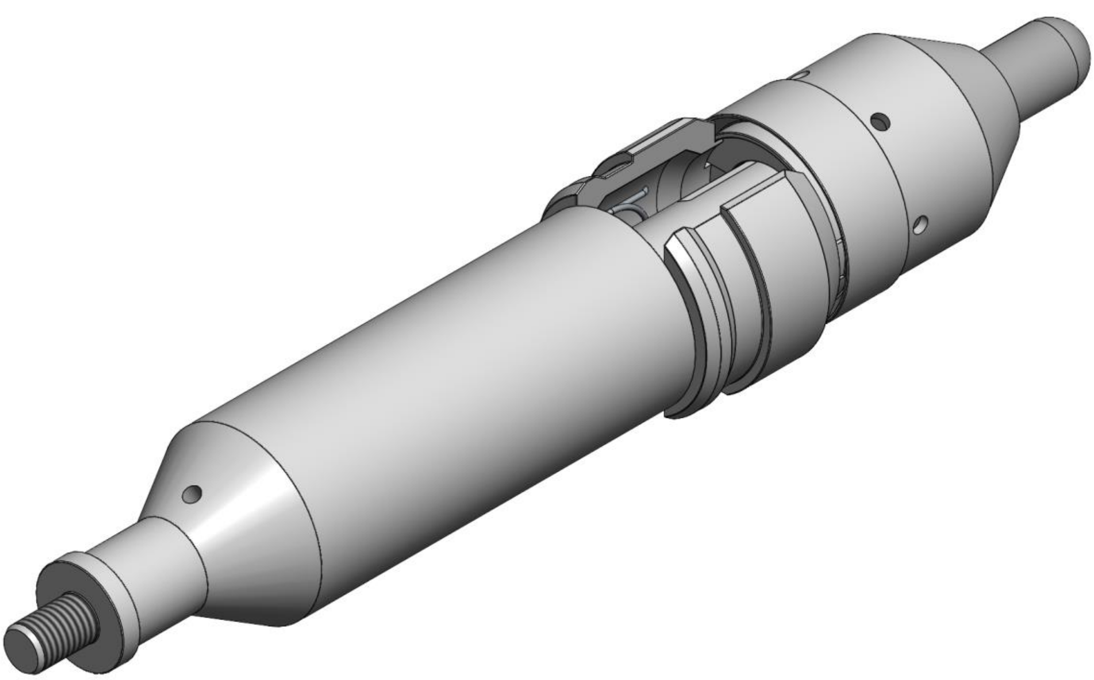
TCO Contingency Shifting Tool



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Bachelor thesis in Ocean Technology

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TCO Contingency Shifting Tool

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Preface

This Bachelor thesis is written in collaboration with TCO AS and the Institution for Machin and Marine (IMM) at Bergen Western University (HVL). During the three years of studying Ocean technology, I was fortunate enough to get an internship at TCO AS in my 5th semester. This semester I was able to get to know the company and the amazingly talented employees. And they gave me the opportunity to write my bachelor thesis with them. We sat down and looked at different options on a possible bachelor thesis together and agreed upon the thesis where I would design a new Shifting Tool for the contingency operations on TCO's Glass Barrier Plugs. Optimize geometry towards latching on to lower-set Otis "B" profile in the Sliding Sleeve Door. I will be working on the bachelor thesis alone, since I did not want to pass on the opportunity to work with TCO on this exciting and educational project.

The problem description of my bachelor's thesis will cover multiple of my subjects through my bachelor's degree. The topics covered by the thesis are:

- 3D – Modelling and technical drawings
- Flow area (Erosion)
- Shear stress and failure
- Tolerance study
- FMEA (Risk Analysis)

I want to thank the Project Manager at TCO, Thomas Stigen, who has been my mentor throughout this project. Thomas Stigen has been available to answer questions and for guidance whenever necessary. And a big thank you to every employee at TCO that has taken time out of their busy schedules to help me, by answering my questions and by sharing their knowledge with me.

I would also like to thank the Associate Professor at HVL Ragnar Gjengedal meeting me to discuss the thesis, and gave me information that helped me look at my thesis with different perspective.

Karina A. R. Risjord

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Abstract

The purpose of this thesis is to design a new Shifting Tool for the contingency operations on TCO's Glass Barrier Plugs. Optimize geometry towards latching on to lower-set Otis "B" profile in the Sliding Sleeve Door. The new replacement tool will lead to material and cost savings in the production of TCO's new DTHP, after performing a revision with the optimized geometry.

A literature study has been carried out, where a search has been made for a patent for the glass plug of TCO, and an existing Shifting tool on the market. Relevant standards for the new Shifting Tool and well interventions in completion operations have also been sought.

The new design must achieve the customers' expectations of the flow area between the Shifting Tool and the inside of the glass plug with a flow rate of 10bbl / min, and the environmental conditions down in the well. It has therefore been important to calculate the flow area and the tolerance between the outer diameter of the shift tool and the inner diameter of the glass plug DTHP. Furthermore, the shear stress on the shear pin has been calculated. It is important that the shear pin has the correct properties for the SSD to slide into the closed position, before the shear pin shear, but it is also important that it shear at the desired traction. The FMEA risk analysis has also been carried out, in order to identify and analyze possible hazards and errors that may occur and adversely affect the shifting tool and well interventions when using the shifting tool.

Sammendrag

Hensikten med denne oppgaven er å designe TCO ett nytt skifteverktøy for brønnintervensjoner. For å optimalisere geometrien ved nedre Otis "B" profil for Sliding Sleeve Door (SSD). Det nye skifteverktøyet vil føre til material- og kostnadsbesparelser ved produksjon av TCO's nye DTHP, etter å ha utført en revidering med den optimaliserte geometrien.

Det har blitt foretatt en litteraturstudie, hvor det har blitt gjort søk etter om det eksisterer patent på glasspluggen til TCO, og eksisterende skifteverktøy ute på markedet. Det har også blitt søkt etter relevante Standarder for det nye skifteverktøyet og brønnintervensjoner i kompletteringsoperasjoner.

Det nye designet må gå under kundenes forventinger av strømningsareal mellom skifteverktøyet og innsiden av glasspluggen med en strømningsrate på 10bbl/min, og de tøffe forholdene nede i brønnen. Det har derfor vert viktig å foreta utregning av strømningsarealet og toleransen mellom ytre diameter av skifteverktøyet og indre diameter av glasspluggen DTHP. Videre har det blitt regnet ut skjærspenningen for skjærpinne. Det vil være viktig at skjærpinnen har de riktige egenskapene for å sette SSD i lukket posisjon, før skjærpinnen ryker, men også viktig at den ryker ved ønsket trekkraft. Det er også blitt foretatt risikoanalysen FMEA, for å identifisere og analysere mulige farer og feil som kan oppstå og påvirke skifteverktøyet og brønnintervensjoner ved bruk av skifteverktøyet negativt.

Abbreviations

APRS	Annulus Pressure Relief System
BOP	Blow Out Preventer
CI	Chemical Injection Systems
DSBP	Deep Set Bypass Plug
DTHP	Disappearing Tubing Hanger Plug
ID	Inner Diameter
OD	Outer Diameter
SSD	Sliding Sleeve Door
TDP	Tubing Disappearing Plug
XT	Christmas Tree

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The Company

TCO AS is a company that started up in Voss in 1999 as a Well Service Company that is recovering equipment that either is stuck or lost in the oil wells. This is where the origin of their name Total Catcher Offshore originates from. In 2001 they changed the name to TCO, the Acronym of their old company name. The company realized that the time they were using to recover lost, stuck or destroyed equipment in the oil wells, could be drastically reduced by equipment that had the ability to disrepair when desired. This realization led the company to develop the idea of the intervention-free glass plug, which is used as a barrier and gives complete control in well operations. [1]

"The creation of the laminated glass plug represented a turning point within the oil and gas industry, and TCO attracted significant attention and acclaim as an industry leader within technology, innovation, and sustainability."[1]

TCO is a company built on talented employees with various background and experiences in different countries worldwide. TCO are solution finders and offers innovative products and service that provides solution to challenges quickly and safely. TCO is therefore recognized for being a leading inventor and competitor within the oil and gas industry. [2]

The company has different departments where they are focusing on one field. The fields are:

- Chemical Injection Systems (CI)
- Annulus Pressure Relief System (APRS)
- Completion Barrier Plugs.

This Bachelor thesis will only be focusing on the department of Completion Barrier Plugs. TCO has departments all over the world e.g., Aberdeen and North America, and customers such as Equinor and Wintershall Dea.

TCO is getting recognized for its invention of the laminated glass plug barrier used in operation for well completion. The glass plug can open the oil well by running pressure cycles with a specific force with the help of the well fluid. This is time saving, safer and a more efficient way, since the old ones were made of solid and massive materiel. After the oil well is opened with the help of pressure cycling with the help of the heavy mud fluid, they change the fluid to a lighter fluid e.g., brine (saltwater), diesel or other completion fluids.

1. Introduction

TCO is at the moment renting shifting tools from the company Wellvene, when they need to perform different tests where the shifting tool is needed and/or when customers are purchasing DTHP, or similar products where the shifting tool needs to be a part of the product purchase. TCO are at the moment providing the Shifting Tool out of their own founds. If TCO were to design their own Shifting Tool, they would then be able to use their own tool that would be customized to their products and be able to sell and/or rent their shifting tool to other costumers. This bachelor thesis intends to design a new Shifting Tool, to move the dogs on the tool from the middle and down to the end of the tool without changing its function.

Problem description

Design a new Shifting Tool for the contingency operations on TCO’s Glass Barrier Plugs. Optimize geometry towards latching on to lower-set Otis “B” profile in the Sliding Sleeve Door.

Scope

In this bachelor thesis will it be used Solidworks to 3D-model the parts then make assembly of the Shifting Tool. The next step would then be to make a technical drawing (2D- design) of each part and the assembly. There will be done patent searches to collect data and to be sure that there will not be any patent that could interfere with the project of the new Shifting Tool. It will be necessary to perform various calculations e.g., flow area for well displacement, shear strength of the shear pin, tolerance study and finding the necessary properties of spring used. There will be performed a FMEA (risk analysis) of the Shifting Tool assembly and some of the most important part of the Shifting Tool, and decision making considering the design of the Shifting Tool regarding its function.

This bachelor thesis will not contain any data (documentation or reports) from the different function test performed on the Shifting Tool, because that process has not yet started.

Purpose of the assignment

The purpose of this project is to design a new Shifting Tool that will be customized to the products of TCO. This makes it possible for the DTHP to be shorter and less cost-efficient. TCO is now buying the Shifting Tool that they are using for the DTHP from a different company. By designing their own, will they then be able to rent or sell their Shifting Tool, and to now use their own Shifting Tool with their DTHP as a package deal. This gives TCO the possibility of earning money on the tool.

2. Theory

This chapter will explain the well operation, equipment, and information relevant to this bachelor thesis. The importance of the theory is giving the readers a holistic understanding of the information that will be used further in this bachelor thesis.

2.1 Completion Operation

Well completion is the operation where the drilled well is transformed into a production well. The purpose of well completion is to ensure the recovery of the maximum possible volumes of oil at a responsible cost. [3] There are multiple steps in a completion operation, and the steps are:

- Casing
- Cementing
- Perforating
- Gravel packing
- Installing Production tree
  [4]

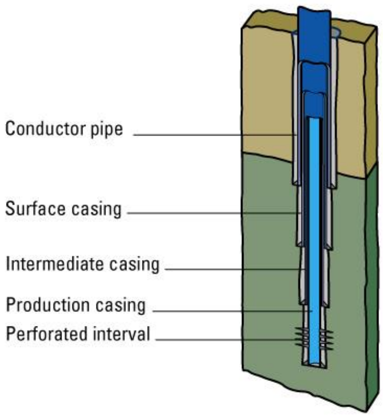


Figure 1: Casing [4]

After the well is drilled, the casing is installed to protect the well stream from the outside incumbent and ensure the well not close upon itself. [4]

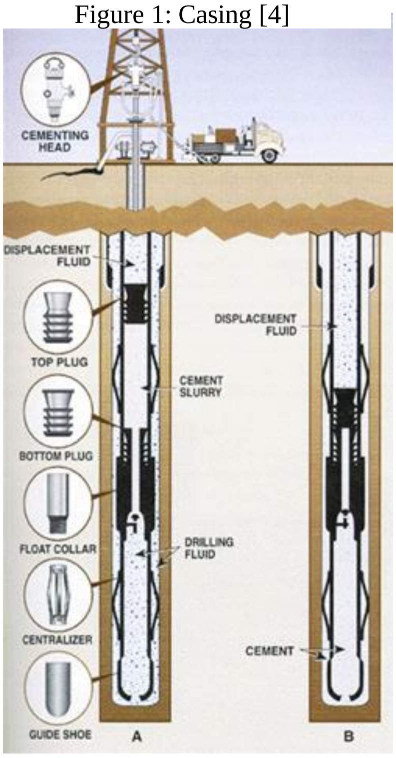


Figure 2: Cementing [4]

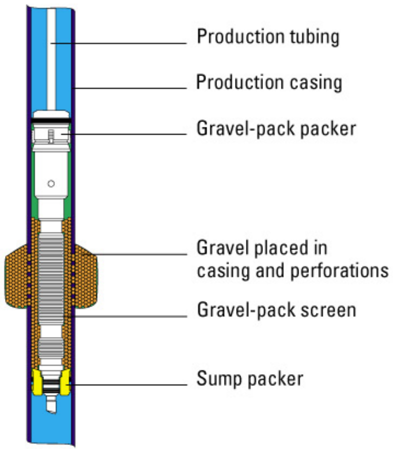
Next step is cementing the well. The existing drilling fluids in the space between the casing and the drilled well are displaced by cement slurry into the well. The cement is left to harden, and the casing is permanently positioned. [4]

Open-hole or Cased-hole are the two types of completion methods used on wells on the reservoir level. Open-hole Completion is used where the reservoir is solid and reduce the casing cost. The well is being drilled to the top of the reservoir and then cased at the top level of the reservoir and left open at the bottom. [4]

The casing and cement must be perforated to start the production. A perforation gun and reservoir location device are run into the wellbore by a wireline, slickline, or coiled tubing. Then the gun shoots holes in the side of the well at reservoir level to allow the hydrocarbons to enter the well streams.[4]

A gravel pack is a filtration system. It is installed over the reservoir to prevent sand from entering the well stream.[5]

The Production tree also called the Christmas tree (XT,) is the last installation step. It contains of valves and gages and serves as the primary barrier under production. It is installed on top of the wellhead installed at the surface of the well, which contains of casing heads and tubing heads. Surface control of the subsurface conditions of the well is provided by casing heads and tubing heads combined.[5]



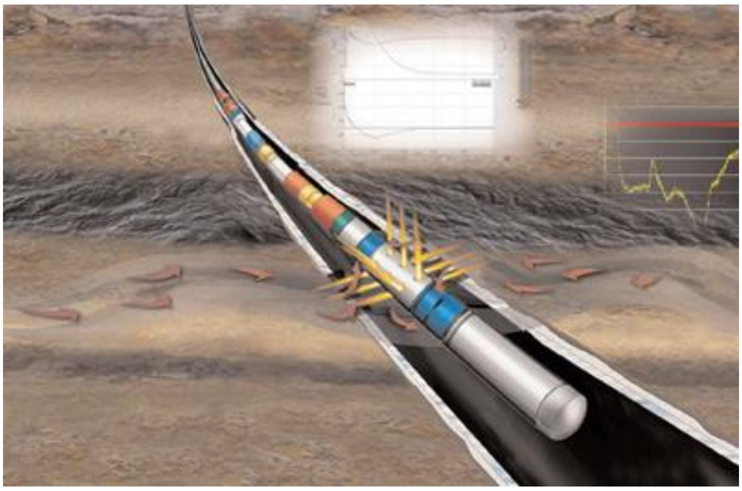


Figure 3: Gravel-pack [4]

Figure 4: Perforating [4]

Well compilation types, methods, and modes vary depending on the reservoir type, the design of the well, or the geology in the area where the well is drilled. The choice, design, and installation of pipes and equipment significantly impact the productivity of an oil and gas well. [3], [4]

The type of well completions depends on many variables, including the targeted volumes of oil and gas to be produced, the type of fluids that will be pumped, temperatures at the surface and the downhole, the depth of the production zone, the rate of production, the expected pressure, the location of the well, the surrounding landscape and environment, and the costs and expected returns on investment.[3]

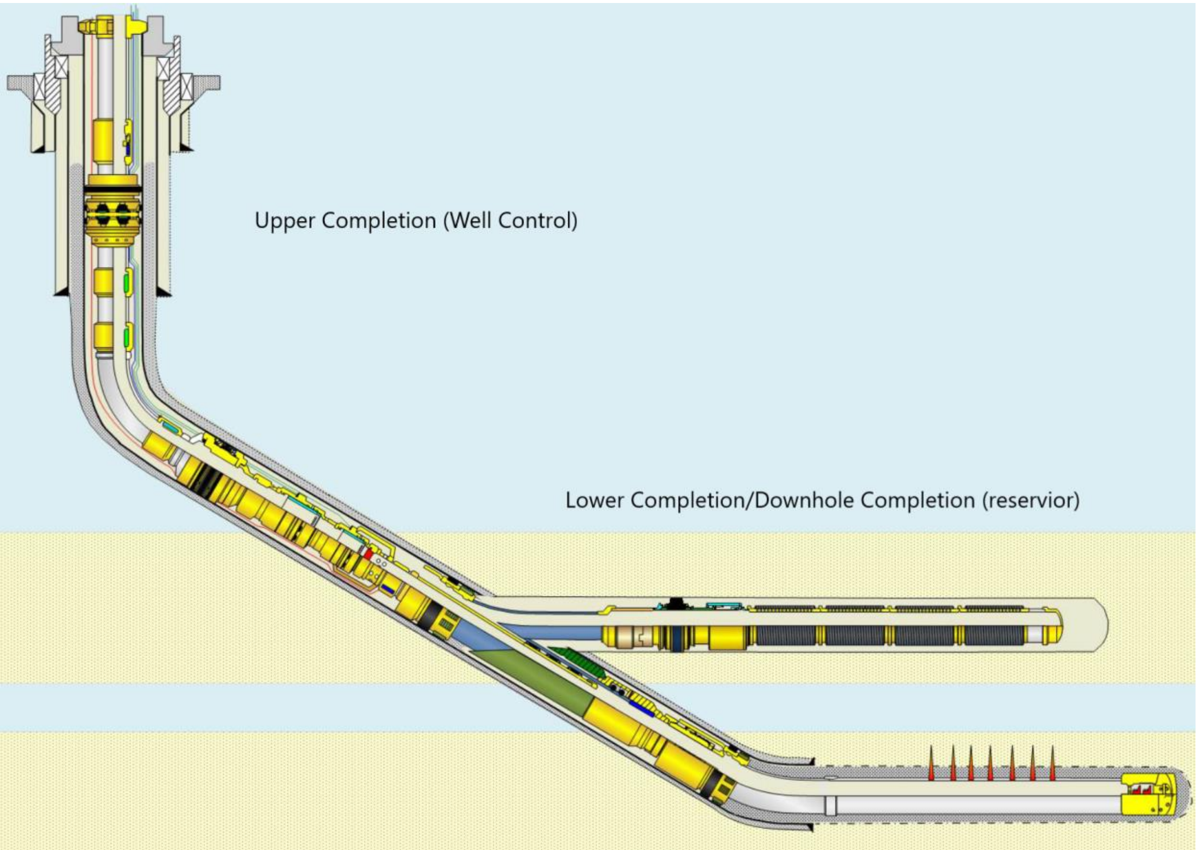


Figure 5: Upper and lower completion [5]

The completion of oil and gas is divided into an upper completion, a lower completion, or downhole completion. The lower completion is installed in multiple different required device types of equipment in the reservoir zone. It connects to the oil and gas formation with the wellbore, and the purpose is to produce as much oil and gas from the reservoir as possible. The upper completion is the link between the surface and the lower completion. The equipment used contributes to maintaining well control by directing the flow from the reservoir to the surface inside the pipes. The external environment is secured against unwanted outflow from the well.[3], [6], [5] Most of the completion equipment is the same for production, and injection wells. They may also have advanced equipment that will contribute to easier oil production.[5]

This bachelor thesis is based on the upper completion where the new DTHP is installed in the well. The new Shifting Tool is therefore designed to be used in the upper completion. TCO can revise the Shifting Tool for it to be used in different locations of the well completion, when needed.

2.2 Tubing Hanger Plug.

The function of a tubing hanger plug is to perform test operations in the oil wells, and to locate possible leaks between the plugs sat in different locations in the oil wells. There is installed at least two or more plugs in other areas down the wellbore. The first plug is located in the lower end of the compilation, which is the furthest away from the wellhead, and the second one is placed in the upper end of the compilation, usually in the tubing hanger. There may also be further plugs installed in between these two plugs to increase the safety. [7]

There are different kinds of tubing hanger plugs. [7] The options are:

- Conventional set barrier plug
- Disappearing Tubing Hanger Plug

The Conventional set barrier plug is of massive and solid material that must be retrieved or opened after the test. These heavy and complicated operations on and above the wellhead are time-consuming and costly. The Christmas Three (XT) must be replaced with a Blow Out Preventer (BOP) to conduct various operations through the BOP. Before conducting further tests, the BOP must then be replaced with the XT. Each replacement operation is time-consuming and involves high costs. The tubing hanger plug must be removed by an operation involving the XT and BOP back and forth with these conventional methods and apparatus, even if the tests are successful. [7]

Some conventional plugs may be opened instead of removed. These operations are also time-consuming and complicated and therefore costly. Under operations too many plugs do not open as planned, and further operations involving the XT and BOP back and forth are required. Workover riser operations are typically used to deploy and remove wireline set plugs. These operations are time-consuming and involve high costs. [7]

The Disappearing Tubing Hanger Plug: some plugs are comprising crushable, and others are dissolvable. Dissolvable plugs are encapsulated in e.g., rubber material, being dissolvable by exposure to a degrading chemical. Dissolvable ceramic discs, glass disks, hard-pressed salt or sand elements dissolve when exposed to well fluids. [7]

If tests with these disappearing plugs should fail, they are not easily replaceable, and therefore none of these plugs have been used as tubing hanger plugs. Instead, the plug is installed as part of the tubing hanger pipe in the well and allows fluid communication through a channel past the plug body. Since there are fluid communication channels past the plug body, this plug can be used as a tubing hanger test plug, allowing communication across the plug body without having communication to the annulus side of the tubing. This has shown advantageous since the operators do not have to drive a workover riser, which is considerable in cost savings. All though these plugs have significant merit, it is not easily replaceable. [7]

2.3 TCO Disappearing Tubing Hanger Plug.

For temporary suspension of a subsea well DTHP is one of the two primary barriers required. DTHP (Disappearing Tubing Hanger Plug) has a larger bore ID and E-Trigger cycling device and is certified as an ISO 17998 V0 barrier. ”*V0 is a design validation degree, and explains the degree of the seal against fluids, under extreme conditions.*” This barrier gives a total seal against all fluids under extreme conditions. There is no need for a rig or intervention vessel to pull a conventional set barrier plug to open the well for production, because the well can be opened by pressure cycling the plug from the production vessel.[8]

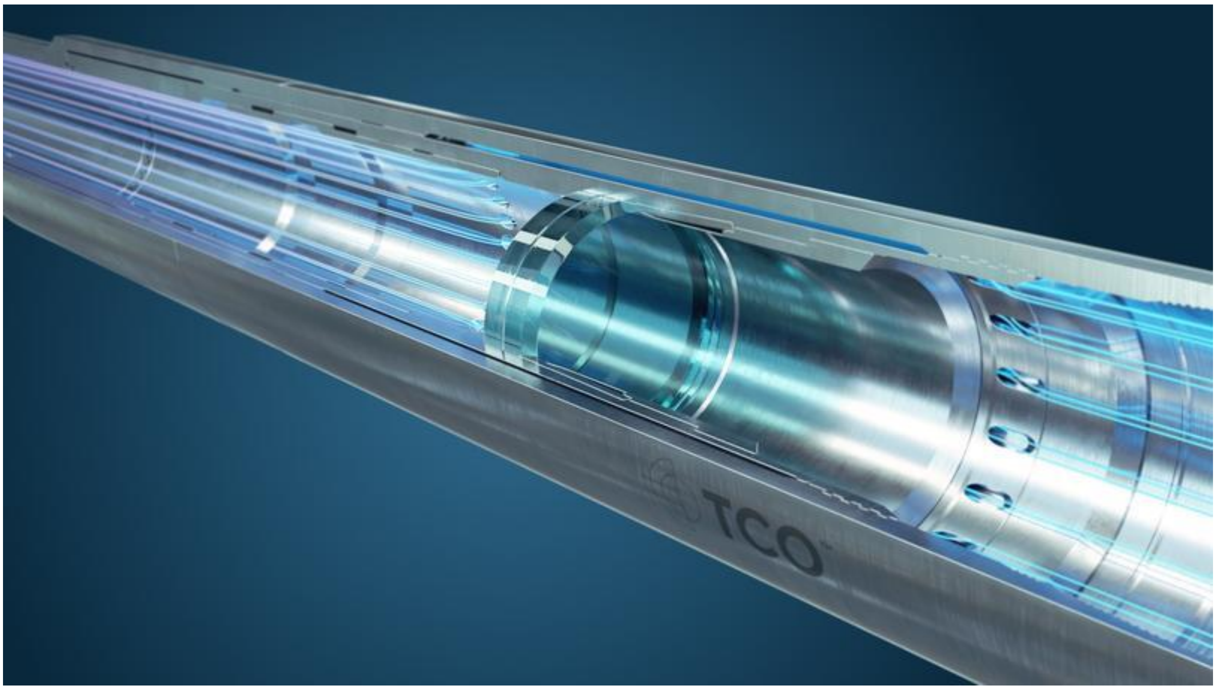


Figure 6: DTHP [8]

The TDP-DTHP is a tubing-conveyed shallow-set barrier plug. It forms an ISO 14998 V0 tight barrier when the bypass at the DTHP is closed. In the open position, the plug is run with the bypass making it possible for the operator to perform the completion operations. This barrier plug saves cost and time offshore during the compilation of subsea wells with vertical Christmas trees. It is necessary to use a workover riser to rig down the BOP and land the XT. At any subsea well, the remote opening function saves rig time for operators. [8]

The DTHP incorporates a bypass since it is tubing conveyed. The bypass is called SSD, and it is pressure activated. The SSD is closed with the help of the E-trigger and forms an ISO 14998 V0 approved barrier. When the SSD is open, the operator can perform all necessary operations. [8], [9]

The DTHP requires a shifting tool as a backup contingency tool that can close the SSD after the DTHP is set. If the primary mechanism in the E-trigger should fail to close the SSD, this shifting tool that runs on wireline, slickline, or coiled tubing, will then be used. [9]

"*The DTHP has been designed to be installed and run as an integrated part of the completion string or liner. This increases the efficiency of the installation process and provides large-bore access when the plug is opened."* [8]

Glass plug

TCO's patented laminated glass barrier is non-corrodible and is withstanding extreme levels of differential pressure from both sides. It provides a secure seal under axial loads, and at high temperatures. The laminated glass plug disintegrates into small particles (silica) with pressure cycling mud down the wellbore with a specific force.[8] The laminated glass plug consists of two glass discs on top of each other. A lamination sheet or film is between these two glass discs, and it can be comprised of fluid, plastic, paper, etc. With just the two glass discs stacked upon another, without any kind of lamination, a tension would appear. The importance of the lamination layer in between the discs is to provide load distribution of this tension. Therefore, the plug will enable the desired strength and toughness during use by the layer. Because the glass disc will never have a completely smooth and flat surface, it will arise point loads with a load applied on just two glass discs stacked on top of each other.[10]

"The TDP-DTHP is configured to be cycled open with pressure pulses from the surface." The plug can be cycled open from FPSO (Floating Production, Storage and Offloading) which is a floating oil platform or the production vessel to make the rig available for other operations. [8]

TCO has developed a glass plug that can be used in different applications with various opening mechanisms and dimensions. The other glass plugs can have opening mechanisms such as explosives, mechanical braking with pressure-cycling, e-line, coil tubing, drill pipe, or spear open on slickline. [11] And the different glass plugs that TCO has in their product line are:

- TDP-NonEx
- TDP-MO
- TDP-3
- TDP-PO

- DSBP
- DTHP

  [12]

In this bachelor thesis, it is just the DTHP that will be described in detail since that is the plug the bachelor thesis concerns.

Sliding Sleeve Door

The communication between the tubular area and the annular area of a completed production oil and gas well is opened and closed by sliding sleeves. Multiple sleeves can be installed in the "pipes." These multiple sleeves can be installed at different depths to operate production zones independently or commingle production. Depending on the customer`s requirements, sliding Sleeves can be configured to open, up or down. They can be configured with a profile nipple to accommodate wireline locks and plugs. A slick-line unit is typically used to open the Sliding Sleeve Door by lowering tools to the device. A shifting tool or a mechanical device is used to open it with jar action.[13]

E-trigger

E-trigger`s user area is to activate downhole devices. It can be used alone. It can also be used with a mechanical trigger system for redundancy and an extended operational window. The E-trigger can be activated using a pre-set or pressure-activated timer or pressure cycles. "*TCO`s E-trigger has been developed to fit all plugs in the TDP-3 range and is also used in the DTHP and TiWo*." [14]

Figure 7: E-trigger [14]

<u>The functionality of the E-trigger</u>

- *"The E-Trigger can be set up with one of two principle modes:*
    - *It will establish the pressure at depth as reference zero when the pressure is stabilized, and further pressure variations will be treated relative to that*
    - *The E-trigger will read the absolute pressures at plug depth, and predefined absolute pressure thresholds are used for activation*
- *The E-Trigger will pick up pressure changes in the wellbore through the plug communication sub*
- *A predefined combination of pressure and time parameters must be recorded by the E-trigger to activate and manipulate the downhole device*

The successful activation will either release a pressure activated firing pin or let pressure through to operate a sliding sleeve" [14]

2.4 Shifting Tool

A downhole tool is used to open, close, or shift the position of downhole flow control or circulation devices, such as sliding sleeves. It is associated with slickline operations. "*The shifting tool generally features some means of engaging the components to be shifted.*" To deliver the necessary force or impact, the Shifting Tool is typically run with upward or downward operating jars. [15]

Sliding sleeves or similar production and completion equipment are adjusted with a downhole tool. Shifting tools may be used with coiled tubing in deviated or horizontal wellbores. It is typically run on slickline. A specific model and size of sliding sleeve require a careful selection of the appropriate shifting tool, which is correctly prepared or dressed. [15]

Figure 8: Shifting Tool

The shifting tool in this bachelor thesis can only adjust the position of the SSD upwards in the closed position with the help of the wireline. The shifting tool is modelled specifically to the dimension of the new DTHP that TCO just released. This is an Otis "B" positioning shifting tool. Otis "B" is the DOG profile that will attach itself to the SSD in the DTHP. It is used as a backup contingency tool should the E-trigger mechanism fail to set the SSD in the closed position. Therefore, the Shifting Tool makes it possible for the DTHP to be certified as an ISO 14998 V0 barrier when the mechanism fails. And it will therefore be sent with the DTHP as a package deal.

2.5 Wireline

A wireline is used in well-intervention operations in oil or gas wells. This is a wire or cable, and it can either be a single-strand or multi-strand wireline used in these types of procedures. A wireline can be used to lower tools into the borehole, and by using an electrical cable, it also transmits data. [16]

To differentiate operations performed with single-strand wire or braided lines, the term slickline is used. By reeling in and out the wire hydraulically, the slickline is raised and lowered in the well. Slicklines are nonelectrical cables used to place and recover equipment, such as plugs, gauges, and valves in the wellbore and adjust valves and sleeves located downhole. They can also be used to repair tubing within the wellbore.[17]

Wirelines are electric cables, single-strands, or multi-strands, that transmit data about the well. And they are useful in gathering data about the well in logging activities and workover jobs that require data transmitted. Wireline is used for well intervention and formation evaluation operation.[7]

Formation properties in a well are measured by wireline logs. To help geologists, engineers, and drillers to make real-time decisions about drilling operations, the wireline logs are constant downhole measurements sent through the electrical wireline. This is different from the MWD and mud logs. Wireline logs can measure wellbore dimensions, sonic properties, formation pressure, conductivity, and resistivity.[17]

Workover Operations are when producing wells require remedial work to sustain, enhance, or restore production. Workover operations many times require production shut-in, but not always. A well-servicing unit is used in workover operations to winch items in and out of the wellbore. Braided steel wireline or a single steel slickline can be used to lower and raise equipment. Workover operations conducted can include production logging, setting plugs, perforation through explosives, or well clean up.[17]

2.6 Material Requirements

When designing a product, it is crucial to choose a suitable material. The mechanical and physical properties of the material are the material requirement, which is an important criterion to consider when selecting the material. It is essential to understand this information to understand how the material will react to the physical force applied. Characteristics of the material give information on what tool or equipment where the material is most suitable and what environments the material is typically used.[18]

This chapter will detail the properties of the chosen material used in the different parts of the Shifting Tool. It will then later use this information to explain why the material is selected for the specific part of the Shifting Tool. Also, it will be described in detail the properties of corrosion resistance and shear strength

2.6.1 Mechanical properties

These mechanical properties describe the material's behaviour from the effects of the external force applied. The manufacturing of the shifting tool and the material characteristics relevant to the design are necessary to ensure that they meet the essential requirement.[18]

Stainless Steel.

Especially in the ambient atmosphere and in various environments, stainless steel is highly resistant to corrosion. [19]

Copper and Copper Alloys

In science antiquity, copper and copper-based alloys have been used in various applications, and they possess a desirable combination of physical properties. It is difficult to machine unalloyed copper, and it is soft and ductile. Also, it has an almost unlimited capacity to be cold worked. In the ambient atmosphere and diverse environments, such as seawater, and some industrial chemicals, it is highly resistant to corrosion. By alloying copper, the mechanical and corrosion resistance may be improved. To improve these mechanical properties, cold working and/or solid-solution alloying must be used because most copper alloys cannot be hardened or strengthened by heat-treating procedures. [19]

Plastic

Plastic is a type of polymeric material. Plastic is used in general-purpose applications, and they are materials that have some structural rigidity under load.[19]

There are many classifications of plastic like polyethylene, polypropylene poly (vinyl chloride), polystyrene, and fluorocarbons, epoxies, phenolics, and polyester. They have many varieties of combinations and properties. There is very rigid and brittle plastic, and there is flexible plastic. When stressed, flexible plastic exhibits both elastic and plastic deformations, and sometimes before fracture, it experiences considerable deformation.[19]

Ductile and Brittle

Ductile measures the degree of plastic deformation before fracture, while with brittle material sustain up to non-plastic deformation upon fracture. [19]

Yield Strength

The point where material bends over is the Yield strength, of the stress-strain curve, in the plastic region. This yielding curve determines the departure from linearity when the material is elastic to plastic deformation. When the material has reached the proportional limit where the material has reached permanent deformation in shape, it is the plastic deformation. [19]

Fracture Stress

The ratio of the applied shearing force to the cross-sectional area being shared is defined by the property Shear Strength. "Fracture is a type of failure." To prevent machinery damage in the case of overloads, the shear pin is usually used as a safety.[18]

In this Bachelor thesis, the shear pin is used as a release mechanism in the Shifting Toole and will have the property to brake at a specifically applied force lode to make it possible for the shifting tool's sliding sleeve with the Otis "B" profiled DOG to slide down and release the shifting tool from the profile of the SSD in the DTHP.

Corrosion Resistance

Regarding the material selection, an essential property of the material is the Corrosion resistance. Particularly at elevated temperatures, environmental oxidation and corrosion of components and structures are a significant concern when chemical reactions occur from elements and compounds present in the environment. The material composition and the environment are essential because the resistance depends on it. [19]

"*Corrosive media may be chemicals (acid, alkalis, and salts) and the environment (oxygen, moisture, pollution, and acid rain), including water (fresh or salt water). Nonferrous metals, stainless steels, and non-metallic materials generally have high corrosion resistance. In contrast, steels and cast iron generally have poor resistance and must be protected by various coatings and surface treatments.*" [19]

Erosion - Corrosion

Erosion - Corrosion occurs when a chemical attack is combined with mechanical abrasion or wear due to fluid motions. To some degree, all metal alloys are susceptible to erosion-corrosion in time. Corrosion may appear when the protective coating on the alloy can no longer be re-formed as a protective barrier. The appearance of waves characteristic of the flow of the fluid and surface grooves helps identify erosion-corrosion. The Rate of corrosion is usually enhanced by increasing fluid villosity. When bobbles and suspended particulate solid such as sand are present, the fluid flow is also more erosive. [19]

2.7 Tolerance study

The parts that make up the assembly must always fit together; therefore, making sure of mechanical fit is the importance of the tolerance study. And it is related to the study of mechanical performance requirements and the study of accumulated variation of mechanical fit.[20], [21]

Tolerance Stack-Ups are vital to address mechanical fit and mechanical performance requirements. Mechanical fit simply answers the question, "*Do the parts that make up the assembly always go together?"* Mechanical performance requirements would include the performance of mechanisms, like switches, latches, actuators, and better performance requirements could consist of alignments or motor efficiency. So what is a "stack-up"?[20]

Tolerance stack-up calculations represent the cumulative effect of part tolerance concerning an assembly requirement. The idea of tolerances "stacking up" would refer to adding tolerances to find total part tolerance, then comparing that to the available gap or performance limits. [20] There are different methods of tolerance study:

- Worst-Cases Analysis
- Statical Analysis

Worst Case Analysis

The traditional type of tolerance stack-up calculation is the Worst-Case Analysis. The range of acceptability for a dimension is a maximum and a minimum value each dimension will have in a Worst-Case Analysis. "*Worst-Case answers the question, if I take the maximum range on each input, what is the maximum range for measuring interest or stack up?"* Stack up therefore dealing with the limits of acceptability and not a probability.[20]

Statistical Analysis

Statistical analysis is used to calculate the expected variation of an output of interest when you take the variation of a set of inputs. A product design in mechanical engineering is composed of multiple features. The features tolerance values control the variable aspects of features. Statistical tolerance analysis is used to understand how these tolerances contribute to the various performance characteristics of the design. [20]

In this bachelor thesis, it will be used the excel sheet that TCO uses to calculate the tolerance

2.8 Hooke's Law

Hooks law is about elastic deformation (tension and compression), which is the relationship between engineering strain and engineering stress. Strain and stress are proportional to each other through the relationship, for most metals are stressed in tension and at relatively low levels. [19]

"*Hooks law is the degree to which a structure deforms or strains depending on the magnitude of an imposed stress*".[19]

2.9 Standard

Standard is an acceptable level that is used as guidance. Standard describes the best solution for doing something and covers many activities like supplying materials managing a process, making a product, or delivering a service. [22]

Standards are the distilled wisdom of people with expertise in their subject matter and who know the needs of the organizations they represent – people such as manufacturers, sellers, buyers, customers, trade associations, users, or regulators.[22]

- Quality management standards to help work more efficiently and reduce product failures.
- Environmental management standards help reduce environmental impacts, reduce waste and be more sustainable.
- Health and safety standards to help reduce accidents in the workplace.
- Energy management standards to help cut energy consumption.
- Food safety standards to help prevent food from being contaminated.
- IT security standards to help keep sensitive information secure.
  [22]

Standard is an authoritative principle or rule that usually implies a model or pattern for guidance, by comparison with which the quantity, excellence, correctness, etc. of other things may be determined. [23]

Standards ensure the safety, quality, and reliability of products and services; they facilitate trade and protect our health and the environment.[24]

Norwegian standard

It is standard Norge that determines and publishes Norwegian standards. This applies to both standards prepared in Norway, Europa, or internationally. All Norwegian standards have an identifier consisting of a letter code and a number. Norwegian standard is a trademarked wordmark. [25]

NS - mark is a trademark-protected marking used to show that a given product has been produced according to Norwegian standards. Norway owns the brand, while management of the use is outsourced to others. While standards with the designation NEK are electrotechnical standards managed by the Norwegian Electronic Committee. [25]

European standard (CEN)

As a member of the European standardization organization CEN, Norway is committed to implementing all European standards and setting them as Norwegian standards. Of all the new Norwegian standards today, about 95% have European origins. [25]

International standard (ISO)

International ISO standards are published as Norwegian standards based on a professional and needs assessment. We are not obligated to set ISO standards as Norwegian standards. [25]

ISO qualification

Users and suppliers of complementary accessories have developed NS-EN ISO 14998:2013. The intention is to use it in the petroleum and natural gas industry worldwide. The standard shall provide requirements for information to both parties in the sample, production, testing, and use of the supplementary accessories. Furthermore, these international standard addresses supplier/manufacturer requirements that set the minimum requirement that suppliers/manufacturers must comply with to require compliance with this international standard. This international standard has been structured to allow for increased levels of design validation requirements. These variations will enable the user/buyer to select the grade required for a selected accessory. [26]

Design Validation Grade (V0-V6)

The seven standard design validation degrees (V0-V6) give the user/buyer a choice between requirements to meet a specific preference or application. Design validation grade V6 is the minimum grade and represents equipment where the validation method is defined by the supplier/manufacturers. The complexity and severity of validation testing increase as the grade decreases. Design validation grade V0 is the maximum grade. [26]

"15.1 Sliding sleeves
Sliding sleeve shall be designed and manufactured in accordance with ISO 14998, validation grade V0 or V3 with quality control level Q1. Sliding sleeves shall be able to repeatable open against a supplier/manufacturer defined and recommended differential pressure without damaging the dynamic seals and other parts of the sliding sleeve."[27]

2.10 Patent

Patent law deals with new inventions and is the branch of intellectual property law. Tangible scientific innovations, such as genetically modified organisms, business practices, or coding algorithms, have been protected by patents. "*In general, a patent can be granted if an invention is not a natural object or process, new, useful and not obvious.*" [28]

"*A patent is an exclusive right granted for an invention.*" A patent is an exclusive right to a new technical solution to a problem, process, or product that generally gives a new way of doing something. In a patent application, technical information about the invention must submit to the public to get a patent. On mutually agreed terms, the patent owner may give permission or license for others to use the invention. Someone else can also become the patent's new owner if the owner sells the rights to the invention. The invention enters the public domain once a patent expires, and the protection ends. At that time, without infringing the patent, anyone could commercially exploit the invention.[29]

3. Method

The method is the strategy of how a scientist proceeds to produce valid and credible knowledge of reality. There are different types of methods, quantitative method is collecting data in the form of numbers or other units of quantity and analysing the results, e.g., calculation. Qualitative method is expressed in the form of text, e.g., literary review.[30]

The method used in this bachelor's thesis is mixed method, where both quantitative and qualitative method is used. This thesis contains of five methods: literary review, Engineering design, material, risk analysis, and calculations. This chapter will explain the five methods used to solve the problem.

3.1 Literary review

The search for relevant articles first started on the web page "Engineering Village" online library, using words like "Shifting Tool" or "Tubing Hanger Plug." This search did not give many relevant results besides some Shifting Tool and SSD information. The search words seemed too specific. It was used different names, broadening the search words by adding words like company names or oil well. Still, there were not many relevant research articles to be found. This thesis is based on specific components. And therefore, made more sense to use patent articles and Standards to help compile information. It has also been used the web page of the companies for information on their products, and web pages from other companies to contribute information to the same types or similar products. Information about theory and equation that has been relevant or needed to calculate different material properties, is collected from engineering literature bought and used in the three years of studying Ocean technology.

The different patent searches that have been done:

- Shifting Tool
- Tubing Hanger Plug
- Glass Plug

The standards that were relevant for this project:

- ISO 14998 V0
- Otis "B" profile

Patent search

As mentioned, patent search has been a part of the information search in this bachelor thesis. The patent search has also been an essential step of the bachelor thesis, where it has been necessary to search for a patent on an existing shifting tool to see if there are any patent that protects against competitors producing and selling the product where the solution has been used. The patent gives the holder the exclusive right to exploit their invention. This search has been done using Google patent and Free Patent Online (FPO).

3.2 Calculations.

The calculations are quantitative method, where the calculated data is used to help make decisions. The results of the calculations will then be verified by doing different function tests that gives the same results, or results of failures where it will be necessary to perform new calculations.

Workshop

To start on the 3D modeling of the new Shifting Tool in SolidWorks, it was necessary to use Shifting Tools that already existed to measure the components and understand how the shifting tool works and the function of each component.

Therefore, the first task was finding different shifting Tool that TCO already was equipped with and take them apart to learn their function and measure the components. Since it is used existing Shifting Tools by other companies as inspiration to design the new Shifting Tool, was it necessary to research if there exists patent on the existing Shifting Tools.

With this knowledge in hand, it was time to start sketching a design of the shifting tool, and present it to the TCO mentor. When the sketch was agreed upon, the next step was to begin the process of 3D – modeling the Shifting Tool in SolidWorks and modifying the parts as needed in the process.

Threads

The decision of which threads to use stood between two types, TPI (Threads Per Inch) Stub ACME threads and ISO Metric threads. The TPI Stub ACME threads were calculated with the help of an Excel sheet that the employees in the engineering department of TCO are using.

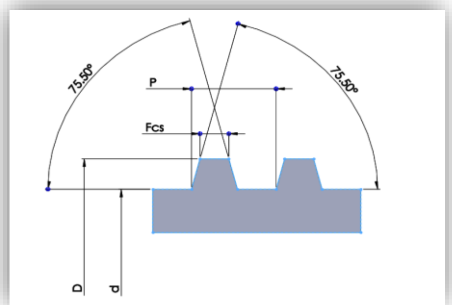


Figure 9: PIN

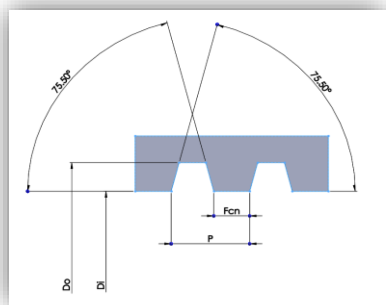


Figure 10: BOX

The ISO Metric threads were obtained from a table found on the ACCU web page. To find the correct dimension of the Internal threads (BOX) and External threads (PIN).

Flow areal for well displacement

To reach the maximum pump rate between the ID of the DTHP and the OD of the shifting tool, there must be a tolerance between the different ID of the DTHP, such as the SSD, and the OD of the different parts of the Shifting Tool, to make sufficient flow area for well displacement. The maximum pump rate from the top is 10 bbl/min and is qualified through a 2.73in² bypass. The question then is if it is possible to make equal or higher area differences between the ID of the SSD and the OD of the Shifting Tool than 2.73in².

To calculate the differential of the ID of the DTHP and the OD of the Shifting Tool, the assembly of the Shifting Tool was assembled inside of the DTHP assembly, where the Otis "B" profile DOG of the Shifting Tool was pleased to latch onto the Otis "B" profile of the SSD. By mating the shifting Tool into the DTHP where it will be placed in the well, made it possible to calculate the flow area for well displacement at each section.

The calculation of flow area shows which parts that needed adjustment to get a big enough flow area.

Running Fluids	*Water Based Mud/ Oil Based Mud*	*Test Reports:* *0705-1356-01 – NORCE Erosion Test Report* *0507-1357-02 – TCO Erosion Test Report*
Erosion Test Fluid	*1.49sg. Water Based Mud with 500kg /m3 High Gravity Solids*	*Test Reports:* *0705-1356-01 – NORCE Erosion Test Report* *0507-1357-02 – TCO Erosion Test Report*
Filter particle tolerance	*400-500µm (40 MESH)*	*Test Reports:* *0705-1356-01 – NORCE Erosion Test Report* *0507-1357-02 – TCO Erosion Test Report*
Total Volume in Erosion Test	*10 000 bbl / 1590m³*	*Test Reports:* *0705-1356-01 – NORCE Erosion Test Report* *0507-1357-02 – TCO Erosion Test Report*
Flow Rate of bypass fluid	*10 bbl/min, 1590l/min*	*Test Reports:* *0705-1356-01 – NORCE Erosion Test Report* *0507-1357-02 – TCO Erosion Test Report*
Minimum Total Flow Area	*1760mm² / 2,73in²*	*Hand Calculations – 0301-1356-01*
Tool Body material	*13Cr80ksi – standard* *1Cr80ksi -custom* *13Cr110ksi – custom* *Inconel 718 - custom*	*0701-1356-01 - Calculation Report* *DWG:2032603 - BOM*

Table 1: Information on fluid flow in DTHP

The equation used to calculate the sufficient flow area for well displacement:

$$A = \pi r^2$$
$$\Delta A = A_2 - A_1$$
$$\Delta A = \pi r_2^{\,2} - \pi r_1^{\,2}$$

$$A = l \cdot h$$
$$\Delta A = 6 \cdot l \cdot h$$

Tolerance Study

The new Shifting Tool was 3-D modeled after the measurements of existing shifting tool, which were done in the first stages of the project. The tolerance of the parts that can slide in the shifting tool, was measured from the dimension given from the measurement of the existing shifting tools. Changes was made throughout the period. The tolerance used on the other parts was decided from the ISO 2768 linear dimension table:

A M S

STANDARD ISO 2768–1

General tolerances for linear and angular dimensions. Extract from the standard

04-09-2001

Table 1 - Permissible deviations for linear dimensions except for broken edges (external radii and chamfer heights)

Tolerance class		Permissible deviations for basic size range							
Designation	Description	from 0,5* up to 3	over 3 up to 6	over 6 up to 30	over 30 up to 120	over 120 up to 400	over 400 up to 1000	over 1000 up to 2000	over 2000 up to 4000
f	fine	± 0,05	± 0,05	± 0,1	± 0,15	± 0,2	± 0,3	± 0,5	--
m	medium	± 0,1	± 0,1	± 0,2	± 0,3	± 0,5	± 0,8	± 1,2	± 2
c	coarse	± 0,2	± 0,3	± 0,5	± 0,8	± 1,2	± 2	± 3	± 4
v	very coarse	--	± 0,5	± 1	± 1,5	± 2,5	± 4	± 6	± 8

* For nominal size below 0,5 mm, the deviation shall be indicated adjacent to the relevant nominal size(s).

Table 2: Standard ISO 2768-1

The ID and OD dimension value and the tolerance given, were plotted into an Excel sheet that calculated to see if there were enough clearance between the parts.

Calculation 1			
Value	Housing	Pin	Pin Part No-Rev
Nominal dia			Drawing-rev
min tol.			Description 1
max tol.			
Min dia	0,000	0,000	
Max dia	0,000	0,000	
Max gap	0,000	NO CLEARANCE!	
Min gap	0,000	NO CLEARANCE!	

Table 3: Tolerance Study Calculation

Shear Strength

The shear pin is holding the sliding sleeve in the shifting tool attached to the big mandrel in the right position. It will be necessary for the material property of the Shear Pin to be able to shear at a specific force, for the SSD to slide from open to the closed position. It is essential that the shear pin does not shear before the SSD is at closed position. It will also be important that the strength of the wireline is not insufficient compared to the strength of shear pin. The equations used to calculate this is:

Shear stress τ

$$\tau = \frac{F}{A}$$

Spring Constant (Hooke's law)

The shifting tool consists of multiple springs that have different jobs. When choosing the spring, it was essential to consider the environment where they will be used (e.g., water-based mud or temperature).

Two of the springs were chosen from the Leseförsj product catalogue. The first task was to select the correct spring type for the job. The next step was to select the material. It was essential to select a material that is corrosion resistance with regards to the well environment. After that, it was time to look at the different springs from the chosen category, and chose the spring with the right properties:

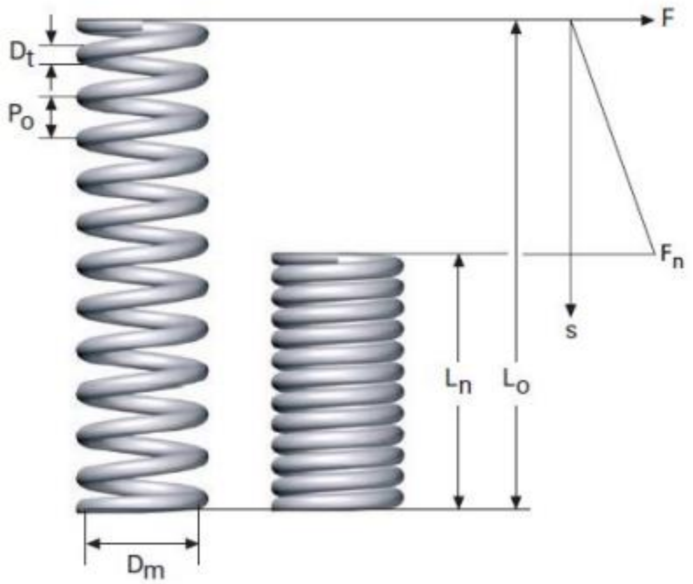


Figure 11: Spring [31]

Material Code	Mtr
Wire diameter	D_t
Inner diameter, min	D_i
Free length	L_0
Total number of coils	n_t
Max loaded length	L_n
Compression	F_n
Rate	R
Mean diameter	D_m

Table 4: Necessary properties for the springs [31]

The third spring located under the DOG in the Sliding Sleeve assembly, was 3D – modeled to have the properties required and fit underneath the DOG. This spring would have to have the same requirements for the choice of material and the type of spring as the two other springs. Before sending the technical drawing (2D model) of the Spring to Lesjeförsj for production, it was necessary to calculate the properties of the spring.

Material Code	Mtr
Wire diameter	D_t
Free length	L_0
Max loaded length	L_n
Compression	F_n
Rate	R

Table 5: Necessary properties for the spring underneath the DOG

It was necessary to calculate the Rate of the compression based on values of the desired compression force and the change in spring length from the starting position, based on the function of the Shifting Tool. The equation used to calculate the rate of the compression is expressed by Hooke's law:

Fs = kx

Fs = Spring force
k = Spring constant (ratio of the force affecting the spring to the displacement caused by it).
x = change in spring length from the starting position.

$$F_n = Rx$$

$$R = \frac{F_n}{x}$$

3.3 Engineering Design

Engineering design was the method used to design the Shifting Tool. The Tools used to perform this task were SolidWorks to 3D – model the Shifting Tool and 2D – design the worksheet (Technical drawing) of every part and assembly.

SolidWorks

After measuring and calculating the dimension of each part of the shifting tool, and then sketch it out on paper, it was time to start 3D – modelling the parts in SolidWorks. The step of 3D – modelling the shifting tool, was done by modelling each part and then assemble them together as one assembly.

To be sure that every component fit together and worked as they should, the component was assembled to see whether it was necessary to make some changes. By doing this, it was then much easier to see if the threads fit as they should, or if there was enough tolerance or not.

The assembly consists of two assemblies (the Sliding Sleeve assembly mounted inside of the Shifting Tool assembly). After the assembly of the shifting tool was done, the assembly was placed inside of the DTHP assembly. This was to ensure that the assembly would function as planned or to change what was needed to be changed. After finishing the 3D- and 2D modelling, it was time to send them in for review and approval. The last step was then to send it to the production of a prototype to start the testing phase.

3.4 Design Review

Throughout the period, there were held design review meetings, where the design of the shifting tool was presented and explained. The meetings started with explaining the Shifting tool function, then each component of the shifting tool, and ended with the shifting tool being placed inside the DTHP assembly to show the function and the tolerance.

The purpose of these meetings were to get input from the workers from the different departments. With the expertise of the employees, it was discussed what worked and what would or may be a problem and needed to be changed.

3.5 Choice of Material

The decision of what material to use for the different parts of the shifting tool was decided by discussing with the employees at TCO, researching the properties of the material, and comparing additional possible materials against each other. It was essential to take the oil well environment where the shifting tool will be considered in this decision. And the function of each part of the shifting tool, the shear pin would need a material that is strong enough to hold the position of the sliding sleeve while jarring the SSD to closed position, but weak enough to shear at a specific shear force. While other parts of the shifting tool need to be made of a rigid enough material to withstand deformation when the force is applied.

3.6 Risk Analysis

Risk analysis is the process of identifying and analysing potential hazard and failure that can occur, and negatively impact the project. By performing a risk analysis, the companies retrieve information needed to decide whether the risk is worth taking or if the risk of failure is too high and hazardous. [32]

FMEA

In this thesis FMEA is used, which is the step-by-step process of identifying all the grounds for the failure of as many parts, assemblies, and subsystems in a system as possible, and what the effect will be. A specific FMEA worksheet is prepared where the assembled product is documented, where the construction / assembly, testing, transport and installation of the product, each component's failure mode and what effects the result will have on the rest of the system are covered. The purpose of the FMEA worksheet is to analyze the different risks and categorize them into different levels as low, medium, and high risk. This risk analysis is used to find a solution to reduce the risk, or to draw a conclusion on whether it is acceptable to continue the operation. [33]

Operation		Characteristics of failure				Rating			
No.	Component/Step	Failure mode	Causes of failure	Effects of failure on part/system	Test method	Severity of Effect	Frequency	Detection	RPN
9,03	Make-up of Shifting Tool.	Wrong torque applied during make-up.	Human error.	Damage/deformation on the assembly.	Verify torque against thread type prior to make-up.	3	1	1	3

Table 6: Operation, Characteristics of failure, and rating

Table 6 shows the first stage of the FMEA, this is where it is filled in what component or step of the project that it is concerning, failure mode (types of failure that could occur), Cause of failure (different scenarios in which the failure occur), effects of failure on part/system, test method (different test method to identify this failures) and rating (Severity evaluation criteria, frequency, detection possibility and severity evaluation criteria). If the rating gives an acceptable rating than there is no need for change, but if the rating does not give an acceptable rating than the next step is to give a recommendation of how to lower the risk and achieve an acceptable rating.

Action Status						Rating			
Recommendations	Decisions Taken	Type	Responsible	Deadline	Completed actions	Severity of Effect	Frequency	Detection	RPN
Handle assembly and tool/equipment with care.									

Table 7: Action Status and rating

Table 7 shows the next step where the criteria was not achieved. First recommendation (recommending a solution), Decisions taken (e.g., what advice to give to the customers), Type (e.g., equipment), Responsible (Who is responsible, e.g., TCO), deadline (the deadline to make the changes), Completed action (e.g., where the action will be completed) and new rating of the change done. If this rating gives an acceptable rating, then there is no need for further changes on that part, but if it is not an acceptable rating, then it is need for further discussion whether there is another solution or if it is not acceptable.

Severity Evaluation Criteria		
5	CATASTROPHIC	Death or > 5.000.000 NOK damage
4	CRITICAL	Serious injury/invalidity or > 1.000.000 NOK damage
3	SEVER	Serious injury or > 250.000 NOK damage
2	MINOR	Medical treatment or > 50.000 NOK damage
1	NEGLIGIBLE	First aid or < 50.000 NOK damage

Table 8: Severity Evaluation Criteria

Table 8 Severity Evaluation Criteria is used to determine the severity level of the failure outcome. Whether it is a high or low risk.

Frequency		
5	Very High	0 - 14 days
4	High	14 days - 6 months
3	Moderate	6 months - 1 year
2	Low	1-5 years
1	Very Low	> 5 years

Table 9: Frequency

Table 9 Frequency is the rating of how often the failure would occur and whether it is a high or low risk.

Detection Possibility		
5	Absolute Uncertainty	Design / Test Control cannot / will not detect a potential course, mechanical error; or there is/has been no design control.
4	Remote	A Remote Chance that - Design / Test Control cannot / will not detect a potential course, mechanical error;
3	Low	A Low Chance that - Design / Test Control cannot / will not detect a potential course, mechanical error;
2	Moderate	A Moderate chance that the Design / Test Control WILL detect a potential course or mechanical error.
1	High	A High Chance that the Design / Test Control WILL detect a potential course or mechanical error.

Table 10: Detection Possibility

Table 10 Detection Possibility is the rating on certainty of the possibility of the failure is to be detected by the tests done on the part after manufactured and before releasing it to the customers.

Severity Evaluation Criteria	
1 - 4	Acceptable
5 - 8	Warning
>9	Unacceptable

Table 11: Severity Evaluation Criteria

Table 11 Severity Evaluation Criteria is the end result of the previous ratings, this is where it shows result of whether the risk is acceptable or not.

In this bachelor thesis it is not performed a FMEA of every component of the Shifting Tool, rather just the important parts, e.g., the Shifting Tool assembly, the Otis “B” profiled DOG and the springs.

4. Results

4.1 Patent Search

There has been done numerus searches for patented contingency tool that could claim that the holder has the exclusive right to exploit their design and the mechanical function of the invention. There have been found patents regarding different types of contingency tool and their mechanical function, but there has not been found any patent that could claim the rights on the design and the mechanism regarding the Shifting Tool in this thesis.

4.2 Calculation of Flow Areal for Well Displacement

Areal difference: $2,73in^2 \Rightarrow 1761mm^2$

The ID of the DTHP and OD of the Top Sub

$$\Delta A = A_{OD} - A_{ID}$$
$$= \pi r_{OD}^2 - \pi r_{ID}^2$$
$$= \pi \cdot (59,31mm)^2 - \pi \cdot (55mm)^2$$
$$= 1547,79mm^2 < 1761mm^2$$

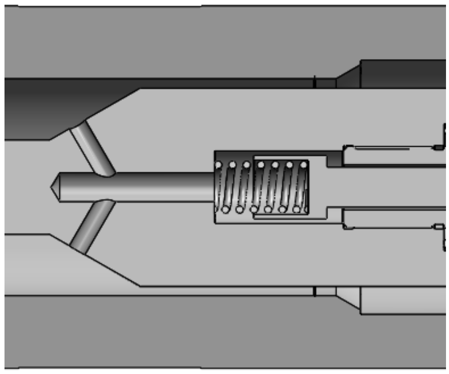


Figure 12: ID of the DTHP and OD of the Top Sub

Changing the OD of the Top Sub from Ø110 to Ø109

$$\Delta A = A_{OD} - A_{ID}$$
$$= \pi r_{OD}^2 - \pi r_{ID}^2$$
$$= \pi \cdot (59,31mm)^2 - \pi \cdot (54,5mm)^2$$
$$= 1719,79mm^2 < 1761mm^2$$

Changing the OD of the Top Sub from Ø109 to Ø108

$$\Delta A = A_{OD} - A_{ID}$$
$$= \pi r_{OD}^2 - \pi r_{ID}^2$$
$$= \pi \cdot (59,31mm)^2 - \pi \cdot (54mm)^2$$
$$= 1890,22mm^2 > 1761mm^2$$

- ➔ **OK**

By changing the OD of the Top Sub from Ø110 to Ø108, the Shifting Tool still has its structural strength and enough flow area for the well displacement, for the tolerance between the ID of the DTHP and the Top Sub OD of the Shifting Tool.

The ID of the SSD and OD of the Top Sub

$$\Delta A = A_{OD} - A_{ID}$$
$$= \pi r_{OD}^2 - \pi r_{ID}^2$$
$$= \pi \cdot (59{,}31mm)^2 - \pi \cdot (55mm)^2$$
$$= 1547{,}79mm^2 < 1761mm^2$$

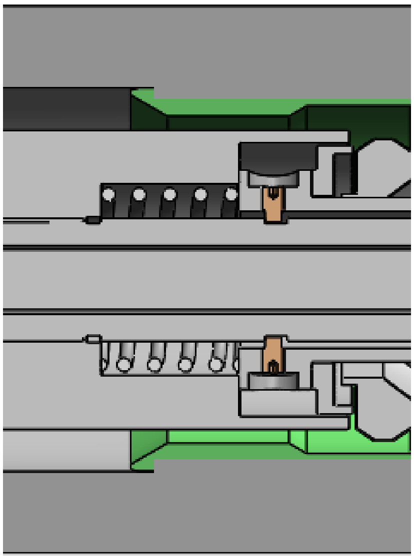


Figure 13: ID of the SSD and OD of the Top Sub

Change the OD of the Top Sub Ø110 to Ø109

$$\Delta A = A_{OD} - A_{ID}$$
$$= \pi r_{OD}^2 - \pi r_{ID}^2$$
$$= \pi \cdot (59{,}31mm)^2 - \pi \cdot (54{,}5mm)^2$$
$$= 1719{,}79mm^2 < 1761mm^2$$

Changes the OD of the Top Sub from Ø109 to Ø108

$$\Delta A = A_{OD} - A_{ID}$$
$$= \pi r_{OD}^2 - \pi r_{ID}^2$$
$$= \pi \cdot (59{,}31mm)^2 - \pi \cdot (54mm)^2$$
$$= 1890{,}22mm^2 > 1761mm^2$$

➔ **OK**

By changing the OD of the Top Sub from Ø110 to Ø108, the Shifting Tool will still have its structural strength and now have enough flow area for the well displacement in the tolerance between the SSD ID of the DTHP and the Top Sub OD of the Shifting Tool.

The ID of the SSD and OD of the End Cap

$$\Delta A = A_{OD} - A_{ID}$$
$$= \pi r_{OD}^2 - \pi r_{ID}^2$$
$$= \pi \cdot (59{,}31mm)^2 - \pi \cdot (57{,}5mm)^2$$
$$= 664{,}21mm^2 < 1761mm^2$$

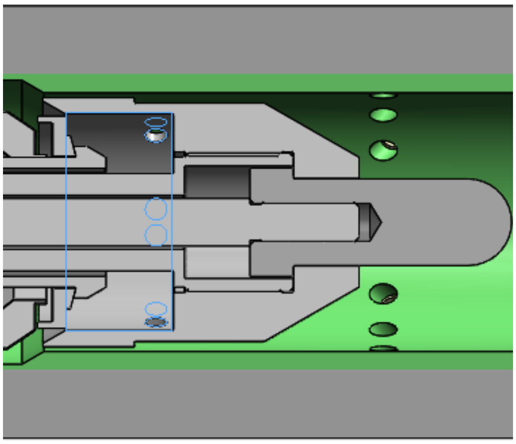


Figure 14: ID of the SSD and OD of the End Cup

Adding the area of the space of the fingers on the Sliding Sleeve

$$\Delta A = 6 \cdot A$$
$$A = l \cdot b$$
$$= 16mm \cdot 10mm$$
$$\Delta A = 6 \cdot 160mm^2$$
$$= 960mm^2$$

$$664,21mm^2 + 960mm^2$$
$$= 1624,21mm^2 < 1761mm^2$$

Calculating the area between the ID of the End Cup and the OD of the Disc, and the area between the ID of the Sliding sleeve and the OD of the Big Mandrel.

$$\Delta A = A_{OD} - A_{ID}$$
$$= \pi r_{OD}^2 - \pi r_{ID}^2$$
$$= \pi \cdot (23mm)^2 - \pi \cdot (22,5mm)^2$$
$$= 71,47mm^2$$

$$= \pi r_{OD}^2 - \pi r_{ID}^2$$
$$= \pi \cdot (50mm)^2 - \pi \cdot (49mm)^2$$
$$= 311mm^2$$

$$1624,21mm^2 + 311mm^2 + 71,47mm^2$$
$$2006mm^2 > 1761mm^2$$

➔ **OK**

The calculation showed that there is enough flow area.

The ID of the SSD and OD of the End Cap

$$\Delta A = A_{OD} - A_{ID}$$
$$= \pi r_{OD}^2 - \pi r_{ID}^2$$
$$= \pi \cdot (59,31mm)^2 - \pi \cdot (57,5mm)^2$$
$$= 664,21mm^2 < 1761mm^2$$

Area of the six circles in the End Cup

$$\Delta A = 6 \cdot A$$
$$A = \pi r^2$$
$$\Delta A = 6\left(\pi \cdot (5mm)^2\right)$$
$$= 471,24mm^2$$

$$664,21mm^2 + 471,24mm^2$$
$$1135,45 < 1761mm^2$$

Changing the circles of the End cup from Ø10 to Ø16

$$\Delta A = 6 \cdot A$$
$$A = \pi r^2$$
$$\Delta A = 6\left(\pi \cdot (8mm)^2\right)$$
$$= 1206,37mm^2$$

$$1206,37mm^2 + 664,21mm^2$$
$$2341,82 > 1761mm^2$$

➔ **OK**

By changing the diameter of the circles on the End Cup, the flow area is big enough for the well displacement.

4.3 Calculation of Shear Strength

To calculate the Shear Stress of the Shear Pin with the material UNS C63000, will it be necessary to use the properties of the material UNS C63000. The shear stress needs to be more than the material's Tensile strength for the material to fail.

Properties	Metric	Imperial
Tensile strength	760 MPa	110000 psi
Yield strength	470 MPa	68200 psi
Elongation at break (in 50 mm, 10% reduction in area)	10%	10%
Elastic modulus	117 GPa	17000 ksi
Poisson's ratio	0.34	0.34
Reduction of area (at 316°C/601°F, cold finished)	9%	9%
Shear modulus	44.0 GPa	6380 ksi
Fatigue strength (at number of cycles 1.00e+8, reverse bending)	255 MPa	37000 psi
Hardness, Rockwell B	94	94
Machinability (UNS C36000 (free-cutting brass) = 100)	30	30

Table 12: UNS C63000 Properties [34]

Single Shear Failure

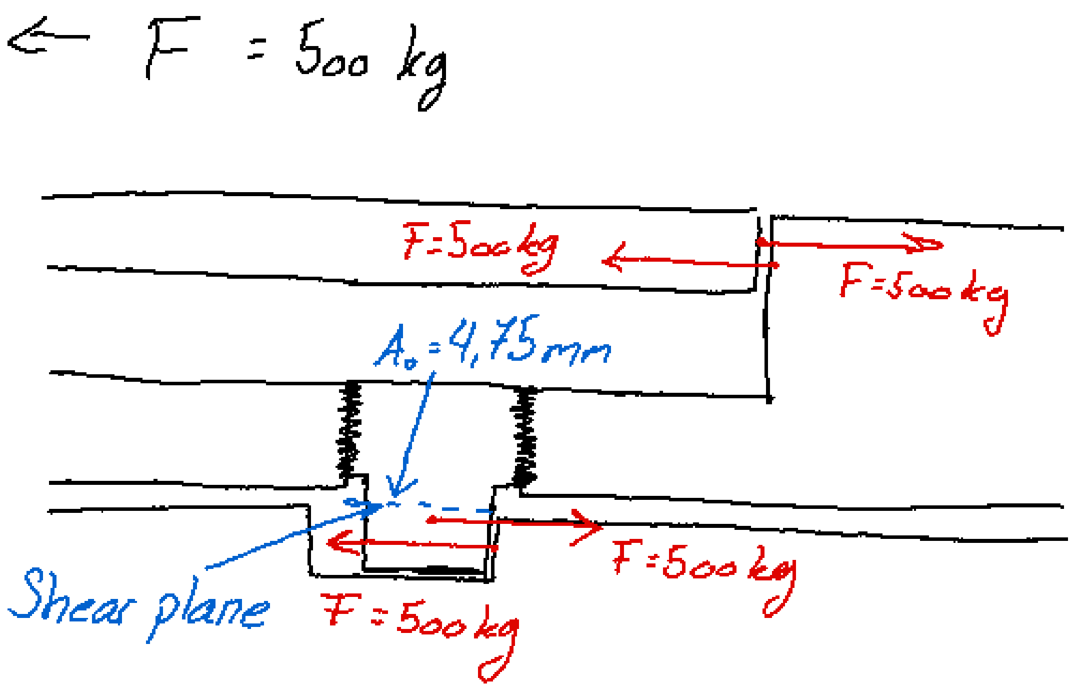


Figure 15: Singel Shear Failure

$$A = \pi r^2$$
$$= \pi \cdot 3^2$$
$$= 28,27mm^2$$

$$\text{Shear Stress} = \frac{\text{Shear Force}}{\text{Shear Area}}$$

$$\tau = \frac{F}{A}$$
$$= \frac{500kg}{28,27mm^2}$$
$$= 17,69\frac{kg}{mm^2} \Rightarrow 17,69\frac{kg}{mm^2} \cdot \frac{1MPa}{0,102kg/mm^2}$$
$$= 173,43MPa$$

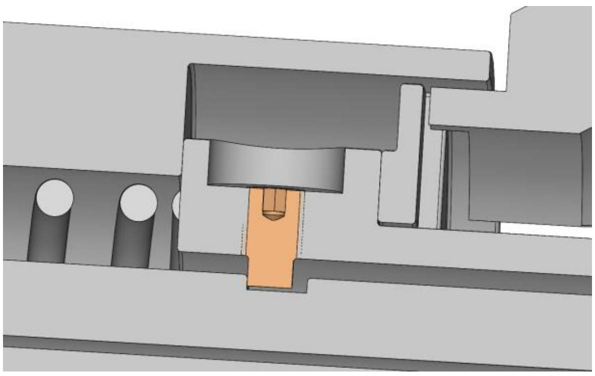


Figure 16: Shear Strength of Ø6mm Shear Pin

$$173,43MPa << 760MPa$$

The shear stress will not be big enough for the shear pin to shear at this force.

Finding the radius at the end of the shear, where the share pin will shear at the applied force.

$$A = \frac{F}{\sigma}$$
$$= \frac{500kg}{760MPa} \Rightarrow \frac{500kg}{760MPa} \cdot \frac{1MPa}{0{,}102kg/mm^2}$$
$$= 6{,}45mm^2$$

$$r^2 = \frac{\pi}{A} \Rightarrow r = \sqrt{\frac{\pi}{A}}$$
$$r = \sqrt{\frac{\pi}{6{,}45mm^2}}$$
$$= 0{,}6979mm$$

With the shear force of 500kg and the tensile strength of the material of 760MPa, the shear pin will shear with a radius of 0,6979mm.

Changing the OD of the end of the shear pin from Ø6 to Ø3

$$A = \pi r^2$$
$$= \pi \cdot 1{,}5^2$$
$$= \frac{9}{4}\pi mm^2$$

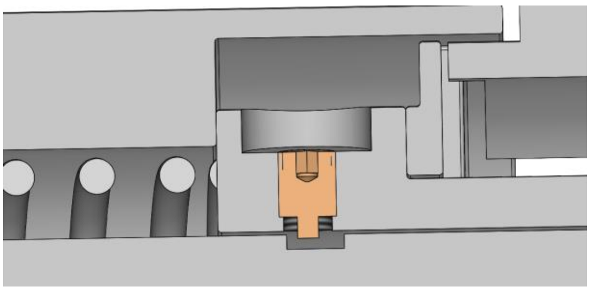


Figure 17: Shar strength of Ø3mm Shear pin

$$\tau = \frac{F}{A}$$
$$= \frac{500kg}{\frac{9}{4}\pi mm^2}$$
$$= 70{,}74\frac{kg}{mm^2} \Rightarrow 70{,}74\frac{kg}{mm^2} \cdot \frac{1MPa}{0{,}102kg/mm^2}$$
$$= 693{,}49MPa$$

$$693{,}49MPa < 760MPa$$

By changing the diameter on the end of the shear pin from Ø6mm to Ø3mm, the shear stress will be nearly enough to shear at the specific force of 500kg.

6.6 Shear Pin Calculated – Shear Force Values

Shear Pin Calculated - Shear Force Values

DIA	Material	SHEAR FORCE
0.093	Brass	394 lb
0.109	Brass	495 lbs
0.125	Brass	650 lbs
0.187	Brass	1401 lbs
0.25	Brass	2405 lbs
0.312	Brass	3440 lbs
0.375	Brass	4473 lbs
0.5	Brass	7938 lbs
0.125	Mild Steel	1006 lbs
0.187	Mild Steel	2142 lbs
0.25	Mild Steel	3436 lbs
0.312	Mild Steel	5046 lbs
0.375	Mild Steel	5522 lbs
0.5	Mild Steel	9800 lbs
0.312	Aluminium	3540 lbs

Table 1: Shear force values

Wireline running tool: Red - Shear pin Lock, Yellow – Shear pin Overpull, Dark blue – Shear pin Tell tail and shear pins plug

Table 13: Shear force value calculation from GS Oilfield

TCO is renting Shifting Tool from the companies Wellvene with the GS Oilfield as their intermediary. When TCO rents the Shifting Tool, they present all the information on the tool needed. Table 6. shows the calculation of the shear force value of the shear pins in different materials and shear diameters that GS Oilfield uses on the shifting tool they are renting.

From the table, a Shear Pin with a diameter of 0,187'' (0,187'' x 25,4 = 4,75mm) made from brass, will have a shear force of 1401lbs (1401lbs x 0.45359237 = 635,48 kg).

$$A = \pi r^2$$
$$= \pi \cdot (2{,}375mm)^2$$
$$= 17{,}72mm^2$$

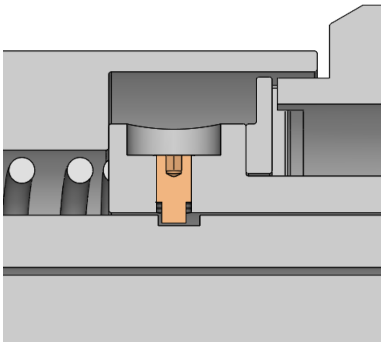


Figure 18: Shear strength of Ø4,75mm Shear pin

$$\tau = \frac{F}{A}$$
$$= \frac{500kg}{17{,}72mm^2}$$
$$= 28{,}22\frac{kg}{mm^2} \Rightarrow 28{,}22\frac{kg}{mm^2} \cdot \frac{1MPa}{0{,}102kg/mm^2}$$
$$= 276{,}63MPa$$

$$276{,}63MPa << 760MPa$$

From the calculation of a shear pin with a 4,75mm diameter, will the shear pin have shear stress at 276,63MPa, which is not a big enough force for the material to shear, with a tensile strength of 760MPa.

4.4 Calculation of Tolerance Study

The tolerance of the Shifting Tool is mainly taken from the calculation of the tolerance between the different parts in the shifting tool rented by TCO. While other tolerances are calculated regarding the threads or new parts for this specific Shifting Tool.

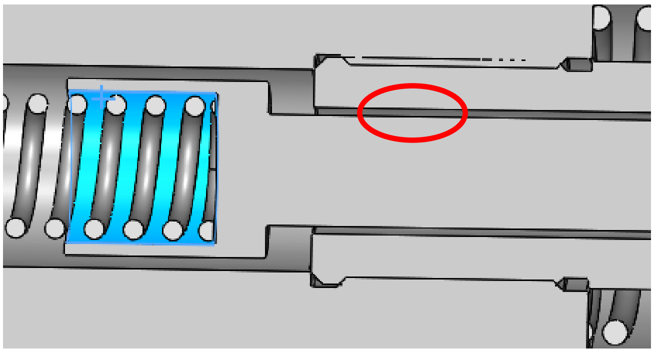


Figure 19: Tolerance Study between Small Mandrel and Big Mandrel

Figure 12. shows the tolerance between the Small Mandrel and the Big Mandrel. The Small mandrel will be sliding inside the Big Mandrel, and there must be enough tolerance between these two parts for it to be possible. This tolerance is also taking the threads on the Small Mandrel into consideration.

Calculation 3			
Value	Housing	Pin	Pin Part No-Rev
Nominal dia	25,00	22,00	Drawing-rev
min tol.	-0,100	0,000	Description 1
max tol.	0,000	0,100	2037074-00
Min dia	**24,900**	**22,000**	Small Mandrel
Max dia	**25,000**	**22,100**	Big Mandrel
Max gap	**3,000**	**OK, clearance**	
Min gap	**2,800**	**OK, clearance**	

Table 14: Tolerance Study between Small Mandrel and Big Mandrel

The Tolerance between the Small Mandrel and Big Mandrel gives enough clearance. It is a big clearance and could probably have had a smaller clearance.

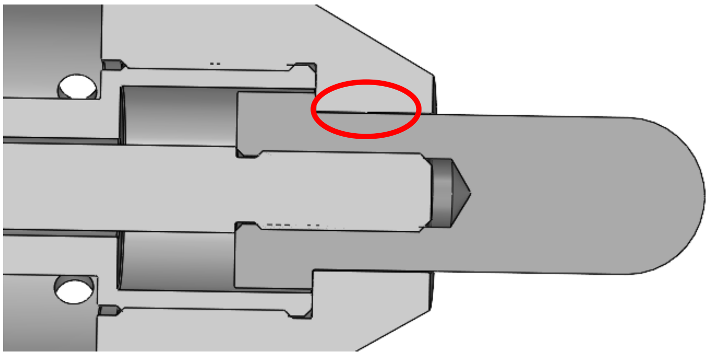


Figure 20: Tolerance Study between Soft Nose and End Cup

Figure 21 shows the tolerance between Soft Nose and the End Cup. The Soft Nose will slide inside of the End Cup. There must be enough tolerance for it to slid.

Calculation 6			
Value	Housing	Pin	Pin Part No-Rev
Nominal dia	40,50	40,00	Drawing-rev
min tol.	0,000	-0,100	Description 1
max tol.	0,100	0,000	2037069-00
Min dia	**40,500**	**39,900**	Soft Nose
Max dia	**40,600**	**40,000**	End Cap
Max gap	**0,700**	**OK, clearance**	
Min gap	**0,500**	**OK, clearance**	

Table 15: Tolerance Study between Soft Nose and End Cup

There is enough tolerance between the Soft Nose and the End Cup.

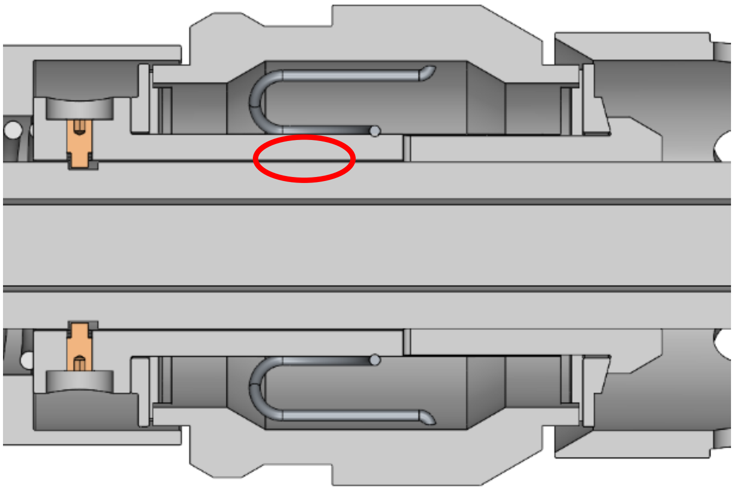


Figure 21: Tolerance Study between Big Mandrel and Sliding Sleeve

Figure 22 shows the tolerance between the Big Mandrel and the Sliding Sleeve. The Sliding Sleeve will be sliding on the Big Mandrel when the shear pin fails at a specific force applied to the diameter of the part of the Sliding Sleeve assembly. Therefore, there must be enough tolerance for the sliding sleeve to slide and take the threads on the Big Mandrel into consideration while having small enough tolerance for the Shear pin to shear at the correct plane.

Calculation 9			
Value	Housing	Pin	Pin Part No-Rev
Nominal dia	46,00	45,00	Drawing-rev
min tol.	0,000	-0,100	Description 1
max tol.	0,200	0,000	2037068-00
Min dia	46,000	44,900	Big Mandrel
Max dia	46,200	45,000	Sliding Sleeve
Max gap	1,300	OK, clearance	
Min gap	1,000	OK, clearance	

Table 16: Tolerance Study between Big Mandrel and Sliding Sleeve

There is enough tolerance between the Big Mandrel and the Sliding Sleeve.

The rest of the calculations of the tolerance study for the shifting Tool are available to find in the Excel sheet of the Tolerance Study of the shifting Tool attachment.

4.5 Selection and Calculation of Spring

When choosing the spring for the tool, it is essential to look at the properties of the spring.

Part Number	Description	Dt (mm)	Dm (mm)	Di min (mm)	L0 (mm)	nt (pcs)	Ln (mm)	Fn (N)	R (N/mm)	Mtr
6771		4,00	25,0	20,60	61	7,5	33	734	27	EN 10270-3 1.4310-NS
6771	CSS 4X25X61	4,00	25,00	20,60	61,0	7,5	33,0	734,00	27,00	EN 10270-3 1.4310-NS

Product Attribute	Ref.	Value
Material Code	Mtr	EN 10270-3 1.4310-NS
Wire diameter	Dt	4,00 mm
Inner diameter, min	Di min	20,60 mm
Free length	L0	61 mm
Total number of coils	nt	7,5 pcs
Max loaded length	Ln	33 mm
compression	Fn	734 N
Rate	R	27 N/mm
Mean diameter	Dm	25,0 mm

Table 17: Properties of the 6771 Spring, placed inside the end of the Small Mandrel [31]

The spring located inside the end of the Small Mandrel needs to be of a corrosion-resistant material because of the environment inside the DTHP in the oil well.

The force of the spring to compress the spring to the max loaded length need to be big enough for the spring to take the compact force when the soft nose reaches the glass disc. A wireline, slow and steady, will install the Shifting Tool. The force of the spring does not need to be that big.

The result of which spring to select comes down to where the spring will be used and which type of properties it needs for the job. After deciding what compression load the spring would need, the search for the spring would start with selecting the spring with the right dimension.

The selection of springs to use inside of the end of the Small Mandrel were small. There were not many springs to choose from with the correct dimensions and properties needed, and therefore the spring was decided upon where the spring with the part number 6771 from the Lesjöforsj product catalog.

Part Number	Description	Dt (mm)	Dm (mm)	Di min (mm)	L0 (mm)	nt (pcs)	Ln (mm)	Fn (N)	R (N/mm)	Mtr
6810		5,00	63,0	57,2	120	5,5	33	564	6,5	EN 10270-3 1.4310-NS
6810	CSS 5X63X120	5,00	63,00	57,20	120,0	5,5	33,0	564,00	6,50	EN 10270-3 1.4310-NS

Product Attribute	Ref.	Value
Material Code	Mtr	EN 10270-3 1.4310-NS
Wire diameter	Dt	5,00 mm
Inner diameter, min	Di min	57,2 mm
Free length	L0	120 mm
Total number of coils	nt	5,5 pcs
Max loaded length	Ln	33 mm
compression	Fn	564 N
Rate	R	6,5 N/mm
Mean diameter	Dm	63,0 mm
Note		x

Table 18: Properties of the Spring 6810 [31]

The selection of springs to use behind the Sliding Sleeve assembly was also small. There were not many springs to choose from with the correct dimensions and properties needed. Therefore, the result of the spring was decided upon where the spring with the part number 6810 from the Lesjöforsj product catalog.

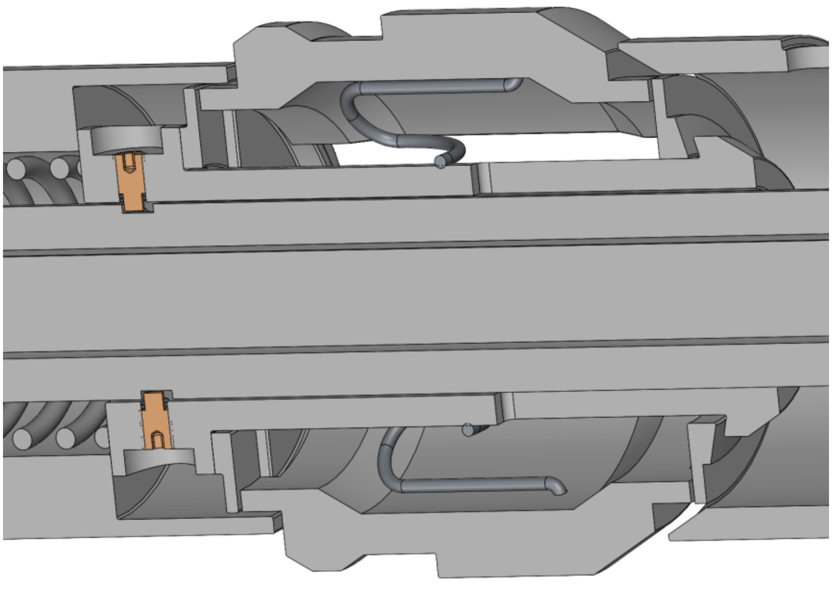


Figure 22: Spring inside the Sliding Sleeve Assembly

The Spring located under the DOG is inspired by one of the Shifting Tool TCO has been renting. The spring is 3D modeled and sent to Lesjeförsj for production. Before Sending the technical drawing of the spring to Lesjeförsj for production, the properties of the spring needed to be calculated with the help of Hooke’s Law:

Fs = kx

Fs = Spring force

k = Spring constant (ratio of the force affecting the spring to the displacement caused by it.)

x = change in spring length from the starting position.

$$F_n = Rx$$

$$R \Leftrightarrow k = \frac{F_n}{x}$$

$$F_n = 59N \Rightarrow 6kg$$

$$x = 15mm$$

$$k = \frac{59N}{15mm} = 3,93\frac{N}{mm}$$

The property of this spring needs to have a force that is bigger than the force of the DOG. This is for the spring to force the DOG to latch onto the Otis “B” profile of the SSD.

The decision was made for the spring to need a force double the DOG force for the spring to reach its max loaded length.

Product Attribute	Ref.	Value
Material Code	Mtr	EN 10270-3 1.4310-NS
Wire diameter	Dt	3,00 mm
Free length	L0	26 mm
Max loaded length	Ln	11 mm
compression	Fn	59 N
Rate	R	3,93 N/mm

Table 19: Spring

Table 19 is the information on the properties of the spring that is needed for Lesjöforsj to be able to start the production of the spring.

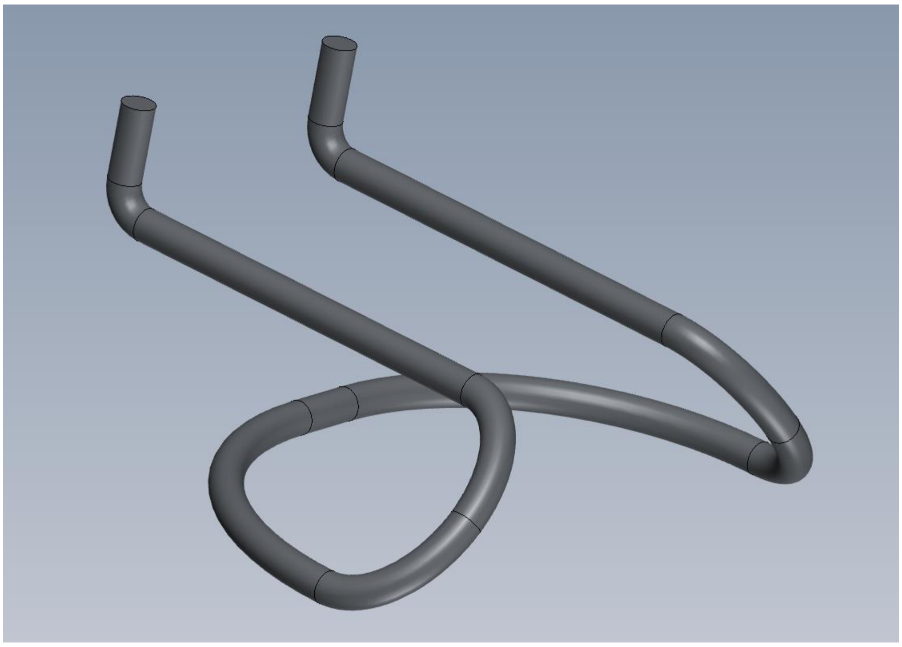


Figure 23: 3D model of the spring

4.6 Material Selection

AISI 4140 L80

AISI 4140 is hardened and tempered in the tensile range of 850 – 1000 MPa and is a 1% Chromium molybdenum medium hardened general purpose high tensile steel. AISI 4140 Modified is a low alloy hardened and tempered steel. It is used in production and completion processes and is suitable for manufacturing gas and oil tools. Shaft, gear, bolts etc are construction components exposed to heavy strains, and are included in General Engineering applications. When machine parts are exposed heavy wear, AISI 4140 can be used in hardened conditions. AISI 4140 is then hardened at 180 degrees, followed by water quenching, then tempering at min 650 degrees and cooled in air. *"Moderate can be welded"* [35]

AISI 302

"This is the cold-drawn wire for the manufacture of springs exposed to corrosive agents and slight temperature increases. Even though stainless steel has a certain degree of magnetic permeability (the magnet attaches)." [36]

UNS C63000

C63000 (AMS 4640 - CDA 630) Aluminium Bronze alloy is excellent for use in applications involving heavy loads, friction, corrosion, abrasive wear, and abrasive wear-resistant. C63000 Nickel Aluminium Bronze is typical for applications included aircraft landing gear components, trunnion bearings, strut bearings, main piston, and similar vital components. The alloys strength is increased by the addition of nickel, without diminishing its excellent ductility, corrosion, and toughness. [37]

POM

POM plastic has high mechanical strength and rigidity, excellent wear resistance, low moisture absorption and good sliding characteristics. The material has excellent machining ability and is a versatile engineering material. The material has also excellent fatigue strength, and good dimensional stability. [38]

4.7 Choice of threads

TPI 4 Stub ACME

INPUT		PIN		BOX	
TPI =	4	P =	6,35	P =	6,35
D =	45	d =	40,24	Di =	41,25
		Fcs =	2,51	Do =	46,01
				Fcn =	2,68
TPI=4	major	+0/-0,15	minor	+/-0,05	
	minor	+0/-0,1	major	+/-0,1	

Table 20: 4 TPI Stub ACME Ø45

INPUT		PIN		BOX	
TPI =	4	P =	6,35	P =	6,35
D =	70	d =	65,24	Di =	66,25
		Fcs =	2,46	Do =	71,01
				Fcn =	2,68
TPI=4	major	+0/-0,15	minor	+/-0,05	
	minor	+0/-0,1	major	+/-0,1	

Table 21: 4 TPI Stub ACME Ø70

Tables 20 and 21 are of the calculation done in Excel, of the 4TPI Stub ACME threads, with the diameters Ø45mm and Ø70mm, with a major/minor tolerance for the Pin and the Box.

ISO Metric Threads

Thread Size	Nominal Diameter (mm)	Core Diameter (mm)	Thread Pitch (mm)	Effective Diameter (mm)	Tapping Drill (mm)	Clearance Hole (mm)
M1.6	1.6	1.1706	0.35	1.373	1.25	2.0
M1.8	1.8	1.3706	0.35	1.573	1.45	2.3
M42	42.0	36.4790	4.50	39.077	37.50	47
M45	45.0	39.4790	4.50	42.077	40.50	50
M48	48.0	41.8646	5.00	44.752	43.00	53
M52	52.0	45.8646	5.00	48.752	47.00	57
M56	56.0	49.2522	5.50	52.428	50.50	61
M60	60.0	53.2522	5.50	56.428	54.50	65
M64	64.0	56.6388	6.00	60.103	58.00	69
M68	68.0	60.6388	6.00	64.103	62.00	73

Table 22: ISO Metric Threads.[39]

ISO Metric Threads were obtained from table 22. The first decision was the thread size (M8, M45 and M64), then the information for those specific threads was used. This is a table of standard sizes of the metric threads. Companies often use this table as a starting point, then customize the threads after what they need, such as the information of the thread pitch.

After talking to the TCO employees, the thread pitch's decision on the shifting tool was 3mm instead of 6mm on M64 and M45. TPI Stub ACME Threads is typically used on equipment used in the well, since the threads in the Shifting Tool will not need to withstand huge forces, the decision of using ISO Metric Threads were made.

4.8 Design Decision

The design of the Shifting Tool was first sketched with a pen on paper. The design was inspired by two different Shifting Tool that TCO has been renting from other companies. It is at this stage that the decisions were made, on how and where to move the parts inside of the shifting tool, for the Otis “B” profile DOG to be moved from the middle of the tool to the end of the tool.

This was done by attaching the soft nose to a small mandrel with a spring placed in the upper end of the shifting tool. This spring was originally placed in the lower end behind the soft nose (in one of the shifting tools that TCO has been renting). The next decision was to please the shear pin on the upper end of the sliding sleeve, to be able to remove the material from the lower end of the sliding sleeve. By making these changes and removing material where possible, the Otis "B" profile spacer DOG would be placed at the lower end of the shifting tool. After figuring out the mechanics inside, for the DOG to be moved and give the tool the best geometrical advantage in the DTHP. The next step was to 3D model the shifting tool in Solidworks and make some changes for the better.

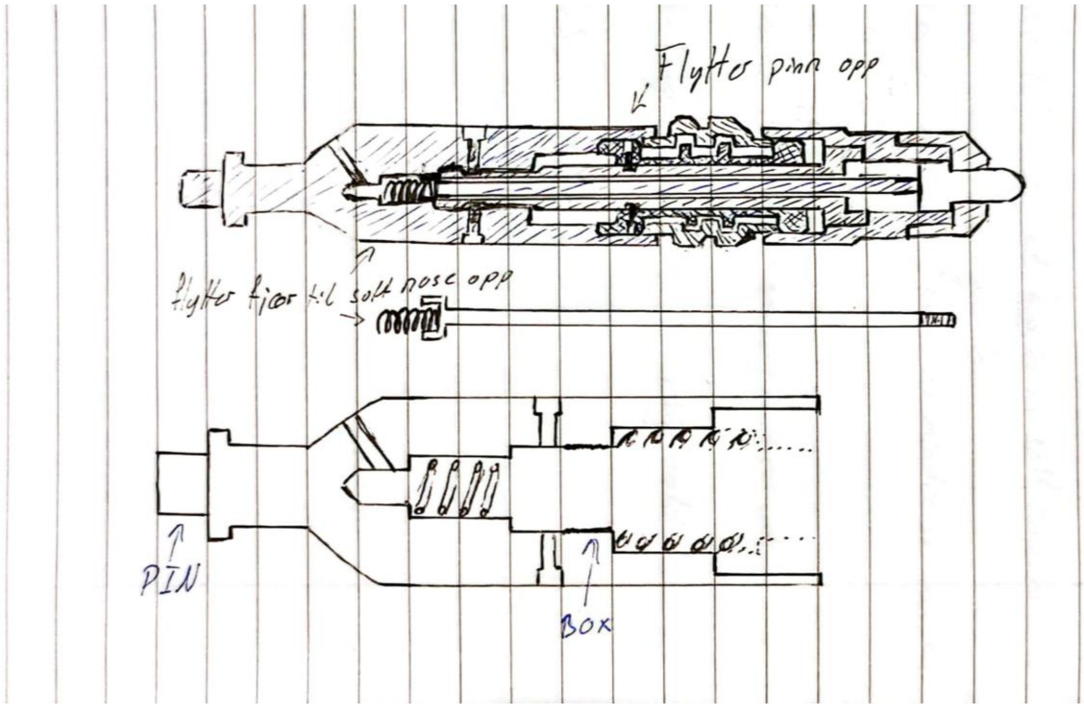


Figure 24: Sketch of the Shifting Tool

While 3D modelling the Shifting Tool, changes were made. Figure 26. Shows the design result of the Shifting tool.

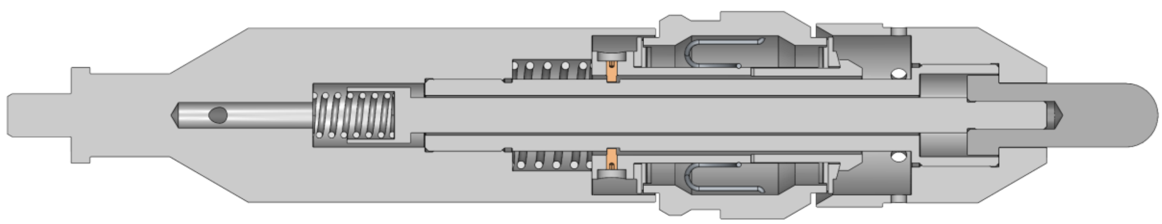


Figure 25: Cross Section of the Shifting Tool

Since the flow area of the well displacement was not big enough between the OD of the Top Sub and The ID of the DTHP, the first decision was to make traces on the surface of the Top Sub, as shown in figure 27.

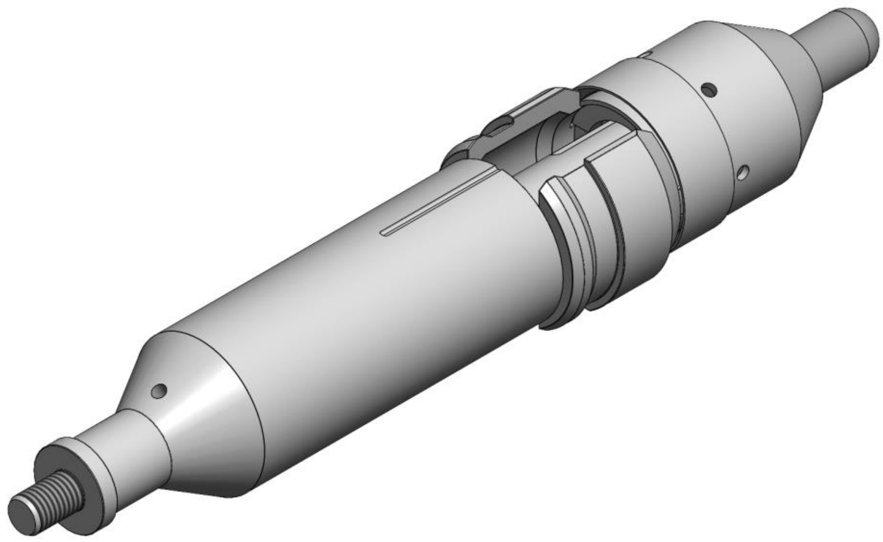


Figure 26: Shifting Tool with traces for flow area for well displacement.

There were two traces, one on each side. A decision was made for the traces to go to the end of the Top Sub.

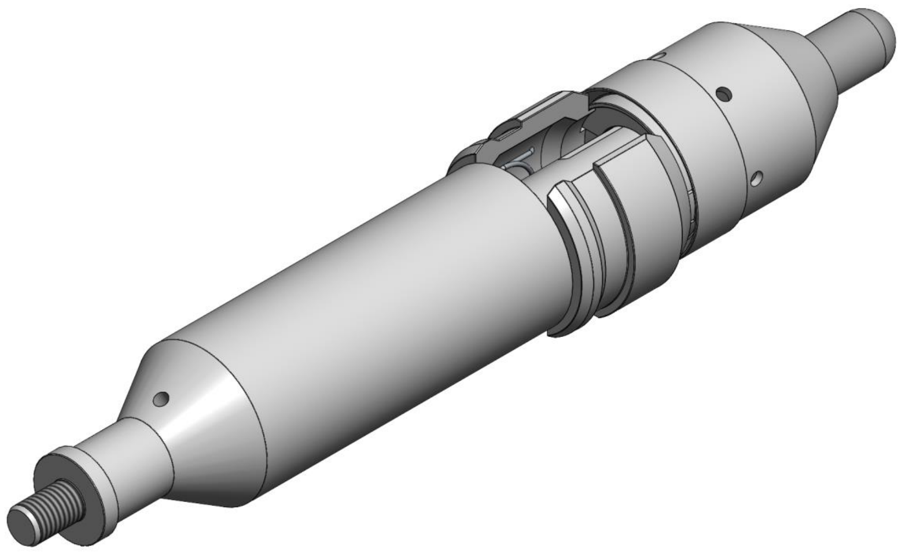


Figure 27: Shifting Tool after changing the OD of Top Sub.

By changing the OD of the Top Sub, the traces on the Top Sub were no longer necessary, and the flow area for well displacement was big enough. Another design decision was to have two drainage holes in the top of the Top Cap. The function of the drainage holes is to release the compression pressure of the fluid when the spring inside of the Small Mandrel, is being compressed by the Soft Nose reaching the glass discs. Since the water-based mud is an incompressible fluid, will there be a pressure in the chamber where the spring sits. It is therefore necessary to have drainage holes for the spring to work as intended.

4.9 Design review

These meetings made it possible to look at the 3D model of the Shifting Tool from different perspectives, then make changes for the better.

4.10 FMEA

Operation		Characteristics of failure				Rating			
No.	Component/Step	Failure mode	Causes of failure	Effects of failure on part/system	Test method	Severity of Effect	Frequency	Detection	RPN
Manufacturing and Assembly									
1,00	Contingency Shifting Tool Assembly PN 2037206								
1,00									
1,01		OD too big.	Manufacturing errors.	Problems to enter the DTHP and not enough flow area for well	Inspection and measurement of part after manufacturing.	4	1	1	4
		OD too small	Manufacturing errors.	Problems to enter the SSD profile	Inspection and measurement of part after manufacturing.	4	1	1	4
1,02		Corrosion, bad or damaged surface.	Wrong material quality, wrong specifications, drawing/assembly procedure not followed, insufficient transport protection, reckless mounting.	Insufficient strength in parts.	Internal control of dimensions and surfaces, documentation QA/QC.	4	1	1	4
1,03		Damaged pin and box connections while assembling	Damaged during handling/assembling	Seal surface or threads damaged	Visual inspection after assembly.	3	1	1	3
2,00	SSD Spacer Dog 2037236								
2,01		Dog profile not fitting with SSD profile	Manufacturing errors.	SSD might not close	Inspection and measurement of part after manufacturing.	4	1	1	4
2,02		OD too big.	Manufacturing errors.	Might not fit inside End Cap.	Same as above	4	1	1	4
2,03		Sharp edges externally	Manufacturing errors.	Might damage inside of DTHP, can cause the the Dog to attach itselft to an edge	Same as above	2	2	1	4
2,04		Length of the Dog to big	Manufacturing errors.	Might not fit in the Sliding Sleeve Assembly or be jammed inside the assembly.	Inspection and measurement of part after manufacturing.	4	1	1	4

Table 23: Manufacturing and Assembly (Shifting Tool Assembly and SSD Spacer DOG)

Table 23 shows the FMEA of the shifting Tool assembly and the SSD Spacer DOG. This risk analysis contains of the failure mode (what kind of failure that can occur), the cause of failure, what affects the failure will have, and how to detect the failure. The rating system of the failure mode shown in this table, is based on the rating of the risk in the form of the severity level of the failure outcome (Whether it is a high or low risk), how frequent the risk will appear and the likelihood of it to be found before sending the product to the costumers. The result showing in Table 23. are all in the green specter, which means that one can conclude that the risk is acceptable.

Operation		Characteristics of failure				Rating			
No.	Component/Step	Failure mode	Causes of failure	Effects of failure on part/system	Test method	Severity of Effect	Frequency	Detection	RPN
Operations									
9,00	Make-up and RIH								
9,01	Pickup and transportation to rig floor.	Dropping the assembly, or other hard impact with surroundings.	Weather conditions, or reckless handling.	Damage/deformation on the assembly and tool/equipment.	Visual inspection.	3	1	1	3
9,02	Make-up of Shifting Tool.	Wrong wireline crossover applied during make-up.	Human error.	Damage/deformation on the assembly and tool/equipment.	Crossover avalible on rig	3	1	1	3
9,03	Make-up of Shifting Tool.	Wrong torque applied during make-up.	Human error.	Damage/deformation on the assembly.	Verify torque against thread type prior to make-up.	3	1	1	3
10,00	At depth								
10,01	Tagging glass disc	Soft Nose not mounted	Human error.	Damage to the glass disc	Visual inspection.	4	1	1	4
10,02	Displacement of well	Shifting tool OD too big	Manufacturing errors.	Not enough flow area for well displacement	Inspection and measurement of part after manufacturing.	4	1	1	4
10,03	Connecting to Otis B-profile	Not connecting to the SSD profile	Manufacturing errors.	SSD not closing	Inspection and measurement of part after manufacturing.	4	1	1	4
10,04	Release of tool from Otis B-profile	Mechanical strength	Wrong material quality, wrong calculations, wrong specifications.	Insufficient strength in shear pins, break before closing SSD. Might not shear at intended force load. Strength in shear pins higher than the strength of wireline, causing wireline to shear and glass disc to	Calculations and testing	4	1	1	4
11,00	Contingency Operations								
11,01	Lost tool in well	Mechanical strength	Insufficient strength of wireline compared to the strength of shear pin	Causing wireline to shear and the shifting tool lost on top of glass plug.	Calculations and testing	3	2	1	6

Table 24: FMEA - Operations

Table 24 shows the FMEA where the Shifting Tool Assembly is used in the operation. In this section of the FMEA analysis the risks of a failure to occur in the operation of transportation, application, assembly, and the mechanical strength of the wireline operation. The risk analysation is done in the same way as in table 16. In this table of the operation, the rating results shows that every operation except from one is in the green spectre (acceptable risk). The contingency operation, that is in the yellow spectre, will then be given a recommendation to how to make the risk acceptable (showed in table 25.).

Rating				Action Status						Rating			
Severity of Effect	Frequency	Detection	RPN	Recommendations	Decisions Taken	Type	Responsible	Deadline	Completed actions	Severity of Effect	Frequency	Detection	RPN
3	2	1	6	Contingency fishing tool can be used to overshoot the Top Sub.	Advise customer of Top Sub dimensions	Equipment	TCO	Ongoing, before performing a job	To be done on CWOP`s	3	1	1	3

Table 25: Action Status

Table 25 shows the action status of FMEA for the contingency operation. In this section, it is given a recommendation on what to do in a situation where the Shifting tool would be lost in the well, due to the insufficient strength of wireline compared to the strength of shear pin. The recommendation is to use a contingency fishing tool to overshoot the Top Sub, it is then important to advise the customers of the Top Subs dimensions.

The full FMEA can be found in the attachment of the Excel sheet called: 0302-1385-01 - FMEA and Risk Analysis.

4.11 Final Design

Technical drawing of the Shifting Tool

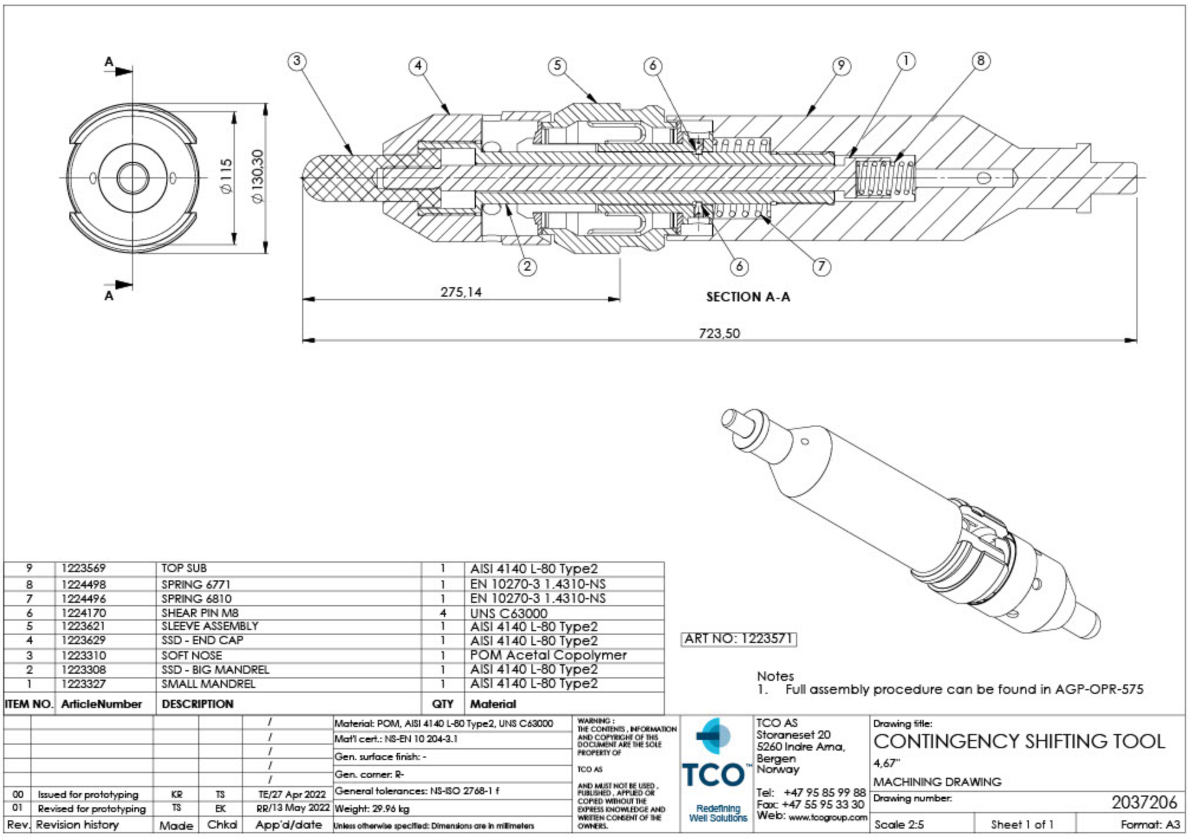


Figure 28: Technical drawing of the Shifting Tool Assembly.

3D – Model of the final design

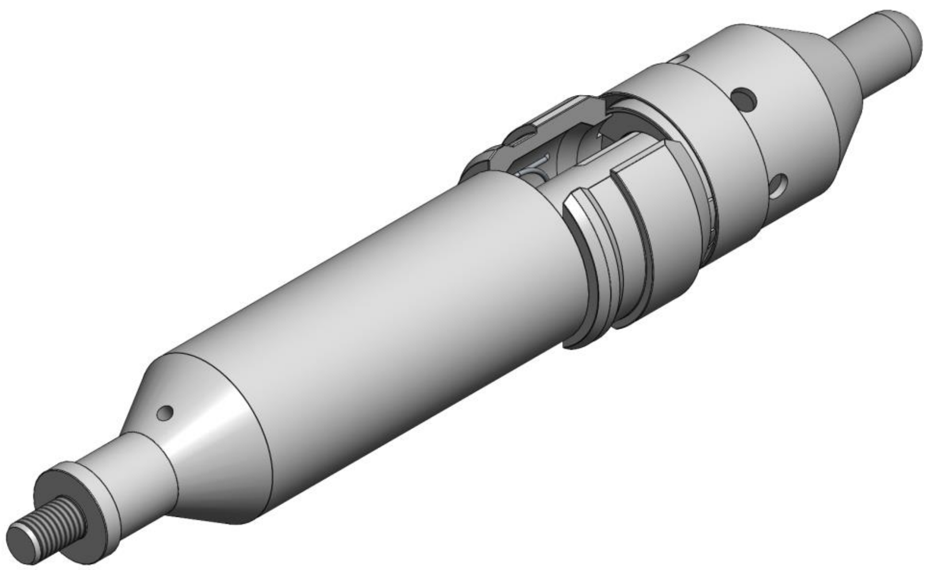


Figure 29: Shifting Tool Assembly

Technical Drawing of the Sliding Sleeve

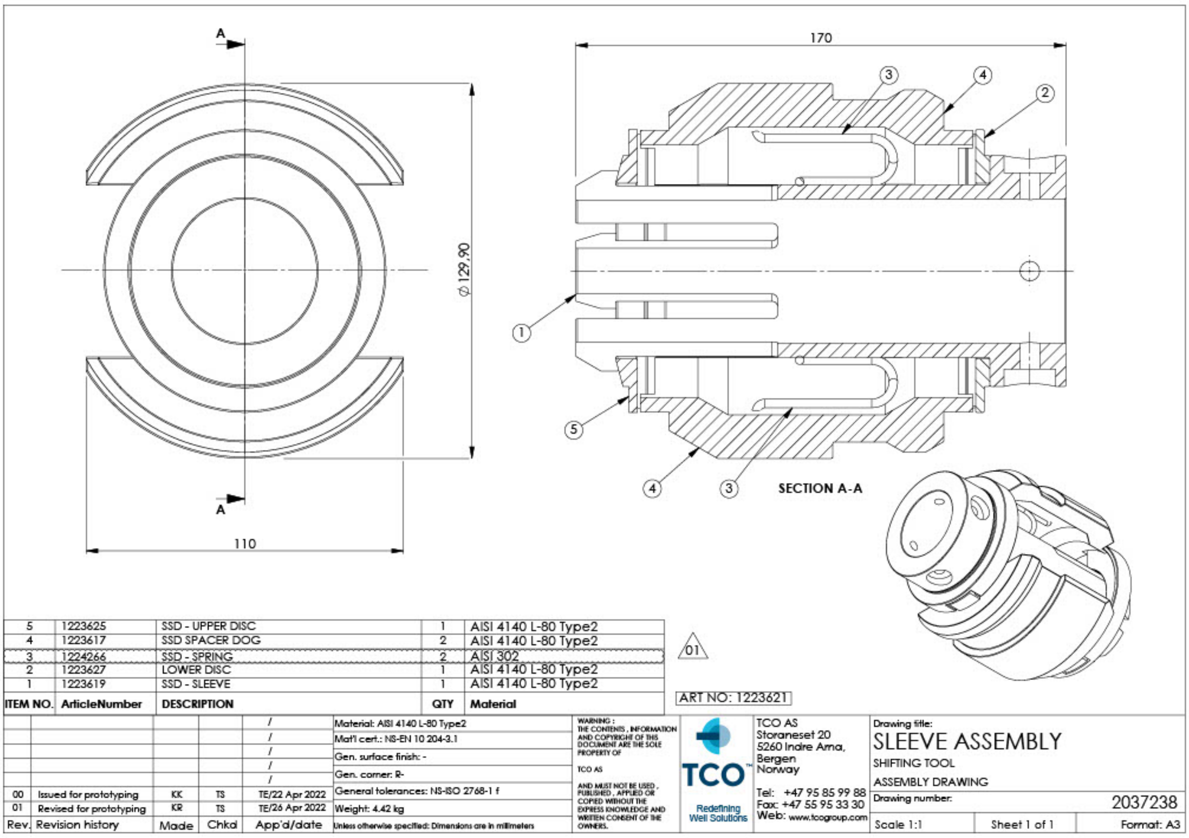


Figure 30: Technical drawing of the Sliding Sleeve

3D – Model of the Sliding Sleeve Assembly

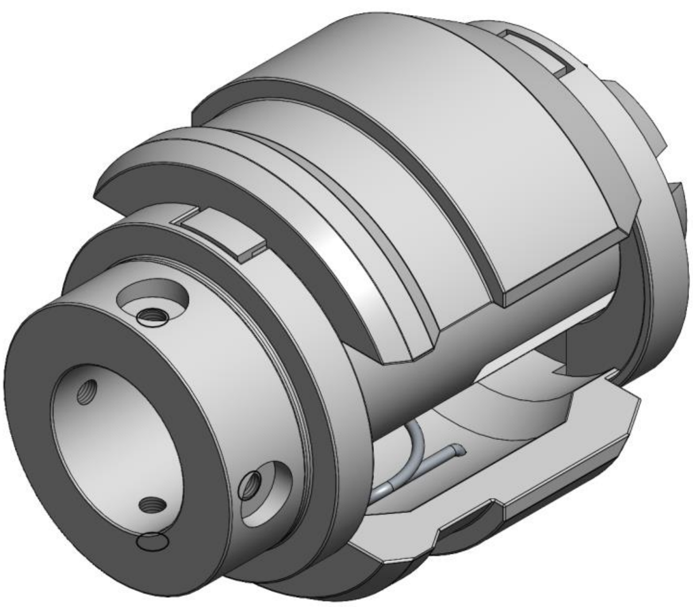


Figure 31: Sliding Sleeve Assembly

4.12 The result from the new Shifting Tool

Mating the assembly of the Shifting Tool with the assembly of the DTHP to show the distance between the soft nose and the glass disc inside of the DTHP when the Otis “B” profile of the Shifting Tool is attached to the Otis “B” profile of the SSD.

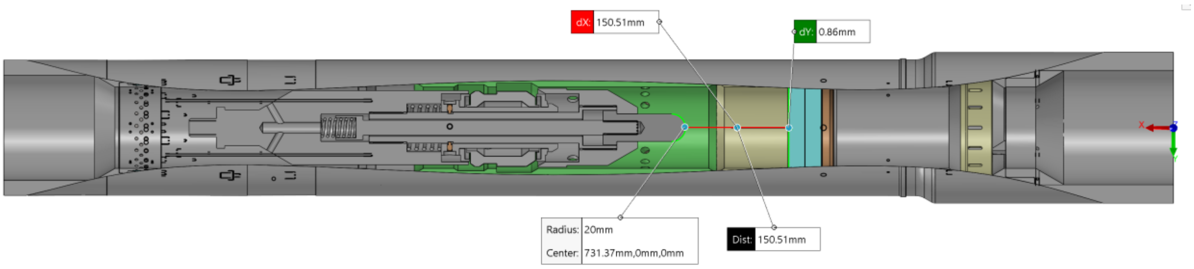


Figure 32: Shifting Tool inside of DTHP

The distance between the end of the soft nose and the glass disc will be about 150,51mm when the Otis “B” profile of the Shifting Tool is attached to the Otis “B” profile of the SSD. This gives the opportunity to remove about 150,50mm of the length of the DTHP.

5. Discussion

5.1 Shear Pin

After calculating the shear stress of the shear pin with a diameter of 6mm in the shear plane, the outcome of the calculation shows that the shear stress will not be bigger than the tensile strength and therefor the force applies will not be enough for the shear pin to shear. The next step was to calculate what shear area is needed for the shear pin to shear with the specific force applied on the shear pin, with its material properties. But the given diameter of the new shear area seems to be very small.

With the new calculated shear area as a "starting point", there was done some new calculation with bigger diameters of the shear area, to see if any of them could work if the force where just a little bigger. The problem that could occur with this solution would be the wireline to shear before the shear pin, if the force tolerance of the shear pin was bigger than the tolerance of the wireline. This could cause catastrophic damage and hazard on the environment, personnel and/or equipment, if the tool was to break the two-glass disc with the force of the tool falling. A solution would be to milling tracks with the needed diameter in the shear pin for it to shear at the specific force.

TCO are at the moment renting Shifting Tools from companies such as Wellvene where they send all needed documentation of the tool with it. One of the documents are of the shear pin that they are using in their Shifting Tool. The document consists of a table of the material used, the force applied and the dimension of the shear pin. This document does not give the information of the exact material used and its properties. It is therefore possible that their shear pin has different properties then the shear pin in this thesis. But this data can be used in the testing face of the shear pin, to determine whether it will work.

5.2 Flow Area for Well Displacement

As presented in chapter 4.1 the first design of the Shifting Tool did not give enough flow area for well displacement. The decision on how to solve this problem, is presented by two different solutions for the Top Sub and The End Cup.

The first solution was to make two traces in the Top Sub for the water-based mud to flow through. This decision would on the positive side make the flow area big enough for the well displacement, but on the other hand, could the edges on the trace, if sharp enough, make scratches inside of the DTHP. The second solution was to make a smaller OD of the Sub Top, this would make it easier to manufacture than the Top Sub with the traces, but for this to be possible, there must be enough wall thickness for the Top Sub to be structurally strong enough.

It is desirable to achieve a flow capacity of 10bbl/min past the Shifting Tool, which amounts to 1590 l/min. This has been qualified on a previous project of the 833x580 DSBP, with an area of 1761 mm^2. The costumer's expectation is a 10bbl/min flow capacity for well displacement, based on previous erosion tests done on the project Dev-1356. The tests shows that the necessary flow area to satisfy the flow area is $x \geq 1761mm^2$.

5.3 FMEA

The FMEA gives a risk analysis over the scenario where the wireline would break before the Shear Pin, due to the misunderstanding that the shear pin will have the same properties since each production is made of the same type of material. Shear pin that is of the same type of material, can have slight changes in its properties when it is not of the same production batch. This may lead to the wireline shear because of the force is bigger than the tensile strength of the wireline.

Should this failure mode occur, is there a possibility that the Shifting Tool would land on the two glass discs with a force that causes them to break. The consequence of this failure mode could lead to hazardous outcomes on the environment and personal safety.

6. Conclusion

The result from the theoretical calculation of the shear pins shear stress, show that the dimension of the area where the shear on the shear pin will occur with a radius of 0,6979mm, for it to shear at the specific force applied. There have been done theoretical calculations where the shear pin has different dimensions and the results show that they will not shear with the specific force applied, but rather end up with a plastic deformation since the shear stress is not more than the tensile strength, the ductile property of the material.

TCO has decided upon using the dimension given in the table of calculated shear stress needed with a specific force close to 500 kg (the force used in the given table is 1401 lbs or 635,48kg) with a diameter of 0,187'' (0,187'' x 25,4 = 4,75mm). My calculations shows that this dimension will be too big, and the shear pin will not shear. To determine whether it will shear with these desired properties, will it be necessary for TCO to perform shear tests in the workshop to verify the force at the point the shear pin will shear. If the result from the test shows that the dimension from the table will not give the shear pin the desired properties, they will then start testing different options, until they reach a conclusion.

Each new production batch of the shear pin will have to be tested if they have the desired properties. This is because the shear pin that is made out of the same material batch will have the same properties, but the shear pin made of a different production batch of the material, may have slightly changes in their material properties, which gives the possibility for the shear pin to either shear before desired or the shear pin to contain a more ductile property, where the shear pin does not shear at the desired force applied but rather just a plastic deformation.

Based on my calculations on the flow area, can I conclude that there will be enough flow area, for the Shifting Tool to satisfy the customers expectation of the flow capacity with a 10bbl/min past the Shifting Tool, inside the DTHP, after the necessary changes of the tolerance was made.

If there was insufficient strength of the wireline compared to the strength of shear pin, causing the wireline to shear and the Shifting Tool break the glass discs, the BOP, which is the primary barrier under the completion operation, would close the oil well. If the two glass disc do not brake, the solution would be to use a contingency fishing tool to overshoot the Top Sub and jarring the Shifting Tool over the SSD and up to the surface.

By removing material from some of the parts, making the parts smaller, moving some components inside of the shifting tool (e.g., shear pin and springs) from the lower end to the upper end. This changes makes it possible to move the Otis "B" profiled DOG from the middle to the lower end of the Shifting Tool. This solution gives a smaller distance from the Otis "B" profiled DOG and the glass disc in the DTHP.

By making these changes, TCO will now be able to revise the DTHP and remove some of the material at the distance between the glass discs and the Otis "B" profile of the SSD.

By designing a new shifting tool for TCO, they can now sell or rent their shifting tool to other companies that needs it to test their products or in the package they are selling to their customers.

6.1 Remaining Tasks

The technical drawings of the Shifting Tool have now been approved, and the process of manufacturing the prototype of the Shifting Tool for the next phase, function testing, has now started. The phase of function testing contains of different types of tests to determine if the Shifting Tool is working properly, and that it has the desired properties. Function testing consists of a series of tests such as erosion tests where the effects of sand are tested, using water-based mud, and other tests that to check that the Shifting Tool can withstand the forces applied on the component, by pulling the SSD. Testing that the shear pin inside the shifting tool breaks at the correct traction. If the tests are not approved, the shifting tool must be adjusted where necessary and retested until the function tests are approved. When all the tests and documentation/reports have been completed, the shifting tool is ready for production and to be used. With the shifting tool finished working and manufactured the next step for TCO will be to revise DTHP with regard to the new Shifting Tool. The revision will lead to material savings from the glass disk and up to the profile of the SSD inside DTHP.

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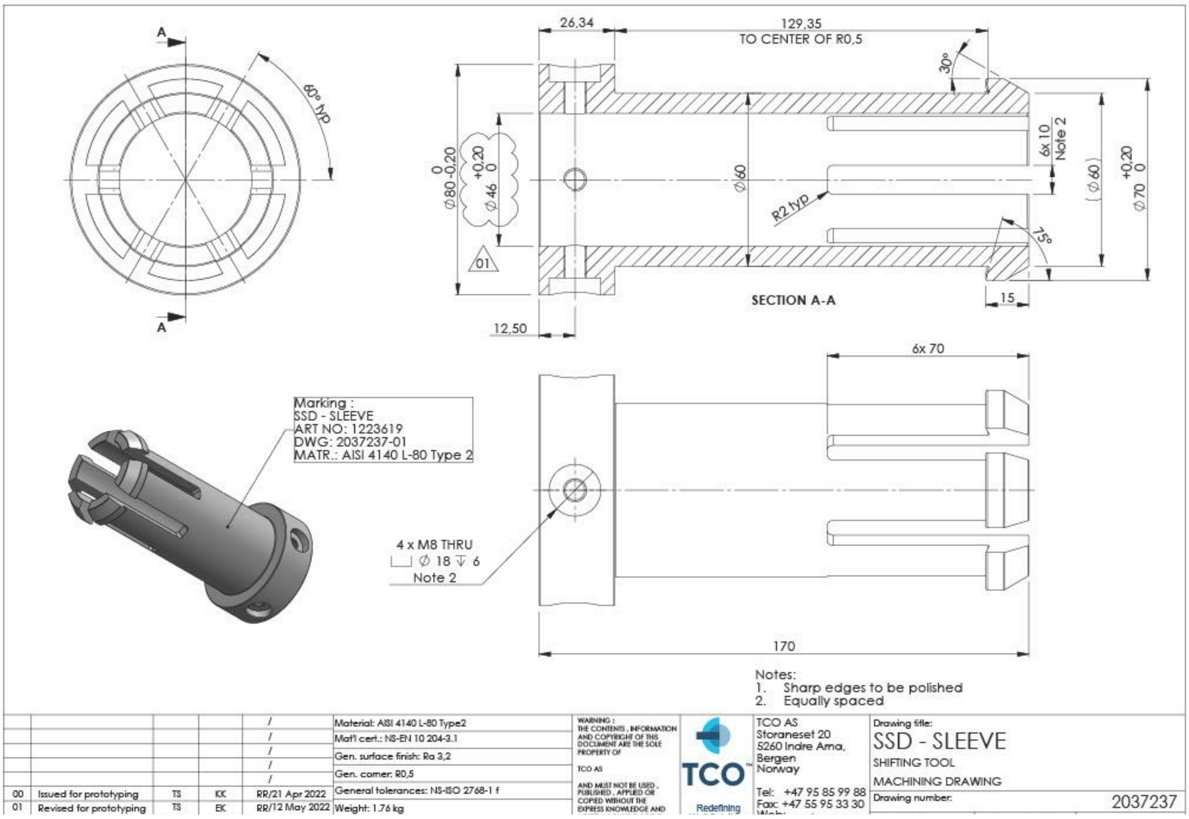
List of figures

List of tables

Attachment



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⌴ Ø 18 ↧ 6
Note 2
Notes:
1. Sharp edges to be polished
2. Equally spaced
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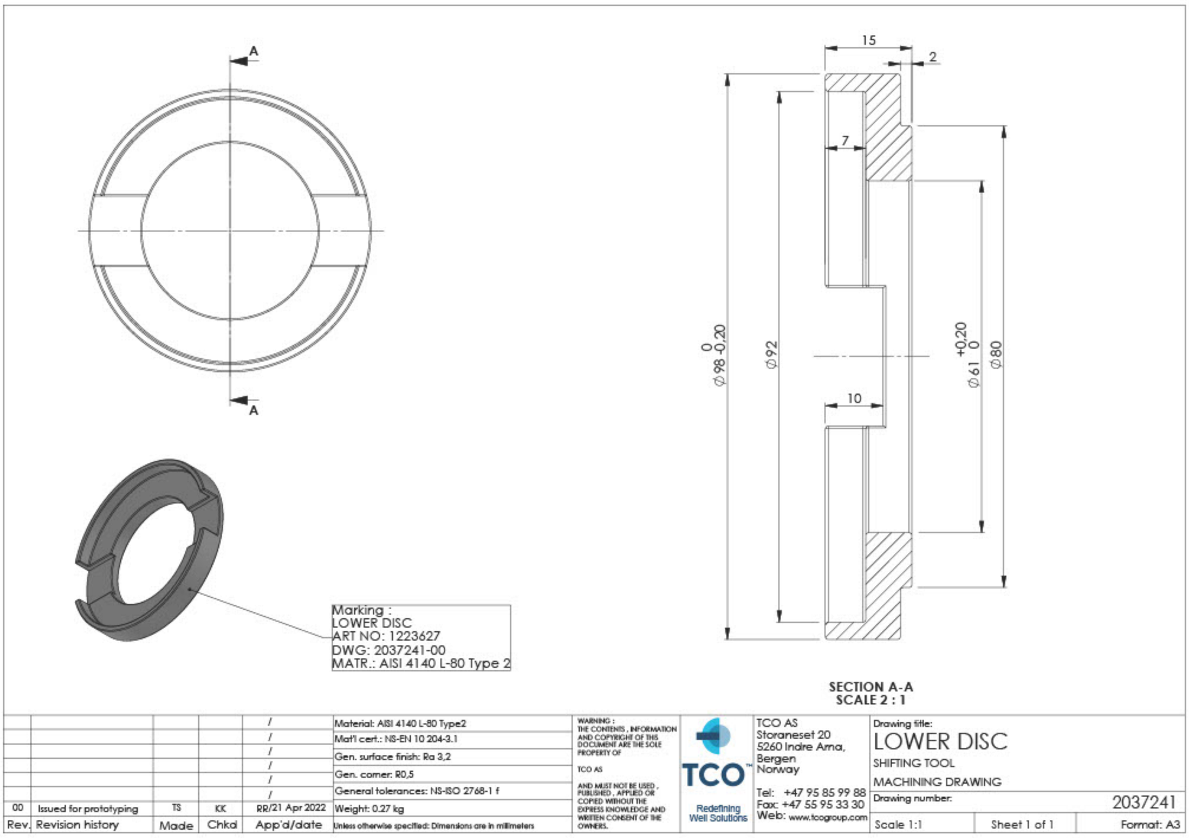
Mat'l cert.: NS-EN 10 204-3.1
Gen. surface finish: Ra 3,2
Gen. corner: R0,5
General tolerances: NS-ISO 2768-1 f
Weight: 1.76 kg
00 Issued for prototyping TS KK RR/21 Apr 2022
01 Revised for prototyping TS EK RR/12 May 2022
TCO AS
Storaneset 20
5260 Indre Arna,
Bergen
Norway
Tel: +47 95 85 99 88
Fax: +47 55 95 33 30
Drawing title:
SSD - SLEEVE
SHIFTING TOOL
MACHINING DRAWING
Drawing number:
2037237



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Gen. surface finish: Ra 3,2
Gen. corner: R0,5
General tolerances: NS-ISO 2768-1 f
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00 Issued for prototyping TS KK RR/21 Apr 2022
Rev. Revision history Made Chkd App'd/date
Unless otherwise specified: Dimensions are in millimeters
TCO AS
Storaneset 20
5260 Indre Arna,
Bergen
Norway
Tel: +47 95 85 99 88
Fax: +47 55 95 33 30
Web: www.tcogroup.com
Redefining Well Solutions
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LOWER DISC
SHIFTING TOOL
MACHINING DRAWING
Drawing number:
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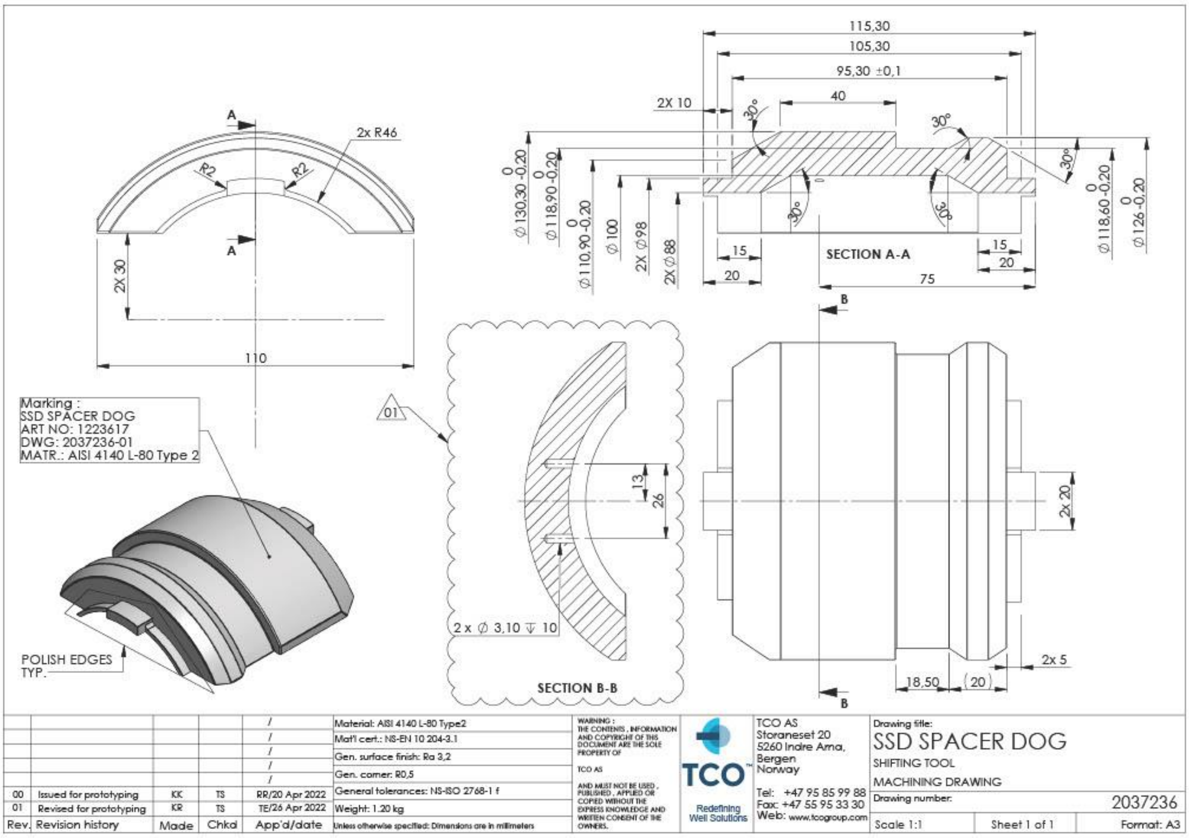
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Mat'l cert.: NS-EN 10 204-3.1
Gen. surface finish: Ra 3,2
Gen. corner: R0,5
General tolerances: NS-ISO 2768-1 f
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01 Revised for prototyping KR TS TE/26 Apr 2022
Rev. Revision history Made Chkd App'd/date
TCO AS
Storaneset 20
5260 Indre Arna,
Bergen
Norway
Tel: +47 95 85 99 88
Fax: +47 55 95 33 30
Web: www.tcogroup.com
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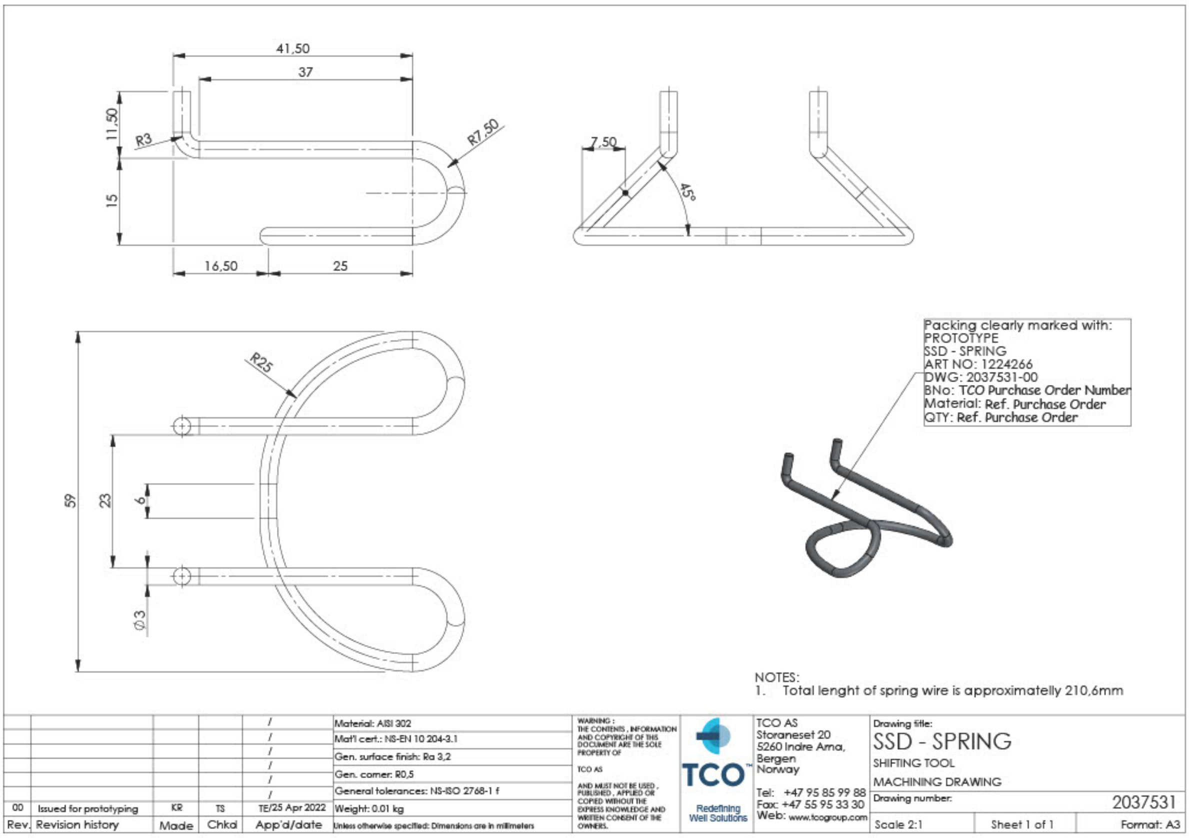
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Material: Ref. Purchase Order
QTY: Ref. Purchase Order
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Gen. corner: R0,5
General tolerances: NS-ISO 2768-1 f
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Storaneset 20
5260 Indre Arna,
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Norway
Tel: +47 95 85 99 88
Fax: +47 55 95 33 30
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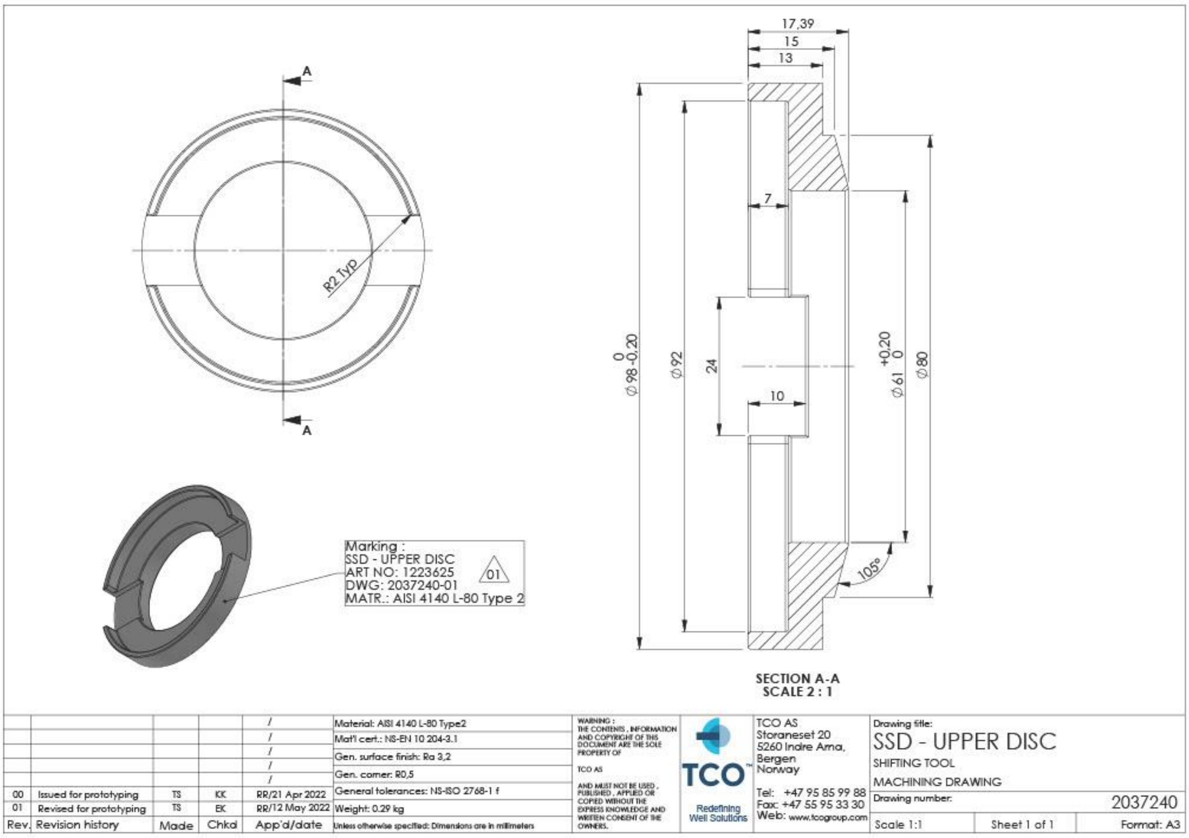

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Gen. corner: R0,5
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00 Issued for prototyping TS KK RR/21 Apr 2022
01 Revised for prototyping TS EK RR/12 May 2022
Rev. Revision history Made Chkd App'd/date
Unless otherwise specified: Dimensions are in millimeters
TCO AS
Storaneset 20
5260 Indre Arna,
Bergen
Norway
Tel: +47 95 85 99 88
Fax: +47 55 95 33 30
Web: www.tcogroup.com
Redefining Well Solutions
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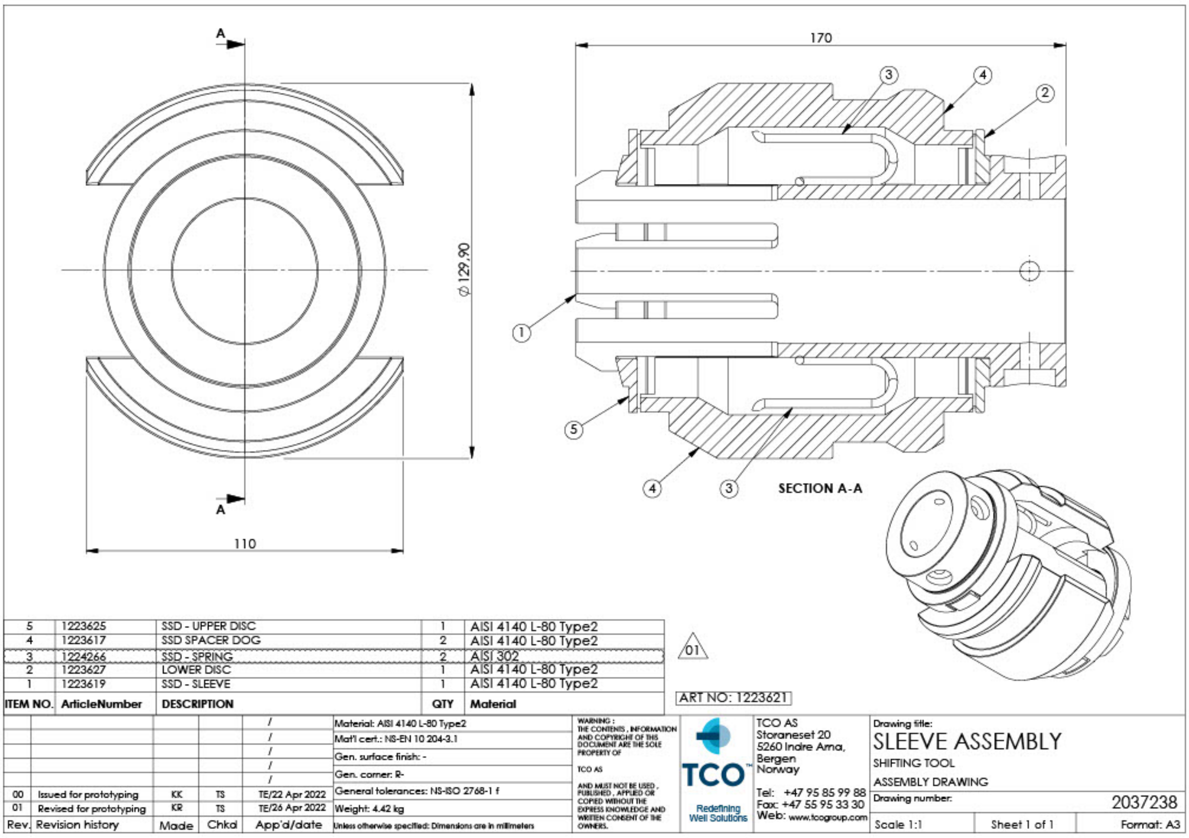

SECTION A-A
ART NO: 1223621
5 1223625 SSD - UPPER DISC 1 AISI 4140 L-80 Type2
4 1223617 SSD SPACER DOG 2 AISI 4140 L-80 Type2
3 1224266 SSD - SPRING 2 AISI 302
2 1223627 LOWER DISC 1 AISI 4140 L-80 Type2
1 1223619 SSD - SLEEVE 1 AISI 4140 L-80 Type2
ITEM NO. ArticleNumber DESCRIPTION QTY Material
Material: AISI 4140 L-80 Type2
Mat'l cert.: NS-EN 10 204-3.1
Gen. surface finish: -
Gen. corner: R-
General tolerances: NS-ISO 2768-1 f
Weight: 4.42 kg
00 Issued for prototyping KK TS TE/22 Apr 2022
01 Revised for prototyping KR TS TE/26 Apr 2022
Rev. Revision history Made Chkd App'd/date
Unless otherwise specified: Dimensions are in millimeters
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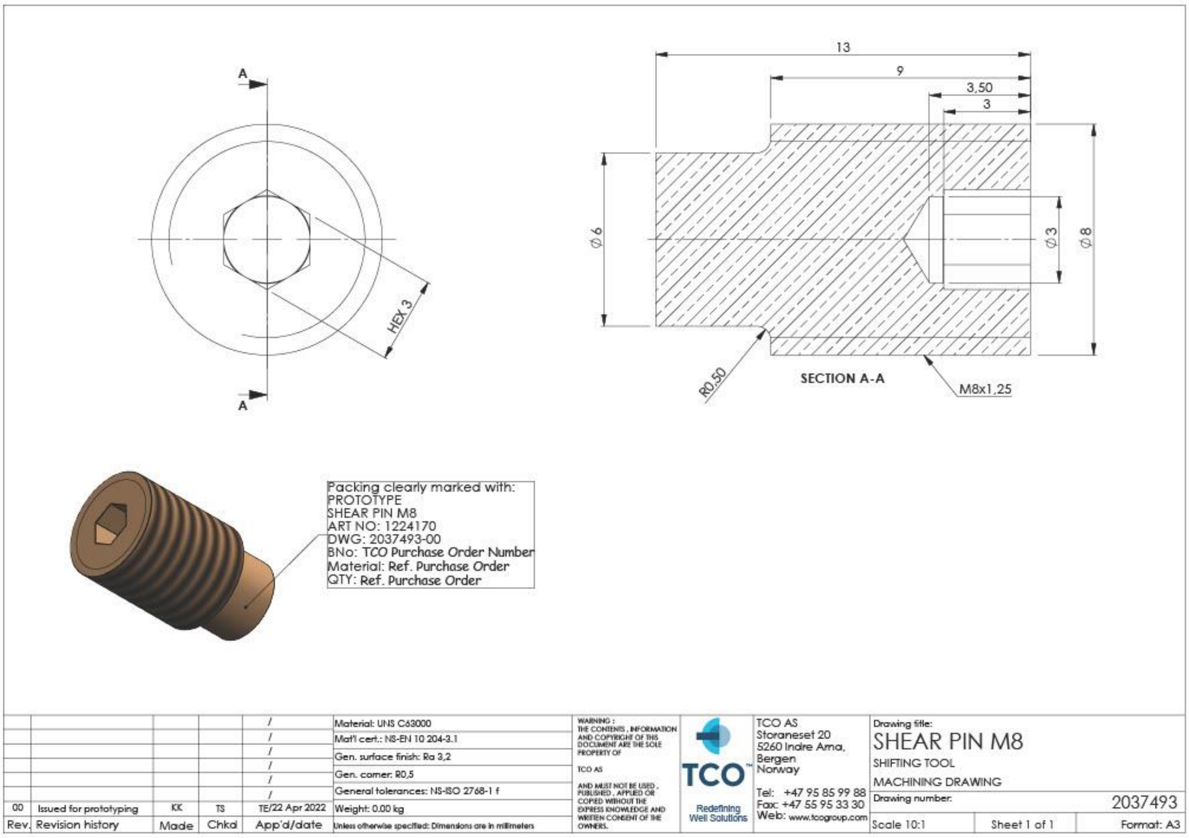
Fax: +47 55 95 33 30
Web: www.tcogroup.com
Redefining Well Solutions
Drawing title:
SLEEVE ASSEMBLY
SHIFTING TOOL
ASSEMBLY DRAWING
Drawing number:
2037238
Scale 1:1
Sheet 1 of 1
Format: A3



13
9
3,50
3
HEX 3
Ø6
Ø3
Ø8
R0,50
SECTION A-A
M8x1,25
Packing clearly marked with:
PROTOTYPE
SHEAR PIN M8
ART NO: 1224170
DWG: 2037493-00
BNo: TCO Purchase Order Number
Material: Ref. Purchase Order
QTY: Ref. Purchase Order
Material: UNS C63000
Mat'l cert.: NS-EN 10 204-3.1
Gen. surface finish: Ra 3,2
Gen. corner: R0,5
General tolerances: NS-ISO 2768-1 f
Weight: 0.00 kg
Unless otherwise specified: Dimensions are in millimeters
00 Issued for prototyping KK TS TE/22 Apr 2022
Rev. Revision history Made Chkd App'd/date
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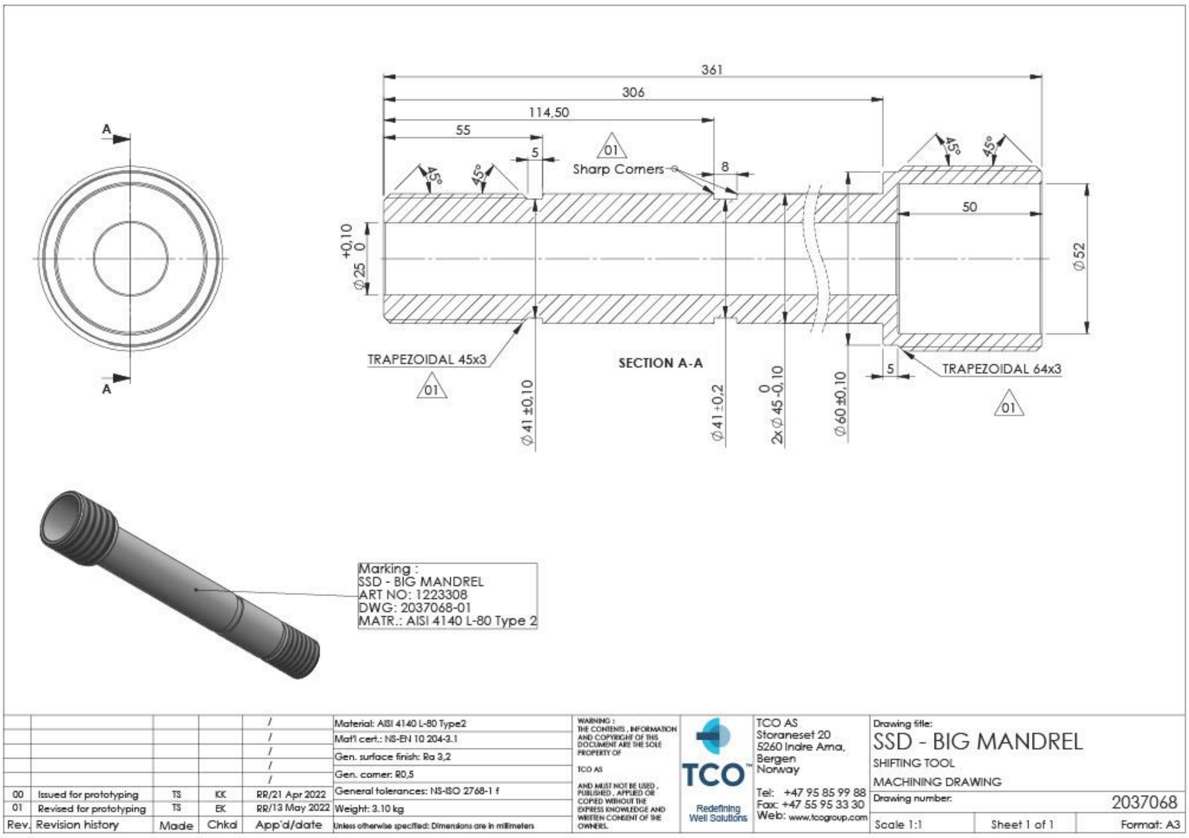
Redefining Well Solutions
Drawing title:
SHEAR PIN M8
SHIFTING TOOL
MACHINING DRAWING
Drawing number:
2037493
Scale 10:1
Sheet 1 of 1
Format: A3



361
306
114,50
55
5
8
50
45°
Sharp Corners
Ø25 +0,10 0
Ø52
TRAPEZOIDAL 45x3
SECTION A-A
TRAPEZOIDAL 64x3
Ø41 ±0,10
Ø41 ±0,2
2x Ø45 0 -0,10
Ø60 ±0,10
Marking :
SSD - BIG MANDREL
ART NO: 1223308
DWG: 2037068-01
MATR.: AISI 4140 L-80 Type 2
Material: AISI 4140 L-80 Type2
Mat'l cert.: NS-EN 10 204-3.1
Gen. surface finish: Ra 3,2
Gen. corner: R0,5
General tolerances: NS-ISO 2768-1 f
Weight: 3.10 kg
Unless otherwise specified: Dimensions are in millimeters
00 Issued for prototyping TS KK RR/21 Apr 2022
01 Revised for prototyping TS EK RR/13 May 2022
Rev. Revision history Made Chkd App'd/date
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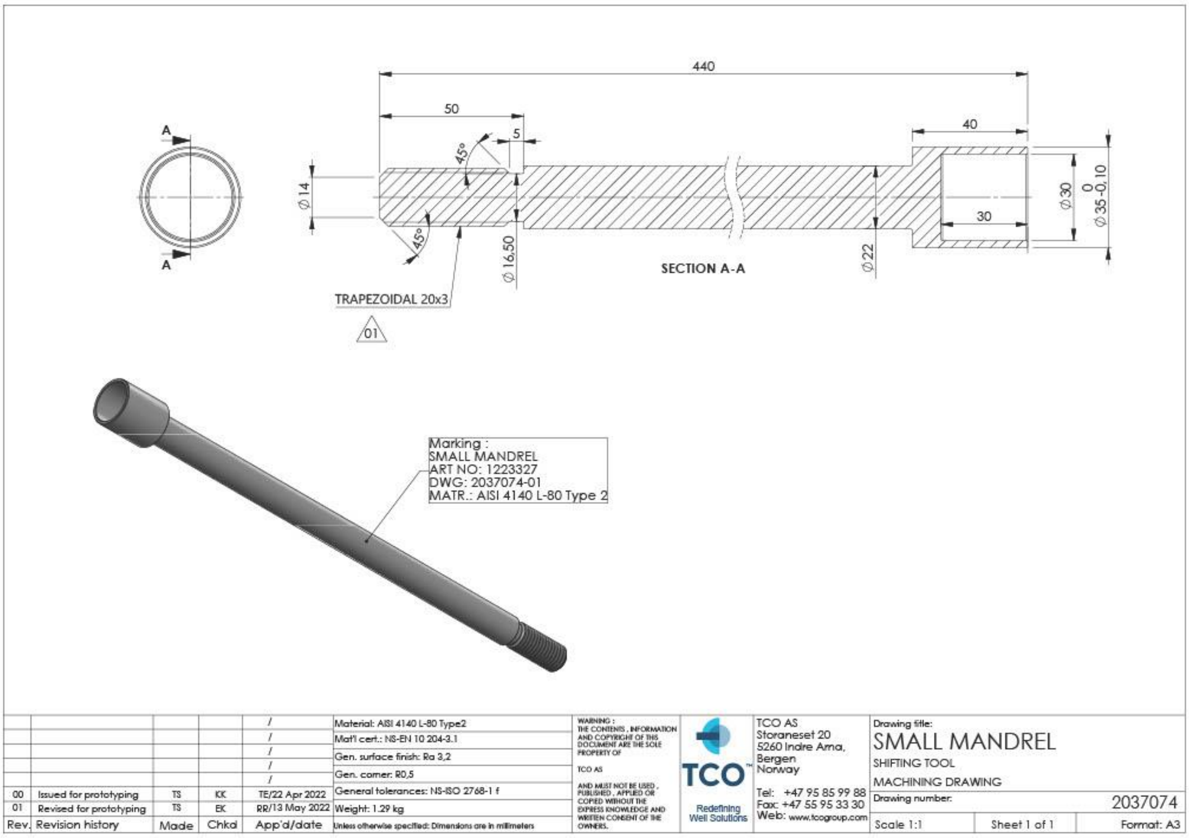
Web: www.tcogroup.com
Redefining Well Solutions
Drawing title:
SSD - BIG MANDREL
SHIFTING TOOL
MACHINING DRAWING
Drawing number:
2037068
Scale 1:1
Sheet 1 of 1
Format: A3


440
50
5
45°
40
Ø14
Ø16,50
30
Ø30
Ø35-0,10
Ø22
SECTION A-A
TRAPEZOIDAL 20x3
01
Marking :
SMALL MANDREL
ART NO: 1223327
DWG: 2037074-01
MATR.: AISI 4140 L-80 Type 2
Material: AISI 4140 L-80 Type2
Mat'l cert.: NS-EN 10 204-3.1
Gen. surface finish: Ra 3,2
Gen. corner: R0,5
General tolerances: NS-ISO 2768-1 f
Weight: 1.29 kg
Unless otherwise specified: Dimensions are in millimeters
00 Issued for prototyping TS KK TE/22 Apr 2022
01 Revised for prototyping TS EK RR/13 May 2022
Rev. Revision history Made Chkd App'd/date
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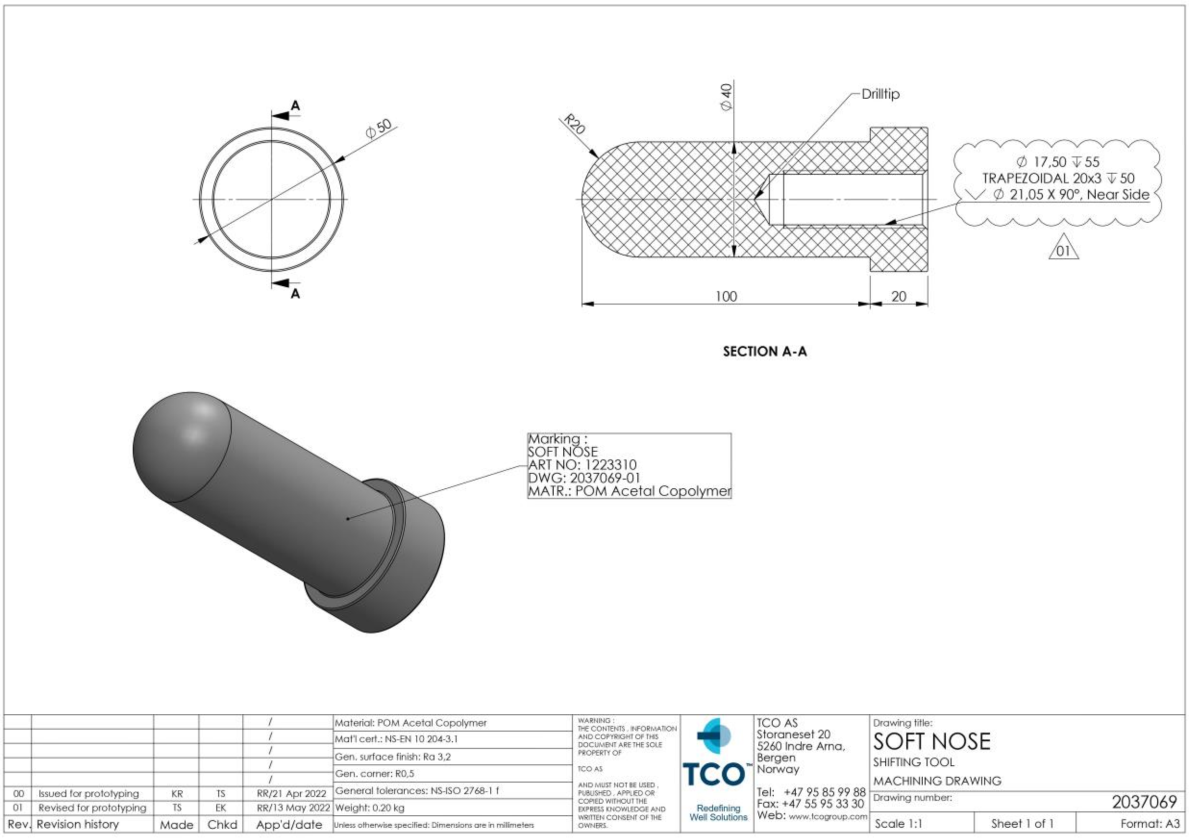
Drawing title:
SMALL MANDREL
SHIFTING TOOL
MACHINING DRAWING
Drawing number:
2037074
Scale 1:1
Sheet 1 of 1
Format: A3


Ø50
R20
Ø40
Drilltip
Ø 17,50 ↧ 55
TRAPEZOIDAL 20x3 ↧ 50
Ø 21,05 X 90°, Near Side
01
100
20
SECTION A-A
Marking :
SOFT NOSE
ART NO: 1223310
DWG: 2037069-01
MATR.: POM Acetal Copolymer
Material: POM Acetal Copolymer
Mat'l cert.: NS-EN 10 204-3.1
Gen. surface finish: Ra 3,2
Gen. corner: R0,5
General tolerances: NS-ISO 2768-1 f
Weight: 0.20 kg
Unless otherwise specified: Dimensions are in millimeters
00 Issued for prototyping KR TS RR/21 Apr 2022
01 Revised for prototyping TS EK RR/13 May 2022
Rev. Revision history Made Chkd App'd/date
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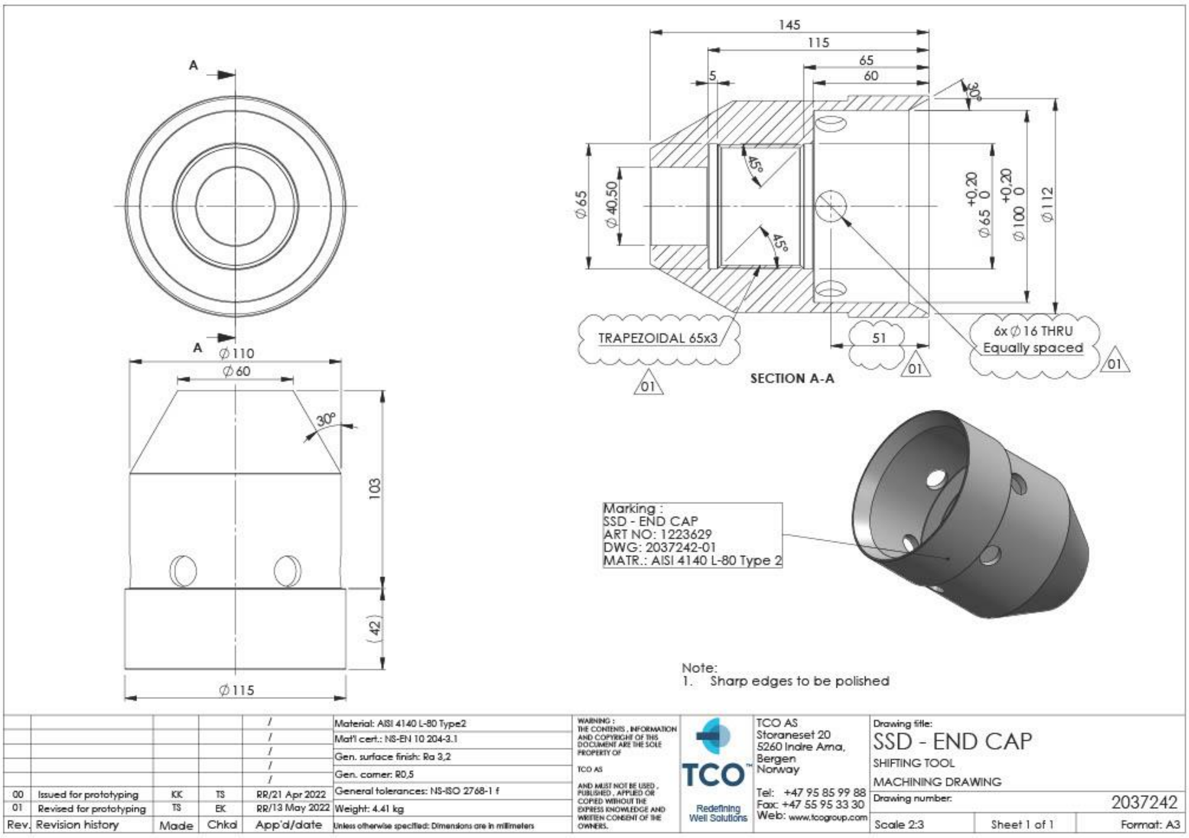
Web: www.tcogroup.com
Drawing title:
SOFT NOSE
SHIFTING TOOL
MACHINING DRAWING
Drawing number:
2037069
Scale 1:1
Sheet 1 of 1
Format: A3


A
A
145
115
65
60
5
30°
45°
45°
Ø65
Ø40,50
+0,20 0 Ø65
+0,20 0 Ø100
Ø112
TRAPEZOIDAL 65x3
01
51
01
6x Ø16 THRU
Equally spaced
01
SECTION A-A
Ø110
Ø60
30°
103
(42)
Ø115
Marking :
SSD - END CAP
ART NO: 1223629
DWG: 2037242-01
MATR.: AISI 4140 L-80 Type 2
Note:
1. Sharp edges to be polished
Material: AISI 4140 L-80 Type2
Mat'l cert.: NS-EN 10 204-3.1
Gen. surface finish: Ra 3,2
Gen. corner: R0,5
General tolerances: NS-ISO 2768-1 f
Weight: 4.41 kg
Unless otherwise specified: Dimensions are in millimeters
00 Issued for prototyping KK TS RR/21 Apr 2022
01 Revised for prototyping TS EK RR/13 May 2022
Rev. Revision history Made Chkd App'd/date
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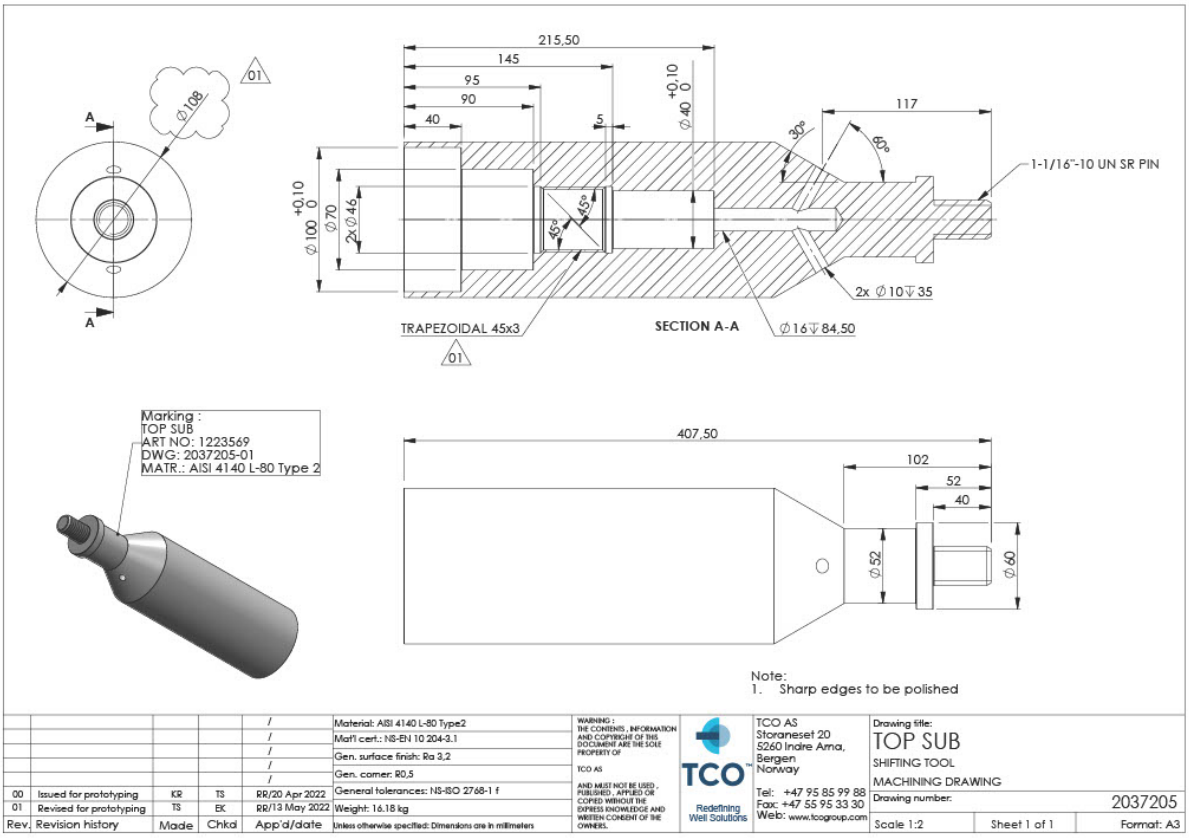
Drawing title:
SSD - END CAP
SHIFTING TOOL
MACHINING DRAWING
Drawing number:
2037242
Scale 2:3
Sheet 1 of 1
Format: A3


01
Ø108
A
A
215,50
145
95
90
40
5
+0,10 0 Ø40
117
30°
60°
1-1/16"-10 UN SR PIN
+0,10 0 Ø100
Ø70
2x Ø46
45°
45°
2x Ø10↧35
TRAPEZOIDAL 45x3
01
SECTION A-A
Ø16↧84,50
Marking :
TOP SUB
ART NO: 1223569
DWG: 2037205-01
MATR.: AISI 4140 L-80 Type 2
407,50
102
52
40
Ø52
Ø60
Note:
1. Sharp edges to be polished
Material: AISI 4140 L-80 Type2
Mat'l cert.: NS-EN 10 204-3.1
Gen. surface finish: Ra 3,2
Gen. corner: R0,5
General tolerances: NS-ISO 2768-1 f
Weight: 16.18 kg
Unless otherwise specified: Dimensions are in millimeters
00 Issued for prototyping KR TS RR/20 Apr 2022
01 Revised for prototyping TS EK RR/13 May 2022
Rev. Revision history Made Chkd App'd/date
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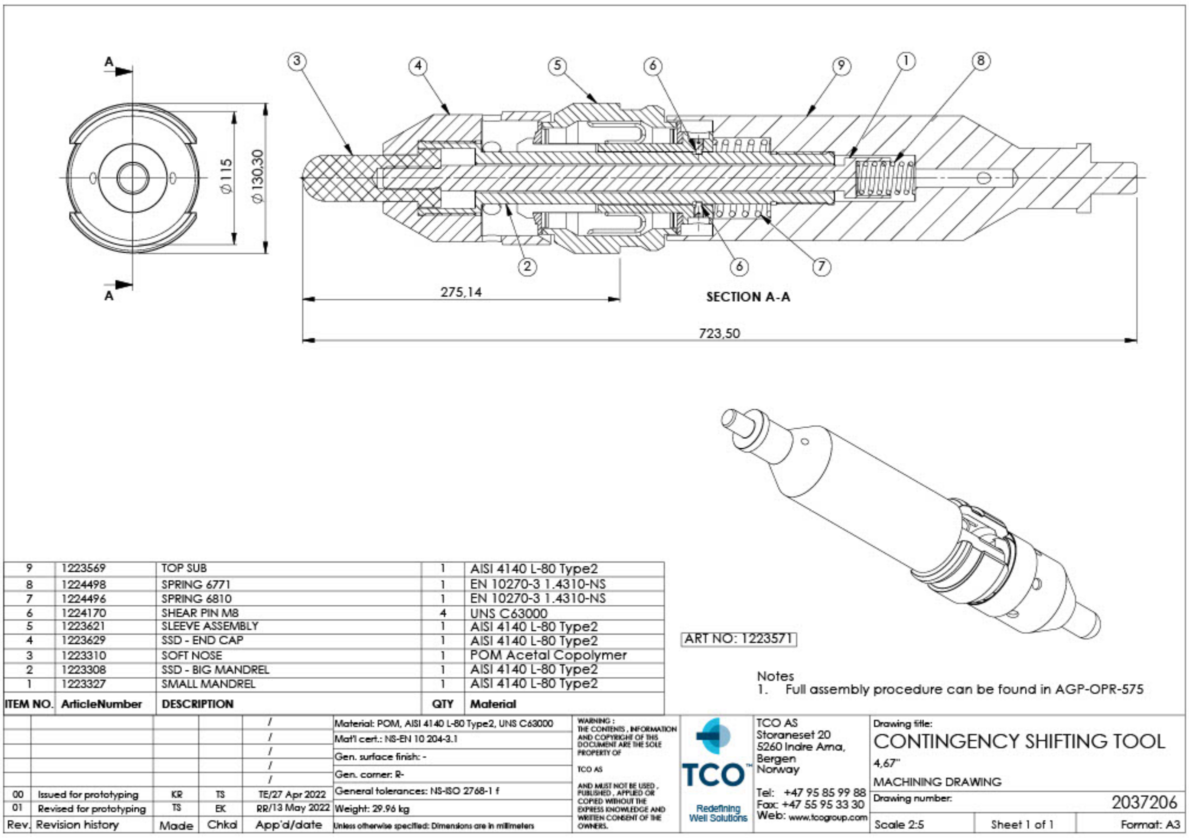
Drawing title:
TOP SUB
SHIFTING TOOL
MACHINING DRAWING
Drawing number:
2037205
Scale 1:2
Sheet 1 of 1
Format: A3



ITEM NO.	ArticleNumber	DESCRIPTION	QTY	Material
9	1223569	TOP SUB	1	AISI 4140 L-80 Type2
8	1224498	SPRING 6771	1	EN 10270-3 1.4310-NS
7	1224496	SPRING 6810	1	EN 10270-3 1.4310-NS
6	1224170	SHEAR PIN M8	4	UNS C63000
5	1223621	SLEEVE ASSEMBLY	1	AISI 4140 L-80 Type2
4	1223629	SSD - END CAP	1	AISI 4140 L-80 Type2
3	1223310	SOFT NOSE	1	POM Acetal Copolymer
2	1223308	SSD - BIG MANDREL	1	AISI 4140 L-80 Type2
1	1223327	SMALL MANDREL	1	AISI 4140 L-80 Type2

Rev.	Revision history	Made	Chkd	App'd/date
				/
				/
				/
				/
				/
00	Issued for prototyping	KR	TS	TE/27 Apr 2022
01	Revised for prototyping	TS	EK	RR/13 May 2022

Material: POM, AISI 4140 L-80 Type2, UNS C63000
Mat'l cert.: NS-EN 10 204-3.1
Gen. surface finish: -
Gen. corner: R-
General tolerances: NS-ISO 2768-1 f
Weight: 29.96 kg
Unless otherwise specified: Dimensions are in millimeters

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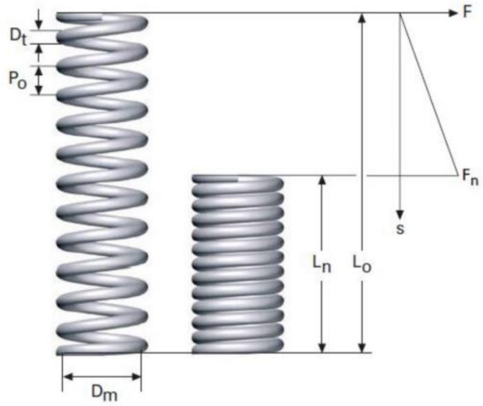
Drawing title:
CONTINGENCY SHIFTING TOOL
4,67"
MACHINING DRAWING
Drawing number: 2037206
Scale 2:5 | Sheet 1 of 1 | Format: A3

LESJÖFORS
STOCKHOLMS FJÄDER AB



Part number
6810

Description
CSS 5X63X120

Product Attribute	Ref.	Value
Material Code	Mtr	EN 10270-3 1.4310-NS
Wire diameter	Dt	5,00 mm
Inner diameter, min	Di min	57,2 mm
Free length	L0	120 mm
Total number of coils	nt	5,5 pcs
Max loaded length	Ln	33 mm
compression	Fn	564 N
Rate	R	6,5 N/mm
Mean diameter	Dm	63,0 mm
Note		x

Created: 2022-05-10 23:50:59

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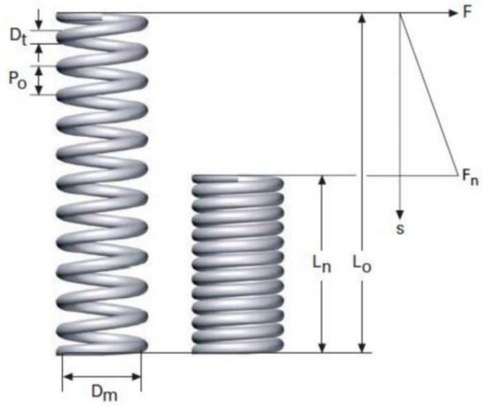
LESJÖFORS
STOCKHOLMS FJÄDER AB



Part number
6771

Description
CSS 4X25X61

Product Attribute	Ref.	Value
Material Code	Mtr	EN 10270-3 1.4310-NS
Wire diameter	Dt	4,00 mm
Inner diameter, min	Di min	20,60 mm
Free length	L0	61 mm
Total number of coils	nt	7,5 pcs
Max loaded length	Ln	33 mm
compression	Fn	734 N
Rate	R	27 N/mm
Mean diameter	Dm	25,0 mm

Created: 2022-05-10 23:50:33

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