NTNU – Trondheim
Norwegian University of
Science and Technology

"ROV Intervention Tool Skid (RITS)"

Development of a new ROV tool

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Master's thesis in Subsea Technology

Development of the
"ROV Intervention Tool Skid (RITS)"

A design report

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Oppgave tekst

1)   Design a ROV Skid called RITS – equipped with a torque tool, hot stab, manipulator and a tool tray.

2)   Create the documentation FMC Technologies normally require for a project.
   - Except documents that explain additional equipment, like test units and transport units.

3)   Present at least one example of how the robotics can improve subsea operation with its increased accuracy.

The rest of the pre-study report is implemented in the SPC (Appendix D) - the progress reports are added as appendix E.

Declaration

I, Magnus Nørstebø, hereby declare that this dissertation is all my own work and the sources of information and material I have used have been fully identified and properly acknowledged as required.

Acknowledgment

I would like to thank all of those who have helped me through the process of writing this dissertation.

First of all, I would like to thank my supervisor Olav Egeland and Dan Lindkjølen for their guidance and helpful tips, while supporting me through the process of finalizing this dissertation.

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I want to credit the Norwegian University of Science and Technology in Trondheim for making it possible to combine university studies and an athlete career with Drammen Håndballklubb at top national level. In a unique way NTNU facilitates for Master of Science studies during a sports career. A special thanks to Mr. Jan-Erik Tangen who has been my contact with the university in this respect.

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Executive Summary

Most subsea installations have their own, integrated control and automation systems. In cases where this is impossible or the mechanism fails, the only unit that can handle such problems is the ROV. This makes the ROV essential for subsea intervention. However, challenging conditions makes the ROV operations difficult. This report will present a new tool called RITS - ROV Intervention Tool Skid, created to simplify these subsea operations.

The RITS system is developed by utilizing conventional subsea technology only. The main idea is to introduce a fixed docking solution. It will ensure a rigid and fixed position between the ROV and the ROV panels. The docking receptacle, an API 17D, will secure a completely locked connection to the subsea unit. From this rigid position the operator may perform the work without any disturbance of the water flow.

The locked position provides new opportunities for the ROV; it opens for pre-programmed control of the manipulator and other tools. Robotics technology is frequently used in the onshore industry; however lack of fixed positions has previously excluded robotics subsea. This is changed by the new docked position, and an example of a pre-programmed manipulator will be presented as a part of this thesis.

A manipulator requires a hydraulic system, which can be designed to operate more than one manipulator. The hydraulic systems are controlled by an embedded control unit connected to a computer with a control screen (HMI). The extra capacity of the hydraulic system is used to operate special tools, which are installed inside cassettes. RITS will be able to carry three cassettes at the time, and the customer can choose between five cassettes depending of what kind of operation the ROV is supposed to perform. The different cassettes all contain different tools, and since an HPU is installed, even a hot stab cassette is possible.

This study indicates that the cassettes, the manipulator and the HPU system developed will work. The docking system however needs extensive testing before RITS can be produced. If the docking gives satisfying results during the tests, all the required documentation and design specifications are presented. The docking solution is the component making all the other systems possible.

The RITS should therefore be able to improve the working situation for the ROV operations.

Sammendrag

De fleste undervannsinstallasjoner har egne systemer for installasjon. I situasjoner hvor dette er umulig eller mekanismen feiler er det eneste hjelpemiddelet en ROV. Dette gjør ROVen avgjørende for undervannsoperasjoner. Utfordrene arbeidsforhold på havbunnen gjør undervannsoperasjoner vanskelige. Denne rapporten vil presentere et nytt verktøy som vil forbedre arbeidsposisjonen til ROVen, verktøyet er kalt RITS, Rov Intervention Tool Skid.

RITS er laget ved hjelp av normale undervannsløsninger, hvor hovedideen er basert på en ny tilkoblings metode. Denne faste tilkoblingen vil sikre en solid kobling mellom ROVen og ROV panelet på komponenten under vann. Koblingen som brukes er en API 17D kobling, og planen er at denne vil sikre roligere arbeidsforhold nede på havbunnen.

Den nye oppdaterte koblingen åpner et marked av nye potensielle løsninger, hvor blant annet forhåndsprogrammerte manipulatorer vil forbedre undervannsarbeidet. Roboteknikk gjør dette mulig, og er et verktøy som er mye brukt i landindustrien. Mangelen på faste punkter har ført til at roboteknikk har vært lite brukt under vann. Med den nye oppkoblingsmetoden kan derimot roboteknikk tas i bruk også i undervannsbransjen, og et eksempel på hvordan dette kan gjøres er vist i oppgaven.

En manipulator krever et hydraulisk system. Slike systemer kan enkelt oppjusteres til å håndtere flere komponenter. De hydrauliske systemene krever kontrollenheter koblet til en skjerm om bord i fartøyet på havoverflaten. Siden disse systemene allerede er laget kan andre undervannsverktøy også installeres i RITS. Verktøyene plasseres i standardiserte kassetter. RITS vil kunne håndtere tre kassetter av gangen, mens det finnes fem forskjellige alternativer når det kommer til kasser. Kunden velger de kassettene som passer best for den planlagte operasjonen. RITS inneholder et HPU system som muliggjør bruk av en Hot Stab, som er et viktig verktøy under vann.

Studien viser at teknologien som får kassetter, manipulator og HPU system til å virke er tilfredsstillende. Det er ingen grunn til å tro at RITS ikke skulle fungere. Likevel er tilkoblingsmetoden og RITS sine bevegelse i vann uprøvd. Skulle testene av disse to tingene være tilfredsstillende er all annen dokumentasjon klargjort, og RITS klar for operasjon. Likevel henger alt på om hovedideen med ny tilkoblingsmetode fungerer godt i virkeligheten.

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Sources market with MN → Created by: M.Nørstebø, spring 2014

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Abbreviations

API	American Petroleum Institute
CDB	Communication Distribution Board
CoG	Center of Gravity
FMC	Food Machinery Corporation
GUI	Graphic User Interface
HMI	Human Machine Interface
NTNU	Norwegian University of Science and Technology
NDT	Non Destructive Testing
RCU	Remote Control Unit
RITS	ROV Intervention Tool Skid
RLWI	Riserless Light Well Intervention
ROV	Remotely Operated Vehicle
VC	Visual Components
WROV	Working Class ROV
XT	Christmas Three

Chapter One - Introduction

The purpose of the new ROV Intervention Tool Skid (RITS) is to improve subsea intervention. Subsea intervention in this context is the tooling making subsea installation, operation and maintenance possible under water. By definition all "hands-on" activities made by the ROV and its tools is subsea intervention. It does not include inside bore operation.

The main idea is to replace the present grabber manipulator on the ROV with a new and more solid interface connection. It will provide a more rigid position which will make the operation subsea easier. A rigid system will open for other features.

Figure 1 illustrates the main idea of RITS create some new situations that will open for new system for subsea use.
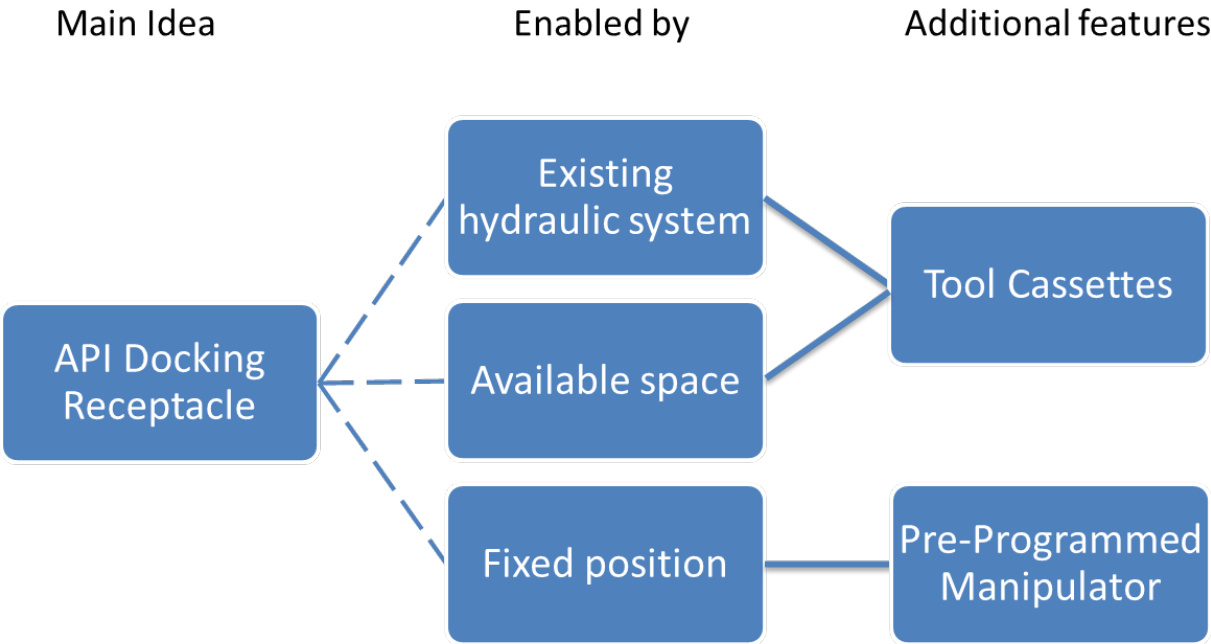
Figure 1: New systems provided by the docking interface on RITS [MN]

1.1   The RITS idea

RITS will be designed with an API 17D interface which will provide the skid with a more stable position on the subsea equipment. Combined with the manipulator it opens for an opportunity to pre-program the manipulator to do tasks automatically. This pre-programming can be planned before the ROV goes subsea while the day-rate is running.

The manipulator mounted on RITS is operated by the supplier of the equipment that shall be installed. The manipulator provides the same flexibility as the solution used today. A new pre-programmed option will be possible because of a fixed docking point by using the API 17D interface.

RITS will carry special tools in cassettes that can be activated by using cylinders. This is an advantage since the present technology requires the ROV to collect the tools from other locations such as onboard on the vessel or in a basket on the seabed.
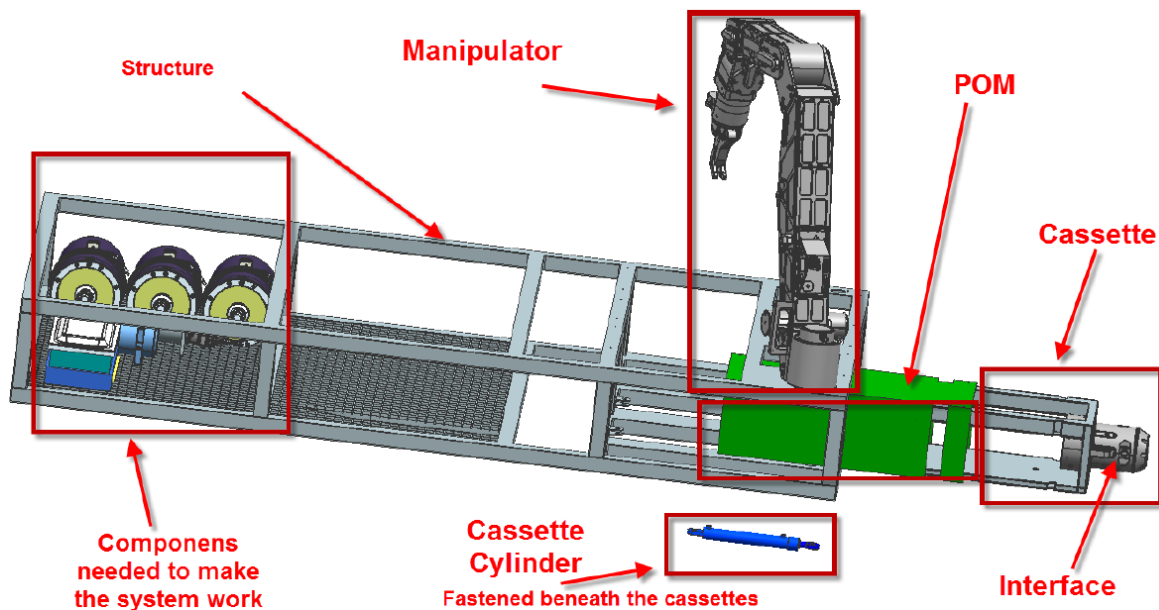
Figure 2: Components in RITS [MN]

1.1.2 Need for RITS

Bad visibility, flowing water and old systems makes the ROV operation difficult, inefficient and time-consuming - and it leads to high costs for the installation company. The new docking system will provide a solution that can solve this issue. A solid parking allows the ROV to be more accurate and apply more force on the installation, in addition to improve the working situation for the operator.

The present ROV operations require two skilled ROV operators. One operator keeps the ROV in place with the grabber manipulator, while the other operates the equipment. This arrangement makes the operators dependent on each other, in addition to communicate with the equipment experts (the suppliers). The equipment engineers know how the installation should be handled. An efficient operation is therefore depended on good communication between at least three people, which not necessarily are sitting in the same room. Figure 3 illustrates the present solution that requires three people, while the right side only need two people.

Figure 3: Illustration of decreasing number of human interactions [MN]

RITS will decrease the number of human interactions since the parking of the ROV requires one ROV operator only. The manipulator mounted on RITS is operated by the supplier which also results less work for the ROV operator. An additional benefit is a closer cooperation between to areas of the industry that during the years has driven apart.

1.2 Market for RITS

An evaluation of the existing subsea wells is made in order to analyze the potential market for RITS. This is required to provide the project with a reasonable technological aim since there are considerable costs related to creating a system that can handle all depths and challenges. The development cost can be significantly reduced if the design criteria are limited to handle 80 % of the market. A successful system can be developed further to handle the entire market. This chapter will explain which external mechanisms that will limit the first edition of the RITS.

1.2.1 Areas in the world have different sea depths[1]

The cost of a skid that can withstand the pressure on the deepest wells of more than 3000 meter can be excessive. The marginal cost of larger depths designs increases exponentially due to the increase of external pressure. To have manageable cost RITS will be designed to operating conditions for wells depths down to 2000 meters.

The table and graph below provides an overview of all the subsea wells in the world. The data is taken from Quest Subsea Database and shows existing and forecasted wells until 2017.
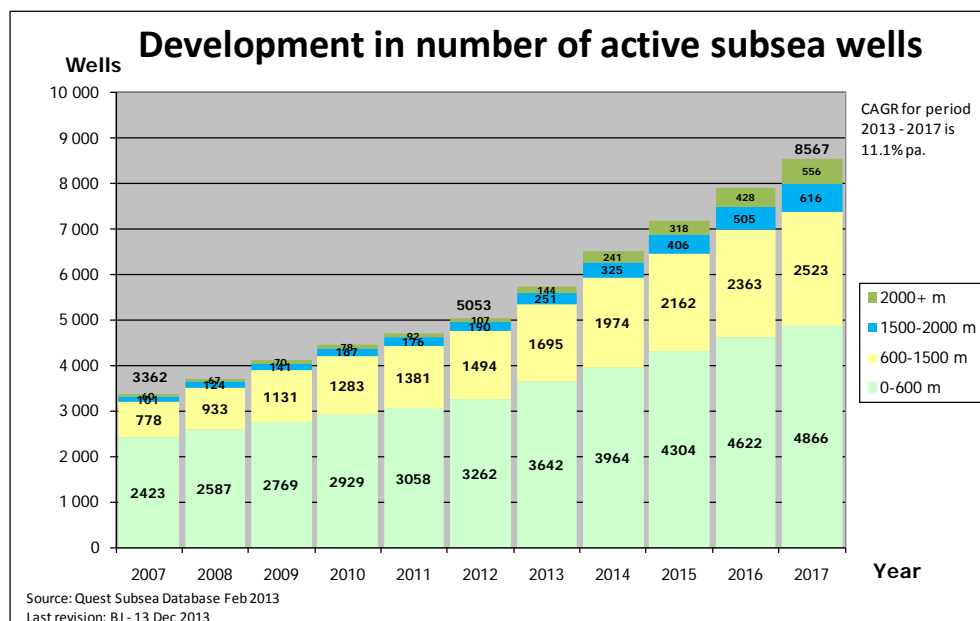
Figure 4: Graph that illustrates numbers of wells in the world - by depth [source 1].

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[1] (B.Jahnsen, 2013)

Figure 4 illustrates the depths of the existing and forecasted subsea wells in the world. Even if the deep wells seem to increase, the main market is wells less than 2000 meters. Experiences by FMC-engineers show that the expenses of going deeper than 2000 meters usually cost more than it is worth. The table below confirms that a design depth on 2000 meters covers more than 90 % of the market

Table 1: Percentage well less than 2000 meters.

Year	All Wells	Wells less than 2000 meters	Percentage less than 2000 meters
2013	5732 wells	5588 wells	97.5 %
2017	8561 wells	8011 Wells	93.5 %

Subsea wells worldwide
5053 active subsea wells at end of 2012

835
997
701
397
888
904

Other areas: 331 wells
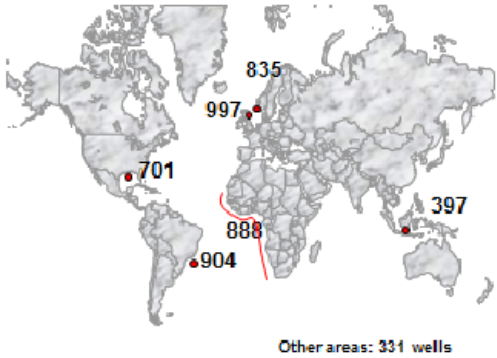
Table 2 and figure 5 gives an overview over areas where use of the RITS might be impossible.

Figure 5: Wells over the world in 2012 [Source 1]

Table 2: Depths of subsea wells - and the deepest existing well in area (2013)[2]

Area	0-69 m	70-600 m	601-1500 m	1500+ m	Deepest
Norway	-	815 wells	20 wells	-	1100 m
British	74 wells	923 wells	-	-	507 m
West Africa	-	240 wells	617 wells	31 wells	1654 m
Brazil	16 wells	298 wells	445 wells	135 wells	**2580 m**
Gulf of Mexico	48 wells	229 wells	293 wells	131 wells	**3048 m**
Asia/Pacific	32 wells	297 wells	68 wells	-	1343 m[2]

The only area in the world where a skid's design limited to 2000 meters may cause a problem is in the Gulf of Mexico (GoM) and in Brazil. Although, in these fields the majority of subsea wells are still less than 1500 meters deep.

Based on this analysis the skid's design depth is found sufficient when rated at 2000 meters.

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[2] (B.Jahnsen, 2013)

1.2.2 Forecasted Wells - tie-in and tree on wire

RITS is designed as a product to help subsea components that are not signal/power-wired with the surface. In addition to intervention work (maintenance on existing wells) RITS can be useful for new installation of XTs. Both tree on wire and tie-in operations are subsea tasks that can benefit from using RITS.

Tree on wire is an installation of a XT without the marine riser, which is a continuous pipe from the platform down to the seabed. Since the riser is not installed, it is challenging to communicate with the XT down on seabed. To be able to operate the XT, a ROV is frequently used. Installations like this require the ROV to handle the landing of the XT in addition to connecting the communication line afterwards (Umbilical).

Tie-in operations are in a similar non-commuting state as the tree on wire. Tie-in means the operation to plug/connect the production line to the XT. It has been developed systems to make this operation easier; however all of them are heavily dependent of the ROV.

Table 3 is a result of the information provided in Figure 4 - overview of depths of wells; however separated into percentage increase of forecasted wells due to depth.

Table 3: Planned forecasted wells, and depths that are increasing most in percentage.

Area	0-600 m	601-1500 m	1501-2000 m	2000+ m
2013 - existing wells	3642 wells	1695 wells	251 wells	144 wells
2014	8.8 %	16.5 %	29.5 %	67.4 %
2015	8.6 %	9.5 %	24.9 %	32 %
2016	7.4 %	9.3 %	24.4 %	34.6 %
2017	5.3 %	6.8 %	22 %	29.9 %

The table points out a tendency that the wells in the future will get deeper. Tree on wire is a method that first of all is used on deep wells, while tie in is a work performed on all depths. The calculation in table 3 exemplifies a high percentage increase in deep wells: yet the number of wells will still be lower than the wells less than 2000 meters. Knowing from table 2 that the deepest wells are over 3000 meters deep, it is assumed that the cost of calculating RITS with a 3000 meter design will be expensive.

This information gives an indication that RITS may be more suited to handle tie-in and intervention than tree on wire; however it the depths are less than 2000 meters RITS still an option.

1.3 Working class ROVs

The size of the ROVs will determine the size of RITS as the large ROVs will not have any difficulties carrying a small skid; while the smallest ROVs will have a max allowable size of RITS. Skid-structure which are larger than the ROV are problematic as they are exposed to hits from the sides.

The table below presents the ROVs commonly used in the offshore industry.

Table 4: Overview of common ROVs sizes - with operational depths over 2000 meters

WROV - type and supplier[3]	Width	Length	Height	Weight
HD-ROV Schilling	1.7 meter	2.5 meter	1.9 meter	3700 kg
UDH-ROV Schilling	1.9 meter	3 meter	2 meter	5270 kg
Centurion QX,200 Subsea 7	1.7 meter	2.5 meter	1.7 meter	2500 kg
Centurion QX, 300 Subsea 7	1.7 meter	2.5 meter	1.7 meter	2900 kg
ACV Subsea 7	1.9 meter	3.4 meter	2 meter	-
Hercules Subsea 7	1.85 meter	2.4 meter	2.05 meter	2750 kg
Quantum Subsea 7	2 meter	3.58 meter	2 meter	5350 kg
Diablo Subsea 7	2.04 meter	2.65 meter	1.82 meter	3050 kg
Demon Subsea 7	1.83 meter	2.95 meter	2 meter	3500 kg
Magnum Plus Oceaneering	1.55 meter	2.59 meter	1.85 meter	3060 kg
Maxximum Oceaneering	1.83 meter	3.048 meter	1.85 meter	4850 kg
Millenium Plus Oceaneering	1.68 meter	3.3 meter	1.92 meter	3990 kg
Triton XTR Slingsby	1.7 meter	2.5 meter	1.7 meter	3600 kg

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[3] (Oceaneering, 2013) , (Subsea 7, 2013), (Technologies, 2013), (i-Tech, 2013),

Chapter Two - RITS Interface

The RITS interface unit is the component that shall ensure a rigid and stable position. The present ROV systems require a 5 function grabber manipulator that is operated manually by personnel topside. The grabber manipulator will grab the ROV handles mounted on the subsea installation. This operation is challenging because of movement in the sea and poor 2D visibility. The idea is to replace the manipulator with a connector that allows RITS to dock onto the subsea equipment and keep the ROV in a defined stable position resulting in faster and more accurate operation.

2.1　API 17D - interface
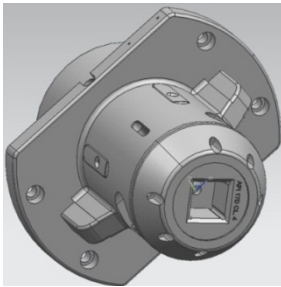
Figure 6: Model of an API 17D size 1-4 [MN]

The American Petroleum Institute has developed various standards for use by the petroleum industry. The API 17D is the standard describing the most common connector interface. FMC guidelines demand that an API 17D to be applied in an attempt to standardize the interface.

Subsea systems are installed with override functions. Common for those overrides is that they require a special tool as e.g a hot stab or torque tool. To ensure a proper access for the tools, a solution where all the special tool interfaces are installed inside an API 17D interface is selected.

The API 17D has three standardized sizes. The most suitable size for RITS is the API 17D 1-4 the dimensions of the interface are given in figure 6.

The interfaces are built in workshops, which causes a free material selection. It is preferred to use the same material as the rest of RITS to avoid galvanic corrosion. The front may be installed with a rubber element to decrease the impact forces of the landing.
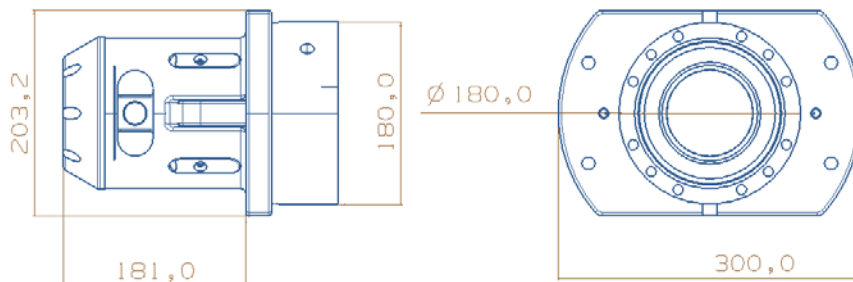
Figure 7: API 17D - drawing modified from FMC archive [MN]

2.2 API 17D interface - Bucket

The API 17D interface require modifications on the ROV panel. The ROV panel is the unit where all ROV handling and override mechanisms are placed. Many ROV panels are installed with API 17D interfaces; however they are installed in a way that may cause problems for RITS. If RITS should dock on an existing interface bucket, the ROV and the manipulator will be disabled because of no working space. To avoid this problem a new API 17D interface bucket needs to be installed.
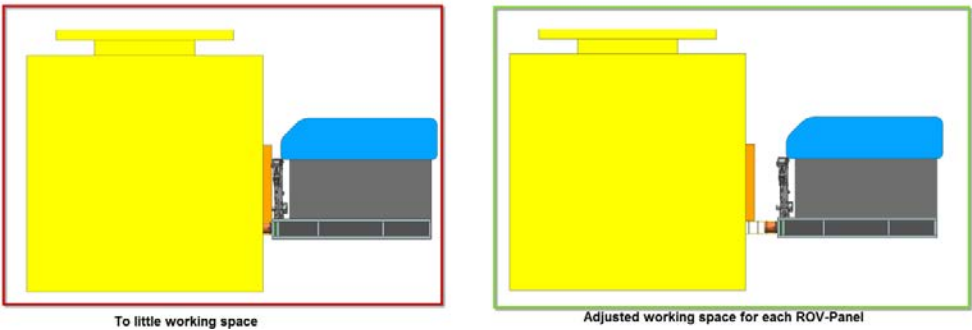
Figure 8: Extended interface bucket capability [MN]

The extended bucket is important to make RITS functional, and it is a critical unit to secure the new connection method. The ROVs are installed with thrusters that can make the ROV neutral weighted. The principle with extended interface buckets will need testing before RITS can be tried in operation; yet the grabber manipulator method make it work with a less rigid system. It is an indication of that the API 17D method should work.
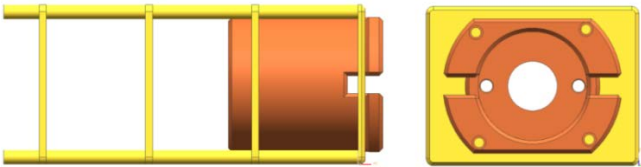
Figure 9: An extended API bucket [MN]

The API 17D interface buckets are commonly used on several subsea projects. They are, as the receptacle, created in many different materials, while the size is standardized. Figure 9 illustrates an API 17D interface bucket, and an example of how the buckets may be extended to satisfy the demands of RITS.

The strength requirements will depend of the ROV model - and will require a separate dimensioning for each specific project.

2.3   The locking dog system[4]

The API 17D interface will ensure that RITS has a steady position during the operation; still there is a chance that RITS will "fall out" of the interface. To avoid this problem a locking system are implemented between the bucket and the receptacle.

Figure 6 reveals two holes that seem without purpose. Those two holes are actually important for the locking system, and are called locking dogs. A locking dog is a pin in the receptacle that will be pushed into a fitting hole in the interface bucket. RITS will be totally fastened as long as the pin is pushed inside the bucket.

This system is standard on the API 17D interface; however the locking dog pin is not always installed. The system on figure 10 is actually an Oceaneering invention, but by implementing a dedicated hydraulic line to the locking dogs in RITS will make this system possible for all the interfaces.
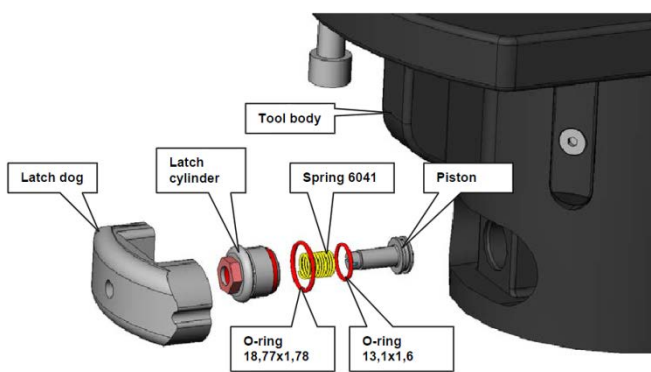
Figure 10: Locking dog assembly [Source 4]

As figure 10 is illustrating, the locking dog has a spring installed. The purpose of this spring is to retrieve the locking pin if the system loses its power. It is a safety mechanism that makes it possible for the ROV to pull away in an emergency situation.

If the locking dogs are not installed, the hydraulic lines will be plugged with a blind-flange.

In addition to a solid extended bucket it is possible to install a system that mechanically informs when the locking dogs are installed. The locking dogs will push a pin out, and the camera on the ROV will be able to verify the status of the connection.
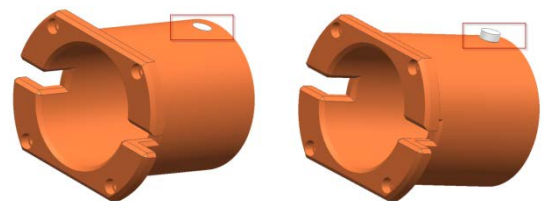
Figure 11: The spring loaded locking dog pin [MN]

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[4] (Oceaneering, 2009)

Chapter Three - Tools

RITS will be designed with tool packages, called cassettes. The cassettes will contain the API interface and the special tools. The tools in the cassettes will be protected inside RITS during transportation subsea and a cylinder will activate the cassette by push it in operational position.

This chapter will explain the cylinders that activate the tool-cassettes, and a brief explanation of the special tools inside the cassettes.

3.1 Cylinders

RITS need three cylinders to be able to activate all three cassettes. It is important that the cylinder can withstand the design depth determined to be 2000 meters depth.

Hydraulic cylinders exist in all sizes. A combination of available space and need of strength will determine which type of cylinder that is applicable for RITS. The diameter of the piston and the hydraulic pressure acting on the piston determines the strength of the cylinder. It means that the needed force can be important when determining the cylinder size; however it is preferable to use a small cylinder to reduce the weight of the skid.

The required strength for the cassette cylinders in RITS is limited. Their only purpose is to push the cassettes, in addition to withstand the forces applied when RITS connects the interface bucket.

The idea is to design the skid with a lock mechanism that will reduce the forces on the cylinder when connected. It decreases the demands for strengths, which reduce the size of the cylinder.

The cylinder shall handle the friction between cassette and structure, while the locking mechanism should handle the parking forces.

As a result, small cylinders will be strong enough for RITS, and results in the desired low constructional weight.

Pneumatic cylinder[5]

In an attempt to reduce the weight of the construction an idea of using a pneumatic cylinder was presented. Since there is no pneumatic system in the RITS system the idea was to fill the pneumatic cylinder with oil. The idea was rejected pretty fast since there are very strict requirements for subsea cylinders, and reconstruct and re-certificate a pneumatic cylinder to be operated with oil as a hydraulic cylinder would be very demanding.

Pneumatic cylinders have stricter requirements as the compressed gas will have explosive behavior. Additionally they operate with a working pressure less than 30 bar which result in need to fine-tune pressures by a few bars. Cylinders in RITS should be reliable and robust, and Sylinderteknikk warned for mechanical problems if the design was dependent controlling with of fine-tuned pressures.

Hydraulic cylinder

The hydraulic cylinders are commonly used subsea as hydraulic units are reliable and powerful. The cylinder needs to operate on the same fluid as the rest of the components. These components are operating on oil. To avoid complications with the fluids and pressure it is natural to pick a hydraulic cylinder for the cassettes.

The main reason to seek other solutions than hydraulic cylinders was the concern regarding weight. The requirements of RITS-cylinders are limited, and results in a low weight component. Sylinderteknikk weighted a Ø30 cylinder (250 mm long) to 2.5kg, which means that the cylinder is a light component compared to other units inside RITS. It is not worth the risk to choose a pneumatic cylinder to reduce the weight by 1 kg.

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[5] Information and recommendation from meeting with Sylinderteknikk - Terje Grimsrud, date: 28/02-14

3.1.1 Double acting cylinder[6]
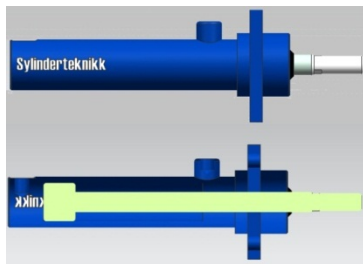
Figure 12: Simplified how the Cylinder works [source 6]

A double acting cylinder has two hydraulic lines connected to the cylinder house, one each side of the piston. The cylinder is operated by filling fluid on one side of the piston. When one side is filling up, the other side will drain and the piston and stem will move. Double acting means that both sides of the piston can be filled. Single acting cylinders are often installed with a spring to force the stem back into start position when the pressure is bled off.

3.1.2 Fastening method
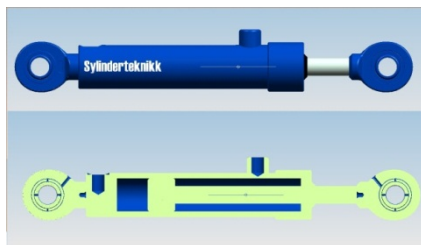
Figure 13: Cylinder with two fastening rings [source 6].

The cylinder on figure 12 is a double acting cylinder, with a flange connection. Figure 13 is showing a double acting with two rings. These two types are identical when it comes to size and strength, but the fastening methods are different. The position and space inside RITS will determine what fastening method that is the best choice. RITS is designed with a double acting cylinder with two rings as fastening method; the reason is presented in chapter 3.1.3.

Safe-fail-close or safe-fail-open

A safe-fail-close system is often used in situations where cylinders need to go to lock during failure. It is performed by installing a spring on one side of the piston. This contingency mechanism will not be required for the cylinders activating the cassettes. It is not critical if RITS will not be able to pull the cassettes in during transport - it will only require a more careful transportation.

The contingency spring solution is illustrated on the locking dogs system. It is required for the locking dogs because RITS will not be able to pull back if the dog pins are activated. The contingency mode has to be designed for the solenoid valve system in a way that allows the fluid to drain.

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[6] (Hydex Sylinderteknikk, 2014)

3.1.3 Cylinder position

A cylinder consists of cylinder housing and a steel stem. Steel is a strong material, but it is still quite flexible when the construction is thin. The most suitable cylinder is small and therefore the stem is thin. To avoid problems with that the stem bends or get overloaded, the cylinder must be mounted to give as low unnecessary loads as possible.
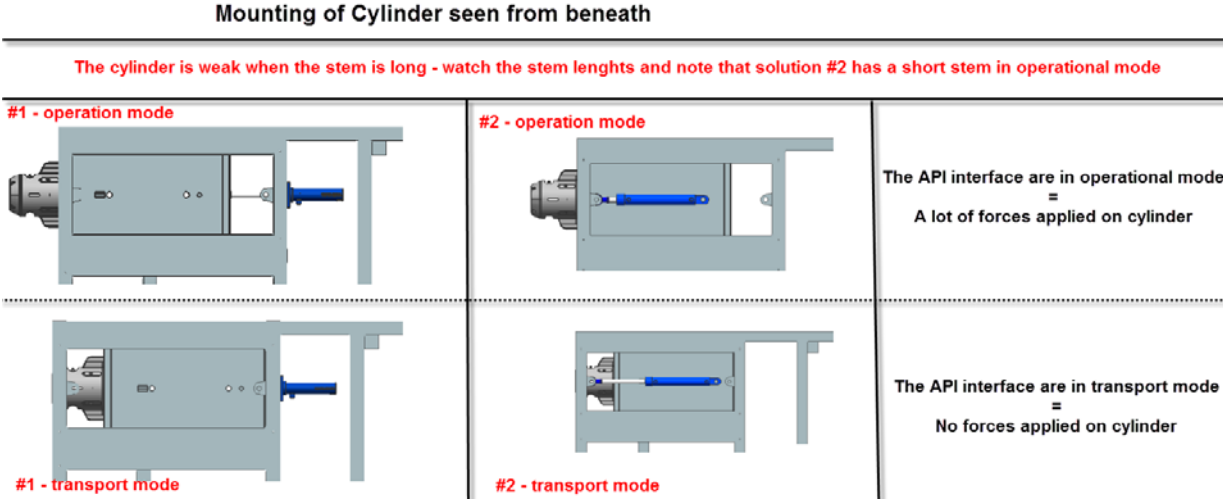
Figure 14: Solution for mounting of cylinder beneath the structure [MN]

A cylinder is strongest when the stem is pulled inside the cylinder. When the stem is pulled fully out it will be exposed for force from the sides. As a result there is a risk that the stem will bend. It is possible to calculate how much force that can be applied before the stem breaks. As figure 14 illustrates will the cylinder be mounted in the "opposite" direction of what may seem as the natural way, to protect the stem. The idea is to apply the highest forces on the cylinder when the stem is pulled in - as solution number 2 illustrates. When the stem is pushed out - the interface receptacle is hidden inside RITS and will not be exposed for radial forces.

In the position with the stem pulled in, it is easy to calculate the capacity of the cylinder. When the stem is pulled in the there is no need to be concerned about the limited stem capacity - which means that full strength of the cylinder can be estimated (area of stem multiplied by working pressure).

It will not be necessary to calculate the capacity of the stem at "full stroke" since there will be no forces applied at this point.

3.2 Guiding System

POM (Polyoxymethylene) is a plastic material, widely used to protect equipment from dirt and scratches in the subsea industry. The RITS project will use POM to reduce the friction between the cassettes and the structure. In addition to lower the friction it will secure a proper guiding of the cassettes. The combination of a proper guiding, and an optimal position of the cylinder, will secure a reliable handling of the cassettes.
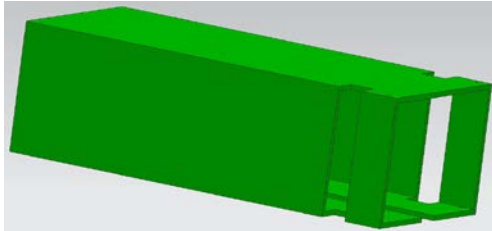
POM is a low cost material. It is softer than the aluminum, which makes the wear and tear to appear on the component easiest to replace. The POM will be fastened to the structure by clips or bolts.

Figure 15: Guiding system of POM [MN]

3.3 Brackets locking mechanism

The most critical situation for the cylinder is the impact forces when the interface receptacle is pushed into the interface bucket. To avoid that the cylinder will handle all the forces a locking mechanism for the cassettes is installed.

There are several different methods to lock a cassette. RITS will use a simple and mechanical solution since the manipulator can be programmed to do the locking automatically.

The system consists of a half-cylinder with a handle on top. The cylinder allows the cassettes to slide freely in one position, but when the cylinder is turned 90 degrees the cassette will be locked.
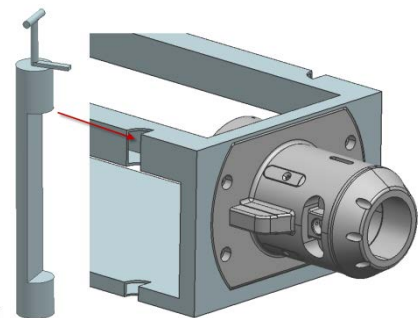
Figure 16: Locking cylinder for the cassettes [MN]

It is important that the design prevents the locking pin to turn during operation, which may happen due to vibrations during operation.
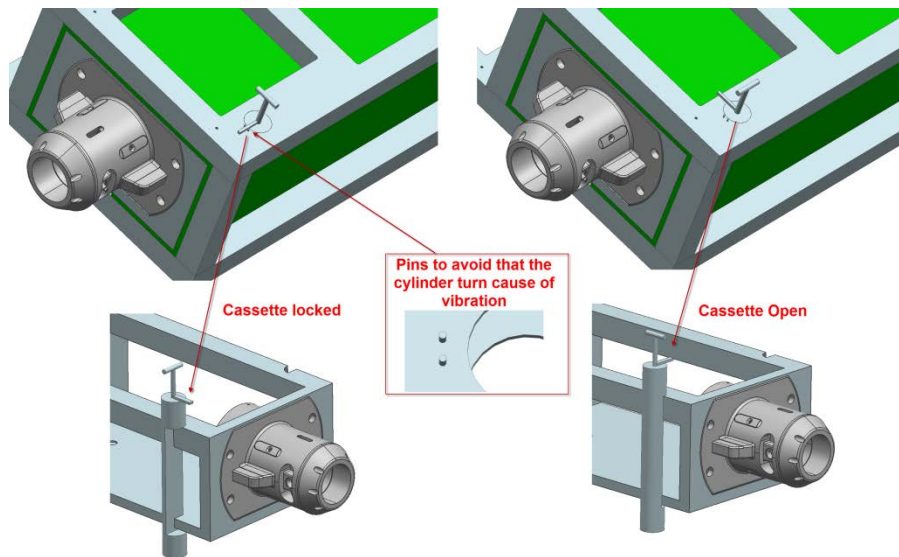
Figure 17: Locking mechanism for the cassettes [MN]

The manipulator lift the cylinder 5 mm up and then turn the handle 90 degrees (it is not possible to pull to long since the geometry of the pin is designed in a way that prevents the pin to be pulled more than 10 mm).

Subsea cylinders adjustment[7]

There are strict requirements to equipment used subsea, and there are a few suppliers approved to deliver hydraulic cylinders to FMC. Sylinderteknikk is an FMC approved supplier, and because of that their cylinders are used in RITS. Their expertise and long experience ensures the requirements due to corrosion, pressure limitations and other demands of the subsea business are met.

It is required a special corrosion protection ring on the stem. The ring will increase the length of the cylinder housing with approximately 25 mm. Table 5 does not include the extra 25 mm protective ring extensions, and needs to be added when selecting the cylinder size.

---

[7] (Hydex Sylinderteknikk, 2014)

3.4   Force capacity of the cylinder

The force the cylinder needs to overcome is quite small. The strength is calculated by the piston area multiplied by the fluids pressure. The smallest standard cylinder from Sylinderteknikk with enough stroke-length is the Ø30 cylinder.

$$area_{piston} \times pressure_{psi} = Strength\ of\ Cylinder_{Axial\ direction}$$

$$(\Pi \times 0.015^2) \times 207 \times 10^5 = 14\ 625\ N$$

Using POM guiding and the locking mechanism for the cassettes, the cylinder of Ø30 is strong enough.

The capacity of the cylinder is that strong that there is no point of calculate the friction. The friction will be reduced because of the guiding system; however the cylinder is strong enough to relive the cassettes locking mechanism when the impact force appears.

3.5   Cylinder Lengths

RITS will need four cylinders to be able to perform the task it is designed for. Three of the cylinders will be installed to push the cassettes into operational mode and back to transport mode. The last cylinder is needed for the cylinder stab cassette. Common for all cylinders is the limited stroke lengths, which are restricted to push the length of the interface, 181mm (given in figure 7 - measurements of the interface receptacle).

Table 4: Cylinder lengths

	A -length +25mm* Length of stem	Stroke length	OD-outer diameter	IN Diameter	Total length
Tray Cylinder	203 mm	181 mm	Ø40 - (50)	Ø30	384mm
Hot Stab Cylinder	203mm	181 mm	Ø40 - (50)	Ø30	384mm

* Extra length to customize the cylinder for subsea use (ref. Terje Grimsrud, Sylinderteknikk)

3.5.1 The RITS cylinders
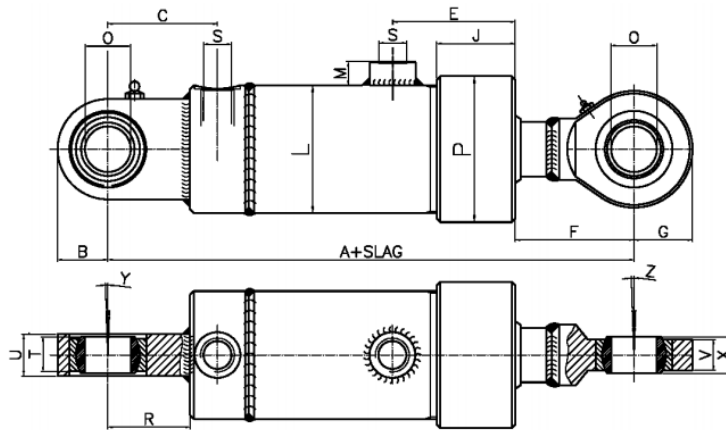
Mål i mm

Syl. Ø	25	30	40		50			60			70	80	
Stang Ø	**12**	**16**	**20**	**25**	**25**	**30**	**35**	**30**	**35**	**40**	**40**	**40**	**50**
A	136	189	203		245			253			250	270	
B	17.5	23	25		27.5			27.5			32.5	32.5	
C	23	46	50.5		62.5			60			64	71	
E	41	49	56		65			67			58	62	
F	31	48	56		58			65			68	68	
G	17.5	23	26.5		32			32			36.5	36.5	
H	ø12	ø16	ø20	ø25	ø25	ø30	ø35	ø30	ø35	ø40	ø40	ø40	ø50
J	26	33	37		43			43			37	37	
L	ø35	ø40	ø50		ø60			ø70			ø80	ø90	
M	12	14	14		14			14			14	14	
O	ø10(-0.008)	ø17(-0.008)	ø20(-0.01)		ø25(-0.01)			Ø25(-0.01)			ø30(-0,01)	ø30(-0.01)	
P	ø45	ø45	ø60		ø70			ø80			ø90	ø100	
R	14	35	38		45			45			51	51	
S	1/8"RG	¼"RG	¼"RG		3/8"RG			3/8"RG			3/8"RG	3/8"RG	
T	9	14	16		20			20			22	22	
U	8	11	19		23			23			28	28	
V	8	11	19		17			17			19	19	
X	9	14	16		20			20			20	22	
Y	12°	10°	9°		7°			7°			6°	6°	
Z	12°	10°	9°		8°			8°			6°	6°	

Forbehold om trykkfeil og rett til endring av mål.

Table 5: Measurements of Sylinderteknikk cylinders [source 7]
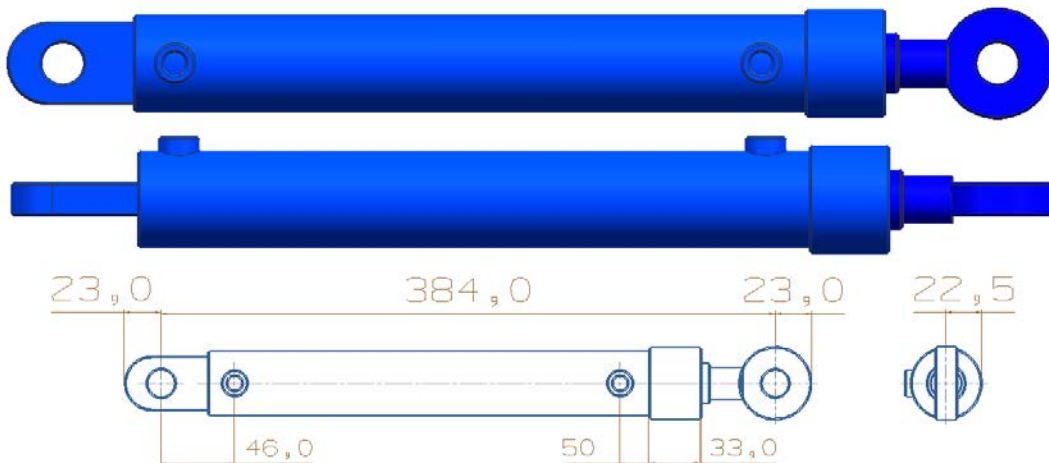
Figure 18: The cylinder used in RITS [MN]

3.6   Torque Tool

A torque tool is the wrench used subsea. Most subsea tasks are performed by the manipulator, e.g. operation of ROV handles. The torque tool performs more "advanced" task as mechanical override of failed valves or to mechanically power up a motor or a pump. It is also required to connect/disconnect Multi-Quick Connectors (MQC), which is a common task since the MQC has more restricted life cycle than the XTs. The torque tool has an API 17D interface receptacle which is useful since all the special tools will have a "true API 17D interface" option, ref chapter 5.3.

The torque tool exists in several different sizes, RITS will use the most common, the 2700 NM with 200OMM motor.

Table 6: System requirements needed to meet FMC (customers) needs
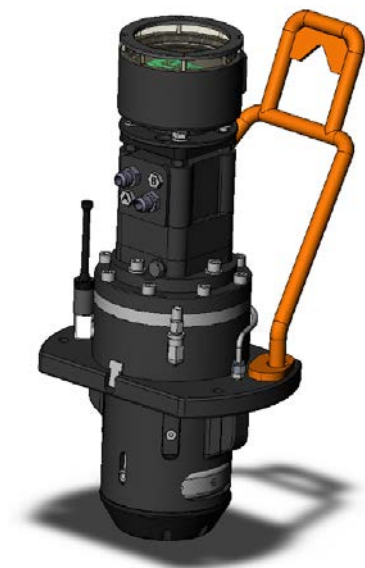
Mechanical Data[8]	
Length	600mm
Width	360mm
Diameter	300mm
Weight in Air	39 kg
Weight in Water	30 kg
Torque Range	2700 Nm
Hydraulic Data	
Pressure	200 Bar
Flow	36 l/min
Fluid	ISO VG22 (Shell Tellus or equal)
General Data	
Axial Force on latches	3000 N
Max Water depth	3000 meters

Figure 19: Torque Tool with ROV handle[9]

Figure 19 illustrates a torque tool. The ROV handle (the orange grip) will be removed for RITS use. The torque tool is the only tool that has locking dogs integrated from the supplier. The locking dog system planned for RITS is a copy of the torque tool system.

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[8] (FMC Technologies, 2010)
[9] (Oceaneering, 2009)

3.7 Hot Stab

It can be challenging to operate all the valves one by one. In cases like that a hot stab becomes in handy. The purpose of a hot stab is to apply pressurized fluid into a subsea installation, through a number of ports. The ports send high pressured fluid to open or close integrated valves in the subsea installation. The advantage with the hot stab is thus that it can operate several valves at the time.

When the stab gets connected it opens one or several supply lines and return lines to operate valves. In addition to override scenarios the stab can use its external fluid to operate motors/pumps. Pressurized fluids are also used to check that connections are properly tightened; by adding a hot stab to the RITS it becomes more useful also for tie-in projects.

The number of function depends of how many lines the stab has. RITS will use 6 lines 345 bar hot stabs, which can handle three valves (3 supply lines and 3 return lines).
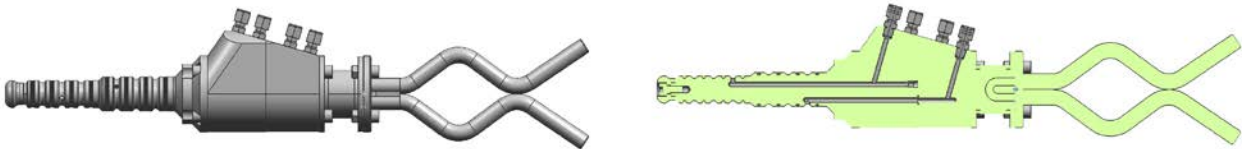
Figure 20: A 6 Line Hot Stab - both inside and outside [Source 10]

While the torque tool normally has API 17D interface connection the hot stab does not have any standardized interface connection, but are normally put in operating position by a manipulator arm. For RITS a new solution is proposed, where the hot stab is installed to an API 17D interface. It requires some modification of the normal 6L hot stab; though there will not be any change of function - it will simply be a bit longer than the normal.
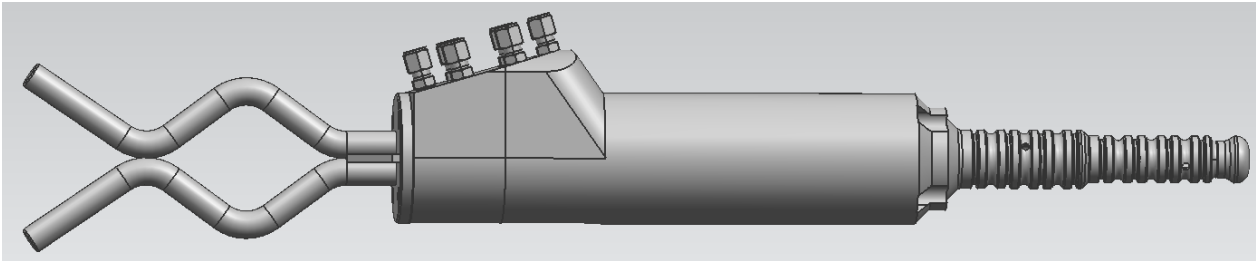
Figure 21: An extended hot stab, customized to fit inside an API 17D [MN and Source 10]

3.7.1 Two hot stab Cassettes solutions

To increase the flexibility of RITS, it will have a cassette providing a "loose" hot stab. It means a hot stab that can be operated by the manipulator.

The hot stab system requires more adjustment than the other tools; however to be able to handle existing XT's this unit is required, as existing subsea installations not are designed to handle a hot stab true a API 17D interface.

Table 7: Info of a hot stab

Mechanical Data[10]	
Length	438 mm
Width	various
Diameter	140 mm
Weight in Air	4.5kg
Weight in Water	3.5kg
Hydraulic Data	
Pressure	207 Bar (design 380 Bar)
Flow	30 lpm
Fluid, oil	Depending of external system
General Data	
Max Water depth	2500 meter
Hydraulic interfaces	
Hydraulic hoses	7/16" x 20 JIC

Clean system - Hydraulic Power Unit

A hot stab applies fluid into external systems. Subsea system usually have strict requirements due cleanness to fluids. RITS is powered by the ROV auxiliary valve pack, which consist of "dirty" fluid (Tellus). To insert a usable hot stab a special clean system is needed inside RITS.

Systems that provide clean fluids are called a Hydraulic Power Unit (HPU). It is a system that can make a secondary system flow without mix fluids. The schematic will show what components that are needed inside the RITS to make a clean fluid system possible.

See Appendix A for a detailed explanation of a hot stab and how it is works.

---

[10] (FMC Technologies, 2010)

Chapter four - The Structure design

The structure will protect all the sensitive tools inside RITS with its frame. It is important that the structure is designed so that it will not expose the manipulator or other tools. To work as intendant it is important to choose the right material, form and profiles of the pieces that become the structure.

Subsea equipment is exposed to some of the most corrosive environments in the world, even if the oxygen level is low down on seabed. Equipment stored on the vessels is particularly exposed to corrosion. It is problematic that equipment, like RITS, is exposed for seawater and then be stored on deck where the oxygen level is high.

Another material sensitive factor is the weight. Offshore equipment should be easy to handle. Waves and wind makes lifting operations dangerous; therefore it is important to keep weight as low as possible.

In addition to the issues mentioned above, costs are an important factor. There are many materials that fulfill the environmental challenges, however they usually are expensive. The cheapest material commonly used for equipment in similar environment as RITS is Aluminum 6082-T6.

This chapter explains the material choices for the structure. Further, different solutions for how to assemble the structure are discussed.

4.1 RITS material choice

Steel is a normal choice of material because of the strength and the experience from many other subsea projects. There is a design goal to keep RITS as small as possible to make the ROV moveable. Steel is heavy, which require more buoyancy elements to make RITS neutral in water. Buoyancy elements are quite big, and exclude the steel solution since it will increase the size of RITS.

Al 6086-T6, is an aluminum quality commonly used for equipment moved up and down in the sea. The prices are acceptable and the strength is within the wanted range.

Table 8: Al 6082-T6 material features

Properties[11]	Metric Values
Density	2.7 g/cc
Hardness, Vickers	95
Tensile Strength - Yield *Wall thickness less than 5mm*	250 MPa
Tensile Strength - Ultimate *Wall thickness less than 5mm*	290 MPa
Thermal Conductivity	170 W/m-K

Aluminum meets the design requirements to RITS. Aluminum is ranked low in the galvanic series which makes it vulnerable for galvanic corrosion connected to most other metals. An advantage with RITS is easy access for maintenance and an objective is to create RITS into a structure that easily can be changed - if corrosion is considered a problem.

If the aluminum structure should be too weak - steel or "expensive" solutions as titan would be replacement alternatives.

Buoyancy elements are needed to make RITS buoyant in water. FMC guidelines demands ROV-tools to not exceed 50 kg under water. Tools that are heavier than 50 kg will cause a dysfunctional ROV and prevent the RITS from improve the present subsea technique. From a subsea intervention point of view tools heavier than 50 kg is called ROT (remotely operated tool), and is another kind of equipment than what RITS are supposed to be. To meet the requirement from FMC, RITS cannot exceed 50 kg in water.

Chambers filled with air could make the RITS more buoyant. An air-filled system must stand an outer pressure on 2000 meters sea depth to avoid breaking the air chambers, and require a thicker, and heavier, layer of material.

The material called BMTI or Syntactic Foam has proved to stand a sea depth level of 3000 meter. The Syntactic Foam (SF3000) could be blasted into different profiles[12] to improve the buoyancy (ref table below). Normally Syntactic Foam is delivered in elements that are easy to customize.

---

[11] (Mat Web, 2014)
[12] Phone call with DIAB Norway

Table 9: Important capabilities for Syntactic Foam

Properties[13]	Metric Values
Weight in air	495 kg/m^3
Seawater Buoyancy	30.2 kg/block
Block size	57 liters
Depth rating	3000 meters

The buoyancy elements can be customized into the shapes that are needed by use of glue and saw. The Syntactic Foam is also quite hard, and can be used on the outside of RITS (combined with the aluminum structure). Syntactic foam is normally used on ROVs, and the foam elements are seldom more protected than figure 23[14] illustrates.
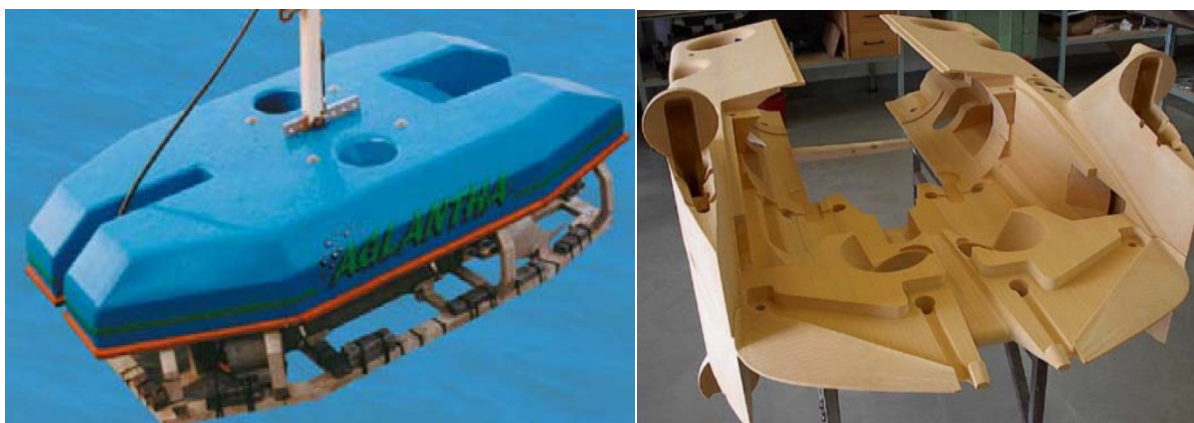
Figure 22: Examples of syntactic foam [source 14]

Acetal Polymer[15] (POM) is a hard plastic material normally used as protection for flanges and seals. RITS will use POM elements for tasks that do not require any strength. A typically area for POM will be the chambers where the tool cassettes will be placed.

The material will have a deformation of 1% at 4500 psi (equal to 300 bar). This is within acceptable range for the POM elements, and should not cause any trouble for RITS. If it should be too tight for the guiding system it is easy the grind the POM.

---

[13] (DIAB-Group, 2014)
[14] (DIAB-Group, 2013)
[15] (FMC Technologies, 2006)

Aluminum weight in water

Archimedes law tells that weight of components in water is calculated to be:

$$Weigth\ in\ water = Weight\ object - Weight\ of\ displaced\ fluid$$

This can be changed to a simpler and more usable equation:

$$\frac{Object\ Density - Water\ Density}{Object\ density} \times Object\ Weight\ in\ air = Object\ Weight\ in\ water$$

The density of salt water is approx. 1030 kg/m^3 and the density of aluminum is 2700 kg/m^3, it makes it possible to calculate a percentage to calculate the aluminum weight in water

$$\frac{2700 - 1030}{2700} = 63\ \% \times Object\ Weight\ in\ air$$

4.2 Corrosion[16]

Corrosion is an everyday problem for all equipment stored nearby the sea. The problems are worst in the splash zone where the sea water frequently splashes over the materials where access to oxygen is good. The salt water makes the environment more corrosive since salt creates an ionized bridge that leads to galvanic corrosion between different rated steels. Storing the equipment inside, where the humidity is lower than outside, will decrease the rate of corrosion.

Down on seabed there is less oxygen, and the corrosion rate is lower than in splash zone; though it does not mean that the environment is good for RITS. Aluminum has a low Poisson number, which makes it frequently used as an anode for higher valued materials. Low weight and acceptable strength also makes it a good material choice for RITS. The corrosion problem is handled by avoiding material with high Poisson number combined with regular maintenance.

The idea is to build RITS in aluminum, without using a not ionizing material between RITS and the ROV. Experience will show whether it will be enough to prevent RITS from corrode. If not, it is possible to install anodes or other corrosion protectors during the regular maintenance.

RITS will be topside very often, therefore corrosion is not considered as a significant problem. Experience from FMC intervention and tool department is that corrosion on tools seldom causes any problem.

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[16] <mark>Corrosjons bok</mark>

4.3 Profile of structure
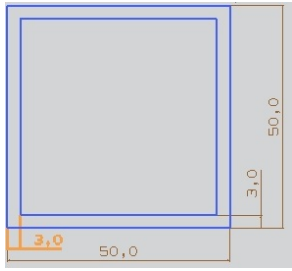
It is important to select the right profile of the aluminum beams for the structure. The following four criteria need to be fulfilled:

- The profile should all be mass-produced to avoid extra cost.

- The profiles need to withstand corrosion under severe conditions. It is difficult to calculate the different profiles ability to withstand corrosion since this is a matter of experience. Advanced profiles will corrode faster because of the tendency to trap salt water inside the structure; however the advanced profiles may benefit of a stronger profile at a lower weight.

- The profiles should allow easy guiding of the cassettes. This is a challenge for advanced profiles which make them not competitive. A structure with a square cross section is an easy design that allows cassettes to glide upon. It is also easy to calculate the strength of such profile.

- The profiles need to withstand the external pressure at sea depth of 2000 meters. A square hollow profile is weaker towards outer pressure since it will trap air inside. By use of hollow profiles it is important to equalize the pressure by creating holes in the structure. The holes will equalize the pressure on both side of the element.

Square profile (50x50x3) - without any substance in the middle

A square profile with the dimensions 50x50x3 is selected for the structure. The dimension 50x50x3 is chosen because it is a standardized aluminum 6082-T6 profile size[17]. The tools inside the RITS will be installed with customized cassettes designed to slide to the operating position. The cassettes will be guided on "traces" in the structure, and square profiles will make this guiding easier.

Table 10: Square Profile measurements in millimeters [MN]

Properties	Metric Values	
Aluminum area	2,91 cc	Illustration of profile
Inner area	0,001963 mm^2	
Weight per meter - In air	7,86 kg/m	
Weight per meter - Water	6,1308 kg/m	
Pressure capacity (depth rating)	~ unlimited as long there are holes in the profile	
Areal Moment[18]	7600 mm^3	

The strength of the structure can be calculated by use of NX and ANSYS. If the profile should be too weak a second solution of the same profile is presented.

Square profile (50x50x3) - Frame filled with buoyancy (Syntactic Foam)

A profile filled with buoyancy (syntactic foam) will create a sandwich effect between the upper and lower part of the profile. This kind of profiles is known for being very strong.

Syntactic foam inside the profile makes the structure lighter. The choice between the two profiles will be determined in chapter 10.1 (Buoyancy) due to need for buoyancy elements. Syntactic foam may solve the issue by filling the profile; however from an economical point of view it is not ideal since the process of filling a structure with foam increases the cost.

---

[17] (Smith Stål, 2014)
[18] (Johannesen, 2002)

4.4 Assembling the structure

There are different ways to assemble a square profile into a structure. Subsea structures are normally welded together. FMC wanted other options than welding to be considered. Bolted and welded structures are discussed in this chapter while glue and other assemble methods has been considered too unsecure/innovative and will not be further discussed.

4.4.1 Bolted structures

The main advantage with bolting a structure is to make it easier to replace broken pieces. The challenge is to get the structure solid enough. Important concerns for design of a bolted construction are:

- A bolted structure needs to be designed in a way that allows the bolts to fasten into the profiles; since profile is hollowed it will not be possible to fasten bolts on the ends.
- It is a challenge to bolt the structure in a way that prevents the square profiles to turn around. They need a fastening system that makes them stay in the same position at all times.
- The system needs to provide a solid connection to prevent stress issues as fatigue.
- The bolt assembly should not increase or decrease the size of the structure.
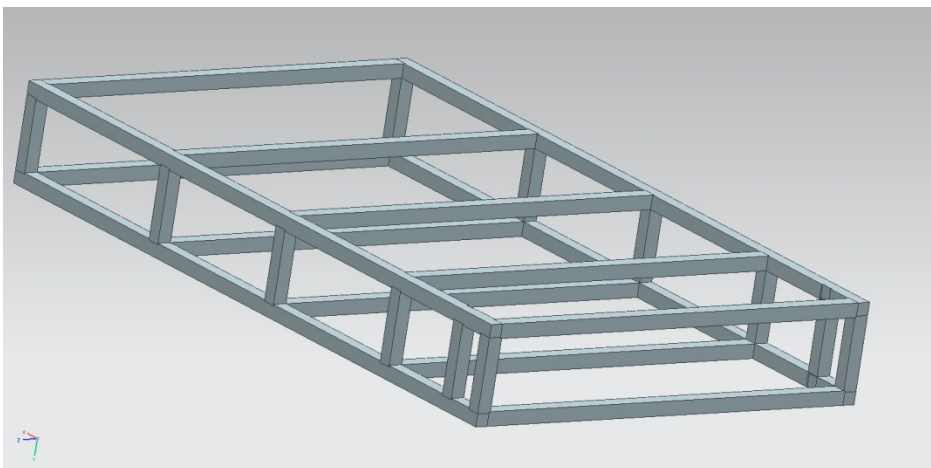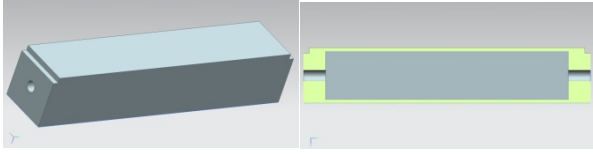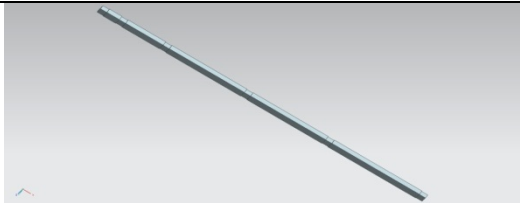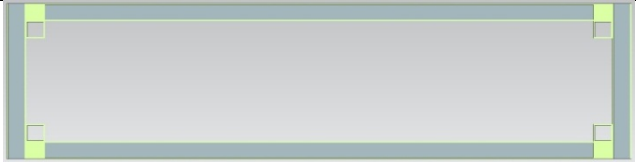
Figure 23: Example of a skid structure [MN]

The table on next page presents the most realistic bolt connections. They are evaluated according to the criteria listed above.

29

First idea
Strategy: Make the bolt assembly as similar as possible to a welded solution
Evaluation: To prevent the bolts from spinning custom made cuts in the elements are required. This ends need a lot welding to be able to fasten bolts.   **_Conclusion:_** It requires as much welding as it takes to weld the whole construction.   Bolt Assembly First Idea is **REJECTED**

Second idea
Strategy: Use the profiles square geometry to prevent spinning - easy to bolt true the sides.
Evaluation: This bolt assembly leads to a higher structure, or a smaller inside.   **_Conclusion:_** One of the design criteria was to keep RITS as small as possible. At this point of the project it is hard to estimate the needed space inside RITS; however it is not a good idea to let the bolt connection be dimensioning.   Bolt Assembly Second Idea is **REJECTED**
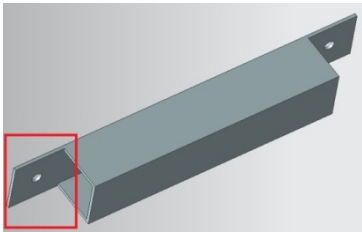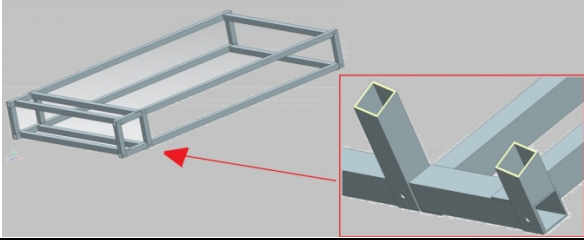
Second idea
Strategy: Adjust the ends without need for welding - and make it possible to bolt true the elements.
Evaluation: This bolt assembly method should be cheap to create; however the fastenings between the elements consist of only 3mm thick aluminum. It is assumed that this connection will surge which will expose the structure for fatigue.   **_Conclusion:_** The fatigue issue is evaluated to unsecure, there is not acceptable to loose RITS while operating on 2000 meters depth.   Bolt Assembly Third Idea is **REJECTED**

Table 11 presents some different bolt assemblies, none of them suited for RITS

4.4.2 Welded structures

The most common method to assemble a structure is by welding. As the bolt assemblies were found inappropriate - welding came out as the most ideal assembly method.

A welded structure allows an easier fastening of profiles perpendicular on each other. The welds are solid and usually stronger than the material in the elements. The welding will additionally provide a more adjustable geometry than a bolted connection since it is easier to fasten welded elements in any direction.

Many details on the structure, in addition to joining the elements, require welding. It is details as fastening of the cylinder and mounting of the instruments inside RITS. Non-destructive tests (NDT) of all the welded joints are required to control that the welds are properly made. The NDT methods for weld joints are x-ray or ultrasound, and the documentation that follow welded joints are more complicated than for a bolt connection.

The documentation is considered a disadvantage of welding since it requires a welding procedure which is developed by FMC and the operator welding RITS. When the documentation procedure is developed it can be used for all welds which make the process smoother.

Welding of aluminum require another technique than for steel which must be documented through a separate procedure. Except for that welding of aluminum elements is not considered a problem.

4.5   Outer Dimensions of RITS

The "footprint (length and width)" of the structure is decided by the size of the smallest ROV. The skid should not be bigger than the smallest ROV allows because it will increase the chance of hits towards the structure. The shortest and less wide ROVs are market in table 1 and result in a skid footprint size of 1550 x 2700 mm. 300 mm is added to the length to make space for the manipulator.

The skid will be mounted under the ROV with the risk of being exposed to hits from under. The skid height needs to have enough space for the tool package all the special tools are installed inside an API 17D interface receptacle. It is assumed that the tools do not need any more space than the interface receptacle. To be on a safe side a few millimeters are added to reduce potential complications later on. The dimensional tool height is determined to be 250mm, and the skid structure will build 50mm on both the lower and upper frame. This gives a total height of 350mm.

The skid's outer frame dimensions is: 1550x2700x350mm
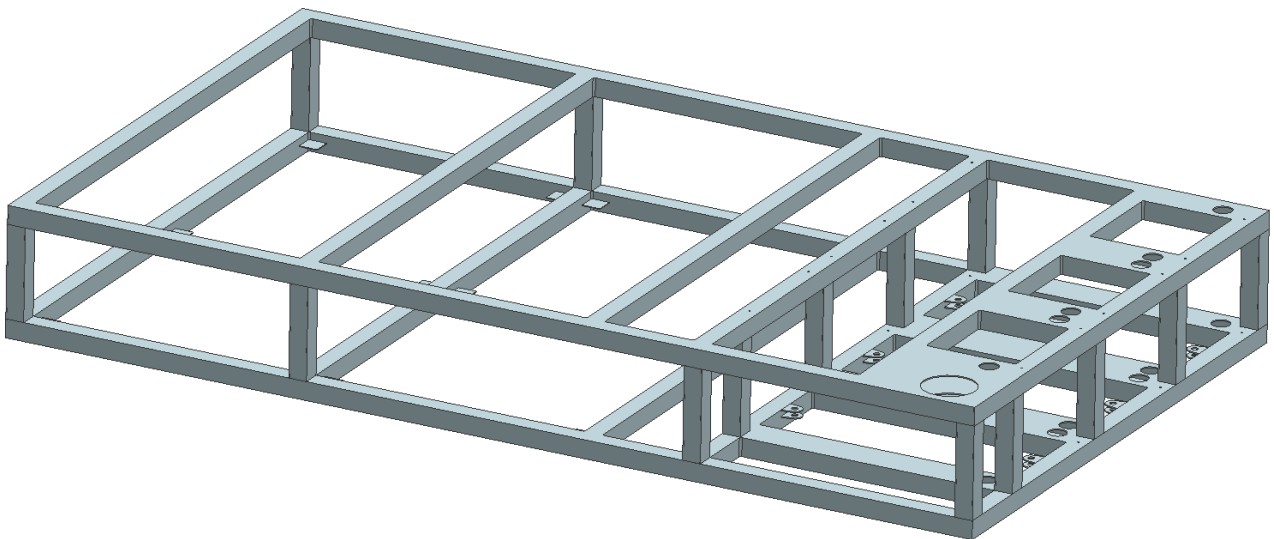
Figure 24: The Structure of RITS [MN]

4.6   Strength of structure

There is important to verify that RITS are solid enough to operate subsea, and can handle the impact load while the ROV will park upon existing subsea equipment. This calculation will be performed in ANSYS by use of the 3D-model presented in chapter 4.5.

RITS is built by 50x50x3 profiled aluminum 6082-T6, and the model created is fully compatible for a strengthen analysis in ANSYS. The CAD software needs material strength as input- which is 250 MPa for aluminum 6082. The model in ANSYS will be market with a color code if the forces on the structure overstep 250 MPa.

ANSYS does the analysis knowing the structure and material of RITS. However, there is a challenge to calculate the applied forces on RITS. "Det Norske Veritas" standard, **<u>DnV No 2.7-3: Portable Offshore units</u>**[19] describe the force that applies on subsea structures.

The forces presented in DnV 2.7-3 are the actual forces added safety factors. The actual weight of the structure and the landing speed of RITS need to be determined before the safety factors can be calculated. The most significant weight of RITS is the ROV mounted on the top of the structure. The figures in table 1.3 inform that a common ROV weigh approximately 5000 kg even though the interface receptacle will be designed with a rubber element on the end to reduce the impact load. The interface between RITS and the ROV will have some flex resulting in that the actual "impact weight" is estimated to 75% of 5000 kg.

The landing speed is presented in a FMC document, FMC SPC60099795: Intervention/Tie-In**,** ROV Interface Handbook - Design Guidelines[20], based on experiences from previous FMC projects. . The handbook assumes a realistic impact speed to be 0.5 m/s. The speed combined with the "impact weight" gives the actual impact force of:

$$Impact\ Weight = 5000kg \times 0.75 \quad Impact\ Load = Impact\ Weigth \times Speed \ \times g$$

$$5000 \times 0.75 = 3750 \ kg \qquad \boldsymbol{Impact\ Load} = 3750kg \ \times 0.5\tfrac{m}{s} \ \times 9.81\tfrac{m}{s \times s} = \textbf{18393N}$$

---

[19] (DnV, 2011)
[20] (Reinert, et al., 2013)

DnV 2.7-3: Impact load for strength analysis

RITS is a Portable Offshore Unit less than 25 ton and with a "high" risk (ref DnV standard 2.7-3) that makes it a **R45** class unit. This risk classification gives the opportunity to calculate impact forces that can be inserted in ANSYS.

Horizontal impact:

The force that will be the basis towards RITS in horizontal direction is given in chapter 3.6.1 in DnV 2.7-3. The test in CREO will be performed by inserting the calculated horizontal impact load, F_{HIR}, perpendicular to the structure.

F_{HIR} is the greatest of following factors (see table 5.2 in DnV 2.7-3):

$$Fhir = 2.5 \times Impact\ Load \qquad or \qquad Fhir = Impact\ load \times \left(1.4 + 0.8 \times \sqrt{(50/MGW)}\right)$$

$$Fhir = 2.5 \times 18393 \qquad or \qquad Fhir = 18393 \ x \ \left(1.4 + 0.8 \times \sqrt{\left(\frac{50}{3750}\right)}\right)$$

$$Fhir = 45982\ N \qquad or \qquad Fhir = 27449\ N$$

The horizontal impact load will be applied on the front of the structure on one of the longest elements with a force of:

$$Fhi = 45982\ N \times 0.08$$

$$Fhi = 3678\ N$$
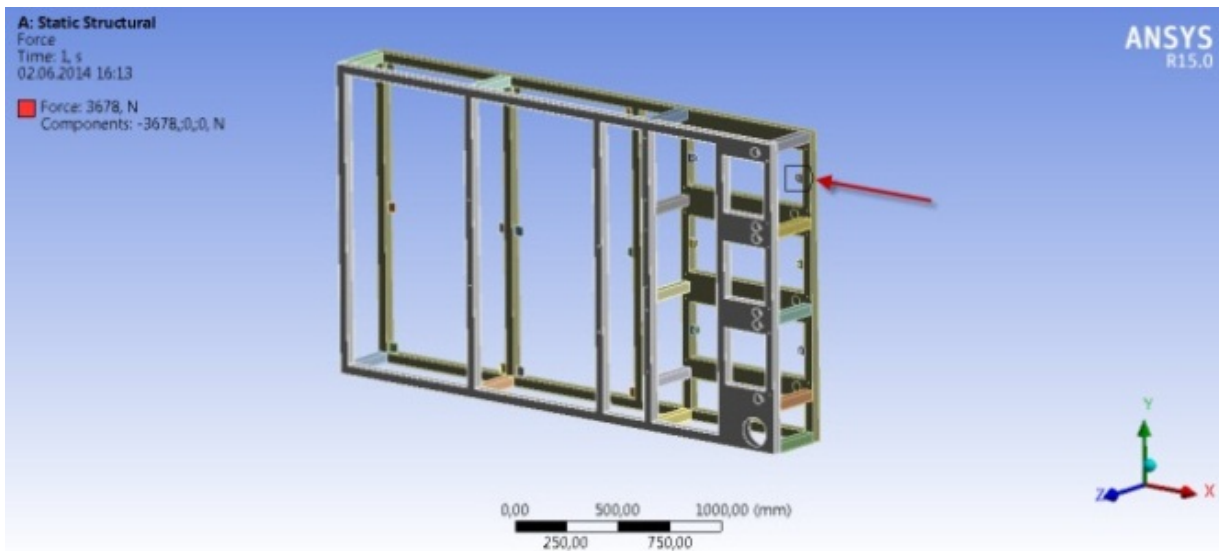
Figure 25: Horizontal Impact Load - and impact position (Case 1) [MN]

Vertical impact:

There are two scenarios that need to be fulfilled due to vertical impact.

All actual forces are applied at one corner. It is a possible scenario when RITS is put down on ground. This force is already calculated and is the same as "impact load" = 18939 N.
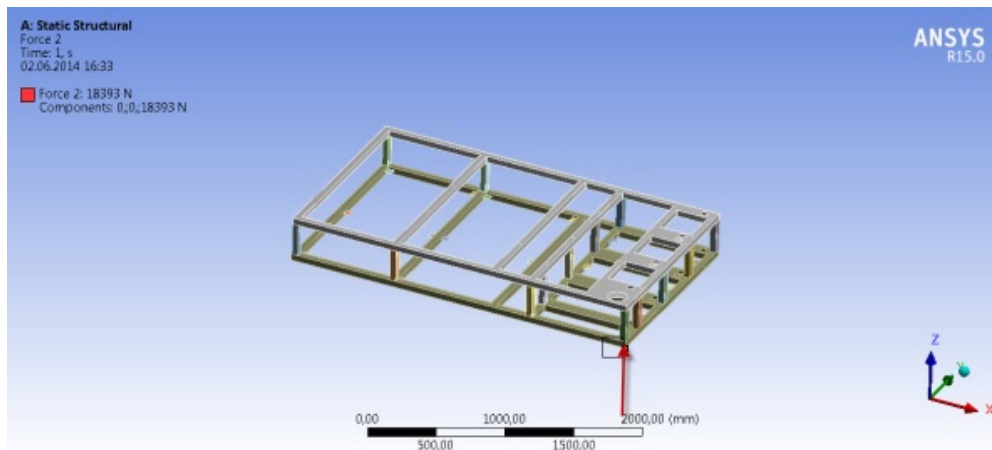
Figure 26: Force applied from beneath (Case 2) [MN]

The second scenario is similar the horizontal impact (3678 N); however it will be applied to the weakest point of RITS. The weakest point of RITS is on the longest element, which is one of the elements going perpendicular on the length of the structure.
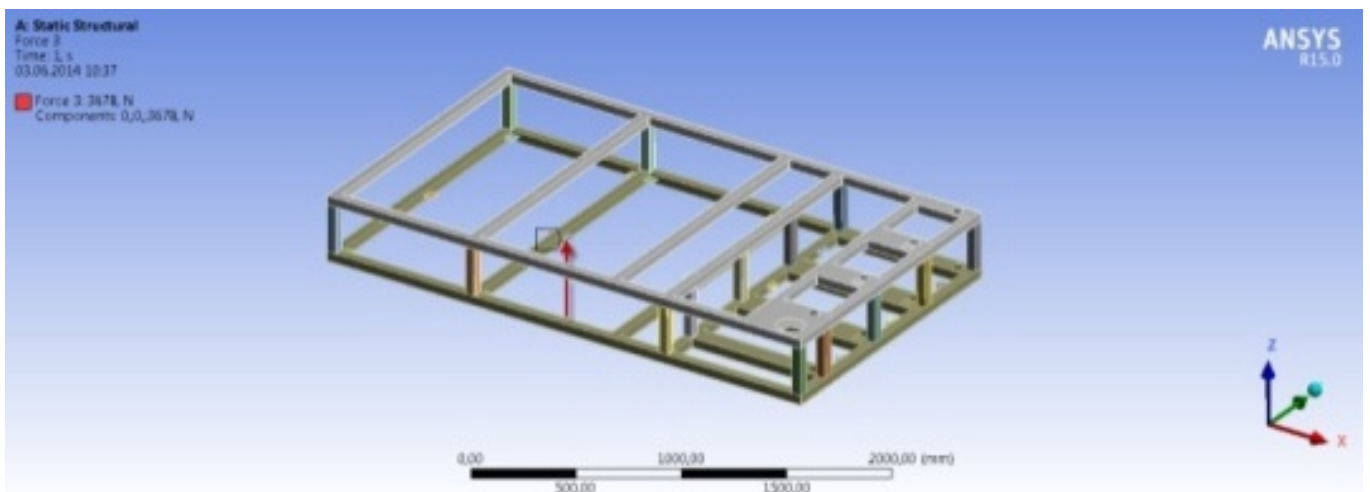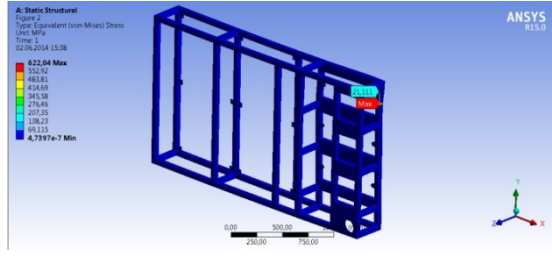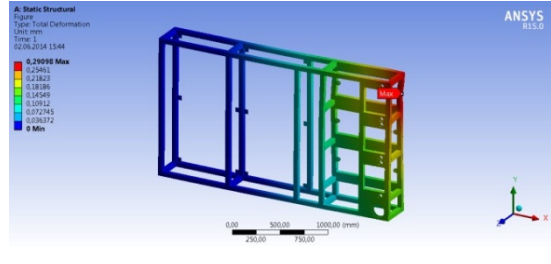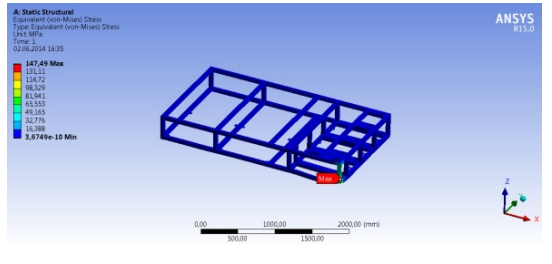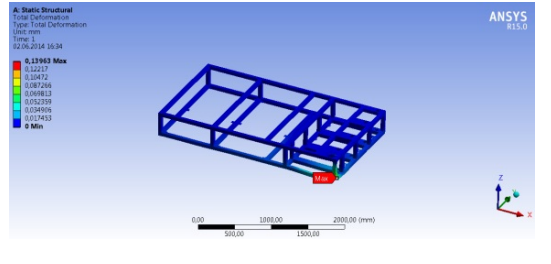
Figure 28: Vertical Impact Load on exposed element, Case 3 [MN]

The results from the analyses are presented on the next page.

4.7   Strength analysis

Case 1	
Requirements	
Stress Max 250 MPa* (Aluminum)	No requirements - should be functional
Stress = 21.11 MPa* = **ACCEPTED**	Deformation = 0.3 mm = **ACCEPTED**
*= Hot Spot, see Appendix B for explanation.	

Case 2	
Requirements	
Stress Max 250 MPa (Aluminum)	No requirements - should be functional
Stress = 147.5 MPa = **ACCEPTED**	Deformation = 0.14 mm = **ACCEPTED**
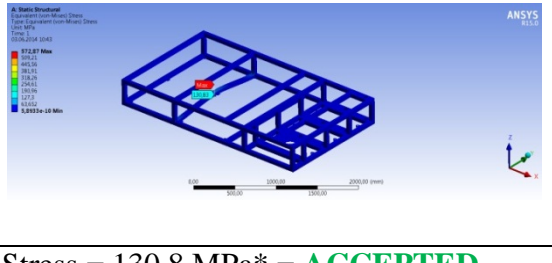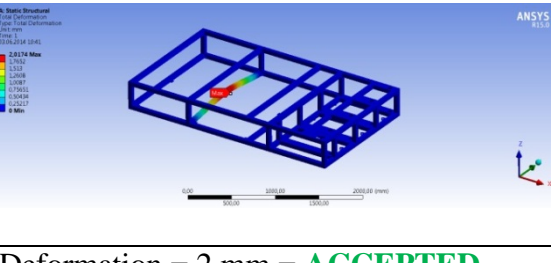
Case 3	
Requirements	
Stress Max 250 MPa (Aluminum)	No requirements - should be functional
Stress = 130.8 MPa* = **ACCEPTED**	Deformation = 2 mm = **ACCEPTED**
*= Hot Spot, see Appendix B for explanation.	

Table 12: All tables is stress and deformation analysis of structure

Chapter Five - The Cassettes

The cassettes are an important part of RITS, almost all the capabilities in RITS are in the cassettes. There are two types of cassettes; one with an API 17D interface and one without the API 17D interface. The main purpose of the first type is to be able to dock on to subsea equipment while main purpose with the last one is to provide RITS with loose tools.

There will be designed five different cassettes - all with different capabilities. There is space for three cassettes on the RITS at the time, so the customer can choose which of the five alternatives they need for the exact operation.

5.1 Modes of operations

Few systems in the subsea business are module based. Normally there is a new special design to every project, even if a similar project is developed earlier. The RITS design should be modified to a system that is more flexible.

All the different tools will be installed in the cassettes and the customer should be able to choose which tools they need. The manipulator should also be a part of customer package choice. By defining the cost of each piece a flexible module system is created, and the customer can pay due to their need; however it is recommended to have the manipulator installed at all times to maintain the flexibility.
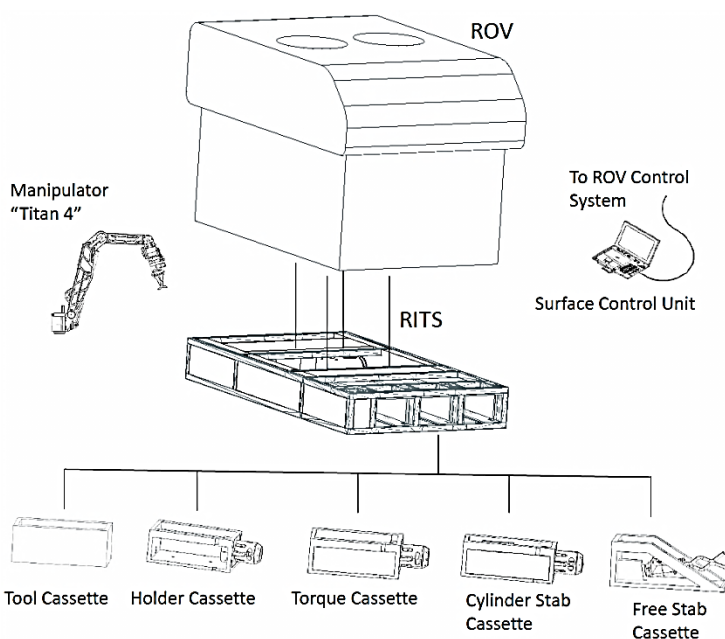
There is only possible to install one torque cassette and one cylinder stab cassette at the time. It is because the control system limited, it is not enough hydraulic components to handle more than one of these components at the time.

Figure 29: Cassette Configuration [MN].

5.2 The Cassette Design

There are a few design requirements that count for all cassettes.

1. Equal size to fit in the same guiding system.
2. Approximately the same weight - It is an advantage that the people handling RITS can switch between the cassettes without concerning about the center of gravity.
3. Mounting system - which way the cylinder is mounted

Equal Size

The size of the cassettes is dependent on the outer dimensions of RITS while the size of the skid was determined by size of the tools. The height was dimensioned to allow space for the largest tool, the torque tool. The length of the cassettes is slightly increased to make space for additional buoyancy and also to make the cylinders fit. It results in cassette outer measurements of 230x360x600.

Equal Weight

The cassettes are designed in the same material as RITS, aluminum 6082-T6, to avoid galvanic corrosion. The cassettes will be filled with syntactic foam in all hollow areas to make the cassettes buoyant in water. The plate elements consist of two aluminum plates with room for syntactic foam in between, the resulting in a sandwich construction that makes the cassettes both lighter and stronger (see figure 31).

There is not necessarily enough room for buoyancy to make the cassette neutral in water. The tools inside the cassettes will increase the weight, and to compensate this weight dedicated areas for extra buoyancy elements are created in the structure - chapter 5.2.1.

The weight and volume measurements of all cassettes are performed in NX - the buoyancy is calculated in Excel.

Different mounting system

The two different cassette types have different methods for mountening the cylinders and for fastening to RITS. Cassette type one is fastened on the mounting ears in front of RITS. This is because type one cassettes will be exposed to the impact load when the ROV parks RITS.

The second cassette type does not have the same requirements due to strength, and they will not be functional unless the cylinder is mounted in the opposit direction - chapter 5.4.

5.2.1 Cassette Buoyancy

The areas in front of the structure where the cassettes are installed will prevent too much variation of the center of gravity (CoG).

The calculation of buoyancy is the volume of the elements multiplied with the floating capacity of syntactic foam, the volume is measured in NX, while the calculation is performed in excel (a document added the source list)[21]

The dedicated elements are located over and under the structure in the front. The right combination of these three alternatives will make the cassettes equally weighted.

Figure 30: The buoyancy elements dedicated the cassettes [MN]
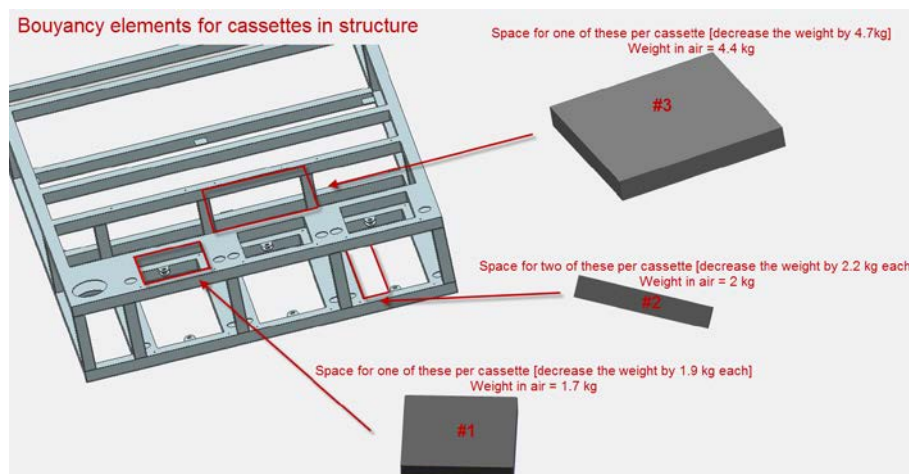
Table 13: An overview of which cassettes and the use of elements

Cassette	#1	#2	#3	Weight reduced	Weight in air
"Tool" Cassette	-	-	-	-	-
"Holder" Cassette	1	-	-	-1.9 kg	1.7 kg
"Torque" Cassette	1	2	1	-10.9 kg	10.1 kg
"Cylinder Stab" Cassette	1	2	1	-10.9 kg	10.1 kg
"Free Stab" Cassette	1	-	-	-1.9 kg	1.7 kg

The table reveals how many elements the different cassettes will need. It is based on an evaluation of the weight of the tool combined with the cassettes.

---

[21] Excel: Buoyancy calculation

5.3   The Cassettes Type One with an API interface

The cassettes have tracks and holes to make it fit the structure. In front it is hole made to fit the API 17D interface. On the other side there is a hole created to make room for the hydraulic and electric lines. The lines connect the cassettes to the structure where the control units are postioned.

These traces and holes makes it possible to create a standard cassette structure and buoyancy.
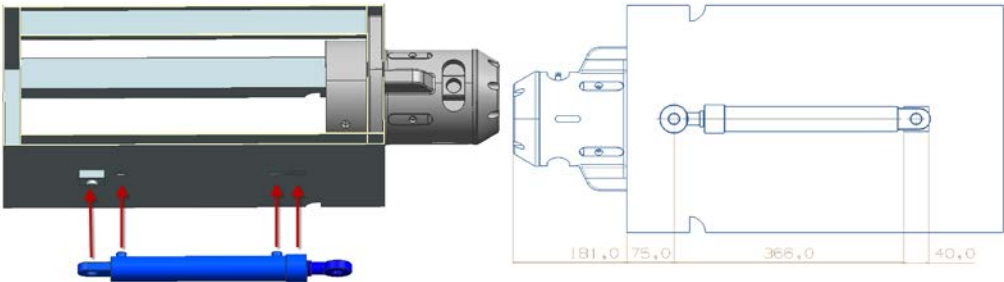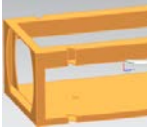
Figure 31: Adjustments created to fit the cylinder [MN].

The most challenging customization are the tracks to make the cylinder fit - the cylinder is the same as presnted in chapter 3. The tracks in the cassette will have extra 75mm applied in the front to adjust the cylinder to be fastened to the mounting ears in the structure.

The type one cassettes are installed with the interface receptacle to be able to dock on to subsea equipment. Some of the type one cassettes have additional capabilities because of integrated tools. Cassettes of this kind have similar structure and a "standard" buoyancy package.

Table 14: Standard Cassette type 1 - weights

	Weight in Air	Weight in Water	
Cassette structure	6.044 kg	3.8 kg	
Standard Buoyancy Package	3.3 kg	-3.6 kg	

Cassette type one is fastened on the mounting ears in front of RITS. This is because type one cassettes will be exposed for the impact load when the ROV tries to park RITS. The impact load will be calculated later on; however the design direction of the cylinder used are explained in the cylinder chapter 3.1.3.

The structure is designed with mounting ears illustrated in Figure 32. The cylinders on the cassettes are adjusted to fit into those ears. Figure 32 illustrates the first 800 mm in front of the structure of RITS.
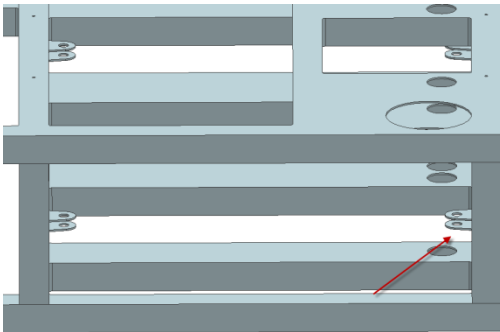
Figure 32: Cylinder mounting ears, cassette type one [MN]

This is the main difference between the two cassette types. Chapter 3.1.3 Cylinder Position explains the main idea of the placement of the cylinders that will handle the impact load of parking RITS.

The cassettes type two has other limitations due to strength and functionallity, the reason is explain in chapter 5.4 - The Cassette Type Two; however the conclusion is a cylinder mounted in oppocite direction and fastened in the mountings ears behind.
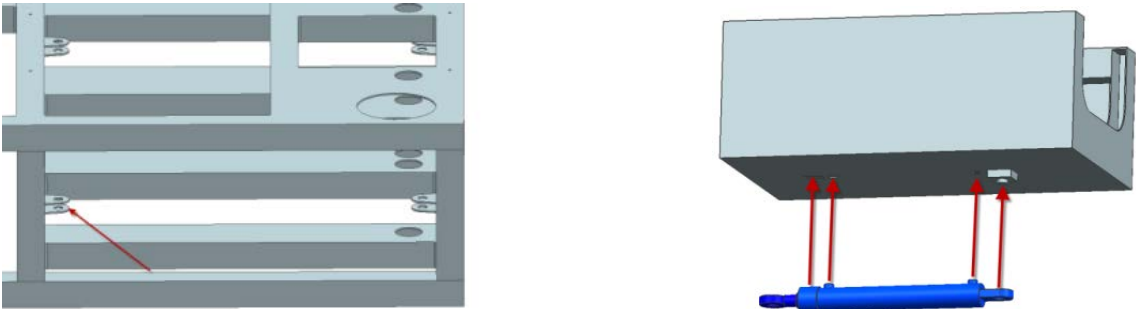
Figure 33: Mounting of cassette type two, note cylinder direction [MN]

Torque Cassette
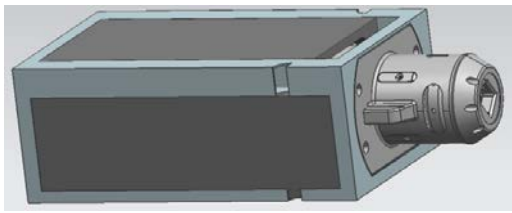
Figure 34: Illustration of the Torque Cassette [MN]

The Torque Tool is hidden behind the buoyancy elements - figure 33. Behind the foam elements it looks like presented in the tool chapter (chapter 3 - figure 19). The ROV handle is not installed in the cassette since there is no need for it, and it will cause extra weight.

The Torque Cassette is the heaviest of the cassettes, since there is not sufficient space for buoyancy elements to make it neutral in water. Consequently, it will determine the weight of the other cassettes

Table 15: Weight of all the components and the total weight of the torque cassette

	Weight in Air	Weight in Water
Cassette structure	6.044 kg	3.8 kg
Tool Weight (ref chapter ___)	39 kg	30 kg
Standard Buoyancy Package	3.3 kg	-3.6 kg
Extra Buoyancy	14.6 kg	-15.6 kg
*Structure cassette buoyancy - See chapter 5.2.1**	*0*	*-10.9 kg*
Total Weight	**63 kg**	**3.8 kg**
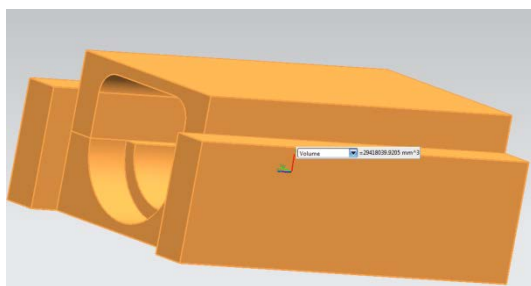
Figure 35: Maximum buoyance possible inside the torque tool [MN]

Figure 24 shows how much syntactic foam that is possible to fill in the Torque Cassette in addition to the standard buoyancy package. The volume is 29418040 mm^3 which results in a weight in water reduction of 15.6 kg.

The lowest weight possible for the Torque Cassette will be 3.8 kg. This weight is determined by the weight of the structure and the tool, in addition to standard buoyancy elements.

It results in an extra cassette buoyancy alternative is implemented that reduces the weight in water by 10.9 kg.

Cylinder Stab Cassette

The cylinder stab cassette is a custom-made solution where the hot stab is installed inside an API 17D interface. It requires a special design of the hot stab interface on the subsea installation.

The system works by using an extra cylinder that can push an extended hot stab through the API receptacle. A guiding system with a rail and tractor is integrated in the cassette to secure a proper guiding.
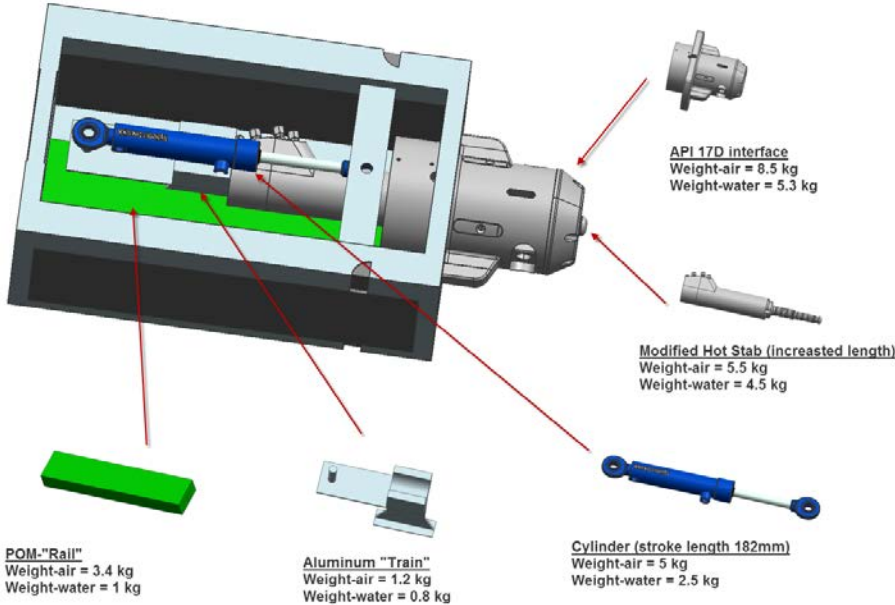
Figure 36: The Cylinder Stab Cassette, with all the extra components making it work [MN]

The components needed to push the hot stab, makes this unit similarly weighted as the torque cassette. The structure is a bit modified which results in a higher weight in addition it results in a lower buoyancy effect. By using extra buoyancy calculated in chapter 5.2.1 it is possible to lower the weight in water to 2.4 kg, which is approximately the same as the weight of the torque cassette.

Table 16: Weight of all the components and the total weight in the cylinder stab cassette

	Weight in Air	**Weight in Water**
Cassette structure	6.22 kg	3.92 kg
Tool Weight	22.52 kg	13 kg
Buoyancy in structure	3.3 kg	-3.6 kg
Structure cassette buoyancy - See chapter 5.2.1	0	-10.9 kg
Total Weight	**32 kg**	**2.4 kg**

Holder Cassette
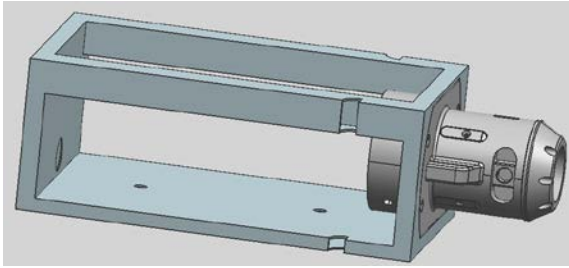
Figure 37: The holder cassette [MN]

The holder cassette will not have any function except from parking RITS onto the interface bucket. The structure will still be built in the same way as the rest of the cassettes type one,

with a standard buoyancy package and standard aluminum profile.

The cylinder underneath has a maximum stroke length of 181mm, which is restricted to only push the interface out. To be able to get access inside the holder cassette, an extra stroke length will be required, figure 37 illustrates the problem.

Since stem is pulled completely inside the cylinder housing when cassette edge and the structure edge are aligned there will be no access to the inside of the cassette. It results in a cassette that will not be able to carry any tools. The cassette type two is more suitable in cases where a tray should be required the holder cassette must be installed to provide the API 17D docking option.

The most likely usage for the holder cassette is when two, type two cassettes are need. The holder cassette is easy to make buoyant because of the available space inside; however it is preferable to install the buoyancy in the dedicated structure areas to keep low weight of the cassette in air.

The extra needed buoyancy should be installed in the structure and not inside the cassette since it will make the handling of the cassettes on deck easier. It is a strategy that applies for all the cassettes.

Table 17 Weight of the components and the total weight of the cassette

	Weight in Air	Weight in Water
Cassette structure	6,044	3.8 kg
Tool Weight	8.5 kg	5.3kg
Buoyancy in structure	3.3 kg	-3.6 kg
*Structure cassette buoyancy - See chapter 5.2.1**	0	-1.9
Total Weight	**17.8 kg**	**3.6 kg**

5.4   The Cassette type two for Tool Carriers

The main purpose of the cassette type two is to bring special tools subsea. It function as a tray and will not be installed with the API 17D interface.

The lack of the API 17D interface requires a different fastening of the cylinders. Normally the cassettes with API interface are in operational mode when the cassette edge is aligned with the structure edge (the API will then be pushed 181 cm out in operational mode). The same stroke lengths apply for cassettes type two, and there will be no access of the tools inside. A different setup is therefore required for the cassette type two cylinders.

When the cylinder is mounted in the original direction there is not possible to push the cassette longer than

By turning the cylinder the cassette will be able to open, and the manipulator can pick out the tools inside
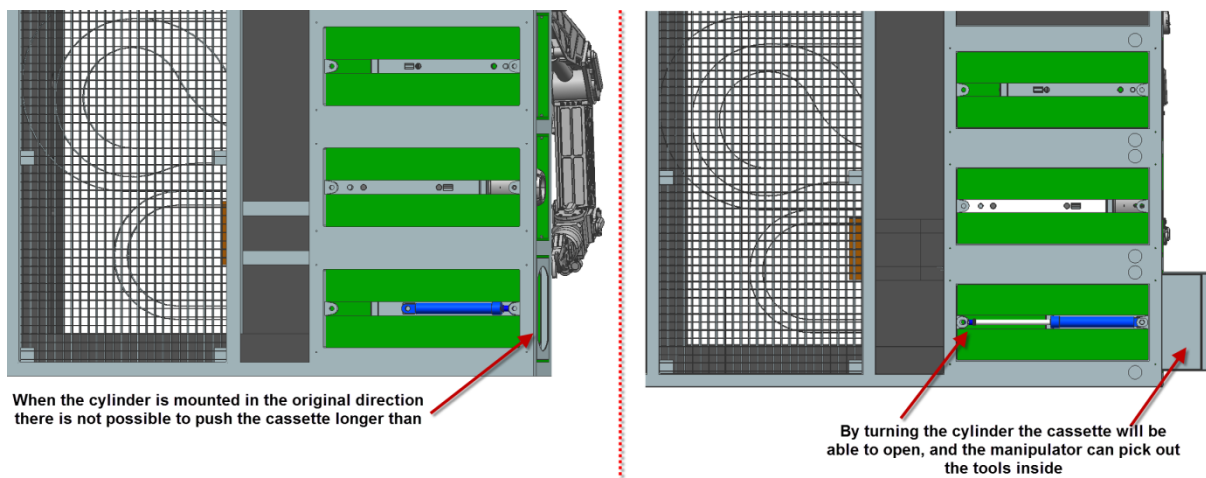
Figure 38: Direction of cylinder due to cassette type [MN]

A simple solution is to mount the cylinder on the mounting ears behind the cassette. The tool carriers will merely bring tools subsea, and are not designed to handle any impact loads because they do not have any API interface. As a result, the Cylinder Position presented in chapter 3.1.3 will not apply for cassette type two.

RITS are designed with two different tool carriers and there is not possible to create a standard cassette structure or buoyancy profile. The cassette structure will nevertheless be filled with as much syntactic foam as possible.

The "tool" Cassette
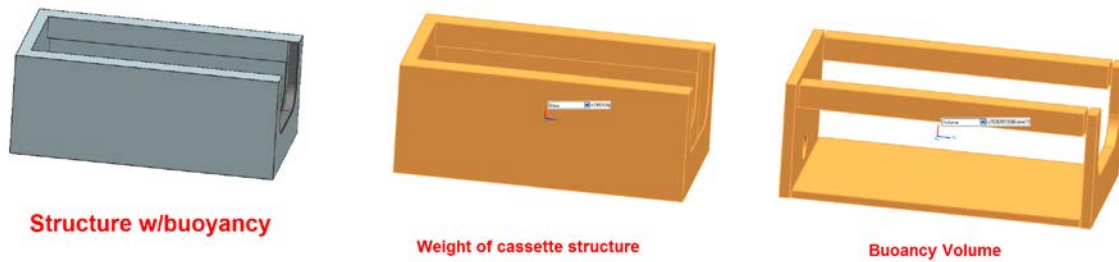
Figure 39: Weight of the components and the total weight of the tool cassette [MN]

The tool cassettes have a unique and simple design which is suited for this cassette only. The aluminum structure is heavier than the other cassettes since there is no need for hole to make the API 17D interface fit, however it is partly compensated with more space for buoyancy. There is no tooling other than the structure itself. The cassette weight is 1 kg in water.

Table 18: Weight of all the components and the total weight if the cassette

	Weight in Air	Weight in Water
Cassette structure	7.65 kg	4.8 kg
Buoyancy in structure	3.5 kg	-3.8
Total Weight	**11.2 kg**	**1 kg**

Free Stab Cassette
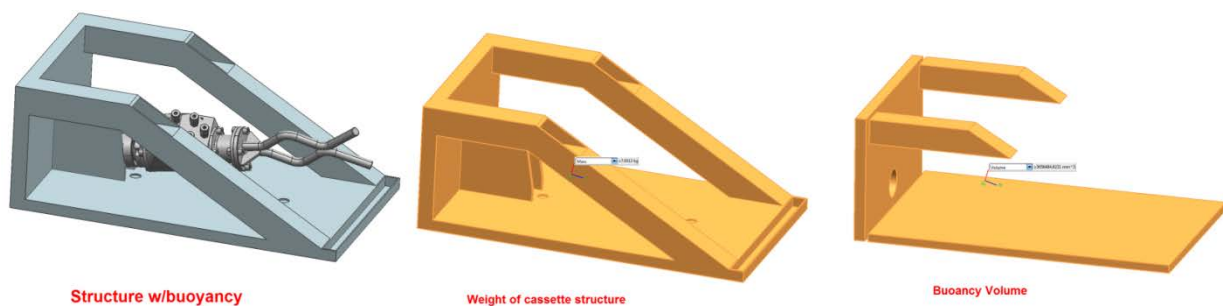
Figure 40: Free stab cassette [MN]

The free stab cassette is more customized than the others. The cassette structure is without any front so it is possible to reach the hot stab. The modified structure requires a different buoyancy package than the other cassettes, and the structure will therefore be of different weight.

Table 19: Weight of all the components and the total weight if the cassette

	Weight in Air	Weight in Water
Cassette structure	7.0 kg	4.4 kg
Tool Weight*	4.5kg	3.5 kg
Buoyancy in structure	2.5 kg	-2.7
*Structure cassette buoyancy - See chapter ___ *	0	-1.9 kg
Total Weight	**14 kg**	**3.3 kg**

A structure dedicated buoyancy element is installed to keep the weight of the cassettes approximately equal. It results in a weight in water of 3.3 kg which is within acceptable tolerance compared to the weight of the other cassettes.

In addition the free stab cassette will need more flexible hoses since it will be pulled out by the manipulator. The manipulator will handle the free stab by pulling it out from RITS and into the position on the ROV panel, as illustrated in the upper illustration of figure 41.

Hose for free stab
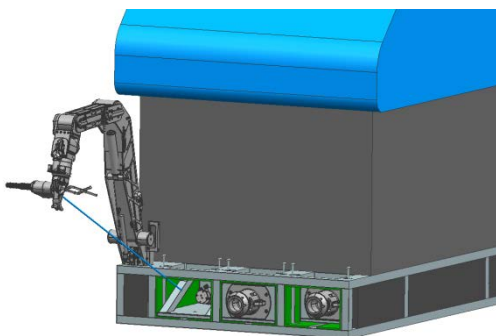
The first idea to handle the flexible requirements of the hose was to install a hose reel; however a hose reels are not tested for subsea. To avoid complications with the reel another system was developed. By installing an elastic band to the hose it will be pulled back as illustrated on figure 41.
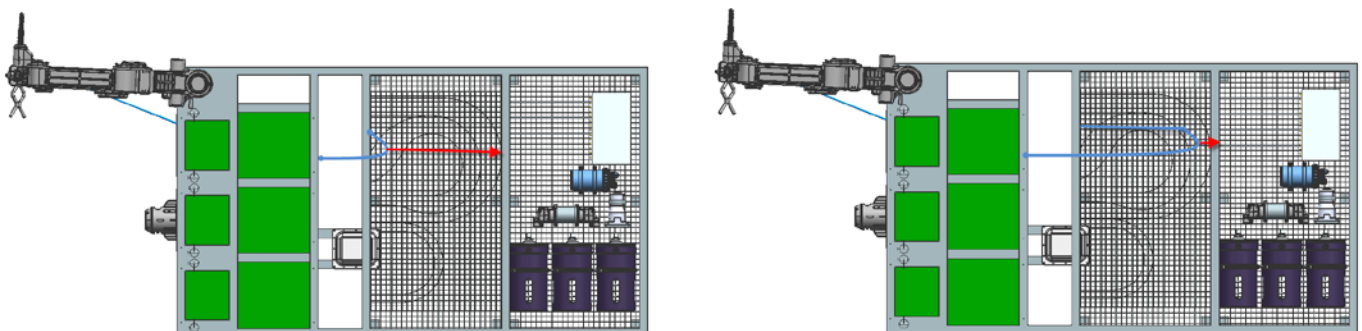
Max pulling length = 2 x middel grating
= 2 x 750mm = 1.5 meter

Figure 41: Hose retrieval system [MN]

The elastic band is connected the hose and will pull the hose in. A disadvantage is that it will be pulled back if the manipulator loses its grip. The advantage is that a system like this is not woundable for deep water.

5.5 Hose - Cassette hydraulic supply[22]

All the cassettes will be moved from operational to transport mode several times, to allow such a system a flexible connection of hydraulic hoses will be required. Hoses are normally strong with respect to pressure from inside, however hoses have a tendency to collapse if the external pressure gets much higher than the outside pressure. Hoses applicable for 200 Bar external pressure is quite stiff because they consist of several layers of steel.

The hose recommended from TESS Kongsberg was the TESS 5040. It meets all the requirements for the RITS. It handles external pressure of 200 bar, internal pressure of 300 Bar and it is capable to supply enough flow. The only challenge with this hose is the minimum bend diameter of 360mm. The bend diameter is demanded to ensure that the hose will not break, and the diameter will be central in the flex system required for the cassettes.

$$Formula\ for\ Circumferece = 2\pi r$$
$$Circumferece, \min inner\ circle = 2\pi\ x\ \left(\frac{360}{2}\right) = 1155\ mm$$

Extra length needed is 200 mm which is the length the cassettes will move.
$$Min\ Diameter, outer = 1155mm + 200mm = 2\pi \times \left(\frac{x}{2}\right) = 431\ mm$$
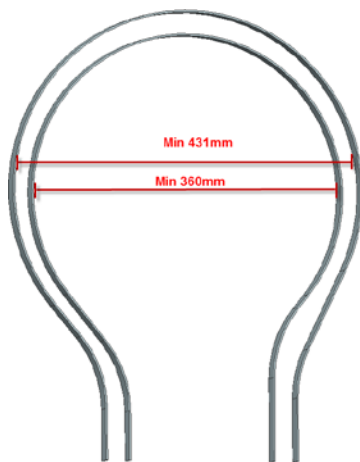
Figure 42: Example of guiding system of flex hoses 200mm [MN]

The figure shows the principle to achieve flexible hydraulic lines. By letting the hose move freely between the guiding "walls" the hose will be able to move 200 mm without any stretching. The stiffness in the hose will ensure a controlled movement - which means that the hose will increase or decrease it diameter in a secure way. The guiding system will be installed in an enclosure built up of two gratings and side walls where the hose freely may move and bend. The hose will be protected with an outer wear-protection from TESS.
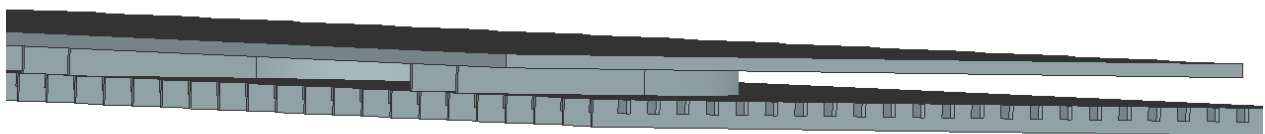
Figure 43: Guiding of the hoses will be arranged between two gratings [MN]

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[22] (Foss, 2014) and TESS catalogue 2014

Chapter Six - Manipulator

Titan 4 is a recommended manipulator from Schilling Robotics. Schilling Robotics is the main supplier of manipulators for the subsea industry, and the Titan 4 is their most successful invention. The control unit is inside the manipulator it only require power and signal cables connected to be able to operate Titan 4 is the natural choice of manipulator for the RITS

Mechanical Data[23]	
Length	1922mm
Width	-
Diameter	-
Weight in Air	100 kg
Weight in Water	78 kg
Hydraulic Data	
Pressure	207 Bar
Flow	19 lpm
Fluid, oil	Shell Tellus Oil 32
Filtrations	3 microns (10 microns absolute)
Electric Data	
Input Power	24 VDC
Power consumption, incl. solenoid	6W start, 12W run
Slave arm current draw	1.875A, at 24VDC
General Data	
Max Water depth	4000 meter

Table 20 Data for Titan 4

The Titan 4 will be installed on the top front of the RITS. The manipulator will during transport be in a position where the ROV protects the manipulator from direct hits. Kinematics for Titan 4

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[23] (Schilling Robotics, 2012)
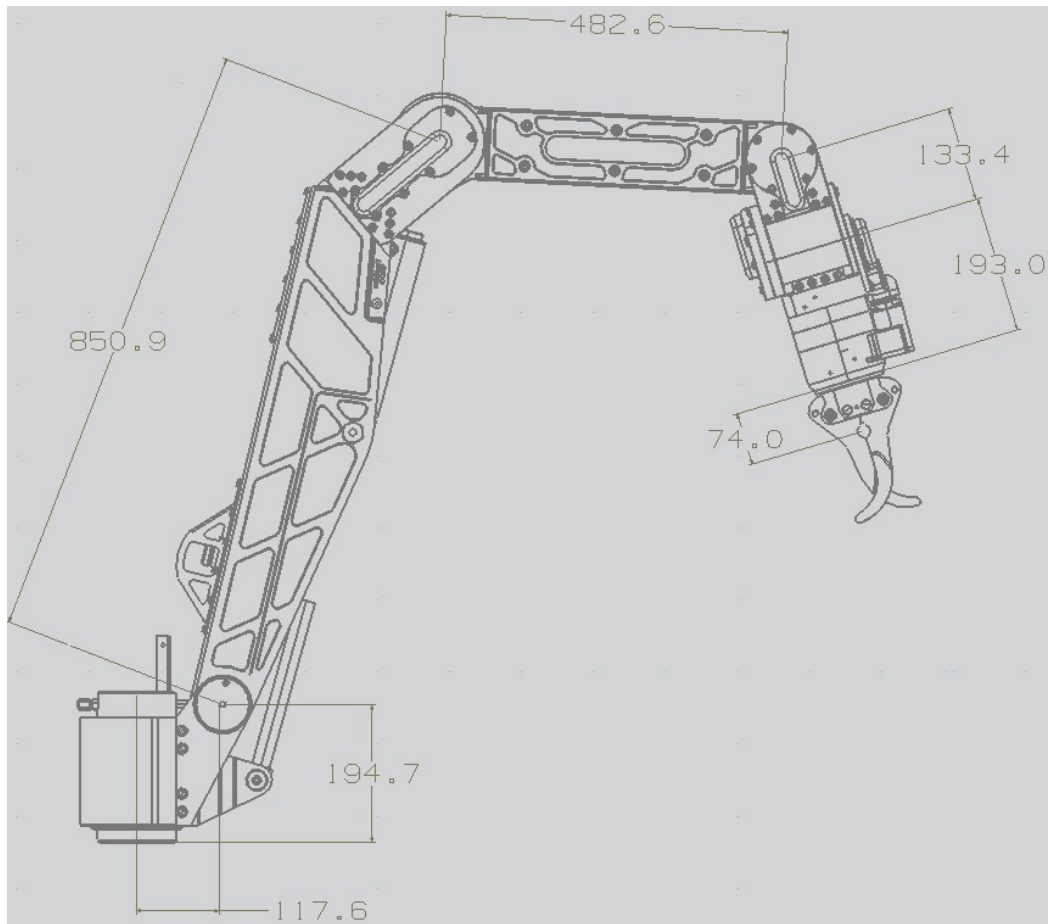
Figure 44: Measurement of Titan 4 [Source 24]

Table 21: Kinematics for Titan 4 - 6 revolute joints and joint lengths

Link[24]	a_i	α_i	d_i	Θ_i
1	121 mm	π/2	195 mm	Θ_1*
2	851 mm	-	-	Θ_2*
3	483 mm	-	-	Θ_3*
4	133 mm	- π/2	-	Θ_4*
5	-	- π/2	-	Θ_5*- π/2
6	-	-	193.0mm +74.0 mm	Θ_6*

---

[24] Source: Robotics book

6.1 Kinematics, Visual Components and Python Programming

The main challenge to operate a manipulator automatically is to create an expression between the angles in the joint and the coordinates in the 3D-space. The manipulator-gripper will get the information to move to a given coordinate; however the issue is what joint angles that give these coordinates.

Each joint will need a separate angle - and to make it a bit harder - there are several different angles that can achieve the same coordinate for the gripper at the end.

6.1.1 Kinematics

The tools solving these problems are called forward and invers kinematics. To avoid going deep into this expressions, a simplified explanation is considered enough for this study. Here only the principles are briefly described, as the software are fully developed and delivered with the Titan 4, and a RITS operator will only be an ordinary user.

The forward kinematics needs an input of the angles in all joints at every time step. The forward kinematics output is the grippers position in 3D space, represented by a [4x4]-matrix that gives the rotation and position.

It is possible to interpolate a [4x4] matrix, and when the interpolation is executed it is possible to add a value to the existing [4x4]-matrix. This new matrix is the first step on the way to the end position. Inverse kinematic will then produce new joint angles and the manipulator moves. The joint angles are presented as a [6x1] vector.

Forward kinematic will produce a new [4x4]-matrix and a new interpolated value can be added. By performing this process enough times the manipulator will finally be at the end position.
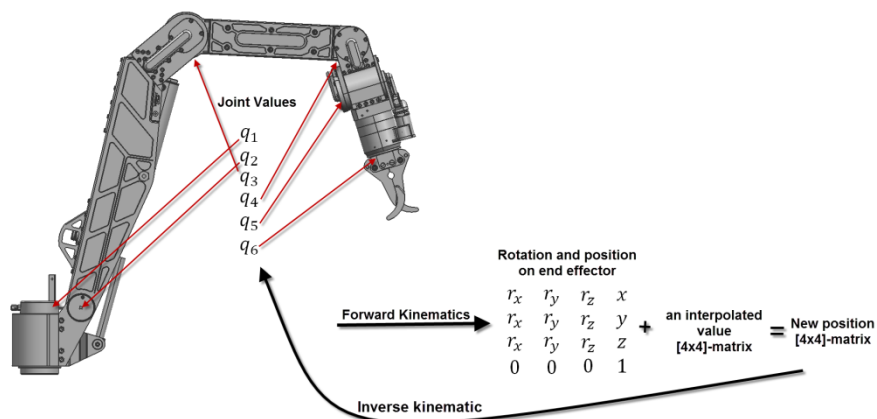
Figure 45: Kinematics explanation of the robotics [MN]

6.1.2 Visual Components

Visual Components (VC) is the software that performs the kinematics calculation. In addition to the calculation it has a good application to illustrate this. VC will be able to give the Titan 4 all its needed joint angles to complete a movement. VC has a database for a number of different manipulators; however Titan 4 was not included in this database. The Titan 4 what to be implemented manually, which required a new geometric model, new kinematics and so on.

The picture in figure 46 is capable to simulate the whole operation, and by adding the subsea unit in the figure it is possible to illustrate exact operations in detail.
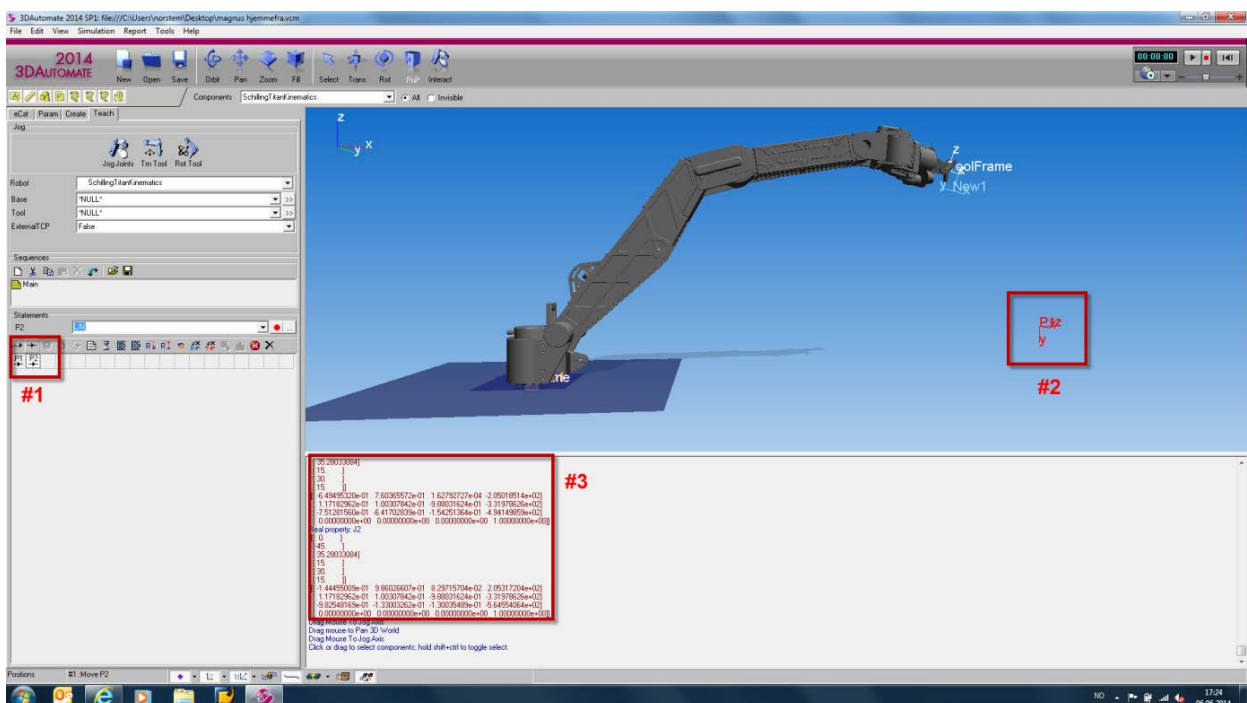
Figure 46: Screen shot of Visual Components

1 Is the function that defines the point the manipulator should move to. A new point in the movement are set by manually move the manipulator to the wanted position and then push the #1 button and a new point in the movement of the manipulator is created.

2 Illustrates the point that the manipulator shall pass through during the programmed motion.

3 The kinematics are presented in box #3. The values in this box can be programmed in to the Titan 4 software, and the manipulator is then ready for a new step/movement.

6.1.3 Python

The biggest challenge to make a fully working Titan 4 in VC, was to implement the kinematics. New kinematic was created for similar manipulators as used in VC and in the NTNU course TPK4170, "Robotteknikk". The coding was done in Python, and the software for the manipulator is able to calculate the joint angles and the end-effectors position.

The kinematics seems to work and the coding is shown in Appendix D.

6.1.4 Example of robotics on a RLWI-stack

The illustration application in VC is a useful tool to present robotics and its abilities. As an example video simulation of the RITS working with a UR5 manipulator is presented.

The video may be found in the source folder following this thesis. It is called:

UR5 simulation - RLWI-panel
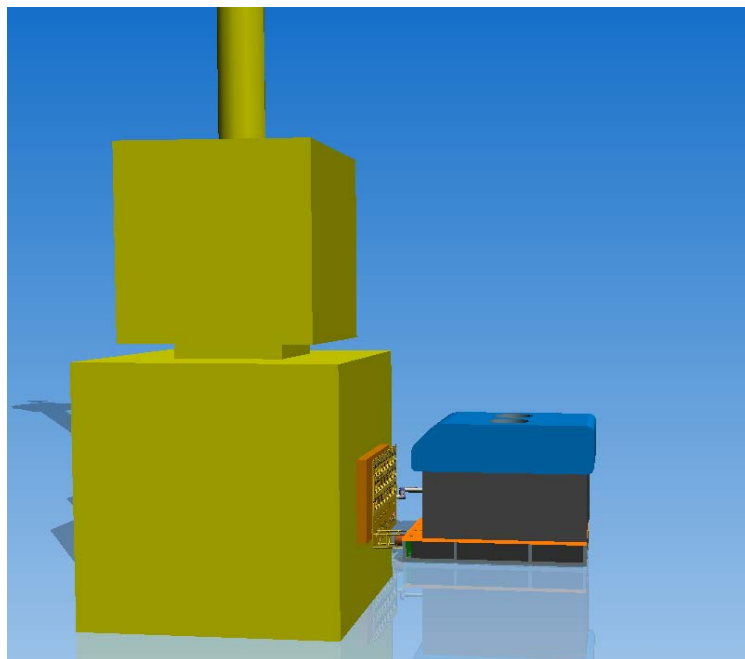
Figure 47: Simulated example in VC

Chapter Seven - Hydraulic System

RITS has two hydraulic systems because of stricter requirements of clean fluids into a XT. This demands a separate system since the fluid the ROV provides does not meet such requirements. RITS is powered from the ROV's auxiliary valve pack, which is called dirty valve pack. Most tools are able to operate on "ROV-Fluid"; however an extra filter is often installed to reduce the wear on the systems. The fluid supplied from the ROV is in most cases ordinary hydraulic oils as e.g., very often a Tellus oil from Shell, and the "dirty" fluid side is therefore often by slang called Tellus hydraulic side (at least in within the FMC).

The clean system is driven by a motor-pump solution, which avoid the fluids from being mixed. The "dirty" system powers a motor, and the motor is interconnected by a shaft and a coupling to the pump shaft of the clean system. This system is called Hydraulic Power Unit (HPU). The fluid that runs in the HPU system depends of what kind of system the tool e.g. a hydraulic hot stabs, is specified to operate with. It is usually specified oil and can be mineral oil as well as water based oil.

Tellus (32) oil[25]

Viscosity: 32 sST
Density 900 kg/m^3

Clean Fluids

The main reason to use mineral oil is to make XT stay subsea for 20 years. To meet these demanding conditions there are strict requirements for these systems, and where especially the solenoid valves demands clean fluid. To avoid problems as bacteria growth inside the control units a mineral oil are demanded.

There are several different types of mineral oil that varies due to supplier of the XT; typically mineral fluid frequently used is Oceanic HW443.

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[25] (Shell, 2008)

7.1   Hydraulic Schematics[26]
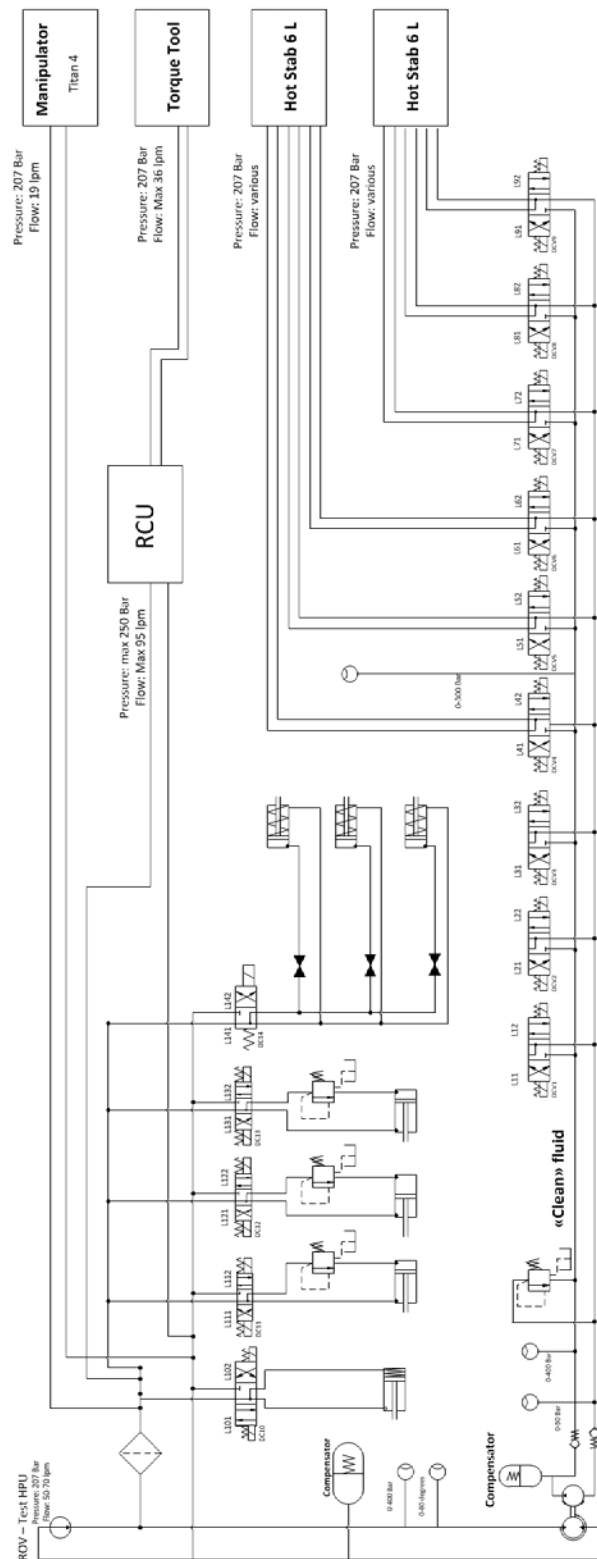
Figure 48: Schematics created in Visio [MN].

Note! The check valves on the hot stab are not implemented in this drawing. See Appendix A

---

[26] Hydraulikk bok

7.1.1 Valves used in the RITS Schematics

The schematic reveals the components that will make RITS work. The electric power, control signals and the hydraulic power are provided by or transferred through the ROV. The electrical power and signals comes from topside through the umbilical to the ROV, while the hydraulic power comes from a tank in the ROV. RITS will not consume any fluid, since the system is a closed circuit and cause of that return all fluid taken from the ROV.

Solenoid Valves

A solenoid valve is a control valve for the hydraulic lines that activates the cylinders or the special tools. The solenoid valve best suited for subsea use need to handle high external pressure and have the ability to be reliable operated from the surface, maybe 2000 meters away.

Figure 49 is illustrating how a solenoid is working. The figure to the left is showing the solenoid valve in normal position. There are springs on each side of the solenoid valve forcing the cylinder in the "normal" position when the solenoid not is powered. When electricity is put on the solenoid valve will overcome the spring force, and the core with the valve openings will move. By putting on electricity on the right side the fluid will circulate in a direction that extends the cylinder (picture in the middle). If the stem of the cylinder shall be pulled back, electricity on the left side is put on. Then the circulation will turn the other way and close the cylinder.
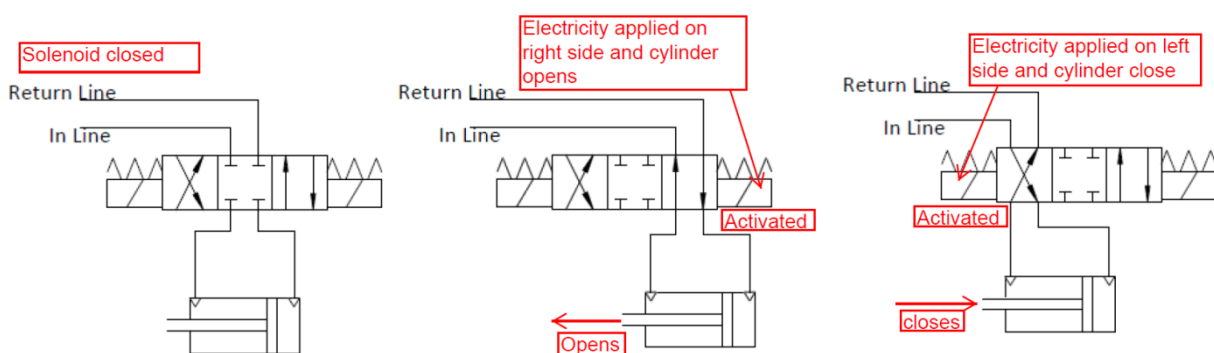
Figure 49: 4-3 Solenoid valves spring loaded [MN]

4/3 solenoid valve

A 4/3 solenoid valve means a valve with 4 ports that has 3 different position - like the solenoids presented in figure 49. This kind of solenoid is suited to handle double acting cylinders and hot stabs.

Wandfluh BM4D32-G24-M55-M35[27] is the solenoid valve that will be used inside RITS. It is a 4/3 spring-electric valve. In the normal position (like it is drawn in the schematics) it is closed, but if an electric voltage is applied the valve switches over and a circulation starts. If power is lost the springs will force the valve back to closed position. It is a contingency mode - and the hydraulic flow stops.

A simplified version of the BM4D32-G24-M55-M35 is used for the locking dogs. This kind of valve is a 4-2 spring solenoid valve. The 4-2 solenoid valve is used in situations where there are no need to change the direction of the flow. The spring inside the locking dog cylinder will force the locking dog back.

Solenoid operated spool valve
• 4/2-way impulse valve
• 4/3-way with spring centred mid position
• 4/2-way with spring reset
• Q_{max} = 15 l/min, p_{max} = 350 bar

NG3-Mini®
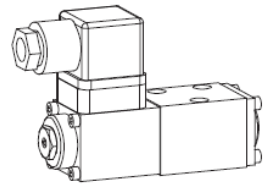
Figure 50: Picture of solenoid valve: Solenoid operated spool valve.
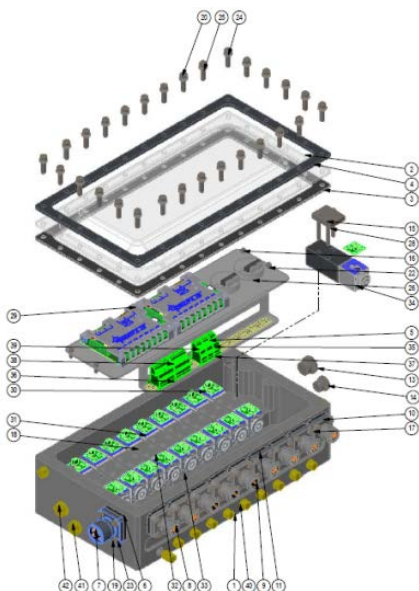
Figure 34 shows what a single valve look like, while figure 36 shows the function principle of the same solenoid. There are several solenoids, and to protect them they will be placed together inside a valve pack as illustrated in figure 35. Installing them in a row inside a valve pack makes it easier to design the control system for the valves.

Figure 51: Drawing from previous FMC project [FMC]

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[27] (Wandfluh, 2006)

The main reason to pick the BM4D32-G24-M55-M35 is because of the ability to handle the external pressure at 2000 meters depth. Figure 52 illustrates two different 4-3 spring loaded solenoid valve. Both valves have the possibility to control the direction of the flow in addition to equalize the flow.
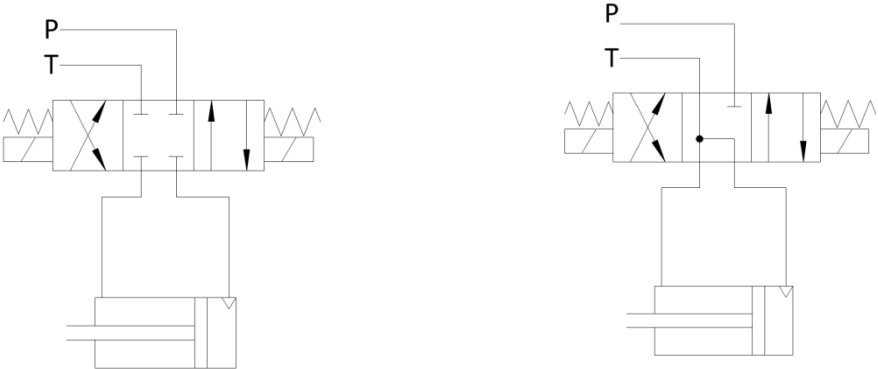
Figure 52: Wandfluh BM4D32-G24-M55-M35 (Schematic) on the left [MN]

The BM4D32-G24-M55-M35 is more suited to handle the pressure at 2000 meters depth because of the way it stays in neutral position. This kind of valve keeps the cylinder in position by applying the same flow and pressure on both sides of the piston. The result is a fully compensated system. The left illustration on figure 36 will not provide the cylinder with a "auto" compensating system as leakages may result in that the piston moves uncontrolled, which is a major problem to handle on 2000 meters depth.

The cylinder illustrated below requires a compensating system and that makes the BM4D32-G24-M55-M35 the best choice of solenoid valve.

Pressure Relief Valve[28]

The pressure relief valve is installed to protect the system for pressure peaks. The valve is connected the return line, and when a peak appear it will open and drain the overload.

Figure 53: A pressure relief valve [Source 28]

This valve will open a line from the supply line to the tank if the pressure gets too high and the system is protected. The relief valve installed on the HPU side of the system has a more active function. The valve will open as long as the hot stabs are closed. See more information in Appendix A - Hot Stab.

---

[28] (Wandfluh AG, 2012)

7.2   ROV hydraulic system (Tellus system)

The Tellus system of the RITS is powered from the ROV. It is the main power system for all components in RITS; however it is not clean enough to risk spill of fluid into the other hydraulic systems.

The "Tellus" system of RITS is the part that can operate with the same fluid as the ROV. It is units as the cylinders, the torque tool (require a RCU - remotely control unit) and the Titan 4 manipulator. The hot stab system is the only component that needs cleaner fluid. The hot stab system is operated by a motor on the "Tellus" side of the hydraulic system. The motor powers a pump that makes the clean fluids run. Systems like this are called a Hydraulic Power Unit (HPU), and ensure that the fluids are not mixed.

All the systems inside RITS are dimensioned to handle a pressure of 207 Bar. The components are more different when it comes to flow demand. The flow represents the speed of action, and the unit with the lowest flow capacity will be the dimensioning. A result is that some units may become a bit slower - yet the work will still be done since the pressure which represents the strength is the same.

The system will have its own compensator to protect RITS if the compensating system inside the ROV fails. A filter is installed as a precaution to avoid unnecessary dirt in the RITS system.

7.2.1 Filter[29]

As for all the components the external pressure at 2000 meter depth is the first demand to be fulfilled for the filter. In addition a 3 micron filter is needs to clean the fluid to meet the manipulator demands.

Pall Norway recommended a filter called 9050. The filter 9050 can handle pressure from both outside and inside up to 700 bars, which is a lot more than needed. Pall is a large supplier of subsea filters, and is frequently used by FMC for other subsea projects. Of standardization reasons within FMC, they are the chosen supplier for filters also for RITS.

---

[29] (Pall Corporation, 2002)

Contingency solution for the filter

The filter will after a period of time be filled with dirt, and reduce the performance of the RITS. If the filter should be clogged between service intervals, Pall has provided a bypass system that opens when the flow cannot pass true the filter. The contingency system for the locking dogs makes sure that the RITS always will be able to disconnect, and turn back topside to clean the filter without expose the system for danger. This contingency system and a regularly access of maintenance makes the bypass system unnecessary. To reduce the risk of clogged filter it will be cleaned regularly, maybe as often as between every RITS operation.

Bypass valve
Full flow low inertia bypass valve mounted in the filter head between inlet and outlet port.
- Operation is independent of clogging indicator.
- Instant response to limit ΔP across element during cold starts and flow surges.
- Fluid flow clear of the element when in bypass mode.

Fully supported element construction for out-to-in flow
- High collapse strength and filtration integrity.
- Uniform diffused flow.

Ultipor III elements
Ultipor III filter media
- Unique composite structure.
- Graded pore construction.
- Inert, inorganic fibres with corrosion protected steel endcap and core.
- Removal ratings:-
  2.5, 5, 7, 12 and 22 micrometres where $\beta_{x(c)} \geq 1000$ to ISO 16889.

Optional visual and electrical differential pressure indicating devices
Accurate and reliable indication of the need for element service.

Sampling port
Sampling via the differential pressure indicator port for sampling without breaking lines.

Mounting
Variety of head mountings for installation versatility. Pipe mounting, or top manifold options available.

Positive sealing
Unique positive sealing interface using standard 'O' rings.

Figure 54: Picture of pall 9050 taken from the datasheet provided from Pall [source 29]

The exact model is called **9050SKH** - where the H specifies the fluid that the filter will clean. A Pall 9050 filter cleans the system to at least 3 microns and handles 700 bar inner and outer pressure, and meets the requirements for the RITS.

7.2.2 The compensator[30]

The compensator on the "Tellus" side of the RITS' hydraulic system will compensate the fluid volume variations for all the components. A compensator is a tank that adjusts the volume by use of a spring and because of that equalizes the pressure when the fluid consumption of the tools etc. varies. Other volume variations are caused by change of volume that occur due to change of temperature and change of external pressure.

The compensator principle is a simple, but it is still challenging to calculate the size of the compensator. In addition to handle the variations of the fluid volume due to physical changes, the calculations also must include the variations of fluid consumed during operation (works like a fluid reservoir). Consumption is typically fluid needed to handle the cylinders. The cylinder consumption is related to different volume on each side of the piston.

The hydraulic system is completely filled when RITS is lowered in the water, which includes the fluid lines. Since the hydraulic lines are not yet designed an estimation of volumes of the lines are made based on experience from previous FMC projects. In the calculation for the RITS compensator length of 4 meter and an inner diameter of 4 mm is estimated. The RCU has its own compensating system and does not need any extra expansion option, while the Titan 4 needs an extra volume of 2.2 liters.

Figure 55: Explanation of compensator volume estimation Excel [appendix C] [MN]

---

[30] (Kystdesign, ?)

The Excel-Sheet in figure 55 shows the compensator volume calculation. By implementing the cylinder data it is possible to calculate the difference in fluid consumed for the cylinder when it is pulled in versus pulled out.

The calculation is made in an Excel datasheet, which is added in the source list. The result reveals a required compensator volume of 5.85 liters. Kystdesign has a compensator of 6 liters active volume, which fits the demands for the RITS.

6 liter compensator
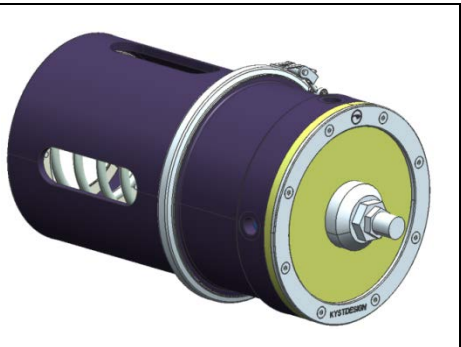
Length w/sensor	588 mm
Width	Ø246mm
Weight, $_{air}$	11.3 kg
Weight, $_{water}$	estimated 7.2 kg*
Material	POM

Figure 56: Data and picture of the compensator [Source 28]

7.2.3 Valve Pack#2 valve pack for the dirty system

Since RITS consists of two separate hydraulic systems it contains two valve packs. To make the system less complicated it has been decided that each system will have its own valve pack to avoid contamination of the cleanest system. The valve pack on "Tellus" side will handle the solenoids that operate the cylinders. The RCU and Titan 4 have integrated hydraulic control system from the suppliers, which are connected to a valve pack on Tellus side built up of:

4 pcs: 4-3 Wandfluh BM4D32-G24-M55-M35: 3 pcs are to activate the trays, while the last is installed to handle the cylinder stab cassette.

1 pcs: 4-2 Wandfluh: to activate locking dogs in the API 17D
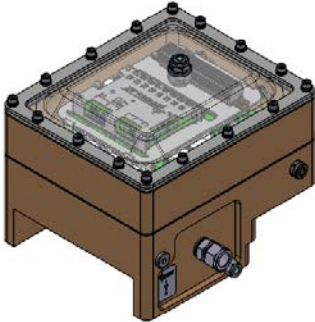
Figure 57: The valve pack two with 5 solenoids [FMC]

7.2.4 The hydraulic motor[31]

The motor is installed provide the HPU-side with power to run a pump to avoid contamination of the clean fluid. HPU systems are developed in many different versions where clean fluids are required. The HPU system used inside the RITS is custom made for the RITS; even if the principle is taken from previous FMC projects.

One of the most common motors for HPU system in use is the Parker F11. The Parker F11 handles pressure over 207 bars, in addition to be able to supply RITS with the needed flow. It is a great advantage that it is small, and that it is used subsea before.

**Figure 58: Picture of a F11 Motor/Pump
[Source 31]**

Model: F11-010
Max Pressure: 305 bar
Displacement: 9.8 cm^3/rev
Flow max: 110 Bar
Max rpm: 10200
Max depth: *used subsea when connected a compensator system.*
Weight in air: 7.5kg
Weight in water:

---

[31] (Parker, 2013)

Determination of the motor size

The F11 is developed in six different sizes. The capacity of the motor is depending of the flow on "Tellus" side of the system. It is an advantage that the motor is not working at max speed at all time to reduce wear and tear. The larger motors will give the same volume and pressure to a lower speed than the small motors. To select the most suitable pump, it will be a trade-off between low speed and low weight - which is two abilities that work against each other.

The flow on the "Tellus" side of the hydraulic system is dependent of the component with the lowest max flow. For the RITS it is the manipulator that needs a flow of 19 liters per minute (lpm). It results in a total system requirement of approx. 20 lpm. When the flow is given it is possible to pick the most suitable pump size.

Basic formulas for hydraulic motors

Flow (q)
$$q = \frac{D \times n}{1000 \times \eta_v} \ [l/min]$$

Torque (M)
$$M = \frac{D \times \Delta p \times \eta_{hm}}{63} \ [Nm]$$

Power (P)
$$P = \frac{q \times \Delta p \times \eta_t}{600} \ [kW]$$

D - displacement [cm³/rev]
n - shaft speed [rpm]
η_v - volumetric efficiency
Δp - differential pressure [bar]
(between inlet and outlet)
η_{hm} - mechanical efficiency
η_t - overall efficiency
($\eta_t = \eta_v \times \eta_{hm}$)

Figure 59 : Basic formulas for hydraulic motors

[Source: 31]
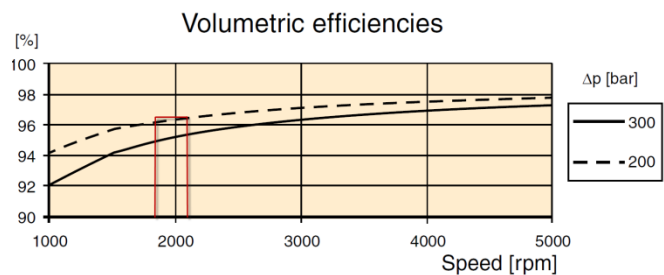
Figure 60: Volumetric efficiency [Source. 31]

RPM is calculated by the formula in figure 60. Table 22 represents the results of the calculation. In the table it is possible to choose the most suitable motor.

Table 22 Abilities for Parker F11 motor sizes [Source 29]

F11- (size)	Weight	Displacement	Flow	Volumetric effectiveness	RPM
-005	4.7 kg	4.9 cm³/rev	20 lpm	Assumed 0.97*	3959 rpm
-010	7.5 kg	9.8 cm³/rev	20 lpm	Assumed 0.965*	1969 rpm
-012	8.2 kg	12.5 cm³/rev	20 lpm	Assumed 0.96*	1536 rpm

*See figure 30: A shaft speed of approx. 2000 rpm is assumed - the small motor will produce a higher RPM on 20l/min, it results in a higher volumetric effectiveness.

The smallest pump works at too high speed to stand required wear resistance. The biggest that are calculated works at a lower speed, which decreases the volumetric effectiveness. As a result too much power is lost.

From these considerations the most suiting motor is the F11-010 with a weight of 7.5 kg.

7.3 The Clean system - HPU system

The clean hydraulic power unit is necessary to make RITS capable to work with hot stabs. Many subsea installations are installed with hot stab interfaces to power up a motor or override a valve etc, where the fluid used for the hot stab gets in contact with the fluid of the subsea fixed installation. All these systems have different tolerances for cleanness of fluids, and they are usually significant stricter than a Tellus oil and a 3 microns filter. The "clean" oil must also be compatible with the oil in the subsea installation.

To control the cleanness of the system a separate reservoir is needed. By installing a compensator on the HPU side of the system two issues are solved. In addition to handle the change of volume of the fluid, it applies an extra fluid reservoir. The clean fluid can be filled into the system before the operation subsea starts, and because of that the customer will have completely control of the fluid, type and cleanness.

7.3.1 The Pump

A motor uses the hydraulic flow to power a shaft, while a pump circulates the fluids by use of the power from the shaft. As the same calculation applies for the pump it will be an advantage to use the same pump as the motor.

The RPM is given in table 12 (=1969). By using the formula for q in table a flow for the HPU side is given.

The flow on the HPU dirty side of the system has a flow of 18.6L

Basic formulas for hydraulic pumps

Flow (q)

$$q = \frac{D \times n \times \eta_v}{1000} \ [l/min]$$

Torque (M)

$$M = \frac{D \times \Delta p}{63 \times \eta_{hm}} \ [Nm]$$

Power (P)

$$P = \frac{q \times \Delta p}{600 \times \eta_t} \ [kW]$$

D - displacement [cm³/rev]
n - shaft speed [rpm]
η_v - volumetric efficiency
Δp - differential pressure [bar]
    (between inlet and outlet)
η_{hm} - mechanical efficiency
η_t - overall efficiency
    ($\eta_t = \eta_v \times \eta_{hm}$)

**Figure 61: Pump formulas from the Parker catalog
(Source 31]**

The coupling between motor and pump

It is difficult to mount the shafts exactly aligned. The misalignment will expose o-rings and seals for forces and tear. Figure 62 illustrates the effect. To decrease the tear a flexible coupling will be installed between the shafts, to reduce the alignment problem. A flex coupling makes also service easier. If one of the parts, either the pump or the motor, has to be taken out, the other may stay by only dismounting the coupling.
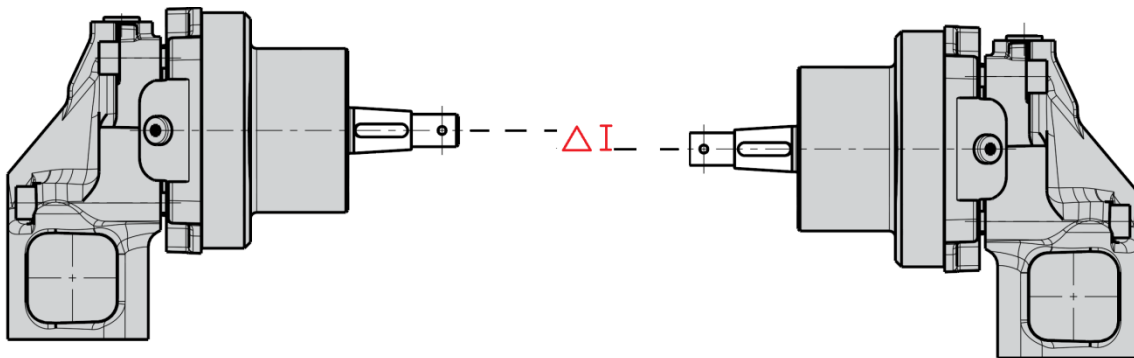
Figure 62: Shaft connection between the motor and the pump [MN and Source 31].

Flex coupling[32]

Huco Dynatorc is a common flex coupling suited to connect two shafts together. There is no air filled chambers in the construction, and it is made of aluminum - which reduces the chances for galvanic corrosion.

Material	Aluminum
Max rpm	5000 rpm
Max torque	140 Nm
Temp range	-40 - 140 ˚C

Figure 63: Huco, multibeam - aluminum [Source 30]

---

[32] (Huco Dynatork, 2013?)

7.3.2 The clean side compensator

The compensator in the HPU has two important purposes. It needs to compensate the external pressure on the clean fluid system and contains the extra fluid needed to operate external subsea units by use of hot stabs.

RITS is designed as a tool carrier for many different projects. It makes it challenging to calculate an exact volume for the compensator. In most cases all fluid are transferred back to the RITS through the return lines; however mineral and water-based fluids are sometimes accidentally released to sea. Assuming that all the fluids usually will be returned to RITS, gives the minimum capacity of the compensator. Another assumption is that powering up a pump or motor will not consume any fluid. The fluid will first of all be consumed when the hot stabs overrides subsea valves. By evaluating the most common valves used for subsea installations it is possible to calculate a dimensioning volume.

Table 23: Summary over consumption of fluids required to operate/override a system

Component	Volume used/ Displacement	Explanation	Source
Motor	0	No consumption of fluids to run a motor, since all the fluid will be flowing back to RITS.	-
1/2" valve	0.016 L	Displacement volume for override (different volume between each side of the piston)*	[33]
2" valve	0.61 L	Displacement volume for override (different volume between each side of the piston)*	[34]
7" valve	0.93 L	Displacement volume for override (different volume between each side of the piston)*	[35]
the displacement volume for an actuator is often the difference of the actuator stem on the stem side of the piston. In an override situation the return fluid will flow into RITS, and the only fluid consumption is the volume of the stem on stem side of the cylinder.			

One of the subsea installations RITS will handle is the Riserless Light Well Intervention stack (RLWI- Stack). For the RITS the capacity of this operation is used to calculate the capacity. The RLWI-stack has two 7" valves, four 2" valves and two 1/2 valves.

In addition some spare compensator volume is added, to handle e.g. failures that cause leakages etc. a 7" valve will flush 7.4 liters.

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[33] (FMC Technologies, 2002)
[34] (FMC Technologies, 2006)
[35] (FMC Technologies, 2007)

Compensator volumes

A similar excel sheet as the one presented for the "dirty" side is set up for the compensator volume on the "clean" side of the system. The calculations estimate a compensator volume of 7.45 liters, but without any spare capacity for failures. It means that one 6 liters compensator as used on the Tellus side is too small.

There are larger compensators than 6 liters; however there could be an advantage to keep compensators of equal size. Knowing that the reservoir will be empty by one flush to sea by the 7" valve there is desirable to increase the reservoir with a few liters. Installing two 6 liters compensator provides a volume of 12 liters - which seems like a satisfying volume for RLWI, and many other subsea projects.

It makes it possible to keep the operation going even if some fluid is lost by one flush to sea. The estimation is not accurate, however there is difficult to make exact volume estimation for a random project.
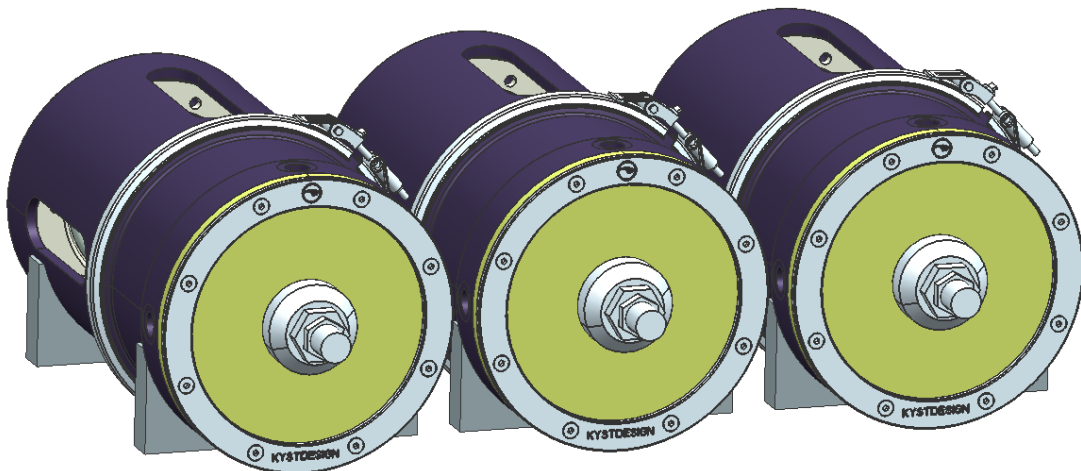
Figure 64: Compensators placed in a rack [MN and source 30]

Compensators of equal size can be installed in a rack which is easier for the people that shall assemble RITS.

7.3.3 Valve Pack

The valve pack on the HPU side of RITS hydraulic system has nine valves of the same; ref figure 66. The nine Wandfluh BM4D32-G24-M55-M35 controls three hot stabs. Each hot stab requires three valves. One valve to each pair of line, and since the 3 position solenoid valves handles one supply and one return line there are only three valves needed.

The three first valves on the figure are planned for a spare hot stab (if the customer wants three hot stabs), and valve four to six is connected the second stab. The last three valves are installed to supply the main hot stab with hydraulic.

Hot Stab 6L[36]
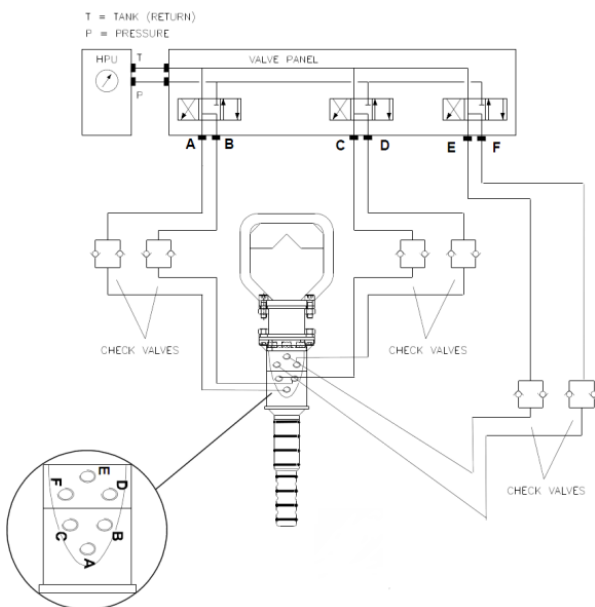
Figure 65 illustrates the three solenoids required to operate one 6L hot stab. RITS will have the possibility to handle three hot stabs, and as a result the valve pack will have nine solenoid valves. The system is explained in Appendix A.

Figure 65: Schematic of a standard hot stab [Source 36]
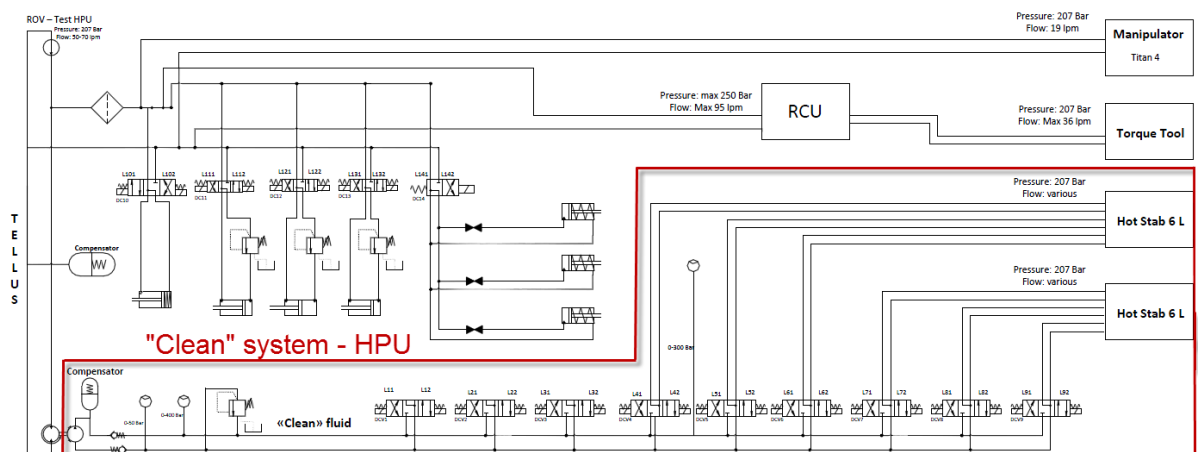
Figure 66: Copy of Schematics [MN]

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[36] (FMC Technologies, 2010)

Chapter Eight - Control Unit

The previous chapters have presented components needed to make RITS work. The hydraulic system is designed; however a system that controls the hydraulic system is required. This chapter will explain how the RITS will be controlled by use of telemetry and other communication components.

7.1   Valve pack - Control Systems[37]

A valve pack is custom designed RCU for the rest of the system in RITS, except for the torque tool. The solenoid valves are positioned in a row with a control card (PWM16) on top. This control card is called an embedded control unit, and controls which solenoid valve that will opens the hydraulic line.

- The control card will send an electric signal to a   magnet that will overcome the spring force in the   solenoid.
- The solenoid valve will only open the hydraulic line   that it is connected to.
- The electricity and the hydraulic lines will at all times be connected to the valve pack, just waiting for signal to be activated.

Figure 67: Picture of a valve pack from Innova [Source 37]

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[37] (Innova, 2014)

7.1.1 PWM16 - Control Card[38]

The signals from the computer topside will end up in the PWM16. This is the unit that applies power to the solenoids valves that opens the hydraulic lines. The hydraulic system will be active at all times, and the control card will decide what line that is open. The solenoid valves presented in chapter 7.1.1 allows the flow go in both direction, which means one line to supply and one to tank/return. It signals are sent to the other side of the solenoid valve it will switch and the circulation will go reverse direction. This is how the operator can control the cylinder to go out or pull back in.

Figure 68: PWM 16 [Source 38]

The PWM16 operates 16 individual 24 VDC loads. It means that one PWM16 operates eight 4-3 solenoid valves.

It has a depth rating on 3000 meters and communicates with both a RS-232 and a RS-485 standard.

7.1.2 Titan 4 - Control system[39]

Titan 4 is an advanced system with the control card integrated inside the manipulator. However there is an issue to be customized as the control card needs a communication board.
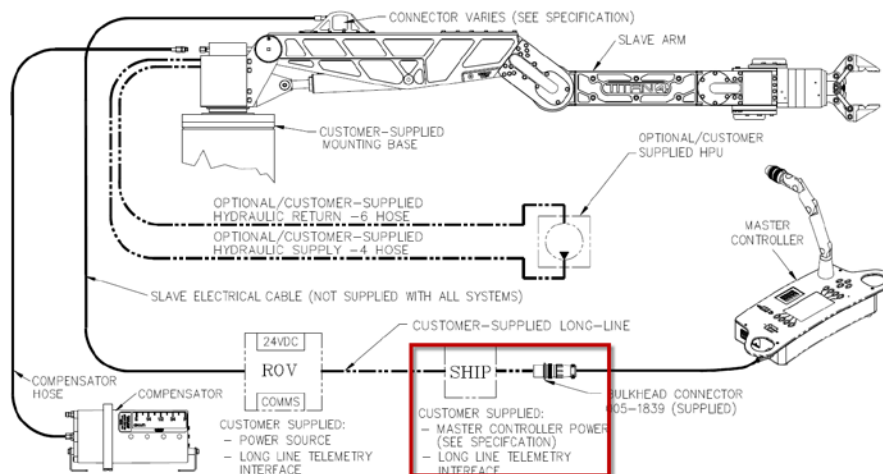
Figure 69: Control card for Titan 4 [Source 39]

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[38] (Innova, 2014)
[39] (Schilling Robotics, 2012)

7.1.3 CUTE - Communication Distribution Board[40]

The system will have several PMW16 control cards. A master communication distribution board (CDB) is required. The CDB supplied from Innova can handle four different control cards, which is exactly the number of PWM16's and Titan control card on the RITS.

Size:
160x100x12mm

Electrisity:
12DC (24VAC optional)

Telemetry:
1 off RS-232 or 4 off RS-485

Figure 70: CDB from Innova [Source 40]

It is designed to be installed in an enclosure without any depth rating. Instead of designing a special container for the CDB, it is planned to integrate it in an electric transformer package.

7.2 Electricity Can

All the control cards, solenoid valves and the distribution board require 24 VAC. Installing a transformer will make the system less complicated since it reduce the customization of all the control units. Innova has developed systems like this earlier; however there is not a standard product. This unit will be customized by Innova due to the system requirements.

Table 24: Electric Can [Source: FMC - Per-Olaf Tangen]

Weight $_{in\ air}$:	11 kg
Weight $_{in\ water}$:	2.3 kg
Material:	Aluminum 082-T6, Hard
Interface:	Burton 5506-2008
Power input:	88-264 VAC, 47-63 Hz
Power output:	24 VDC
Power rating	500W

The info given on the transformer is taken from a previous FMC project. The power input has a wide range which makes it compatible with the RCU's. In addition to make the system less complicated it will contain the CDB to protect it from the external pressure.

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[40] (Innova, 2014)

7.3 RCU - Remote Control Unit[41] for the torque tool.

The RCU described here is installed when the torque cassette are needed. The torque system is an Oceaneering product. The RCU is the control unit for the torque tool, and is delivered with control HMI software. It is the kind of system that will be designed for the rest of the components; however the RCU will only be able to control the torque tool inside the torque cassette while the other system needs to operate several units.
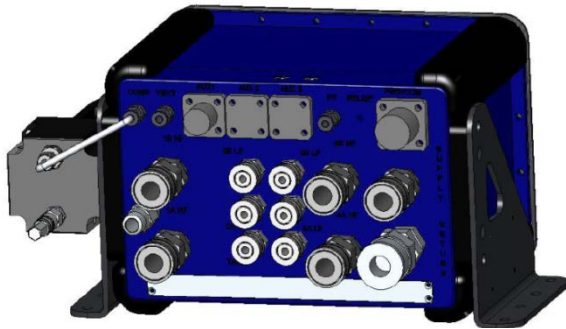
Figure 71: Model of the RCU from the OMM [Source 41]

RCU facts:

Depth rating: 3000 meters
Max Pressure: 250 bar
Max flow 95 lpm
Weight in air: 30 kg

Electricity:
90-132 VAC.

Telemetry:
RS-232 or RS-485

This system requires separate signal and power lines to be able to operate. The hydraulic will be supplied from RITS (on the Tellus side). The configuration of the RITS will ensure that the RCU will be compatible with the other systems due to signal and electricity, but even so it will require separate lines.

7.4 Control system Hierarchy

The RCU of the torque tool has its own system, while the rest of the control units will be controlled through the CDB placed in the electricity can. A consequence is that two signal lines and two electric lines are required when a torque tool is installed.
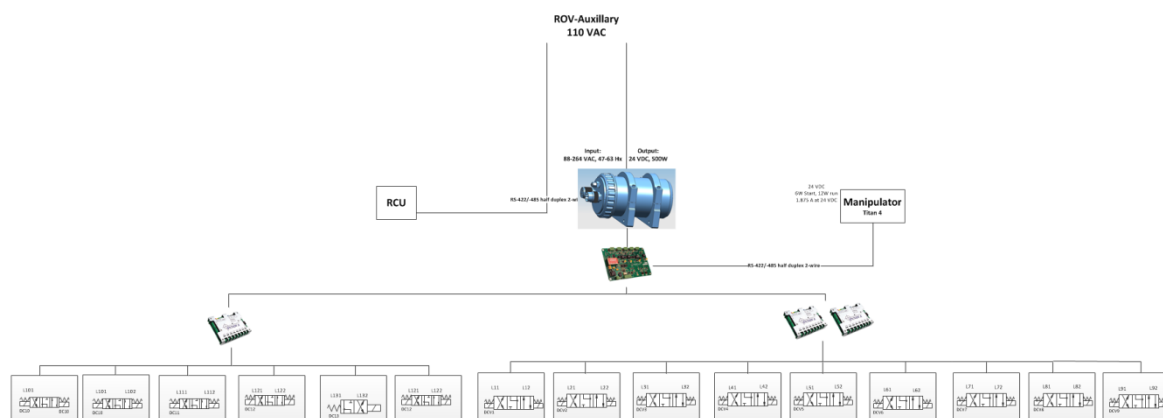
Figure 72: Hierarchy of control units [MN]

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[41] (Oceaneering, 2009)

7.5 Signal

The CDB is capable to handle four control cards as long as the signal is RS-485. RS-485 is a protocol to handle signals. The CDB will communicate with one master signal transfer to/from topside. Signals sent to the CDB are transferred further to the PWM16's that operates the solenoids.

Table 25: Signal configuration

Valve	Tool Lines	Valve pack	Component	Function
DC1	L11	#1	1st Hot stab spare 1st line t/r	Supply A - Drain B
	L12			Drain A - Supply B
DC2	L21	#1	1st Hot stab spare 2nd line t/r	Supply C - Drain D
	L22			Drain C - Supply D
DC3	L31	#1	1st Hot stab spare 3rd line t/r	Supply E - Drain F
	L32			Drain E - Supply F
DC4	L41	#1	2nd Hot stab spare 1st line t/r	Supply A - Drain B
	L42			Drain A - Supply B
DC5	L51	#1	2nd Hot stab spare 2nd line t/r	Supply C - Drain D
	L52			Drain C - Supply D
DC6	L61	#1	2nd Hot stab spare 3rd line t/r	Supply E - Drain F
	L62			Drain E - Supply F
DC7	L71	#1	3rd Hot stab spare 1st line t/r	Supply A - Drain B
	L72			Drain A - Supply B
DC8	L81	#1	3rd Hot stab spare 2nd line t/r	Supply C - Drain D
	L82			Drain C - Supply D
DC9	L91	#1	3rd Hot stab spare 3rd line t/r	Supply E - Drain F
	L92			Drain E - Supply F
DC10	L101	#2	Hot Stab API solution	Activate hot stab
	L102			Pull back hot stab
DC11	L111	#2	1st cylinder	Activate Tray #1
	L112			Closes Tray#1
DC12	L121	#2	2nd cylinder	Activate Tray #1
	L122			Closes Tray#1
DC13	L131	#2	3rd cylinder	Activate Tray #1
	L132			Closes Tray#1
DC14	L141	#2	Locking dogs	Locks RITS to buckets by use of locking dogs.
	L142			Releases RITS

The table shows the signal list for the RITS.. This table is the basis from where a control screen and the software for the control system is created.

Chapter Nine - Graphic User Interface

The GUI (also called HMI) is the screen that allows the operator to send information to the control system. The panel built up of switches that will open or close hydraulic lines that activate the hydraulic lines and the operation given in table 25 will be done.

A GUI for the RITS is shown in fig 73. The Configuration section of the control screen panel is installed to make the system flexible. It is a "tick off" selection system that will activate other panels the will pop-up to the right. The switches will be grey until the box on the configuration panel is "ticked off". It is important that the "tick off "reflects the current tool equipment of RITS, if not the HMI will activate wrong lines. This has to be tested and checked on a test stand before RITS goes subsea.

The manipulator and the RCU have their own system. By push their buttons a new HMI picture will appear - and is the suppliers HMI. If there is enough screens topside, the manipulator should have its own HMI active at all times.
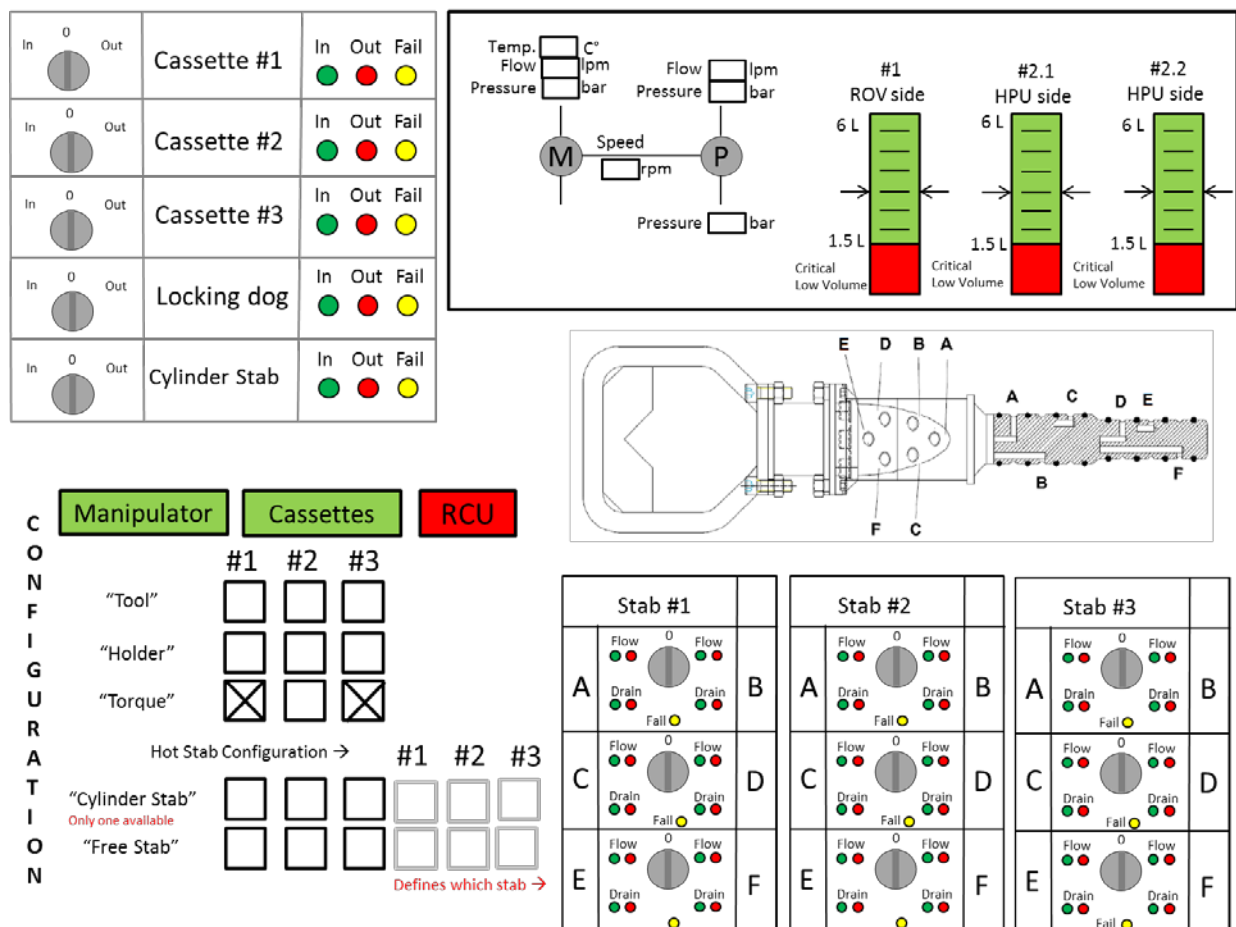
Figure 73: Concept drawing of the HMI [MN]

The Upper right left panel controls valve pack two (DC10-DC14 in table 25). There are five switches that allow the cylinders and the locking dogs to be operated. The locking dog system will activate the dogs in all three interface receptacles; however if one of the cassettes are installed without API 17D interface the hydraulic line will be installed with a blind flange. This blind flange is mounted topside when the cassette configuration is installed.

Lower panel controls valve pack one (DC1-DC9 in table 25). The switches will open a supply line and a return line in one of the hot stabs. Which one is depending of what the operator want. It will be tested onboard of the vessel to avoid wrong couplings etc.

Sensor panel (upper right panel) is installed to be able to monitor the system. There are important to know the status inside the skid when it is in operation. In addition to prevent damage, it may reveal the reason for any malfunction. The RITS and the tools are expensive, and therefore a panel showing the system status will be required to manage a safe and secure operation.

9.1   Sensors

The numbers of sensors that are required inside RITS are limited. In addition to monitor the level in the compensators, it is important to know the pressure on both sides of the hydraulic system (dirty and clean). The flow is also an important factor to monitor, and the motor has an opportunity to install a shaft-speed transducer, This makes it possible to calculate the flow on both sides of the hydraulic system. The last transducer that is required is a temperature transducer to make sure that the motor will not break. The temperature in the motor cannot exceed 80 degrees.

9.1.1   Sensor Signals to surface

The sensors will be connected to the PWM16 installed in valve pack 1, and the signals will be routed true the CUTE and up to the hardware topside (HMI). The position of the sensors varies - some components are developed with sensor-possibilities while other sensors needs to be installed on the piping, or custom made flanges.

Each PWM16 can handle five sensors, and there are two of them in valve pack 1. It is preferable that the sensor signal is 4-20 mA.

Fluid Level Sensor

The 6L compensators from Kystdesign are delivered with a level sensor integrated. To activate the sensor a signal coupling to the PWM16 will be required.

Speed Sensor

The motor is the most charged component, and needs monitoring. The motor has an option for mounting a speed sensor of the shaft. This sensor is useful since it also makes it possible to calculate the flow of the

Figure 74: Speed Sensor [Source 31]
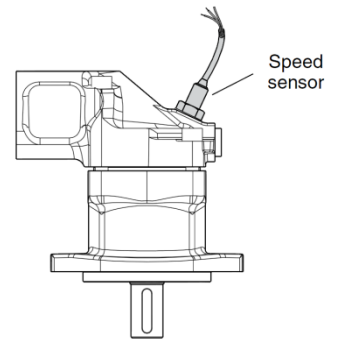
hydraulic oil in the clean and dirty system (by use of the formulas presented in chapter 7.2.4 and 7.3.1).

Pressure Sensor[42]

Figure 75: Pressure sensor [Source 42]

The pressure sensor is essential to have control over the system and to alert failure. A pressure sensor in front of the motor is required to be able to estimate the motor power. There will also be inserted pressure sensors on the clean fluids, one on the supply line and one on the return line. It is to control that the safety relief valve and the other mechanisms do not fail.

The pressure sensors are installed on the piping. The sensors on the inlet line should be rated 0-400 Bar, while the one on the HPU return line does not need to be rated higher than 0-50 Bar. The reason is presented in Appendix A, and has something to do of the way a hot stabs work (relief valve and check valves).

Temperature Sensor

In an overload situation, the first component in the HPU that going to fail is most likely the motor. It is the component that is most heavily charged. The motor has a max design temperature of 80 degrees in the supply line. To avoid protect the pump a temperature sensor is installed on in the piping in front of motor. The required range of the sensor will be 0-100 degrees C.

The temperature sensor looks similar to the pressure sensor on figure 74.

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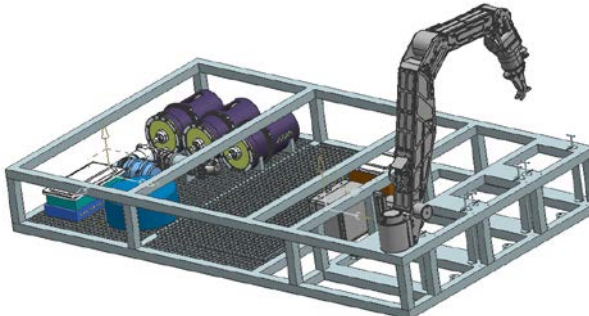
[42] (Measurments Specialities , 2012)

Chapter Ten – Buoyancy

The purpose of the buoyancy elements is to make sure the RITS weight is less than 50 kg in water. At this point all the main components are installed and it is possible to calculate a weight of RITS in water, without buoyancy elements. Installation of foam elements will decrease the weight in water, while it will increase the weight in air. Consequently, it is desirable to use as less foam as possible, primary to avoid a heavy construction in air while securing that the weight in water is ket below 50 kg.

Table 26: Weight of the components in RITS

	Weight Per piece		Pcs.	Weight in sum	
Component	In air	In water		In air	In Water
Structure [1]	55 kg	34.7 kg	1	55 kg	34.7 kg
Filter [3]	12.7 kg	8 kg	1	12.7 kg	8 kg
Titan 4 [2]	100 kg	78 kg	1	100 kg	78 kg
RCU [2]	*30 kg*	*17 kg*	*(1)*	*(30 kg)*	*(17 kg)*
Compensator [3]	11.3 kg	7.1 kg	3	33.9 kg	21.3 kg
Valve Pack#1 [3]	3.25 kg	2 kg	1	3.25 kg	2 kg
Valve Pack#2 [3]	5.85 kg	3.7 kg	1	5.85 kg	3.7 kg
Cylinder [3]	5 kg	2.5 kg	3	20 kg	7.5 kg
Transformer [2]	11 kg	2.3 kg	1	11 kg	2.3 kg
Pump/Motor [2]	7.5 kg	4.7 kg	2	15 kg	9.4 kg
Grid [1]	13 kg	8.19	3	39 kg	24.6 kg
Cassettes					
Std. Cassettes*	Varies	3,8 kg	3	varies	11.4 kg
Locking pins [1]	1.2 kg	0.75 kg	6	7.2 kg	4.5kg
Total Weight	**-**	**-**	**-**	**320 kg**	**208 kg**

*±1.5 kg for the cassettes (final adjustment will be performed in a test pit).
1) Measurements made in NX.
2) From Datasheets → see source for each component
3) Assumption cause lack of information - assumed to consist of aluminum (factor 63% - ref ch.4.1)

The RCU is not implemented in the calculation since it will not be installed at all times. The RCU is also stripped for all protective covers because the buoyancy elements will provide extra protection (see VP-RCU element in chapter 10.1.2).

10.1 Buoyancy in the structure profiles

In chapter 4.3 it was discussed that the structure could be constructed by use of two optional profiles, one filled with syntactic foam and one without. All calculations are performed with the structure without foam because it is the weaker of the two profiles. It means that the analysis made for the first profile will apply for the filled profile since it weigh less (in water) and is stronger.

The area of the cross section is:

$$width \times height = area \rightarrow (50 - 3 \times 2) \times (50 - 3 \times 2) = 19.36\text{mm}^2 = 0.001936\text{m}^2$$

	Pcs.	Length	Total length	Volume	Buoyancy
Height	14	0.25 m	3.5 m	0.0068 m^3	- 3.6 kg
Width	10	1.45m	14.5 m	0.028 m^3	-14.84 kg
Length	4	2.7 m	10.8 m	0.021 m^3	-11.13 kg
Total			**28.8 m**	**0.0558 m^3**	**29.57 kg**

Table 27: Calculation of buoyancy in the structure

Calculated on behalf of volume multiplied by buoyancy density

A filled profile would have decreased the weight by approx. 30kg, and this may be handy if a heavy tool should be wanted for a specific project.

The idea of filling the profile was to reduce the weight of the structure. As the buoyancy issues where solved (se next chapter) without a filled structure the first edition of RITS will consist of a profile without syntactic foam.

10.1.1 The Buoyancy Elements

Four buoyancy elements are required to make RITS function, they are presented in chapter 10.2.2. They will not alone provide enough buoyancy to make RITS neutral in water. Therefore to make the system buoyant, all the empty spaces between the cassettes will be filled with foam elements, in addition to the edges of the structure. It leaves a buoyancy area of 353441427 mm³ (NX measurements).

Which lead to a weight calculation of the buoyancy elements (density of syntactic foam):

Figure 76: The buoyancy package

$$Area \; x \; Density, (air/(water) \; = Weight$$

Weight in Air
$$0.353m^3 \; x \; 495\tfrac{kg}{m^3} = 175 \; kg$$

Weight in Water
$$0.353m^3 \; x \; -530\tfrac{kg}{m^3} = -187 \; kg$$

The structure with buoyancy:

In water: $208kg - 187 \; kg = 21 \; kg$

In air: $320 \; kg + 175 \; kg + 22.5 \; kg = 517.5 \; kg$

The weight in water is less than 50 kg without the piping included. Second element will be installed to avoid complications if the piping and other extra elements is heavy. The design of this element will be determined during the assembly. Figure 76 is an example of an element that is supposed to be installed to balance RITS when it is tested in a test pit.

This element is called adjustment element because it adjust the imbalance and compensates the potential extra weights applied during installation.

Figure 77: Example of the last buoyancy element may look [MN]

10.1.2 Adjusted elements

The buoyancy elements need to allow piping to be installed. Some customization is also required to make space for valve packs and RCU.
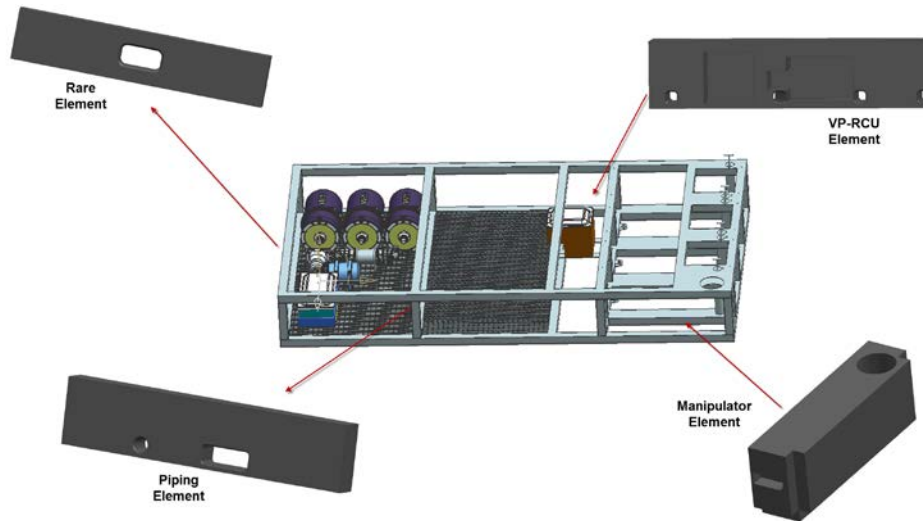
Figure 78: Adjusted Elements

Rare Element is mounted on the rare end of the RITS. A hole is made to provide access to the system inside without need to dismount the ROV on top.

Piping Element is mounted between the machinery in the end - it is installed to protect the machinery from the ROV thruster water flow. An important factor is holes for piping and hoses to be able to supply the cassettes with signal and power.

VP-RCU element is mounted behind the cassettes. As for the piping element it is installed with holes for piping. In addition it has dedicated areas for the smallest valve pack and the RCU. The mounting of RCU and valve pack 2 needs to be in the front to be able to provide the hoses with a flexible length solution see chapter 5.5.

Manipulator Element is the element holding the manipulator. This element is as big as possible to oppose the weight of the manipulator. The modification on this element is adjusted to make space for piping/hose (control and power supply).

10.1.3 Precaution of buoyancy element positioning

All the components inside the RITS are mounted on a grating. It makes it easier to install the components, and it allows water to pass true. The purpose of letting water true the construction is to make the RITS easier to operate in water. To keep the operational advantage it is important to not stop the water flow by installing the foam elements on the top of the structure.

The buoyance elements are produced in 150 mm tick plate, with some variations in length and width. By use of glue and saw it is possible to customize these plates into almost exactly the shape required. It makes the foam element flexible without being too heavy and solid.

Many ROVs[43] have a thrusters mounted in the middle of the system which should be taken into consideration when installing the foam elements. RITS will not have any buoyancy in the middle section simply to allow the main thrusters on the ROV to work.
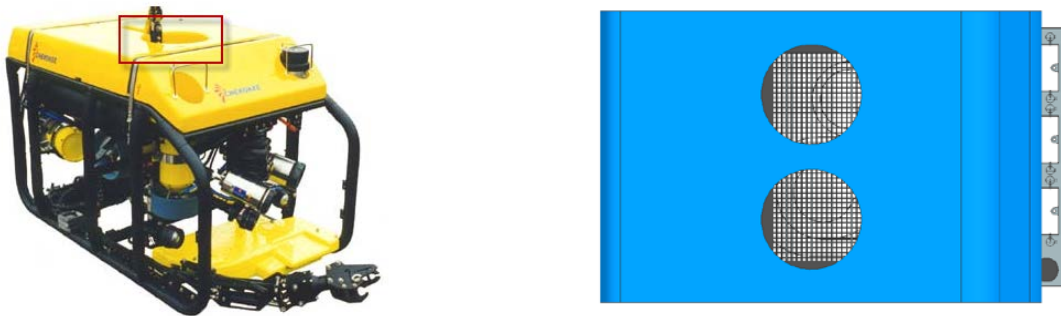
Figure 79: How the thruster will work true RITS [Source 40 and MN]

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[43] http://www.oilandgasonline.com/doc/rov-industry-getting-down-to-the-challenge-of-0001 - date 28/5-14

10.2 Centre of Gravity (CoG)

Handling and lifting of the equipment is simplified with a balanced structure. During the design phase it is difficult to estimate the exact center of gravity since the piping usually is not designed before the unit is in the workshop. The piping will change the CoG which makes it unnecessary to calculate the exact CoG. The various cassettes will have a weight difference of approx. ±1.5 kg, which also will change the CoG.

The components inside the RITS are strategic positioned to avoid too big variations of the CoG, which means that the heaviest components are placed on each side of the center line. This tactic will reduce the fine tuning of the CoG in the assembly phase of the project. Example of this is that the heavy manipulator is installed diagonally with the compensators and the pump-motor.

RITS will be adjusted to be neutral in water by use of buoyancy elements, which not necessarily means it will be fully balanced in air. The launching system of the ROV is assumed strong enough to handle this imbalance, or special lifting sling will be designed for each project.

A lifting sling will by use of different lengths be able to neutralize the imbalance of the skid in air during transportation.
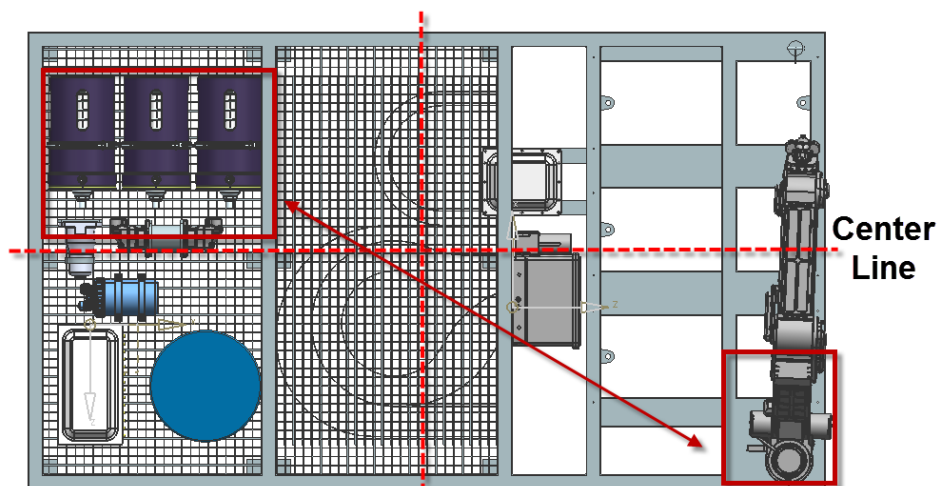
Figure 80: How to adjust CoG [MN]

Chapter Eleven - Interface to the ROV

The ROVs are normally capable to adjust the fastening interfaces as long as the interface guide rod is of standard size. The interface used on the RITS is the same as used on the CAT12 that is a new intervention skid under development.

The ROV will be guided on the top of the guide rods. On the upper part of the guide rod there is a hole. A pin inside the ROV will be thread inside this hole and keep the RITS fastened. This is performed topside.
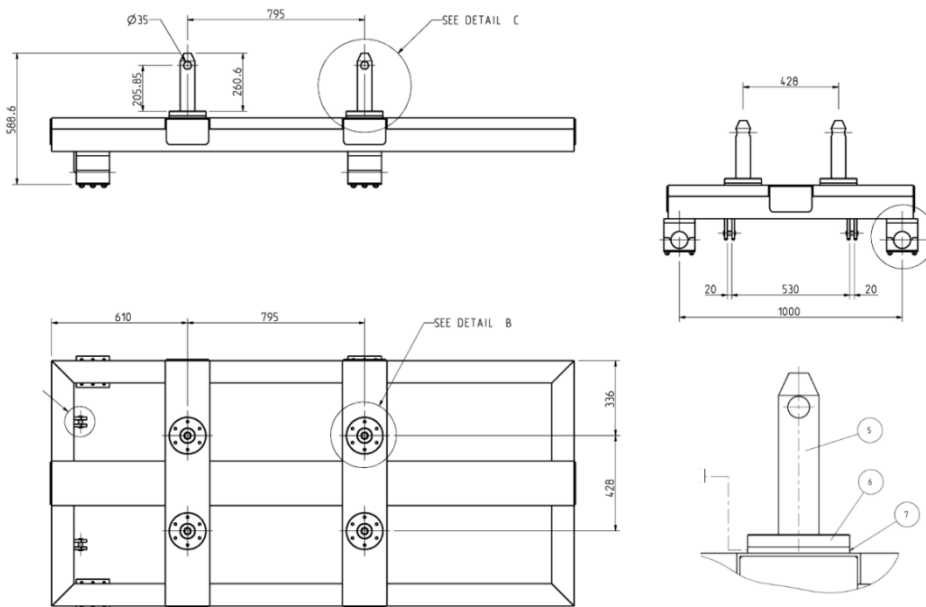
Figure 81: Examples of bolts (CAD12) [FMC]

The bolts are quite large compared with the aluminum elements in the structure. It requires a "platform" to mount the fastening guiding rods. The guiding rods is defined as lifting point of the skid, which results in a new calculation from DnV 2.7-3 to confirm that the structure are strong enough.
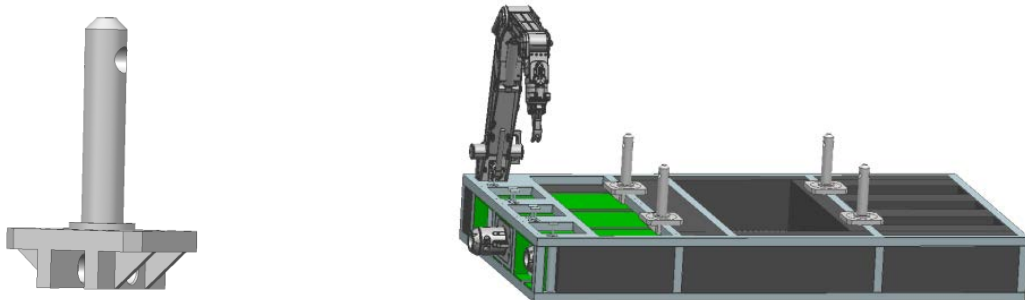
Figure 82: Fastening Rods

The guiding rods will be checked due to the force needed to handle the RITS during operation. DnV 2.7-3 chapter 3.5 require a safety factor to be added the weight of the skid. The weight of the skid is approx. 600 kg (=MGW) in air. The safety factor (DF=design factor) is the greatest of following calculations:
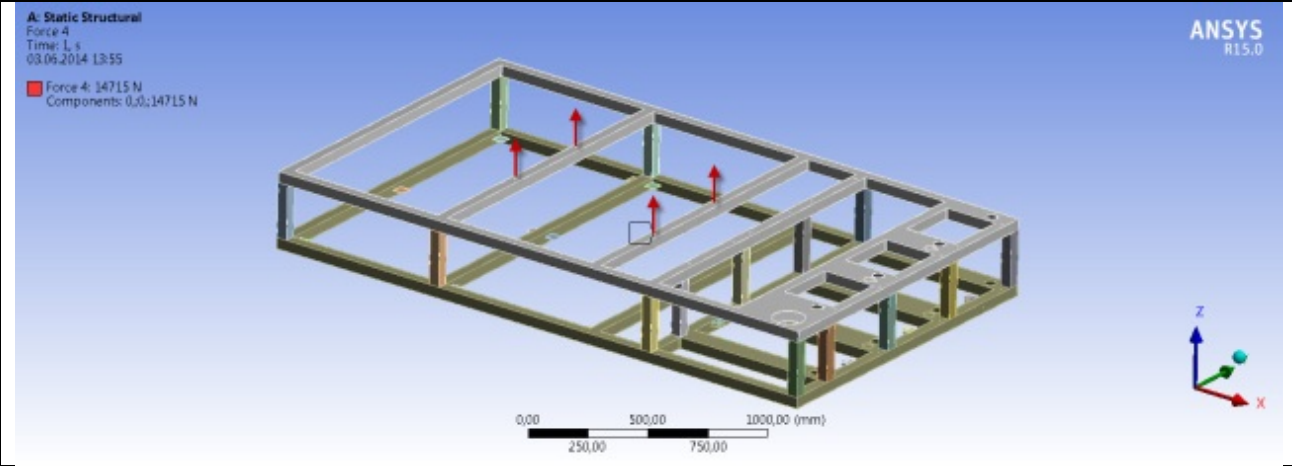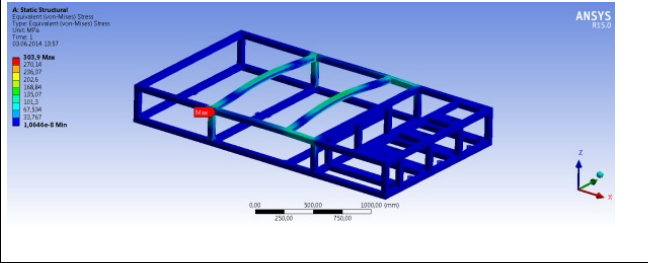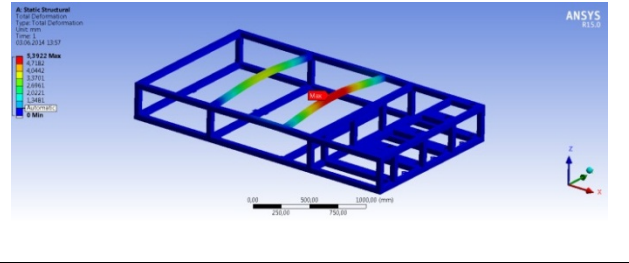
$$DF = 2.5 \qquad or \qquad DF = \left(1.4 + 0.8 \times \sqrt{(50/MGW)}\right)$$

$$\boldsymbol{DF = 2.5} \qquad or \qquad DF = 1.63$$

$$\boldsymbol{Lifting\ force} = DF \times MGW \times 9.81 \frac{m}{s \times s} = \ \boldsymbol{14715\ N}$$
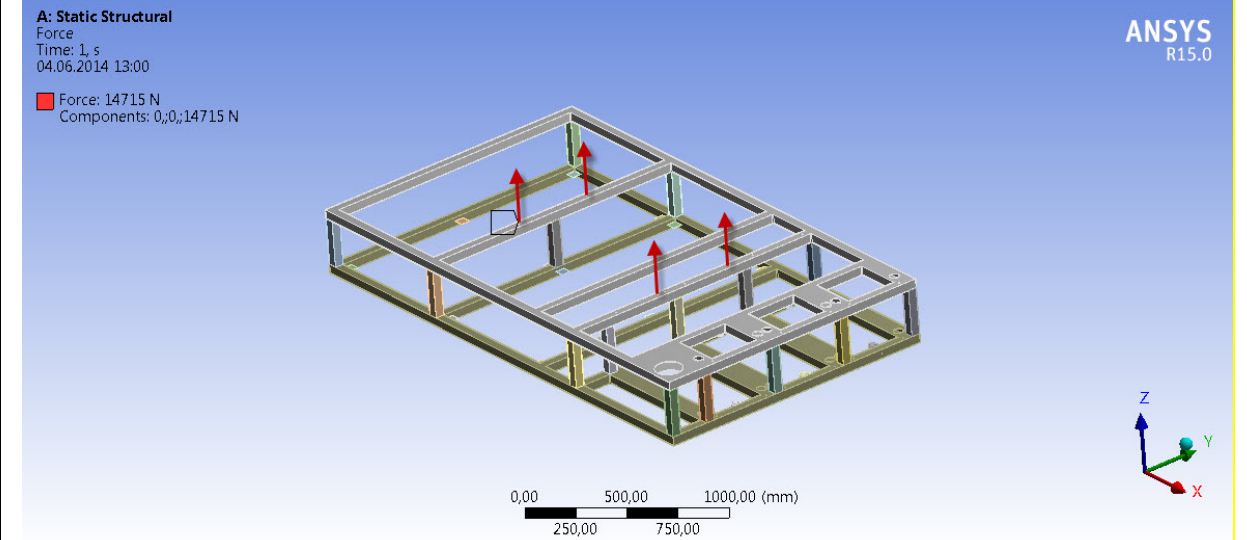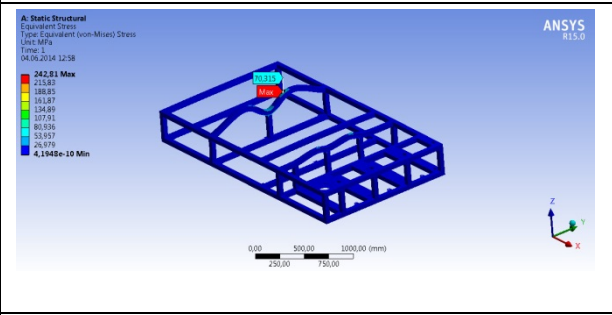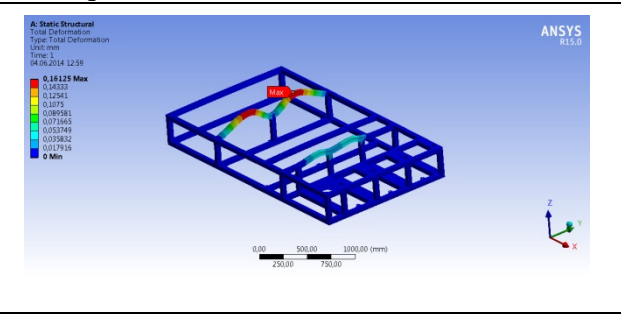
The bolt is dimensioned to handle heavier skid than the RITS, as a result only the structure will require an analysis in ANSYS to verify to be within the requirements.

Table 28: Rejected Interface Connection

Fastening Points	
Requirements	
Stress Max 250 MPa* (Aluminum)	No requirements - should be functional
Stress = 303.9 MPa = **NOT ACCEPTED**	Deformation = 5.4 mm = **NOT ACCEPTED**

The first attempt of the lifting rods was not solid enough. The width elements were simply to long which resulted in too much deformation and too much stress in the fastening of the width element (see red tag on stress figure).

It is possible to shorten the length of the element that bend by installing an element perpendicular on the middle of the beam. It will reduce the spread of the element. In addition the rods in front were moved one beam a head.

Fastening Points	
Requirements	
Stress Max 250 MPa* (Aluminum)	No requirements - should be functional
Stress = 70.3 MPa* = **ACCEPTED**	Deformation = 0.16 mm = **ACCEPTED**
*= Hot Spot see Appendix B	

Table 29: Approved Interface Connection

The buoyancy elements are not adjusted; however it is a small adjustment which will not change the total buoyancy more than acceptable. It will be compensated by adding an extra cm^3 of syntactic foam on the "adjusting element".

To avoid galvanic corrosion the bolt should be treated with a primer, max 50μ thick due to FMC guidelines. Typical zinc rich epoxy or aluminum pigmented epoxy - and lubricated with Tectyl 506.

Chapter Thirteen - Discussion

The main aim for this thesis is to improve the operational situation for the ROV by presenting a new docking solution. The new docking solution should be more solid, ridged and fixed than the present grabber manipulator, while at the same time maintaining the flexibility. RITS will be able to provide such a system, however the quality of the parking stand is essential to make RITS effective. An unstable parking stand will cause difficulties for the operators since the fixed position will be lost. All the other features RITS will provide are depending on a solid connection that creates a fixed position towards the ROV panel. For example will a few cm offset be crucial for the pre-programmed manipulator's movements.

The idea of RITS is based on a design with an API 17D interface, which resulted in no evaluation of other interface units. As the system is fully depending on a solid interface connection, it could be a good idea to search for other options in addition to API 17D. However, there are no indications of the API 17D interface being too weak, since the present solution with a more instable grabber manipulator, are able to perform subsea operations. The grabber manipulator is furthermore not capable of providing a fixed stand for robotics, and it cannot provide any space for a HPU system or a torque tool.

The ROVs that are used today require two manipulators, and the ROV industry will still develop ROVs with two manipulators independent of RITS. Since the ROV will have two extra manipulators available it should be possible to make the position solid by use the grabber manipulator on the ROV and an API 17D interface. It will require cooperation between the supplier of the subsea equipment and the ROV operator; however the result of a rigid and fixed position will open for new possibilities in subsea operation.

RITS is equipped with its own Titan 4 manipulator, and one may ask why the manipulator of the ROV is not used. It is possible, but every ROV has its own geometry, which will interfere with the fixed position and standard VC programming are therefore lost. If the owner of RITS shall pre-program the system it is an advantage that the Titan 4 installed on RITS are used.

The new docking method opens for a market of new technical solutions. The robotics illustrated in this thesis will be one of the many new features provided by RITS. Videos from subsea operations reveal that it is challenging to operate subsea units because of poor (2D)

visibility and movement in the sea. These troubling working conditions cause longer operations, which results in higher costs. Since the ROV is the only component that can operate on 2000 meters depth, it leads to a stressful situation for the ROV operators.

It would be an advantage that the operation could be performed in a non-stressful situation. RITS will be able to provide a solution that makes this possible. Visual Components illustrates how easy it is to pre-program the manipulator. By using the simulation mode integrated in the HMI a safe and controlled operation can be tested before the ROV is subsea. To be certain that the system operates as intended it is possible to make a preview-test on a test stand onshore.

Compared with the present subsea operation RITS will require more planning. The industry is used to dealing with problems as they appear, whereas RITS needs to identify the problems before the ROV goes subsea. The process of implementing this in an already established (and conservative) industry may be difficult; however, the benefits of planned work would gain profit for the suppliers since the operation will be more efficient. If something unexpected should happen, RITS will be able to control the manipulator manually. It will function as a contingency solution if anything should happen, in addition to involving the supplier of subsea equipment to a greater extent. It benefits the subsea industry with improved cooperation between the ROV providers and the equipment suppliers. The suppliers will be able to design a more ROV-friendly unit, which will result in a safer and more efficient subsea operation.

To be able to design improved systems there should not be an obstacle that the special tools are hard to provide. The hydraulic/control system inside RITS will be able to handle several different kinds of special tools by using conventional technology, which makes it possible to create standard size tool cassettes.

The use of the tool cassettes requires strict working procedures by the ROV operator. It is a more complicated operation than to just pick up the tool and put it into the interface, however, the present solution does not either provide easy access of tools. Normally it requires a longer travel to the surface or to a tool basket on the seabed to pick up the right tools. The improved access to the tools provided in RITS would make those trips unnecessary. In order to maintain the flexibility, RITS is designed in a way that it also allows handling of tools in the "normal" way handling of "lose" tools.

At this point RITS seems like a unit without disadvantages; however there is one issue that is not in favor of RITS. All the features in RITS require space, and thereby increase the weight of the ROV when a RITS is carried. The heaviest cassette is the torque cassette with a weight of 63 kg. It is on the breaking point of what is manageable on deck, even by use of lifts.

The total weight of 600 kg should not be a problem since the lifts handling the ROV during the launching process are strong. RITS will not increase the weight of the complete unit more than approximately 10-20 %. It means that the handling and launching of the ROV will not be changed significantly, whether RITS is carried or not. It is the behavior in water that is the uncertain part of this design. The whole system weighs less than 50kg in water, and RITS is designed to allow the ROV thrusters to operate freely. The ROV with RITS attached should behave well; still the behavior of RITS will need testing. The testing of RITS' behavior in water may be conducted simultaneously as the testing of the docking solution. The theory indicates that the system, as it is designed, should work as intended.

As many of the challenges regarding RITS are solved, there have never been set any cost limitations in this project. The advantage of systems built without cost limitations is that they usually will work, but they will also be expensive. It all comes down to evaluating the price up against the cost savings RITS will provide by making the subsea work more efficient.

There is no doubt that the capabilities of RITS are useful, easy access of tools and supplier handled manipulator. The cost of the tools is on the other hand quite high, especially the manipulator. A pilot version of RITS will reveal if the advantage of a rigid position subsea will regain the cost of the tools.

Chapter Fourteen - Conclusion

The focus area of this thesis was the design of a ROV tool that could improve the working situation subsea.

The technological challenges have all been solved, and there have not been found any reason to believe that the unit should not work as intended.

There are however, found two elements that determine the plans of further development:

- The high RITS costs must provide high return on the investment by more efficient subsea operations
- Testing of the docking solution must prove a ridged, solid and fixed stand, making it possible to use robotics in an efficient way.

The conclusion is simply: there is no theoretical reason that RITS will fail, but it requires extensive testing and a thorough evaluation of the cost aspect concerning the design.

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Appendices

Appendix A - Hot Stab

A hot stab is a hydraulic interface tool with many ports. Each port has its own piping and control solenoid valve, which is connected the hydraulic supply/drain hoses.

Many components, like e.g valve actuators on a XT, use a hot stab to operate. A female shape connector will fit the hot stab and provide a hydraulic connection to the valve actuator. There are o-rings separating each port to ensure that the fluid will be added the correct line.
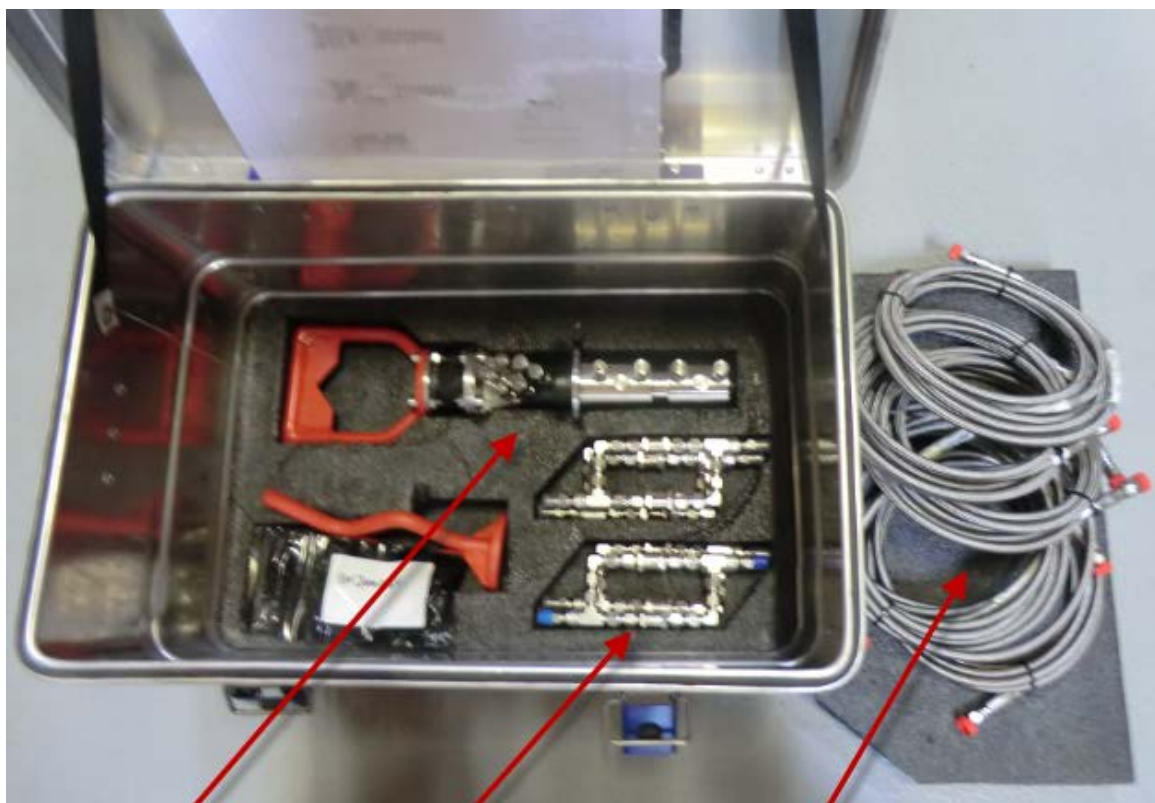
Hot stab   Check Valve   Hose

The fluid supply are controlled by a valve pack, as in RITS. The stab is open to the return tank line when the solenoid valve is in neutral position. The check valves (50 psi) will prevent the water from entering into the tool. The system is compensated which means that the pressure will be the same in the water and inside RITS. The check valves will on the other hand allow the 207 bar pressure through, when the valve is switched to active mode. It is an advantage that the check valves are installed as close to the hot stab as possible to avoid too much water in the lines

Check Valves

A check valve is a spring loaded ball that will be installed in the piping. As long as the force of the flow is weaker than the spring no fluid will pass; however when the pressure increases the flow will go true.

This technique is used in the hot stab system, but also in other parts of RITS as well. It is frequently used to control the direction of the flow.
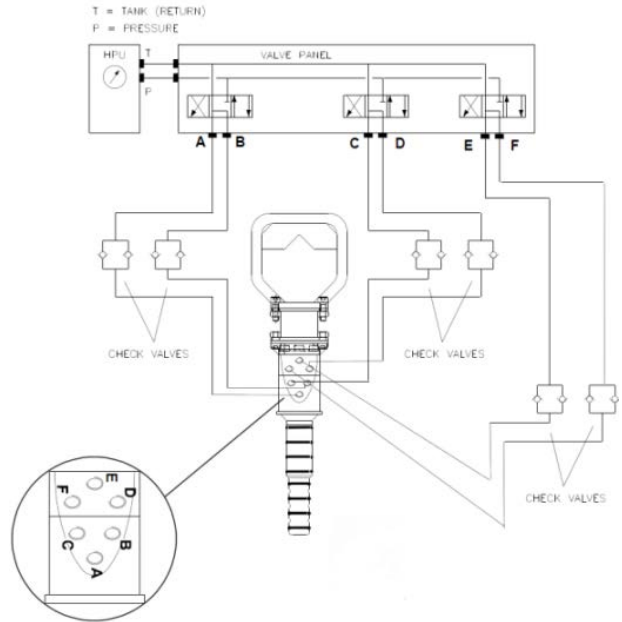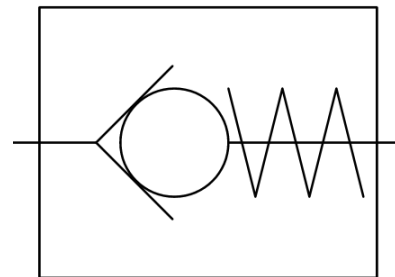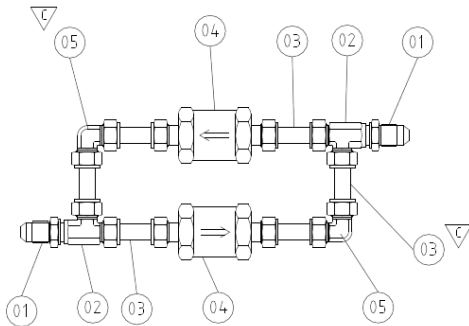
Safety Relief Valve

Normally there is a safety relief valve connected to the supply line. As the HPU will be activated as long as RITS is active it is required flow on the clean side. A pump will apply more and more pressure until something breaks - to avoid that the pressure gets to high there is a by-pass solution that opens when RITS operate without using the HPU.

The relief valve will open at 228 Bar, and the system is protected.
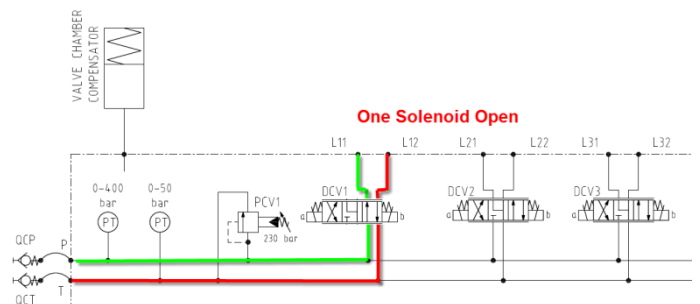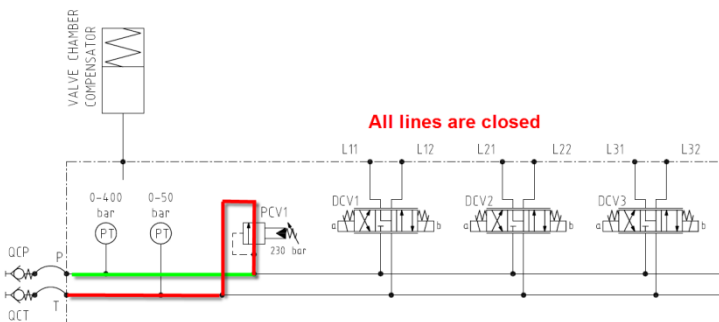
Sensors

There are sensors installed to be able to monitor the system. It is required to know that the signals that are sent from the HMI makes an action down inside RITS, which is important for the hot stabs since it applies pressurized fluids into a system.

The sensors are installed on the piping and are sending electric signals with different voltage. The each specific voltage represents one bar.

Traditional sensors are normally sending a voltage between 4 and 16 mA. A voltage of 4 mA means 0 Bar, while 16 mA means the highest value the sensor can measure (e.g. 690 Bar). The measurements in between is presented by a linear equation between these two values
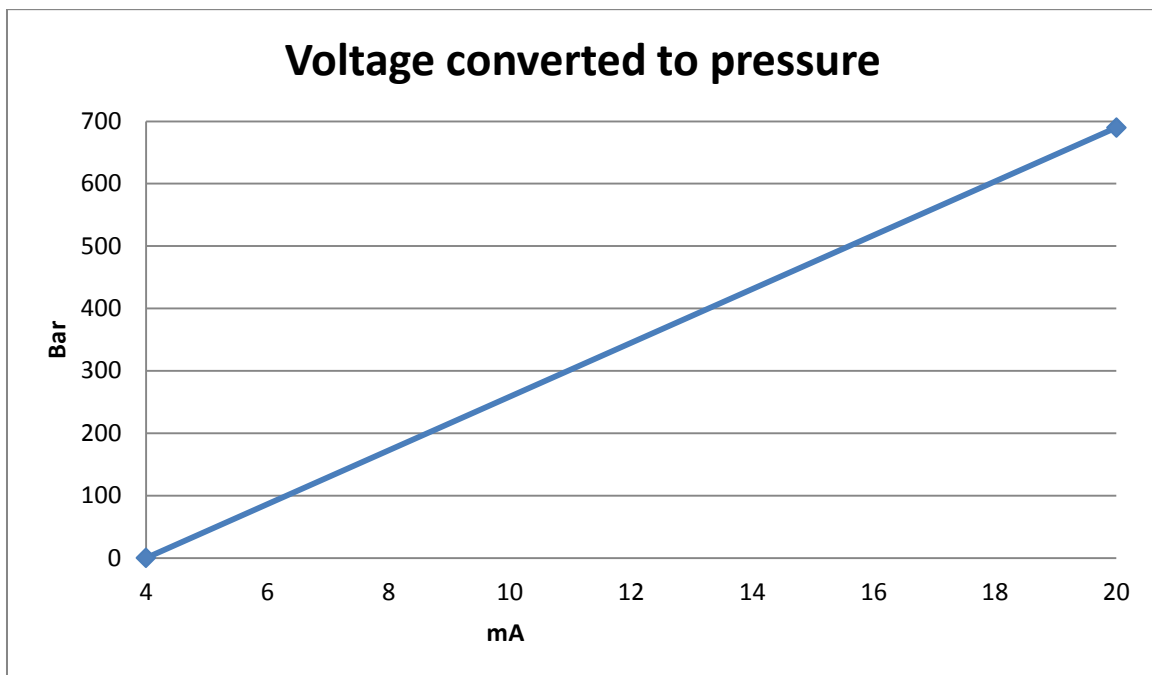
Appendix B - Hot Spots

ANSYS is analysis software which calculates the actual forces on the structure. To be able to put the forces on the correct position there is added small areas to the model. These small areas make ANSYS "over analyze". It results in greater forces than what actually appears.

The figure below illustrates the problem. Red areas are the max forces. The calculation calculate a pressure of 242.81 MPa; yet the stress areas are connected the point where the forces are put.
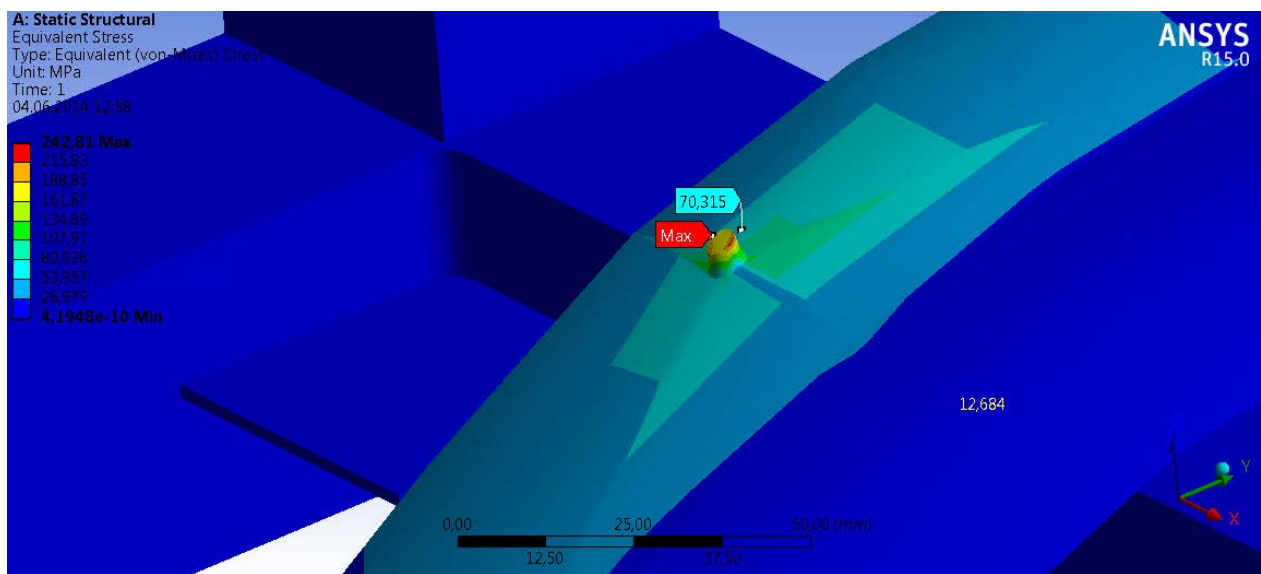
To be sure that the calculation is correct the results was controlled by manual calculations. It is a static calculation, and is

$$\tau = \frac{P}{W}$$

W = 7600 mm^3 (Johannesen, 2002))

L = the length from the elements fastening to where the force are applied.
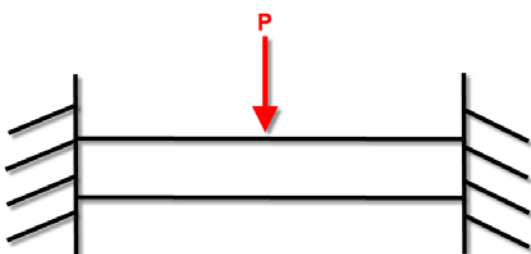
P may typical be:$P = \frac{P \cdot L}{8}$, but it will vary from case to case due to the actual situation.

The manual calculations revealed that the high values appeared on the units created to fasten the force. The tags added the hot spot is the actual max force - controlled manually and combined with the analysis in ANSYS.

Appendix C - Visual Components Programming (Python-script)

```python
from vcPythonKinematics import *
import vcMatrix
import vcVector
from math import *

import numpy as np

# Define the amount of joints and their names
JOINT_COUNT = 6
JOINT_NAMES = ['J1', 'J2', 'J3', 'J4', 'J5', 'J6']

qh = np.array([[0],[0],[0],[0],[0],[0]])
#print qh

global FirstCall, DH_PARAMS
global LO1X, L01Z, L12X, L23X, L34X, L45X, L56X

FirstCall = True

# Init kinematic object information
def OnInitKinObject( kinobj ):
  pass

# Returns the amount of joints this kinematics handles
def OnGetJointCount():
  return JOINT_COUNT

# Returns the indexed joint names
def OnGetJointName(index):
  return JOINT_NAMES[index]

# Constraints kinematic solutions to show only valid choices
def OnConstrainParams(kinobj):
  return True

# Relaxes kinematics solutions to show all choices
def OnRelaxParams(kinobj):
  return True

# Returns Kinematic chain target (matrix) value based on joint values
def OnForward(kinobj):
  #print 'OnForward'
  global DH_PARAMS

  if FirstCall:
    OnFinalize()

  qmag = np.array(kinobj.JointValues).reshape(6,1)
```

```python
    q = qmag+(np.array([[0],[0],[0],[0],[0],[0]]))
    print q

    (J, T) = ForwardKin(DH_PARAMS, q)
    print T

    m = Numpy2vcMatrix(T)

    kinobj.Target = m

    return True

def Numpy2vcMatrix(mat):
    T = np.ravel(mat)

    #T[0,0]

    m = vcMatrix.new()
    N = m.N
    N.X = T[0]
    N.Y = T[4]
    N.Z = T[8]
    m.N = N

    O = m.O
    O.X = T[1]
    O.Y = T[5]
    O.Z = T[9]
    m.O = O

    A = m.A
    A.X = T[2]
    A.Y = T[6]
    A.Z = T[10]
    m.A = A

    P = m.P
    P.X = T[3]
    P.Y = T[7]
    P.Z = T[11]
    m.P = P

    return m

def vcMatrix2Numpy(mat):

    np_mat = np.eye(4)

    N = mat.N
    O = mat.O
```

```python
    A = mat.A
    P = mat.P

    np_mat[0,0] = N.X
    np_mat[0,1] = O.X
    np_mat[0,2] = A.X
    np_mat[0,3] = P.X
    np_mat[1,0] = N.Y
    np_mat[1,1] = O.Y
    np_mat[1,2] = A.Y
    np_mat[1,3] = P.Y
    np_mat[2,0] = N.Z
    np_mat[2,1] = O.Z
    np_mat[2,2] = A.Z
    np_mat[2,3] = P.Z

    return np.matrix(np_mat)

# Returns Kinematic chain joint values based on the target (matrix)
def OnInverse(kinobj):
    global qh
    if FirstCall:
        OnFinalize()

    #print 'OnInverse'
    target = kinobj.Target

    #printMatrix(target)

    ## Convert to numpy
    Tf = vcMatrix2Numpy(target)
    #print Tf

    q0 = kinobj.JointValues
    ## Create numpy array from
    q0 = np.array(q0).reshape(6,1)


    qf = InverseKin(DH_PARAMS, Tf, qh)

    kinobj.JointValues = qf
    return True

def OnRebuild():
    OnFinalize()

def OnFinalize():
    print 'OnFinalize'
    global FirstCall
    global DH_PARAMS
```

```python
   global L01X, L01Z, L12X, L23X, L34X, L45X, L56X

   FirstCall = False
   comp = getComponent()

   L01X = comp.L01X
   L01Z = comp.L01Z
   L12X = comp.L12X
   L23X = comp.L23X
   L34X = comp.L34X
   L45X = comp.L45X
   L56X = comp.L56X


   DH_PARAMS, _ = SetDHParams()
   #print DH_PARAMS

def printMatrix(mat):
  """Usefull utility function for printing matrix value"""
  for Vec in [mat.N,mat.O,mat.A,mat.P]:
    print ("%3.3g\t%3.3g\t%3.3g\t%3.3g\n"%(Vec.X,Vec.Y,Vec.Z,Vec.W))



def SetDHParams():
  global qh
  global LO1X, L01Z, L12X, L23X, L34X, L45X, L56X

  ## Might be errors here!!

  # Initialize DH parameters dh and the zero position qh of the UR5 robot
  dh = np.matrix([[ L01X,        np.pi/2,  L01Z,  0],
          [L12X,          0,        0,  0],
          [L23X,          0,        0,  0],
          [L34X,         -np.pi/2,  0,  0],
          [ 0,          -np.pi/2,  0 ,  0-(np.pi/2)],
          [ 0,          0,        L45X+L56X,  0]])
  return (dh, qh)

def LinkDH2T(dh,i):
  # The homogeneous transformation matrix T of link i with DH parameters dh
  # from the DH parameters dh = [a_i alpha_i d_i theta_i
  xv = np.array([[1],[0],[0]])
  zv = np.array([[0],[0],[1]])
  T    =        AngleAxis2T(zv,dh.item(i,3))      *      Trans2T(dh.item(i,2)*zv)      *
AngleAxis2T(xv,dh.item(i,1)) * Trans2T(dh.item(i,0)*xv)
  return T



def AngleAxis2T(r, theta):
  # The homogeneous trasformation matrix T of a rotation theta about r
```

```python
    S = Skew(r)
    R = np.cos(theta) * np.matrix(np.eye(3)) \
    + np.sin(theta) * S + (1-np.cos(theta))*r*r.T
    T = np.matrix(np.eye(4))
    T[0:3,0:3] = R.copy()
    return T


def Trans2T(p):
    # The homogeneous transformation matrix T of a displacement p
    T = np.matrix(np.eye(4))
    T[0:3,3] = p.copy()
    return T


def Skew(r):
    # The skew symmetric for of a vector
    S = np.matrix([[ 0, -r[2],  r[1]],
             [r[2],  0,  -r[0]],
             [-r[1], r[0],  0   ]])
    return S


def ForwardKin(dh,q):
    # Forward kinematics for revolute joint manipulator
    # Inputs:
    # dh - Matrix of DH parameters
    # q - Vector of joint variables q
    # Outputs:
    # J - Geometric Jacobian
    # Te - Homogeneous transformation matrix of manipulator

    dhf = dh.copy()  # Note: Must use .copy(), dhf = dh makes dhf and dh the same variable
    #Insert joint variable in DH vectors
    dhf[0:,3] = dhf[0:,3] + q
    #print dhf[0:,3]

    # Homogeneous transformation matrices for each link
    T01 = LinkDH2T(dhf,0)
    T12 = LinkDH2T(dhf,1)
    T23 = LinkDH2T(dhf,2)
    T34 = LinkDH2T(dhf,3)
    T45 = LinkDH2T(dhf,4)
    T56 = LinkDH2T(dhf,5)
    # Homogeneous matrices from frame0 to each link frame
    T02 = T01 * T12
    T03 = T02 * T23
    T04 = T03 * T34
    T05 = T04 * T45
    # Homogeneous transformation matrix for manipulator
    Te = T05 * T56
    # Rotation axes
    z0 = np.array([[0], [0], [1]])
```

```python
z1 = T01[0:3,2]
z2 = T02[0:3,2]
z3 = T03[0:3,2]
z4 = T04[0:3,2]
z5 = T05[0:3,2]
# Position vectors
p0 = np.array([[0], [0], [0]])
p1 = T01[0:3,3]
p2 = T02[0:3,3]
p3 = T03[0:3,3]
p4 = T04[0:3,3]
p5 = T05[0:3,3]
# Position vector of manipulator
pe = Te[0:3,3]

# Blocks of position part of geometric Jacobian
J00 = Skew(z0)*(pe-p0)
J01 = Skew(z1)*(pe-p1)
J02 = Skew(z2)*(pe-p2)
J03 = Skew(z3)*(pe-p3)
J04 = Skew(z4)*(pe-p4)
J05 = Skew(z5)*(pe-p5)
# Geometric Jacobian
J = np.bmat('J00 J01 J02 J03 J04 J05; z0 z1 z2 z3 z4 z5')
return (J, Te)


def InverseKin(dh, Td, q0):
  # Inverse kinematics using inverse geometric Jacobian
  # Inputs:
  # dh - DH parameter matrix
  # Td - Commanded homogeneous transformation matrix
  # q0 - Initial value for q
  # Outputs:
  # Solution q

  Rd = Td[0:3,0:3]
  qk = q0.copy()
  for count in range(1,5):
    (Jk, Tk) = ForwardKin(dh,qk)
    #print(Jk)
    Rk = Tk[0:3,0:3]
    Re = Rd * Rk.T
    ep = Td[0:3,3] - Tk[0:3,3]
    # Rotation error is the r sin(theta) vector
    eo = (1./2.)*np.array([[Re[2,1]-Re[1,2]], [Re[0,2]-Re[2,0]], [Re[1,0]-Re[0,1]]])
    e = np.bmat('ep ; eo ')
    K = 1
    dq = K * np.matrix(np.linalg.inv(Jk)) * e
    qk = qk + dq
```

```
    return qk

# Main program
# Initialize UR5 robot parameters
#(dh, qh) = SetDH_UR5()

#(Ji, Ti) = ForwardKin(dh, qh)

# Increment from Ti to Tf to Tf
#dp = np.array([[-0.2],[0.2],[-0.2]])
#ry = np.array([ [0],[1],[0] ])
#rz = np.array([ [0],[0],[1] ])
#Tf = Ti * Trans2T(dp) * AngleAxis2T(ry,-np.pi/6) * AngleAxis2T(rz, np.pi/6);

#q0 = qh.copy()
#qf = InverseKin(dh, Tf, q0)

#print(qf)

#qf = [0.5591  -1.1805  -1.4447  -1.7900   2.0085   1.1492]'

#print "-"
```

Appendix D - RITS Specification

ROV Intervention Tool Skid (RITS)

Document type	Doc.no :	SPC-0000031472		
Specification	**Page :**	1 of 23		
Status	**Change no.**	**Date**	**Version**	**Revision**
In preparation		##	00	##

T A B L E   O F   C O N T E N T S

F I G U R E S

1 INTRODUCTION

1.1 PURPOSE

The purpose of this document is to form the basis for detail design, fabrication and testing of the ROV Intervention Tool Skid (RITS).

The purpose of the RITS is to improve ROV intervention assignments. Installation, testing and retrieval of subsea equipment depending of intervention tools are the main aim for RITS.

RITS is intended to reduce the ROV operational time consumption by improving the working condition without reducing the present flexibility.
This specification will provide the information and requirements necessary for the detailed design and manufacture of the system. The vendor is encouraged to propose alternative solutions to those specified in this document if these can be justified on the basis of improved functionality or can be shown to contribute to a more cost-effective solution. It is expected that any changes proposed be fully justified and must satisfy the functional requirements established in this specification.

1.2 SCOPE

This document provides the requirements and design data for the RITS.

The scope of this document is to define the following:

- System Requirements

- Functional Requirements

- Interface Requirements

- Material Selection and Corrosion Protection

- Documentation

- Outline Operational Procedures

1.3 ABBREVIATIONS

The following abbreviations are used in this document.

DC	Direct Current
FKS	FMC Kongsberg Subsea AS
GUI	Graphical User Interface
HMI	Human Machine Interface
HPU	Hydraulic Power Unit
ICS	Intervention Control System
LPM	Litre/minute
MQC	Multi Quick Connect (Plate)
N/A	Not Applicable
OBSROV	Observation Class Remotely Operated Vehicle
RITS	ROV Intervention Tool Skid
ROT	Remotely Operated Tools
ROV	Remotely Operated Vehicle
SCU	Surface Control Unit
SPC	Design Specification (FKS Document)
WROV	Work Class Remotely Operated Vehicle

1.4 REFERENCES

Industry Standards and Codes

Ref.	Document No.	Title
R1	NORSOK U-CR-008	Subsea Colour and Marking
R2	DnV 2.7.3	Portable Offshore Units
R3	AS 4059	Cleanliness Requirements of parts used in Hydraulic Systems, Maximum Contamination Limits
R4	NS 3471	Projecting of Aluminium Constructions, Calculation and Dimensions
	ISO 13628: 2000	Petroleum and Natural Gas Industries Design and Operation of Subsea Production Systems
R5	Part 8	Remotely Operated Vehicle (ROV) Interfaces
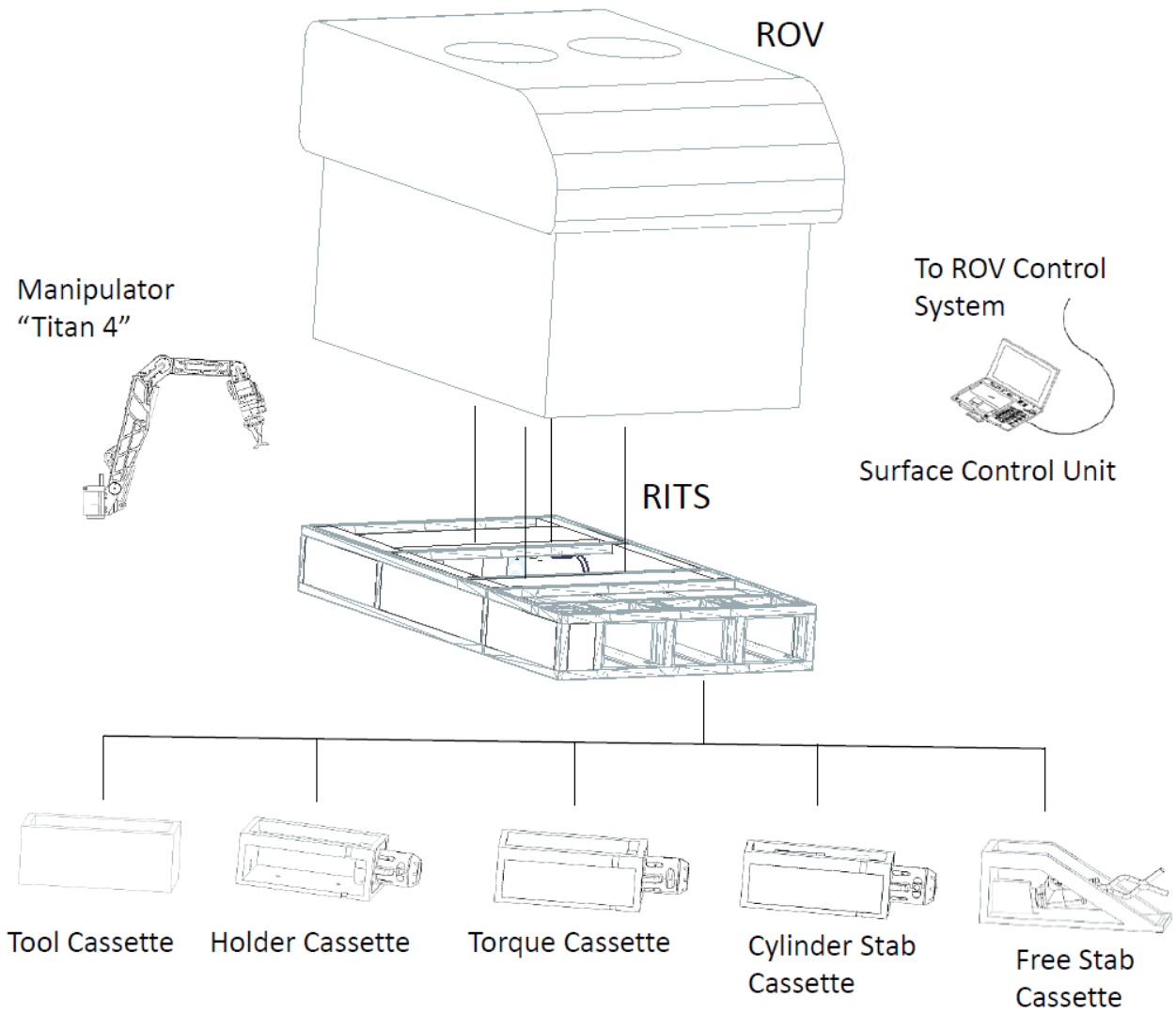
Figure 3   ROV Intervention Tool Skid (RITS) Control System Overview

2   SYSTEM REQUIREMENTS

2.1   SYSTEM COMPONENTS

The RITS System shall as a minimum consist of the following equipment:

- 1 off: ROV Torque Tool API 17D size 1-4.
- 1 off: ROV Hydraulic Power Unit (HPU).
- 3 off: Different Cassettes (5 options)
- 0-3 off: Stab, 6 Line, 345 Bar with hoses
- 3 off: Kystdesign 6L Compensators
- 1 off: Parker F11-10 pump
- 1 off: Parker F11-10 motor
- 1 off: Surface Control Unit (SCU).
- 1 off: Manipulator Titan 4.
- 1 off: Pall filter, 9050.
- 0-1 off: RCU remote control unit, Oceaneering
- At least 1 off: Topside monitor(s)

2.2   SYSTEM CONFIGURATION

The RITS shall be flexible with regard to the configuration required for the various Intervention Tools when used for different applications.

- Dock up to fixed API 17D interface instead of using grabber manipulator.
-         Require a adjusted API 17D interface bucket on the subsea unit.
- Operate ROV-panels with the FMC operated manipulator
- Provide an option for a pre-programmed manipulator.
- Easier access of special tools (can bring three tools at the time).
    - ➢ Hydraulic systems by use of a hot stab.
    - ➢ Mechanical systems by use of torque tools or other tools from the tray.
    - ➢ Bring other tools e.g. LAOT - Linear Actuator Override Tool (100040011 or 100049598)

The RITS system is divided into two main parts - one system operating the hot stabs and the other system handles everything else. It results in control systems and two hydraulic systems; however both systems are operated from the same HMI.

2.3   **SPECIFIC REQUIREMENTS**

2.3.1 Subsea System Requirements

The requirements of the subsea components of RITS are as follows:

1) RITS shall be launched and deployed by Work Class ROV (WROV). The skid shall be made neutrally buoyant in seawater by means of removable buoyancy elements. And with a weight in water less than 50 kg.

2) RITS shall be transportable in the water, at the maximum operating depth, on 3000 meters.

3) RITS shall be powered from the ROV with control signals routed from the surface via the ROV control system. The electrical and hydraulic interfaces shall be industry standard and compatible with a WROV.

4) The RITS structure shall provide the mechanical interface for mounting the RITS beneath the WROV. The structure shall be compatible with the common WROV systems in current use. The mounting system shall have a flex system to decrease the impact load.

5) The interfaces shall be industry standard (API 17 D size 1-4). Special intervention tools shall fit inside the API 17D size 1-4 interface (includes hot stab 6l and Torque Tool – tool tray will have a separate system)

6) The Intervention Tool inside shall be powered from the ROV's auxiliary valve pack. The hydraulic interfaces shall be compatible with the existing interfaces on the subsea equipment with no modifications. In situations where the interface does not fit the necessary task will be operated by the manipulator mounted on the RITS.

7) In the event of equipment failure, the RITS shall be designed with a fail-safe-open mechanism on the locking dogs on the API connectors, and can be retrieved by means of a suitable backup system (i.e. pulled in by the umbilical).

8) The RITS shall not be installed with cameras and lights. Light and visual will be supplied by the ROV system.

9) Facilities shall be provided for emergency lifting of the RITS for recovery to the surface in the event of equipment failure.

10) The system shall enable the retrieval/installation procedure to be aborted at any stage of the operation in the event of equipment failure.

11) Design of the system shall be such that operation with only one WROV.

2.3.2 Topside System Requirements

The requirements of the topside components of the RITS are as follows:

12) The Surface Control Unit (SCU) shall provide the operator interface for control and monitoring of RITS during operation. Control and feedback signals shall be routed via the ROV control system and RITS.

13) The SCU shall have a graphical user interface (GUI) with separate graphics. The graphic shall depict the tool layout with the hydraulic line numbers and be simple to use and understand.

14) The cassette configuration on the HMI will be set according to the cassettes configuration in RITS. The system will be tested on a test stand before the launching process.

3   FUNCTIONAL REQUIREMENTS

The functional requirements of the RITS are as follows:

3.1   GENERAL DATA

Description	Data
Design life of equipment	20 years
Design water depth	2000 meter
Buoyancy water depth rating	Neutral
Maximum landing speed	0.5 m/s
Maximum landing force	20000 N (20kN)

3.2   TARGET MECHANICAL DATA

Description	Data (to be verified by supplier)
ROV Skid dimensions	
Length	2700mm
Width	1550mm
Height	350mm
ROV Skid weight	
In air	517.5-581.5 kg, *depending of cassette configuration*
In water with buoyancy	neutral
Cassettes	
Length	600mm (800mm incl. API interface)
Width	360mm
Height	250 mm
Cassettes Weight, in Water all the same	Approx. 3.8 kg
Tool Cassette, in air	11.2 kg
Holder Cassette, in air	17.8 kg
Torque Cassette, in air	63 kg
Cylinder Stab Cassette, in air	32 kg
Free Stab Cassette, in air	14 kg

3.2.1   RITS

The functional requirements of the RITS are as follows:

The hydraulic power supply in the RITS shall be suitable for operation using mineral oil (Shell Tellus 22 or equivalent) supplied from the ROV. All components are powered by this system except from the Hot Stab that is powered by the motor-pump (HPU system).

The hydraulic power unit (HPU) shall be supplied with water-based fluid (Marston Bentley HW443 or equivalent), filled topside.

Each line to the Hot Stab, 6 Line, 345 Bar shall be fitted with a 50 psi check valve to prevent the loss of hydraulic fluid from the system when disconnected.

The pressure compensators shall have a low level indicator and alarm to the control of the HPU system and the ROV system. In addition there is a speed senor on the shaft between the motor and the pump.
There is installed three pressure sensors in the system (on the motor supply line, on the pump supply line and the pump return line)
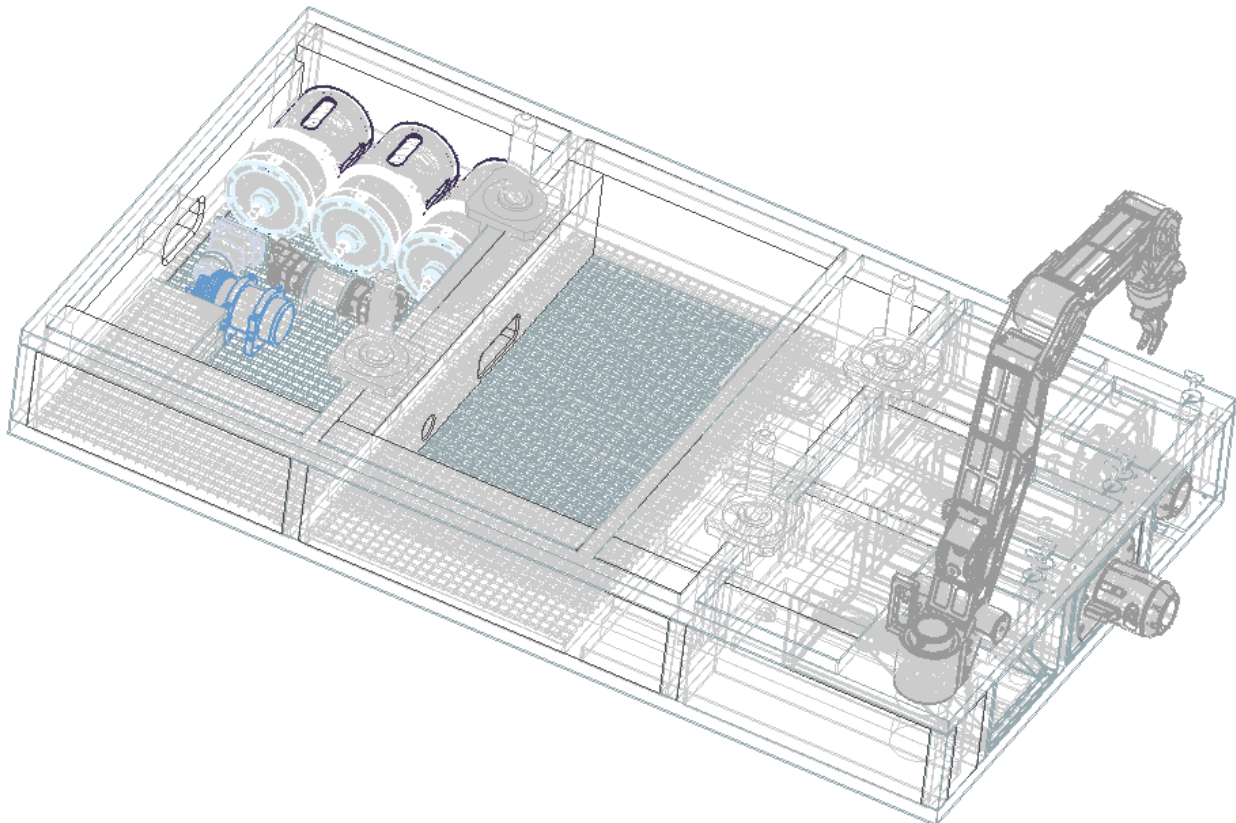
Figure 4 model of RITS

FMC Technologies

3.3 HYDRAULIC SYSTEM

The hydraulic system design shall include all the components necessary to operate the various subsystems. The hydraulic system will incorporate the following design requirements:

Hydraulic supply to RITS

Design pressures (above ambient) for hydraulic system:

Supply pressure:	207 bar (3,000 psi)
Maximum working pressure (WP):	207 bar (3,000 psi)
Test pressure (1.5 × WP):	310 bar (4,500 psi)

Maximum flow at working pressure:	20 LPM (5.3 USGM)
Fluid:	ROV (Tellus VG22, or equal).

Hydraulic Power Unit

(Powered by the Parker F11-10 motor-pump unit - separate fluid from RITS).

Hydraulic fluid:	Mineral Oil (Transeoacic or equal)
Cleanliness requirement:	NAS 1638, Class - (depending off operated system)
Supply pressure	207 bar
Maximum flow at working pressure	18.6 bar
Hydraulic interface:	6L Hot Stab
Number of hot stabs possible:	3 at the time, normally less
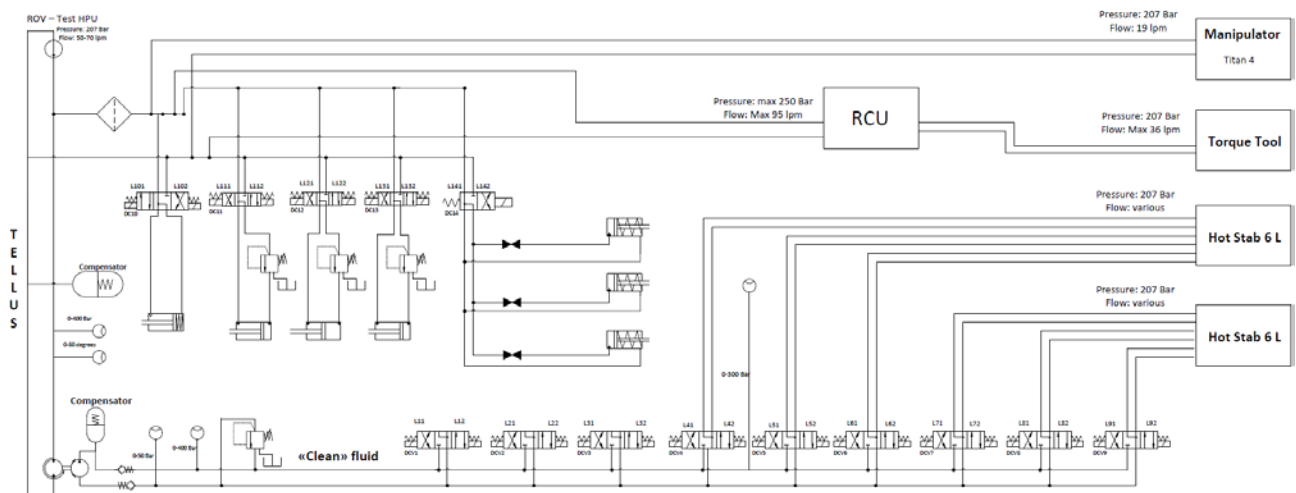
Figure 3 Hydraulic Schematics

3.4 ELECTRICAL SYSTEM

The electrical system will be guided true an electric transformer can.

Mode of operation:
> Electrical power supplied from the WROV via an electric Can or direct to the RCU (only for if the Torque Cassette is mounted).

Electrical supply to RITS

> Power supply:

The electrical system on the WROV shall have sufficient power to run the RCU and the two valve packs inside RITS.
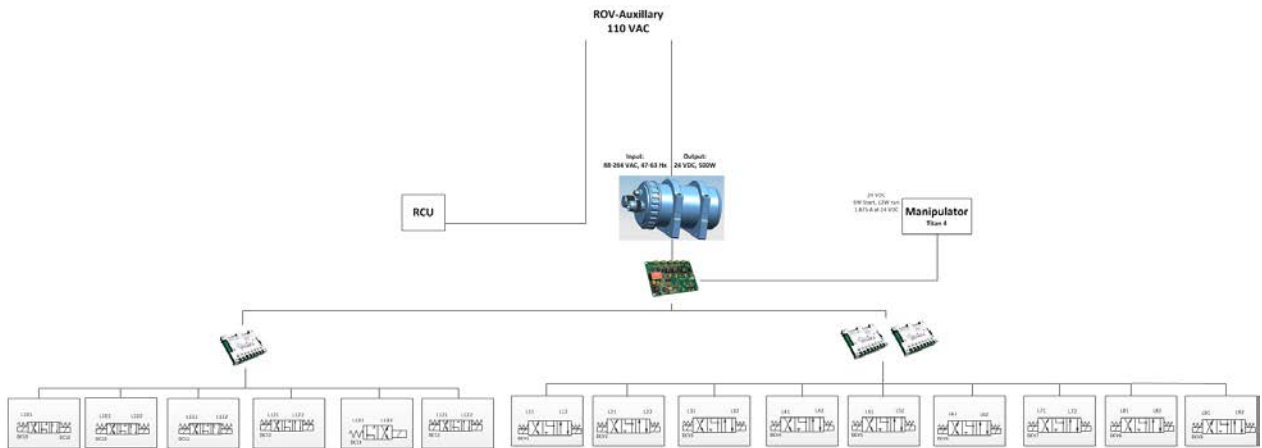
Figure 4 Control system

3.5   CONTROL SYSTEM

3.5.1   Control System General Requirements

3.5.2   Subsea Hydraulic Control Unit

The compensated valve pack shall include the following items:

- Compensated enclosure.

- Hydraulic valves and components.

- Imbedded Controller and driver electronics.

- Pressure transducers.

- Connectors and penetrations.

- Compensation unit(s).

Valve Pack on ROV side of hydraulic system
4 off 4/3 way, Type NG3 solenoid valve with open centre, 20 LPM (5 USGM) @ 200 bar.
1 off 4/2 way, Type NG3 solenoid valve with open centre, 20 LPM (5 USGM) @ 200 bar
-

Valve Pack on ROV side of hydraulic system
9 off 4/3 way, Type NG3 solenoid valve with open center, 20 LPM (5 USGM) @ 200 bar.

The valve pack shall satisfy the following requirements:

Material selection and protective coating shall be suitable for long-term immersion in seawater to a depth of 2,000 metres.

1) A prime consideration in the choice of materials and design shall be to minimise weight and size consistent with fulfilling the functional requirements.

2) All ports and internal passages in the valve block shall be designed to accommodate the maximum flow for each circuit with minimum pressure drop.

3) External hydraulic connections shall be designed to suit BSP hydraulic fittings.

4) A pressure relief valve shall be installed as an over pressure safety valve for the main HPU system. The valve shall be manually adjustable and at least allow adjustment within the range 160 bar to 400 bar.

5) A pressure transducer shall be installed in the valve pack to monitor the inlet hydraulic supply pressure.

6) A temperature transducer shall be installed as a safety mechanism for the HPU motor.

7) Drain and bleed ports shall be installed in positions that allow air to be vented from the enclosure and fluid drained from the enclosure when installed either with the valve block oriented vertically or horizontally.

8) The compensation system shall ensure that at least 0.5 bar over pressure is maintained in the compensated enclosure at an external ambient pressure of 300 bar. An external pressure gauge shall be supplied to monitor the compensation pressure.

The hydraulic valves and components selected for the valve pack shall be standard off-the-shelf catalogue items from a generally recognised manufacturer and available on a world-wide basis. The preferred vendor is Wandfluh but functionally equivalent components from other vendors are acceptable.

An embedded controller shall control the various hydraulic valves and collect data from sensors installed in the valve pack and sensors located external to the valve pack.

I/O Type	Quantity	Application
Digital/PWM Out	28	Hydraulic valve solenoid or proportional valve control
Digital In	1	Electric Can, connected a Communication Distribution Board)
Water Alarm	2	Water Ingress Detection (installed in valve pack).
Pressure sensor analogue input	3	Analogue Input, 4-16 mA (supply pressure, HPU supply pressure and HPU return pressure)
Speed Sensor	1	In motor-pump-shaft (4-16mA)
Level Sensor	3	In compensators (4-16 mA)

Interface circuitry shall be included to provide current drive for the hydraulic valve solenoids and the proportional valve solenoids. The electrical power available for the controller and drive electronics is 24 VDC at 15 Amps.

9) The drive circuitry shall be capable of simultaneously driving 10 solenoid coils without overload.

10) Interface circuitry shall be included to provide power to the pressure transducers and a stable reference voltage for potentiometer type sensors.

11) The embedded controller and supporting electronic components shall be qualified for operation at an external pressure of 300 bar. The qualification shall be accomplished by documenting correct operation of the electronics while cycling the external pressure from 0 bar to 300 bar. A minimum of 10 cycles is considered necessary to adequately demonstrate long-term tolerance to the specified external pressure.

3.5.3 Camera and Light Control System

Camera and light is operated from the ROV. All operation will happen in front of the ROV.

3.5.4 Surface Control Unit

The Surface Control Unit shall provide the control signals to control the hydraulic functions and display the monitored values, in metric units, from various sensors installed on RITS. It shall be based on a laptop PC with a GUI software providing input to all tool functions and display of all monitored values and status/diagnostics information.
The RCU and the Titan 4 will use suppliers' software - linked true RITS normal GUI when they shall operate.

The Surface Control Unit shall be able to operate in the following modes

- **Software master mode**

  - In this mode the GUI software is the control system master and all control system functions are controlled and monitored from the software.

- **Simulator mode**

  - This mode mimics the behaviour of the subsea hydraulic controller. When connected to the communication link, the topside controller will believe that it is talking to the subsea hydraulic controller. The user can set the value of simulated limit switches and analogue sensors. Commands sent from topside will be visualised in the simulator GUI page.

- **Configuration mode**

  - Setting of all the user-configurable options (I/O mapping, interlocks, scaling, etc.). Settings are downloaded to the surface controller's permanent flash memory.

  - Diagnostic mode. Display of all raw and scaled values in the system. Display of communication error and timeout counters.

4 INTERFACE REQUIREMENTS

The interface towards subsea equipment is an API 17D interface.

4.1.1 Mechanical Interface

The ROV Interface Frame provides the mechanical interface between the WROV and RITS. The Interface Frame(s) shall be designed for the Work ROV Systems in common use.

The Work ROV Systems considered to be suitable for deployment of RITS are listed below.

WROV	
HD-ROV	Schilling
UDH-ROV	Schilling
Centurion QX,200	Subsea 7
Centurion QX, 300	Subsea 7
ACV	Subsea 7
Hercules	Subsea 7
Quantum	Subsea 7
Diablo	Subsea 7
Demon	Subsea 7
Magnum Plus	Oceaneering
Maxximum	Oceaneering
Millenium Plus	Oceaneering
Triton XTR	Slingsby
Triton XLX	Slingsby

* Other ROV systems not contained in the list may also be suitable host systems.

The physical requirements for the ROV and handling/deployment system are as follows:

- The minimum through-frame lift capacity of the ROV is 1,000 kg.

- The ROV, A-frame and handling system must be able to handle an additional weight in air and through the splash zone of 600 kg for RITS.

- The height of the A-frame must be able to accommodate RITS height of approximately 350 mm plus 400 mm to install and remove the ROV.

4.1.2 Hydraulic Interface

The hydraulic motor-driven pump shall be supplied with hydraulic fluid directly from the host WROV. The clean fluid reservoir will be filled before every operation due to what system that will be operated. The requirements for the hydraulic supply are as follows:

- Valve Packs: 2 off,

  (4/3 bi-directional control valves with closed centre position)

- Fluid: Mineral oil (Shell Tellus 22 or equivalent)

- Maximum supply pressure: 207 bar (3,000 psi) above ambient

- Minimum flow requirement at 207 bar: 20 LPM

- Minimum oil compensation: 6 liters

- ROV interface connections

  * Supply: Custom (depends of the ROV)

  * Return: Custom (depends of the ROV)

4.1.3 Electrical Interface

RITS shall be supplied with electrical power and control signals directly from the electrical system on the host WROV via oil-filled interconnecting cables with wet mateable connectors. In addition, video signals from cameras on the ROV shall be routed back to the WROV for transmission to the surface. The requirements for the electrical power, communications and video interface are as follows:

Interface	ROV Requirement
Electrical Power	110 - 120 VAC
Electric Interface	Burton 5506-2008
RCU Interface	? probably the same
Data Interface	Serial line, RS485 half-duplex

The electrical system on the WROV shall have sufficient power to run all lights and cameras in addition to RITS.

5 MATERIALS AND CORROSION PROTECTION

5.1 MATERIAL SELECTION

Material selection shall be as follows:

Part Description	Material Type	Material Specification
Structural Framework	Aluminium, AA 6082-T6	NORSOK
Machined Parts	Aluminium, AA 6082-T6	NORSOK M-CR-120 (#R2)
Polymer Parts	POM	N/A
Hydraulic Piping and Fittings	AISI 316L	KOS-DSP-1025
Cylinders	Structural Steel	Hydex-Sylinderteknikk

5.2 SURFACE TREATMENT

Surface preparation, coating application, inspection, testing and repair shall be in accordance to the following:

Part Description	Coating System	Cathodic Protection
Tool frame	N/A	Raw aluminium anodes If needed
Bolted interfaces	Primer, max 50μ (zinc rich epoxy or aluminium pigmented epoxy) Tectyl 506	N/A

5.3 FABRICATION

All fabrication, installation inspection and DE of structural steel and pressure containing equipment shall be conducted in accordance with NORSOK, M-CR-101 and M-CR-601.

5.4 IDENTIFICATION AND TRACEABILITY

Identification and traceability shall be conducted in accordance with FKS Document "Identification and Traceability" (#F3).

5.5 PACKING, STORAGE AND PRESERVATION

Packing, storage and preservation shall be conducted in accordance with FKS Document "Standard and Instructions for Packing, Protection and Preservation" (#F4).

6 TEST REQUIREMENTS

RITS shall be subjected to a test programme in order to demonstrate that the design will satisfy all specified requirements and perform satisfactorily in service.

The test program shall be divided into Unit Qualification and System Qualification, as outlined below.

6.1 UNIT QUALIFICATION

6.1.1 Factory Acceptance Test

The individual components RITS shall be subjected to a Factory Acceptance Test (FAT) to verify that the equipment complies with the requirements of this specification and the applicable regulations, standards and codes. The FAT is to be carried out in accordance with written procedures provided by the supplier and approved by FKS.

The minimum requirements for the FAT are:

- Pressure test of hydraulic system and components.

- Flushing of hydraulic components, cleanliness check.

- External pressure test of the control system components.

- Functional test of all the tool functions. This test shall be carried out several times to verify acceptable design requirements.

- Final inspection to verify dimensional tolerances and weight etc.

The hydraulic systems on RITS shall be pressure tested to $1.5 \times$ design pressure. The acceptance criteria for the pressure test shall be a maximum 2% pressure drop over 15 minutes under stable temperature conditions.

The equipment supplier shall provide documentation to verify the fluid cleanliness level of the hydraulic system equal or better than that specified above at the time of delivery.

The subsea controller enclosure and a minimum of five solenoid valves shall be tested for correct operation at an external test pressure of 200 bar. A successful test shall be accomplished by documenting correct operation of the electronics during cycling of the external pressure from 0 to 200 bar 10 times. During the last cycle, the pressure shall be maintained for a minimum period of 10 hours. Correct operation of the solenoids shall be determined by reading the input to the subsea controller.

The following shall be checked during the final inspection:

- External and internal dimensions.

- Interface dimensions.

- Weight data. Parts to be used subsea shall be weighed both in air and in water with valve pack and compensator filled with oil.

- Correct marking of the equipment.

- Correct marking of individual components, piping, cables and terminal blocks.

6.2 SYSTEM QUALIFICATION

The System Qualification of the ROV Deployed ICS shall consist of two system tests:

- System Test (ST) on land.

- Shallow Water Test (SWT).

Both tests shall be carried out in accordance with the Client's requirements and written procedures approved by FKS if applicable.

7 DOCUMENTATION

The Document Schedule shall be an appendix to the purchase order.

7.1 INTERMEDIATE DOCUMENTATION FROM SUPPLIER TO CLIENT

The equipment supplier shall make the following documentation available to the client throughout the course of the project:

Order Confirmation.

Execution plan.

General assembly drawings. The drawings and documents shall include parts lists, envelope dimensions and interface information.

Factory acceptance test procedures.

7.2 FINAL DOCUMENTATION

The following documents shall be submitted to the client subsequent to delivery of the equipment, in accordance with the document schedule:

- General Arrangement (GA) drawings.

- Piping and Instrumentation diagrams (P&ID).

- Interconnection diagrams.

- Wiring diagrams.

- Hydraulic schematics.

- Component list.

- Spare parts list.

- Detail drawings necessary to show locations of spares parts.

- Software documentation including top level flow diagram and commented source code.

- Hardware documentation including assembly drawings of printed circuit boards with component lists and wiring diagrams.

- Data sheets for major components (hoses, cables etc.).

- Technical Description.

- Operation and Maintenance Manual including packing and preservation procedure.

- FAT report including a cleanliness report.

All documents shall be delivered as hand copies and in electronic format.
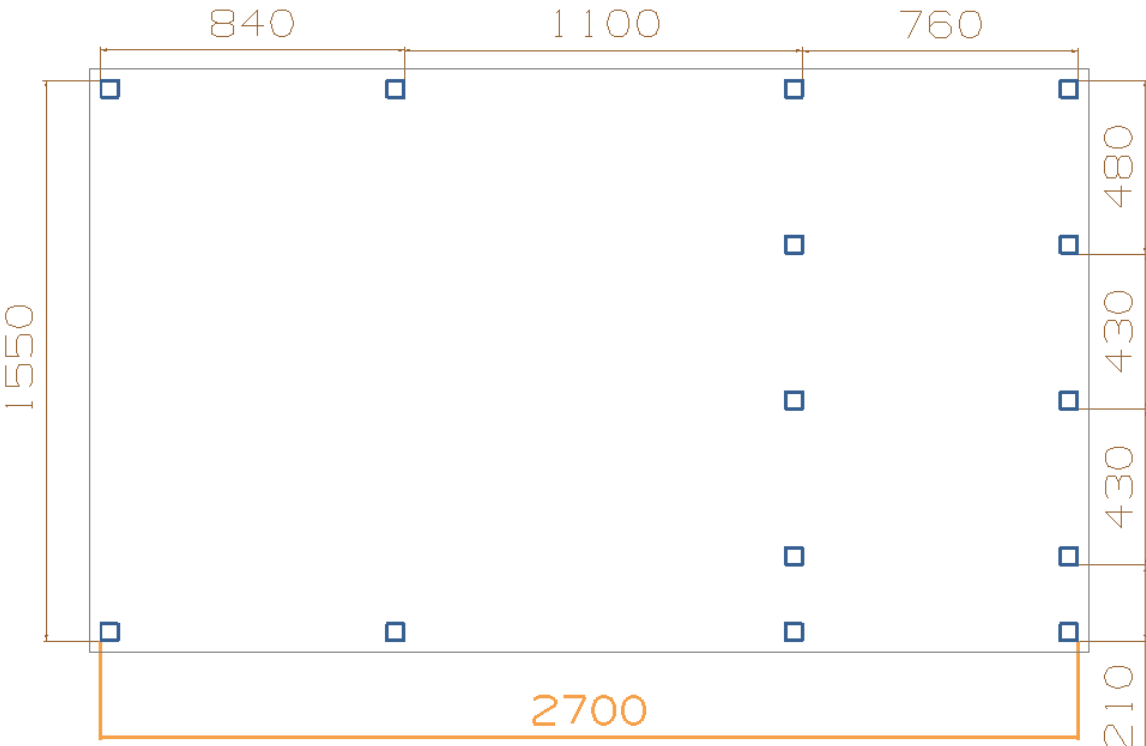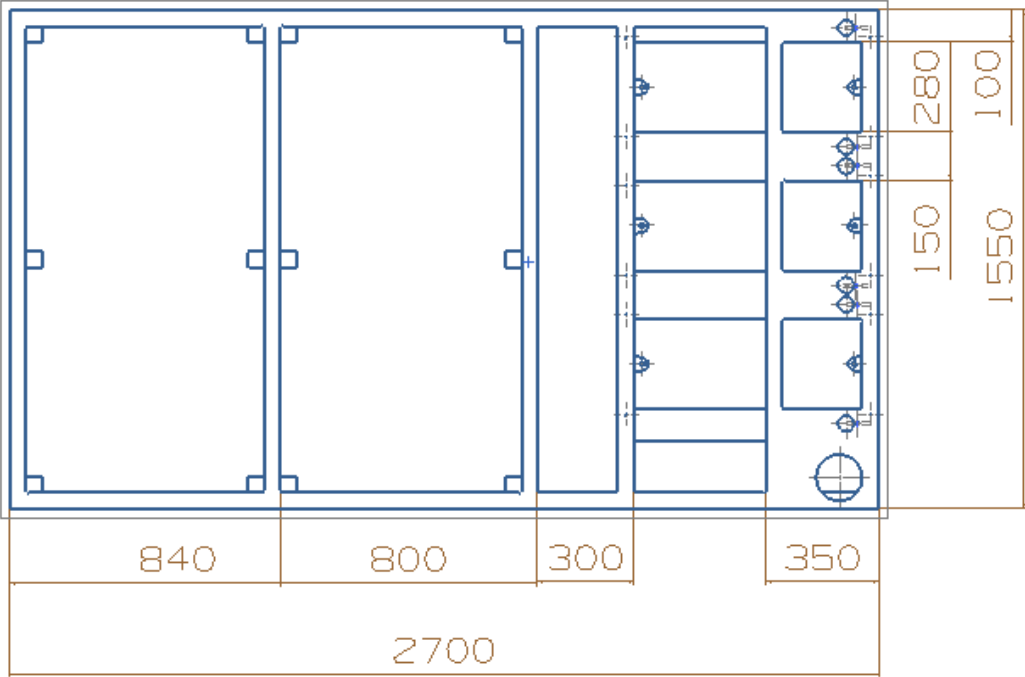
7.3   DOCUMENTATION FOR OPERATION

The following Documentation for Operation (DFO) shall be supplied by the client for the RITS Control System:

Equipment User Manual (USM) including:

- ∗ Technical description and data.

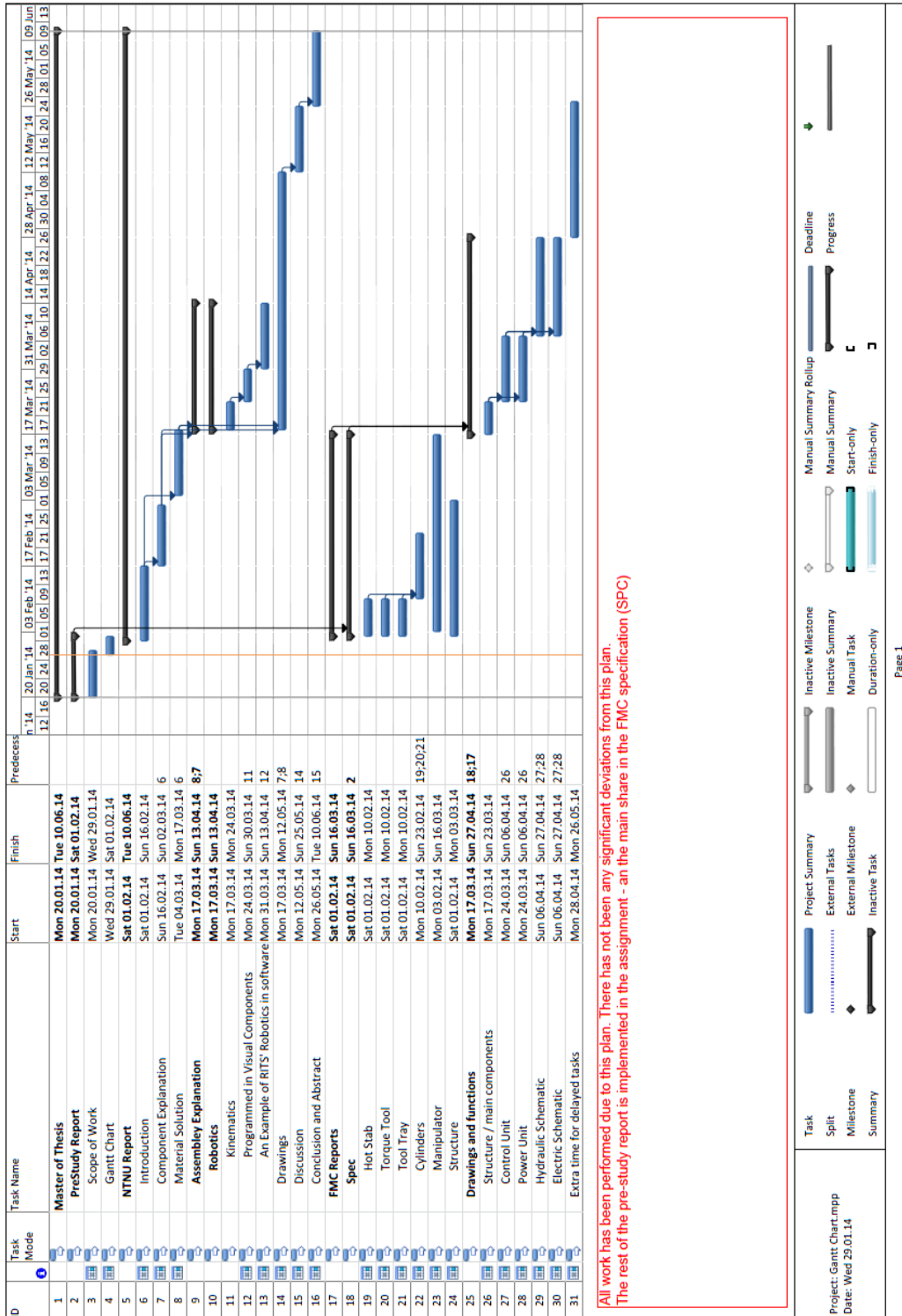- ∗ Transportation and storage.

- ∗ Preservation and maintenance.

Equipment Hook-up and Function Test (HFT).

8 DRAWINGS

Appendix E - Gannt Chart - Progress Report

ID	Task Mode	Task Name	Start	Finish	Predecess
1		**Master of Thesis**	**Mon 20.01.14**	**Tue 10.06.14**	
2		**PreStudy Report**	**Mon 20.01.14**	**Sat 01.02.14**	
3		Scope of Work	Mon 20.01.14	Wed 29.01.14	
4		Gantt Chart	Wed 29.01.14	Sat 01.02.14	
5		**NTNU Report**	**Sat 01.02.14**	**Tue 10.06.14**	
6		Introduction	Sat 01.02.14	Sun 16.02.14	
7		Component Explanation	Sun 16.02.14	Sun 02.03.14	6
8		Material Solution	Tue 04.03.14	Mon 17.03.14	6
9		**Assembley Explanation**	**Mon 17.03.14**	**Sun 13.04.14**	**8;7**
10		**Robotics**	**Mon 17.03.14**	**Sun 13.04.14**	
11		Kinematics	Mon 17.03.14	Mon 24.03.14	
12		Programmed in Visual Components	Mon 24.03.14	Sun 30.03.14	11
13		An Example of RITS' Robotics in software	Mon 31.03.14	Sun 13.04.14	12
14		Drawings	Mon 17.03.14	Mon 12.05.14	7;8
15		Discussion	Mon 12.05.14	Sun 25.05.14	14
16		Conclusion and Abstract	Mon 26.05.14	Tue 10.06.14	15
17		**FMC Reports**	**Sat 01.02.14**	**Sun 16.03.14**	
18		**Spec**	**Sat 01.02.14**	**Sun 16.03.14**	**2**
19		Hot Stab	Sat 01.02.14	Mon 10.02.14	
20		Torque Tool	Sat 01.02.14	Mon 10.02.14	
21		Tool Tray	Sat 01.02.14	Mon 10.02.14	
22		Cylinders	Mon 10.02.14	Sun 23.02.14	19;20;21
23		Manipulator	Mon 03.02.14	Sun 16.03.14	
24		Structure	Sat 01.02.14	Mon 03.03.14	
25		**Drawings and functions**	**Mon 17.03.14**	**Sun 27.04.14**	**18;17**
26		Structure / main components	Mon 17.03.14	Sun 23.03.14	
27		Control Unit	Mon 24.03.14	Sun 06.04.14	26
28		Power Unit	Mon 24.03.14	Sun 06.04.14	26
29		Hydraulic Schematic	Sun 06.04.14	Sun 27.04.14	27;28
30		Electric Schematic	Sun 06.04.14	Sun 27.04.14	27;28
31		Extra time for delayed tasks	Mon 28.04.14	Mon 26.05.14	

All work has been performed due to this plan. There has not been any significant deviations from this plan.
The rest of the pre-study report is implemented in the assignment - an the main share in the FMC specification (SPC)

	Task		Project Summary		Inactive Milestone	Manual Summary Rollup
Project: Gantt Chart.mpp	Split		External Tasks		Inactive Summary	Manual Summary
Date: Wed 29.01.14	Milestone		External Milestone		Manual Task	Start-only
	Summary		Inactive Task		Duration-only	Finish-only

Deadline
Progress

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