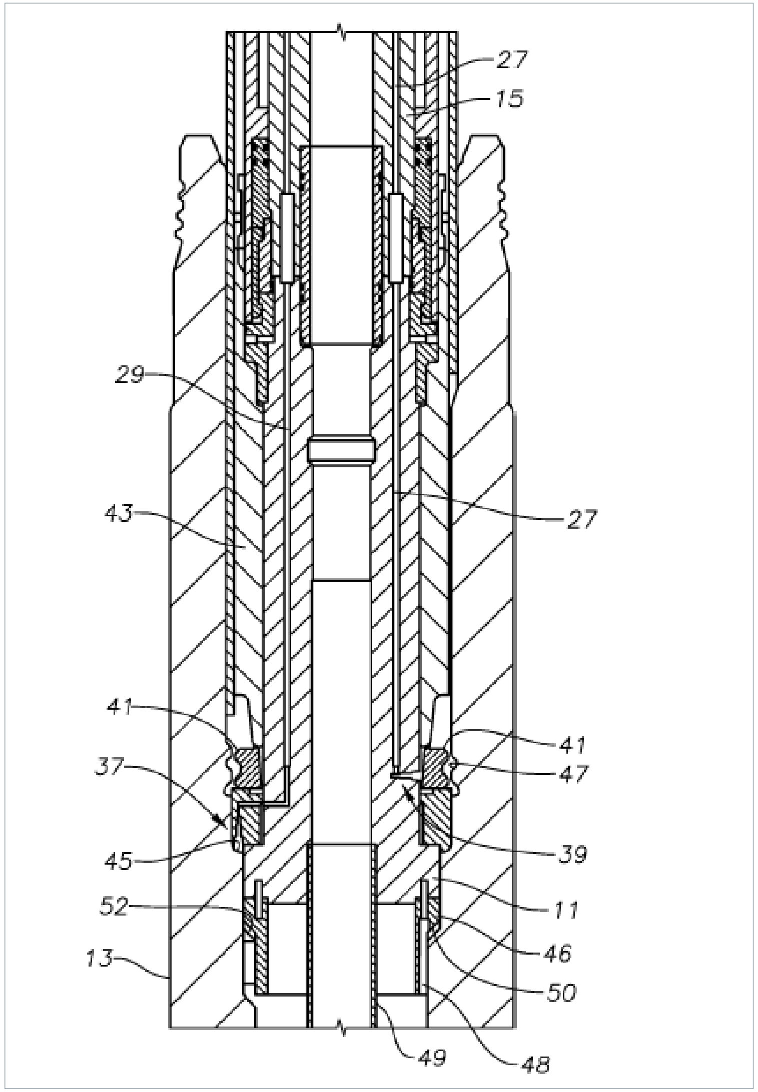


Figure 334: *Schematic illustration of a tubing hanger land and lock confirmation system disposed within a tubing hanger spool. [79]*

Each indicator assembly has an indicator stem that moves from an extended position to retracted position during landing or lock procedures. "A control unit on topside provides fluid pressure thru the communication line that changes when the indicator stem moves to the retracted position." [79]

When indicator stem is in extended position a valve is closed due to a spring pressing two component surfaces together. Movement of indicator stem to retracted position cause spring compression, and opens the valve passage so that hydraulic fluid can pass by a valve. Since there is air/gas on the other side of the valve, the pressure in the communication line will decrease as the valve is opened. "This pressure decrease will be read by high pressure unit" [79] on topside. "High pressure unit will then provide an indication to an operator of the decrease in pressure through control unit, notifying the operator of a successful landing or lock of TH." [79]

E.2.1. Landing Confirmation

For landing verification example provided in the patent document, the indicator assembly is positioned in the lower part of TH, and the indicator stem moves upwards to retracted position as the TH lands. See figure 335 and 336.

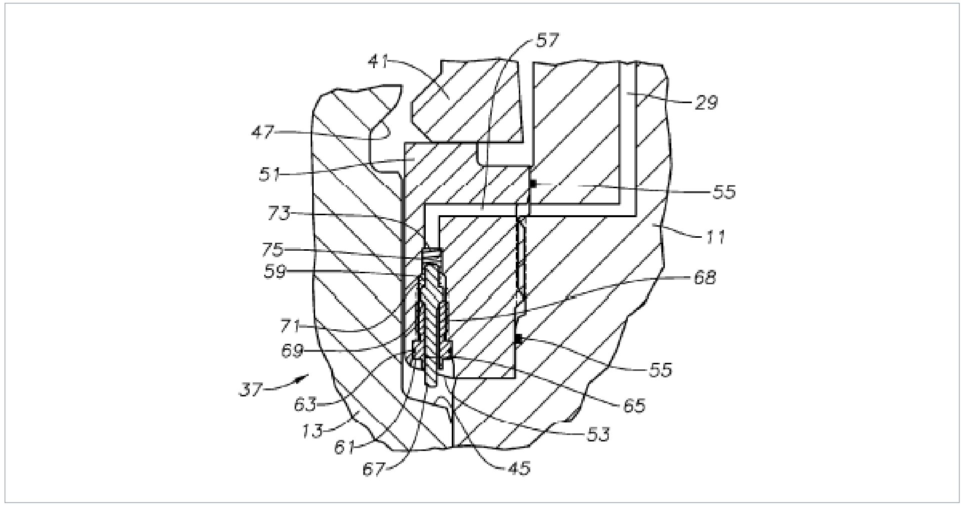


Figure 335: *Schematic illustration of the tubing hanger land confirmation system, just prior to landing. [79]*

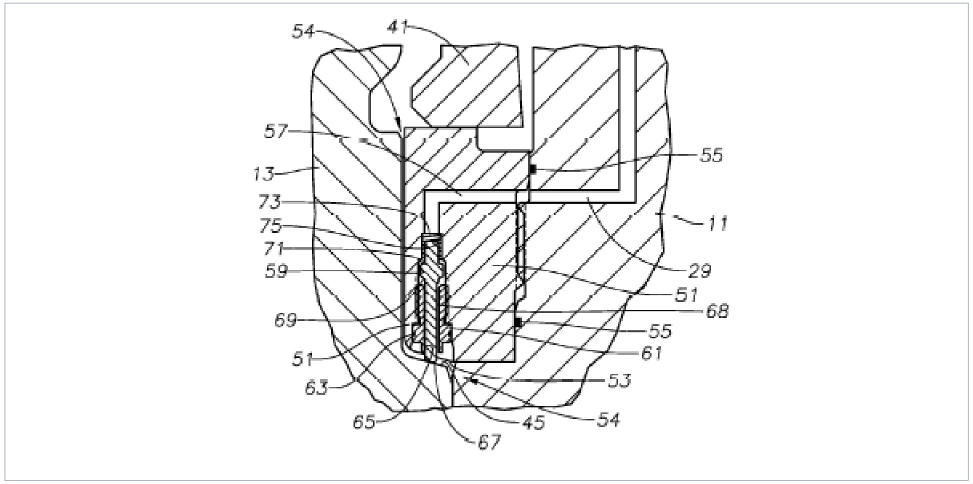


Figure 336: *Schematic illustration of the tubing hanger land confirmation system, just after landing. [79]*

E.2.2. Lock Confirmation

For lock confirmation example given in the patent description, the indicator assembly is located next to a locking dog. (Locking dogs have the same function as a split lock ring, but consist of lock components arranged in a circular path, instead of a more continuous split lock ring structure.) The indicator assembly is positioned radially inward relative to a locking dog.

"Prior to locking of tubing hanger to wellhead assembly, an end of locking indicator stem will protrude beyond the outer diameter of tubing hanger in an extended position." [79] "As actuation sleeve moves radially downward between tubing hanger and locking dogs, an end of actuation sleeve will come close to and touch the end of locking indicator stem." [79] "As actuation sleeve continues moving axially downward between TH and locking dogs, actuation sleeve will force locking indicator stem radially inward into a retracted position."

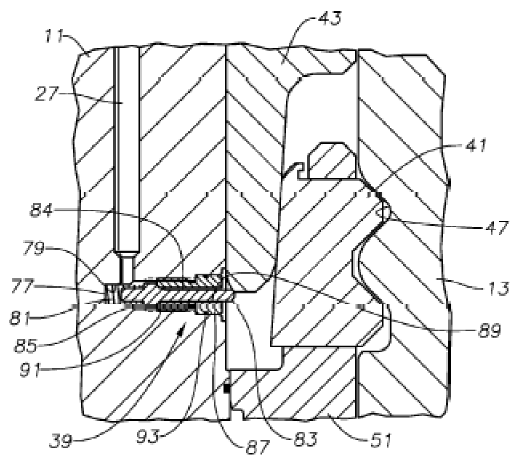


Figure 337: *Schematic illustration of the tubing hanger lock confirmation system, just prior to locking. [79]*

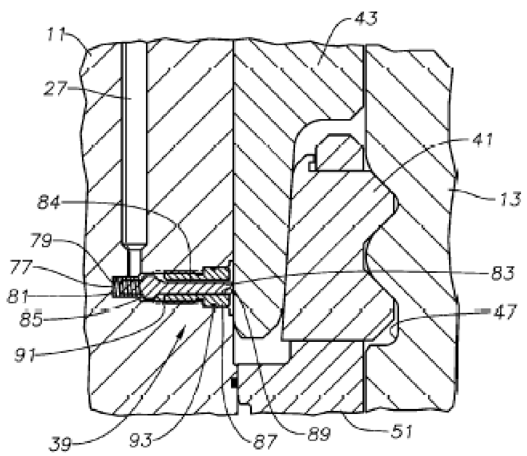


Figure 338: *Schematic illustration of the tubing hanger land confirmation system, just after locking. [79]*

Components mentioned in text above:

11: Tubing Hanger
13: Wellhead assembly
83: Locking indicator stem
43: Actuation sleeve
41: Locking dogs

Remaining labeling references can be found in the patent document.

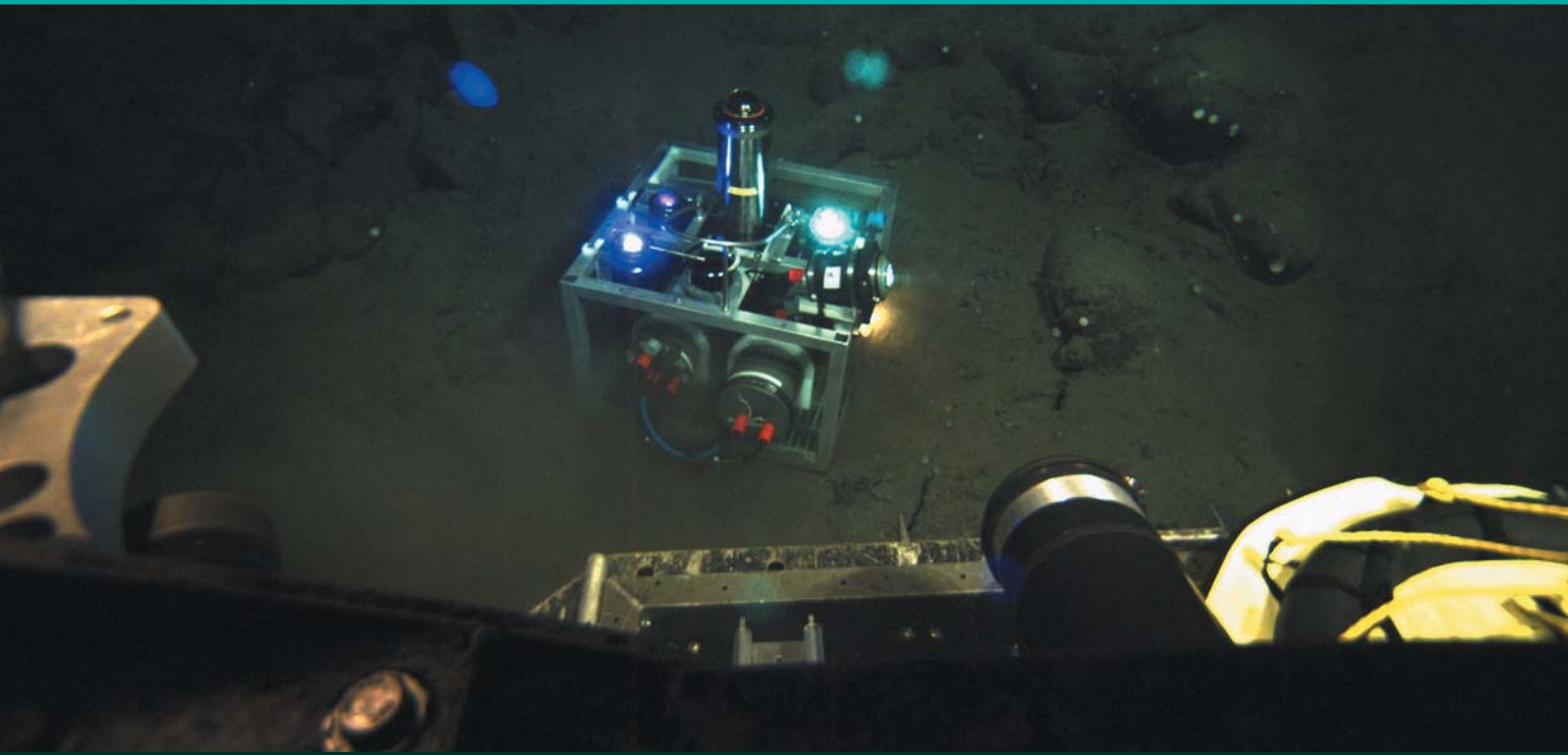
APPENDIX F

Product data sheets for wireless technology

Sonardyne
SOUND IN DEPTH

BLUECOMM™ – ADVANCE INFORMATION

WIRELESS OPTICAL COMMUNICATION SYSTEM



Transmission of full frame rate video from a battery powered seabed node containing optical transmitters, a receiver, camera and acoustic communications.

BlueComm is a short range, through-water wireless optical communication system that is capable of broadband speed data transmission.

Developed by principals at the Woods Hole Oceanographic Institution in the US over the last five years, BlueComm has been proven on oceanographic programs in deepwater where it has been used to transfer high bandwidth sensor data and real-time video imagery.

BlueComm is a unique, patented technology that is being commercialised by Sonardyne for a wide range of subsea applications.

BlueComm uses an array of high power light emitting diodes (LEDs) that are rapidly modulated to transmit data. The receivers use photomultiplier tubes that are so sensitive that they can detect light energy at the level of a few photons. This enables class leading data rate of up to 10-20 Mb per second at 100 metres and 1 Mb per second at 200 metres in deep water where turbidity is typically low. Optical data transmission is highly efficient, enabling 1Gb of data to be transmitted with the energy contained in a single Lithium D sized cell.

An integrated datalogger enables large amounts of data to be recorded locally. Integrated Sonardyne acoustic communications provides long range (>4 km), low bandwidth command and control. This therefore enables functions such as data recording to be turned 'on' and 'off' remotely from the surface, and health or QC information to be transmitted.

To recover the high bandwidth data recorded without costly recovery or physical intervention, an ROV or AUV can be used. Alternatively a 'dunking' system can be lowered from a vessel and the integrated acoustic positioning system used to navigate within 200 metres to command optical data upload.

BlueComm at a glance

- 1 to 20 Mbps through water coms over distance of up to 200 metres
- Applicable for low turbidity deep dark water (>350 metres) applications
- Highly energy efficient
- Integrated datalogger enables data to be recorded locally
- Integrated long range acoustic communications and positioning
- Data recovery via AUV, ROV or surface deployed dunking system
- Contact Sonardyne to discuss your application

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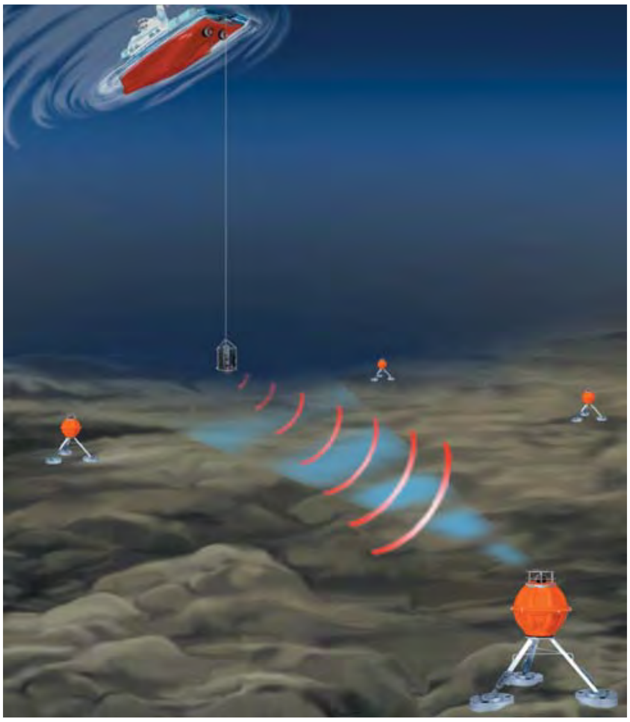
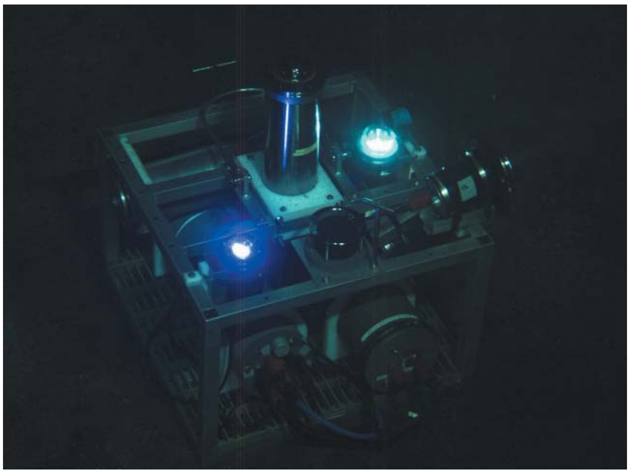




seatooth® S100

wireless datalogger

Product Specification:

Function	Wireless Modem, Wireless Datalogger, Wireless Controller
Operating Range/Environment:	
Range/Antenna	***Standard:*** Internal, 2.5m ***Optional:*** External stub: 3m—5m External Loop: 5m—10m
Depth Rating	***Standard:*** 350m ***Optional:*** 4000m
Operating Temperature	-10 to + 60°C
Storage Temperature	-20 to + 60°C
Interfaces:	
Storage	8MB of non-volatile memory
I/Os	2 x 4-20mA inputs / 2 x Digital outputs / 2 x Digital inputs / 2 x Relay Syncs
Data Interfaces	***Standard:*** 4-20mA, Digital, RS232, RS485 ***Optional:*** Ethernet Adaptor, WiFi, RS422
Data Rate	***Standard:*** 2.4 kbps ***Optional:*** 4.8 kbps
Power Supply	***Standard:*** 18-30V ***Optional:*** 6-30V
Power Consumption	Transmit: 7W Receive: 0.6W Sleep: 0.05W
Physical Characteristics:	
Dimensions	PCB Board size: 90mm x 45mm 350m enclosure: 192mm x 85mm 4000m enclosure: 180mm x 94mm
Additional features:	On board 3-axis accelerometer Addressable 99 unique IDs

100m—350m enclosure

191 mm x 85 mm

OEM version of S100

90 mm x 45 mm

External stub antenna

370 mm

4000m version of S100

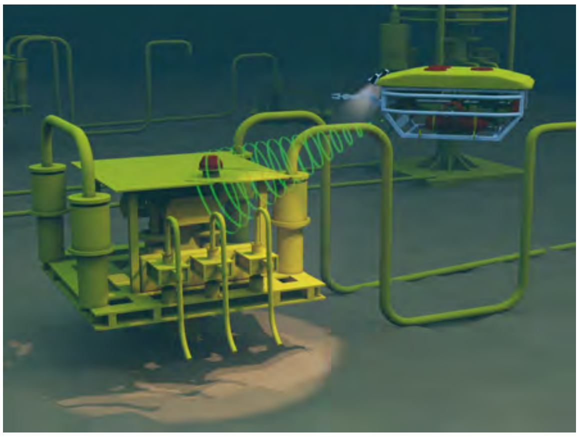
180 mm x 94 mm

OEM version of S100

78 mm x 53 mm

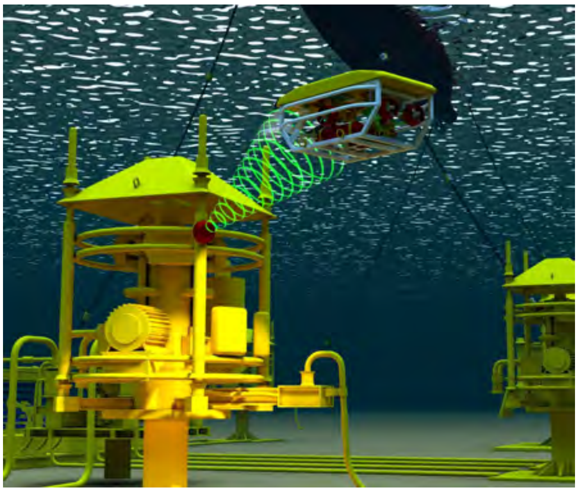
seatooth® S100

wireless datalogger



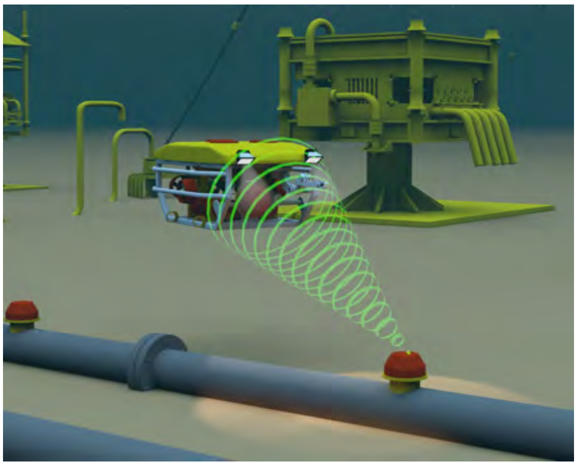
Safety: Subsea Black Box

- Black box functionality for offshore operations
- Logs up to 8MB of operational data
- Can integrate wirelessly with Subsea Control Modules
- Independent storage and data recovery
- Wireless data retrieval above the wellhead
- Allows data retrieval at safe distance



Improved efficiency: Subsea data logging

- Logging of multiple parameters such as pressure, flow, temperature etc.
- Ad-hoc data retrieval by ROV, no hardwire to surface, no physical retrieval of datalogger
- Cost effective compared to dedicated data retrieval mission



Integrity Management: Wireless Sensors

- Standard interfaces for wireless data communication with underwater vehicles
- Wireless harvest of data from subsea sensors
- Simple/flexible deployment of wireless subsea sensors
- More frequent and easier access to data — no wet mate connectors
- Reduced cost of intervention, surface support not required

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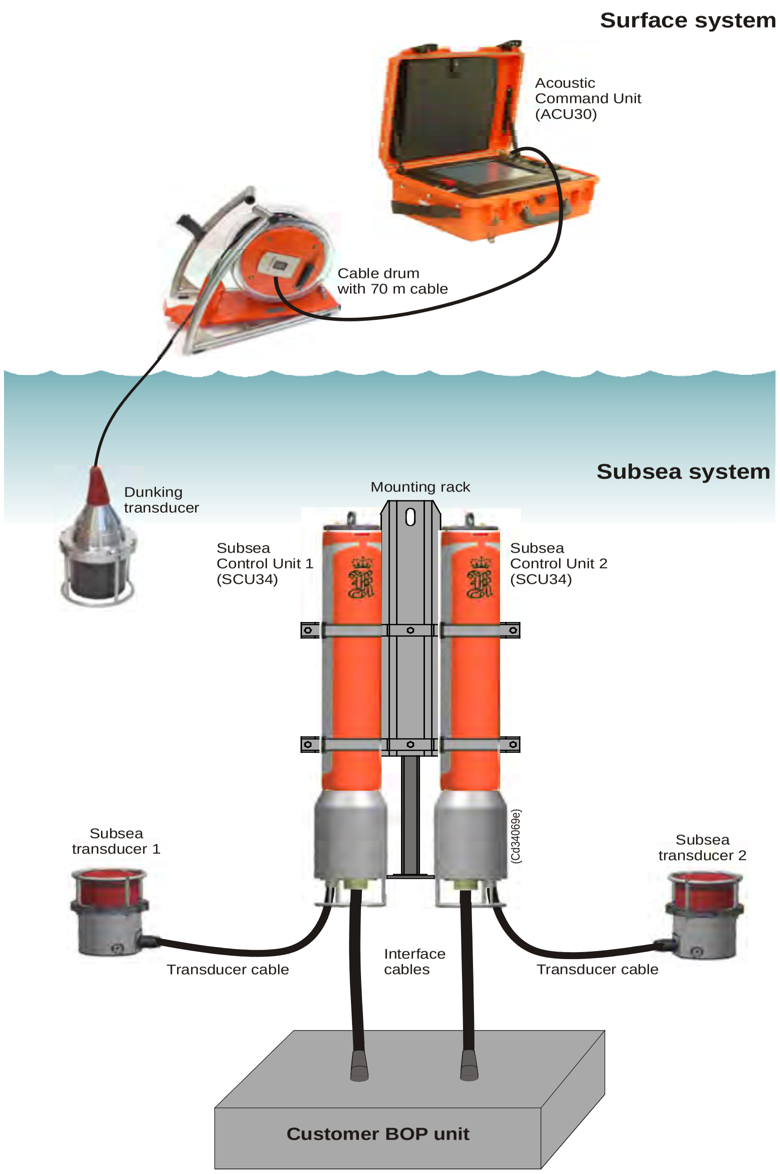
ACS500

KONGSBERG

Emergency Acoustic BOP Control System



Description

The ACS500 system is the new generation of the Kongsberg Martime Emergency Acoustic BOP Control System. It is developed to increase the operational depths and is rated to 4000 m depth.

The ACS500 system is divided into two systems:

- **Surface system (portable)**
- **Subsea system**

Additional equipment delivered with the ACS system:

- **BOP simulator with test cable**

Features

- ACU Internal rechargeable battery with more than 10 hours of operation
- A redundant subsea system with two complete sets of electronics with separate replaceable batteries (two SCUs), two communication transducers and interface cable providing 100% redundancy
- 4000 m depth rating
- The ACU is a splash-proof portable case with carrying handle and shoulder strap for easy handling

The surface system consists of:

- **One (1) Acoustic Command Unit (ACU) w/ charger cable**

The ACU is the main and certified HMI for the Acoustic Control System. The unit is a part of the safety equipment on board an oil rig, and a part of the safety procedure for the rig. It is delivered in a splash-proof portable case, with carrying handle and carrying strap. It has an internal rechargeable battery and a fully charged battery will provide more than 10 hours of operations.

It is operated via the PC display (touch screen / trackball). An alternative operator function is to activate the EME Emergency system available on the ACU. The EME system may perform a single automatic and predefined sequence of valve operations with a two-hand/ two-button operation, if it is defined by the customer.

- **One (1) Dunking Transducer Unit**

The dunking transducer unit is a cable drum with 70 m cable and a dunking transducer. The dunking transducer unit can be carried by one person.

The following dunking transducers are available:

- **TDD 301 MF**

- a transducer suitable for use in water depths down to 4000 m operations.

- **TDD 30V MF**

- this transducer is a further optimised dunking transducer with a 30 degree conical main lobe (operational covering area).

The subsea system consists of:

- **Two subsea control units** (SCU #1 and SCU #2) holding circuit board racks and battery.
- **Two (2) subsea communication transducers** with cables and water-proof titanium connectors.
- **Two (2) interface cables (one from each SCU) to the BOP.**

or:

- **Two (2) interface jumper cables (one from each SCU) to a junction box with one (1) inter face cable to the BOP.**

Subsea system - short description

The SCUs are mounted on the BOP and receives acoustic command signals from the ACU. It translates the signals into operational commands, then acts on those commands sending control signals to solenoids which in turn open or close hydraulic control valves on the BOP. Once the command signal has been given (by the operator), a confirmation signal is transmitted by the SCU to the ACU. The control system can also read the status of the SCU including various hydraulic control valves and sensor read backs.

The ACS500 SCU system is redundant which means that there are two complete sets of electronics with separate replaceable batteries (two SCU) each with one communication transducer to provide 100% redundancy.

Technical specifications

Surface system

ACU

Weight:............Approximately 19.5 kg
Degree of protection:....................IP54

Electronic details

Input voltage:...............100 to 240 Vac (47 to 63 Hz)
Operating voltage:...........10 to 18 Vdc

Environmental

Operation temperature:.....-5 to 55° C*
Storage temperature:......-30 to +70° C
* Operational specification for on deck testing purposes: - 20 to + 55° C. ACU 30 must be in standby/power ON mode before exposed to temperatures below – 5° C.

Battery

Number of batteries:..........................1
Cells per battery:...............................7
Type of cells:.......................Lead/Acid
Battery output:..........................14 Vdc
Transmission power (max):.......300 W
Continual use:......Approximately 10 hours

Dunking Transducer Unit

Length of cable:..........................70 m

Available transducers:

TDD 30V MF Dunking transducer

Beamwidth:.........(approx) 30° at -3dB
Operating frequency:..........21-31 kHz

TDD 301 MF Dunking transducer

Beamwidth:.........(approx) 30° at -3dB
Operating frequency:..........21-31 kHz

Subsea system

SCU

Operating depth (max):............4000 m
Material:................Super Duplex Steel

Electronic details

Operating voltage:............10 to18 Vdc
Operating temperature (electronics):... -5° to 55° C
Communication principle:..........Phase Shift Keying and Frequency Shift Keying
Operating frequencies PSK:....23600 - 27600 Hz
Wake-up codes, PSK:..........M53/M54
Operating frequencies FSK:....25000 - 26500 Hz in steps of 250 Hz
Wake-up frequencies FSK:.................
...............Channel 76: 24 and 23.5 kHz
............Channel 86: 24.5 and 23.5 kHz
Transmission power (max):.......300 W

Environmental

Operation temperature:..-5 to +55° C*
Storage temperature:......-40 to +70° C
* Operational specification for on deck testing purposes: - 20 to + 55° C. ACU 30 must be in standby/power ON mode before exposed to temperatures below – 5° C.

Battery

Weight:.....................................5.9 kg
Number of batteries:..........................1
Cells per battery:.............................48
Type of cells:..........Non-rechargeable, lithium
Battery outputs:.............14 Vdc, single voltage
Total battery energy content (14 V):....
....156 Ah
Battery life, in operation:
.......................Calculations on request

Mounting bracket

The mounting bracket is manufactured of AISI 316L stainless steel.
Weight:.......................................22 kg
Mounting holes:........Compatible with ACS 400

TDR 30V MF subsea transducer

Material:................Super Duplex Steel
Beamwidth:.........(approx) 30° at -3dB
Operating frequency:...........21-31kHz
Weight in air/water (including cable):.
....20 kg/17 kg

SCU Junction box

Weight:.....................................8.6 kg
Material:
- unit:...........................Bronze
- connectors:.......Titan / Bronze

315453 / Rev.A / June 2010

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KONGSBERG

APPENDIX G

Product Data Sheet
for Smart Torque Tool System

Smart Torque Tool System

Oceaneering's Smart Torque Tool System incorporates a Remote Control Unit (RCU) with the features of the standard Torque Tool. The addition of the RCU gives the tool expanded capabilities and flexibility. Specifically, real-time torque feedback and direct control over output torque. These values are monitored and are adjustable via the surface control unit.

The RCU consists of two main parts: the manifold unit, and the topside control unit. The Remotely Operated Vehicle (ROV) has the ability to control all hydraulic functions on the torque tool and provide real-time torque feedback and control for the torque tool. It is designed to interface with the standard work class ROV, using the ROV's umbilical for data communication.

Using a computer as the topside controller, the ROV provides necessary power and control signals to operate the subsea manifold. The manifold proportionally adjusts pressure and flow to meet the requirements of the subsea tooling. Any sensor feedback is entered into the manifold and transmitted to the surface for display or data logging.

The Smart Torque Tool is supplied with an Intelligent Test Jig. Using the Jig, the tool can be calibrated for torque output while subsea. The jig can also change out end effectors on the torque tool while subsea, thus eliminating trips back to the surface to switch out end-effectors for various subsea valves.

Main Components

- Remote Control Unit (RCU)
- Manifold Unit
- Topside Control Unit
- Standard Torque Tool
- Intelligent Test Jig

OCEANEERING®

Oceaneering International, Inc. | Deepwater Technical Solutions (DTS) | 11915 FM 529 | Houston, TX 77041
phone: 832.467.7600 | email: tpool@oceaneering.com | www.oceaneering.com

Smart Torque Tool System Specifications

Dimensions (overall) -Torque Tool

Length	23 in
Width	12.5 in
Height	12 5/8 in
Weight in Air	86 lb
Weight in Water	66 lb

Performance Data -Torque Tool

Output torque	25 -2,000 ft-lb t. 5%
Input pressure	0-3,000 psi (max)
Rotation	Reversible Bi-Directional
Fluid	Petroleum based hydraulic Fluid
Turns counter	Digital Battery Operated
Latches Hydraulic	(1,500 psi max operating pressure)

Materials -Torque Tool

- Aluminum 6061-T6
- Stainless steel
- Nickel-Aluminum-Bronze
- Carbon Steel
- Titanium

Sub-Sea manifold Unit Dimensions (overall)

Length	12 in
Width	9 in (excluding fittings)
Height	6 in
Weight in Air	65 lb
Weight in Water	38 lb

Performance Data - RCU

Depth Rating	10,000 ft.
Temperature Range	0° to 70°
Power Consumption	7 Amps at 24 V DC
Communications	RS232
Hydraulic Working Pressure	3,000 psi max
Hydraulic Flow	5 gpm max
Hydraulic Requirement	3,000 psi at 5 gpm

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APPENDIX H

Minutte of Meeting and e-mails

H.1. Minuttes of Meeting, Phone Meeting with Ole Kristian Holmen

Type of meeting: Phone meeting

Attending: Ole Kristian Holmen and Maren Charlotte Gregersen
Date: 26th March 2013
Time: 16:00-17:30

Agenda: Get more information about the installation procedures used offshore, and possible hazards causing installation failure.

Short about Ole Kristian Holmen:
He is positioned at Stavanger in Norway, and work with installation of Tubing Hanger (TH) offshore. He has written general installation procedures for TH, and he has experience from these subsea projects: Kristin, Dahl, Goliat and Norvind.

Documents received and used during meeting: "Tubing Hanger Installation procedure", and "Best Practice TH and TH guide handling Operations Kristin Templates"

We went through the procedure while Ole Kristian commented the most important parts of the procedure related to verification of TH installation.

- Section 3.2.1 and forward is the part of procedure most relevant for me
- 3.3.1-3.3.7 describes steps shown in "Best Practice TH and TH guide handling Operations Kristin Templates"
- Procedure 2.2
- For 3.4.1 7) Morvin and Kristin, THR; TH release line. An own line on XT suited of release pkt. 6)
- Flow meter:
  - Supplier Flow Meter
  - Return Flow Meter
  - Positioned in container, flow meter on supply lines
  - Accuracy of ± 0.5 Litre.
  - Umbilical goes up in tower on rig and down again, much lower point/lockation, thus oil flows down into the hydraulic box, and one "loses" some hydraulic fluid. Thus the reading might be lower than the one given/stated in the procedure.
    - Return close the obtainable 10.3, and supply 7.5 L, no need to react. If supply 5 L, one should react.
    - 1-2 dl doesn't matter

Div. information:

- One cannot work with an accuracy of mm from a vessel, the nearest one gets is a certainty of ± a few cm. about 1-2cm, since the weather is still when installing TH.
  - From a platform one can get higher accuracy since the platform in fixed to the ground/seabed
  - For a vessel one accounts for tide level models in order to get a good accuracy, but there will always be some inaccuracy due to the fact that. This leads to an accuracy of a few cm.
- TH is placed 45°-90° degree out of rotational position, by installation start
  - First the installation system with TH, THRT and string will rotate some degrees clockwise while running the system subsea. This is probably due to the system characteristics, and the rotation will depend upon the system`s construction. (The sling travels a long way subsea, and has a tendency of rotating clockwise)
  - The last rotation happens while running TH into spool. Then the helix shape meet the guiding in the spool.
- The most accurate installation procedures are the one for Norvind, which is based upon installation procedures for Kristin. Project Dahl also has good TH installation procedures.
- For installation of TH a downward pressure force is applied in work shop in order to make sure that the TH gets into right vertical position the XT. This is not necessary for offshore installation, since the production tubing weights a lot, and will apply the necessary downward force.
- It is important to keep in mind that the umbilical can get twisted and squeezed. In addition it is exposed to retempering (The addition of water and remixing of concrete which has started to stiffen: usually not allowed as it may affect the ultimate strength, http://www.moxie-intl.com/glossaryRS.htm). This cause stretch and tension strain onto the umbilical. Thus it must be very robust.
- Feed Through system can be connected to control pad on XT.
- A Hot line is an umbilical which consist of one line that is moved from place to place.
- 120-200 ton tubing is attached to the THRT

- Ole Kristian has not experienced that failure of TH installation. In some cases one have had to try to run the TH the last part into the XT over again, but succeeded in the end, without having to retrieve any of the installation system to topside. The hazard he has experienced has mainly been system leakage for THRT, but it has been solved by applying extra pressure until full latch or lock is obtained. The cause of this can be seal errors.
- Another system weakness he mentioned was the tendency to "copy-paste" from earlier subsea projects, which might lead to wrong installation step procedures being given to a specific project. The cause of this hazard in that Aker Solutions in in a huge growth period with lots of new employees and a huge time pressure.
- Experience is important!!!
- The installations process mainly goes wrong in cases where the Aker Solutions procedure has been modified by another company, responsible for the offshore installation, or in cases where there are few experienced offshore workers. If one is not experienced, and try to follow the TH installation procedure to every detail, something will eventually go wrong. The reason for this is mainly that one will never get the exact hydraulic readings stated in the procedure, as there always will be some system related weaknesses/errors causing an uncertainty of a few dl. There can be air in the system, and there are height differences related to the hydraulic readings.
- The best TH installation procedures are the once form Kristin project and Morvin project.
- Some modifications were done to the C-plate design, causing huge installation disadvantages and HSE issues for the offshore workers. The amended design caused the TH was position so high up on the rig, that the offshore operators did to reach up in order to guide the THRT into right position above the TH. Thus they had to do this part of the procedure in a much more dangerous way by hanging in a sling….!

Verification methods:

- A laser is used to measure vertical distance. This is started when the TH is in a position directly above the Blow Out Preventer (BOP). Then the last string tubing is attached on topside, and one measure how far this tubing travels down (e.g. about 15m) while running TH through BOP and down into XT.
- A chalk crayon and yard stick is used to verify the last part of the TH installation, when the TH helix is guided into right position. First one observe that the string on topside rotate, before one makes a mark on the pipe to register if the TH travels the right vertical distance after rotation. If installed correctly there should be a translation of about 150mm after the rotation.

Recommendations:

- Visit Aker Solutions at Ågotnes, to get a better impression of offshore procedures.
- Invite employees from the operations department to a concept review as early as possible during the design process
- Ole Kristion world like to attend the meeting. In addition are Nils Nagvik (Østlandet), Knut Gravdal (Østlandet), Kim Blomqvist (Vestlandet) and Steinar Kjelgård people with valuable offshore experience.
- These employees need to be invited to the meeting through the service department at Ågotnes.
- Get access to a picture folder, containing pictures from offshore vessel for project Goliat
- The folder contains pictures from 2005-2010
- Exclude the use of umbilical subsea by designing a new locking mechanism. Instead of applying hydraulic pressure through the THRT, one can apply external pressure instead, that can make the TRT lock TH into XT.
- This will involve a lot of product development for THRT, and will be a solution for the future, but can be good to add as a possible design improvement for THRT and TH installation procedures.
- Some similar solution exists for ITC Multi Service Tool for project Kristin. Inside Drill Pipe, BOP without umbilical connection.
- Single Trip Multi Service Tools is also a good example

What to do next:

- Find out how to invite employees to a meeting through the service department at Ågotnes.
- Ask Magnus F. Urke for help.
- Ask for access to a shared network area for Goliat project (AKS103129 GOLIAT SPS Project), where Ole Kristian has saved a lot of relevant pictures form offshore installations that I can have a look at.
- Relevant folder location: Shared -> VP11SIT -> Supervisor info 14

H.2. Minuttes of Meeting, Quality Assurance Meeting

Time: 9. April, 12:30 – 15:00

Attending: Magus F. Urke, Per-Olaf Queseth, Lars Lundheim, Vinayak Kulkarni, Viktor Grennberg, Harald Martin Aarbogh and Maren C. Gregersen

Agenda: Go through and quality assure HAZID and Basis of design.

H.2.1. HAZID

No major changes to the HAZID, but some good discussions around earlier incidents.
In addition I was informed that there is a final version of GOLIAT TH installation procedure, which is much more up to date, compared to the one I studied earlier.

H.2.2. Basis of Design

Revision of "Ranking of key product requirements" table.

Function:
"Position of TH relative to XT spool before lock." Requirement changed from "should" to "must"

Add

- Position of TH relative to XT spool after lock.

  Reason: The position of TH can change during lock down as the split lock ring is partially guided into the grooves in XT spool. Thus the position of TH must also be checked after lock down.

Add

- Verify when split lock ring is retracted.

  Reason:
  This is not central for the lock down of TH, but when TH is to be retrieved for e.g. maintenance, this is crucial verification information. Thus the verification system should be able to confirm when TH is unlocked from the XT spool.

Add

- Provide continuous verification of TH`s position and locking until TH installation and pressure testing is complete.

  Reason:
  If verification system is able to confirmed that TH is locked properly to XT spool and that it is in correct vertical position, until pressure testing is complete, system safety is increased. It has happened earlier that system leakage has caused components to unlock during pressure test procedures. Continous position and lock verification for TH will give the possibility of alerting the operator, if TH unlock by fault.

Div.:

Know that lock ring is fully engaged when locking sleeves are in lock position.

If one check position of TH before lock, one know that lock ring engage into right position.

Crucial information is position of lock ring before lock and if lock ring is fully engaged. This is covered by:
"Position of TH relative to XT spool before lock." and "When locking sleeves are in lock position"

Economics
Modify the requirement; "Costs related to implementation of verification system to the product design are not to be too high" and add cost/benefit aspect and cost/risk aspect

Technical
Remove DNV requirement as it is aimed at control systems:
- DNV-RP-O401, 9.2.3.1., "As far as practicable the design of control systems should be such that no significant reduction in the safety level exists during maintenance and repair of the control systems."

Durability & serviceability
Change priority from should to must:
- "Possibility of replacing wear parts in the verification system."

Chang from:
- "Life span according to required life span of component(s) which the verification system is implemented in"

To:
- "Life span according to required life span of component(s) which the verification system is implemented in, for permanent installations."

Change from:
- "Easy maintenance of verification system"

To:
- "System is to be maintainable"
  Reason: difficult to define "easy"

Remove:
- "Corrosion resistant verification system"
- "Bear temp interval of -25°C to + 70°C"

Add
- Meet same temperature requirements as mating and surrounding components.
- For verification system inserted in tool, the system should not require more frequent maintenance of tool, but adjust to the tool`s refurbishment cycle.

Presicion
Comments:
- Rotational position verification is not necessary to include in new lock down verification system as the helix shape in spool and key on TH has a tolerance of ± 0,45°, while the HP needs a tolerance of ± 1°. Thus it is precise enough from before.
- First of I included these precision requirements:
  - Alignment: All equipment assemblies should be balanced within 1°.
  - Vertical alignment of TH with precision of ±1.5 mm (after lock down)
  - Concentric alignment of TH and spool with precision of ±1mm
  - Rotational alignment of TH and HP with precision of 1°.

As mentioned above the rotational alignment is secured by helix shape in XT spool. The concentric alignment is also covered by the XT spool. The requirement of assemblies being balanced with 1° is covered by installation of wellhead and XT. Thus only precision requirement the lock down verification system needs to cover is the vertical alignment of TH inside XT spool.

Remove:
- Alignment: All equipment assemblies should be balanced within 1°.
- Concentric alignment of TH and spool with precision of ±1mm
- Rotational alignment of TH and HP with precision of 1°.

Add:
- Vertical alignment of TH with precision of ± ? mm before lock down

H.2.3. General

Important notes
- Helix shape is not an alternative name for TH rotation key, but the part of the spool that TH rotation key slides into.

What to do next:
- Find out how precise position of TH has to be before lock down.
  - Lock ring will align into groove, even though it is slightly misaligned as one start to run locking sleeves.
  - This vertical position precision for TH will be different from required precision after lock down.
- Have a look at the final version of GOLIAT TH installation procedure.
  - Make some changes to table: "Overview of today's verification methods for TH installation", to be according to this procedure.

H.3. Communication with SEACON by e-mail

From: Maren.Gregersen@akersolutions.com [mailto:Maren.Gregersen@akersolutions.com]

Sent: Thursday, May 09, 2013

To: Martin Biehle

Subject: RE: Product specifications for switch products

Hi Martin,

I have not considered the options for using control line with a junction or splice box yet. The system design is quite general at this point, because producer of the wireless communication system, WFS, will not be able to give any technical design details before they have had the opportunity to model and test the system.

As mentioned earlier, the product development work I am carrying out now is my Master thesis project. My supervisor at Aker Solution, Magnus F. Urke will evaluate the work I have done and decide what is to be done next. He will probably need some time after I have handed in my work, in order to find out what will be the next step for the product development process.

Your contact information will be included in my report, so anyone who proceed with the project, will know who to contact.

If you would like to get in contact with Magnus F. Urke, this is his e-mail: Magnus.Fjortoft.Urke@akersolutions.com

I appreciate the help you have provided for my project. I am now finishing of the first part of the product development work, and am going to hand in my report 15.mai.

Thanks and best regards,

Maren Charlotte Gregersen

From: Martin Biehle [mailto:martin.biehle@SEACON-AP.COM]

Sent: 9. mai 2013

To: Gregersen, Maren

Cc: Scot Welch; Steffanie Yeates; Boyd Murphy

Subject: RE: Product specifications for switch products

Hi Maren,

The size restrictions appear to be reasonable. The 15K pressure and 20 year service will require additional research and design.

Would a control line with a junction or splice box be available to the switch to eliminate the need for a connector and rubber molding?

The drawings I sent were only standard products. The shape and size are reasonably flexible when using a Hall Effect Sensor. It appears the greatest challenge will be connecting the switch to the surface. You mentioned wireless for sensing the switch signal, how would power be supplied to the switch?

I believe the request is doable, but will require considerable development.

Thanks,

Martin

From: Maren.Gregersen@akersolutions.com [mailto:Maren.Gregersen@akersolutions.com]

Sent: Friday, May 03, 2013 5:04 PM

To: Martin Biehle

Subject: RE: Product specifications for switch products

Hi,

I do not know exact size restraints, but the Hall effect switch models you sent drawing of have about the same length as the wall is thick (3.9”). Thus I think side sensing will be necessary for that specific concept. I think magnet can have a height/thickness of up to about 0,9” for that concept.

If that is not possible, I have an alternative concept where wall thickness is about 8”. Then side sensing will probably not be necessary.

For that concept, magnet can maximum have a height/thickness of about 0,56”.

Required position accuracy is either 10 mm (0,39”), 5 mm (0,197”) or 1.5 mm (0,059”), it depends on what type of verification switch is to provide (landing verification or lock verification.)

The verification is not to be repeated many times. For the concept I described earlier, the sensor sits in a component that can be installed subsea for about 20 years. Some maintenance work might be carried out during this period, but only rarely.

For other concepts I have been evaluating, it might be possible to install switch in a tool, that is only used during installation of a product component, before being retrieved again. In that case, switch system will be available for maintenance quite frequently, but there is limited with space in the tool for switch component (and communication technology). Length of about 3” and diameter/thickness of about 1,5”.

I hope that it is not too confusing with the variety of information I have given above. As I am at a concept stage there are numerous of alternative solutions. I have attached some pages from my report, with description of alternative positioning of switch and magnet.

Best regards,

Maren Charlotte Gregersen

Note: The attachment I sent is the description of positioning alternatives P1, P4, P5, P6, P7, P8, P9, P10 and P11. The descriptions can be found on page 149-157 in this report.

From: Martin Biehle [mailto:martin.biehle@SEACON-AP.COM]

Sent: 3. mai 2013 18:59

To: Gregersen, Maren

Cc: Scot Welch; Steffanie Yeates; Boyd Murphy

Subject: RE: Product specifications for switch products

Hi Maren,

Ideally a Hall effect switch would be best for this application, but the actuation distance is at the outer limits, which is affected by magnet size and strength.

What are the size restraints for the switch and magnets?

It would be possible to develop one switch with 2 sensors, which would allow detection of 2 different poled magnets. Everything is really subject to size, temperature, pressure and cable requirements.

One or two switches are feasible options. What is the accuracy or repeatability required? The greater the distance, the less accurate or less sensitive the switch will be.

Is this application for long term? What is the expected service life?

In general, it would be 10-12 for design and development, if the 15,000 psi is required additional development is necessary. Then allow 16-18 for development.

Production for max 10,000 psi ,12-16 weeks after approval of design, for 15,000 psi 20-24 weeks.

This is ROM only.

Please provide any additional information available and advise if a ROM quote is desired.

I have attached 2 standard products for reference.

Best Regards,

Martin

From: Maren.Gregersen@akersolutions.com [mailto:Maren.Gregersen@akersolutions.com]

Sent: Friday, May 03, 2013 10:31 AM

To: Martin Biehle

Subject: RE: Product specifications for switch products

Hi Martin,

In the last e-mail I got, you asked about the expected distance between magnet and switch in the activated position.

I have not been able to give you an answer to that before now, because the concept solutions I had earlier had to be amended, due to the fact that switch cannot detect magnet through a wall of ferrous material.

The new solution is to combine your switch technology with a wireless communication system.

The verification system is to confirm landing and lock of Tubing Hanger.

I have developed different concepts for different alternative locations of switch and magnet. Most of the concepts provide either landing or lock verification, but one provide both. If your switch technology is suited for it, the concept solution that can provide both landing and lock verification, is probably the strongest one.

In the attached document I have set up two alternative solutions (for the concept that provide both land and lock verification).

1. One magnet and two switches

2. Two magnets and one switch.

The expected distance between magnet and switch in the activated position is 0.43" (11 mm). Movement of component (activation sleeve) that is to be detected by switch first lands and then move a distance of 2.56" (65 mm) during lock down of Tubing Hanger.

Which solution do you think is the best?

The verification concepts I am developing is part of a master thesis project that I carry out for Aker Solutions, and your switch technology combined with wireless communication system from WFS, will be presented as the final concept solution.

As my project is the first step in the product development process of a new verification system, I will hand over a report where all my work is presented, so that employees at Aker Solution can decide what to do next.

The report should include an estimate of costs related to the new verification system.

Earlier you mentioned that "Currently 10,000 PSI is the maximum pressure rating, but if higher pressures are required we can design to meet your requirements."

Can you give an indication of price and time period that will be linked to development of switch with pressure rating of 15,000 PSI?

If something is unclear or if you need additional information about the concept solutions, don`t hesitate to ask.

Best regards,

Maren Charlotte Gregersen

From: Martin Biehle

Sent: Thursday, April 25, 2013 9:07 AM

To: 'Maren.Gregersen@akersolutions.com'

Cc: Scot Welch

Subject: RE: Product specifications for switch products

Hi Maren,

Thank you for your reply, please see "red" comments below in your email request.

What is the expected distance between magnet and switch in the activated position?

1) Which proximity switch type will be best suited for the two different cases?

(It can be an option to use latching hall effect for case 1, in order to detect when a component is in start and end position.)

All the proximity switches will work for both applications, but any actuation distance greater than .5" will require a reed sensor switch.

A Latching switch requires both North and South magnets. Latching switch will maintain the signal until the other pole is applied. Two sensors may be better than a latching sensor or the ratiometric (Sourcing) which require a north and south magnet for high or low signal, with mid range signal with no voltage applied.

2) What types of magnets do you deliver with your proximity switches? (typical size/strength)

Magnets are selected by application, desired actuation distance and type of switch. For micro switch and hall Effect proximity standard is .5" X.2" 18 SMCO or .75" X.38" 18 SMCO. These are available as bare magnets or with magnet holders. Magnets are supplied separately based on application requirements.

3) Can proximity switch detect magnet through a wall of ferrous material? If so, how thick can a wall of steel be?

In general, No. It may be possible with a very strong magnet, but would be unreliable in actuation distance.

4) Will the system be less accurate when surrounded by ferrous material?

Ferrous metals will affect the accuracy and actuation distance.

5) If possible, is it an advantage to position magnet in non-ferrous material?

Mounting in non-ferrous is best or at minimum allow a space around the magnet.

6) Do you have side sensing switches?

The Reed Sensing switches will sense from the side, but the attached A193-104-X was not designed for side sensing, but any of the switches will work with slide-by, option 1.

From: Martin Biehle [mailto:martin.biehle@SEACON-AP.COM]

Sent: 16. april 2013 16:51

To: Gregersen, Maren

Cc: Sergio Mendez; Scot Welch

Subject: RE: Product specifications for switch products

Hi Maren,

Thank you for your inquiry, I will try to answer your questions on Seacon Switches.

1) What are typical sizes of limit switch models and proximity switch models? (Length + diameter)

Most common is ¾-16 thread, approximately 2" length. Available in bulkhead, molded cable, and modular with connectors. See attached drawing for details.

2) What are the sensing ranges (e.g. min and max) and precisions of the switches (e.g. switch hysteresis; distance between on / off)?

Proximity actuation distance varies by magnet used, minimum .1" to .5" Reed sensor proximity sensors have greater actuation distance.

Limit switch have a maximum travel of .38"

Actuation points are repeatable .020-.050"

Hysteresis is .05-.10" maximum

Maximum current 7 amps for micro switch sensors

Proximity sensors are available with micro switch, reed sensors, and Hall Effect.

3) What is the required maintenance? (what kind of maintenance and how often)

Proximity switches require no routine maintenance.

Limit switches normally do not require routine maintenance, but routine inspection and cleaning if used in severe environments would be beneficial.

4) What are the costs? (Only an indication, and no exact numbers, if possible to evaluate this early.)

Prices vary on product selected and quantities purchased, rough estimates is $800-$1500 for our most common products.

Currently 10,000 PSI is the maximum pressure rating, but if higher pressures are required we can design to meet your requirements.

I have attached a few of the switches for you to consider. If you can provide details of the application and desired installation, I would be glad to assist in the selection or design of your switches.

Custom applications are our specialty.

Feel free to contact me with any questions.

Yours Sincerely,

Martin Biehle

From: Sergio Mendez [mailto:smendez@seaconworldwide.com]

Sent: Tuesday, April 16, 2013 7:36 AM

To: Martin Biehle

Subject: FW: Product specifications for switch products

Hi, Martin,

Can you help with these questions below please?

Regards,

Sergio Méndez

From: Maren.Gregersen@akersolutions.com [mailto:Maren.Gregersen@akersolutions.com]

Sent: Tuesday, April 16, 2013 7:10 AM

To: Sergio Mendez

Subject: Product specifications for switch products

Hi,

Per-Olaf Queseth from Aker Solutions suggested that I should contact you, since I need some product information.

I am developing a verification system for installation of subsea products, and need some information that I could not find in the product data sheets.

The relevant product types are: Limit switches, proximity switches and proximity micro switch.

The product information I need for each of these three products is:

5) What are typical sizes of limit switch models and proximity switch models? (Length + diameter)

6) What are the sensing ranges (e.g. min and max) and precisions of the switches (e.g. switch hysteresis; distance between on / off)?

7) What is the required maintenance? (what kind of maintenance and how often)

8) What are the costs? (Only an indication, and no exact numbers, if possible to evaluate this early.)

In addition I have a general question for all of your switch models: Is the highest pressure rating for your products 10,000 psi or are you able to offer some switch products with pressure rating of 15,000 psi?

Best regards,

Maren Charlotte Gregersen

H.4. Communication with WFS by e-mail

From: Maren.Gregersen@akersolutions.com [mailto:Maren.Gregersen@akersolutions.com]

Sent: 08 May 2013

To: Brendan Hyland

Subject: RE: Wireless communication system

Hi Brendan,

I cannot decide if a modelling phase is to be started.

Therefore I will use the information you have already provided in order to describe the final concept solution in the product development report.

Magnus F. Urke will evaluate the work I have done and decide what is to be done next.

Thus when it comes to the modelling work, you have to contact Magnus F. Urke, but he will probably need some time after I have handed in my work, in order to find out what will be the next step for the product development process.

Your contact information will off course be included in my report, so anyone who proceed with the project, will know who to contact.

I appreciate the help you have provided for my project. I am now finishing of the first part of the product development phase, and am going to handing in my report 15.mai.

Maybe we`ll cooperate in this or another project after I start in a permanent position at Aker Solutions in August!

Best regards,

Maren Charlotte Gregersen

From: Brendan Hyland [mailto:Brendan.Hyland@wfs-tech.com]

Sent: 8. mai 2013 12:16

To: Gregersen, Maren

Subject: RE: Wireless communication system

Maren, these are good questions but we are unable to provide further reliable data without modelling the problem. The results of the model are used to design the system.

Would you like us to go ahead with the modelling phase?

Kind regards

Brendan

From: Maren.Gregersen@akersolutions.com [mailto:Maren.
Gregersen@akersolutions.com]

Sent: 06 May 2013 02:51

To: Brendan Hyland

Subject: RE: Wireless communication system

Hi Brendan,

I have a couple of additional questions.

1) Is power supply/battery included on the electronics component, and will power supply attached to electronics component also be able to provide electric power for the switch?

2) How long can battery last?

3) I have attached a simple drawing of how components can be integrated and linked to each other. After what I can understand, external antenna will require direct electrical line linked to electronics component, as illustrated in the drawing?

4) When it comes to the integration of wireless communication components, have you evaluated any different solution compared to that in the drawing, or is that the most natural way to set up the verification system?

Best regards,

Maren Charlotte Gregersen

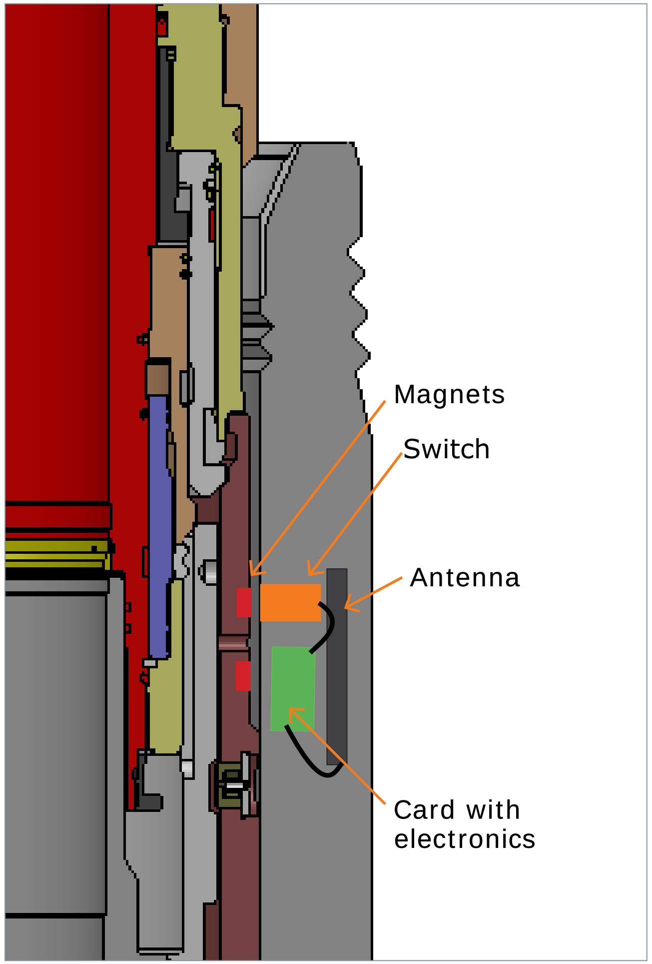


Figure 339: Suggestion to *verification system setup. [5]*

From: Brendan Hyland [mailto:Brendan.Hyland@wfs-tech.com]

Sent: 6. mai 2013 12:16

To: Gregersen, Maren

Subject: RE: Wireless communication system

Hi Maren, our goal is to build a custom device of dimensions similar to the unit below. We will connect to an external antenna and to the switch. The electronics will be housed in a compact enclosure such as oil-filled enclosure. The electronics components include ICs, capacitors, resistors etc. these will need to be selected to match the requirements for oil-filled.

If you have any further questions, do not hesitate to call or email.

Kind regards

Brendan

(OEM = Original Equipment Manufacture.)

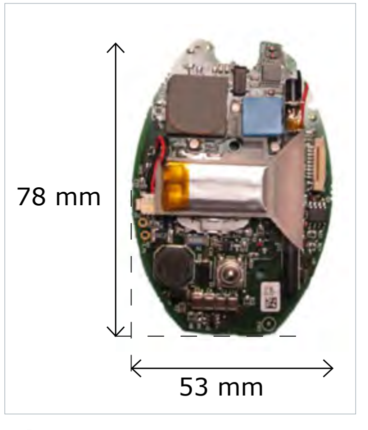


Figure 340: *Card with electronics. [51]*

From: Maren.Gregersen@akersolutions.com [mailto:Maren.Gregersen@akersolutions.com]

Sent: 06 May 2013 02:51

To: Brendan Hyland

Subject: RE: Wireless communication system

Hi Brendan,

I do not need precise size information for the components, but I need to know what type of components that have to be connected to the switch. You sent me a product data sheet earlier (S100), and on the last page there are some pictures of 5 product components, but it is not clear to me how they should be linked to each other.

Can you please answer these questions:

- What type of components will be connected to the switch? (what type of power supply/battery, instrumentation to receive and send information, antenna… any other components?)
- What is the function of the enclosure?
- What does OEM stand for?
- Do the 5 components form a complete communication system, or are they just random product components that can be part of a wireless communication system?
- Which technical components do the PCB (printed circuit boards) contain, in addition to RF chip and IC (integrated circuit)?

The person you should contact is Magnus F. Urke, Magnus.Fjortoft.Urke@akersolutions.com

He is the supervisor for my Master thesis project.

Best regards,

Maren Charlotte Gregersen

From: Brendan Hyland [mailto:Brendan.Hyland@wfs-tech.com]

Sent: 30. april 2013 15:01

To: Gregersen, Maren

Cc: Queseth, Per-Olaf

Subject: RE: Wireless communication system

Hi Maren,

It is difficult to give a precise size form the components until we have completed an analysis of the required link budget. But the transmit circuit will be compact and the antenna can be integrated tightly with the structure. To this end I am confident we will be able to find a practical solution.

Who is the point of contact to take this project forward?

Kind regards

Brendan

From: Maren.Gregersen@akersolutions.com [mailto:Maren.Gregersen@akersolutions.com]

Sent: 27 April 2013 11:58

To: Brendan Hyland

Subject: RE: Wireless communication system

Hi Brendan,

If one choose to go for the 1st option, are you able to give an indication for size of components that will have to be positioned by the proximity switch?

The verification system development project I work on is a task I got from Aker Solutions for my Master Thesis.

All the information you sent in the last e-mail will be included in my report with the two wireless system options and approx. of cost and timescale. It is then up to employees at Aker Solutions to decide what will be done next.

I have been evaluating many different verification system concepts, but proximity switches (from SEA CON) combined with your wireless technology will be presented as the strongest concept, and I will recommend in the report that the concept should be further developed and tested.

Best regards,

Maren Charlotte Gregersen

From: Brendan Hyland [mailto:Brendan.Hyland@wfs-tech.com]

Sent: 26. april 2013 12:32

To: Gregersen, Maren

Cc: Queseth, Per-Olaf

Subject: RE: Wireless communication system

Hi Maren,

Thanks for the attached. Assuming you're seeking a wireless link to the sensor, we see 2 options:

1. Wireless communications through the metal wall

We'll need to know the thickness of the metal and the metal type then prepare a model to determine a system configuration that provides a reliable link.

Pros

- Simple solution
- Off-the-shelf modelling tools to determine critical design parameters
- Off-the shelf products that support through-pipe-wall communications that could be customised to deliver a proof-of-concept

Cons

- Technical challenge to design a system to meet the size and power constraints of the target location

Next steps

- Build model and run simulations to determine critical design parameters
- Build and test proof-of-concept system based on Seatooth S200 platform operating at <300Hz

Cost & timescales

- Modelling: approx. £15k; 4 weeks
- Proof-of-concept: approx. £30k; 6 weeks

2. Wireless communications along the pipe

We could use a relatively low power transmitter to use the pipe as a propagating medium and transmit the signal to a convenient location several metres away where a second transceiver can pick up the signal.

Pros

- Lower power solution than (1)
- Greater bandwidth than (1)
- Off-the-shelf modelling tools to determine critical design parameters
- Off-the shelf products that support through-pipe-wall communications that could be customised to deliver a proof-of-concept

Cons

- Greater complexity – 2 radio systems
- Greater technical risk as reliable propagation along the pipe will be more challenging to model

Next steps

- Build model and run simulations to determine critical design parameters
- Build and test proof-of-concept system based on Seatooth S200 platform

Cost & timescales

- Modelling: approx. £20k; 6 weeks
- Proof-of-concept: approx. £40k; 8 weeks

I trust this is of assistance. Are you available to discuss by phone today or early next week?

Kind regards

Brendan

From: Maren.Gregersen@akersolutions.com [mailto:Maren.
Gregersen@akersolutions.com]

Sent: 25 April 2013 16:47

To: Brendan Hyland

Subject: RE: Wireless communication system

Hi Brendan, and thank you for the quick reply.

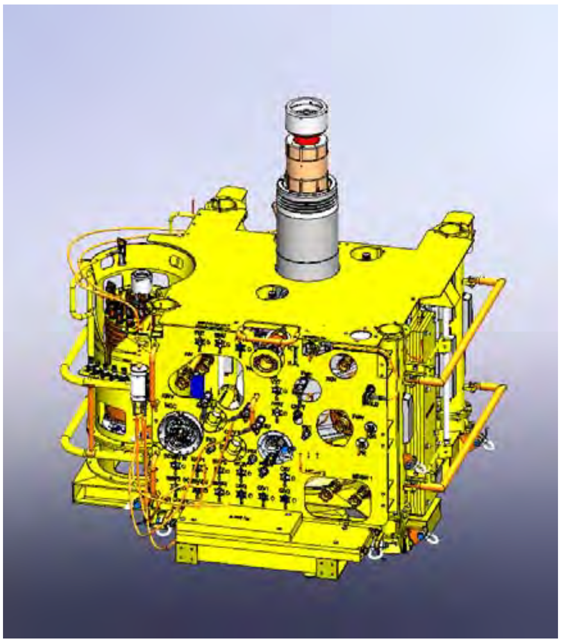
I have attached a pdf. document which explains what kind of verification system I am developing. It also shows two of the concepts I have for location of proximity switch and magnet in the XT system.

Best regards,

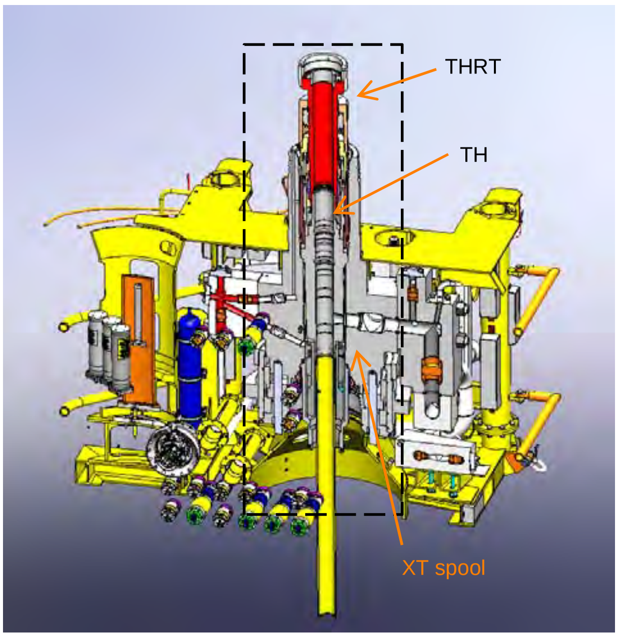
Maren Charlotte Gregersen

Here is a short introduction to the verification system I am developing:

I am going to develop a verification system which can secure correct landing and lock down of Tubing Hanger in XT spool. As I do not know how familiar you are with the X-mas three products from before, I have tried to introduce the system below, by taking cross sections and zooming into the relevant area of the product.

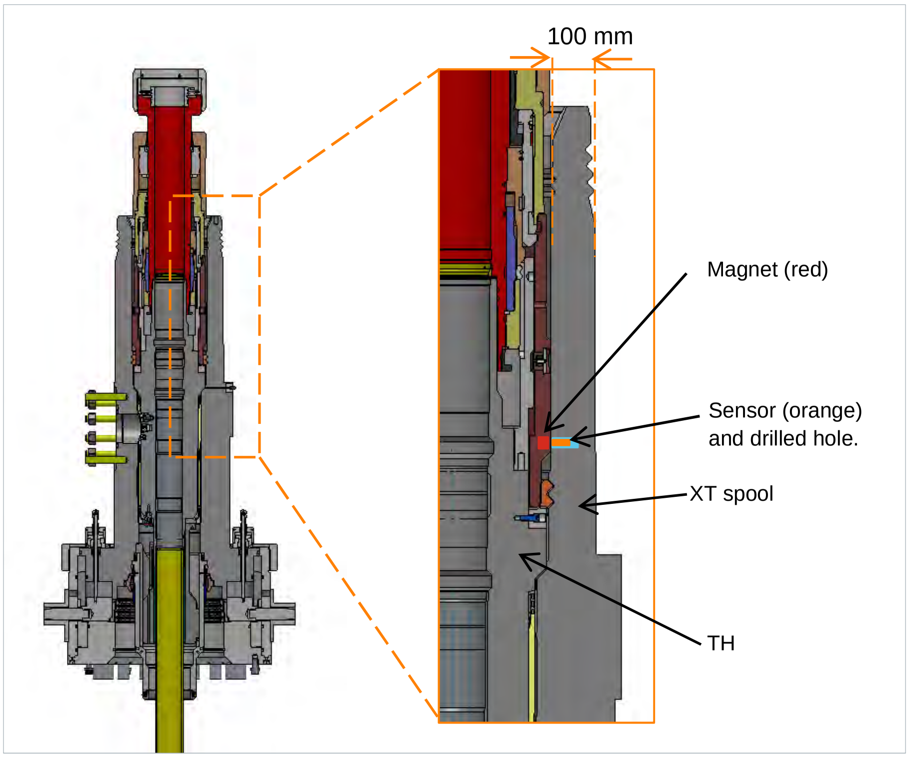


X-mas three (XT)

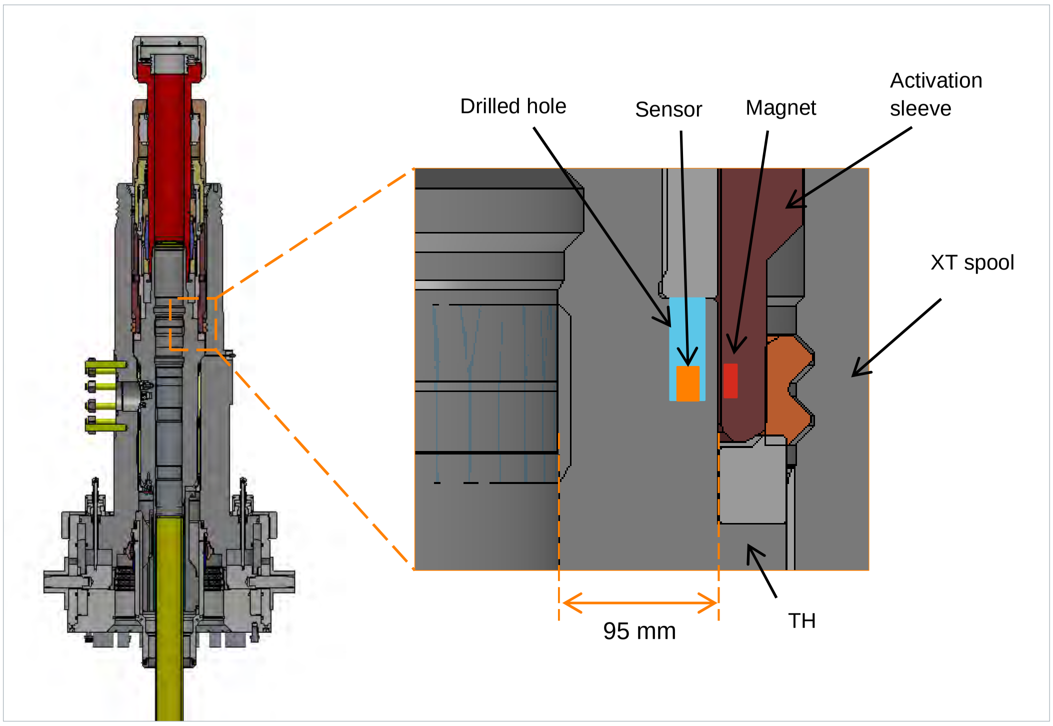


Cross section of XT, and marking around Tubing Hanger Running Tool (THRT), Tubing Hanger (TH) and XT Spool.

Below are 2 (of 7) relevant positioning alternatives, for location of Proximity switch and magnet.



Alternative 1: Proximity switch is positioned in spool body, and verify height of TH`s activation sleeve both during landing and lock down. Hole for Proximity switch can either be drilled from inside or outside the spool, but is not to penetrate the wall fully.



Alternative 2: Proximity switch located in TH`s main body, verify position of activation sleeve during lock down.

From: Brendan Hyland [mailto:Brendan.Hyland@wfs-tech.com]

Sent: 25. april 2013 11:54

To: Gregersen, Maren

Subject: RE: Wireless communication system

Maren, I thank you for getting in touch.

Attached is a datasheet for a subsea wireless modem/datalogger. A proximity sensor can be connected to this device either via the digital input or 4-20mA. The logger can be used to provide time-stamped data on when the proximity switch moved and the data retrieved wirelessly by ROV or via a network back to the umbilical.

Do you have more information on the application so I can advise on installation details and whether it is possible to provide further data monitoring?

Kind regards

Brendan

rom: Maren.Gregersen@akersolutions.com [mailto:Maren.Gregersen@akersolutions.com]

Sent: 25 April 2013 09:36

To: Brendan Hyland

Subject: Wireless communication system

Hi,

Per-Olaf Queseth from Aker Solutions suggested that I should contact you, since I need some information about wireless

communication systems for use subsea.

I am developing a verification system for installation of subsea products, and it is a huge advantage if the verification system can be wireless.

I am at a concept level for the development of verification system, and consider to use proximity switches to detect relative position of two product components. Do you think it will be possible to connect the wireless radio wave communication system you have developed, to a proximity switch?

Best regards,

Maren Charlotte Gregersen

APPENDIX I

Expert Concept Testing

Type of requirement	Requirement	Concept nr.							
		P1	P4	P5	P7	P8	P9	P10	P11
		Score	Score	Score	Score	Score	Score	Score	Score
Function	Verify position of TH relative to XT spool before lock down.	3	1	1	3	3	3	3	3
	Verify when TH is locked to the XT spool.	2	1	1	2	2	2	3	2
	Verify position of TH relative to XT spool after lock down.	3	1	1	3	3	3	3	3
	Continuous verification of TH position and locking until complete TH installation and pressure testing.	3	1	1	3	3	3	3	3
	Verify when TH is unlocked from the XT spool.	3	1	1	3	3	3	3	2
System safety	Low risk of damage on lock down system as well as adjacent components.	2	3	3	3	2	3	3	3
Technical	Verification information is to be sent to the operator located topside.	3	1	1	2	2	3	2	2
Reliability	Low risk of malfunction.[1]	2	2	2	2	2	3	2	2
Simplicity	The verification system is not to be more complex than necessary.[2]	2	3	2	2	2	2	2	2
Durability	Low wear on subsea system during use.	2	3	2	2	2	2	2	2
Serviceability	Good accessibility for inspection, testing and maintenance of system.	1	2	3	3	3	3	3	3
Economics	Not result in comprehensive changes of today`s design.	2	3	2	2	2	2	3	2

Additional comments to concept weakness/strength that is not included in the table above?

P1	
P4	
P5	The system looks good, but always considering that the TH is correctly landed into the spool. The system verifies the expansion of the lock ring, but that could be done also out of the spool. TH – Spool status is not confirmed, do you see my point?
P7	The accessibility for the magnets is optimal, but not for the components located in the spool.
P8	The same as P7 but seems that requires more space in the spool right? That could be a negative point if we are looking at spool structural resistance. Remember that spools are often submitted to extreme loads and tensions coming from the riser, any structural weakness could be critical. As mentioned above, the accessibility for the magnets is optimal, but not for the components located in the spool.
P9	This system is for me matching the most important target, gives information regarding the lock system of the TH in the spool. For me this system is confirming the TH is correctly locked into the spool. In my opinion, this is the best system regarding lock verification of the TH into the spool.
P10	Same philosophy as P5 and P7 systems

P11	The landing verification together with systems as P5 or P7 would be in the same level of verification as P9 system. Possible malfunction with debris.

Let me propose something, as I already said above, I have preference for a system which is able to confirm the lockdown of the TH into the spool. That means the system should be able to confirm that the TH is correctly locked into the spool groove. Therefore, for me the system target is in verifying that the split lock ring expands into the groove.

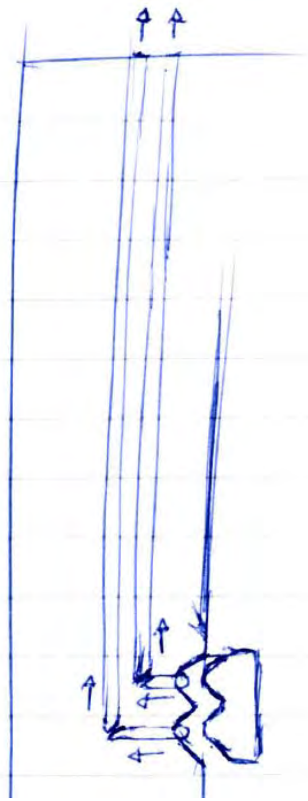
To fix the problem, I am thinking about the combination of two systems. In the spool split lock ring groove, a mechanical system (extremely robust with no maintenance required) will transmit the signal from the spool groove to the top of the spool. There another system which will be easily maintained or replaced will transmit the signal up to the rig.

The principle is very simple, a mechanical buttons (pushers) located into the spool groove will be pushed when the split lock ring is expanded transmitting a designed stroke. Then the movement will be transmitted 90 degrees to another pushers that will convert the stroke to another signal, electric, pressure, etc. The number of parts requires is considerably small.

The intention is to use the same principle as the pushers to open the valves in car engines for example. This system designed in a proper way and accordingly the required specifications could be extremely robust, perhaps designed for the lifetime of the field because is very simple. The impact in the spool should be small as the system could be quite thin and contained inside the spool barrier.

We can take a further discussion regarding the possibilities of the system if you consider it as an option.

Please see the schematic below:



through mechanical systems, the signal is transmitted on the top of the spool when the split-lock ring enter the groove in the spool

Type of requirement	Requirement	Concept nr.							
		P1	P4	P5	P7	P8	P9	P10	P11
		Score	Score	Score	Score	Score	Score	Score	Score
Function	Verify position of TH relative to XT spool before lock down.	3	1	1	3	1	2	3	3
	Verify when TH is locked to the XT spool.	1	1	1	3	3	3	3	1
	Verify position of TH relative to XT spool after lock down.	3	1	1	3	3	3	3	3
	Continuous verification of TH position and locking until complete TH installation and pressure testing.	1	1	1	3	3	3	3	1
	Verify when TH is unlocked from the XT spool.	2	3	3	3	3	3	3	2
System safety	Low risk of damage on lock down system as well as adjacent components.	3	3	3	3	3	2	3	3
Technical	Verification information is to be sent to the operator located topside.	2	2	2	2	2	2	2	2
Reliability	Low risk of malfunction.[1]	3	2	2	2	2	2	2	3
Simplicity	The verification system is not to be more complex than necessary.[2]	3	2	2	2	2	2	2	3
Durability	Low wear on subsea system during use.	3	3	3	3	3	2	3	3
Serviceability	Good accessibility for inspection, testing and maintenance of system.	2	2	2	2	2	2	2	2
Economics	Not result in comprehensive changes of today`s design.	2	2	2	2	2	2	2	2

Type of requirement	Requirement	Concept nr.							
		P1	P4	P5	P7	P8	P9	P10	P11
		Score	Score	Score	Score	Score	Score	Score	Score
Function	Verify position of TH relative to XT spool before lock down.	2	1	1	2	1	1	2	½
	Verify when TH is locked to the XT spool.	1	2	2	2	2	2	2	2
	Verify position of TH relative to XT spool after lock down.	2	1	2	2	2	2	2	2
	Continuous verification of TH position and locking until complete TH installation and pressure testing.	2	2	2	2/3	2	2	2	2
	Verify when TH is unlocked from the XT spool.	1	2	2	3	2	2	2	2
System safety	Low risk of damage on lock down system as well as adjacent components.	2	3	2	2	2	2	2	2
Technical	Verification information is to be sent to the operator located topside.	3	3	3	3	3	3	3	3
Reliability	Low risk of malfunction.[1]	2	2	2	2/3	2	2	2	2
Simplicity	The verification system is not to be more complex than necessary.[2]	2	2	2	2	2	2	2	2
Durability	Low wear on subsea system during use.	3	3	3	3	3	3	3	3
Serviceability	Good accessibility for inspection, testing and maintenance of system.	2	1	2	3	3	2	2/3	2
Economics	Not result in comprehensive changes of today`s design.	2	2	2	2	2	2	2/3	2

Type of requirement	Requirement	Concept nr.							
		P1	P4	P5	P7	P8	P9	P10	P11
		Score	Score	Score	Score	Score	Score	Score	Score
Function	Verify position of TH relative to XT spool before lock down.	2	1	1	2	1	1	2	2
	Verify when TH is locked to the XT spool.	1	3	3	3	2	3	3	1
	Verify position of TH relative to XT spool after lock down.	3	1	1	3	2	3	3	3
	Continuous verification of TH position and locking until complete TH installation and pressure testing.	1	1	1	3	2	3	3	1
	Verify when TH is unlocked from the XT spool.	1	3	3	3	2	3	3	1
System safety	Low risk of damage on lock down system as well as adjacent components.	3	3	2	3	3	1	2	3
Technical	Verification information is to be sent to the operator located topside.	3	3	3	2	2	2	3	2
Reliability	Low risk of malfunction.[1]	2	2	3	2	2	1	2	2
Simplicity	The verification system is not to be more complex than necessary.[2]	2	3	2	3	1	2	2	3
Durability	Low wear on subsea system during use.	3	3	3	3	3	3	3	3
Serviceability	Good accessibility for inspection, testing and maintenance of system.	1	3	2	1	1	1	1	1
Economics	Not result in comprehensive changes of today`s design.	1	2	2	1	1	1	1	2

Comment [MFU1]: Større avstand til sensor enn P7. problem?

Additional comments to concept weakness/strength that is not included in the table above?

P1	Skeptisk til om det lar seg gjøre å plassere wireless utstyr I spoolveggen, vil du ikke måtte plassere en antenne utvendig for å sende signaler? Så vidt jeg forstår er det mulig å penetrere veggen, men en tetningsløsning løsning må kvalifiseres. Videre skriver du at hull må drilles fra innsiden av spool, lar dette seg gjøre fysisk? Spør TTMC om dette, hvis det ikke allerede er gjort.
P4	Krever linjekommunikasjon til rig gjennom landestreng eller wireless. Men jeg tror på at det fungerer bra hvis dette lar seg gjøre.
P5	Krever elektrisk kontakt mellom THRT og TH, ser på dette som en ganske svakt ledd.. Eventuellt kan det hentes signalstrøm gjennom HP, men da må PH aktiveres før posisjon er verifisert.
P7	Generellt for systemer som bekrefter posisjon av TH før lock; her er det akseptabelt med større avvik enn ved posisjon etter lock da split lock ring vil kunne klemme TH litt nedover til 100% riktig posisjon. Ettersom jeg ikke kjenner til i detalj nøyaktigheten på sensorer har jeg svart 2 på en del celler hvor dette blir relevant, i tillegg se P1
P8	Usikker på nyttigverdien av å plassere magnet i shear dog. Ble derfor mye 2 på dette konseptet, i tillegg se P1,
P9	God verifikasjon, men det er risiko for at split treffer sensor, da får vi ingen informasjon.. i tillegg se P1
P10	Større avstand til sensor enn P7, problematisk? Sensor ligger i tetningsflate til ITC. Ikke gunstig for standardisering. Hva med et konsept med to sensorer og en magnet? Vil kunne redusere faren for feillesing av signaler? I tillegg se P1
P11	Se P1

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