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# Automated Rotator
# Automatisert Rotator


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Mechanical Engineering

# Automated Rotator

By

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Master's Thesis in machinery, process and product development

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# Foreword

This master's thesis is written by David Revling Khalili Holm for NMBU, Norwegian University of Life Science. This project is a summation of five years studying mechanical engineering. It represents the transition from student to engineer. I started the thesis the spring semester of 2019. It has been my everyday work for half a year, and I hope it proves an interesting read.

In this thesis, I wanted to explore a particular matter. I have an inspiring part time job as an engineer at MHWirth (Aker Solutions until 2014), and MHWirth wanted to give me insight in the firm as well as the opportunity to look into some of their research and development. This master thesis is built upon a project report which was made as preparatory work in the course TIP300.

Several people have been of great importance in writing this project report. I want to give special thanks to: Arne Albrektsen, Senior Engineer, Riser Products at MHWirth, for guidance and support, Kjetil Antonsen, Senior Manager, Riser Products at MHWirth for offering me a fulltime job during the work, Jan Kåre Bøe, associate professor at NMBU, keeping an open door, and close follow-up and Awin Khalili Holm, my wife, for being patient, supportive, loving and generous.

Oslo, 12.05.19

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# Abstract


The Norwegian oil industry has been a central contestant in the global industry since the 1970's. The Norwegian culture for precision engineering and competence has generated billions of NOK over the last 50 years. However, since the drop in oil price in 2014, the oil and gas industry have met resistance from both the marked and the millennial generation. This has led to a market-driven consciousness regarding both environment and efficiency.

To increase efficiency, automation is introduced for the oil rig to be competitive and safer. For every second of the rig's uptime, money is spent and $CO_2$ waste is generated. This makes the time aspect of the drilling processes extremely important. DP (Dynamic positioning) is used when drilling in deep water, making the thrusters below the rig run to keep the rig in exact position above the well, even in rough weather.

A connection of the entire riser string without human interaction will be a giant leap in the process of automation, and will potential save millions of dollars and tons of $CO_2$ emissions. This will reduce chance of accidents, and decrease time used on connecting the riser string. It is an important to acknowledgement that automation of manual processes happens all across the board in the oil industry and puts this thesis into a greater context. MHWirth wants to investigate this opportunity, because a fully automated system for riser connection has not yet been made.

The concept shall be mounted on top of the spider, not to interfere with moveable objects. The concept needed to open/lock a lock ring, lift/close an index pin and open/lock a locking pin. The lock ring has lugs that can hold the entire riser string when turned. The index pin locks the lock ring in position, and the locking pin secures the index pin. This makes a *double safety*.

In the process of developing the concept, main and intermediate objectives were created. The objectives comprehend the functionality of the coupling, the double safety mechanism, methods applied, function analysis, generation and screening of concepts, manufacturing, stress analysis (FEM/FEA), hydraulic and control systems, technical drawings and implementation.

For quality insurance, an iterative process is used. The process consists of the following iterative steps: Definitions and methodology, Concept development, Construction and design and Product realization.

In the definition and methodology phase, the background of the problem and methodology was looked at. The portfolio of MHWirth and the greater context of the thesis was explored, and methodic tools such as IPD, Pugh, SCAMPER and Alberto Sol were applied. Relevant standards were found and applied.

In the concept development phase, the problems were identified and split into functions. Each function was treated separately until one concept for each function emerged. All functions were mapped using a function analysis. A total of six functions were discovered: Four functions directly related to the process, and two functions independent to the process. Secondly, concepts were generated for each function. Finally, one concept for each function was chosen using Pugh's screening tool.

During the construction and design phase, the concepts from the different functions were combined into one solution. This was designed using Solidworks. In the design process, FEA/FEM was applied to verify the toughness of the design. In addition, a hydraulic and electrical control system were made.

In the product realization phase, manufacturing methods were applied for every part, and an estimated prize for prototyping was calculated. In addition, an assembly procedure, transportation recommendations and required technical drawings were made.

The result of this product development is a concept that fulfills all project and product goals. Every part is designed with a practical, easy assembled and easy manufactured matter. The concept weights 111,6 kg and has dimensions of (when withdrawn) 1225 x 709,8 x 990,6 (mm). It has three hydraulic actuators that perform a set of movements which eventually opens/locks and secured the lock ring on a riser joint. The hydraulic system is controlled by an electrical relay system using proximity sensors.

An additional result is the design of the index pin assembly. This assembly will replace the present index pin on all riser joints that will be compatible with the concept.

Further work shall be to continue developing the Automated Rotator. The hydraulic- and the electrical control system needs development. Furthermore, the locking pin has no system to control spring failure, and no routines for safe zones around the concept have been made. At last, to validate the functionality of the concept, a prototype needs to be crafted.

# Sammendrag

Den norske oljeindustrien har vært en sentral utfordrer i den globale industrien siden tidlig på 1970-tallet. Den norske kulturen for presisjonsarbeid og kompetanse har generert milliarder av NOK over de siste 50 årene. Olje- og gassindustrien har imidlertid møtt motstand, både fra markedet, men også fra millenniumsgenerasjonen siden oljeprisfallet i 2014. Dette har ført til en markedsdrevet bevissthet vedrørende både miljø og effektivitet.

For å øke effektivitet blir oljerigger automatiserte, både for å bli mer konkurransedyktige og tryggere. For hvert sekund riggen er operativ blir penger brukt, og $CO_2$ dannet. Dette gjør miljøaspektet ved boringsprosessen ekstremt viktig. DP (Dynamisk posisjonering) brukes når man borer i dypt vann. Da kontrollerer thrusterne riggen for å holde den i eksakt samme posisjon over brønnen, til og med i hardt vær.

En kobling av hele riserstrengen uten menneskelig inngripen ville vært et stort steg i automatiseringsprosessen, og ville potensielt spare millioner av kroner og tonn av $CO_2$-utslipp. Dette vil redusere sjansen for ulykker, og senke tidsbruken ved sammenkobling av riserstrengen. Det er en viktig erkjennelse at automasjon av manuelle prosesser skjer på flere plan i oljebransjen, og setter denne oppgaven i en større kontekst. MHWirth ønsker å se på denne muligheten da et fullautomatisk system av riser-koblinger enda ikke har blitt laget.

Konseptet skal festes på toppen av spideren, og skal ikke være i veien for bevegelige objekter. Konseptet trenger å åpne/lukke en låsering, løfte/stenge en indekspinne og åpne/lukke en låsepinne. Låseringen har ører som holder hele riserstrengen når denne er låst. Indekspinnen låser låseringen i posisjon, og låsepinnen sikrer indekspinnen. Dette er en *dobbel sikkerhet*.

Hovedmål og delmål har blitt laget i løpet av utviklingsprosessen. Målene omfatter funksjonaliteten omkring koblingen, den doble sikkerhetsmekanismen, metodebruk, funksjonsanalyse, konseptgenerering og vekting av konsepter, produksjon, spenningsanalyse (FEM/FEA), hydraulikk og kontrollsystemer, tekniske tegninger og implementering.

En iterativ prosess har blitt benyttet for å kvalitetssikre. Den prosessen består av følgende iterative steg: Definisjon og metodikk, Konseptutvikling, Konstruksjon og design og produktrealisering.

I definisjon og metodikkfasen ble problemets bakgrunn og relevant metodikk utforsket. MHWirths portefølje og prosjektets større sammenheng ble sett på. Metodiske verktøy som: IPD, Pugh, SCAMPER og Alberto Sol ble benyttet, og relevante standarder ble funnet og tatt i bruk.

I konseptutviklingsfasen ble problemer identifisert og delt inn i funksjoner. Hver funksjon ble behandlet separat inntil et konsept for hver funksjon skilte seg ut. Alle funksjoner ble kartlagt ved hjelp av en funksjonsanalyse. Seks funksjoner ble funnet: Fire funksjoner var direkte knyttet til prosessen og to funksjoner var prosessuavhengige. Dernest ble det generert konsepter innenfor hver funksjon. Til slutt ble et konsept innenfor hver funksjon valgt ved hjelp av Pughs utvelgingsverktøy.

I konstruksjon og designfasen ble de utvalgte konseptene innenfor hver funksjon satt sammen til en ferdig løsning. Denne ble designet i Solidworks. FEA/FEM ble brukt for å verifisere styrken til designet. I tillegg ble et hydraulikksystem og et elektrisk kontrollsystem laget.

I produktrealiseringsfasen ble fabrikasjonsmetoder valgt for hver enkel part, og en pris på bygging av en prototype ble estimert. I tillegg ble en sammenstillingsanvisning, transportanbefalinger og påkrevde tekniske tegninger laget.

Resultatet av denne produktutviklingsoppgaven er et konsept som oppfyller alle prosjekt- og produktmålsetninger. Hver del er designet med tanke på montasje, fabrikasjon og praktisk bruk. Vekten på konseptet er 111,6 kg, og dimensjonene i tilbaketrukket tilstand er 1225 x 709,8 x 990,6 (mm). Den har tre hydrauliske aktuatorer som utfører et sett med bevegelser som til syvende og sist åpner/lukker og sikrer låseringen på en riser-joint. Det hydrauliske systemet er kontrollert av et elektrisk relésystem som benytter seg av nærhetssensorer.

I tillegg har det blitt designet en indekspinne-sammenstilling. Denne sammenstillingen erstatter de nåværende indekspinnene på alle riser-joints som skal være kompatible med den automatiske rotatoren.

Videre arbeid blir å fortsette utviklingen av den automatiske rotatoren. Hydraulikk- og det elektriske kontrollsystemet trenger utvikling. Videre mangler låsepinnen et sikkerhetssystem til å sikre seg mot defekt tilbaketrekning. Heller ingen rutiner for sikkerhetssoner har blitt utviklet. Til slutt trengs en prototype for å validere konseptets funksjonalitet.

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# 1 Introduction

## 1.1 Background

Ever since the industrial revolution, humanity have become increasingly more dependent upon oil. Oil has been extracted from the soil, with oil companies neglecting the consequences. In Norway, oil has been the largest exporting commodity since the early seventies. Today, the Norwegian oil industry has applied American engineering standards as well as being subjected to EU's and Norway's own regulations. This mix makes the Norwegian oil industry one of the most well tested, documented, regulated and ecologically aware oil industries in the world where safeguarding against oil spills is crucial.

Whether the world decides to downscale the oil industry or not, the Norwegian oil industry needs to needs to lead other countries, and be able to compete with the more polluting oil industries in other countries with less regulations. This is especially important if the global society decides to downscale the oil production.

## 1.2 Central developments and research status

### Automating the industry

To be a competitor, the Norwegian oil industry needs to be a frontrunner in the matter of efficiency, automation and HSSE (Health safety, security and environment). This includes, to gain efficiency in processes and eliminate the chances of human mistakes. Automating also removes workers from hazardous zones. Therefore, the Norwegian oil industry tends to spend great amounts on automated equipment.

### Conservativism

The oil industry is conservative by nature, and automation does not happen overnight. Most drilling companies want equipment to be tested offshore for at least five years to avoid any risks. This leads to an inconsistency between R&D and what the drilling companies are willing to buy. Hence, R&D are often not prioritized, especially by relatively small companies like MHWirth. However, at some point, the industry will embrace a fully automated drilling riser system. MHWirth wants to be ready for this shift of paradigm.

### HSSE (Health, safety, security and environment)

The Norwegian oil industry has a reputation as one of the most safe and secure as well as technologic and competent oil industries in the world. The industry is under legal control from both industry standards and Norwegian legislation. This combination yields high standards and high requirements regarding knowledge in Norwegian companies. Norwegian oil companies are not able to compete globally on a quantitative level. Typically, the Norwegian culture delivers products with high demands when it comes to HSSE, technology, quality, tolerances, material, functionality, post-production etc. These high demands make the Norwegian oil industry competitive, even though the expenses are greater than those of a number of competitors.

### MHWirth

MHWirth is one of the leading global providers of first-class drilling solutions. They have offices in 12 countries and more than 1400 employees. The main office is located in Kristiansand, Norway, with more than 500 employees. Until 2014, MHWirth was part of Aker Solutions. It is currently owned by Akastor. This project is executed for the Oslo office, who employs around 50 people. The Oslo office is located at the top floor of Snarøyveien 36 at Fornebu.

*Figure 1 – MHWirth's Oslo office* [28].

## 1.3 Macro process in offshore drilling

### The oil creation

Oil is made by plants, animals, planktons and other organic material that dies and is covered by dirt and mud. In a non-oxygen environment, the organic materials decay for millions of years under high pressure and temperatures. Eventually the material is turned into deposits of liquid and gas, which is trapped under layers of rocks.

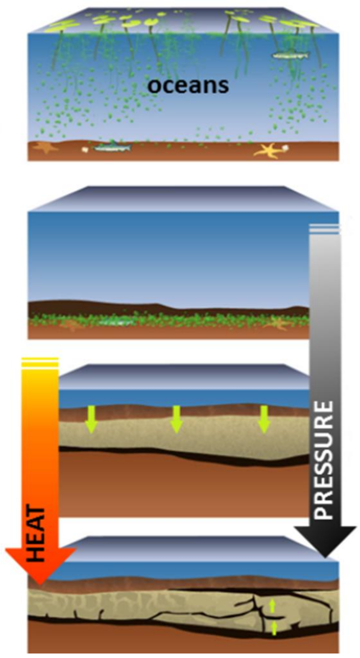



*Figure 3 - Oil and gas illustration* [31].

### Seismic surveying

In the search for oil underneath the seabed, different methods are used. The use of seismic reflection is common. A shockwave is made by an air gun or explosives and travels through the sea and into the ocean floor. In the ocean floor different layers of rocks give different reflections of sound that is picked up by a hydrophone floating behind the ship. Thus, computers, seismologists and scientists are able to analyze the output from the hydrophone to decide the probability for the existence of an oil reservoir. The big oil companies are dependent on thorough

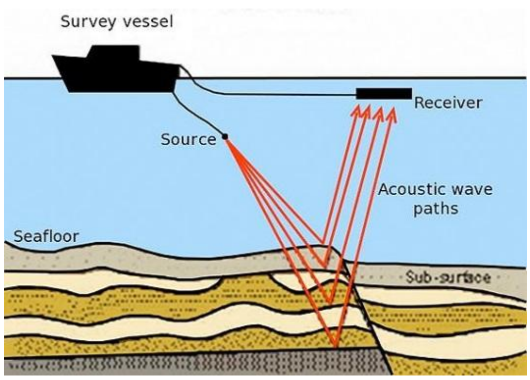



*Figure 2 – Seismic Survey* [32].

test results not to jeopardize millions of dollars on expensive exploratory drilling. Therefore, petroleum geology is an important actor when it comes to offshore drilling. [2]

## Exploratory drilling

To verify the findings of the seismic survey, exploratory drilling is introduced. The drilling vessel finds the position from the seismic survey and connects a wellhead to the ocean floor. This wellhead is the pedestal of the well soon to be installed. First, castings are cemented in the drilled hole underneath the wellhead making sure the hole can withstand collapses. Secondly, the BOP (Blow out preventer) is attached on top of the wellhead. The BOP is connected to the vessel with *marine risers*. The marine risers are similar to long straws, hollow inside, creating a closed system from the vessel to the well. Thirdly, the drill bit is guided through the riser system and to the bottom of the casting underneath the ocean floor. This is where the drilling process starts. When drilling, many sediments are to be removed. For this purpose, *drilling mud* is pumped through nozzles on the drilling bit. The drilling mud has lower viscosity than water, making it possible to pump rocks and dirt up to the vessel, where the mud is analyzed for oil findings. When leaving the well head, either a "Christmas three" is put on top of the wellhead making the well easily accessible for further production, or the well is plugged. [2]

## Production well

If the findings are promising, a production platform is built, or a subsea system is applied. A well could last 10-20 years depending on the parameters and the size. One production platform could operate several wells. This is due to directional drilling, which allows the platform to drill away from the platform. [2]

*Figure 4 - Illustration of vessel, riser string and BOP.*

## 1.4 Conceptual background

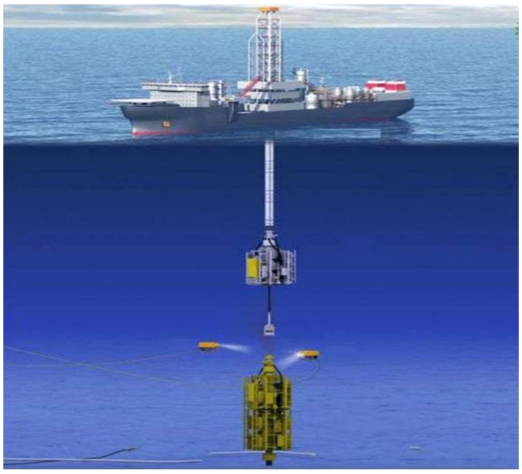


*Figure 5 - Drilling Vessel with riser submersed in the water* [19].

The concept of this master's thesis is founded in the exploration phase of oil drilling. Due to depths of over 3000 meters, the riser is divided into sections at about 30 meters for manageability. When connecting the risers, a connector made by MHWirth is used for connecting each section incrementally, until the riser reaches the wellhead at the seabed. This connection operation is done on the deck of the rig. Due to MHWirth's effective connector system, the process of connecting one riser joint only takes six minutes. However, today the connector is connected by turning a lock ring 30 degrees by human force. MHWirth wants to automate this process in the interest of saving both time and minimizing risk of personnel.

### Present process

Below, the process of the MHWirth QTR4000LS connector is shown. This is to be automated.

*Table 1 – Present coupling process.*

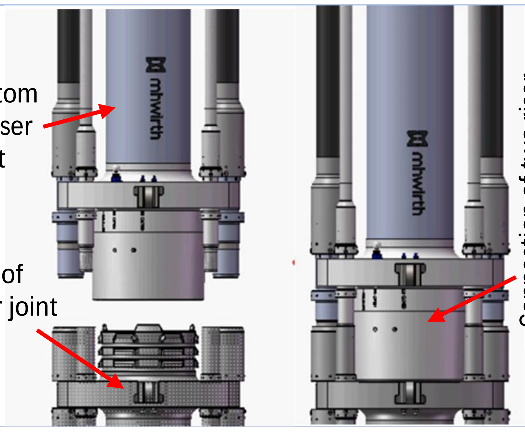
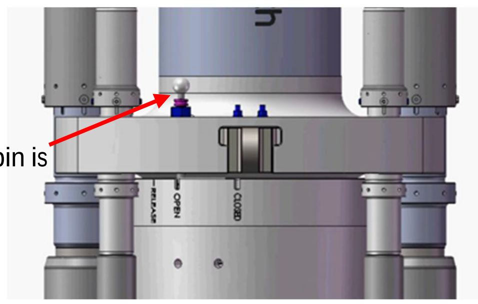
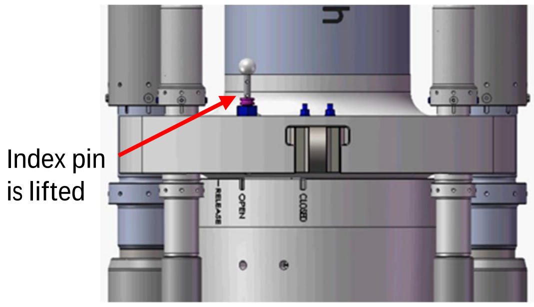
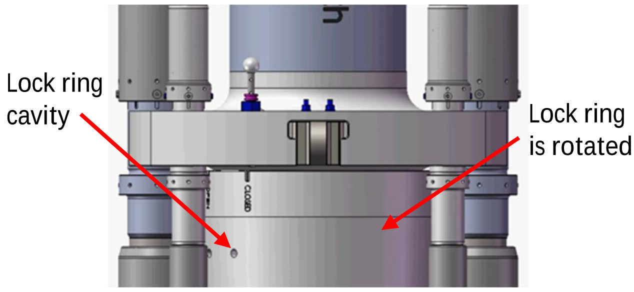
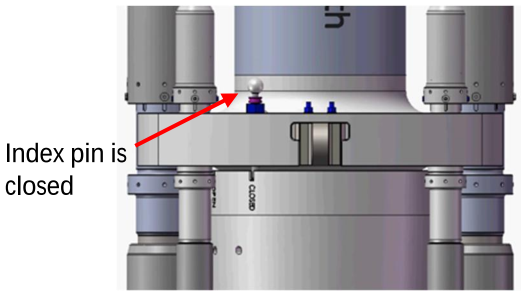
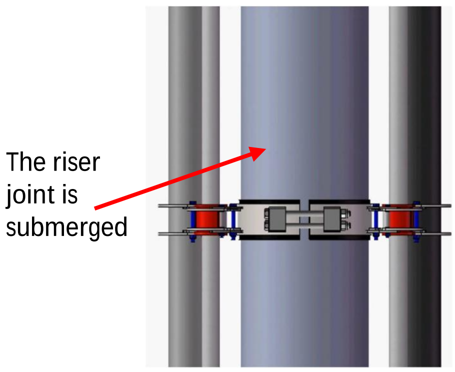
| | Process step | Illustrations |
|---|---|---|
| 1 | The risers are connected incrementally on the deck of the platform. The risers slides into each other forming a tight seal preventing seawater from getting in, and mud and hydraulic oil from getting out. After this, the lock ring needs to be rotated to ensure a closed seal and a secured coupling. | Bottom of riser joint<br>Top of riser joint<br><br>Connection of two riser joints |
| 2 | After being connected, the index pin is closed by default. This is due to a locking pin (not shown in the picture), which keeps the index pin from falling out. This locking pin needs to be removed to continue the process. | Index pin is closed<br> |

*Table 1 continues.*

| | Process step | Illustrations |
|---|---|---|
| 3 | The index pin needs to be lifted manually. This is done by human force. |  |
| 4 | The lock ring is rotated 30 degrees. This is done by human force, putting a rod in the lock ring cavity |  |
| 5 | The index pin is now closed to secure the coupling. Following this, the locking pin is closed, and the riser joint is immersed into the sea. |  |
| 6 | The riser is submerged into the water, and the process is repeated. Operated manually, this process takes about 6 minutes. Hence, a riser string of 100 riser joints for a depth of 3000 m, takes approximately 10 hours. The illustration to the right shows the middle of the riser, while it is submerged. |  |

## Concept of operation (ConOp)

The concept is supposed to open the locking pin, lift the index pin and rotate the lock ring by 30 degrees. Following this, the concept will ensure that the index pin and locking pin is back in place, hence the lock ring forms a double sealed coupling.

## 1.5 Problems and focus points

The concept is to automate the riser connection. This happens by lifting the index pin, turning the lock ring by 30 degrees, and ensuring the index pin is in the locked position. Both electricity, hydraulics and pneumatics are present, and are suitable energy sources.

When accessing the lock ring, the main line is surrounded by peripheral lines. The configuration of these varies from different rigs and companies, but four or five p-lines is normal. The p-lines have an impact on the metric specification of the mechanism, because the concept needs to operate between these.

The concept is supposed to be mounted on top of the spider, which supports the weight of the riser string. Currently, this is where operators conduct the manual operation of the lock ring.

*Figure 6 – Two riser joints are being connected in the spider* [17].

*Figure 7 - The Lock ring is turned manually* [17].

The different focus points and objectives are:

- Project objectives
    - Perform function analysis
    - Generate and choose concepts
    - Use of tools and methods:
        - IPD
        - Pugh's method
        - SCAMPER
- Product objectives
    - Find most feasible solution for all functions
    - Combine functions into one product
    - Implement the product to the surroundings
    - Create hydraulic and electronic control system
    - Execute all necessary calculations and analyses
    - Create required technical drawings (assembly and exploded view)

## 1.6 Issues and technological bottlenecks

The main bottleneck in this report is time. Many aspects are to be dealt with, but there is not time for all. Assumptions could be made, but to prove the functionality, testing and prototyping is necessary. Possible bottlenecks are:

*Table 2 - Technological bottlenecks.*

| *Bottlenecks* | Explanation |
|---|---|
| *Friction when turning the lock ring* | This problem is important, and somewhat hard to decide without testing the resistance of a lock ring. |
| *Energy supplies* | Moment of inertia and friction of the system are possible bottlenecks. In addition, the choice of an ideal energy supply is time consuming. |
| *Automation and programming* | For the solution to work properly, software needs to be implemented. |
| *Sensors* | Sensors and their signals are possible bottlenecks when communicating with an existing system. |
| *Hydraulics, hydraulic lines and mapping.* | Hydraulics are a bottleneck, and it will take time to find an applicable solution. In addition, mapping of the hydraulic system is a bottleneck. |
| *Bearings* | Different bearings for different purposes are bottlenecks. |
| *Materials* | Applicable materials have to be chosen. The materials must be relevant for the mechanism and the environment. |
| *Coating* | Coating has to be done according to relevant standards and internal routines. |
| *Validating the system* | Validation of the functionality of the system must be done to set the system in production. This is done by prototyping. For this master's thesis, this is not a priority due to time constraints. |

# 2 Project planning

In this chapter, planning and time estimates are made. Preparatory work has generated the foundation of the project; hence a base concept already exists. Therefore, the objectives are built upon this previously done work.

## 2.1 Objectives

### 2.1.1 Main objective

The main objective for this master's thesis is:

> "To improve and further develop relevant technology concepts and design the most feasible solution for automation of lock ring coupling for riser joints. The development process shall be evaluated and documented, and contain corresponding analysis and calculations, technical drawings, recommendations and conclusions."

### 2.1.2 Intermediate objectives

The following list shows the intermediate objectives for the entire project period.

- Investigate technology status, challenges and background for the project.
- Establish a time management plan [1].
- Establish methodology, choose relevant standards and define process-steps and procedures.
- Establish relevant theory, technological principles, existing solutions and layouts.
- Generate and develop concepts according to function analysis.
- Optimize design based on feedback from colleagues
- Design, develop and present the most feasible concept.
- Calculate costs and ecological footprint.
- Perform test of downscaled prototype if time permits.
- Completion of report and presentation of results.

## 2.2 Time management

The intermediate objectives are summed up as milestones in the following Gant chart:

*Table 3 - Gant Chart for time management.*

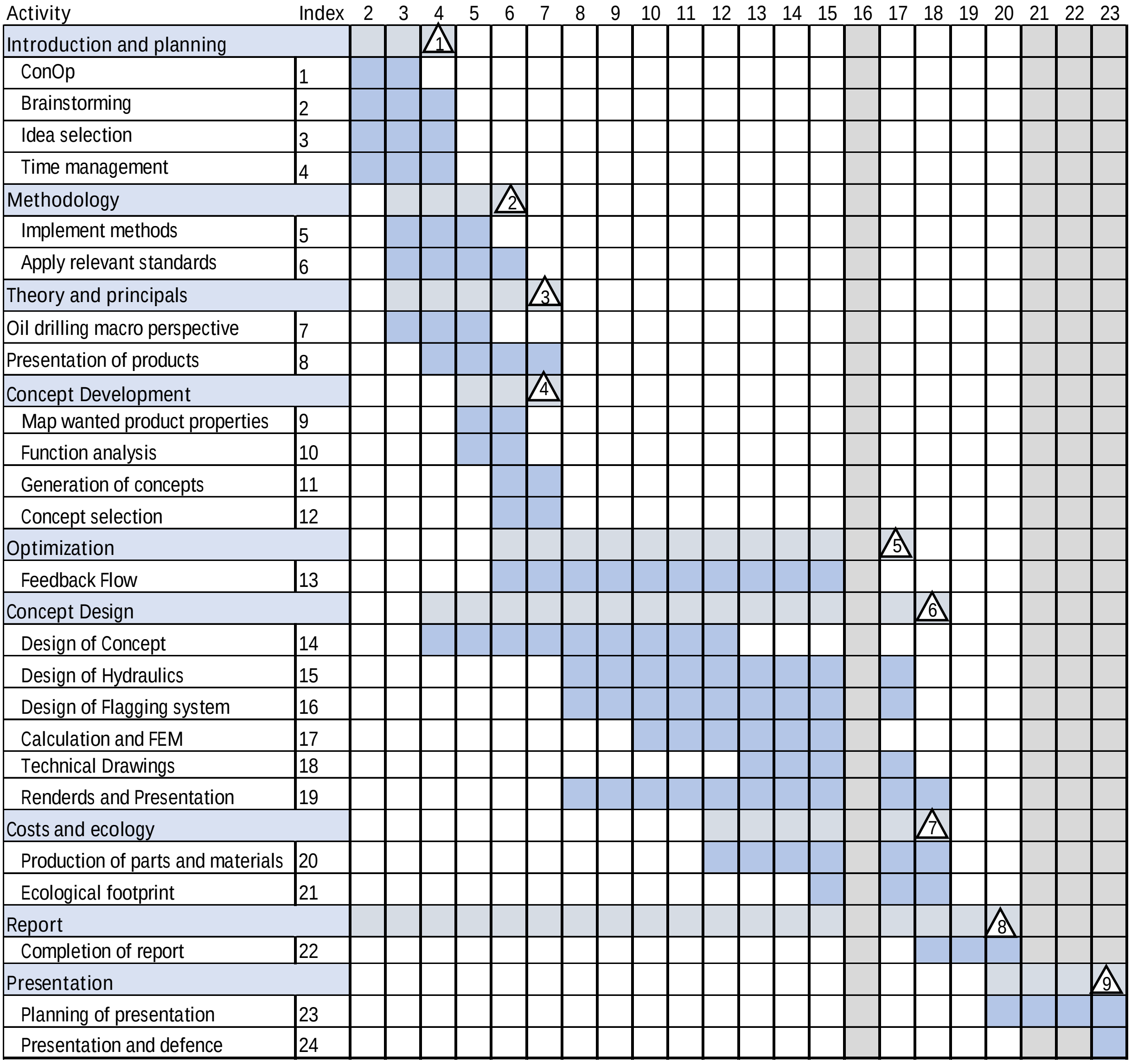



*Table 4 – Milestones corresponding to the Gant chart.*

| | Milestones: | Date: |
|---|---|---|
| *1.* | Introduction and planning | 24th January 2019 |
| *2.* | Implement methods used for the project report | 7th February 2019 |
| *3.* | Theory and principals | 14th February 2019 |
| *4.* | Concept development | 14th February 2019 |
| *5.* | Optimization | 21st February 2019 |
| *6.* | Concept design | 11th April 2019 |
| *7.* | Cost and ecology | 11th April 2019 |
| *8.* | Completion of report | 15th May 2019 |
| *9.* | Presentation | 7th June 2019 |

## 2.3 Limitations and constraints

Constraints regarding design:

- A prototype of the system will not be made, hence system validation will not be completed.
- Comprehensive calculation of hydraulic or electric systems will not be done.
- A feedback system to the operator will not be made.
- The FEA will be done without welds and is simplified.
- Topology and structural optimization have not been looked into.
- The design of hydraulic system will be designed schematically, not in CAD.
- The design of electric control system will only be designed schematically, not in CAD.
- The proximity sensors will not be implemented in the design. Only location-related recommendations are done.

Cost

- Only rough cost estimates will be made.

HSSE

- A HSSE procedure regarding the surroundings and the concept will not be made.

Methodology

- An external expert survey will not be done due to constant feedback from the work environment.

# 3 Methodology

This chapter introduces applicable methods. Terminology, symbols and formulas are listed. Tools for quality assurance are introduced.

Axes

The axes are configured as follows:

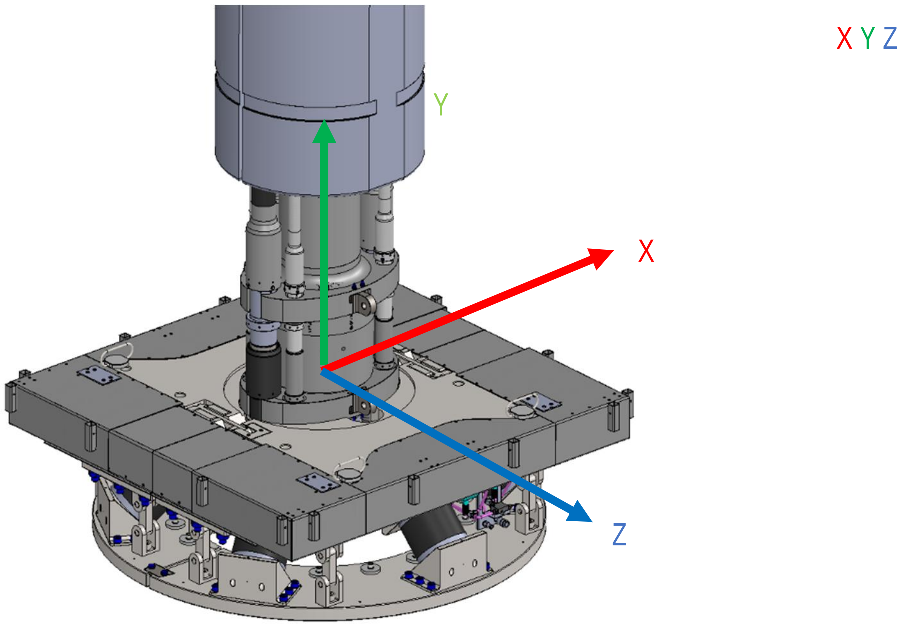



*Figure 8 - Configuration of Axis on Spider. Positive rotation is defined as looking in against origin, rotating counterclockwise.*

## 3.1 Terminology

*Table 5 – Abbreviations used in report.*

| Abbreviations | Explanation |
|---|---|
| HTHP | High Temperature High Pressure |
| FEM | Finite Element Method |
| FEA | Finite Element Analysis |
| CAD | Computer Aided design |
| AR | Automated Rotator |
| SP | Steel Plate |
| RT | Retailer |
| HPU | Hydraulic Power Unit |
| DCV | Directional Control Valve |
| SOL | Solenoid (electric coil) |
| BoM | Bill of Materials |
| P-line | Peripheral Line |
| PROX | Proximity sensor |

*Table 6 – Main symbols used in report.*

| Symbols | Description | SI units |
|---|---|---|
| $\boldsymbol{F}$ | Force | $N$ |
| $\boldsymbol{l}$ | Length | $mm$ |
| $\boldsymbol{A}$ | Areal | $mm^2$ |
| $\boldsymbol{V}$ | Volume | $mm^3$ |
| $\boldsymbol{\sigma_b}$ | Bending stress | $MPa$ |
| $\boldsymbol{\sigma_s}$ | Tensile and compressive stress | $MPa$ |
| $\boldsymbol{\sigma_{vm}}$ | Von Mises stress | $MPa$ |
| $\boldsymbol{\tau}$ | Shear stress | $MPa$ |
| $\boldsymbol{M_b}$ | Momentum | $Nm$ |
| $\boldsymbol{I}$ | Second moment of inertia | $mm^4$ |
| $\boldsymbol{y_0}$ | Y-directional distance | $mm$ |
| $\boldsymbol{\mu}$ | Friction coefficient | $-$ |
| $\boldsymbol{a}$ | Acceleration | $m/_{s^2}$ |
| $\boldsymbol{g}$ | Gravitation | $m/_{s^2}$ |
| $\boldsymbol{\delta}$ | Deformation | $mm$ |

*Table 7 – Main formulas.*

| Formula | Description | Index |
|---|---|---|
| $\boldsymbol{\sigma_s = \frac{F}{A}}$ | Calculation of pressure on an area | 3.1 |
| $\boldsymbol{\sigma_b = \frac{M_b}{I} \cdot y_0}$ | Calculation of stress caused by bending | 3.2 |
| $\boldsymbol{M_b = F \cdot r}$ | Calculation of bending caused by force | 3.3 |
| $\boldsymbol{\sigma_{vm} = \sqrt{\sigma_{tot} \cdot 3\tau}}$ | Calculation of von Mises | 3.4 |
| $\boldsymbol{F_f = F_n \cdot \mu}$ | Calculation of friction force | 3.5 |
| $\boldsymbol{F = m \cdot a}$ | Newton's 2. law | 3.6 |
| $\boldsymbol{F = m \cdot g}$ | Newton's 2. law of gravitation | 3.7 |
| $\boldsymbol{A = \frac{\pi}{4} \cdot d^2}$ | Area of a circle | 3.8 |
| $\boldsymbol{\frac{\delta}{L}}$ | Deformation per length unit | 3.9 |
| $\boldsymbol{V = A \cdot l = \frac{\pi}{4} \cdot d^2 \cdot l}$ | Volume of a cylinder | 3.10 |
| $\boldsymbol{Q = \frac{V}{t}}$ | Volume flow | 3.11 |

## 3.2 Methods and tools

### Integrated product development (IPD)

IPD is used to integrate different disciplines. IPD differs from traditional product development, because the valued work is broader than engineering and economy. This is achieved by including several departments in an early stage to get more data flow and advice on areas of uncertainty. IPD has four main pillars: Product development, HSSE, Economy and Production. All pillars are influenced by the general objectives creating data and information flows in between the pillars. [7]

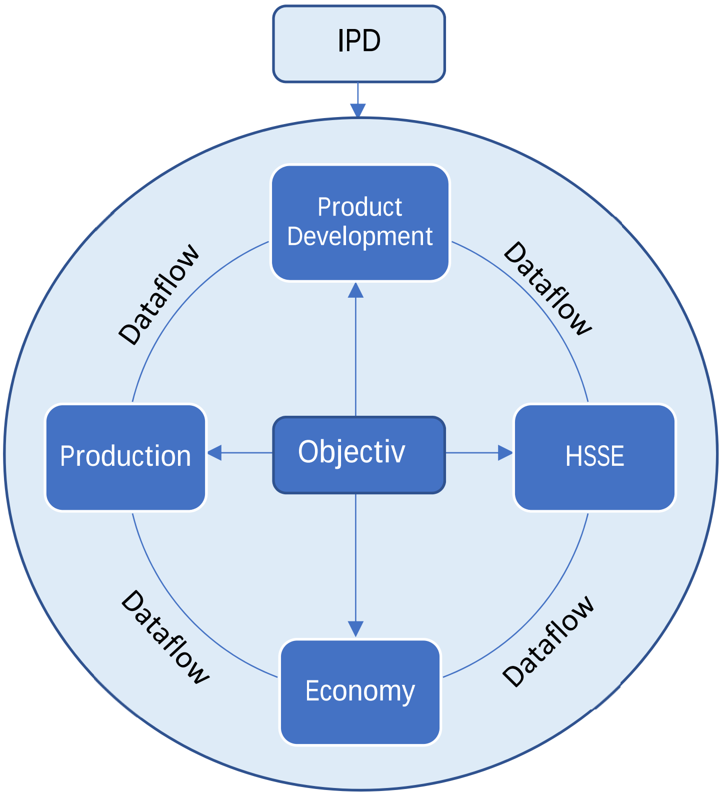



*Figure 9 – IPD illustration.*

### Pugh´s method

Pugh's method is a decision matrix for choosing the most feasible concept. The matrix is multi-dimensional, which means it combines different criteria. The criteria are of different importance; hence, they are weighted. The criteria also need to be measurable on a predefined scale. This is an important statement, as Pugh is a metric tool. To implement Pugh's method, the following steps are needed [8]:

1. Criteria and their relative importance
2. Relevant concepts
3. A multi-dimensional matrix
4. Pre-defined scales
5. Objective scoring
6. A concept with the highest score. This one should be the most feasible.

### SCAMPER

Scamper is an acronym and creative tool to come up with more ideas. It is used in creative processes both subconsciously and purposely. Scamper takes an idea and uses one of the seven abbreviations to change it. After a few iterations, the idea is completely new. Scamper is an acronym for [4]:

*Table 8 – SCAMPER.*

| *Abbreviations* | Explanation |
|---|---|
| *S – Substitute* | Substitute parts of the concepts to generate new ideas. |
| *C – Combine* | Combine concepts into something new. |
| *A – Adapt* | Adapt the concept in a new environment. |
| *M – Modify* | Modify the concept to be better or have a new function. |
| *P – Put to another use* | Use an existing idea for something new. |
| *E – Eliminate* | Remove parts of the concept. |
| *R – Reverse* | Turn the process backwards. |

## Alberto Sol's model

Alberto Sol's model is a comprehensive method for systems engineering. It is based on rounds of iteration, verification and validation. Alberto Sol's model is a model for controlling the entire work process of a project. The model could be summarized with:

- Problem definition, leading to requirements
- Iterative work. Check work for compliance between problem definition and requirements.
- Generate concepts and compare them to requirements.
- Validate and verify concepts to requirements along the way and at the end.

An edited version of Alberto Sol´s model is shown below. For the full version, see appendix III [9].

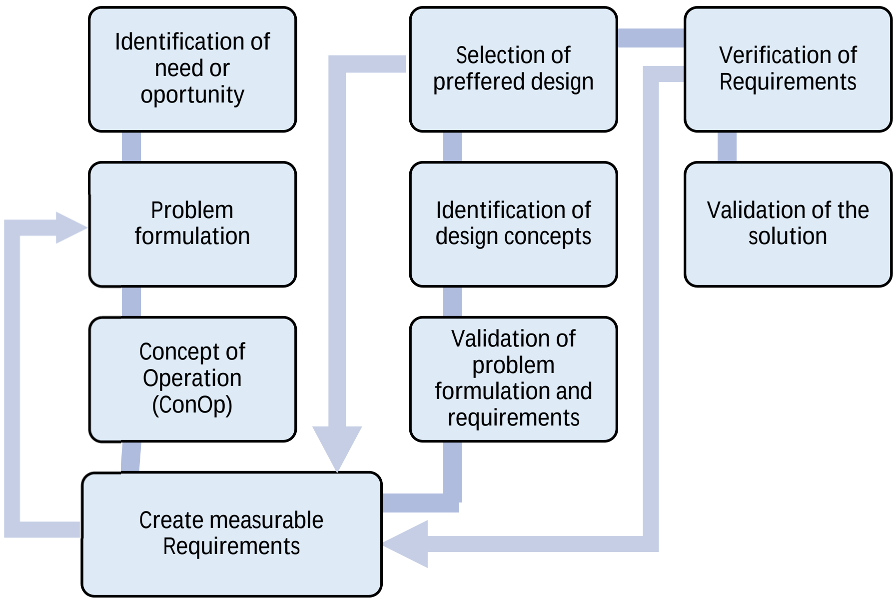



*Figure 10 - Alberto Sol's model* [9].

### Software

*Table 9 - Software and use in the project process.*

| *Software model* | Use |
|---|---|
| *Solidworks 2015* | Modelling, construction and technical drawings. |
| *CES Edupack 2018* | Lifetime cycle and ecological footprint. |
| *Microsoft Word 2018* | Reporting, tables and figures |
| *Microsoft Excel 2018* | Tables |
| *Google patent* | Search for relevant patents and competitors. Limited patent search. |
| *Google* | Search for everything else |

## 3.3 Quality assurance and literature study

The preparatory work of this thesis was done with a comprehensive literature study. Ultimately, five years leads up to this master's thesis, and therefore all books and compendiums relevant during the study period composes the literature study for this thesis However, only relevant books, standards and compendiums are listed below.

To ensure quality, methods mentioned in the latter chapter are used in combination with technical standards and mechanical cyclopedias.

*Table 10 - Quality assurance.*

| *Publication* | Explanation |
|---|---|
| *ISO 9000* | Contains system of leadership, measuring, analysis and improvement of the process [15]. |
| *ISO 9001* | International standard for quality management [16]. |
| *ISO 128* | Standard used for technical drawings [13]. |
| *ISO 7200* | Standard used for title block technical drawings [14]. |
| *NORSOK M-501* | Standard used for surface preparation and protective coating [12]. |
| *API RP 17Q* | Recommended Practice on Subsea Equipment Qualification – Second edition.<br>Relevant for FMECA ("Failure mode, effects, and criticality analysis"). Ensures the safety of the system [11]. |
| *"Tekniske Tabeller" by Jarle Johannessen* | Mechanical encyclopedia [6]. |
| *"Forskrift om maskiner" by the Norwegian Ministry of climate and environment.* | Standards applicable for all machines produced and used in Norway [24]. |
| *"Subsea engineering handbook"* | Yong Bai, Qiang Bai [2]. |

## 3.4 Process

ISO 9001 comprises quality management and illustrates a general process in the figure shown to the right.

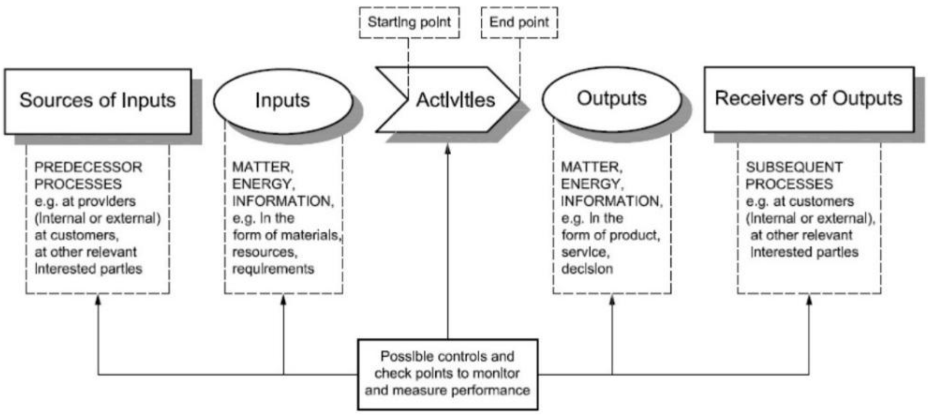



*Figure 11 – A process according to ISO 9001* [16].

In according to ISO 9001, a process needs defined inputs in the form of materials, resources and requirements. These inputs define the workload, methods and output.

Unlike a general process, a major part of an engineering master's thesis is to find and make requirements relevant for problem solving. Therefore, a master's thesis is generally bigger than the process itself. The inputs are defined in chapter 5. The output is presented in the conclusion, chapter 16.

The flow chart to the right describes the process used in this thesis. The arrows pointing backwards is where quality revision and an iteration is applied. These iterative processes are a part of the quality insurance loop. In the process of optimization, the ideas are reviewed, and even the product specification needs change (longest arrow). [1]

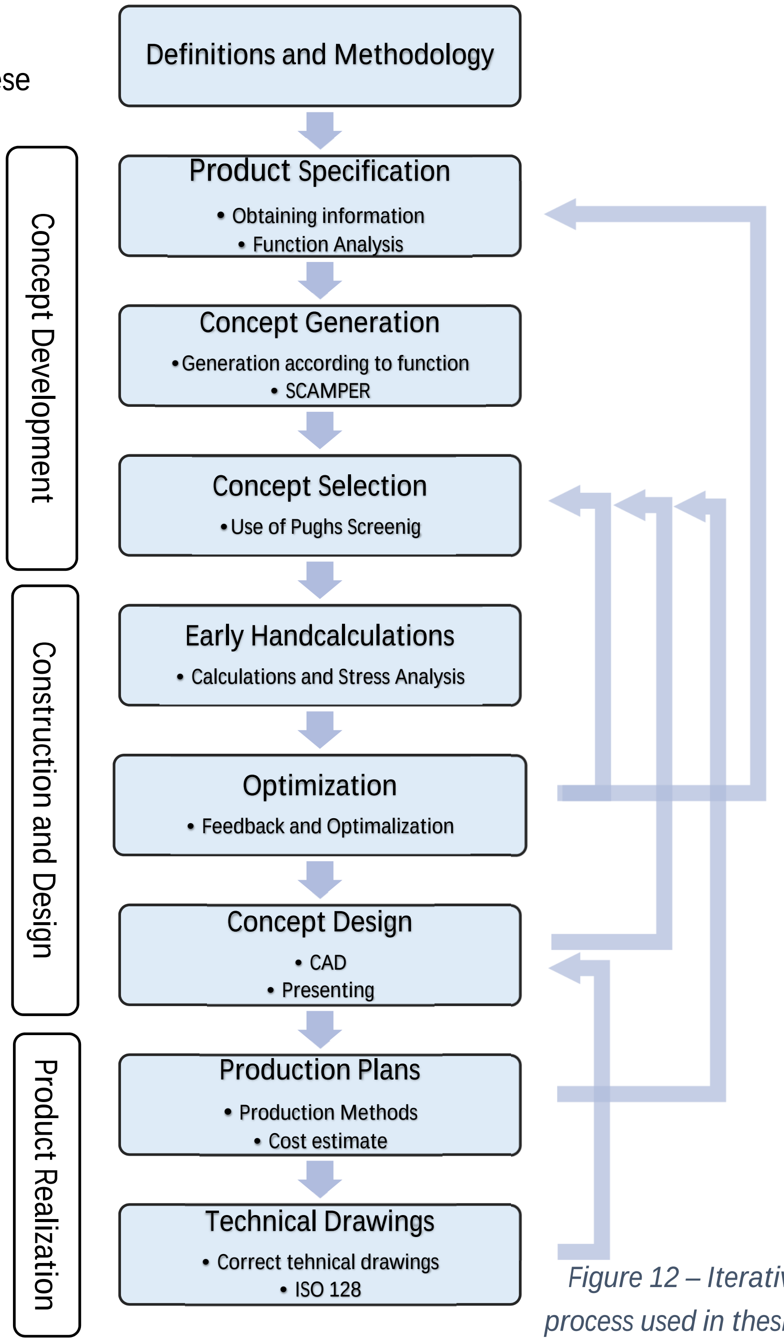



*Figure 12 – Iterative process used in thesis.*

# 4 Theory and technology review

This chapter gives a background of and an insight into relevant components in the riser system as well as control systems.

## 4.1 The riser system

The marine riser is used in the exploratory phase of the drilling. Conceptually, the marine riser is a straw that yields the oil rig a connection to the ocean floor. However, in reality this is somewhat more complex. To achieve desired depths, the riser string has to be more than 3000 meter long. In the matter of practicality, the riser string is separated into riser joints each about 30 meters long. To reach depths of 3000-meters, 100 riser joints needs to be connected. Any competitive advantage is important for the engineering firms selling riser systems to oil and gas companies. Therefore, a quick connection of the riser joints is of great importance.

## 4.2 The QTR4000LS connector

Competitive solutions use bolts (see chapter 4.10) connecting the riser joints. MHWirth have based their riser system on a QLR4000LS connector system. This system is based on female and male pipes situated on the ends of the riser joints, which is pressed into each other to obtain a tight seal. The tolerances of the female and male pipes are of great importance for the seal to have sufficient safety factor against leakage. When the pipes are coupled, the lock ring is rotated 30° to lock the system. The female side of the riser joints has outside barbs, which correspond with barbs in the lock ring. This feature makes it possible to either lock or open the coupling between the riser joints. When all riser joints are connected, and the riser string is about 3000-meter-long, the upper lock ring carries 240 metric tons (2354,4 kN).

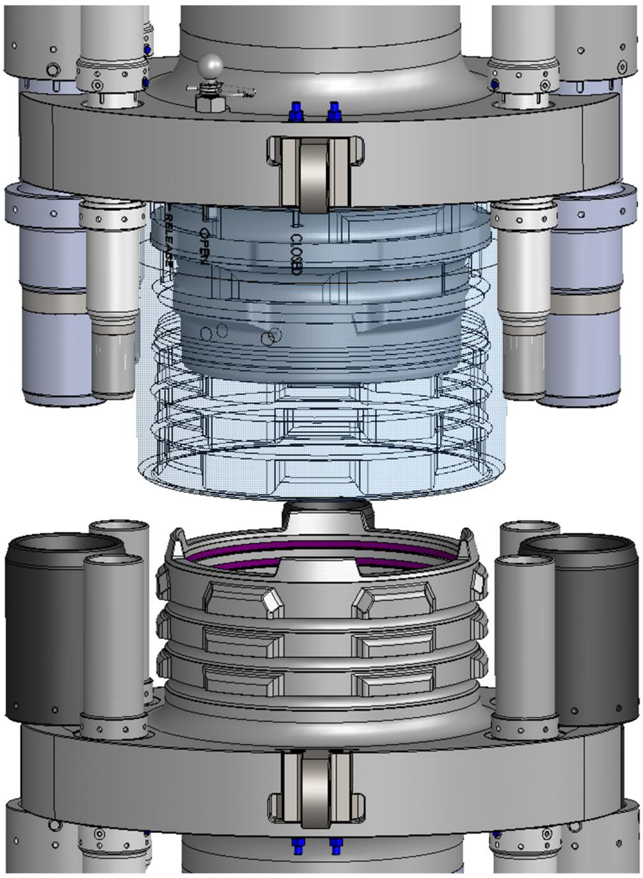



*Figure 13 - The QLR4000LS connector. The lock ring is transparent.*

## 4.3 The spider and gimbal

In the incremental process of connecting the riser joints, a spider and gimbal is used. A riser joint is lifted with a handling tool inside the opened spider, and the spider closes around the riser joint. When the spider is closed, the riser joint rests upon the spider. This is possible due to the flange on the upper part of the riser joint, which is lowered onto massive steel profiles on the spider. When the riser joint rests on the spider, a new riser joint is coupled on top of the riser joint in the spider. This is done by turning the lock ring, as mentioned above.

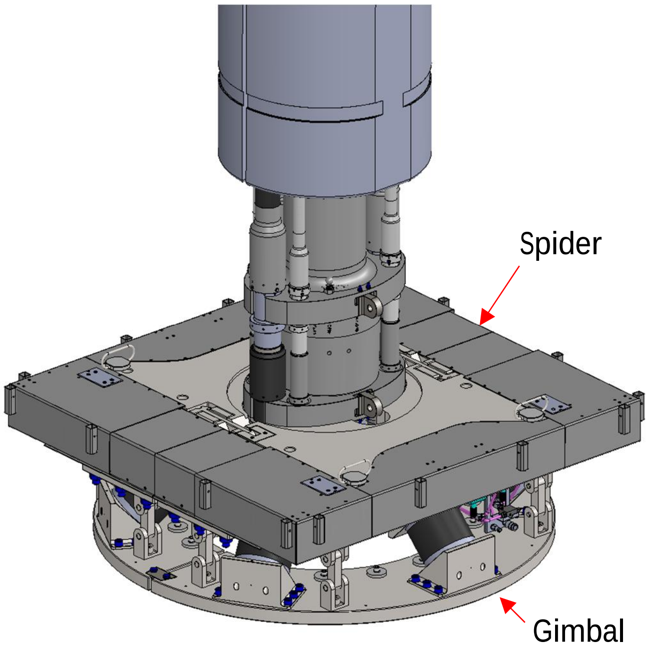



*Figure 14 - The riser joint secured in the spider and gimbal on board the rig.*

The gimbal ensures that the movements of the rig does not affect the riser string, working as a suspension.

## 4.4 The lock ring and general theory

The lock ring secures the coupling between the riser joints. To secure the coupling, the lock ring is turned 30°. When rotating the lock ring, friction needs to be dealt with. Friction occurs where the lock ring rests on a flange of the male riser joint. The force needed to overcome this friction lays the foundation of the stresses and strains of the system.

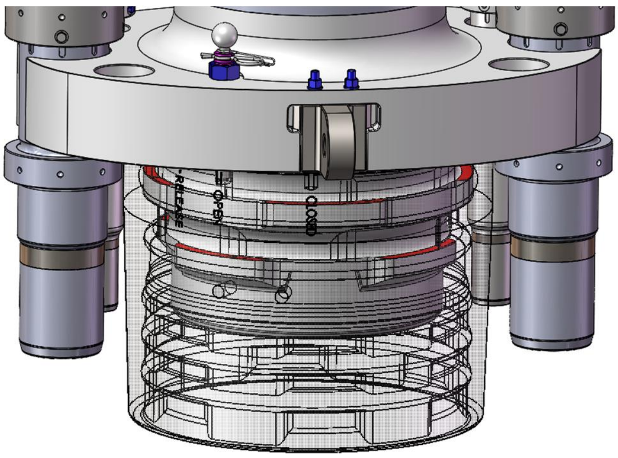


*Figure 15 - The red areas shows the contact faces between the QLR4000LS connector and the lock ring.*

### Friction force

The lock ring and male connector is coated with a molybdenum coating. This coating is effectively self-lubricant on a wide range of loads. The coefficient of friction of molybdenum against molybdenum is:

$$\mu_{static} = 0{,}19 \quad (26)$$

$$\mu_{kinetic} = 0{,}16 \quad (26)$$

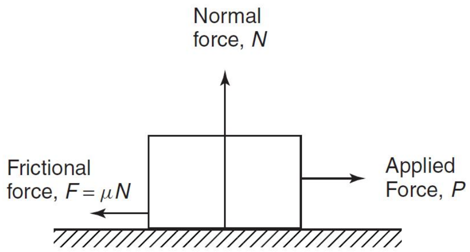



*Figure 16 – Friction force illustration* [25].

The rotation needs to deliver the following force to rotate the lock ring:

$$F_{lock\ ring} = m \cdot g = 400 \cdot 9{,}81 = 3924\ N \qquad (3.7)$$

$$F = F_f \cdot \mu = 3924\ \text{N} \cdot 0{,}19 = 745{,}56\ \text{N} \qquad (3.5)$$

This yields the following momentum requirement:

$$M_{lock\ ring} = \text{F} \cdot \text{r} = 745{,}56\ \text{N} \cdot 0{,}3577\ \text{m} = \mathbf{266{,}69\ Nm} \qquad (3.3)$$

## 4.5 Index pin and locking pin

The index pin and locking pin represent a double security. The index pin prevents the lock ring from rotating when in use, and the locking pin prevents the index pin from falling out. These pins are not designed for automation. MHWirth expect to change these when an automated system is applied. Whether or not the pins are changed, the double security is essential and needs to be preserved into the new system.

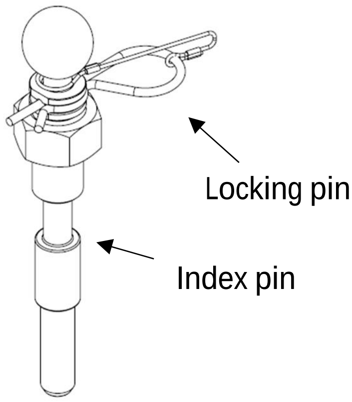



*Figure 17 – Original Index Pin Assembly.*

### Safety objective

MHWirth have experienced index pins that move due to dynamics in the riser string. Therefore, a double safety is wanted. The index pin prevents the lock ring from rotating, and the locking pin prevents the index pin from falling out. The double safety is an important part of the FMECA applied to the product.

## 4.6 Main pipe and mud column

The main pipe of the riser string is the “straw” that makes the sealed connection between the drilling vessel and the ocean floor. The drilling strings travel through the main pipe to make a closed system between the vessel and the reservoir.  Drilling, *mud* is flushed out through nozzles on the drilling bit. This mud has lower viscosity than water, hence sand, stone and residues from drilling is transported up to the vessel for analysis. Mud is a complex chemical compound that can be altered with different additives to obtain a certain set of properties.

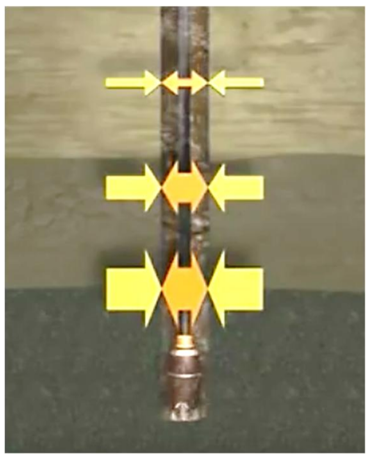


*Figure 18 – The mud column is used to prevent the well from collapsing from the surrounding segments* [21].

One of the most important properties of the mud column is to neutralize the pressure of the reservoir. If the reservoir has very high pressure, a mud compound with high density is mixed. The weight of the mud column should neutralize the pressure of the reservoir.

## 4.7 Peripheral lines

Peripheral lines surround the main pipe of the riser string. These lines have different purposes and different configurations according to the customer. The most usual configuration is two C&K-, two hydraulic- and one booster line.

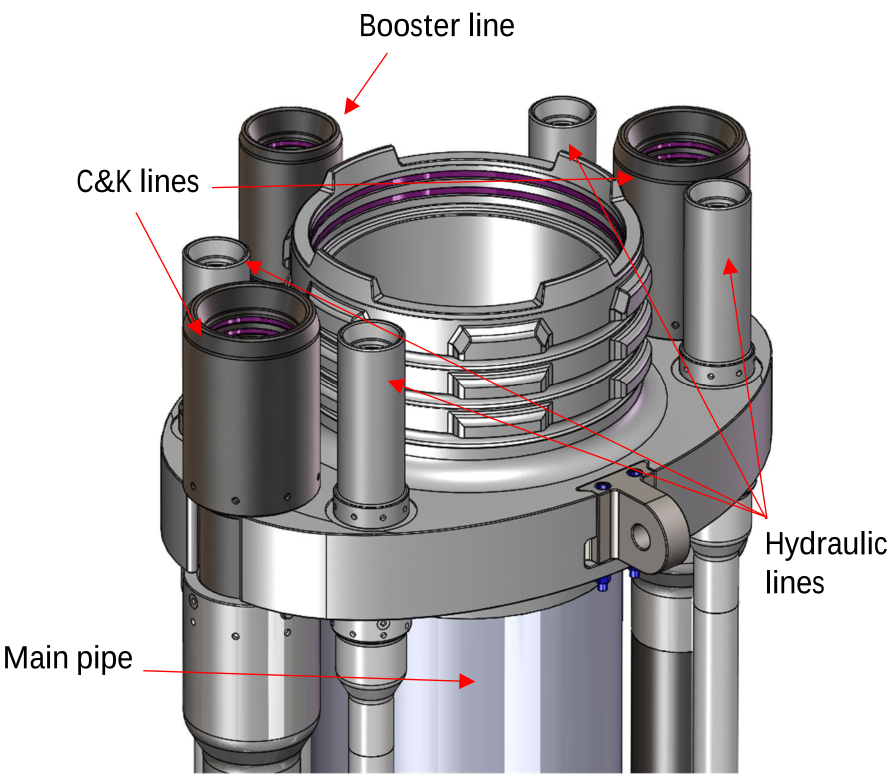



*Figure 19 – Riser joint with maximum amount of P-lines.*

### C&K lines

A riser string always has two choke and kill (C&K) lines used to control unwanted pockets of gas (called kicks) that occurs in the oil reservoir. These pockets of gas enlarge when approaching the surface as the pressure gets lower, and the gas expands. This is a normal problem in exploratory drilling, and need to be handled in a safe way.

### Booster line

To refill and boost the amount of mud in the main pipe, a booster line is needed. This line is used for filling additional mud to the mud column in the main pipe.

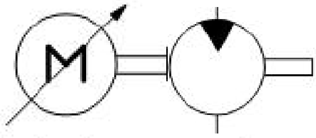
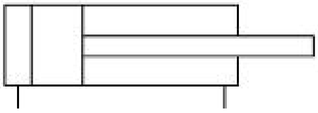
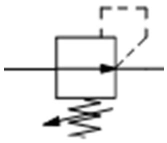
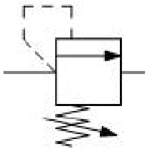
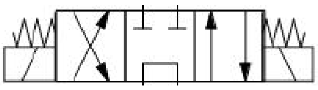
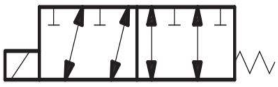
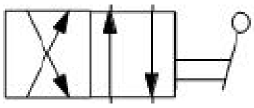
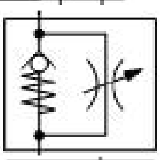
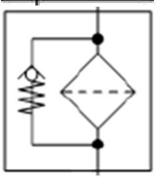
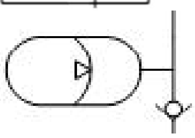
### Hydraulic line

The hydraulic line is used to control vital equipment at the ocean floor like the BOP. The BOP (Blow out preventer) is connected to the weld head at the ocean floor and is the link between the subterranean drilling and the riser string. If the oil reservoir reaches abnormal pressure values, the BOP is used to cut the link from the reservoir to the oilrig at the ocean surface. This is the most important safety mechanism used in oil industry.

## 4.8 Hydraulic system

A hydraulic system is used to control the AR. The hydraulic system used for controlling the actuators of the AR is a low pressure system operating at 30 $bar$. A hydraulic system is described with certain symbols. These are listed in the following table:

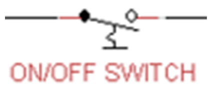
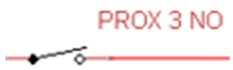
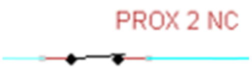
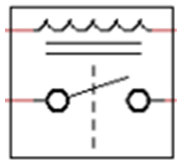
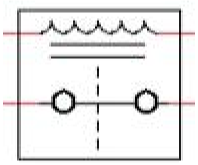
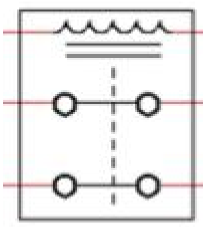
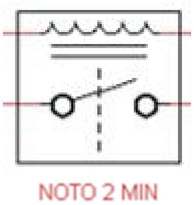
*Table 11 - Hydraulic components and symbols* [3].

| Symbol | Description |
|---|---|
|  | Hydraulic pump with regulatable electric motor<br>One-directional hydraulic pump. Supplied by electric motor. |
|  | Double working hydraulic actuator<br>An actuator using hydraulic pressure for high force motion. |
|  | Pressure reduction valve<br>Normally open valve, which closes when pressure is above set value. |
|  | Pressure relief valve<br>Opens when a certain pressure is present in the system |
|  | 4/3 Directional Control Valve (DCV)<br>A Valve with 3 different modes and 4 different hydraulic couplings. Solenoids are used to control the valve. The spring makes sure the valve is back to original position when deactivated. |
|  | 6/2 Directional Control Valve (DCV)<br>A Valve with 2 different modes and 6 different hydraulic couplings. A solenoid controls the valve. The spring presses the valve back, when the solenoid is deactivated. |
|  | 4/2 Directional Control Valve (DCV)<br>A valve with 2 different modes and 4 different hydraulic couplings. The valve is manually operated. |
|  | Flow control Valve<br>A valve that controls hydraulic flow in one direction, and lets the excess flow through the check valve when turned around. |
|  | Hydraulic filter<br>Used to filter out pollution from hydraulic fluid. If the filter gets clogged, the hydraulic fluid flows through the check valve. |
|  | Accumulator<br>Used to withstand fluid hammers from shocking the system. |

## 4.9 Electric system

An electric system is used to control the hydraulic system using sensors. The system uses low voltage and relays for controlling the solenoids of the hydraulic system. Below follows a list of electric symbols.

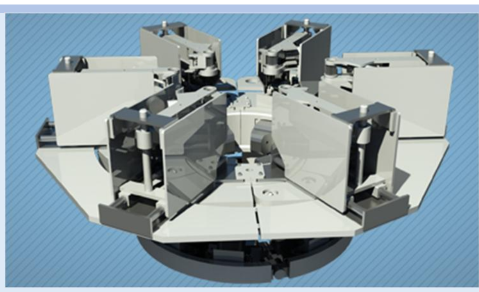
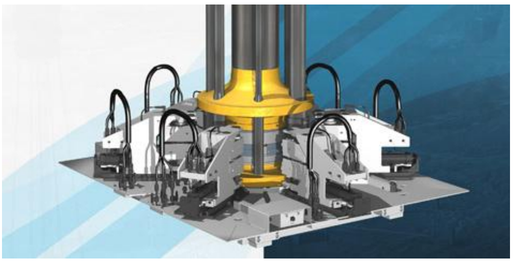
*Table 12 Electrical components and symbols* [10].

| Symbol | Description |
|---|---|
|   | ON/OFF switch<br>Is a hand-toggled switch used for turning the system on/off. |
|   | Battery<br>A battery or power supply. |
|   | Solenoid<br>A coil named SOL represents the solenoids in the hydraulic system. Circuits are powered, the solenoids are active. |
|   | Proximity sensor NO – Normally Open<br>Is a switch that closes the circuit when proximity occurs. |
|   | Proximity sensor NC – Normally Closed<br>Is a switch that opens the circuit when proximity occurs. |
|  | SPST NO – Single Pole Single Throw Normally Open Relay<br>Is a relay that closes when control circuit is powered. |
|  | SPST NC – Single Pole Single Throw Normally Closed Relay<br>Is a relay that opens when control circuit is powered. |
|  | DPST NC – Double Pole Single Throw Normally Closed Relay<br>Is a relay that opens two other circuits when control circuit is powered. |
|   | SPST NO – Single Pole Single Throw Normally Open Relay with time delay 2 min<br>Is a relay that closes when control circuit is powered. However, when control circuit is unpowered, the relay stays closed for another 2 minutes. |

## 4.10 Competitive products in the industry

A thorough analysis of the competitive products was done in the preparatory study [5]. Therefore, this chapter mostly sums up earlier findings.

*Table 13 - Competitive products for coupling risers.*

| Competitive products | Illustrations |
|---|---|
| Schlumberger – Robo Spider<br><br>Automated solution for bolted risers. Six drills mounted on spider working simultaneously. | <br>*Figure 20 –Robo Spider* [5]. |
| Dril Quip – HFRe (Hands Free Riser system)<br><br>The other automated solution for bolted risers on the market. Six drills mounted on spider working simultaneously is present here, just as the first competitive. | <br>*Figure 21 – HFRe* [5]. |

The following table sums up the advantages and disadvantages of the Robo spider and HFRe compared to the automated rotator.

*Table 14 - Pros and cons for the two solutions mentions above.*

| Competitors advantages | Competitors disadvantages |
|---|---|
| Has been tested | High complexity |
| - | High energy demand |
| - | High weight |
| - | Large solutions |
| - | Slow operational pace |

As the above table shows, the automated lock ring concept scores high compared to its competitors. This is mostly because of a lightweight potential, lower price and a smaller energy requirement. Hence, the marketing potential is large.

# 5 Product specification

This chapter sums up project objectives, and which properties of the product that are the most important.

## 5.1 Product objectives

The product objectives comprehend the different aspects of the concept. A general form of the product objective is:

| |
|---|
| The product objective is to make a concept that grips and rotates the lock ring within 6 seconds and opens and closes both the index pin and the locking pin. The concept needs to verify the safety of the coupling, and handle differences in placement of the riser. The concept should have low weight, small size, low complexity, be cheap to build, have small demand of maintenance, be made according to HSSE and set a small ecological footprint. |

The general form of the product objective could be divided into main objectives, which are objectives relevant for the function of the concept, and property objectives, which are measurable objectives, but not important for the functionality of the system.

Both main objectives and property objectives are used for rating in the screening test (Pugh´s method) in chapter 7.

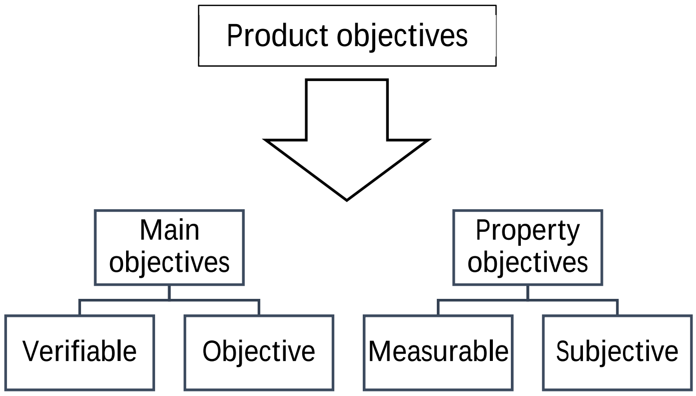



*Figure 22 - The relation between main and property objectives.*

*Table 15 – Main objectives.*

| | Main objectives |
|---|---|
| *M1* | Grip of lock ring |
| *M2* | Rotate lock ring within 6 seconds |
| *M3* | Open and close locking pin |
| *M4* | Lift and close index pin |
| *M5* | Verify coupling |
| *M6* | Handle delivery variance |

*Table 16 – Property properties.*

| | Property objectives |
|---|---|
| *P1* | Low weight |
| *P2* | Small size |
| *P3* | Low complexity |
| *P4* | Cheap prototyping and production |
| *P5* | Low maintenance |
| *P6* | Health, security, safety and environment |
| *P7* | Ecological footprint |

The achievement regarding main and property objectives are evaluated in the conclusion. However, to validate the obtained objectives a prototype is needed. As stated in chapter 2.3. “limitations and constraints”, this will not be done due to time limitation. Therefore, most objectives will not be validated.

## 5.2 Metric specifications and limits

### 5.2.1 Available area

In the process of automating the connector, a landing frame has been made, independently from this thesis. This landing frame is assembled on the spider floor and occupies a lot of space. However, it has been designed with a hollow standing, making it possible for the automated rotator to use the hollow space in the standing.

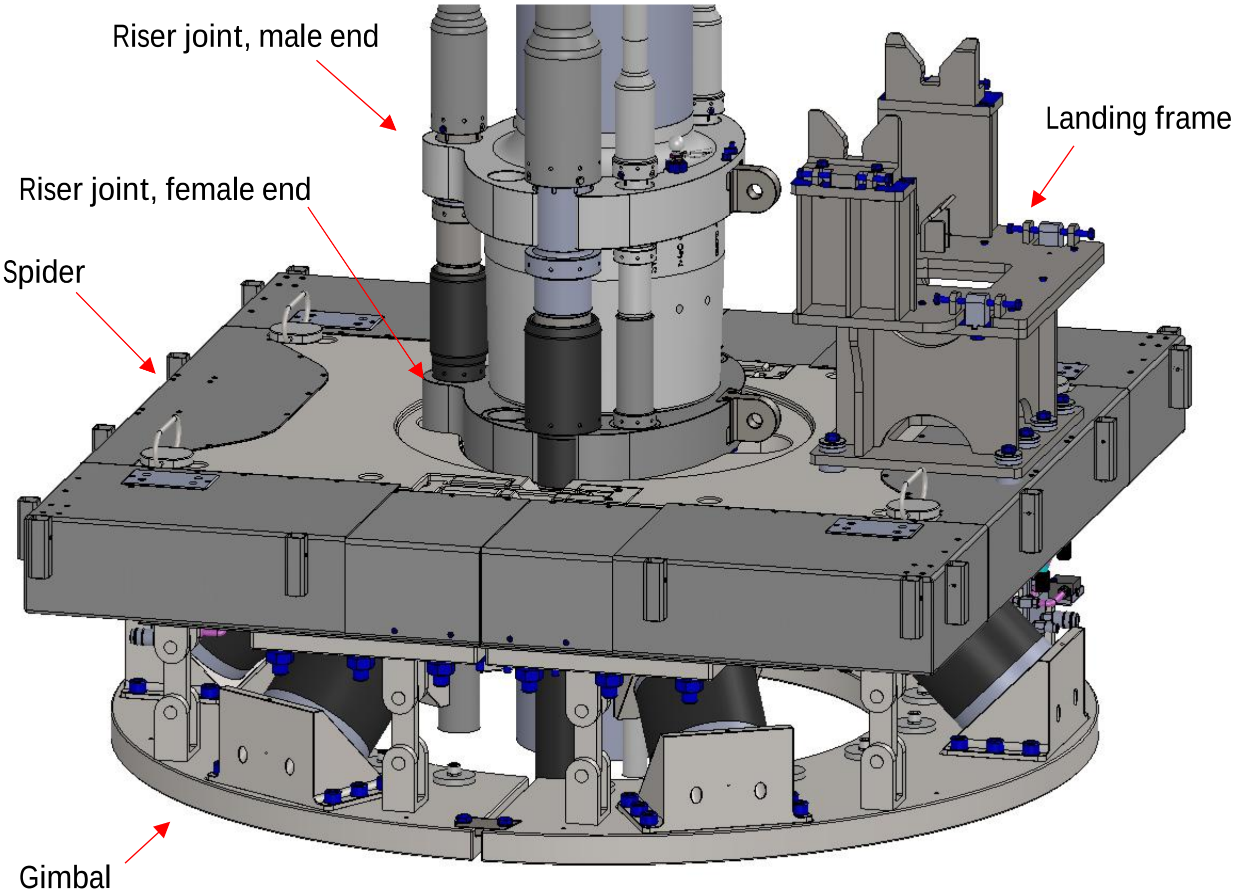



*Figure 23 – Spider and gimbal without Automated Rotator.*

### 5.2.2 Pressure and voltage specification

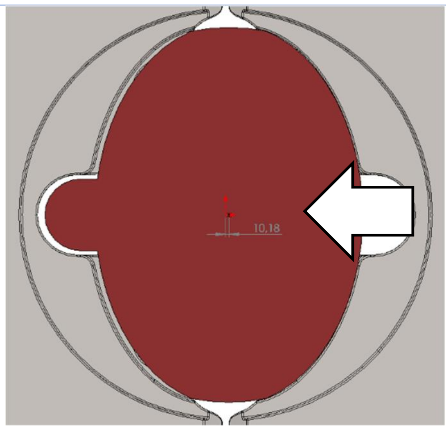
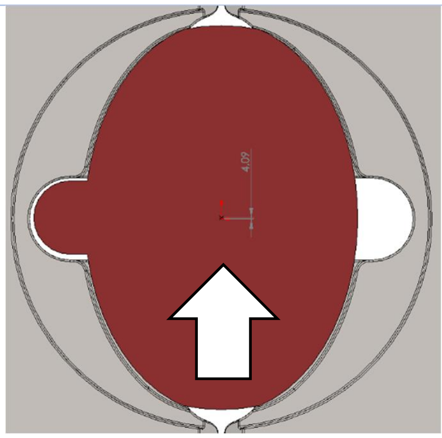
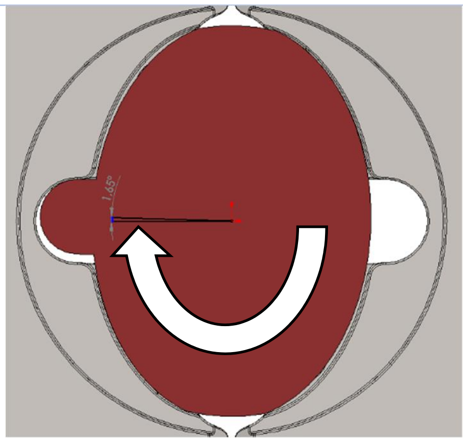
The hydraulic system is a low-pressure system. The maximum pressure in the system is 30 bars.

The electrical system is a low voltage system operating at 24 V.

### 5.2.3 Misplacement and variance

The gap in the spider is slightly bigger than the riser joint. Therefore, a variance occurs when the riser joint is fastened in the spider. The variance is a misplacement in the x-z plane, as well as rotation around the y-axis. The variances are presented underneath. The red field represents the silhouette of the riser joint.

*Table 17 - Delivery variance of the riser joint in the spider.*

| *Variance* | Illustration |
|---:|---|
| *Z-axis*<br>*When the riser is misplaced along the Z-axis, the variance is:*<br>$\pm 10{,}18\ mm$ |   |
| *X-axis*<br>*When the riser is misplaced along the X-axis, the variance is:*<br>$\pm 4{,}09\ mm$ |  |
| *Rotation*<br>*When the riser is rotated around the Y-axis, the maximum misplacement rotation of the riser joint is:*<br>$\pm 1{,}64\ °$ |  |

## Calculations regarding misplacement and variance

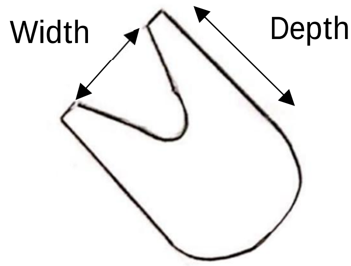



Figure 24 - Width and Depth.

The automated rotator enters the locking pin 42° from the $z - y$ plane due to geometrical conditions. This yields the following variances that the system needs to handle:

Z-axis:

$Variance = \pm 10{,}18\ mm$

Variance in width:

$$opposite = hypotenuse \cdot sin\alpha$$
$$= \pm 10{,}18 \cdot sin42° = \pm 6{,}81\ mm$$

Variance in depth:

$$adjacent = hypotenuse \cdot cos\alpha$$
$$= \pm 10{,}18 \cdot cos42° = \pm 7{,}56\ mm$$

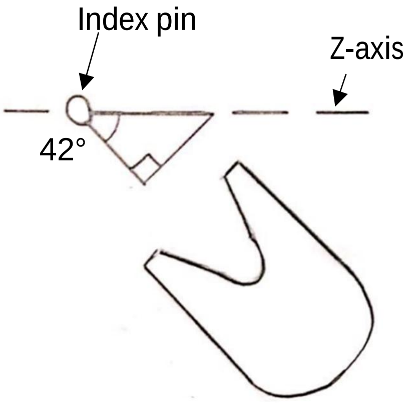



Figure 25 - Z-axis.

X-axis:

$Variance = \pm 4{,}09\ mm$

Variance in width:

$$adjacent = hypotenuse \cdot cos\alpha$$
$$= \pm 4{,}09 \cdot cos42° = \pm 3{,}03\ mm$$

Variance in depth:

$$opposite = hypotenuse \cdot sin\alpha$$
$$= \pm 4{,}09 \cdot sin42° = \pm 2{,}74\ mm$$

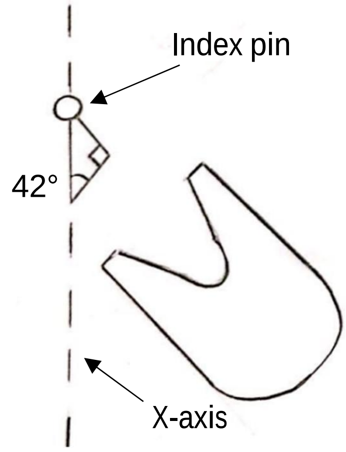



Figure 26 - X-axis.

Rotation about Y-axis:

Degrees: 36° ± 1,64° = 34,36° $and$ 37,64°

Distance from center axis to index pin: 343 $mm$
Distance from $z - y$ plane to index pin: 201,6 $mm$
Distance from $x - y$ plane to index pin: 277,5 $mm$

Minimum value: 34,36°:
X-axis: $201{,}6 - (343 \cdot \sin 34{,}36°) = 8{,}01\ mm$
Z-axis: $(343 \cdot \cos 34{,}36°) - 277{,}5 = 5{,}65\ mm$
Maximum value: 37,64°:
X-axis: $(343 \cdot \sin 37{,}64°) - 201{,}6 = 7{,}87\ mm$
Z-axis: $277{,}5 - (343 \cdot \cos 37{,}64°) = 5{,}89\ mm$

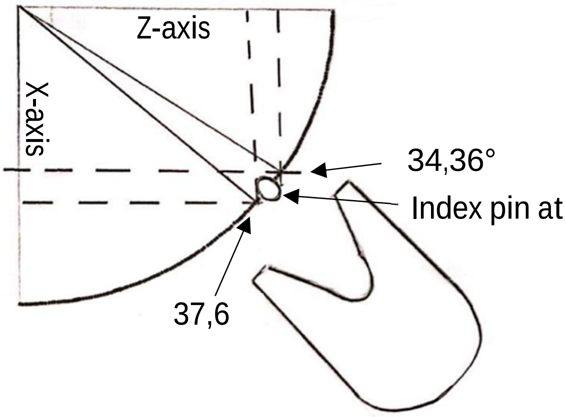



Figure 27 – Rotational variance illustration.

X-axis: from rotation (only extremal values):

$Variance = \pm 8{,}01\ mm$

Variance in width: $adjacent = hypotenuse \cdot cos\alpha = \pm 8{,}01 \cdot sin42° = \pm 5{,}36\ mm$

Variance in depth: $opposite = hypotenuse \cdot sin\alpha = \pm 8{,}01 \cdot cos42° = \pm 5{,}95\ mm$

Z-axis: from rotation (only extremal values):

$Variance = \pm 5{,}89\ mm$

Variance in width: $adjacent = hypotenuse \cdot cos\alpha = \pm 5{,}89 \cdot cos42° = \pm 4{,}38\ mm$

Variance in depth: $opposite = hypotenuse \cdot sin\alpha = \pm 5{,}89 \cdot sin42° = \pm 3{,}94\ mm$

Combined Variance:

Worst-case scenario is when all variance occurs at the same time. This yields the following combined width and depth:

Width: $\pm 6{,}81 \pm 3{,}03 \pm 5{,}36 \pm 4{,}38 = \pm 19{,}56\ mm$

Depth: $\pm 7{,}56 \pm 2{,}74 \pm 5{,}95 \pm 3{,}94 = \pm 20{,}19\ mm$

## 5.3 Path of motion

This chapter shows the location of the prats relevant for the coupling process. These are the references of the system when developing concepts.

### Sequential motions and relations

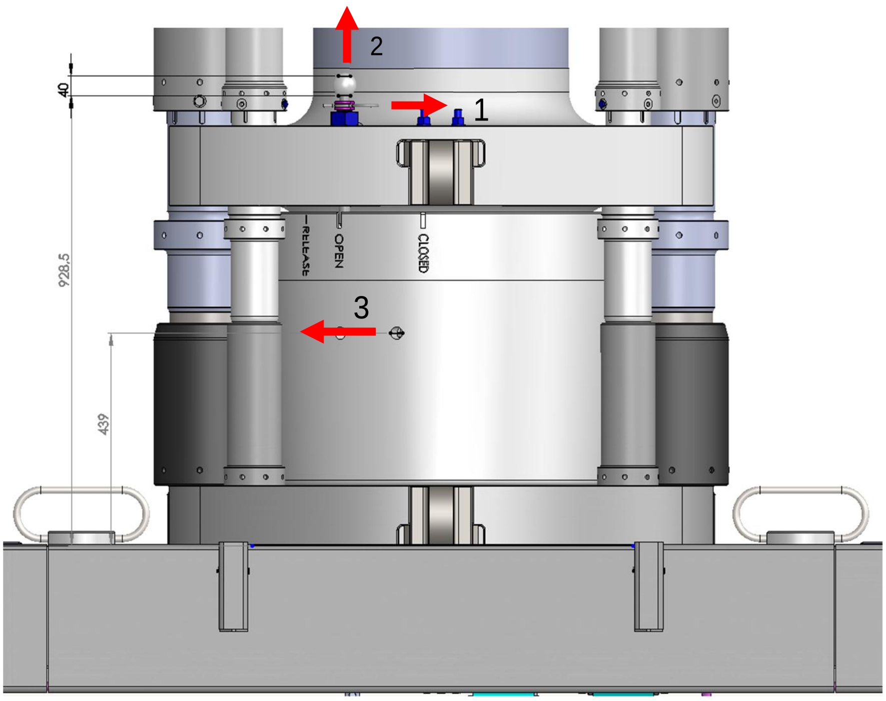



*Figure 28 – Motions and relations in the lock ring turn process.*

Sequential motions:

1. Pull out the locking pin: 50 $mm$
2. Lift the index pin: 40 $mm$
3. Rotate the lock ring: 30°

The concept needs to pull out the locking pin and to lift the index pin. The index pin is 928,5 $mm$ above spider floor level. The index pin needs to be lifted 40 $mm$ to get clear of the lock ring. The hole for rotation of lock ring is 439 $mm$ above spider floor level.

## Radial relations

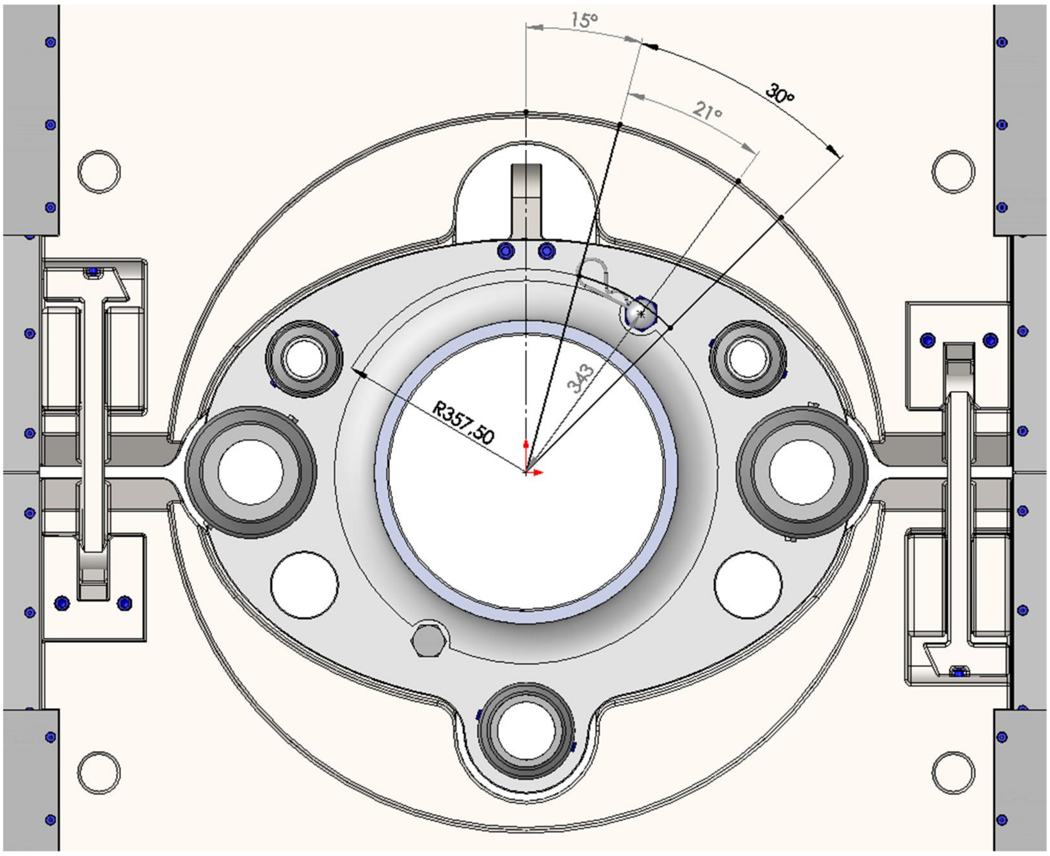



*Figure 29 - Radial relations between the lock ring and index pin.*

Sequential motions

1. Pulling out the locking pin and lifting the index pin
2. Rotate the lock ring 30°.

Index pin is located in the radius 343 mm from the centric axis. The index pin is located 36° from the vertical axis.

The rotation cavity of the lock ring is located in the radius 357,50 $mm$ from the centric axis. The lock ring is in open position when 15° from the vertical axis, and in the closed position when moved to 45°.

# 6 Concept generation

To generate concepts, the functions of the system are separated and worked with individually. Eventually, the concepts for each function is combined into a solution.

## 6.1 Function analysis

The function analysis is a tool to survey all the functions the concept needs to handle. The function analysis is the basis for the generation of concept. The functions are split into process functions, which are directly affected by the process, and independent functions.

### Process functions

The system has a distinct process characteristic with six subsequent functions:

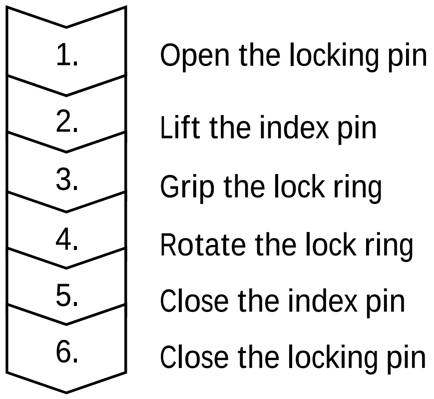



*Figure 30 - Process chart.*

Function 1 and 6, and 2 and 5 are the same functions, but in opposite order. This yields four process dependent functions:

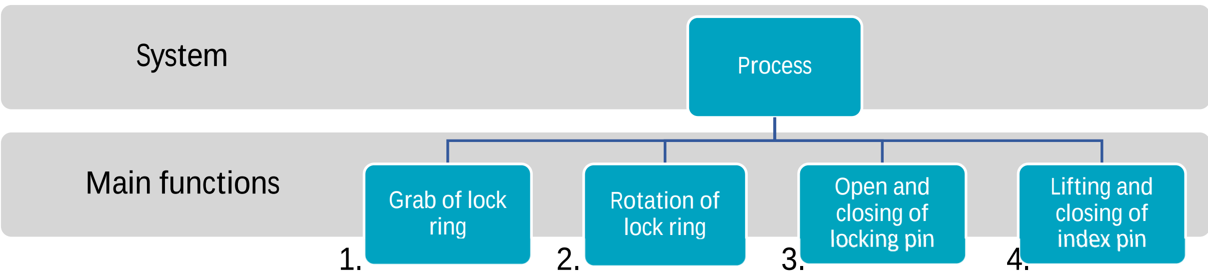



*Figure 31 - Process functions.*

### Independent functions

The system has two additional functions, which are independent of the process characteristic.

1. A system needs to verify that the coupling is secure
2. A system needs to tolerate a certain degree of delivery variance

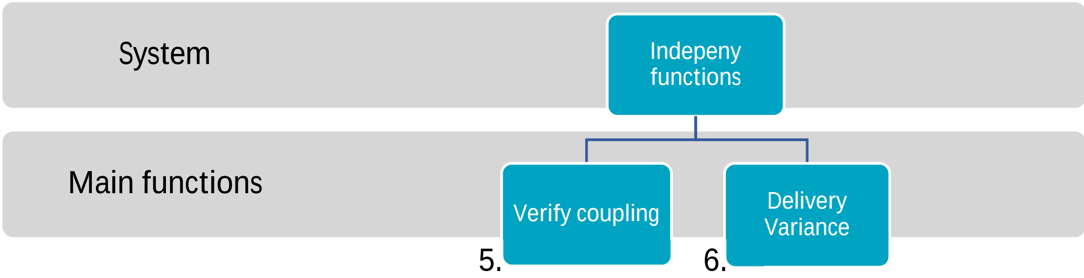



*Figure 32 – Independent functions.*

### Combined function analysis

This yields the following combined function analysis:

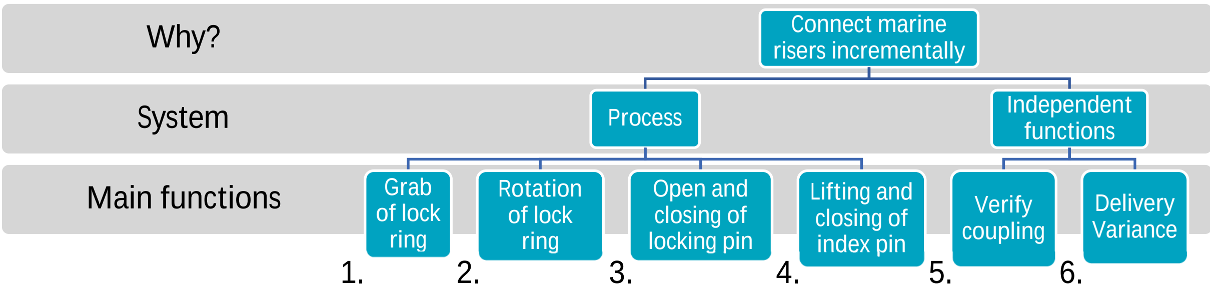



*Figure 33 – Combined Function Analysis.*

## 6.2 Function alternatives with drawings

The next chapter shows different concepts for each function. For each function, a set of concepts are generated. These are screened in chapter 7. There are six functions with different concepts that are screened.

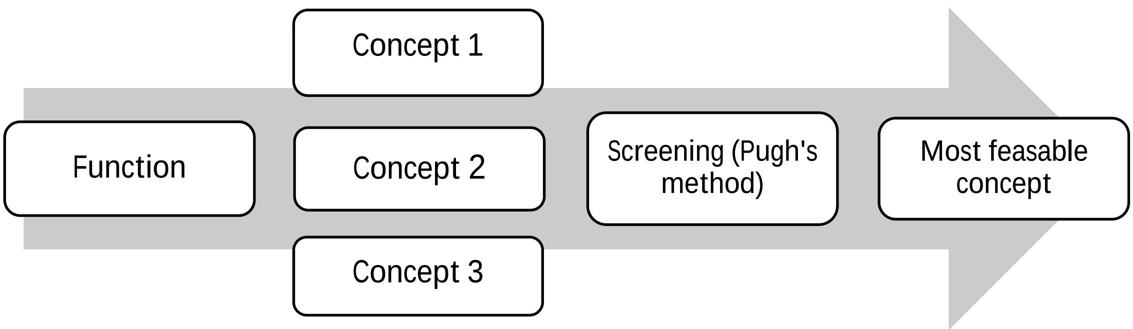



*Figure 34 - Function analysis process flow.*

### 6.2.1 Function 1: Grab of lock ring

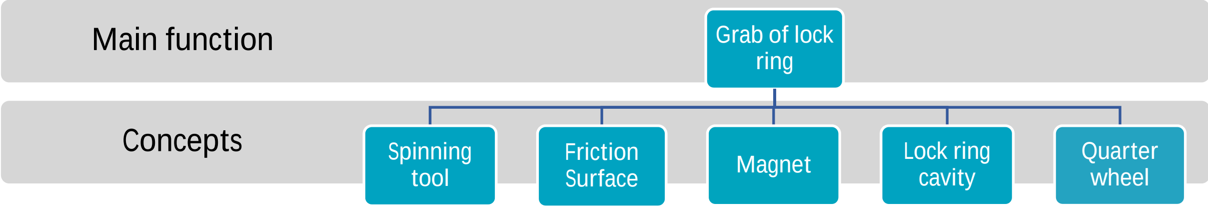



*Figure 35 – Function 1.*

The ability to grip the the lock ring is important. The lock ring is coated with a sink epoxy layer according to NORSOK M-501, and has the corresponding friction coefficient.

*Table 18 - Concepts for function 1.*

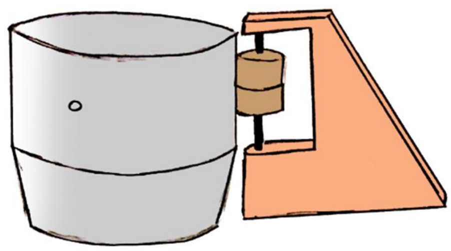
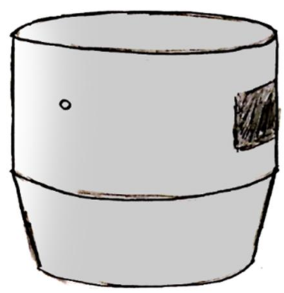
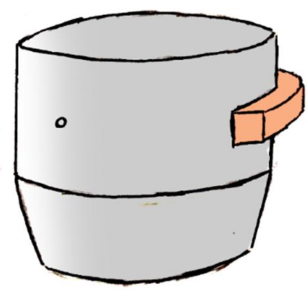
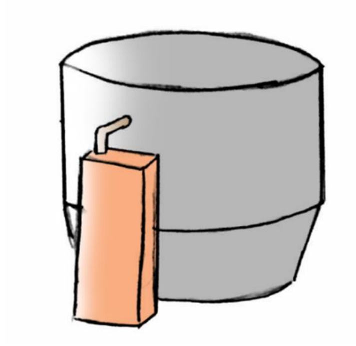
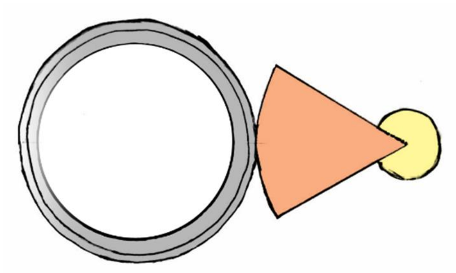
| Description | Illustration |
|---|---|
| Spinning tool. |  |
| Tires are pressed against the lock ring and rotated. | |
| Characteristics: | |
| + Easy to combine with rotation.<br>+ Space efficient.<br><br>- Needs force for obtaining friction. | |
| Friction surface. |  |
| A surface is used to obtain frictional contact. | |
| Characteristics: | |
| + Simple concept.<br><br>- Needs force for obtaining friction. | |
| Magnet. |  |
| A magnetic connection uses a magnetic field to connect to lock ring. | |
| Characteristics: | |
| + No force needed.<br><br>- Possible to magnetize unwanted parts.<br>- Electronic demand. | |

*Table 18 continues.*

| Description | Illustration |
|---|---|
| Lock Ring Cavity. |  |
| Uses the hole in the lock ring, used for manual turning. | |
| Characteristics: | |
| + Gives a good grip for rotation.<br>+ Use of existing cavity.<br><br>- Hard when introduced to misplacement (chapter 5.2.3.). | |
| Quarter wheel. |  |
| A quarter wheel with a large radius is pushed against the lock ring and rotated. | |
| Characteristics: | |
| + Few parts to assemble.<br><br>- Not space efficient.<br>- Demands high torque.<br>- Needs force for obtaining friction. | |

### 6.2.2 Function 2: Rotation of lock ring

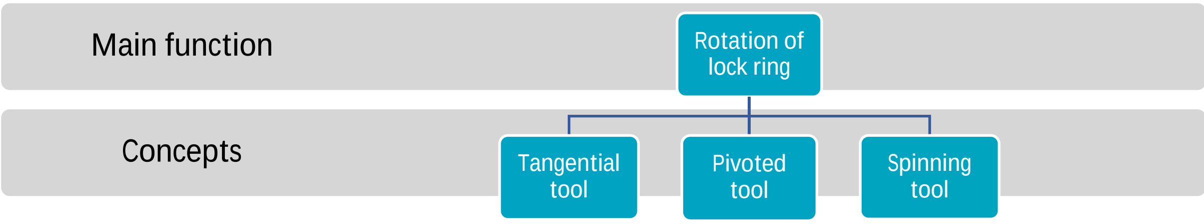



*Figure 36 – Function 2.*

The lock ring needs to be rotated to lock the coupling. To rotate the lock ring, the force used needs to overcome the friction of the lock ring. The lock ring weights approximately 400 kg.

*Table 19 - Concepts for function 2.*

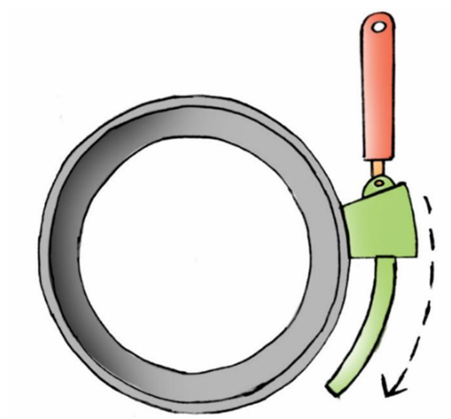
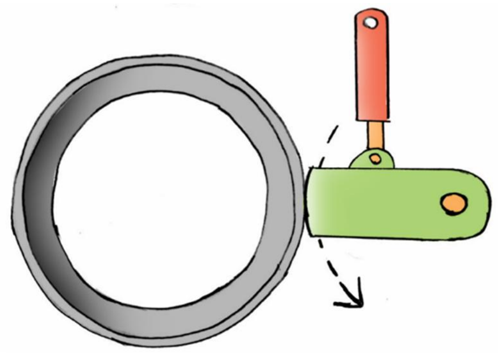
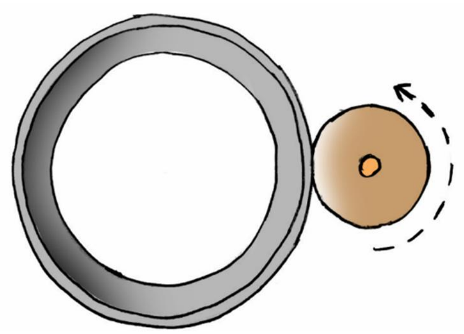
| Description | Illustration |
|---|---|
| Tangential tool. |  |
| The tool moves along tangent to follow path of the lock ring. | |
| Characteristics: | |
| + Natural movement according to rotation.<br><br>- Makes the concept looser.<br>- All tension needs to go through rails, hence wheels.<br>- Not space efficient. | |

*Table 19 continues.*

| Description | Illustration |
|---|---|
| **Pivoted tool.** |  |
| The tool is pivoted outside the lock ring, to rotate next to lock ring. | |
| Characteristics: | |
| + Simple design.<br><br>- Small contact area between tool and lock ring.<br>- Not space efficient. | |
| **Spinning tool.** |  |
| The tool is mounted, and the end piece is spinning for obtaining rotation. | |
| Characteristics: | |
| + Simple design.<br>+ Space efficient.<br><br>- Small contact area between tool and lock ring.<br>- Needs radial force to obtain sufficient contact. | |

### 6.2.3 Function 3: The opening and closing of locking pin

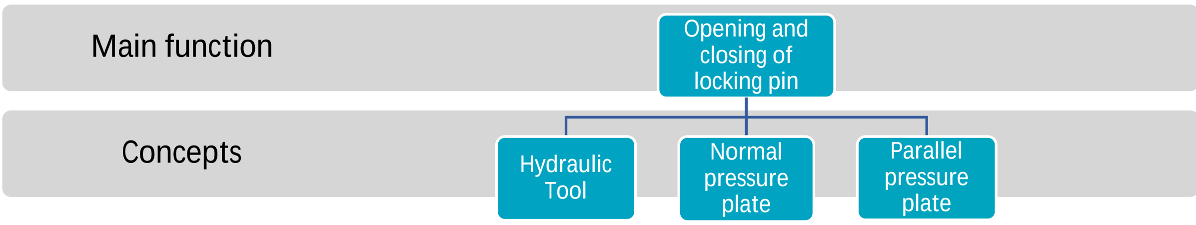



*Figure 38 – Function 3.*

The locking pin locks the index pin and needs to be removed before the index pin is lifted. The locking pin/index pin assembly needs to be changed to be compatible with the automated coupling. It is considered difficult for a machine to pull out the locking pin without any redesign.

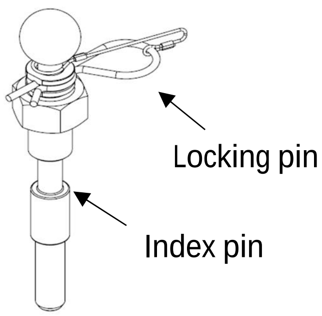
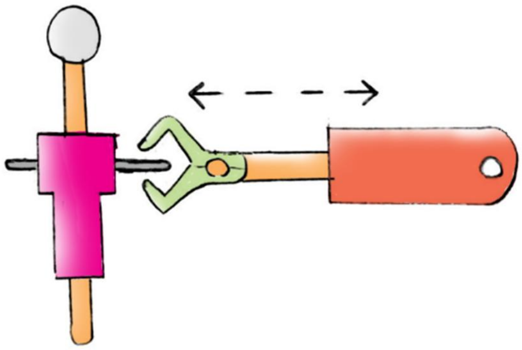
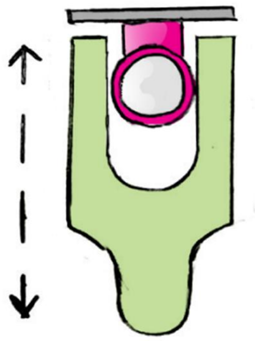
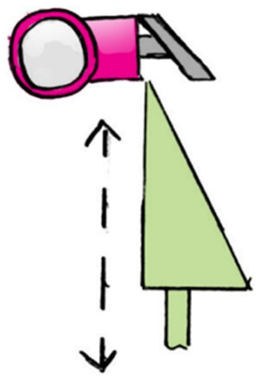



*Figure 37 - Index and locking pin.*

*Table 20 - Concepts for function 3.*

| Description | Drawing |
|---|---|
| Hydraulic tool. |  |
| Grabs the locking pin with one actuator and pulls it out with another. Puts it back the same way. | |
| Characteristics: | |
| + Powerful concept.<br><br>- Complex solution.<br>- Needs of two hydraulic actuators.<br>- Sensitive for differences in deliverance.<br>- Needs change of locking pin. | |
| Normal pressure plate. |  |
| Opens the locking pin with a pressure plate normal to the path of motion. The locking pin is assembled with spring for effective return. | |
| Characteristics: | |
| + Uses existing motion.<br>+ No external energy needed.<br><br>- Use of spring in harsh environment.<br>- Needs change of locking pin. | |
| Parallel pressure plate. |  |
| Opens the locking pin with a wedge with rollers installed. The locking pin is assembled with spring for effective return. | |
| Characteristics: | |
| + Uses existing motion.<br>+ No external energy needed.<br><br>- Use of spring in harsh environment.<br>- Possible problem to prevent it from rotating when pressed.<br>- Needs change of locking pin.<br>- Locking pin may crack. | |

### 6.2.4 Function 4: Lifting and closing of index pin

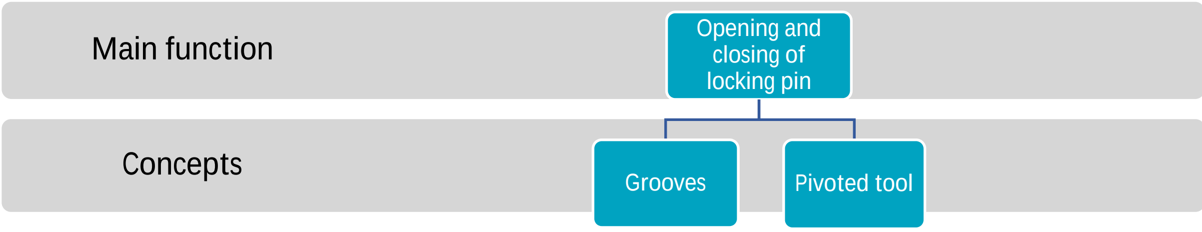
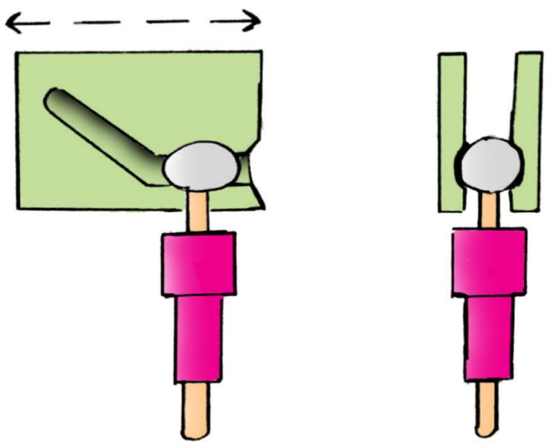
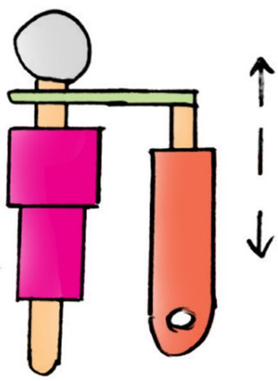



*Figure 39 – Function 4.*

To be able to rotate the lock ring, firstly the index pin needs to be lifted. Following this, it needs to be closed. This is of severe importance, as each lock ring holds the entire riser string.

*Table 21 - Concepts for function 4.*

| Description | Illustration |
|---|---|
| Grooves. |  |
| Geometrical lifting, using grooves. | |
| Characteristics: | |
| + Simple design.<br>+ Applicable for both radial and tangential motion.<br>+ Chamfer for guidance.<br>+ Possible to combine with locking.<br><br>- Erodes index pin due to sliding friction.<br>- Needs to be stiff in case index pin does not lock. | |
| Hydraulic lifting arm. |  |
| An arm is used to lift the index pin. | |
| Characteristics: | |
| + Careful handling of index pin.<br>+ Chamfer for guidance.<br>+ Compact concept.<br><br>- Needs own hydraulic cylinder.<br>- Needs spring or pressing tool for closing index pin. | |

### 6.2.5 Function 5: Verify coupling

| | | | | | |
|---|---|---|---|---|---|
| Main function | | | Grab of lock ring | | |
| Concepts | Flagging system | LVDT | PID regulator | Optical sensor | Image recognition |

*Table 22 – Function 5.*

To validate the coupling of the riser string, each coupling needs to be verified as safe. There are several methods for doing this.

*Table 23 - Concepts for function 5.*

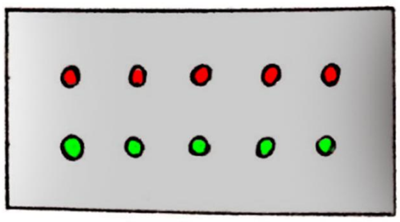
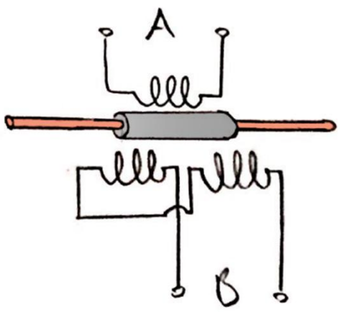
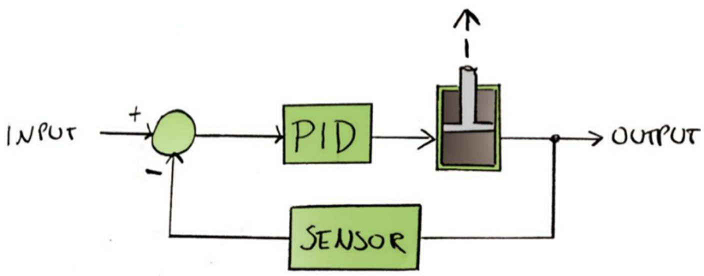
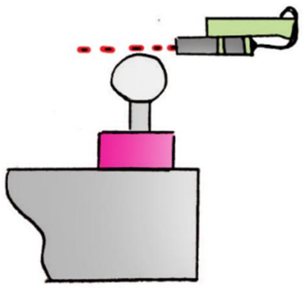
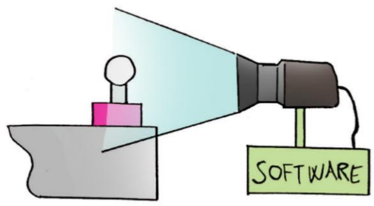
| Description | Drawing |
|---|---|
| Flagging system.<br>Binary electromagnetic sensors tell whether a part is in the right position or not, giving a red or green light.<br>Characteristics:<br>+ Binary signals.<br>+ Simple technology.<br><br>- Uses control panel.<br>- No position control. |  |
| Linear Variable Differential Transformer (LVDT)<br>Checks the index pin's position by reading electrical output.<br>Characteristics:<br>+ Gives exact position for index pin.<br><br>- Demands electrical circuit.<br>- Yields unnecessary information. |  |
| PID-regulator<br>Control all hydraulics with PID regulating.<br>Characteristics:<br>+ Well controlled system.<br><br>- Needs PLC.<br>- Use of volume flow valves.<br>- Complicated system. |  |

*Table 23 continues.*

| Description | Drawing |
|---|---|
| Optical sensor.<br>Ensures the index pin is shut with an optical sensor.<br>Characteristics:<br>+ No stress on index pin.<br>+ Light weight concept.<br><br>- Needs element for reflection.<br>- Vulnerable in muddy environment. |  |
| Image recognition.<br>Uses image recognition to tell if the index pin is closed or not.<br>Characteristics:<br>+ Could place system away from splash zone.<br><br>- Expensive technology.<br>- Vulnerable in muddy environment. |  |

### 6.2.6 Function 6: Delivery Variance

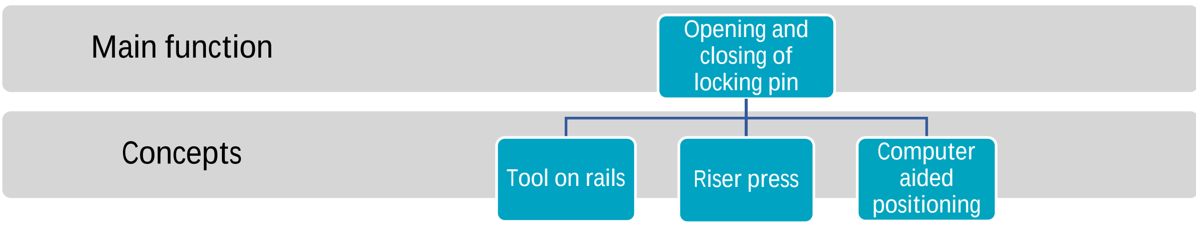



*Figure 40 – Function 6.*

The spider has a certain gap in which the riser can move. It is important to overcome this variance for the system to function properly. This problem is described in chapter 5.2.3.

*Table 24 – Concepts for function 6.*

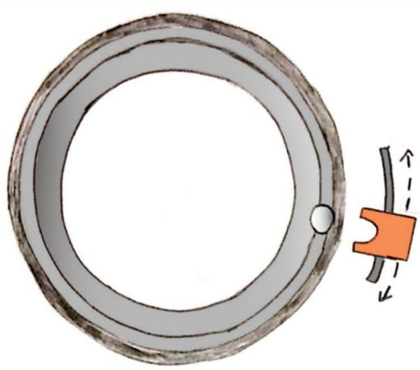
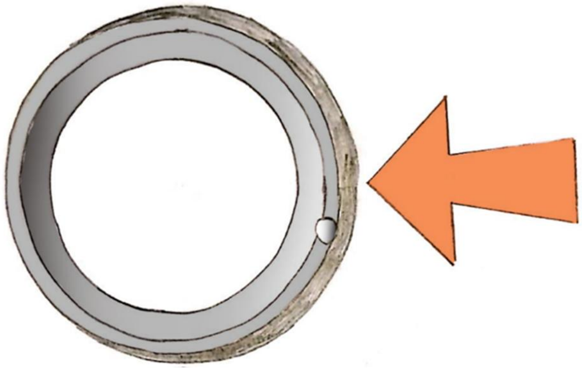
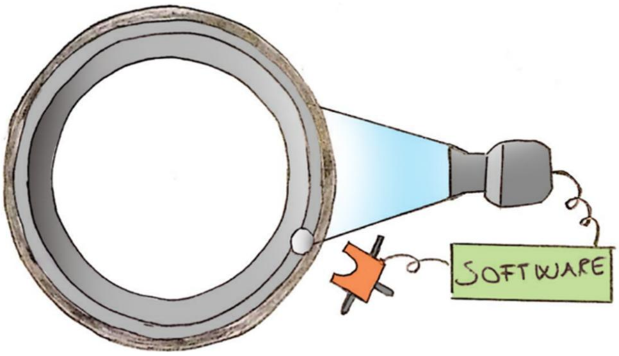
| Description | Illustration |
|---|---|
| Tool on rails.<br>The tool is mounted on rails making the tool correspond to the variance.<br><br>Characteristics:<br>+ Ideal for variance in rotation.<br><br>- Does not take tangential forces.<br>- Not ideal for variance in x-z direction. |  |

*Table 24 continues.*

| Description | Illustration |
|---|---|
| Riser Press.<br>The riser is pressed against one side of the spider opening, eliminating variance.<br><br>Characteristics:<br>+ Reduce variance.<br><br>- Large amount of force.<br>- Possible damage to the lock ring. |  |
| Computer aided positioning (CAP).<br>The tool is regulated according to the riser with computer aided positioning.<br><br>Characteristics:<br>+ Precise positioning.<br><br>- Expensive technology.<br>- Need of electrical motors.<br>- Need of PLC. |  |

# 7 Screening and choice of concept

During this chapter, concepts generated for each function are screened. The screening is done using main objectives and product properties from chapter 5.1. Using these parameters to score each concept is called Pugh's method of selection. After each concept has been rated, the most feasible concepts are brought along and build as the finished concept.

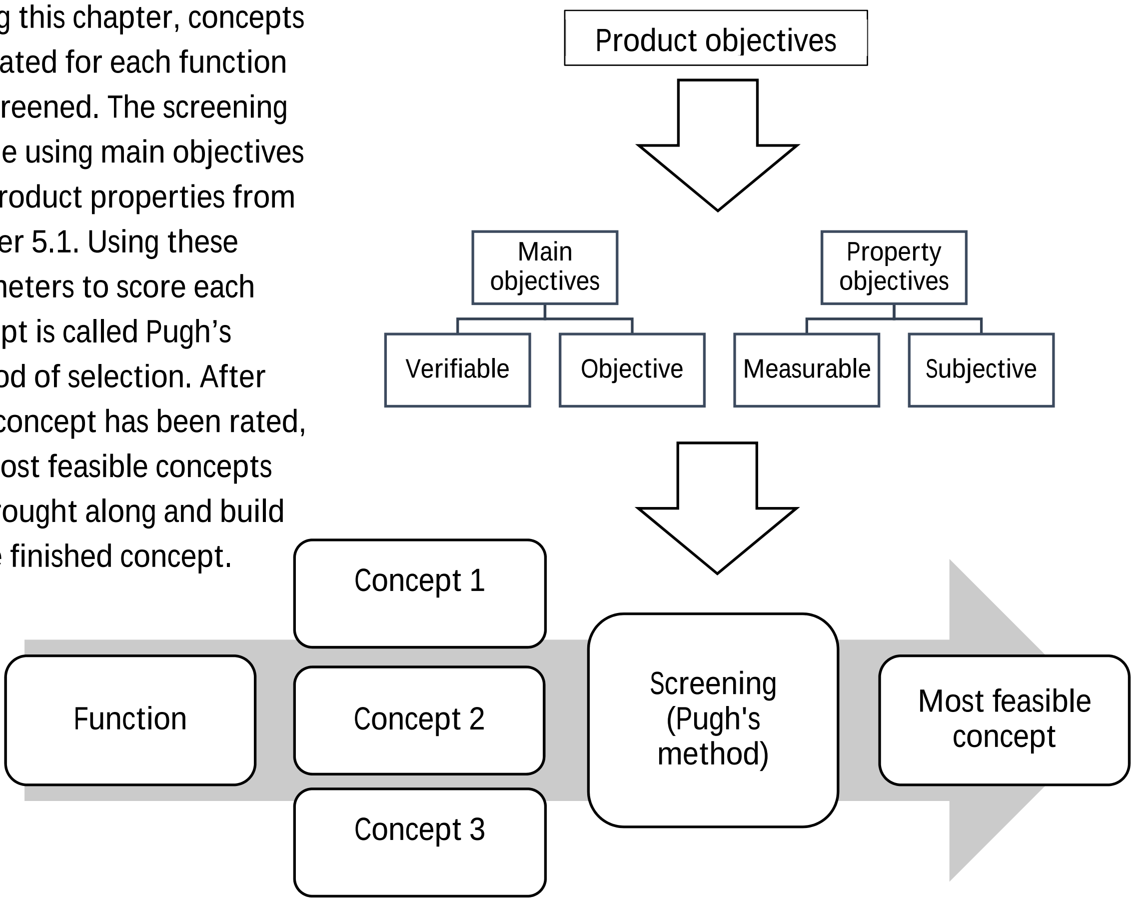



*Figure 41 - Objectives, properties and concepts are combined in a flow chart.*

## 7.1 Design of selection matrix

To be able to screen the concepts using the product objectives, the range of the objectives must be defined. The "Range"-column yields what a high score means. E.g. A high score in weight means low weight. Traceability makes the rating traceable back to chapter 5.1.

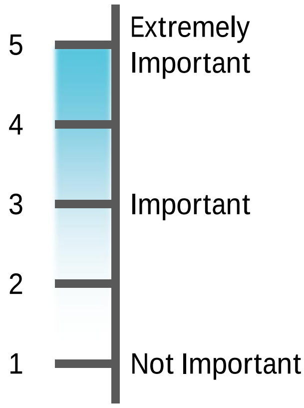



*Figure 42 – The scale parameter shows the value of the numbers used for scaling.*

*Table 25 – Product objectives with defined range values.*

| *Description* | Range | Importance | Traceability |
|---|---|---|---|
| ***Functionality*** | | | |
| *Able to grip lock ring* | High functionality | 5 | M1 |
| *Able to rotate lock ring within 6 seconds* | High functionality | 5 | M2 |
| *Able to open locking pin* | High functionality | 5 | M3 |
| *Able to lift and close index pin* | High functionality | 5 | M4 |
| *Able to verify coupling* | High safety and security | 5 | M5 |
| *Able to handle delivery variance* | High tolerance | 4 | M6 |
| ***Dimensions and complexity*** | | | |
| *Weight* | Low weight | 1 | P1 |
| *Size* | Small size | 2 | P2 |
| *Complexity* | Low complexity, few parts and small control systems | 2 | P3 |
| ***Economy*** | | | |
| *The estimated cost of the concept.* | Cheap prototyping and production | 2 | P4 |
| ***Post production*** | | | |
| *Maintenance* | Low maintenance needs | 1 | P5 |
| *HSSE (Health, security, safety and environment)* | Safe and secure construction | 1 | P6 |
| *Ecological footprint* | Low contamination, maintenance and scrapping | 2 | P7 |

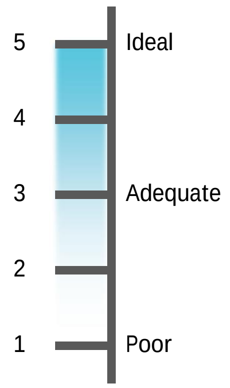



*Figure 43 – Scaling.*

## 7.2 Concept screening

All the functions are crucial; thus, functionality is given top importance for all main functions, except delivery variance. This gives an equal importance factor for most main functions. The distributed importance factor is shown in the figure to the right.

When screening the functions, a scale from 1 - 5 is used. 5 represents ideal, and 1 represents poor.

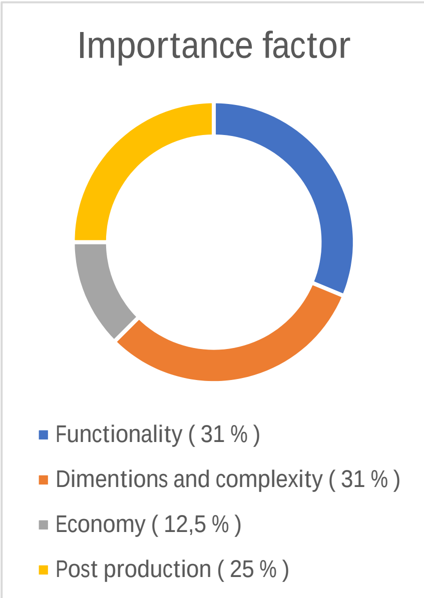



*Figure 44 - Cake diagram with importance factors shown.*

### 7.2.1 Function 1 – Grab of lock ring

*Table 26 – Screening of grab of lock ring.*

| *Categories* | Functionality | Dimensions | | | Economy | Post production | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Subcategories* | Function | Weight | Size | Comp-lexity | Cost | Main-tenance | HSSE | Ecological footprint | Sum |
| *Importance Factor:* | 0,313 | 0,063 | 0,125 | 0,188 | 0,125 | 0,063 | 0,063 | 0,125 | 1 |
| *Concept:* | | | | | | | | | |
| *Spinning Tool* | 3 | 4 | 5 | 4 | 5 | 3 | 3 | 4 | 4,06 |
| *Friction Surface* | 2 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 3,56 |
| *Magnet* | 3 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | 4,06 |
| *Lock Ring Cavity* | 5 | 5 | 3 | 3 | 3 | 4 | 3 | 4 | 4,13 |
| *Quarter Wheel* | 2 | 2 | 1 | 3 | 2 | 2 | 1 | 3 | 2,25 |

Highest score: Lock ring cavity

### 7.2.2 Function 2 – Rotation of lock ring

*Table 27 – Screening of rotation of lock ring.*

| *Categories* | Functionality | Dimensions | | | Economy | Post production | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Subcategories* | Function | Weight | Size | Comp-lexity | Cost | Main-tenance | HSSE | Ecological footprint | Sum |
| *Importance Factor:* | 0,313 | 0,063 | 0,125 | 0,188 | 0,125 | 0,063 | 0,063 | 0,125 | 1 |
| *Concept:* | | | | | | | | | |
| *Tangential Tool* | 5 | 3 | 2 | 5 | 4 | 2 | 3 | 4 | 4,25 |
| *Pivoted Tool* | 3 | 2 | 4 | 2 | 2 | 5 | 2 | 4 | 3,125 |
| *Spinning Tool* | 4 | 3 | 4 | 4 | 4 | 3 | 2 | 4 | 4 |

Highest score: Tangential Tool

### 7.2.3 Function 3 – The opening and closing of locking pin

*Table 28 - Screening of opening and closing of locking pin.*

| *Categories* | Functionality | Dimensions | | | Economy | Post production | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Subcategories* | Function | Weight | Size | Comp-lexity | Cost | Main-tenance | HSSE | Ecological footprint | Sum |
| *Importance Factor:* | 0,313 | 0,063 | 0,125 | 0,188 | 0,125 | 0,063 | 0,063 | 0,125 | 1 |
| *Concept:* | | | | | | | | | |
| *Hydraulic Tool* | 3 | 3 | 2 | 1 | 3 | 4 | 4 | 3 | 2,81 |
| *Normal Pressure Plate* | 5 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 3,63 |

*Table 28 continues.*

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Parallel Pressure Plate* | 4 | 3 | 3 | 2 | 3 | 2 | 3 | 3 | 3,25 |

Highest score: Normal pressure plate

### 7.2.4 Function 4 – Lifting and closing of index pin

*Table 29 - Screening of lifting and closing of index pin.*

| *Categories* | Functionality | Dimensions | | | Economy | Post production | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Subcategories* | Function | Weight | Size | Comp-lexity | Cost | Main-tenance | HSSE | Ecological footprint | Sum |
| *Importance Factor:* | 0,313 | 0,063 | 0,125 | 0,188 | 0,125 | 0,063 | 0,063 | 0,125 | 1 |
| *Concept:* | | | | | | | | | |
| *Grooves* | 3 | 4 | 2 | 4 | 5 | 2 | 2 | 3 | 3,44 |
| *Hydraulic Lifting Arm* | 4 | 3 | 4 | 3 | 3 | 4 | 3 | 3 | 3,5 |

Highest score: Hydraulic Lifting Arm

### 7.2.5 Function 5 – Verify coupling

*Table 30 - Screening of verify coupling.*

| *Categories* | Functionality | Dimensions | | | Economy | Post production | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Subcategories* | Function | Weight | Size | Comp-lexity | Cost | Main-tenance | HSSE | Ecological footprint | Sum |
| *Importance Factor:* | 0,313 | 0,063 | 0,125 | 0,188 | 0,125 | 0,063 | 0,063 | 0,125 | 1 |
| *Concept:* | | | | | | | | | |
| *Flagging System* | 4 | 4 | 3 | 4 | 4 | 5 | 5 | 3 | 4,13 |
| *LVDT* | 4 | 5 | 4 | 3 | 3 | 4 | 5 | 4 | 4,06 |
| *PID Regulator* | 5 | 3 | 3 | 1 | 2 | 3 | 5 | 4 | 3,56 |
| *Optical Sensor* | 2 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3,69 |
| *Image Recognition* | 5 | 4 | 1 | 1 | 1 | 2 | 5 | 3 | 3,06 |

Highest score: Flagging system

### 7.2.6 Function 6 – Delivery Variance

*Table 31 - Screening of delivery Variance.*

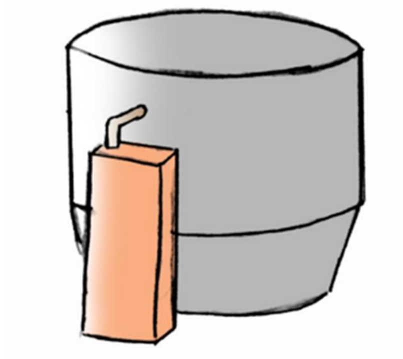
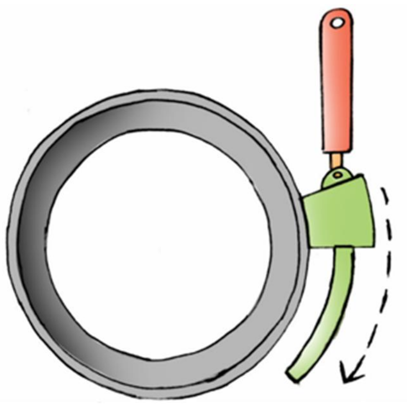
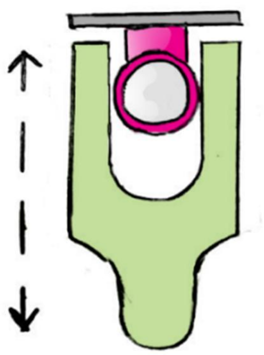
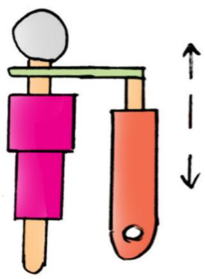
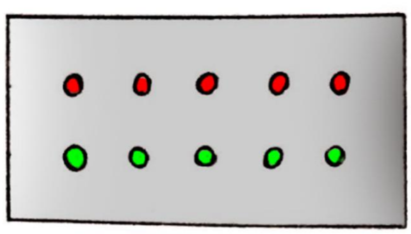
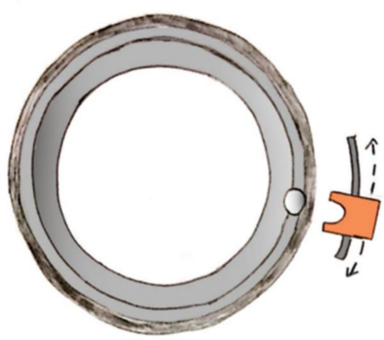
| *Categories* | Functionality | Dimensions | | | Economy | Post production | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Subcategories* | Function | Weight | Size | Comp-lexity | Cost | Main-tenance | HSSE | Ecological footprint | Sum |
| *Importance Factor:* | 0,313 | 0,063 | 0,125 | 0,188 | 0,125 | 0,063 | 0,063 | 0,125 | 1 |
| *Concept:* | | | | | | | | | |
| *Tool on Rails* | 4 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4,06 |
| *Riser Press* | 2 | 2 | 2 | 4 | 3 | 4 | 2 | 3 | 2,88 |
| *CAP* | 5 | 3 | 2 | 1 | 2 | 2 | 3 | 4 | 3,25 |

Highest score: Tool on Rails

## 7.3 Output from concept screening

The output from the concept screening have given six feasible concepts, which are to be combined into one solution. The final solution will contain:

*Table 32 - The output from the concept screening is presented.*

| | |
|---|---|
| 1. A cavity pin used to grip the lock ring:  | 2. A tangential tool used to rotate the lock ring:  |
| 3. A normal pressure plate used for opening the locking pin:  | 4. A hydraulic lifting arm used to lift the index pin:  |
| 5. A flagging system to verify if the coupling is safe:  | 6. A tool on rails to handle the delivery variance:  |

# 8 Concept design

In this chapter, the finished concept is presented with bill of materials and exploded view. Then all details of the concept are presented.

## 8.1 Automated Rotator

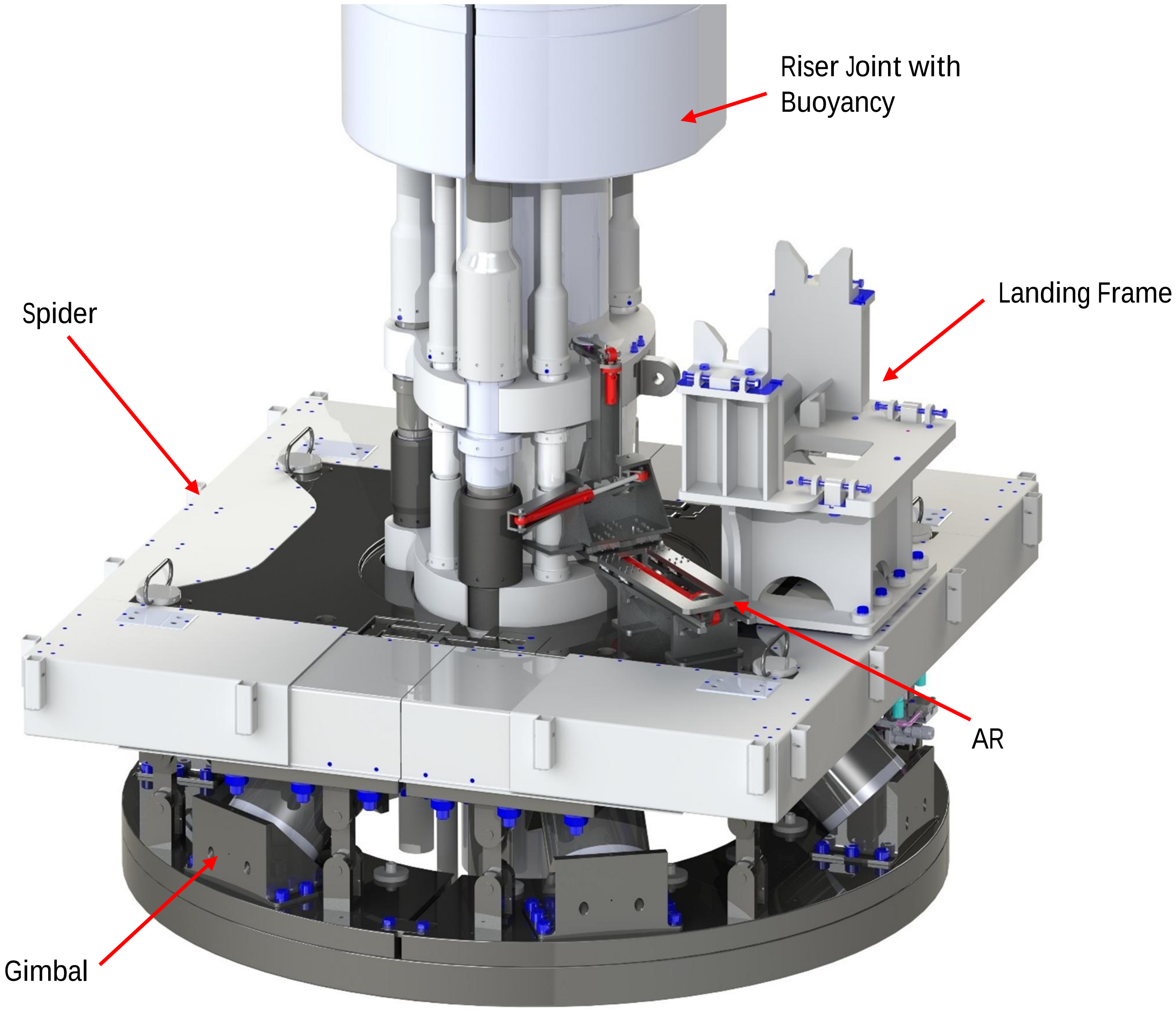



*Figure 45 - Automated Rotator Assembled on Spider alongside landing frame.*

The above picture shows the Automated Rotator (AR) mounted to the spider floor. This picture shows two riser joints about to be coupled by the activated AR. The landing frame is mounted next to the AR, limiting available space.

The pictures on the next page will show the motion when the AR is activated and deactivated.

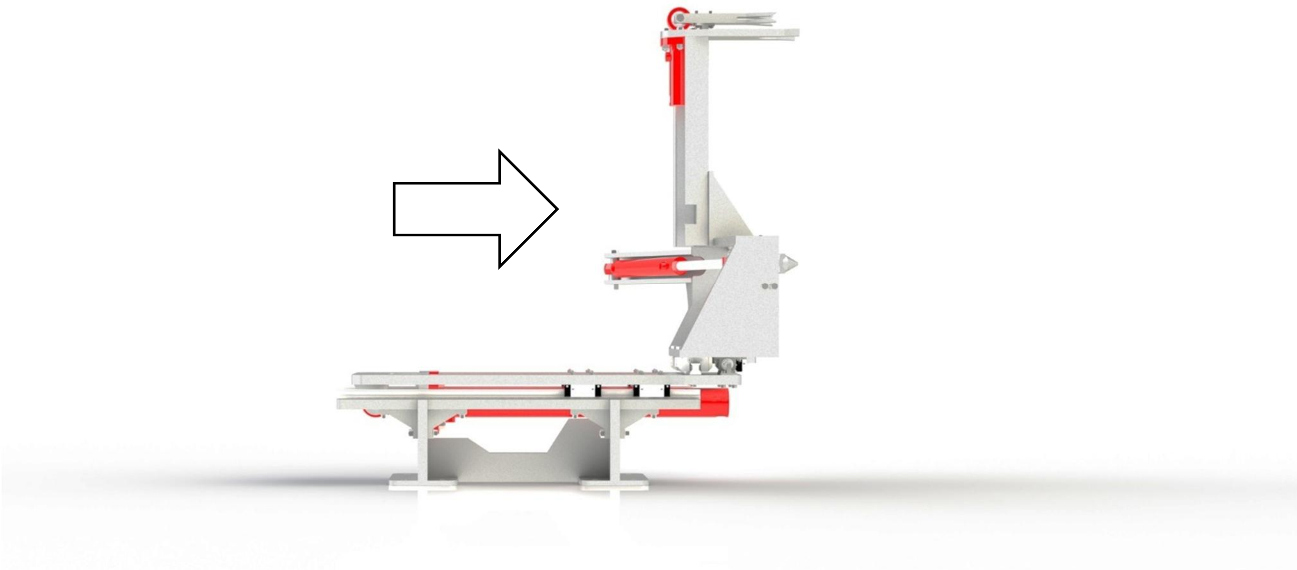


Figure 46 – Automated Rotator Activated Position.

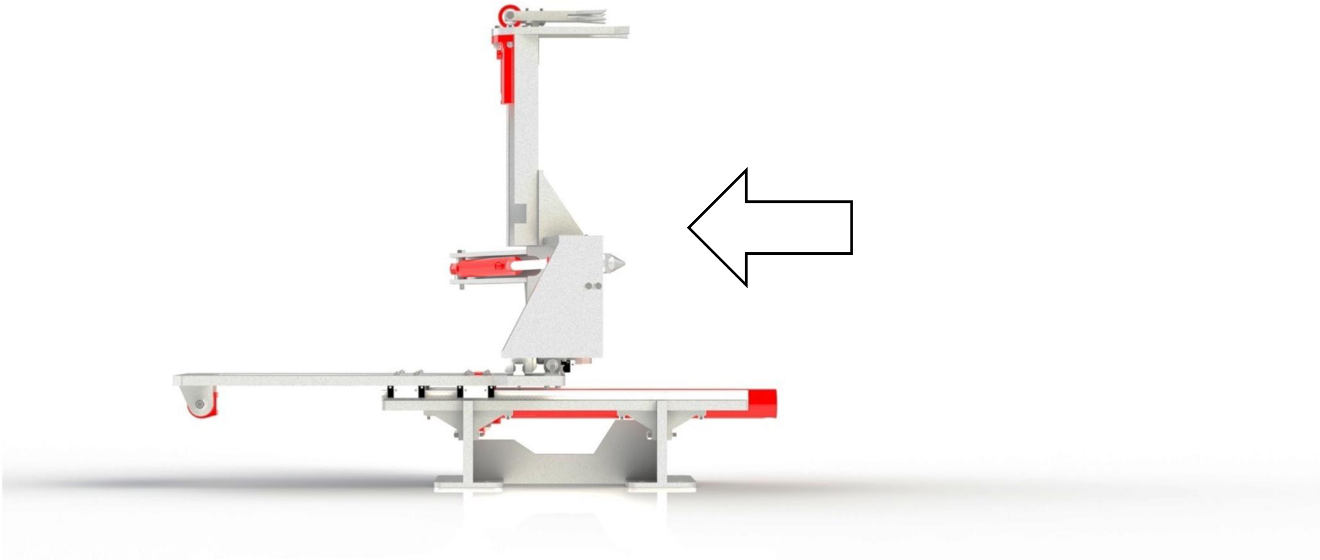


Figure 47 - Automated Rotator Deactivated Position.

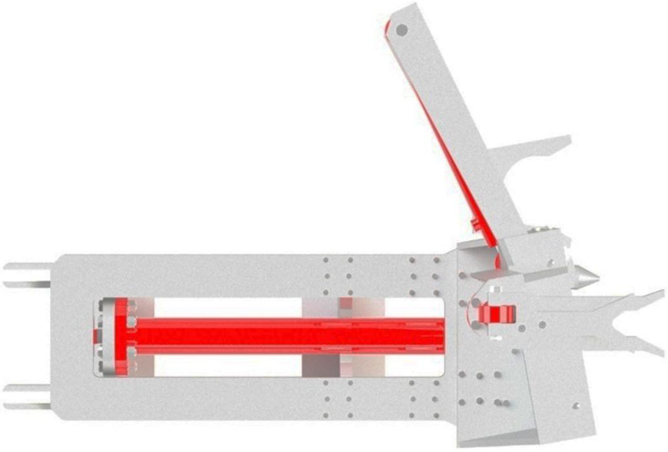


Figure 48 - Automated Rotator from Above.

*Figure 49 - Stylized pictures of Automated Rotator.*

## 8.2 Exploded views of Automated Rotator

General arrangement show the Automated Rotator with all parts numbered. All drawings are in original sizes in appendix V. The parts are listed in the Bill of Materials for the Automated Rotator. The total weight of the assembly is about 111,6 kg.

The AR is divided into three main assemblies:

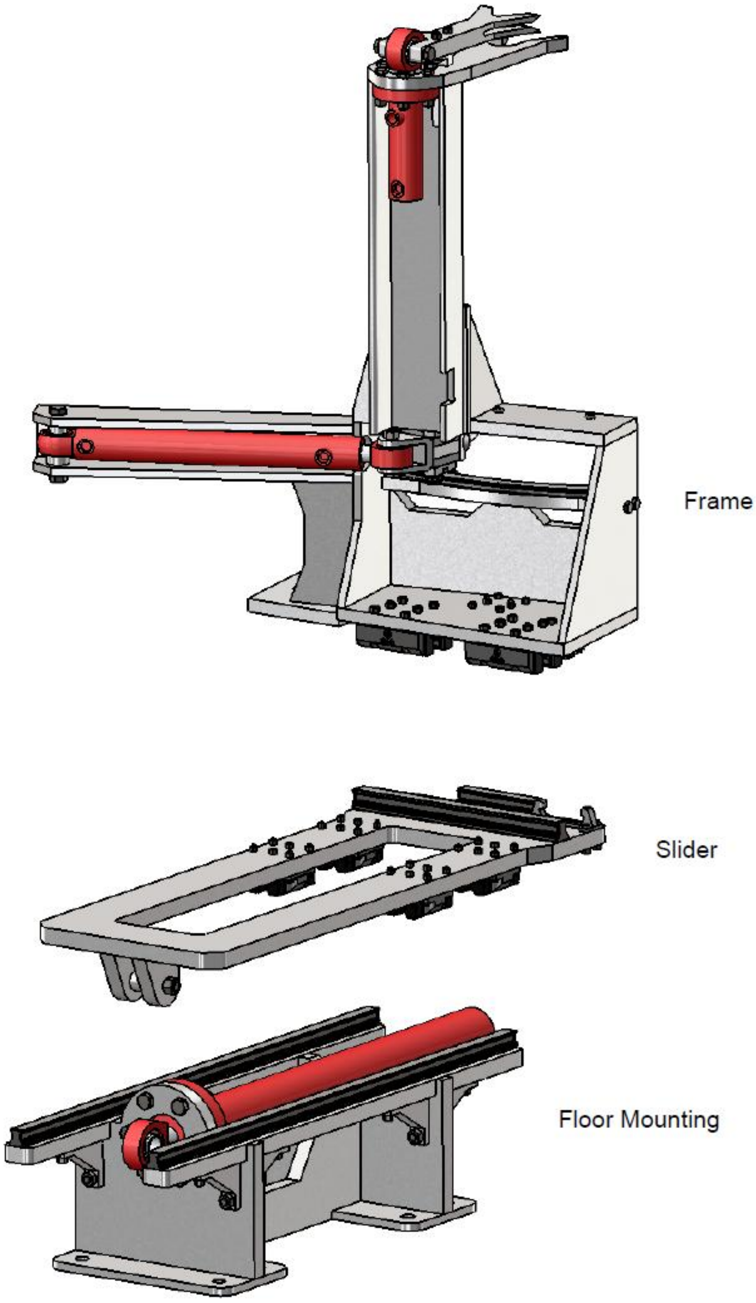



*Figure 50 - Main Assemblies.*

Frame:

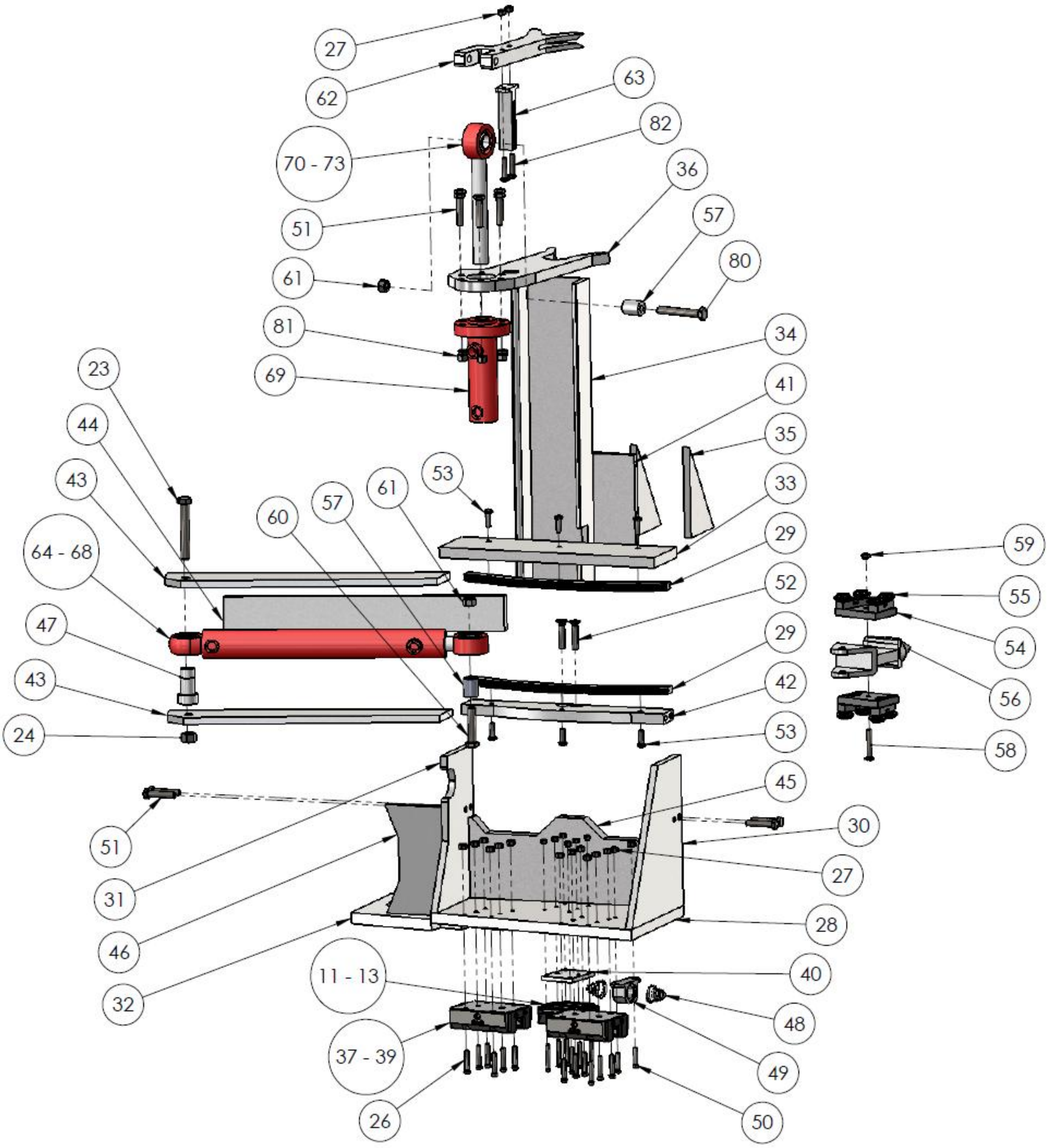



*Figure 51 - Exploded view of Frame.*

Number indication is explained in the complete BoM in appendix I. In addition, the table on the next page shows all part numbers relevant to the exploded frame. The yellow areas indicate retail parts with more than one part.

*Table 33 - Parts Relevant to the Frame – Entire table in appendix I.*

| ITEM NO. | PART NUMBER | QTY. | Production method |
|---|---|---|---|
| 11 to 13 | Linear Roller 20 mm | | RT |
| 11 | R200180131 | 1 | |
| 12 | R200180102 | 2 | |
| 13 | R343706101_Z | 4 | |
| 23 | ISO 4014 - M12 x 80 x 30-N | 2 | RT |
| 24 | Hexagon Nut ISO - 4034 - M12 - N | 8 | RT |
| 26 | ISO 14580 - #5 x 30 x 28.4 - 4.8-N | 16 | RT |
| 27 | Hexagon Nut ISO - 4034 - M6 - N | 20 | RT |
| 28 | Frame | 1 | Cut from SP |
| 29 | _GCT0141045_3_2 - Curved Rail | 2 | RT |
| 30 | Frame Bracket 1 | 1 | Cut from SP |
| 31 | Frame Bracket 2 | 1 | Cut from SP |
| 32 | Guide bracket | 1 | Cut from SP |
| 33 | Top Bracket | 1 | Cut from SP |
| 34 | Channel steel with cutaway | 1 | Milled standard part |
| 35 | Support | 2 | Cut from SP |
| 36 | Pusher bracket | 1 | Cut from SP |
| 37 - 39 | Linear Roller 23 mm | | RT |
| 37 | 1 | 2 | |
| 38 | 2 | 2 | |
| 39 | 3 | 2 | |
| 40 | Spacer | 1 | Cut from SP |
| 41 | Momentum Bracket | 1 | Cut from SP |
| 42 | Radii bracket | 1 | Cut from SP |
| 43 | Cylinder side bracket | 2 | Cut from SP |
| 44 | Cylinder back bracket | 1 | Cut from SP |
| 45 | Stiffener | 1 | Cut from SP |
| 46 | Cylinder stiffener | 1 | Cut from SP |
| 47 | hydraulic pin | 1 | Lathe |
| 48 | 6701-Lesjofors - Spring | 2 | RT |
| 49 | spring fastener | 1 | Milled |
| 50 | hexalobular socket cheese head_iso | 2 | RT |
| 51 | ISO 4014 - M8 x 40 x 22-N | 10 | RT |
| 52 | ISO 7046-1 - M8 x 40 - Z --- 40N | 2 | RT |
| 53 | ISO 7045 - M6 x 20 - Z --- 20N | 6 | RT |
| 54 | _GCT01_1_4 | 2 | RT |
| 55 | _GCT01_180_45_2_6 | 4 | RT |
| 56 | Cavity pin | 1 | CNC Machined |
| 57 | Pin | 2 | Lathe |
| 58 | ISO 7045 - M6 x 40 - Z --- 40N | 1 | RT |
| 59 | Hexagon Nut ISO - 4032 - M6 - W - N | 1 | RT |
| 60 | ISO 4014 - M10 x 50 x 26-N | 1 | RT |
| 61 | Hexagon Nut ISO - 4034 - M10 - N | 2 | RT |
| 62 | Lifting bracket | 1 | CNC Machined |
| 63 | Non momentum pin | 1 | CNC Machined |
| 64-68 | Cylinder CD25 240 | | RT |
| 64 | cylinder-CD25-32_20x240-SS-HR-SSN-NNN-servi | 1 | |
| 65 | bearing-ring-CD25-32_20x240-SS-HR-SSN-NNN-servi | 2 | |
| 66 | bearing-ball-CD25-32_20x240-SS-HR-SSN-NNN-servi | 2 | |
| 67 | rod-CD25-32_20x240-SS-HR-SSN-NNN-servi | 1 | |
| 68 | rod-end-CD25-32_20x240-SS-HR-SSN-NNN-servi | 1 | |
| 69-73 | Cylinder CD25 40 | | RT |
| 69 | cylinder-CD25-32_20x40-AS-HR-SSN-NNN-servi | 1 | |
| 70 | rod-CD25-32_20x40-AS-HR-SSN-NNN-servi | 1 | |
| 71 | rod-end-CD25-32_20x40-AS-HR-SSN-NNN-servi | 1 | |
| 72 | bearing-ring-CD25-32_20x40-AS-HR-SSN-NNN-servi | 1 | |
| 73 | bearing-ball-CD25-32_20x40-AS-HR-SSN-NNN-servi | 1 | |
| 80 | ISO 4014 - M10 x 70 x 26-N | 1 | RT |
| 81 | Hexagon Nut ISO - 4034 - M8 - N | 6 | RT |
| 82 | ISO 7045 - M6 x 30 - Z --- 30N | 2 | RT |

Slider:

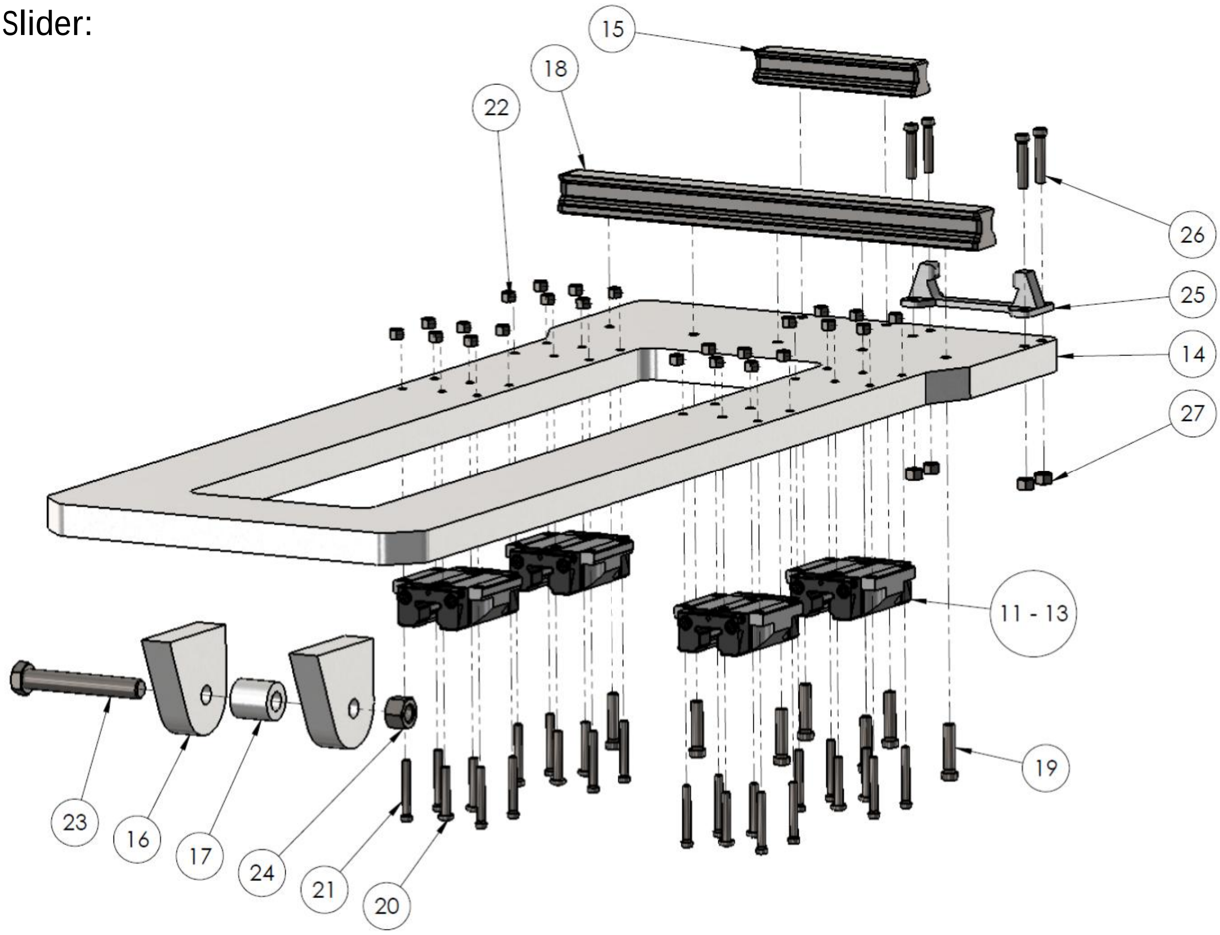



*Figure 52 - Exploded view of Slider.*

The slider is the connection between the frame and the floor mounting. The slider slides upon the floor mounting. It also has rails (part 15 and 18), which the frame is fastened upon. The frame slides on the rail to handle misplacement/delivery variance.

*Table 34 – Parts Relevant to the Slider – Entire table in appendix I.*

| ITEM NO. | PART NUMBER | QTY. | Production method |
|---|---|---|---|
| 11 to 13 | Linear Roller 20 mm | | RT |
| 11 | R200180131 | 4 | |
| 12 | R200180102 | 8 | |
| 13 | R343706101_Z | 16 | |
| 14 | Flat steel | 1 | Cut from SP |
| 15 | KUGELSCHIENE_NR_RAIL1_1 | 1 | RT |
| 16 | Hydraulic bracket radial | 2 | Cut from SP |
| 17 | Pin | 1 | Lathe |
| 18 | KUGELSCHIENE_NR_RAIL1 | 1 | RT |
| 19 | ISO 14580 - #6 x 30 x 28 - 4.8-N | 7 | RT |
| 20 | ISO 7045 - M5 x 30 - Z --- 30N | 8 | RT |
| 21 | ISO 14580 - #4 x 35 x 33.6 - 4.8-N | 16 | RT |
| 22 | Hexagon Nut ISO - 4034 - M5 - N | 24 | RT |
| 23 | ISO 4014 - M12 x 80 x 30-N | 2 | RT |
| 24 | Hexagon Nut ISO - 4034 - M12 - N | 1 | RT |
| 25 | Spring clamp | 1 | Milled |
| 26 | ISO 14580 - #5 x 30 x 28.4 - 4.8-N | 4 | RT |
| 27 | Hexagon Nut ISO - 4034 - M6 - N | 20 | RT |

## Floor Mounting:

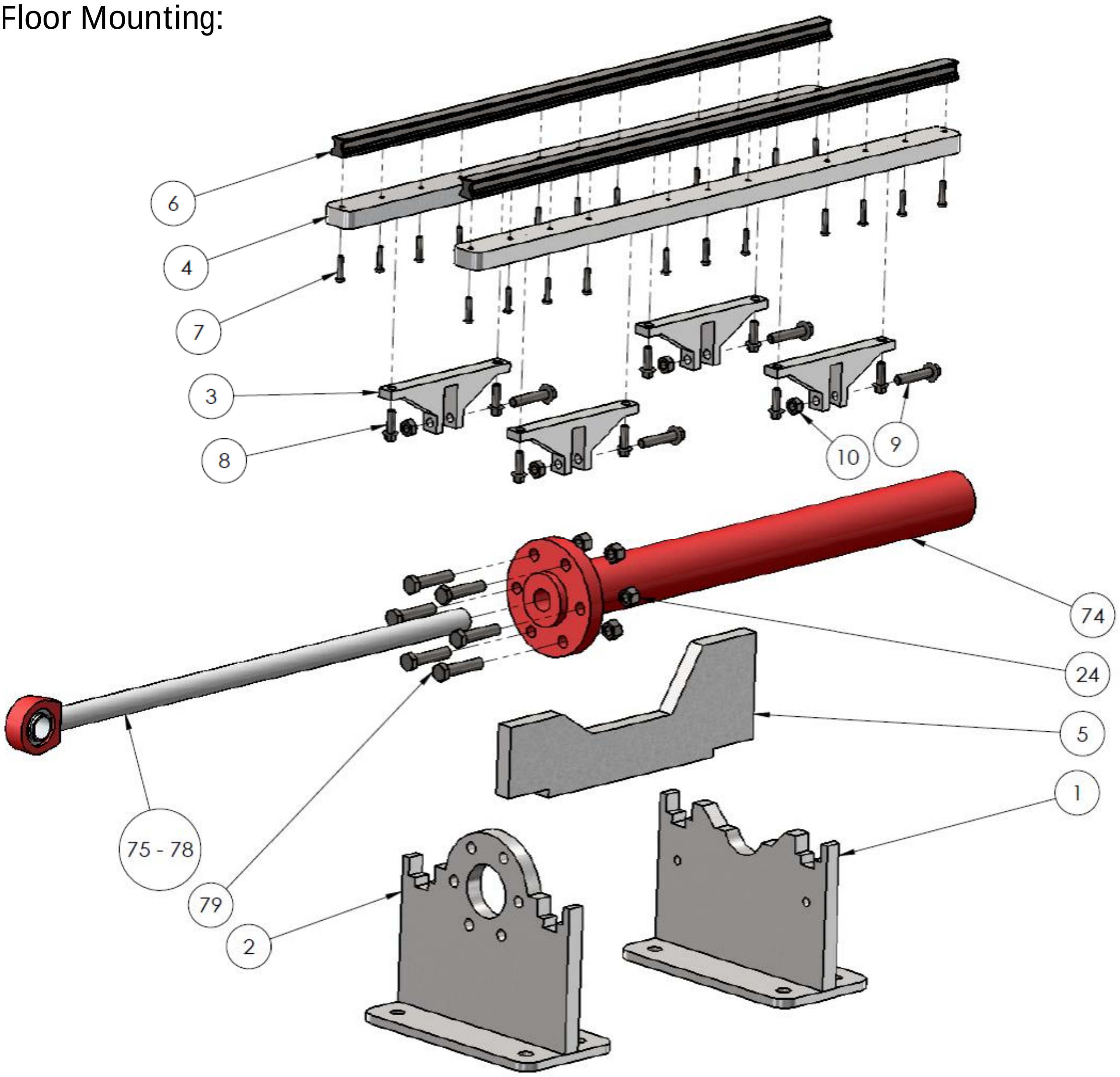



*Figure 53 - Exploded views of Floor Mounting.*

*Table 35 – Parts Relevant to the Slider – Entire table in appendix I.*

| ITEM NO. | PART NUMBER | QTY. | Production method |
|---|---|---|---|
| 1 | Floor Weldment 1 | 1 | Cut from Steel Plate (SP) |
| 2 | Floor Weldment 2 | 1 | Cuts from SP |
| 3 | Floor Bracket | 4 | Cut from SP |
| 4 | Rotating rail component | 2 | Cut from SP |
| 5 | Jack | 1 | Cut from SP |
| 6 | KUGELSCHIENE_NR_RAIL1 740 | 2 | Retailer (RT) |
| 7 | ISO 7045 - M5 x 25 - Z --- 25N | 22 | RT |
| 8 | ISO 4162 - M8 x 25 x 25-N | 8 | RT |
| 9 | ISO 4162 - M10 x 50 x 26-N | 4 | RT |
| 10 | Hexagon Nut ISO - 7413 - M10 - W - N | 4 | RT |
| 24 | Hexagon Nut ISO - 4034 - M12 - N | 8 | RT |
| 74-78 | Cylinder CD25 500 | | RT |
| 74 | cylinder-CD25-50_25x500-AE-HR-SSN-NNN-servi | 1 | |
| 75 | rod-CD25-50_25x500-AE-HR-SSN-NNN-servi | 1 | |
| 76 | rod-end-CD25-50_25x500-AE-HR-SSN-NNN-servi | 1 | |
| 77 | bearing-ring-CD25-50_25x500-AE-HR-SSN-NNN-servi | 1 | |
| 78 | bearing-ball-CD25-50_25x500-AE-HR-SSN-NNN-servi | 1 | |
| 79 | hex bolt gradeab_iso | 6 | RT |

## 8.3 Index Pin assembly

Below, the design of the index pin assembly is shown.

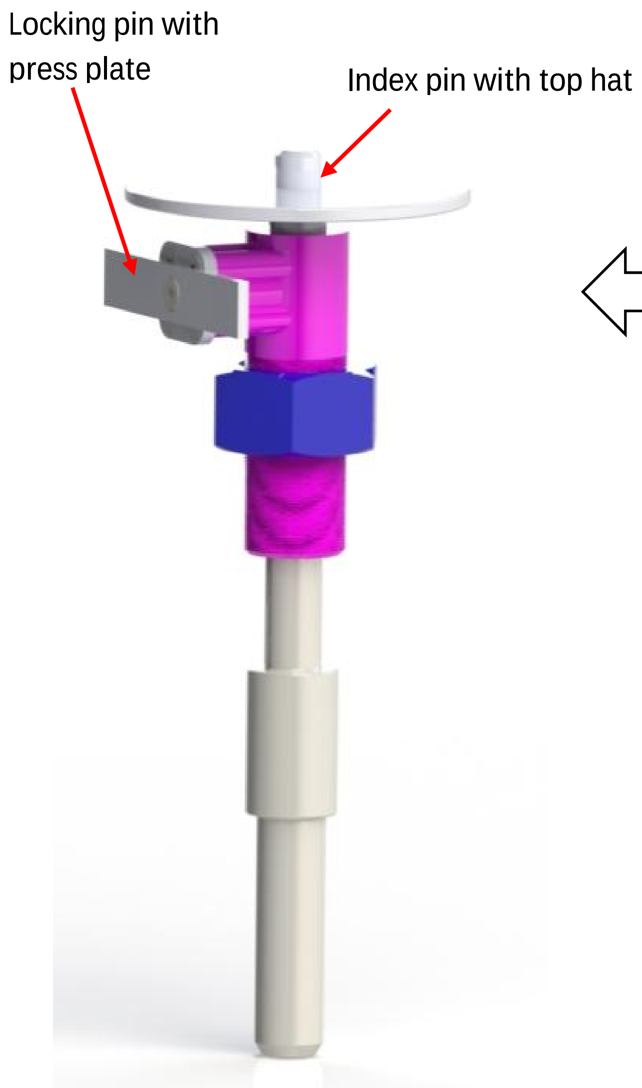



*Figure 54 - Index Pin Assembly in locked position.*

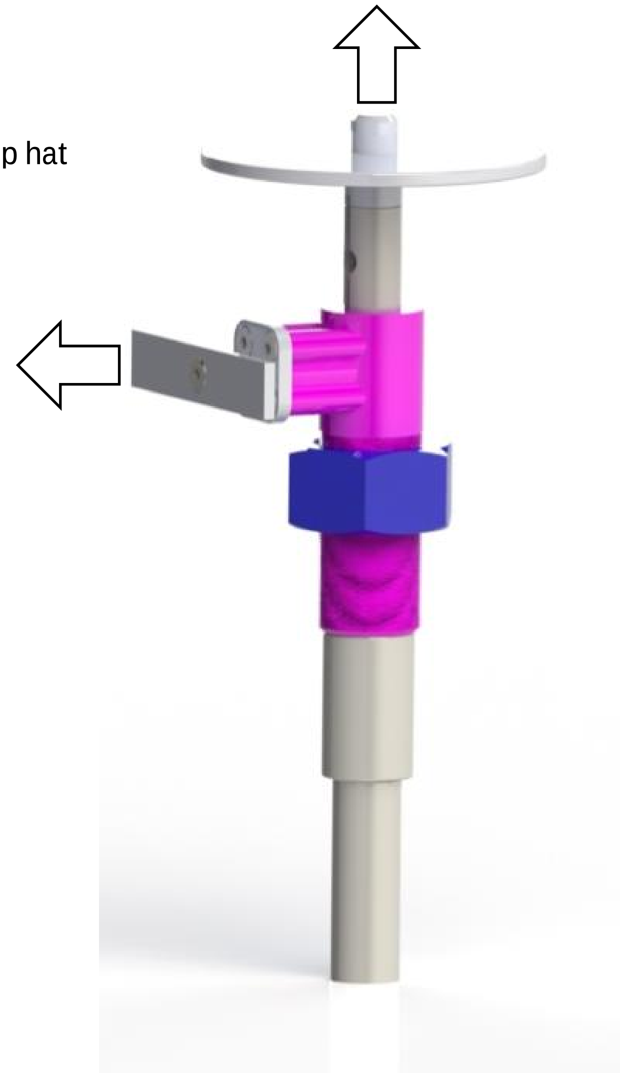


*Figure 55 - Index Pin Assembly in opened position.*

The index pin assembly needs to be modified from its original design. The original hairpin locking pin has been modified into a normal pressure plate that is pressed open by the Automated Rotator. The index pin has been modified from a bulb ideal for human hands to a top hat, which is easy graspable for a mechanical solution.

## 8.4 Exploded views of Index Pin Assembly

Exploded view shows the Index Pin Assembly with all parts numbered. All drawings are enclosed in appendix V.vi and V.vii. The parts are listed in the Bill of Materials for the Index Pin Assembly on the bottom of the page.

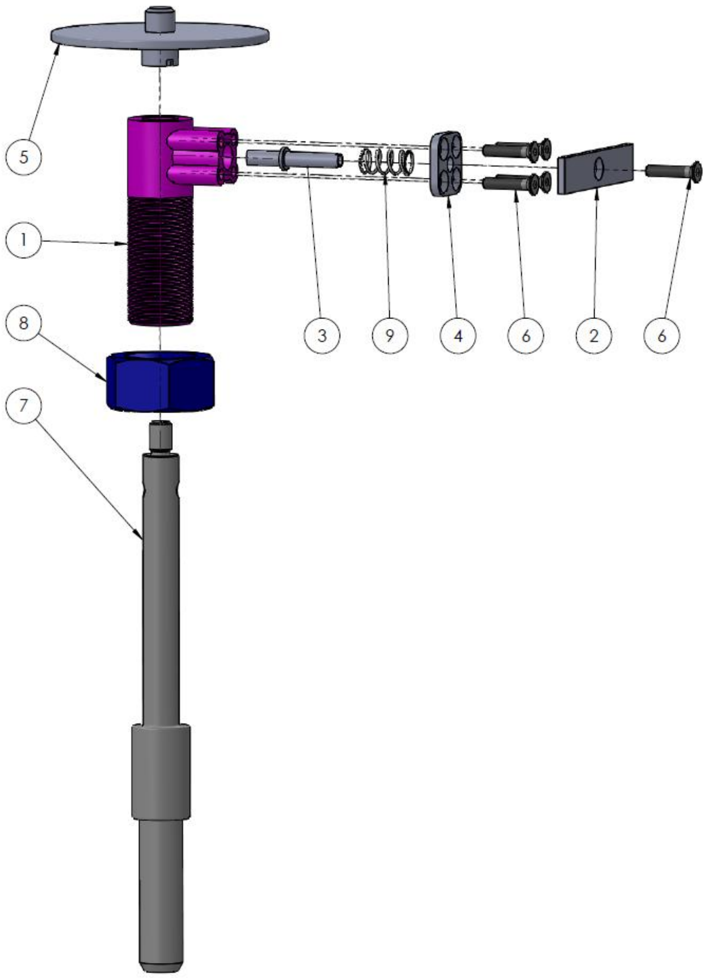



*Figure 56 - Index Pin Assembly - Exploded view.*

Below the BoM for the index pin assembly is shown.

*Table 36 - BoM Index Pin Assembly with production methods.*

| ITEM NO. | PART NUMBER | QTY. | Production |
|---|---|---|---|
| 1 | Two armed sleeve | 1 | CNC Machined |
| 2 | Press plate | 1 | Cut from SP |
| 3 | Locking pin | 1 | Lathe |
| 4 | Spring cover | 1 | Milled |
| 5 | Top Hat | 1 | Lathe |
| 6 | ISO10642-M6x30<br>Inconel 625TC13 | 5 | RT |
| 7 | Index pin | 1 | Lathe and Milled |
| 8 | Nut, ISO4032, M36, A4-80 | 1 | RT |
| 9 | Spring-6046-Lesjofors | 1 | RT |

## 8.5 Detailed product presentation

In this chapter, the detailed design of the Automated Rotator is presented. For the incremental process description, see chapter 9.

### 8.5.1 Grab of lock ring

The concept takes advantage of the original lock ring cavity. The Cavity pin (part 56) penetrates the lock ring cavity when the AR is brought into position. The original lock ring needs additional chamfers to be compatible with the AR.

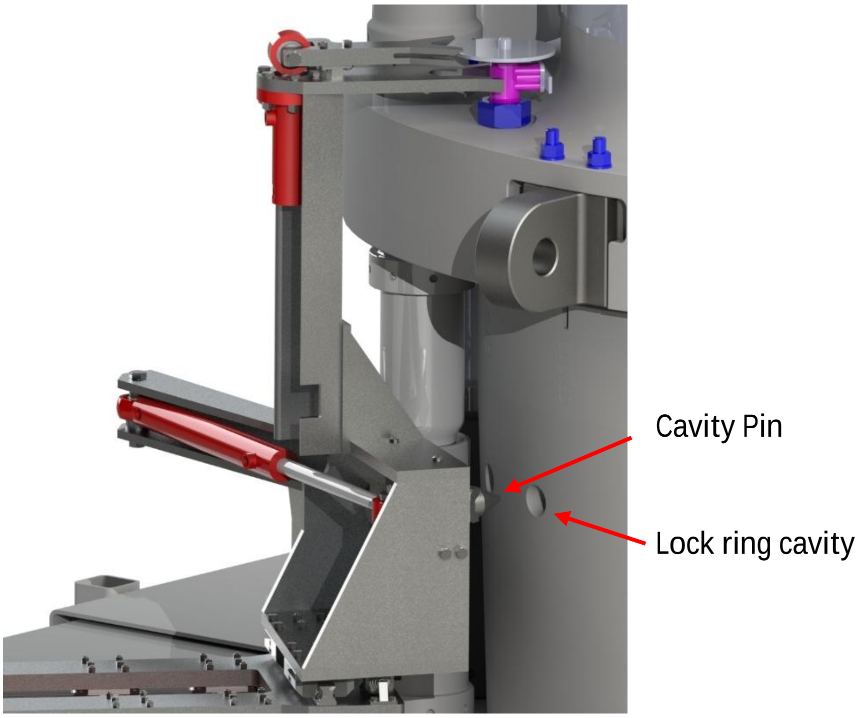



*Figure 57 - The AR is about to enter the lock ring cavity.*

*Figure 58 – The Cavity pin assembly with roller guides.*

Due to limited space, the frame of the AR is slightly twisted relative to the path of motion. The big, red arrow shown on figure 59 on the next page shows the path of motion and the need of fillets on the lock ring cavity for the cavity pin to enter smoothly.

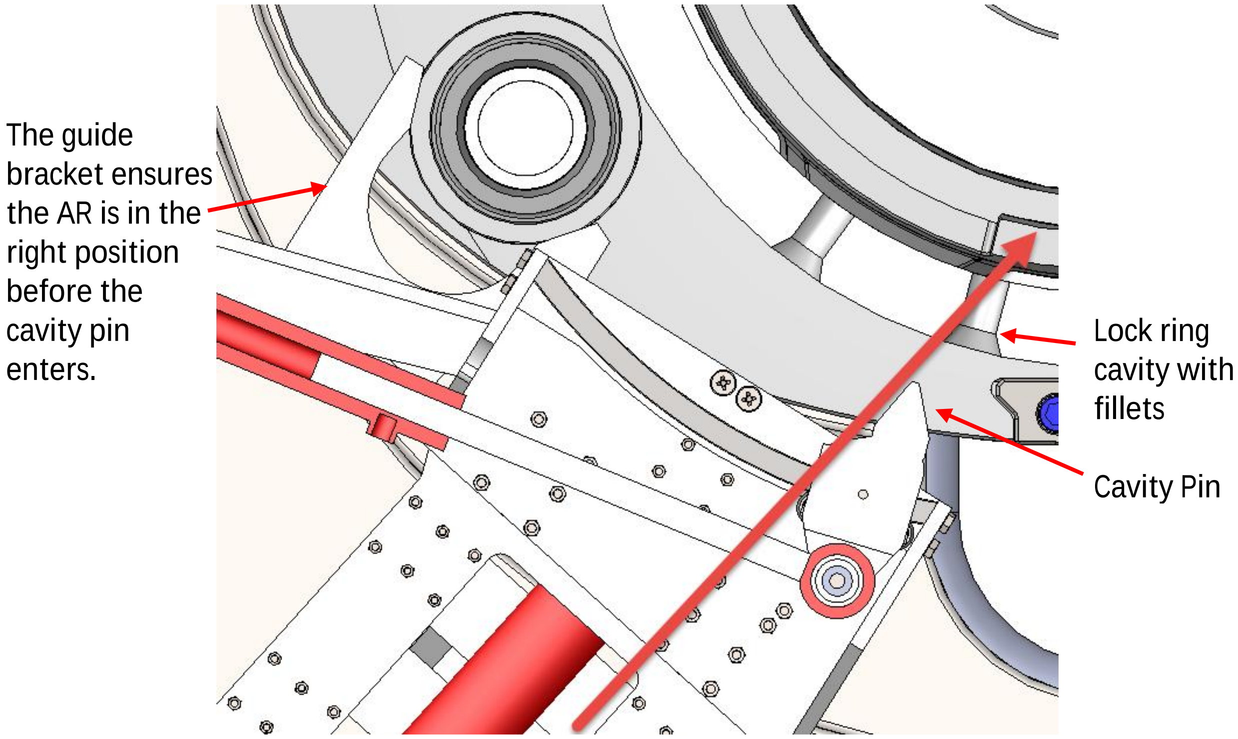



*Figure 59 – Section cut of the cavity pin and lock ring cavity seen from above.*

### 8.5.2 Rotation of lock ring

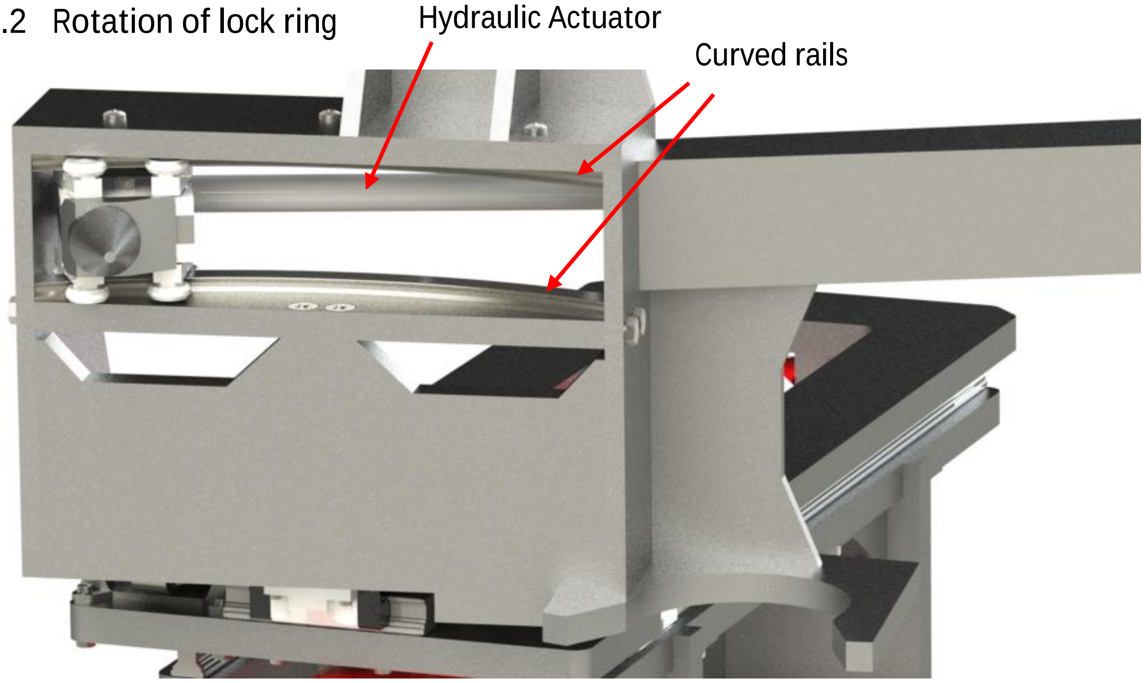



*Figure 60 – Rail and Roller guides follows the curvature of the lock ring.*

The rotation is done by the 3rd hydraulic actuator (part 64-68). The hydraulic actuator follows the curvature of the lock ring due to the curved rails. The cavity pin is an original part, but the rail and guides are from Rollon Group Timken. On the next page, the roller guides for curved rails are shown (figure 61). These are mounted together with the cavity pin entering the lock ring cavity. These are part 55 and 56 of the AR.

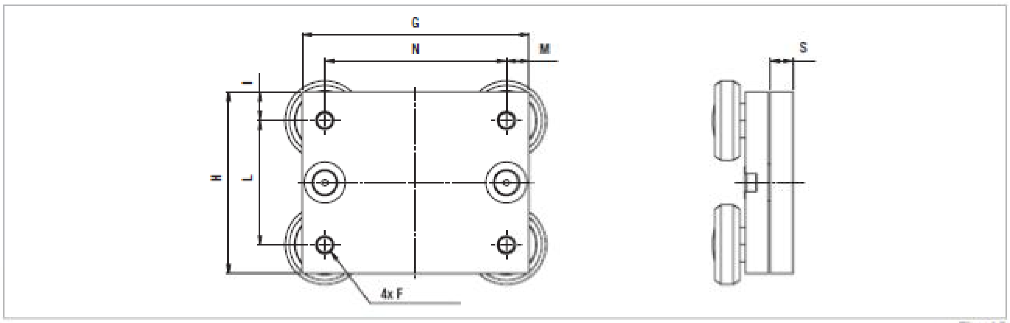



Fig. 19

| Type | G [mm] | H [mm] | I [mm] | L [mm] | M [mm] | N [mm] | S [mm] | F | Weight [kg] |
|---|---|---|---|---|---|---|---|---|---|
| CCTX08 | 70 | 50 | 10 | 30 | 10 | 50 | 10 | M5 | 0,45 |
| CCTX11 | 100 | 80 | 12,5 | 55 | 10 | 80 | 10 | M8 | 1,1 |

Tab. 10

*Figure 61 – Roller Guides from Rollon* [29].

## 8.5.3 Opening and closing of locking pin

The locking pin is opened simultaneously as the AR gets into position. The press plate on the locking pin is pressed open by the Pusher Bracket (part 36) on the frame assembly.

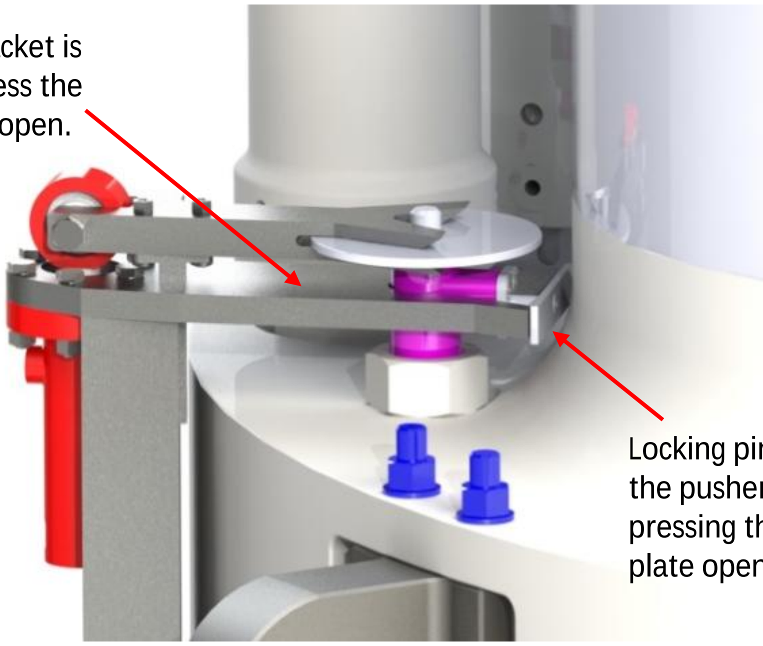



*Figure 62 - Locking pin is pressed open.*

### 8.5.4 Lifting and closing of index pin

The index pin is opened by the second hydraulic actuator (part 69-73). To prevent this hydraulic cylinder from momentum and gasket damage, a Non Momentum Pin (part 63) is assembled on the lifting unit. This pin has fine tolerances, and enters a slot in the Pusher bracket (part 36).

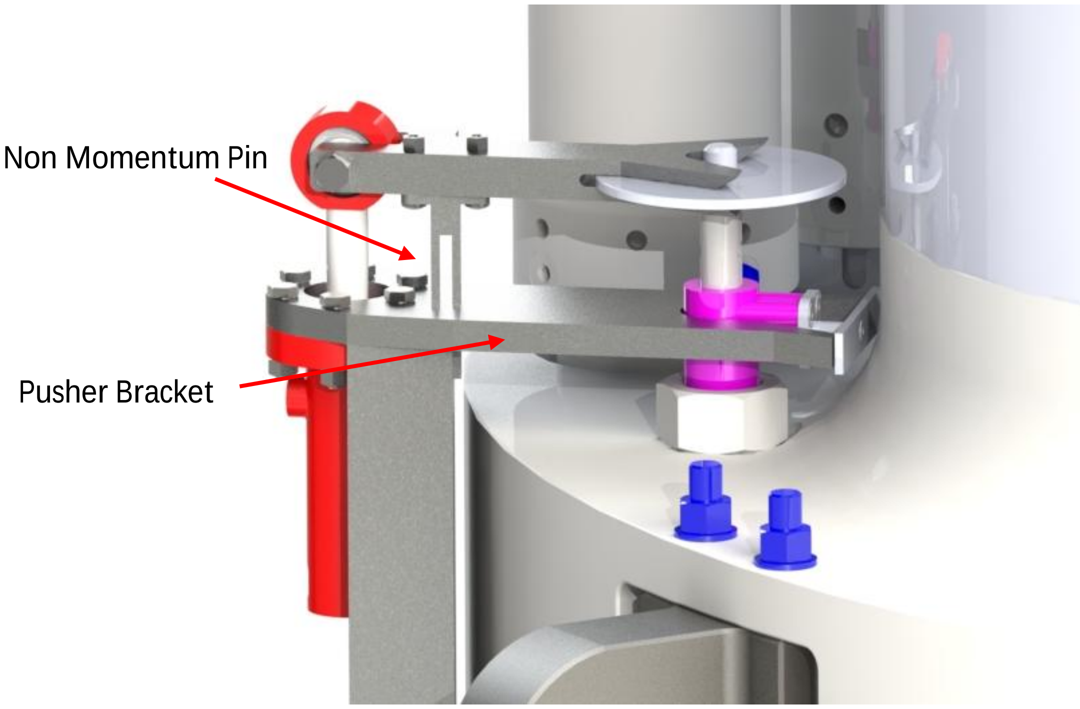



*Figure 63 - Index pin is lifted open.*

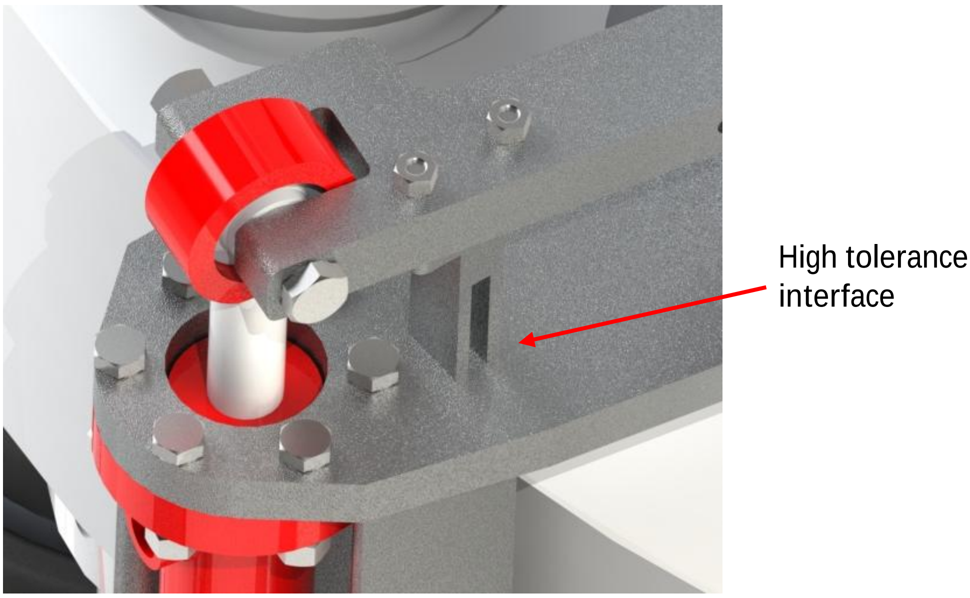



*Figure 64 - The Non Momentum Pin and the Pusher Bracket has a high tolerance interface to avoid any momentum on the hydraulic actuator.*

### 8.5.5 Activation and Deactivation of position

For entering activated position, a hydraulic cylinder is used (part 74-78). To make this motion possible, the slider has runner blocks (part 11-13) that runs over the guide rails (part 6) of the floor mounting.

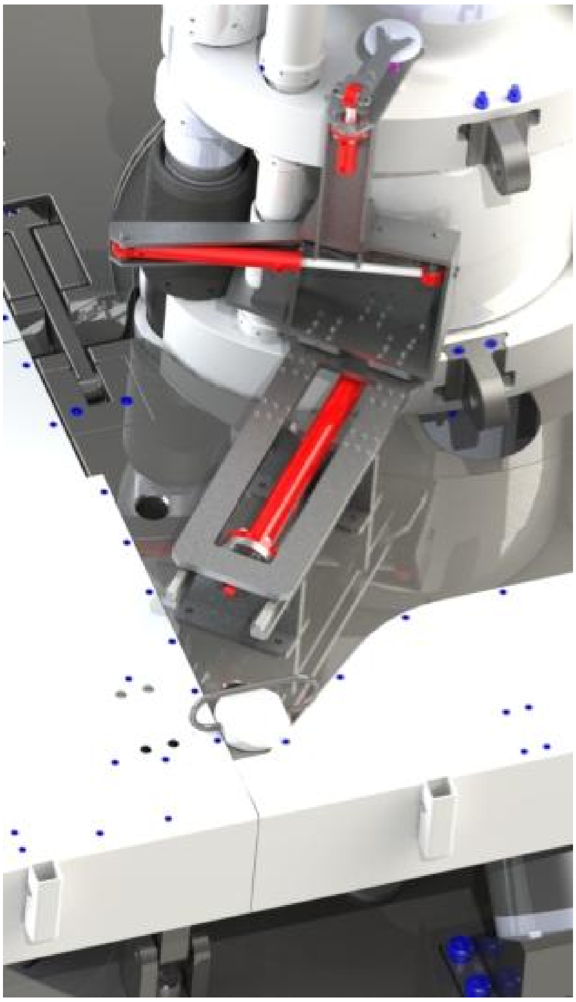


*Figure 65 - AR in activated position.*

*Figure 66 - AR in deactivated position.*

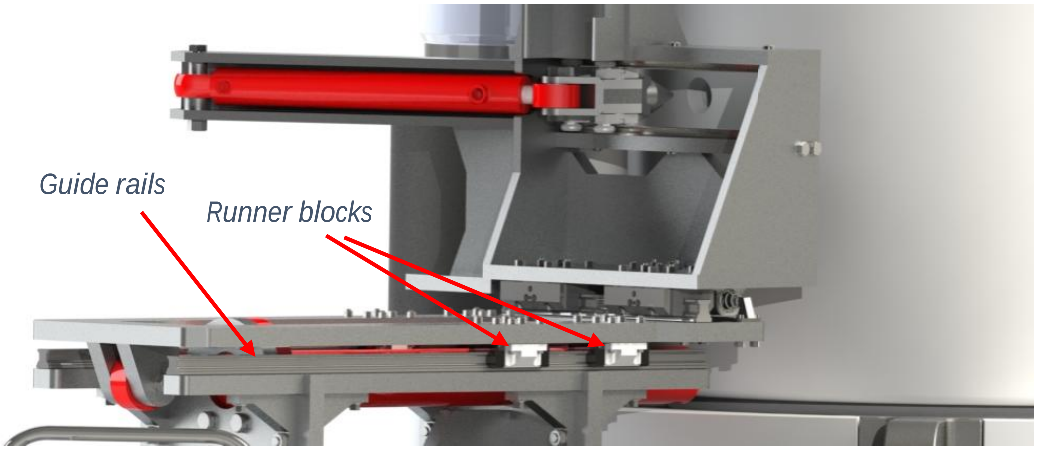



*Figure 67 - Guide Rails and runner blocks.*

### 8.5.6 Misplacement and Variance

Misplacement and variance are discussed in chapter 5.3.3., and it influences the design of the slider and frame. The slider has two guide rails (part 15 and 18) which runner blocks assembled to the frame moves along. These runner blocks move ± 20 $mm$. To make sure the runner block does not run off the guide rails, a spring assembly is installed (part 25, 48, 49). The spring assembly makes sure the frame is centered relative to the slider when retracted.

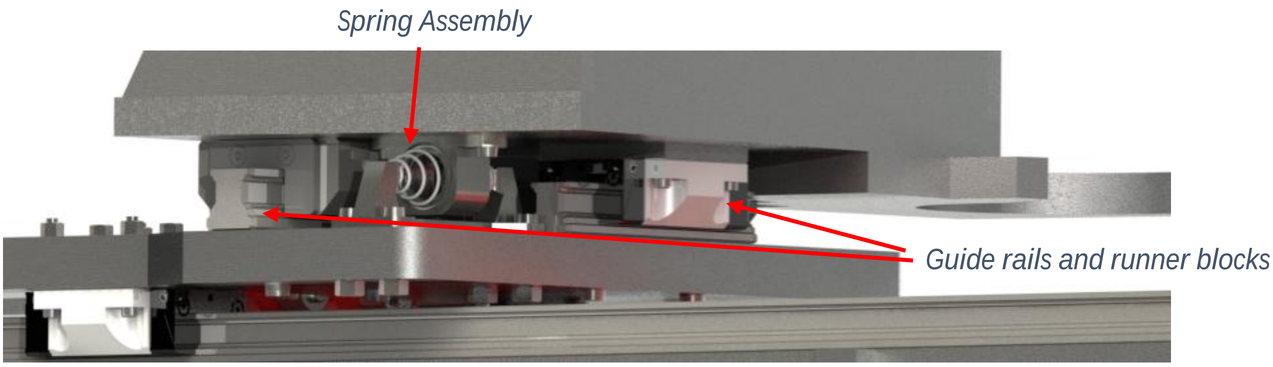



*Figure 68 - Delivery variance Guide Rails and Runner Blocks.*

The Automated Rotator uses a guide bracket (part 32) for guiding itself into the right position. This guide bracket uses the Hydraulic P-line as guidance for entering the lock ring cavity and opening the locking pin. Below, the guide bracket is shown about to enter the P-line.

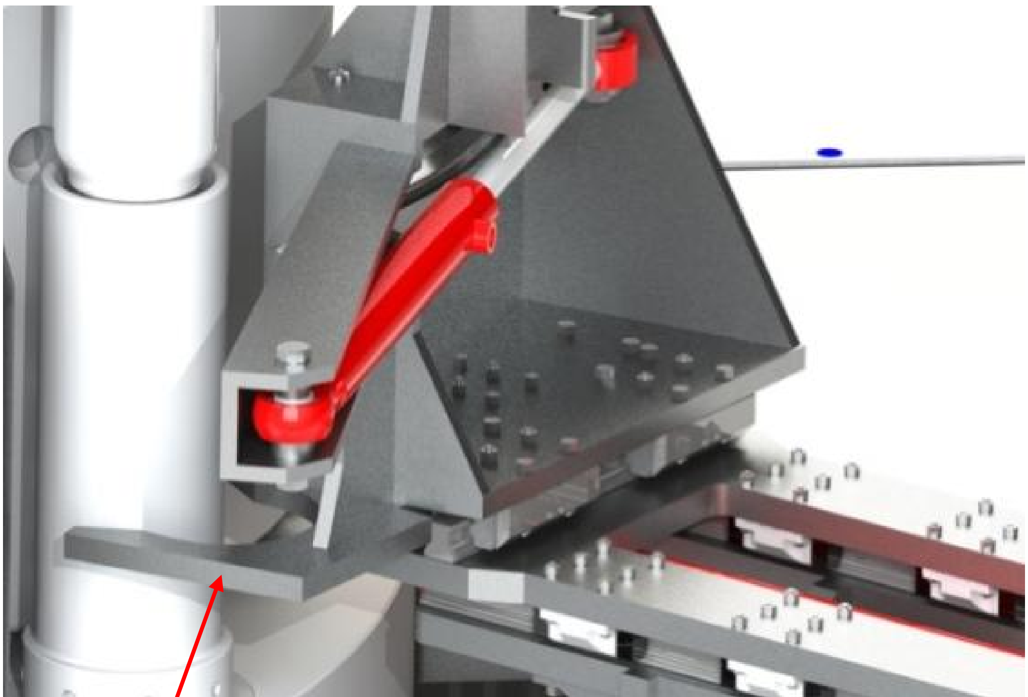



*Figure 69 - Guide Bracket about to enter P-line.*

To reset the offset between each riser joint, a double spring assembly is used (Part 25, 48 and 49). This is applicable to center the frame due to the tight space between the landing frame and the automated rotator when retrieved. Below, the tight gap between the landing frame and the AR is shown. The Channel steel with cutaway (part 34) also has a cutaway for the landing frame to pass smoothly.

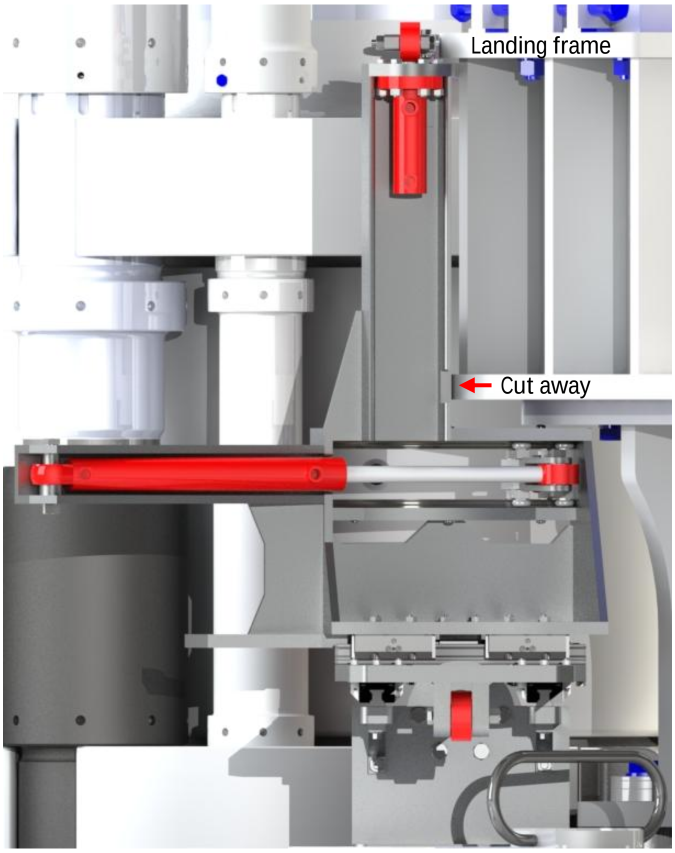



*Figure 70 - Gap between landing frame and AR.*

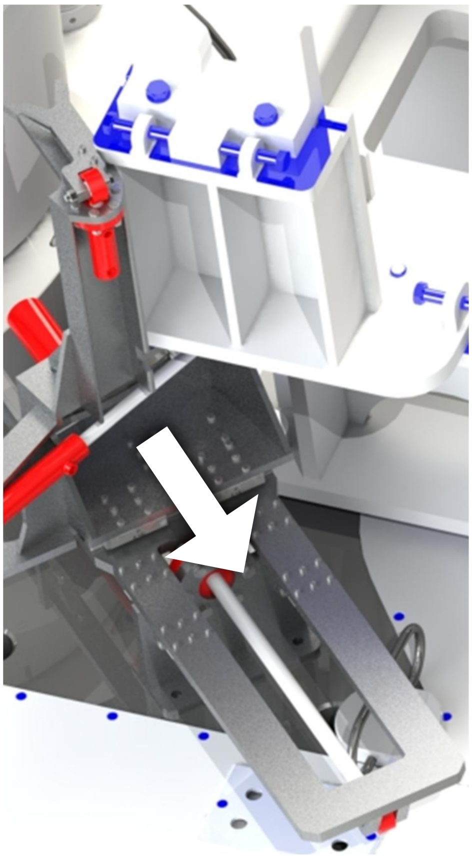
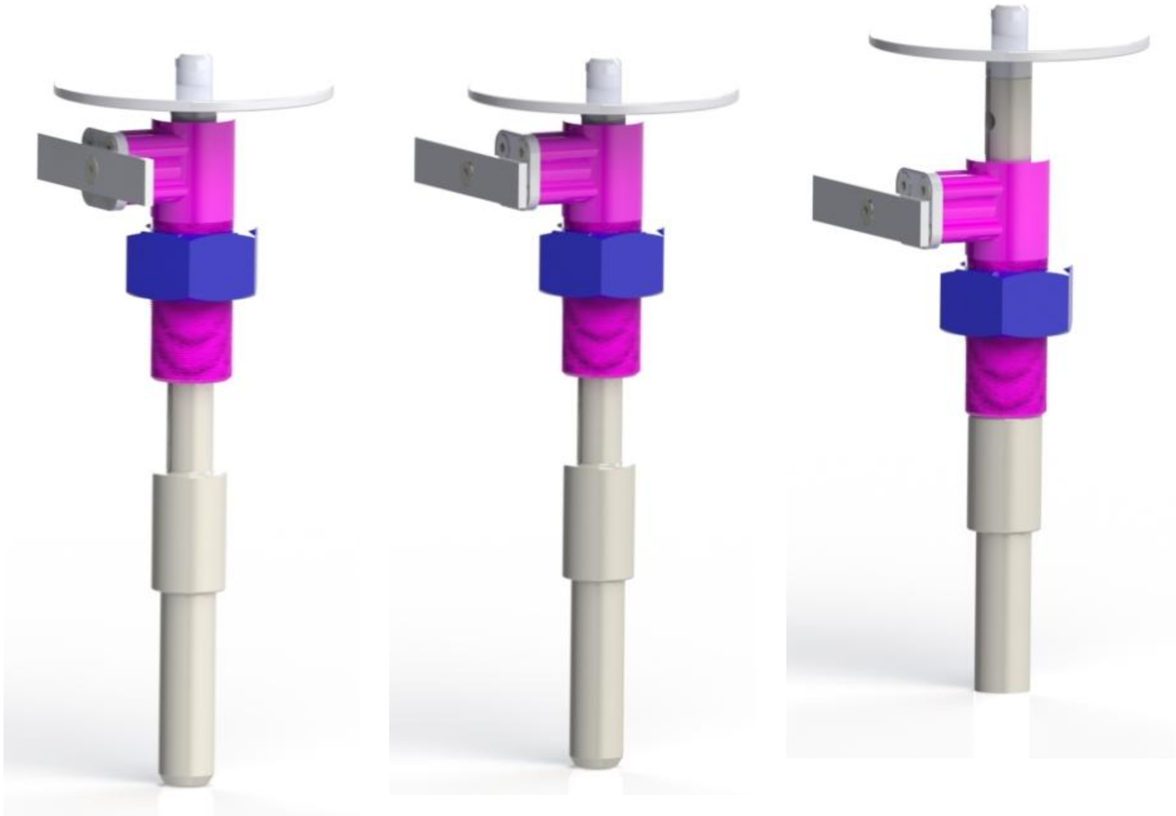


*Figure 71 – Tight gap between landing frame and AR when fully retracted.*

When the Automated Rotator retracts, the gap between the landing frame and the AR is only a few millimeters. This is why the spring assembly (part 25, 48 and 49) is installed. This centers the frame relative to the slider, making sure the frame does not collide with the landing frame.

### 8.5.7 Design of index pin assembly

The index pin assembly must be changed for the AR to be compatible with the riser joint. This means changing the index pin assembly on every joint to make the joints compatible with the automated rotator. The index pin has a spring (part 9 Index Pin Assembly) that presses the pressure plate (part 2 Index Pin Assembly) back to position when the AR is withdrawn. The index pin has three different positions during the process. These positions are shown below.



Assembly locked | Locking pin opened | Locking pin and Index pin opened

*Figure 72 Index Pin Assembly – Positions.*

# 9 Incremental steps

The Automated Rotator solves tasks in a set order. Additional systems are used to control these steps both according to both force and control. The system has certain incremental steps and a path with seven steps. These are presented in the table below.

*Table 37 - Incremental steps.*

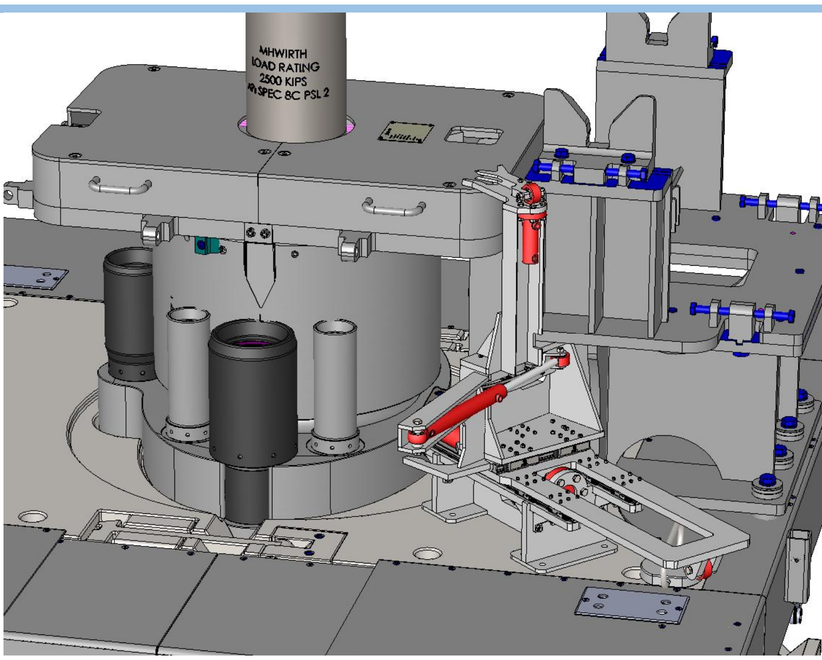
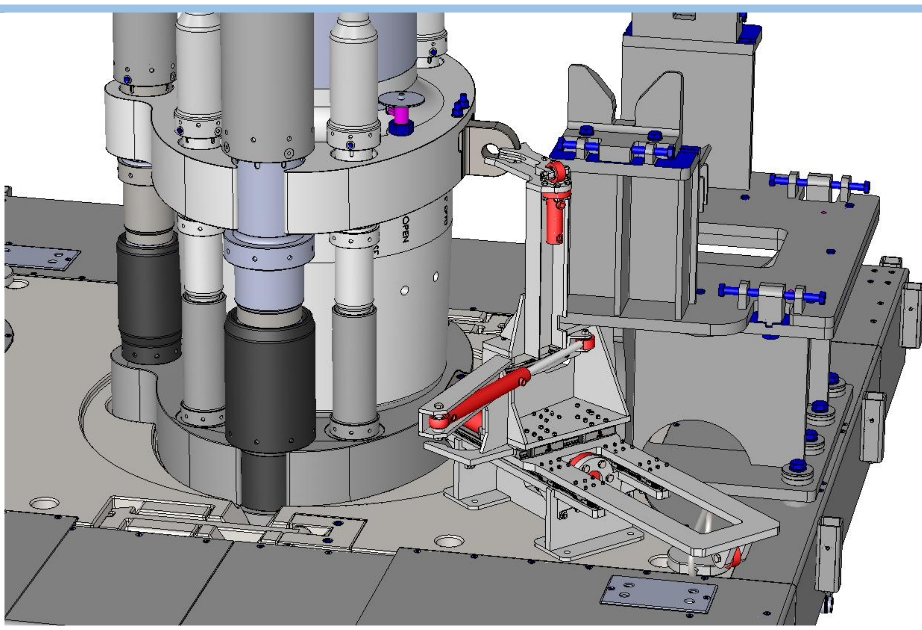
| Steps: | Description: |
|---|---|
| 1 |   The Automated Rotator is in retracted position to give space for the handling tool, which holds the riser until the spider is closed. |
| 2 |   A second riser is put on top of the first. The automated Rotator is still in retracted position. |

*Table 37 continues.*

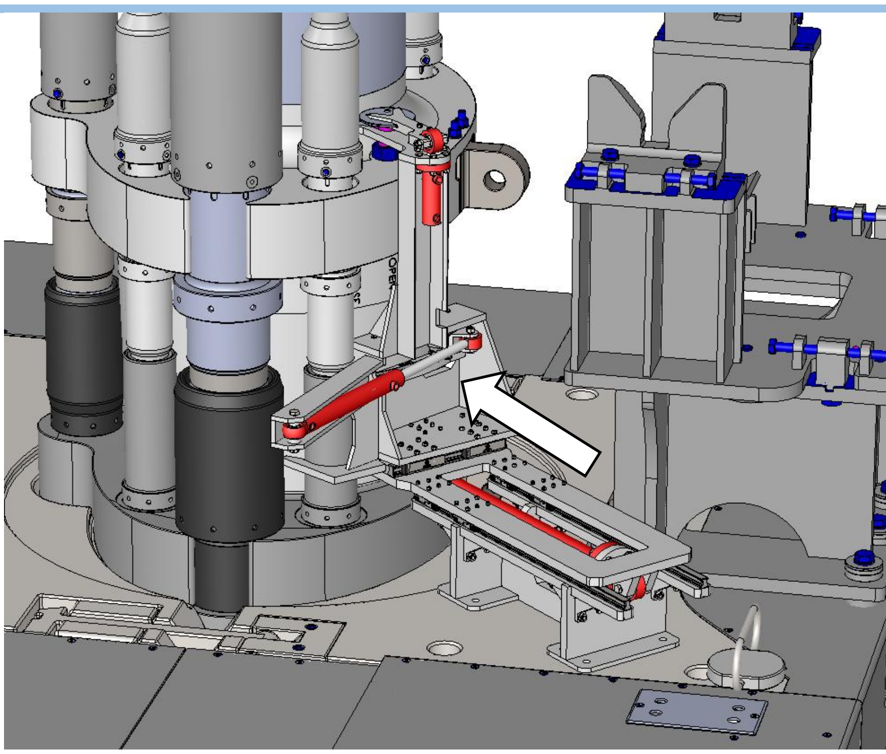
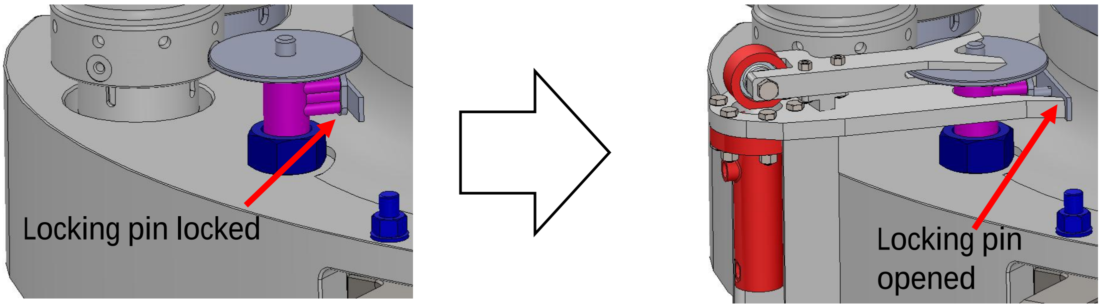
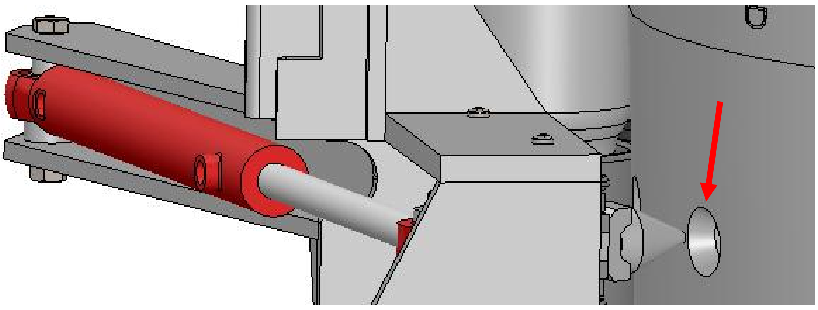
| Steps: | Description: |
|---|---|
| 3 | <br>The Automated Rotator is activated, penetrating the hole in the lock ring and opening the locking pin simultaneous.<br><br><br>Above: The locking pin is pressed open by the activation of the Automated rotator.<br><br>Above: The cavity pin about to enter the cavity in the lock ring. |

*Table 37 continues.*

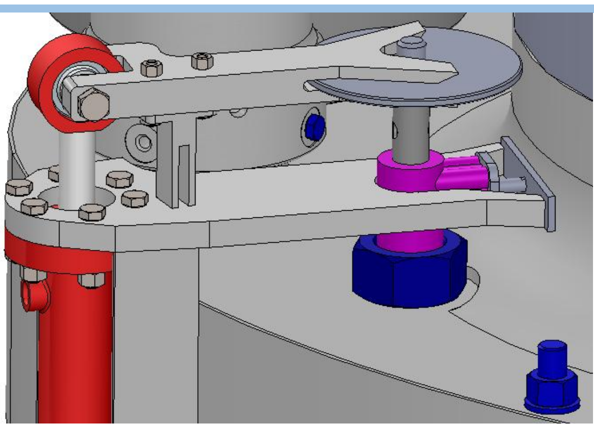
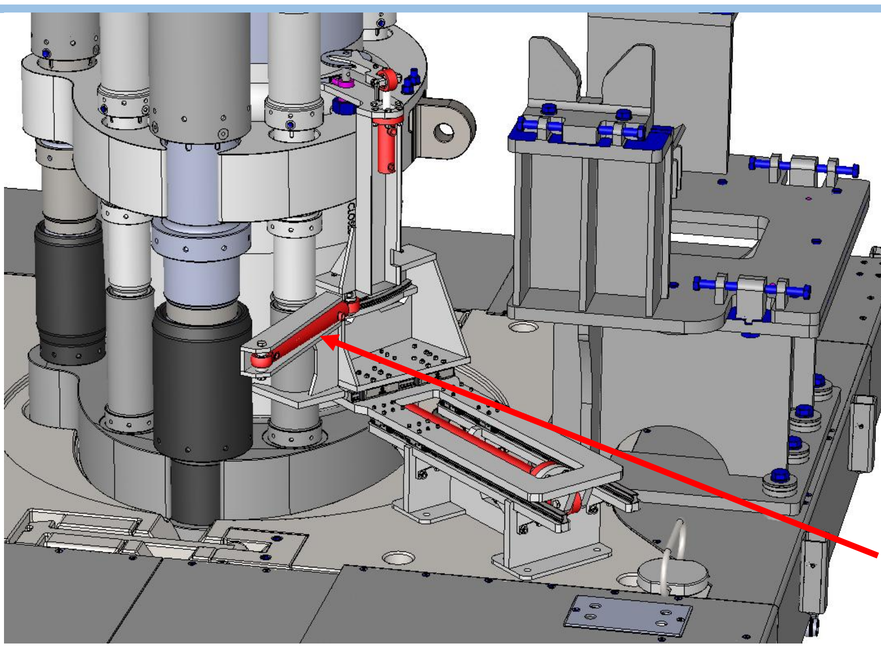
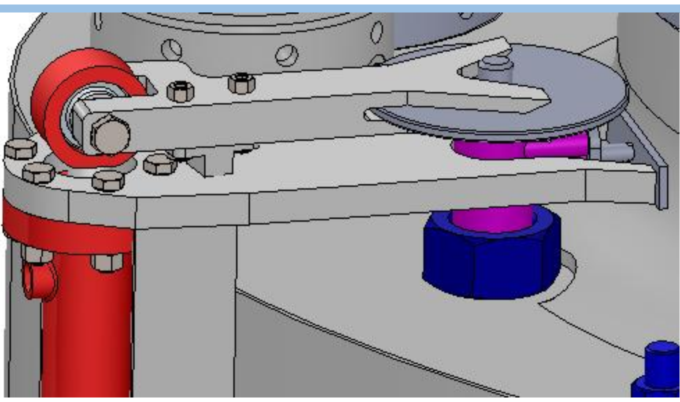
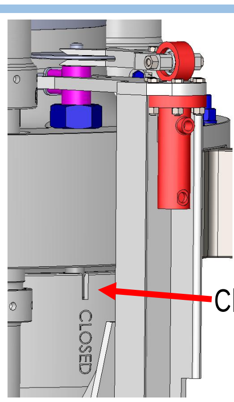
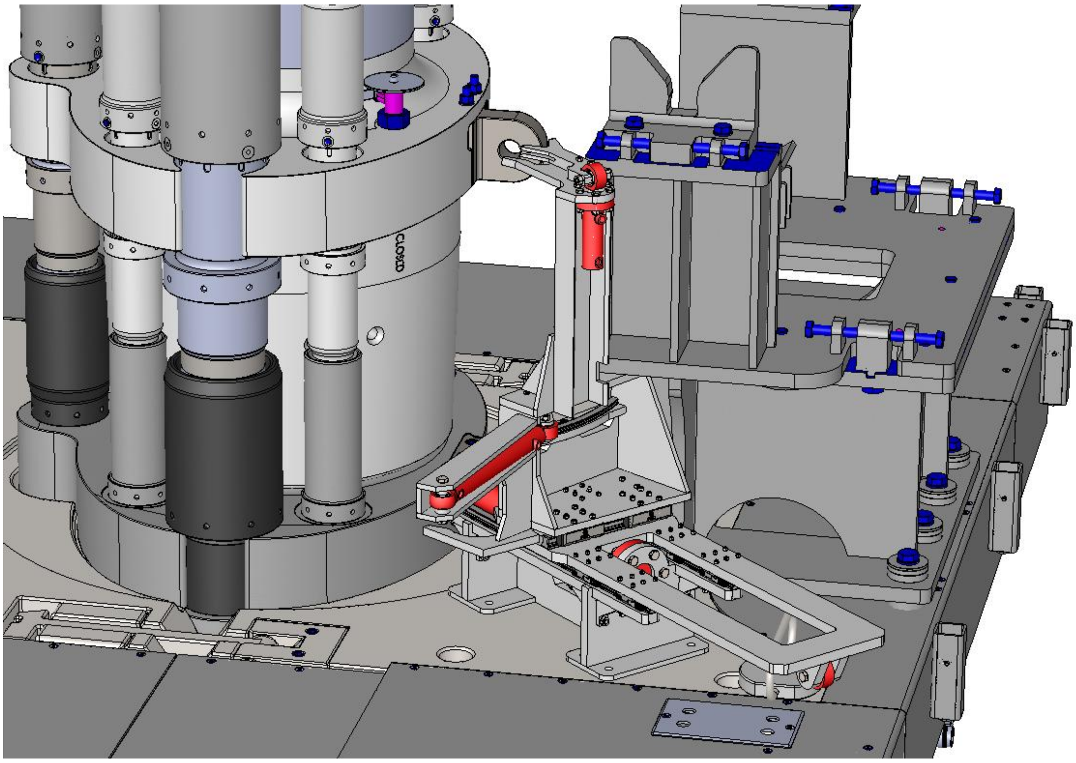
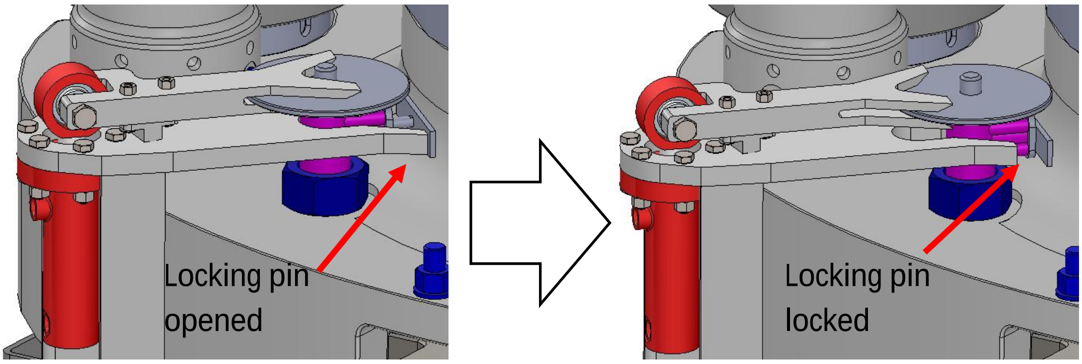
| Steps: | Description: |
|---|---|
| 4 | <br>The index pin is lifted, making the lock ring rotatable. |
| 5 | <br><br>The lock ring is turned to “closed” by the lock ring actuator. |
| 6 |  <br><br>The index pin is closed securing the lock ring (above, left), entering the closed slot on the lock ring (above, right). |

*Table 37 continues.*

| Steps: | Description: |
|---|---|
| 7 | <br>The Automated Rotator retracts and pulls the cavity pin out of the lock ring. The locking pin of the index pin assembly is locked as the Automated Rotator retracts (shown below) due to the spring in the index pin assembly.<br> |

# 10 Control systems

This chapter describes the systems for making the incremental steps illustrated and described in chapter 9.

## 10.1 Hydraulic system

The AR needs a hydraulic system to be able to move the lock ring and index pin. This system is controlled by electrical solenoids (SOL).

Only hydraulic actuators has been made in CAD. However, the system has been made schematically. For symbol explanation, see chapter 4.9.

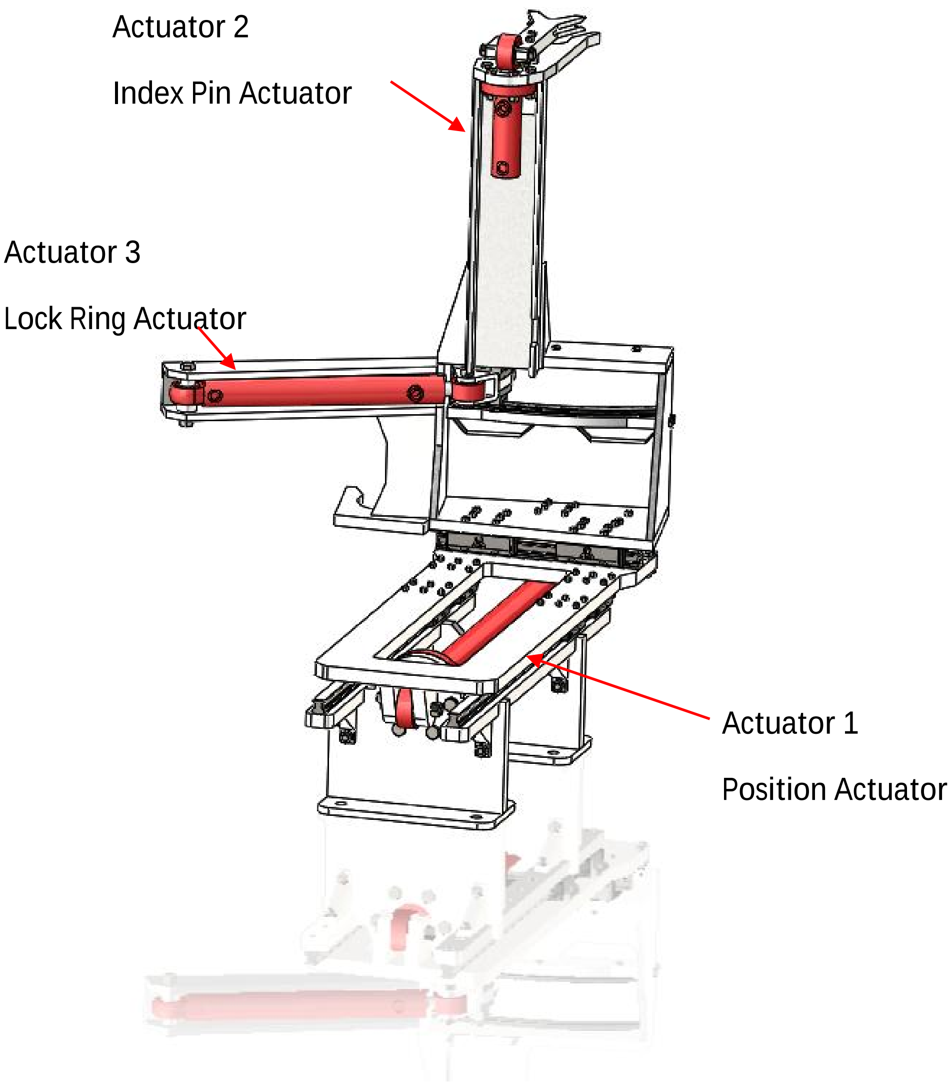



*Figure 73 - Hydraulic Actuator Overview.*

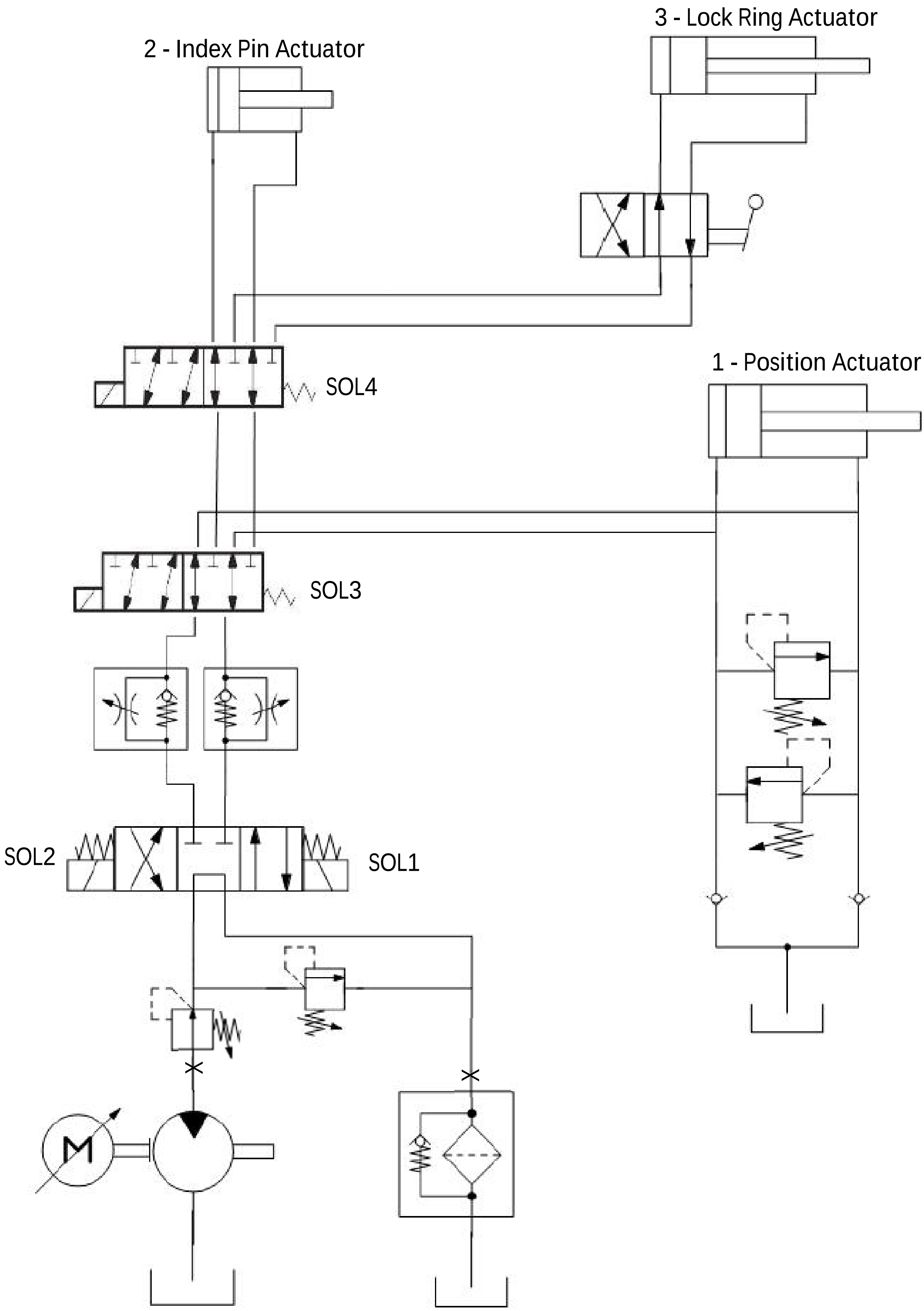



*Figure 74 - Hydraulic System of Automated Rotator.*

## Fluid hammer

A fluid hammer is the force of the flowing liquid that suddenly stops. This is potentially dangerous and can cause damage to the system. On board the rig, pressure is kept constant by the HPU (Hydraulic Power Unit). This system has great volumes flowing, hence making accumulators for preventing fluid hammers unnecessary. However, a shock valve is installed by actuator 1 in case of sensor failure and collision between the AR and marine riser.

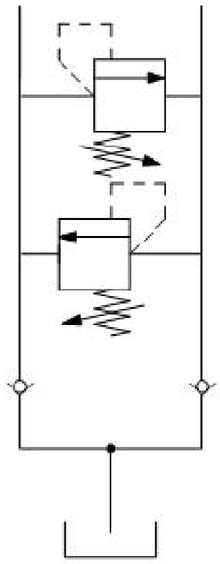


*Figure 75 - Shock Valve.*

## Flow control

The flow potential of the HPU on the rig is very large. To prevent the hydraulic cylinders to move to fast, flow control is introduced. The flow is controlled on the inflow side of the cylinder, and not on the return side. The controller is double as both the plus and minus side of the cylinder needs to be controlled.

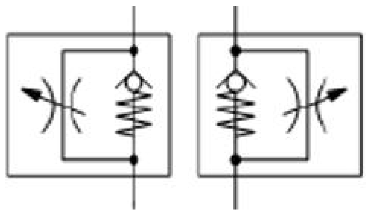


*Figure 76 - Inflow Regulation.*

## Control of DCV

The DCV’s have different configurations. Mostly, the DCV’s are operated by solenoids and electrical sensors, as the process needs to be automatic. However, there are two different modes of the process.

1. Assemble riser string

Locks the lock ring, making a sealed coupling for the riser string.

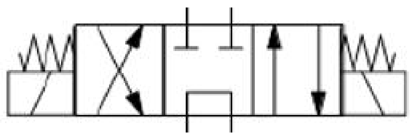


*Figure 77 - Solenoid operated DCV.*

2. Disassemble riser string

Opens the lock ring, breaking the seal and disassembles the riser string. The only difference between these two processes is the way actuator 3 works. Therefore, a manually operated DCV is installed to switch between these two processes for either assembly or disassembly of the riser string.

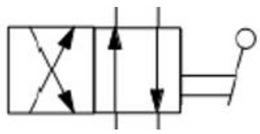


*Figure 78 - Manually operated DCV.*

## Connection points

The X-es represents the connection between the AR-system and the existing system. Hence, everything below the X-es represents the HPU, and is already present on the rig.

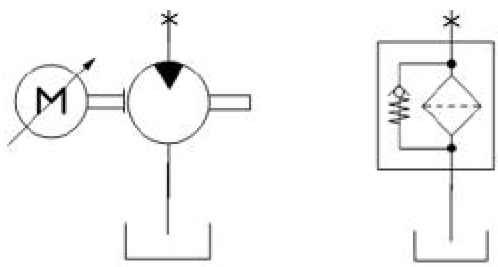



*Figure 79 - Connection points.*

## 10.2 Hydraulic calculations

Rig pressure from HPU: 3000 psi = 207 bar

Operational pressure, Rotator: 30 bar.

$$F = p \cdot A \qquad (3.1)$$

$$A = \frac{\pi}{4} \cdot d^2 \qquad (3.8)$$

Cylinder index pin and Cylinder rotator:

Force from cylinder, plus direction (formula derived from 3.1 and 3.8):

$$F_{plus\ direction} = 30\ bar \cdot 10^{-1} \frac{MPa}{bar} \cdot \frac{\pi}{4} \cdot (32\ mm)^2 = 2412{,}74\ N \qquad (10.1)$$

Force from cylinder, minus direction:

$$F_{minus\ direction} = 30\ bar \cdot 10^{-1} \frac{MPa}{bar} \cdot \frac{\pi}{4} \cdot ((32\ mm)^2 - (20\ mm)^2) = 1470{,}27\ N \qquad (10.2)$$

The momentum needed to rotate lock ring (from chapter 4.4):

$$M_{lock\ ring} = 266{,}69\ \text{Nm}$$

The force needed in the cylinder for rotation:

$$F_{lock\ ring} = \frac{M_{lock\ ring}}{r_{cylinder}} = \frac{266{,}69\ Nm}{0{,}4618\ m} = 577{,}50\ N \qquad (3.3)$$

Conclusion:

$$\boldsymbol{F_{minus\ direction} > F_{lock\ ring}}$$

<u>The cylinder will manage to rotate the lock ring.</u>

Cylinder position actuator

Force from cylinder, strong direction:

$$F_{plus\ direction} = 30\ bar \cdot 10^{-1} \frac{MPa}{bar} \cdot \frac{\pi}{4} \cdot (50\ mm)^2 = \mathbf{5890{,}49\ N} \qquad (10.1)$$

Force from cylinder, minus direction:

$$F_{minus\ direction} = 30\ bar \cdot 10^{-1} \frac{MPa}{bar} \cdot \frac{\pi}{4} \cdot ((50\ mm)^2 - (25\ mm)^2) = \mathbf{4417{,}86\ N} \tag{10.2}$$

Rotational Speed

To meet the requirement M2 *"Rotate lock ring within 6 seconds"* from chapter 5.1., a calculation of the volume flow is needed. The largest volume flow is needed from the cylinder's plus side, hence this flow is critical.

The volume of a cylinder is:

$$V = A \cdot l = \frac{\pi}{4} \cdot d^2 \cdot l \tag{3.10}$$

This yields:

$$V = \frac{\pi}{4} \cdot (32\ mm)^2 \cdot 240\ mm = 193019{,}5\ mm^3 \cdot \frac{dm^3}{10^6\ mm^3} = 0{,}193\ l \tag{3.10}$$

The hydraulic flow is:

$$Q = \frac{V}{t} \tag{3.11}$$

Minimum flow is:

$$Q = \frac{V}{t} = \frac{0{,}193\ l}{6\ s} = 0{,}032 \frac{l}{s} \cdot \frac{60\ s}{min} = \mathbf{1{,}93}\ {}^{\boldsymbol{l}}\!/_{\boldsymbol{min}} \tag{3.11}$$

Conclusion Rotational speed

This flow requirement is easily adjustable on the flow control valves in the hydraulic system. The HPU on the rig ensures required flow.

## 10.3 Electric control system

To control the AR an electrical 24 V control system is used. To keep costs down and rigidity up, a completely relay and proximity based system is used, powered from one power source. The components are explained in chapter 4.9. The electric system is shown below, and the steps in the table on the next page. These should be read alongside with the proximity sensor explanation (starting next page) and the hydraulic schematic (two pages back).

This schematic does not involve the flag system required from chapter 7.2.5. This is considered further work.

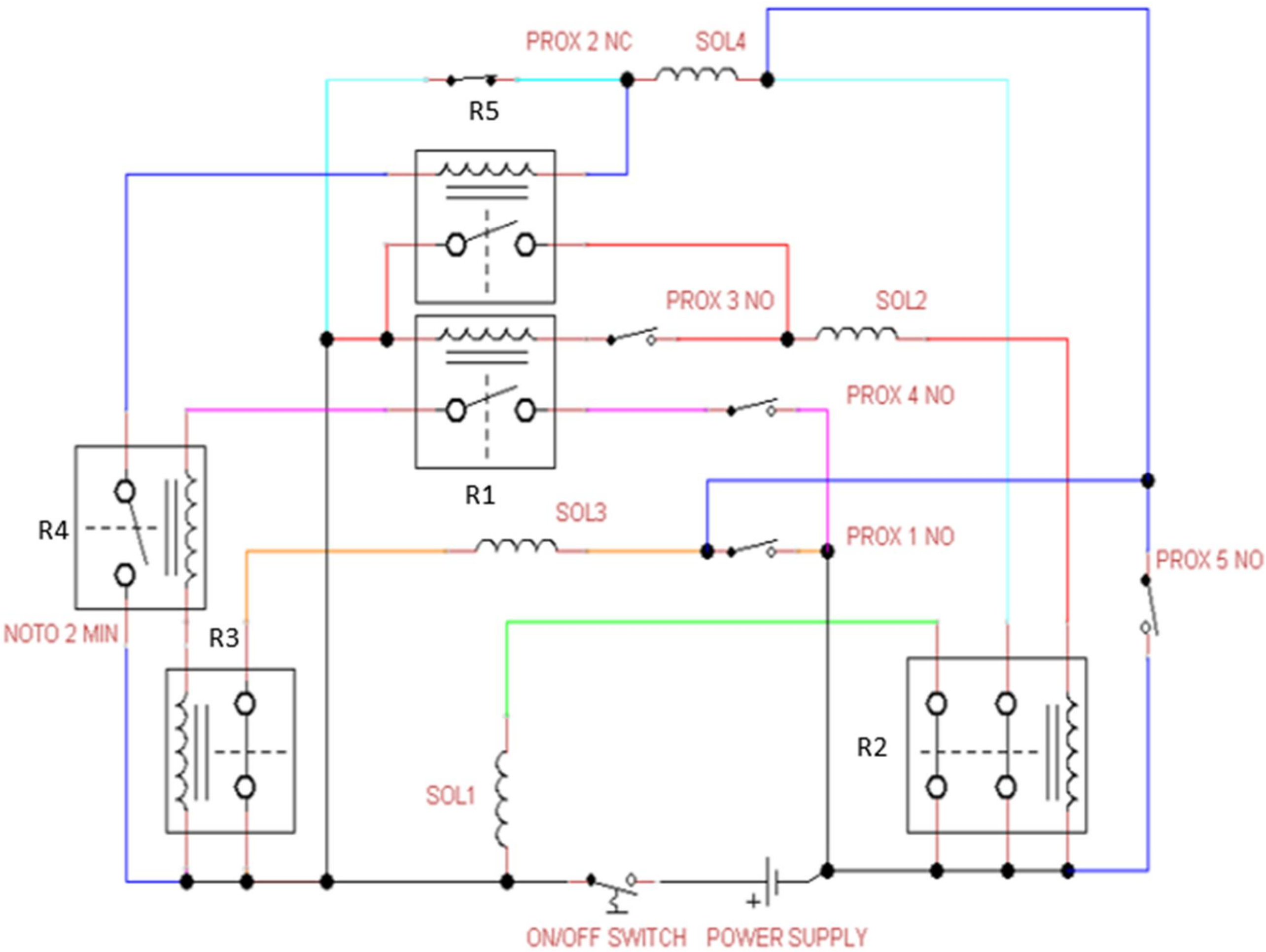



*Figure 80 - Electric Schematics.*

For efficiency, «PROX» is shortened to P on the table on the next page. E.g.: PROX 1 = P1, PROX2 = P2 etc.

Circuits: Green = G, BB = Bright Blue, Red = R, Pink = P, Blue = B

*Table 38 - Circuit steps matrix.*

| | | Active Proximity Sensors | | Active Circuits | | Active Solenoid | |
|---|---|---|---|---|---|---|---|
| *Step* | Action | IN | OUT | IN | OUT | IN | OUT |
| *1* | ON, syl 1 | P2 P4 | P1 P2 P4 | G | G O | 1 | 1 3 |
| *2* | Syl 2 | P1 P2 P4 | P1 | G O | G O BB | 1 3 | 1 3 4 |
| *3* | Syl 3 | P1 | P1 P3 | G O BB | O R | 1 3 4 | 2 3 |
| *4* | Rev Syl 2 | P1 P3 | P1 P2 P3 P4 | O R | R P | 3 2 | 2 |
| *5* | Rev Syl 1 | P1 P2 P3 P4 | P2 P3 P4 P5 | R P | R O B | 2 | 2 3 4 |
| *6* | Rev syl 3, OFF | P2 P3 P4 P5 | P2 P4 P5 | R O B | G | 2 3 4 | 1 |

To understand the system, the placement of the proximity sensors are explained below:

*Table 39 - Proximity Sensor placement.*

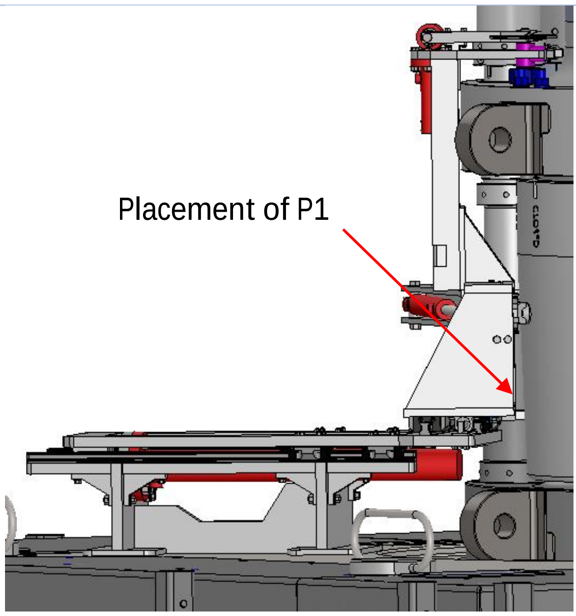
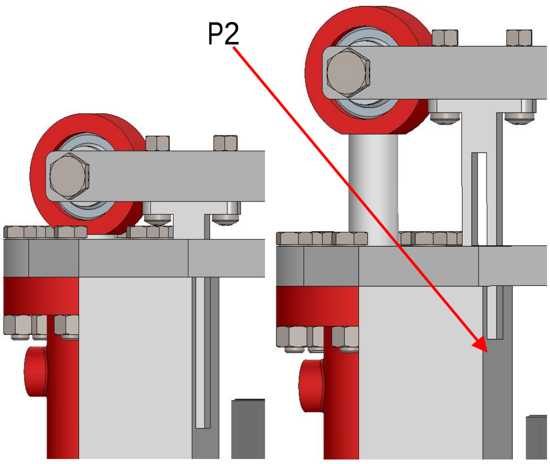
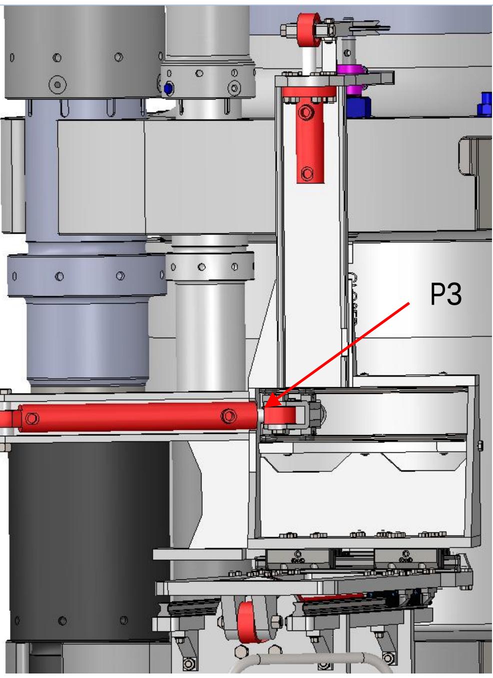
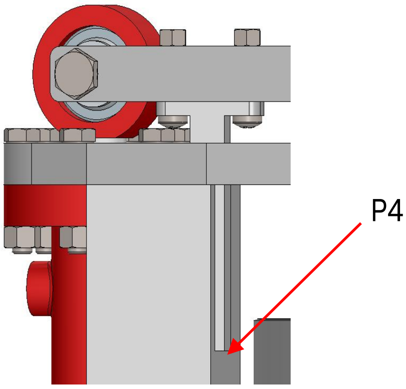
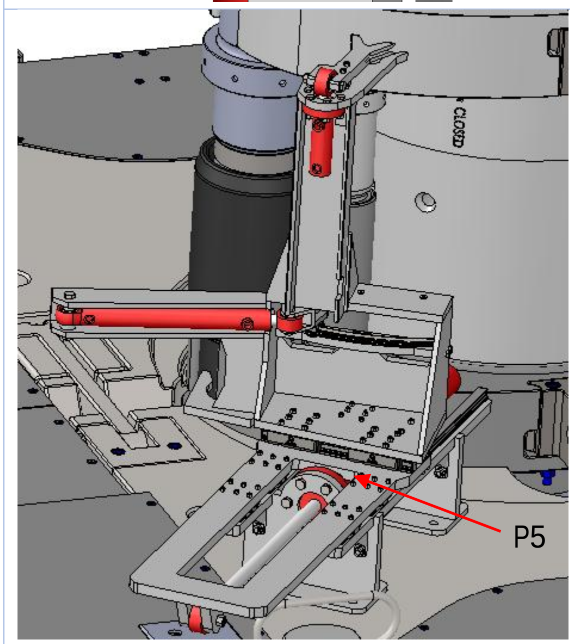
| *Index* | Illustration | Description |
|---|---|---|
| *P1* |  | P1 is placed in front of the frame detecting proximity between the AR and the riser. This sensor ensures that the AR does not crash with the riser due to activating SOL3. |
| *P2* |  | P2 is placed such that it registers proximity with the "'Non Momentum Pin" (part 63) until the index pin cylinder has reached its full extension. Then it powers down, and the BB-circuit is activated alongside SOL4. |

*Table 39 continues.*

| *Index* | Illustration | Description |
|---|---|---|
| *P3* |   | P3 is activated when the lock ring is put to closed position, activating SOL2. P3 activates the R-circuit, deactivating the BB- and the G-circuit with R2. Hence, the SOL1 and SOL4 is deactivated. It also closes R1, making the P-circuit ready for P4 to be activated. |
| *P4* |   | P4 is activated when the index pin cylinder closes, hence the index pin is closed and the coupling is safe. P4 activates the P- circle, deactivating the O-circle with R3, making the B-circle ready for P5 to be activated with R4. |
| *P5* |   | P5 is activated when the AR is fully withdrawn. The B-circuit is activated, activating R5 that deactivates the P-circle, hence R3 and R4. The lock ring cylinder is moved back to its initial position. R4 has a time delay for the B-circle to reset the hydraulic system. |

# 11 Deformational and stress study:

To verify the design, a deformation study is conducted. This study examines three different scenarios related to the three cylinders in the system. The critical deformations are each found if the cylinders are jammed in some way. This can be either because of a collision, a fault in the sensor system or corroded or broken elements. The three cases that needs further study are:

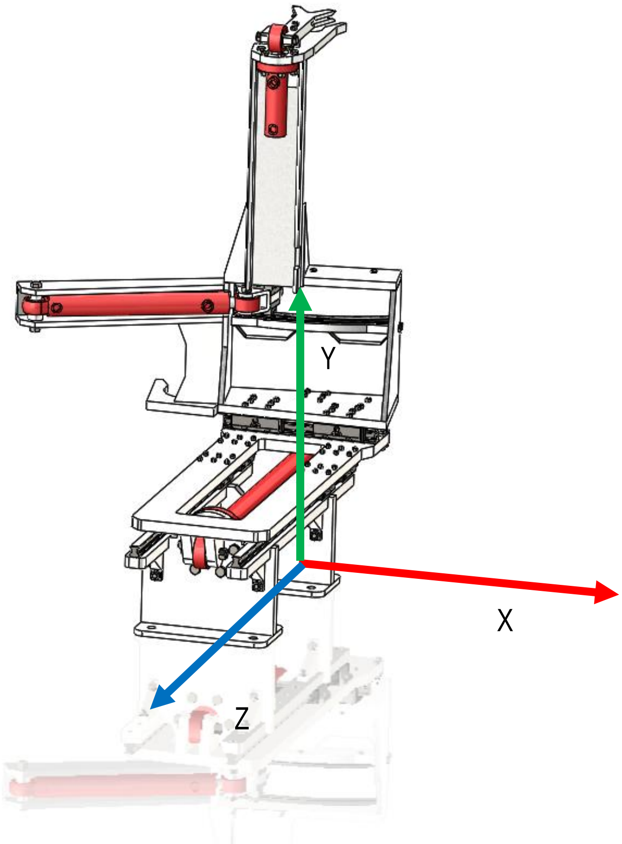



*Figure 81 - Configuration of Axis on AR.*

1. Deformation from index cylinder activated (jammed cylinder)
2. Deformation from rotator cylinder activated (jammed cylinder)
3. Deformation from radial cylinder activated (jammed cylinder)

## 11.1 Requirements

To verify whether the deformation or force is adequate, the following requirements have been made:

*Table 40 – Requirements for deformational and stress study.*

| *Index* | Description | Requirement |
|---|---|---|
| *1.* | Maximum stress: | 355 $MPa$ |
| *2.* | Maximum deformation of the guide rails are: | $\frac{\delta_{maks}}{L} <$ 2,68 $\frac{\mu m}{mm}$ |
| *3.* | Maximum load for the runner blocks are: | 23400 $N$ |

## Runner Blocks

The maximum stress of the Runner blocks are shown in the catalog below:

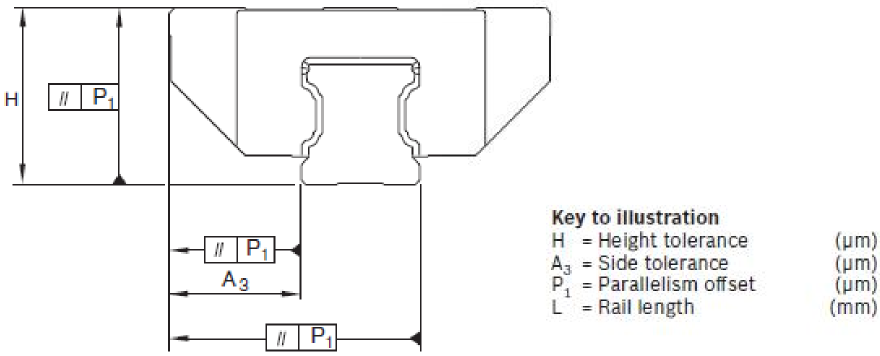
### Product overview, ball runner blocks with load capacities and moments

| Ball runner block | | Page | | Size | | 15 | 20 | 25 | 30 | 35 | 45 | 55 | 65 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Load capacities (N) and load moments (Nm) | | | | | | | |
| Standard, heavy-duty, ball runner block[7] made of steel[3] Resist NR[4] Resist CR[6] | FNS R1651[3)6)] R2001[4)] | 48[3)] 99[4)] | 106[6)] | C | 1) | 9 860 | 23 400 | 28 600 | 36 500 | 51 800 | 86 400 | 109 000 | 172 000 |
| | | | | C | 2) | 8 850 | 22 200 | 26 700 | 34 800 | 49 400 | 82 400 | – | – |
| | | | | $C_0$ | 1) | 12 700 | 29 800 | 35 900 | 48 100 | 80 900 | 132 000 | 174 000 | 280 000 |
| | | | | $C_0$ | 2) | 10 800 | 27 700 | 32 300 | 44 700 | 75 200 | 123 000 | – | – |
| | SNS R1622[3)6)] R2011[4)] | 54[3)] 99[4)] | 106[6)] | $M_t$ | 1) | 95 | 300 | 410 | 630 | 1 110 | 2 330 | 3 480 | 6 810 |
| | | | | $M_t$ | 2) | 85 | 280 | 380 | 600 | 1 060 | 2 220 | – | – |
| | | | | $M_{t0}$ | 1) | 120 | 380 | 510 | 830 | 1 740 | 3 560 | 5 550 | 11 100 |
| | | | | $M_{t0}$ | 2) | 100 | 350 | 460 | 780 | 1 620 | 3 320 | – | – |
| | SNH R1621[3)6)] | 60[3)] | | $M_L$ | 1) | 68 | 200 | 290 | 440 | 720 | 1 540 | 2 320 | 4 560 |
| | | | | $M_L$ | 2) | 62 | 190 | 270 | 420 | 700 | 1 480 | – | – |
| | | | | $M_{L0}$ | 1) | 87 | 260 | 360 | 580 | 1 130 | 2 350 | 3 690 | 7 400 |
| | | | | $M_{L0}$ | 2) | 76 | 240 | 330 | 540 | 1 060 | 2 210 | – | – |

*Figure 82 - Runner block from catalog* [18, page 12].

## Guide rails

The maximum deformation on the guide rails are:




| Ball runner block | | | Ball guide rails N (µm) |
|---|---|---|---|
| N | Tolerance dimension H | (µm) | ±100 |
| | Tolerance dimension $A_3$ | (µm) | ±40 |
| | Max. diff. in dimensions H and $A_3$ on one rail | (µm) | 30 |

*Figure 83 - Runner block from catalog* [18, page 33-34].

This yields a tolerated deformation of the rail for $\delta < 200\ \mu m = 0{,}2\ mm$ per the length of the rail block in Y-direction. The Runner block is 74,6 mm. This yields a maximum deflection of:

$$\frac{\delta_{maks}}{L} = \frac{200\ \mu m}{74{,}6\ mm} = \mathbf{2{,}68\,\frac{\mu m}{mm}} \qquad (3.9)$$

## 11.2 Deformation study 1: Index pin jammed

A jam of the index pin will make the cylinder press up to 30 bars without moving. The study shows the plus side activated to simulate the biggest force.

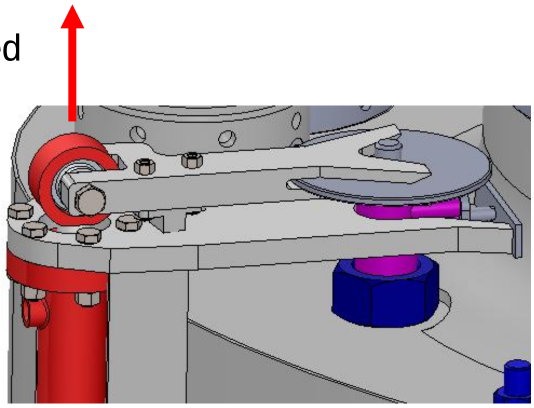


Figure 84 - Jammed Index pin.

### 11.2.1 Study 1: Frame

The mesh of the frame is as shown below.
The Runner blocks are left out of the analysis, as they are retail products. The frame is supported by the Runner blocks, but also by the P-line of the riser.

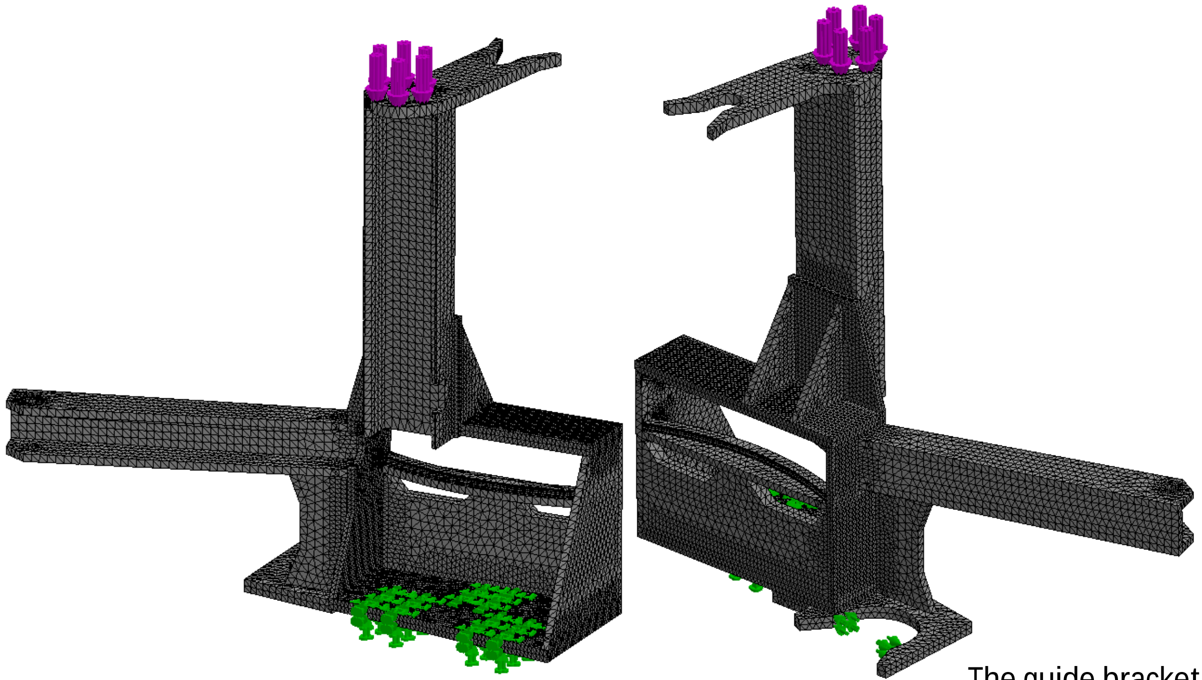



Figure 85 - Study 1 - Force and reactions – Frame.

The maximum deformation of the rails are 0,34 mm (see picture next page). This yields:

$$\frac{340\ \mu m}{L} = \frac{340\ \mu m}{306\ mm} = 1{,}11 < 2{,}68 \qquad (3.9)$$

$$\boldsymbol{\delta = ok}$$

Deformation plot:

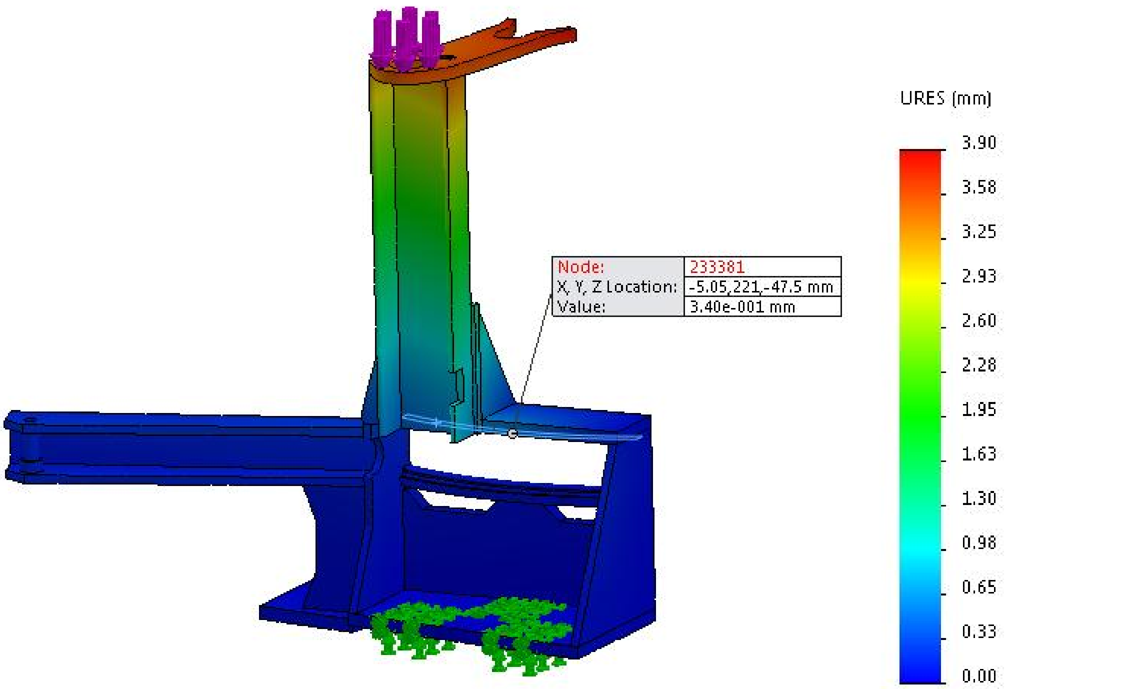



*Figure 86 - Study 1 - Deformation plot – Frame – max deformation on rail = 0,34 mm.*

This yields the following stress plot with maximum values listed in the picture:

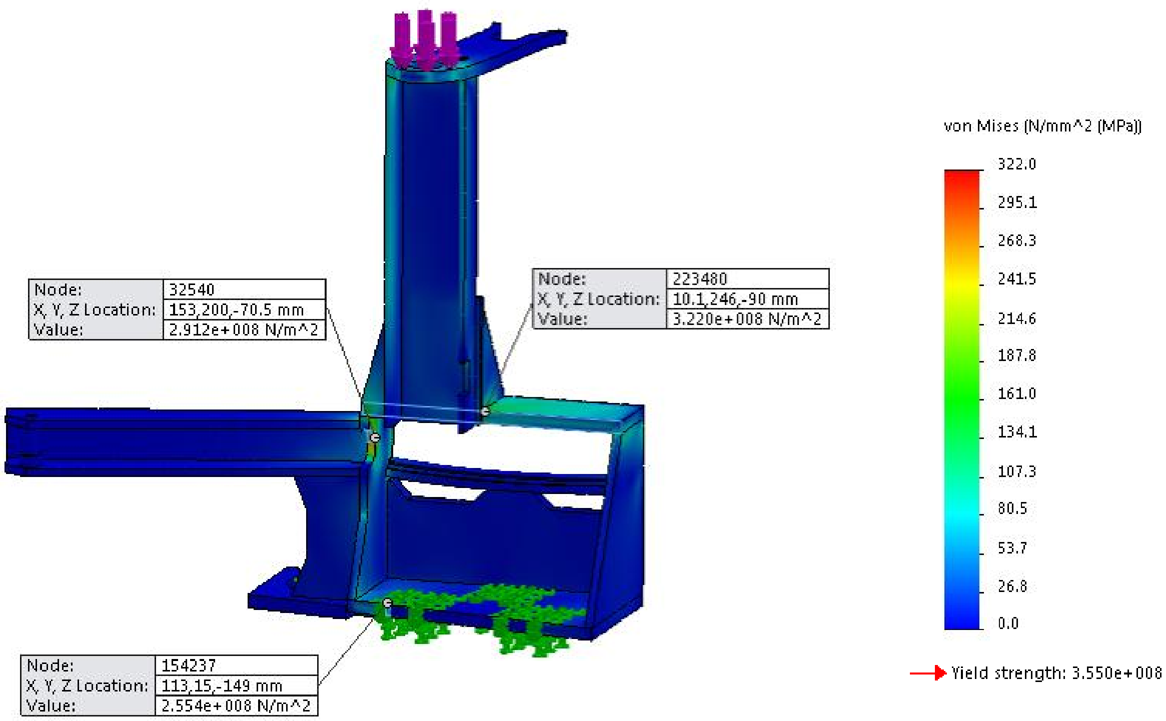
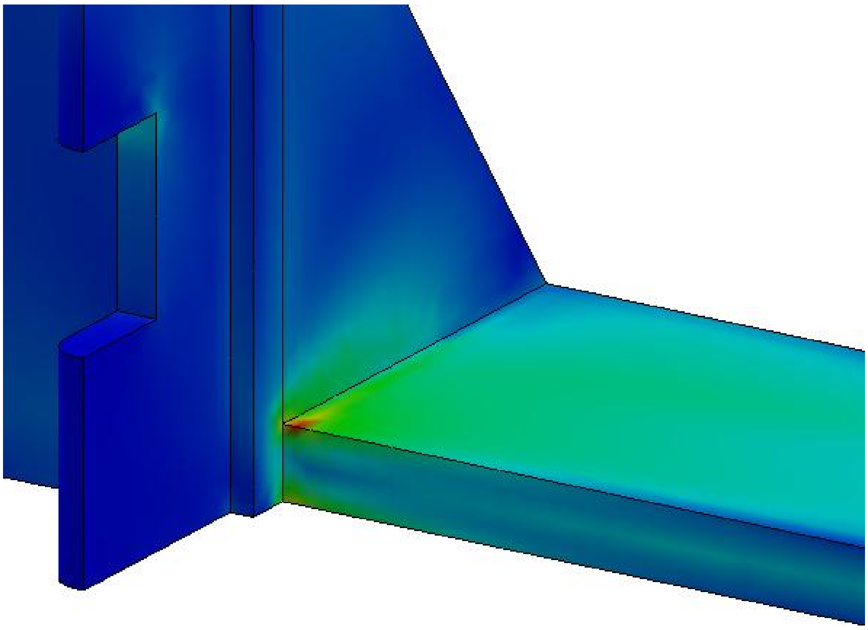



*Figure 87 - Study 1 - Stress plot – Frame – max stress = 322,0 MPa.*

An enlarged picture of the maximum stress is shown below. This hot spot of stress appears due to the sharp corners of the three parts meeting. However, when welding, a fillet between the bracket and top plate is created and the hot spot stress is diluted.



Reaction forces from the frame:

| | |
|---|---|
| Left guide: | 13559 $N$ |
| Right guide | 4101,6 $N$ |
| Middle guide | $-3526$ $N$ |

These are used to dimension the base.

*Figure 88 - Study 1 - Stress hot spot – Frame – max stress = 322 MPa.*

### 11.2.2 Study 1: Slider

The mesh of the slider is shown below. The runner blocks are left out of the analysis, as they are retail products.

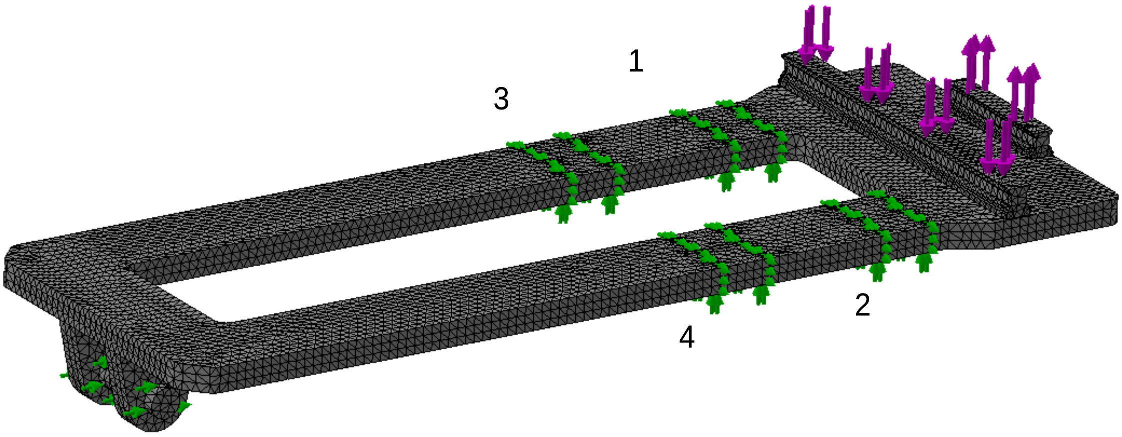



*Figure 89 – Study 1 – Forces and reactions – Slider.*

When the index pin is jammed, the forces from the frame is transferred to the slider, as shown above.

Stress plot:

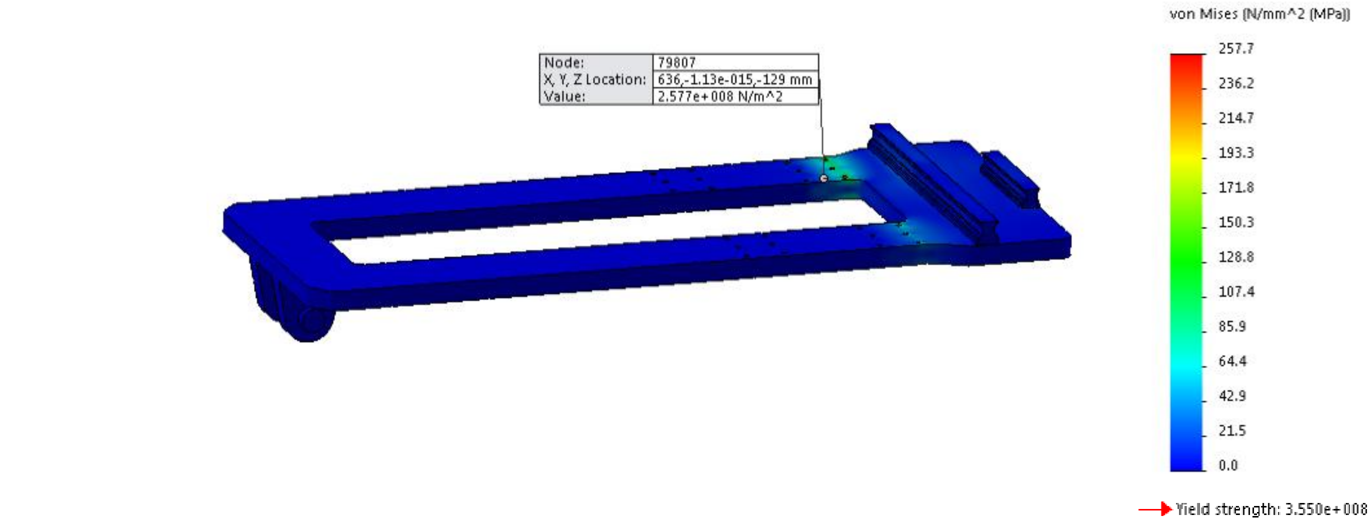



*Figure 90 - Study 1 - Stress plot – Slider – max stress = 257,7 MPa.*

The biggest stress is 257,7 $MPa$. This stress is found on the underside near the screw holes. This hot spot of stress is located on the compressed side of the base. This is not dangerous, as compressed stress do not initiate cracks.

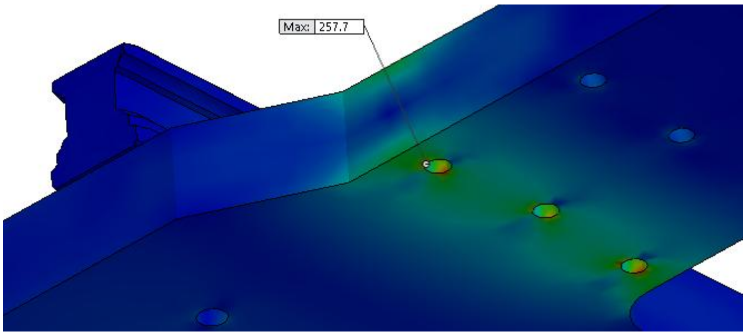



*Figure 91 - Study 1 – Stress hot spot – Slider – max stress = 257,7 MPa.*

Deformation plot:

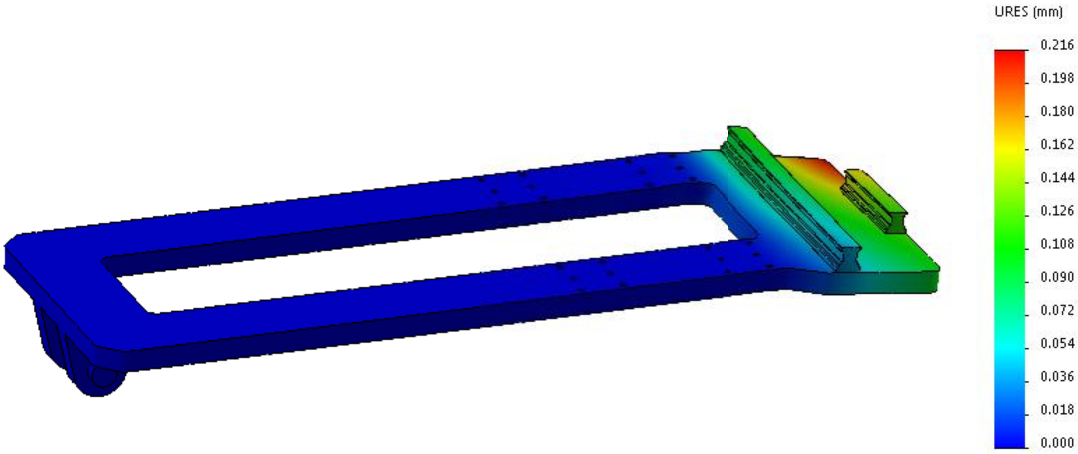



*Figure 92 - Study 1 - Deformation – Slider – max deformation of guide rail = 0,168 mm.*

The largest deformation of the guide rail is 0,168 $mm$. This yields:

$$\frac{168\ \mu m}{L} = \frac{168\ \mu m}{115\ mm} = 1{,}46 < 2{,}68 \qquad (3.9) \qquad \boldsymbol{\delta = ok}$$

The reaction forces of the guides are (indexes are listed by the mesh plot):

1. Front left: 10266 $N$
2. Front right: 3518 $N$
3. Back left: 236 $N$
4. Back right: 116 $N$

### 11.2.3 Study 1: Mounting

The mesh of the mounting is shown below.

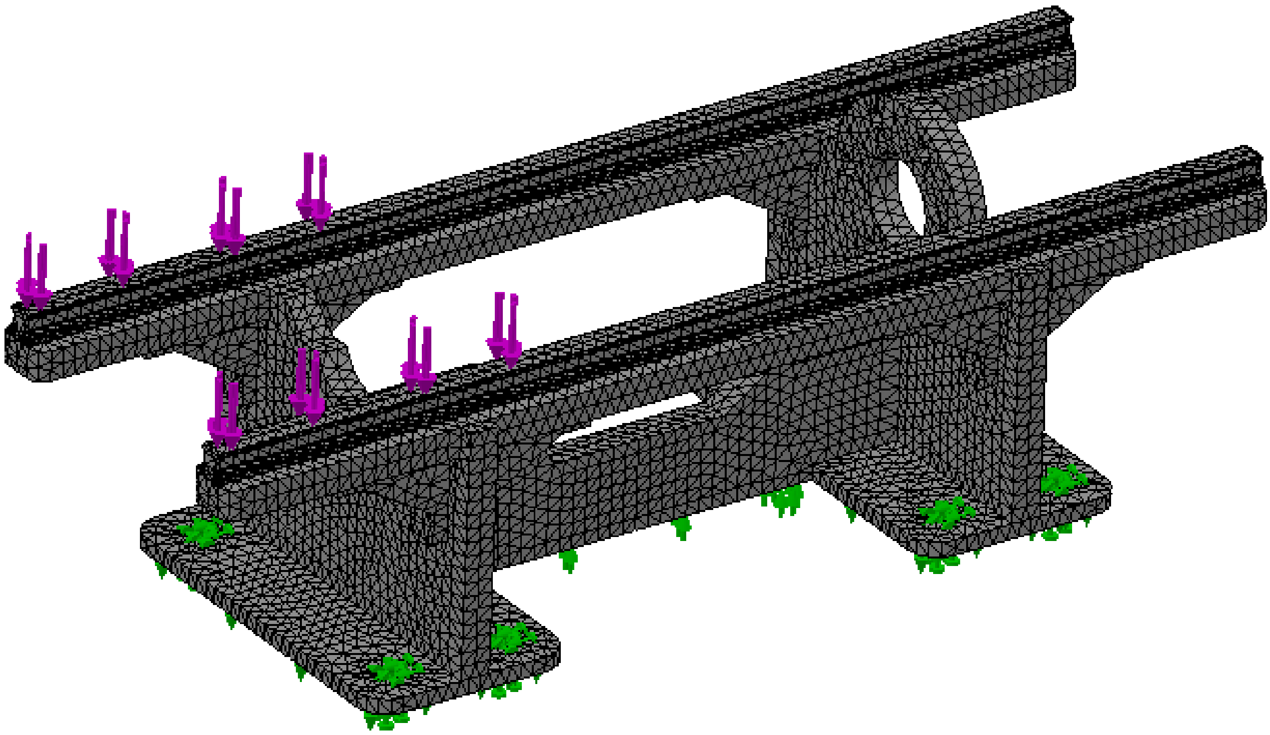


*Figure 93 - Study 1 - Forces and reactions – Mounting.*

Stress plot:

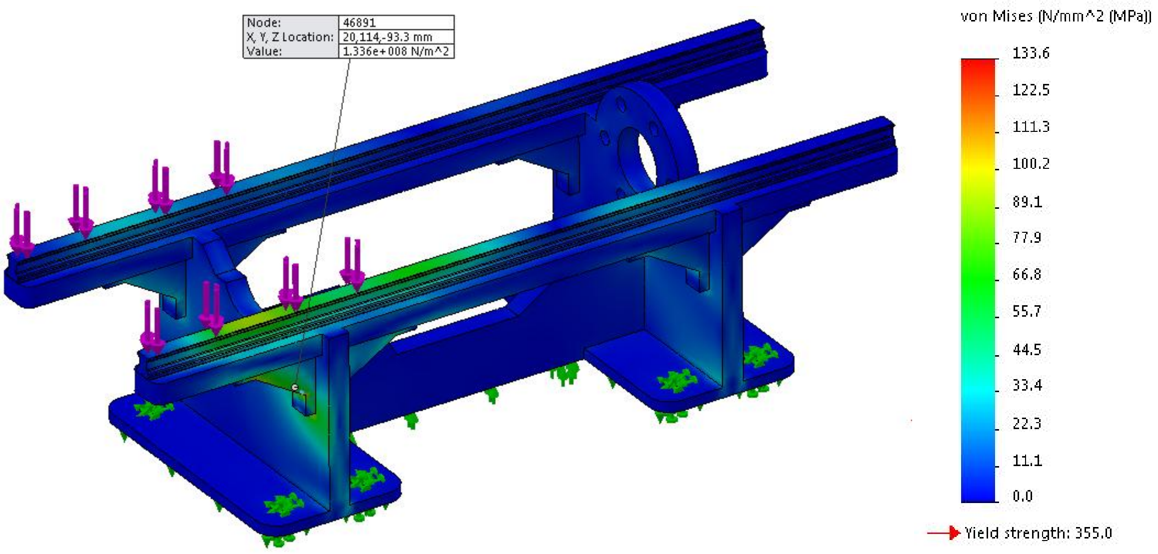



*Figure 94 - Study 1 – Stress plot – Mounting – max stress = 133,6 MPa.*

Deformation plot:

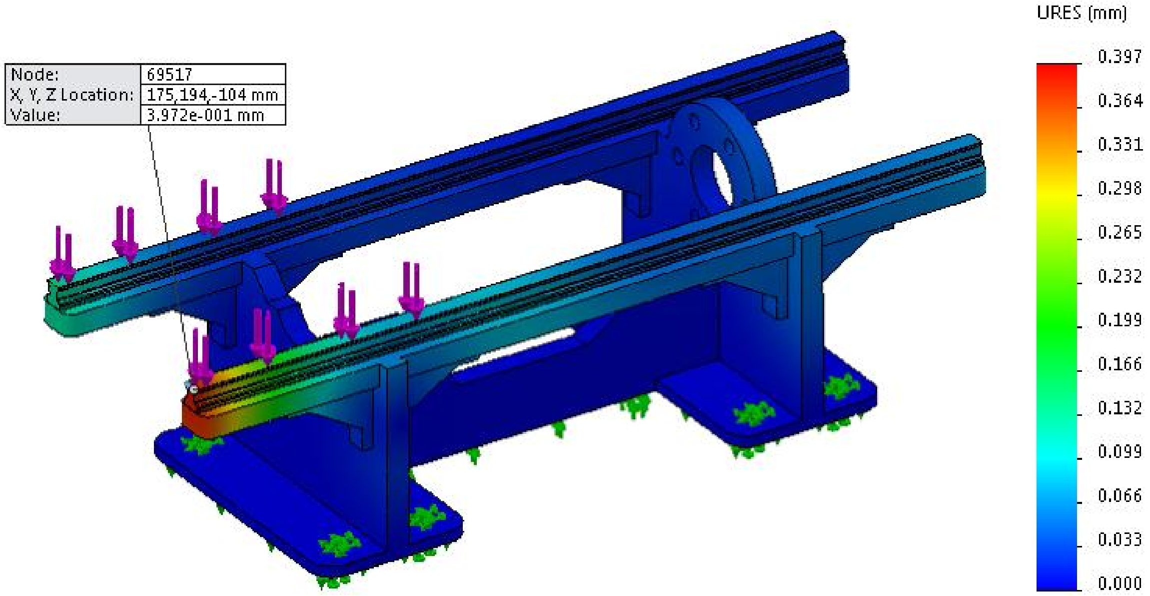



*Figure 95 - Study 1 - Deformation – Mounting – max deformation of guide rail = 0,397 MPa.*

The largest deformation of the rail is 0,397 $mm$. This yields:

$$\frac{397\ \mu m}{L} = \frac{397\ \mu m}{740\ mm} = 0{,}54 < 2{,}68 \qquad (3.9) \qquad \boldsymbol{\delta = ok}$$

## 11.3 Deformation study 2: Possible impact with P-line – sensor failure

A sensor failure rams the frame into the P-line with maximum hydraulic pressure from actuator 1. The P-lines and the frame collides in the guide bracket (part 32) and the frame is twisted due to this offset force.

### 11.3.1 Study 2: Frame

The P-line work as a force when the force of the hydraulic cylinder presses the frame against the riser.

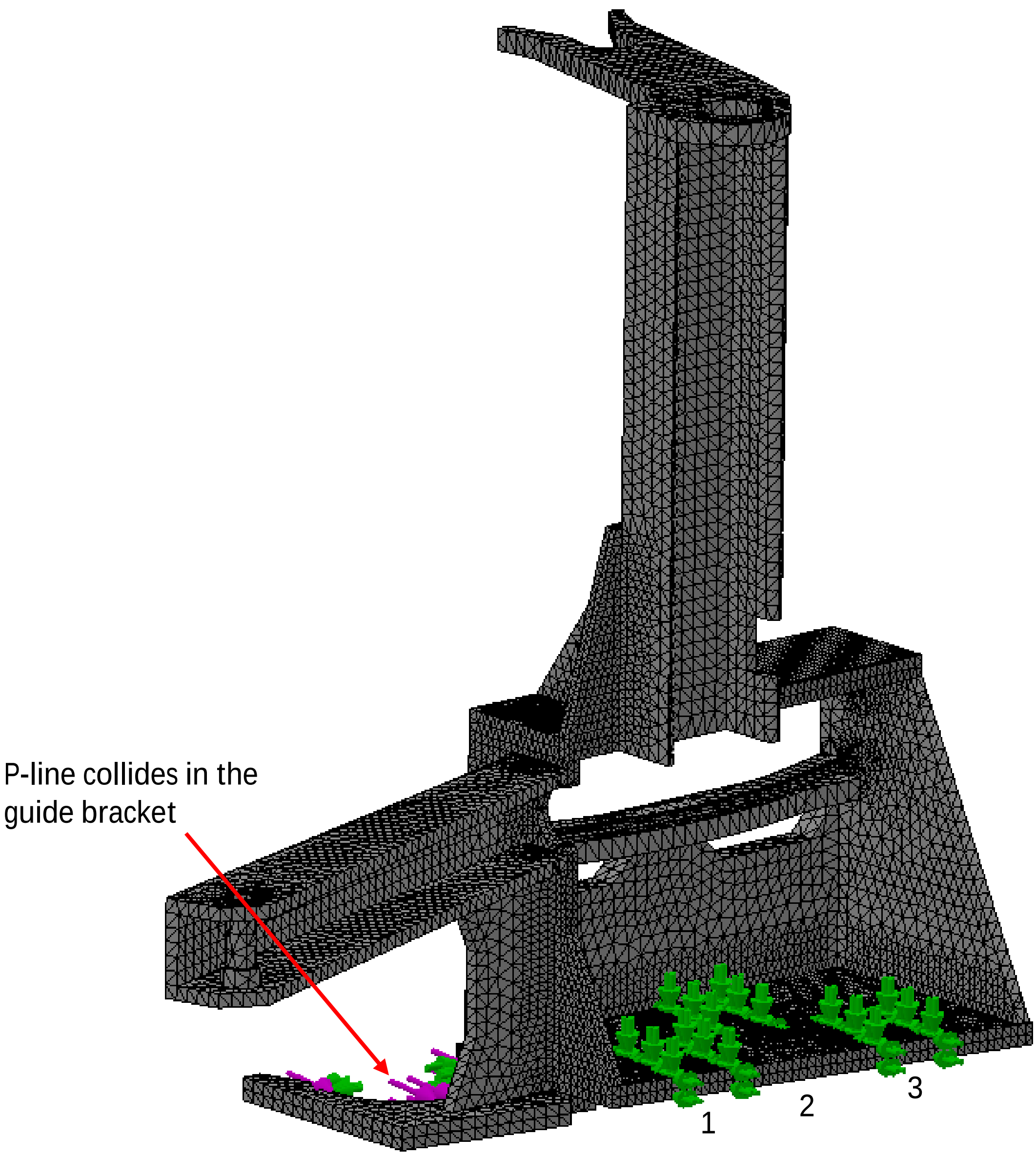



*Figure 96 - Study 2 - Forces and Reactions – Frame.*

Stress plot:

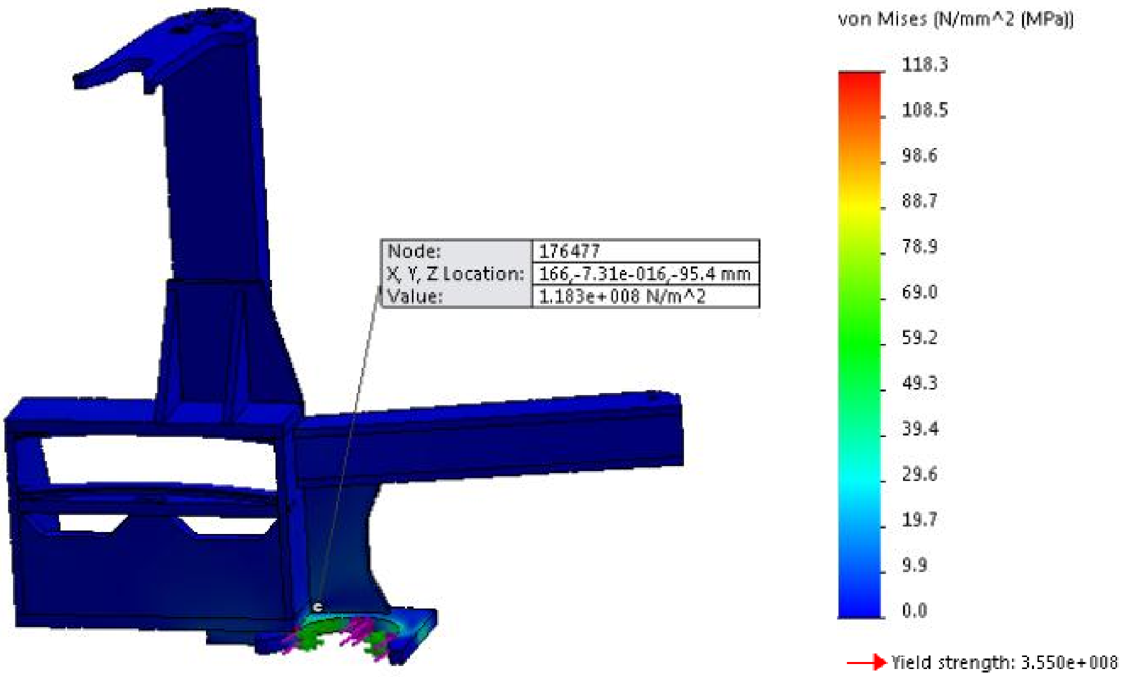



*Figure 97 – Study 2 – Stress plot – Frame – max stress = 118,3 MPa.*

Deformation plot:

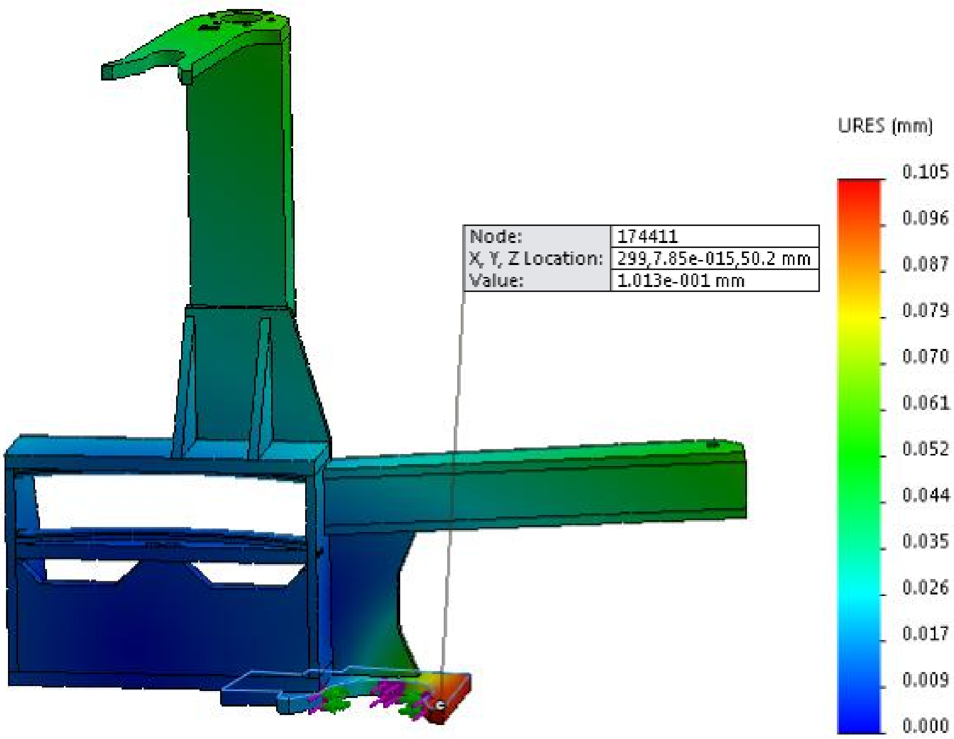



*Figure 98 - Study 2 - Deformation plot – Frame – max deformation = 0,105 mm.*

Reaction forces (indexes are listed by the mesh plot)

1. Left guide: 15721 $N$
2. Middle guide: $-3317{,}8\ N$
3. Right guide: $-3430{,}3\ N$

$$\frac{105\ \mu m}{L} = \frac{105\ \mu m}{306\ mm} = 034 < 2{,}68 \qquad \boldsymbol{\delta = ok} \qquad (3.9)$$

### 11.3.2 Study 2: Slider

Forces and reactions:

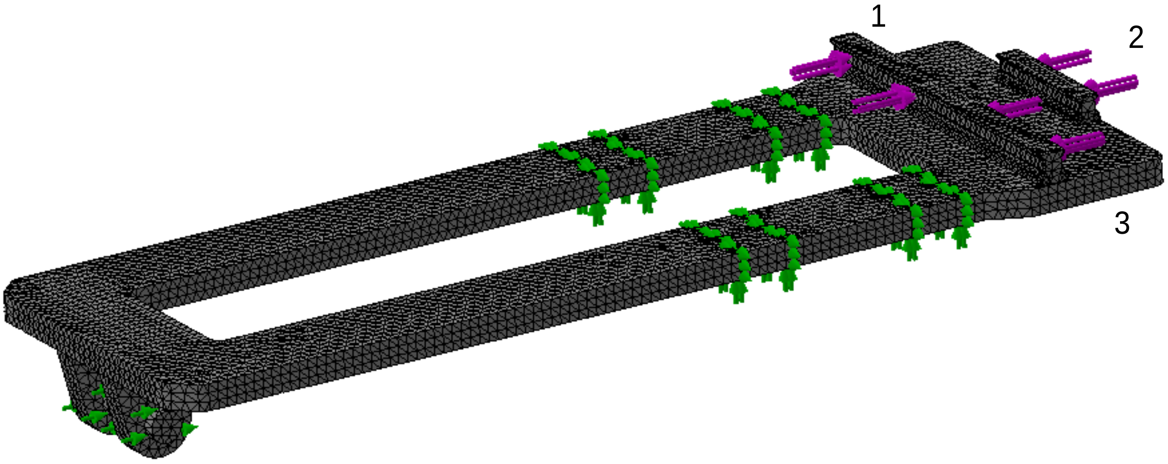



*Figure 99 - Study 2 - Forces and reactions – Slider.*

Stress plot:

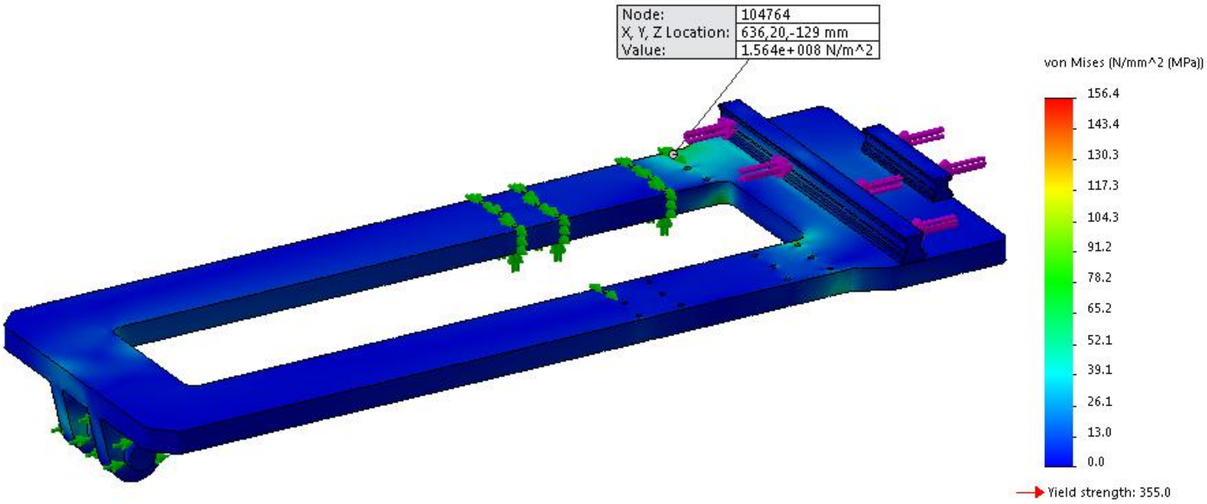



*Figure 100 - Study 2 - Stress plot – Slider – max stress = 156,4 MPa.*

Deformation plot:

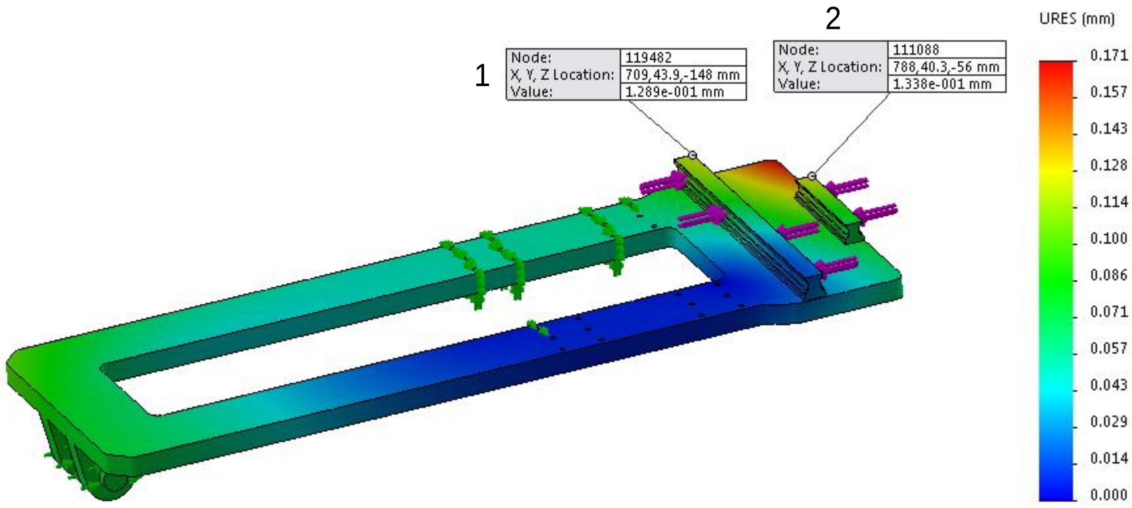



*Figure 101 - Study 2 - Deformation – Slider – max deformation of guide rails = 0,129 and 0,134 mm.*

The largest deformations of the rails are 0,129 $mm$ and 0,134 $mm$. This yields:

1 $$\frac{129\ \mu m}{L} = \frac{129\ \mu m}{300\ mm} = 0{,}43 < 2{,}68 \qquad (\mathbf{3.9}) \qquad \delta = ok$$

2 $$\frac{134\ \mu m}{L} = \frac{134\ \mu m}{115\ mm} = 1{,}16 < 2{,}68 \qquad (\mathbf{3.9}) \qquad \delta = ok$$

### 11.3.3 Study 2: Mounting

Forces and Reactions:

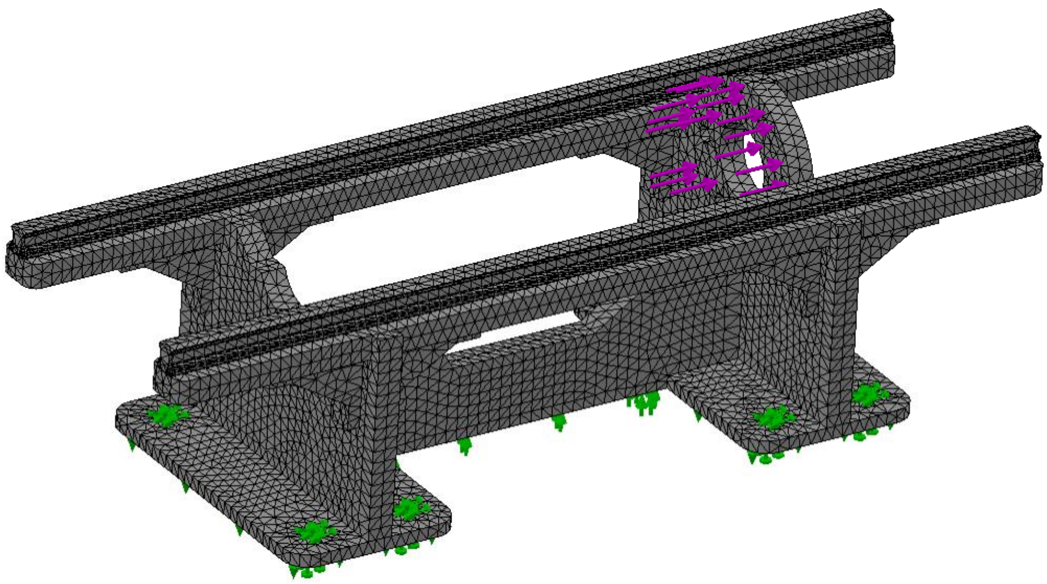


*Figure 102 – Study 2 – Forces and Reactions – Mounting.*

Stress plot:

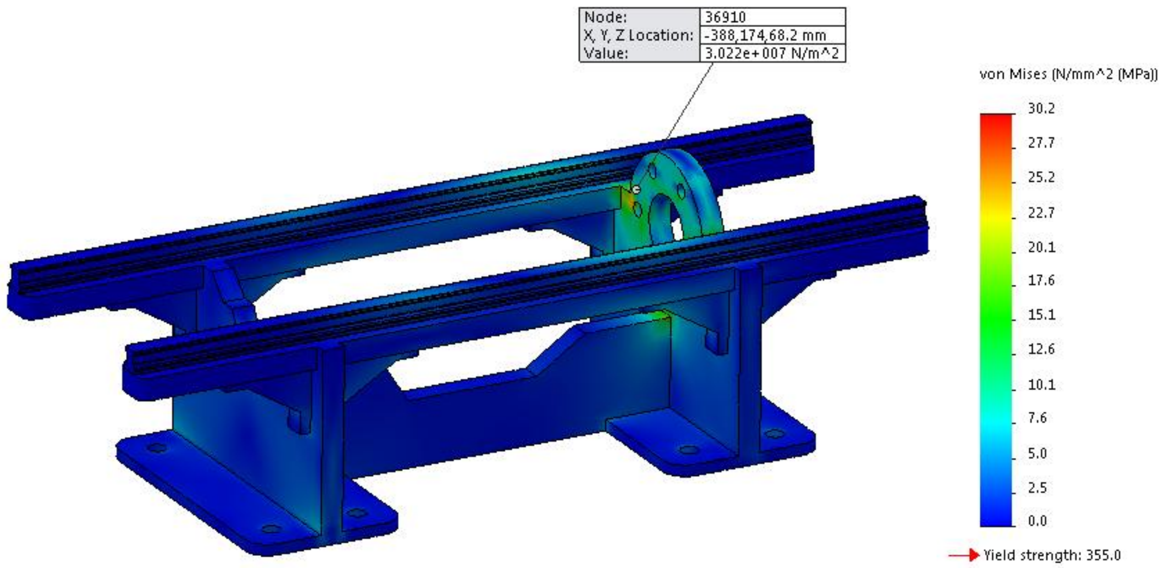



*Figure 103 – Study 2 – Stress plot – Mounting – max stress = 30,2 MPa.*

Deformation plot:

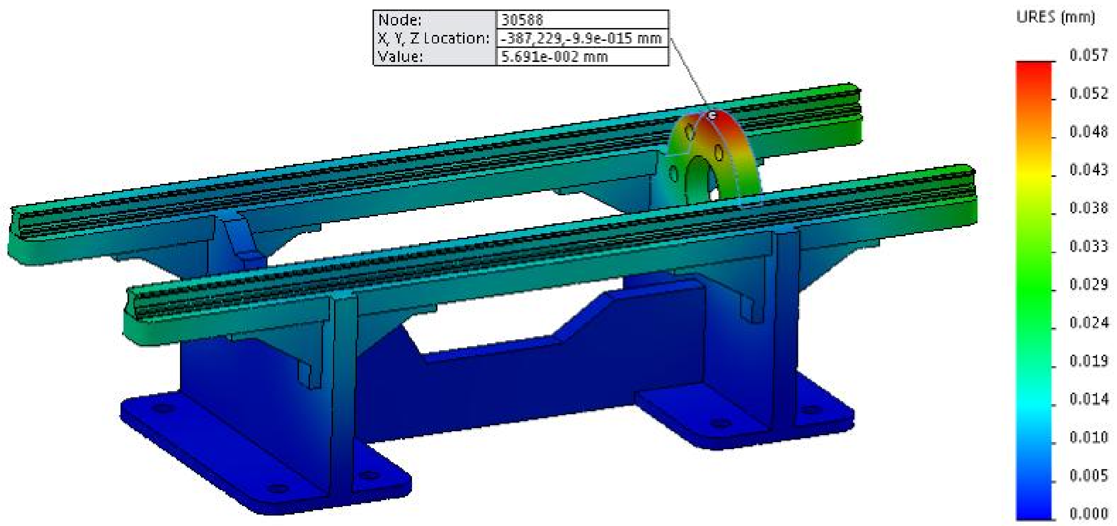



*Figure 104 – Study 2 – Deformation – Mounting – max deformation = 0.057 mm.*

Comment:

As the reaction force of the hydraulic cylinder is more than 8000 N, it is clear that almost half of the force applied at the frame goes into either the side of the P-line or similar. Therefore, this study is very conservative.

## 11.4 Deformation study 3: Lock ring jammed – plus side of cylinder

If the lock ring is jammed, the lock ring cylinder will press until the pressure relief valve opens at 30 bars. In this scenario, the frame is fixated on the P-line next to the frame. This scenario yields maximum 0,34 mm deformation of the rails shown on the probe in the picture below.

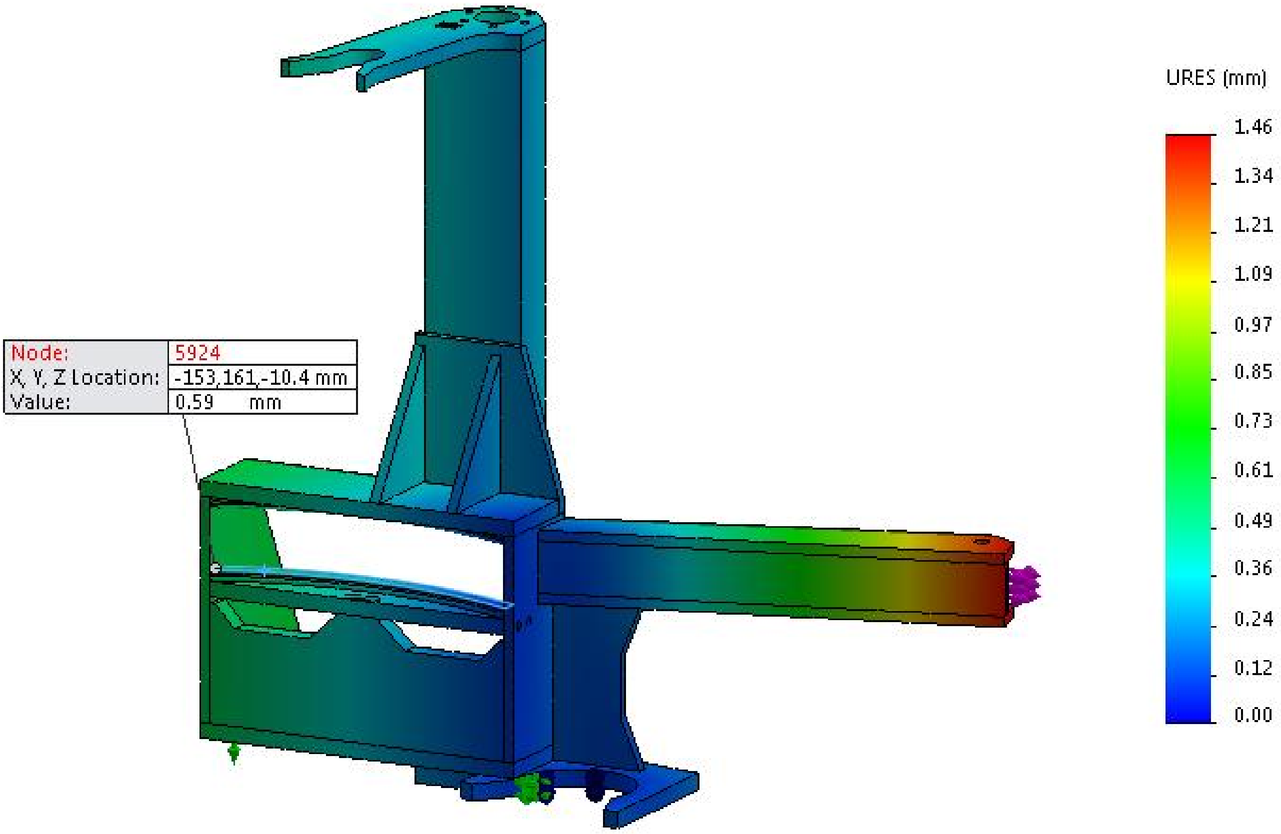



*Figure 105 – Study 3 – Forces, reactions and deformation – Frame – max deformation on guide rails = 0,59 mm.*

The largest deformation of the rail is 0,59 $mm$. This yields:

$$\frac{590\ \mu m}{L} = \frac{590\ \mu m}{306\ mm} = 1{,}93 < 2{,}68 \qquad (3.9) \qquad \boldsymbol{\delta = ok}$$

This yields the following stress plot with the maximum values listed in the picture:

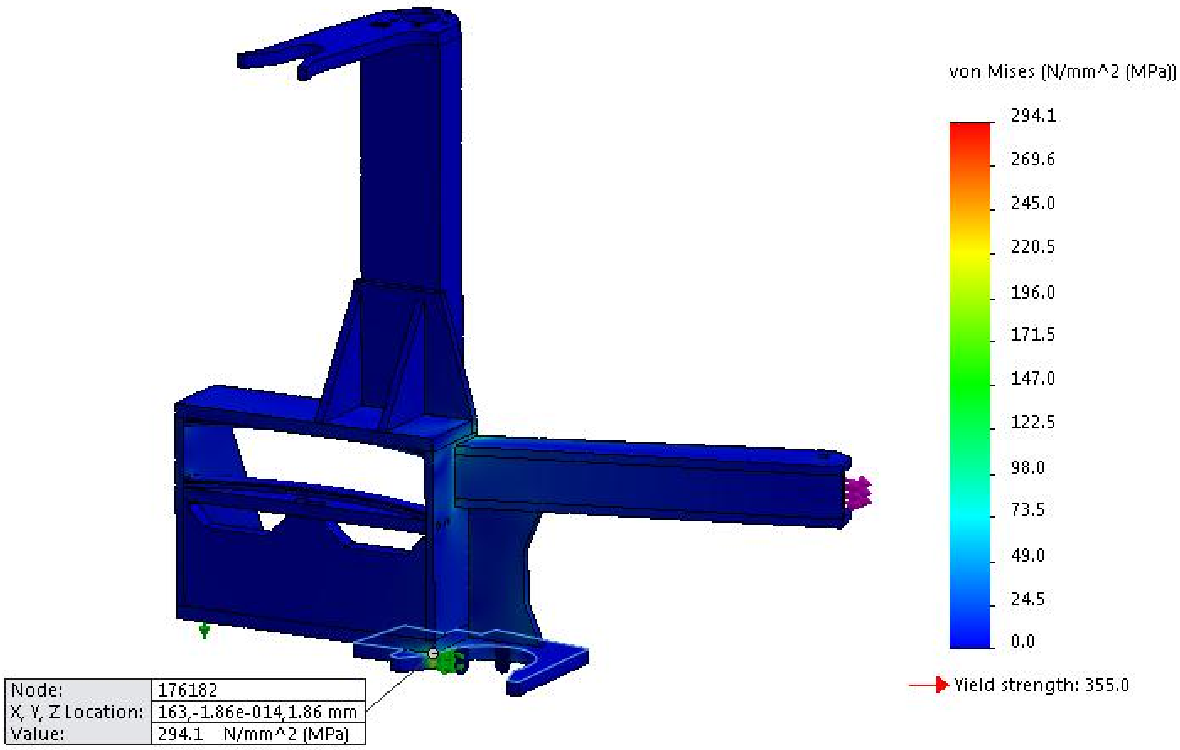



*Figure 106 - Study 3 - Stress plot – Frame – max stress = 294,1 MPa.*

The hot spot stress is shown below. This hot spot occurs on the compressed side of the P-line slot. Hence, the spot does not initiate cracks.

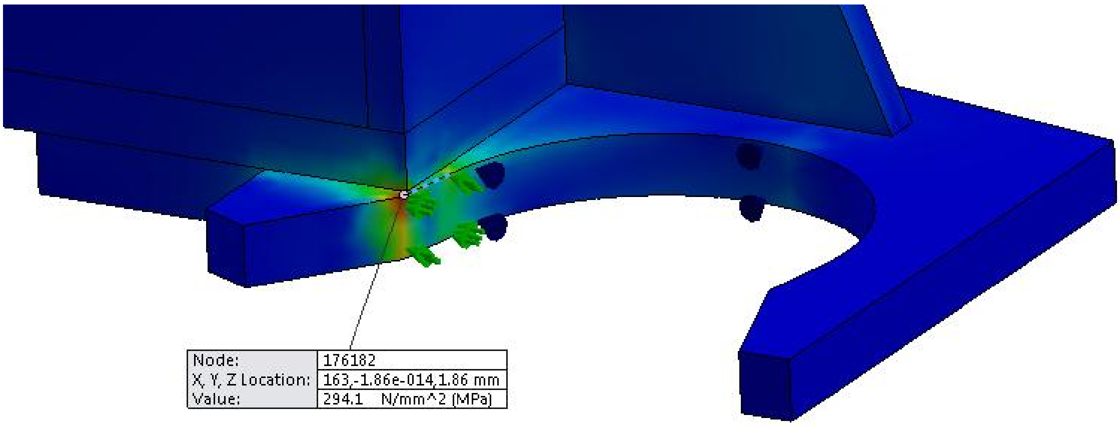



*Figure 107 - Study 3 - Hot spot stress – Frame – max stress = 294,1 MPa.*

# 12 Roughness, maintenance and recycling

## 12.1 Materials and strength

The material used for the Automated Rotator is S355. To withstand cold environment, S355J2 is chosen due to its thermal properties. A selection of material properties is listed below [5]:

*Table 41 - S355J2, selected properties.*

| | Value | Unit |
|---|---|---|
| *Yield Strength* | 355 | $MPa$ |
| *Tensile Strength* | 450 | $MPa$ |
| *Young's modulus* | 210000 | $MPa$ |
| *Density* | 7580 | $^{kg}/_{m^3}$ |

This yields a total weight of 111,6 kg (estimated using Solidworks).

## 12.2 Coating

According to NORSOK M501 [12], inorganic zinc epoxy is used for marine atmospheric exposures from $-30°$ to $85°$. This epoxy is baked on in three layers, where all layers have different chemical compositions. The thickness of the layers are standardized as follows:

*Table 42 - Coating NORSOK M501.*

| Coating | Thickness |
|---|---|
| Primer coating | $64 - 90\ \mu m$ |
| Second coating | $100 - 150\ \mu m$ |
| Outer coating | $64 - 90\ \mu m$ |
| Sum | $\mathbf{228 - 330\ \mu m}$ |

## 12.3 Maintenance

The maintenance mostly involves the guide rails and runner blocks. Below is an excerpt from the brochure from Borsch Rexroth. Borsch Rexroth states that maintenance is needed every eight hour for the Ball rail system.

Maintenance

**Cleaning cycle**

Dirt can settle and encrust on guide rails, especially when these are not enclosed.
To ensure that seals and cover strips retain their functionality, this dirt must be removed at regular intervals.
It is advisable to perform at least one full cleaning cycle over the entire installed rail length at least twice a day, but at the latest every 8 hours.
Before shutting down the machine, always perform a cleaning cycle.
Shorten the maintenance intervals for systems exposed to metalworking fluids.

*Figure 108 - Maintenance of linear equipment* [18, page 228].

## 12.4 Environmental demands and recycling

CES Edu Pack is used to calculate both the net energy spent and $CO_2$ footprint of the automated rotator. This ECO audit uses the weight of the material as input, and yields a recycling potential as output. However, the ECO audit does not include cuttings from the milling etc. All parts in the study have been made fully from virgin steel, and 10000 km of ocean shipping has been accounted for. The full ECO audit report is found in appendix IV.

The following energy distribution is calculated when 43,7 % of the parts have been casted, and 56,3 % have been rolled or extruded (percentiles are estimated).

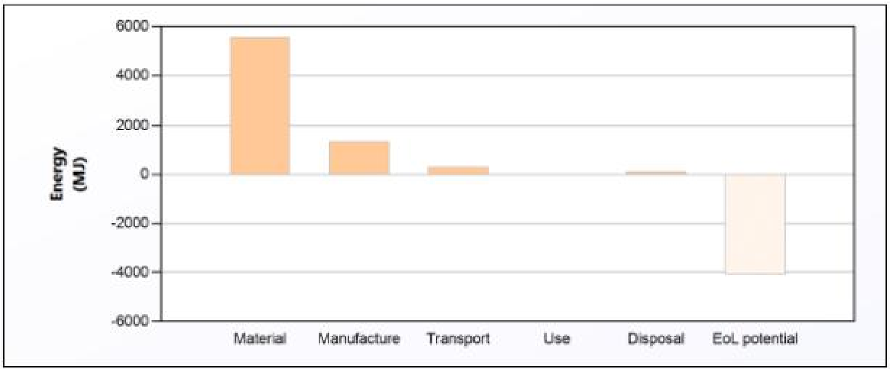



*Figure 109 - Energy distribution during the life time of the AR.*

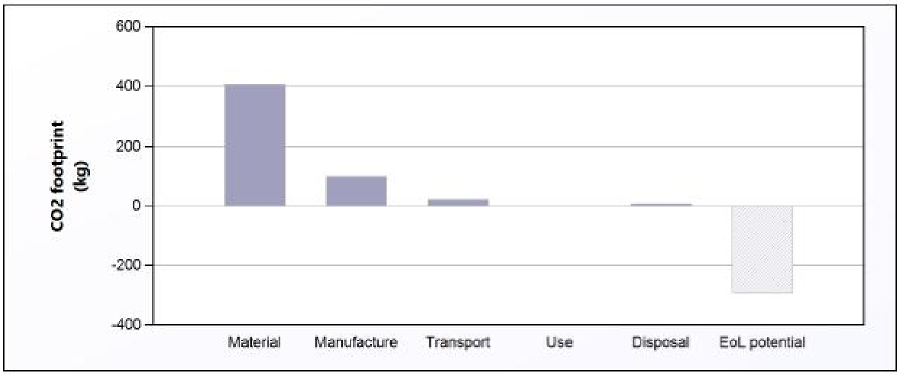



*Figure 110 - $CO_2$ distribution during the lifetime of the AR.*

The EoL potential represents the End of Life potential if the steel used are recycled. If this potential is reached the following energy and $CO_2$ distribution is obtained after ten years of usage and recycling:

*Table 43 – Net sum after EoL potential have been reached.*

| Phase | Energy (MJ) | $CO_2$ footprint (kg) |
|---|---|---|
| Material | 5540 | 407 |
| Manufacture | + 1361 | + 102 |
| Transport | + 309 | + 22 |
| Use | + 0 | + 0 |
| Disposal | + 120 | + 8 |
| Total (for first life) | = 7330 | = 539 |
| End of Life potential | - 4080 | - 292 |
| Net SUM | = 3250 | = 247 |

# 13 Production and production costs

This chapter involves production methods and estimated cost for making a prototype.

## 13.1 Manufacturing processes

The Automated Rotator consist of 82 unique parts and the index pin assembly consist of 9 parts. This yields a total of 91 parts, both retail and originals. In this chapter all parts with instructions will not be accounted for independently. However, the production methods mentioned in the BoMs will be explained. The full BoM for the automated rotator with production references is enclosed in appendix I "*BoM for Automated Rotator with production methods*". The BoM of the index pin assembly is found in chapter 8.2.1. with corresponding production methods.

*Table 44 - Manufacturing processes used in producing the AR.*

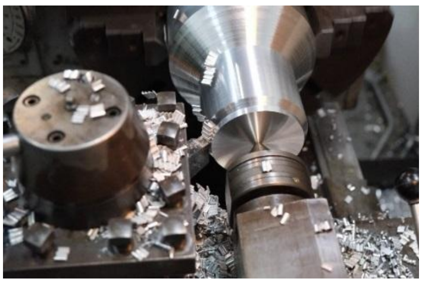
| *Illustration* | Production method |
|---|---|
| <br>Figure 111 - Illustration of waterjet cutting [27]. | **Cut from steel plate – Waterjet Cut**<br>Most plates used in the AR is between 5 mm and 20 mm, making waterjet cutting most suitable for this purpose.<br>Waterjet cutting is based on pressurized water stream flowing through a nozzle making fine cuts. The water has a pressure of 60000 – 90000 $PSI$ before exiting the nozzle. To cut hard metals, abrasives are added for penetrating the metal and transport cuttings more efficient. |
| <br>Figure 112 - Illustration of milling [30]. | **Milling**<br>Milling is used for shaping metals using a rotary cutter. A regular milling machine has three axes which it can move. This way complex forms can be made out of plates. CNC milling machines are programable and automatic. |
| <br>Figure 113 - Illustration of lathe [23]. | **Lathe**<br>Lathe is used for shaping metals rotating the metal piece, and machine it with different cutting tools. This way the result gets symmetrical around the rotational axis. This method is used for most cylindrical parts. |

*Table 44 continues*

Figure 114 - Illustration of CNC machining [20].

| 5 axis CNC machining |
|---|
| 5 axis CNC machining is used for complex parts where more than 3 axis are needed. The 5 axis CNC machine is able to move the workpiece in three axis, as well as spinning both the tool and the work piece, making it five axes in total. |

## 13.2 Estimated costs for prototyping

To estimate price for prototyping, a rough cost estimate has been made.

*Table 45- Cost estimate for Prototyping.*

| Product development | | | |
|---|---|---|---|
| Development cost | Hours | Price per hour (NOK) | Sum (NOK) |
| 1. Definitions and Methodology | 184 | 600 | 110.400 |
| 2. Concept Development | 235 | 600 | 141.000 |
| 3. Construction and Design | 415 | 600 | 249.000 |
| 4. Product Realization | 263* | 600 | 67.800 |
| Partial sum: | 1097 | - | 658.200 |
| **Prototyping** | | | |
| Working cost | Hours | Price per hour (NOK) | |
| 1. Cutting, machining and lathing | 50 | 800 | 40.000 |
| 2. Welding | 55 | 800 | 44.000 |
| 3. Coating | 15 | 800 | 12.000 |
| 4. Assembly | 15 | 800 | 12.000 |
| Partial sum: | 135 | | 108.000 |
| Materials and components | Quantity | Price | |
| 1. Steel plates | 100 kg | $35\ {}^{kr}/_{kg}$ | 3.500 |
| 2. Standard Profiles | 10 kg | $40\ {}^{kr}/_{kg}$ | 400 |
| 3. Coating | 1 | 15.000 | 15.000 |
| 4. Hydraulic and electric system | 1 | 250.000 | 250.000 |
| 5. Linear guides and rails | 7 | 25.000 | 175.000 |
| 6. Screw and nuts | 180 | 30 | 5.400 |
| 7. Other parts | - | 5000 | 5.000 |
| Partial sum: | | | 454.300 |
| **Sum product development and prototyping** | | | SUM |
| Product development | | | 568.200 |
| Working cost | | | 108.000 |
| Materials and components | | | 454.300 |
| SUM | | | 1.130.500 |

Product development is the cost of the engineering for developing the product. This report is a part of the product development, but there have not been made enough technical drawings fin this report to finalize the product. In addition to the students work an additional amount of 150 hours is added to the post "product realization" (*) to create all necessary technical drawings. Hence, the net time used by the student is:

$$1097\ hours - 150\ hours = 947\ hours$$

"Working cost" is the cost of a mechanical workshop for making all parts by using technical drawings. It also involves the price for welding, coating and assembling the product.

The mechanical workshop needs material and retail components. The hydraulic and electrical system combined with the linear motion system is the high expenses of this post.

Product development combined with working cost and materials and components yields an estimated price of 1.130.500 NOK for producing a prototype. When producing more than one, the development cost is distributed for all produced units. This yields a lower price per unit. To the right a pie chart shows the money distribution when producing only one unit.

Only about 30 riser strings have been sold since early 1990s, hence mass production is not applicable for the AR.

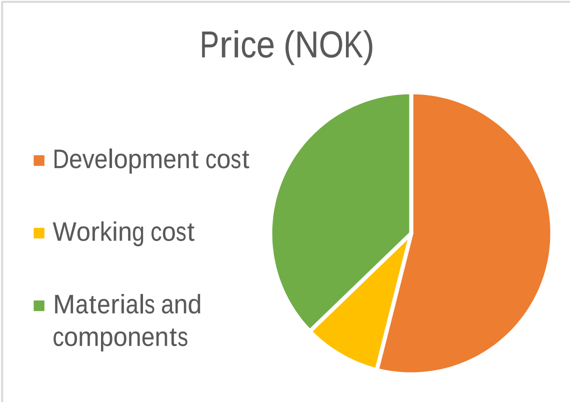



*Figure 115 - Price distribution for one prototype.*

# 14 Assembly Procedure and Transportation

This chapter shows the assembly procedure for the floor mounting, the slider, the frame and the index pin assembly. It also shows how the AR should be transported.

## 14.1 Assembly procedure for Floor mounting

*Table 46 - Assembly procedure for floor mounting.*

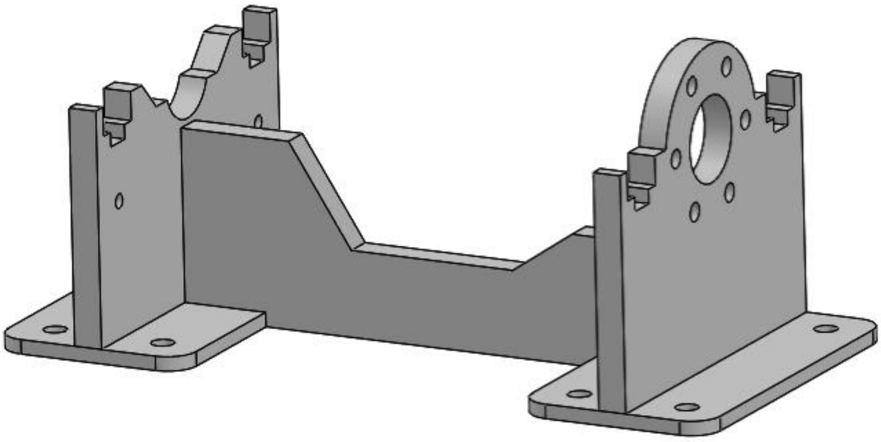
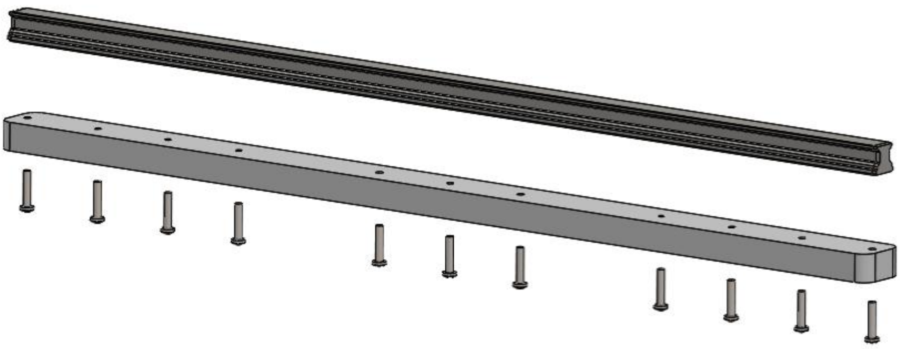
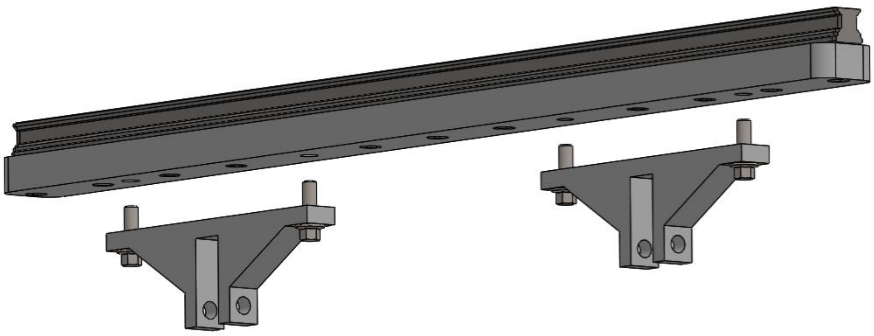
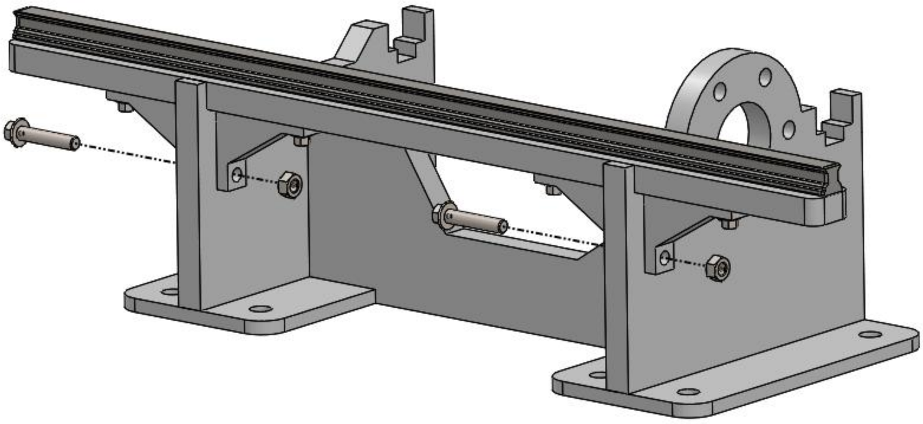
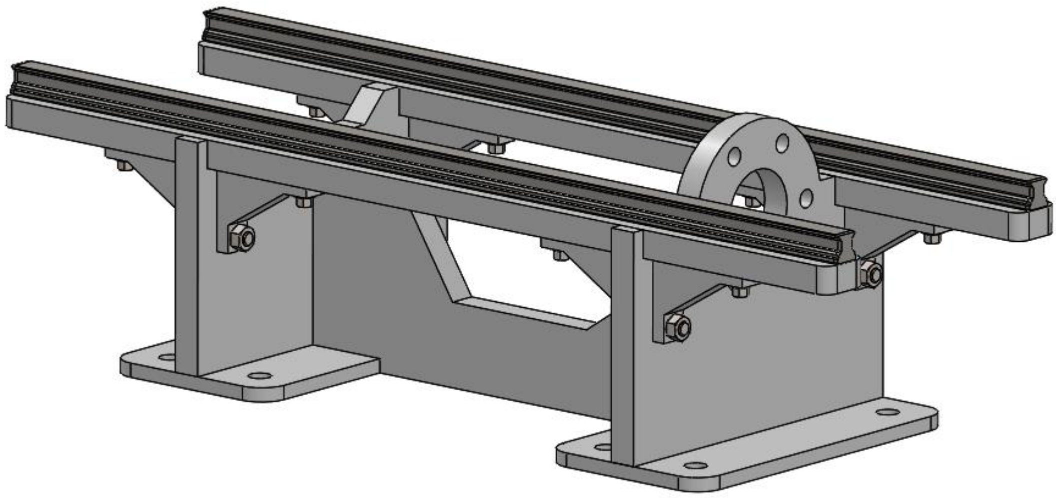
| Step | Description |
|---|---|
| 1 | <br>Weld the two floor weldments (part 1 and 2) together with the jack (part 5). |
| 2 | 2x<br><br>Fasten the rail (part 6) onto the rail bracket (part 4) using 11xM5 screws (part 7).<br><br>Attach the floor bracket (part 3) to the rail bracket (part 4) using 4xM5 screws (part 8). |

*Table 46 continues.*

| | |
|---|---|
| 3 | 2x  Fasten the floor bracket (part 3) to the floor weldment (part 1 and 2) using 2xM10 bolt and nut (part 9 and 10). |
| 4 |  The finished floor assembly is shown above. |

## 14.2 Assembly procedure for Slider

*Table 47 - Assembly procedure for Slider.*

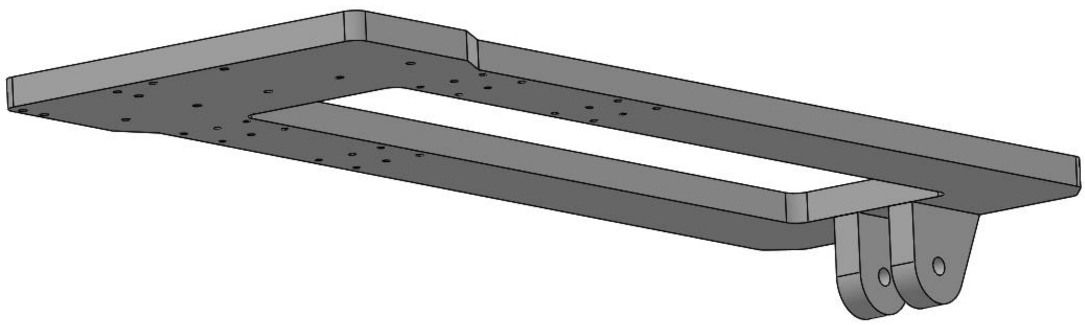
| Step | Description |
|---|---|
| 1 |  Weld the two hydraulic brackets (part 16) to the Slider Flat steel (part 14). |

*Table 47 continues.*

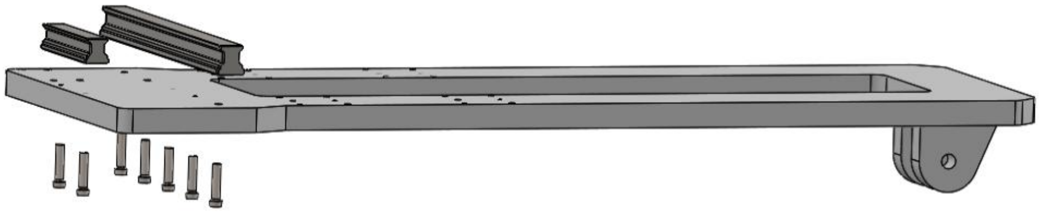
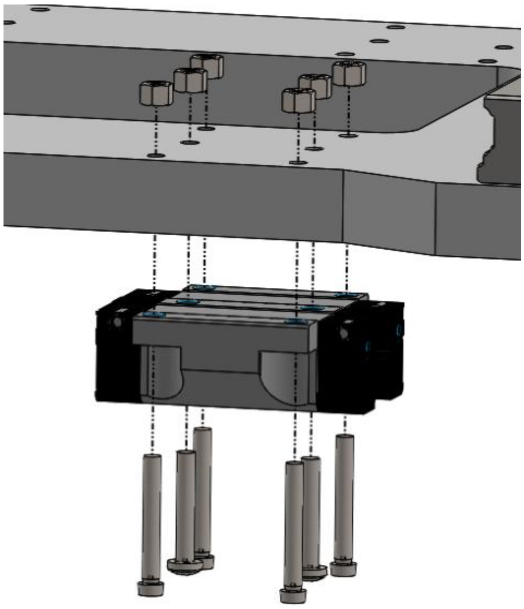
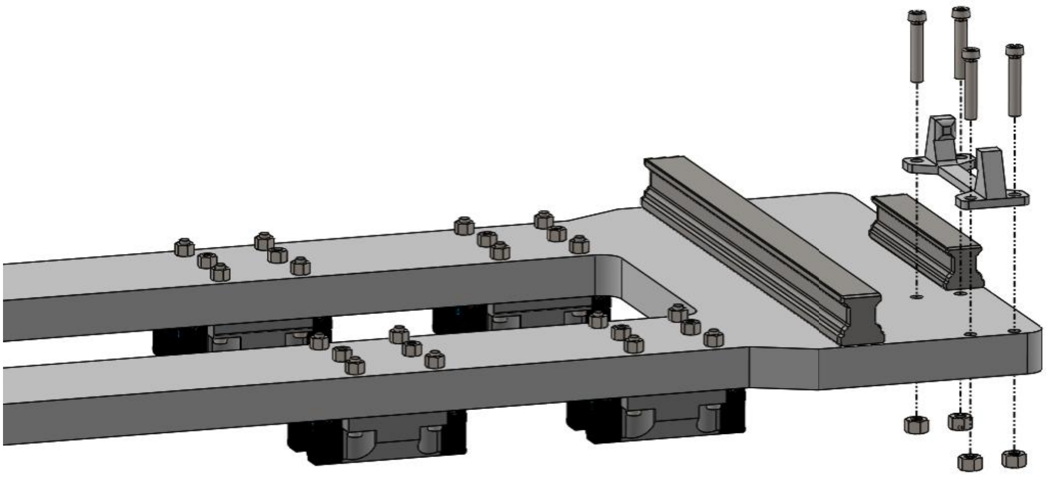
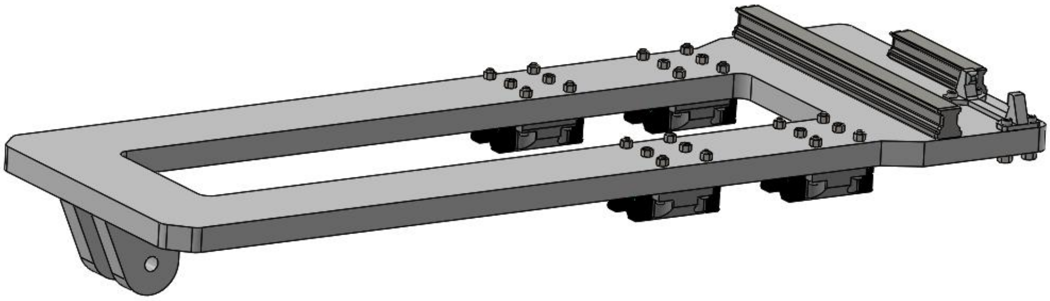
| | |
|---|---|
| 2 |  Fasten the two rails (part 15 and 18) using 7xM6 screws (part 19). |
| 3 | 4x  Attach the linear roller 20 mm (part 11-13) using 2xM5 (part 20) as inner screws, 4xM5 (part 21) as corner screws and 6xM5 nuts (part 22). Repeat four times. |
| 4 |  Fasten the spring clamp using 4xM6 screws (part 26) and 4xM6 nuts (part 27) |

*Table 47 continues.*

| | |
|---|---|
| 5 |  The finished Slider assembly is shown above. |

## 14.3 Assembly Procedure for Frame

*Table 48 - Assembly procedure for Frame.*

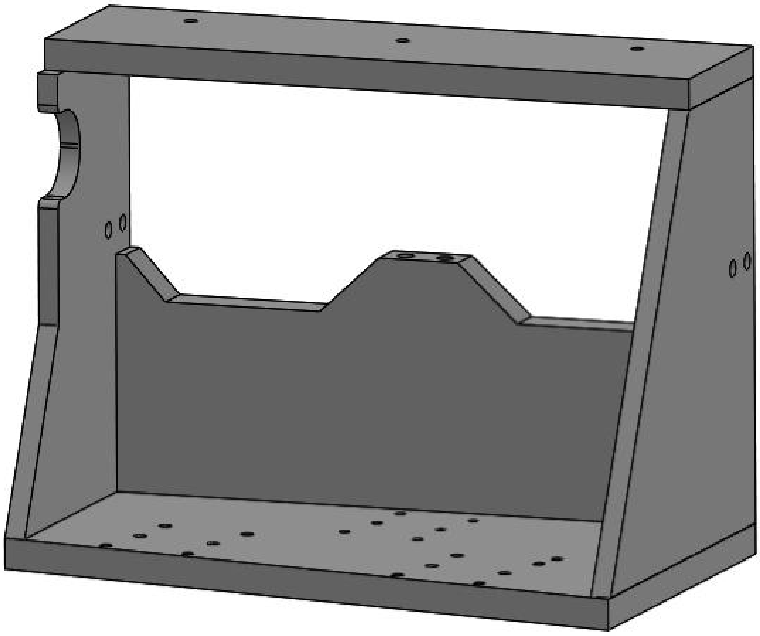
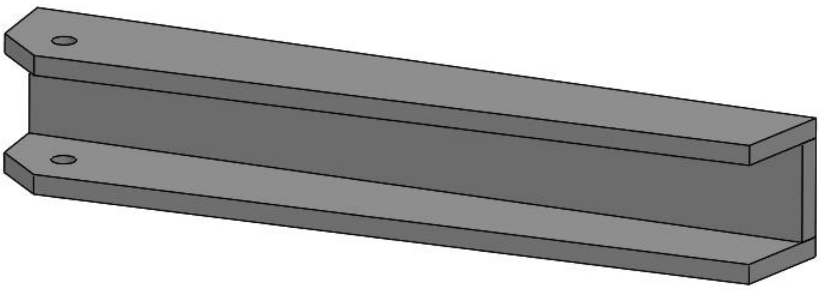
| Step | Description |
|---|---|
| 1 |  Weld the frame (part 28), frame bracket 1 and 2 (part 30 and 31), the top bracket (part 33) and the stiffener (part 45) as shown above. |
| 2 |  Weld 2x Cylinder side bracket (part 43) and 1x Cylinder back bracket as shown above. |

*Table 48 continues.*

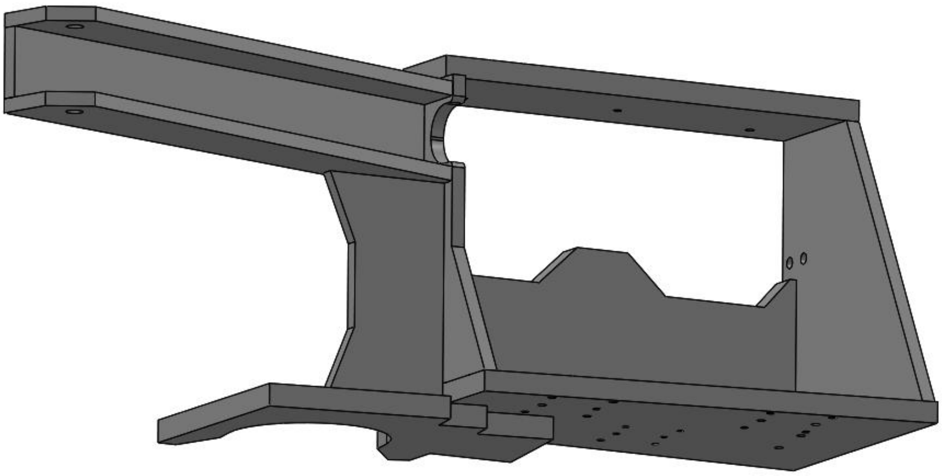
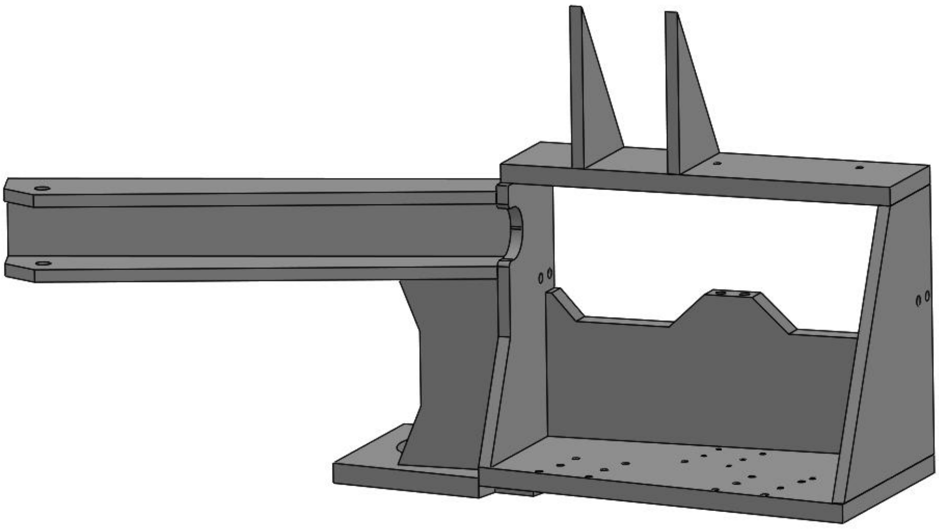
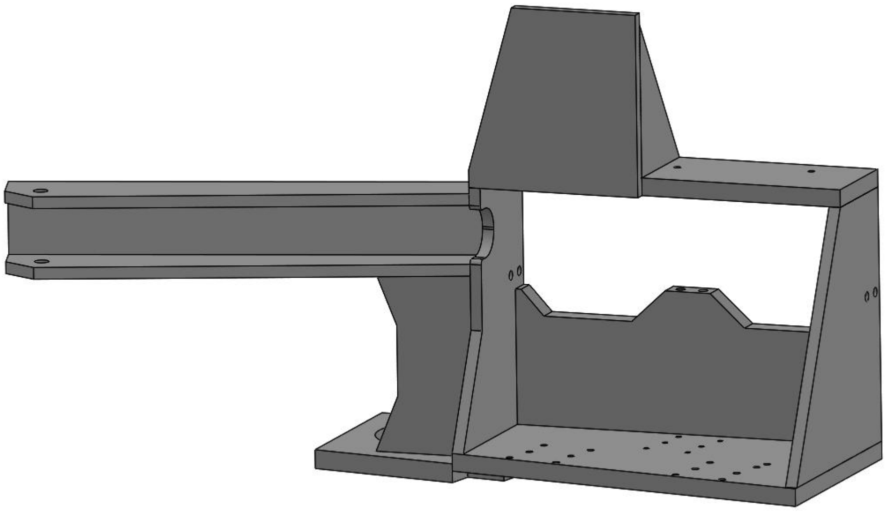
| | |
|---|---|
| 3 |  Weld the cylinder brackets from step 2 onto the frame. Also weld the Cylinder stiffener (part 46) and the guide bracket (part 32) to the frame. |
| 4 |  Weld 2x Support (part 35) onto the top bracket (part 33). |
| 5 |  Weld the momentum bracket (part 41) to the top bracket (part 33) and the supports (2x part 35). |

*Table 48 continues.*

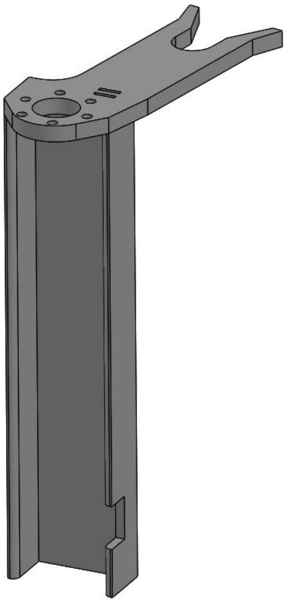
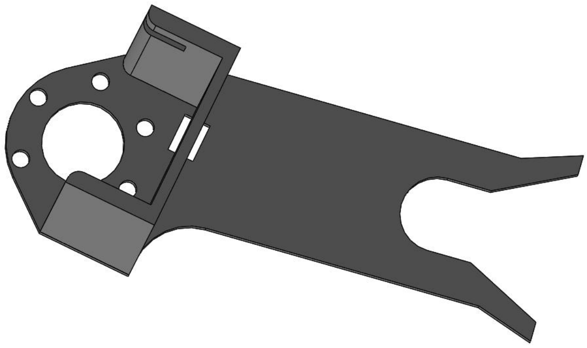
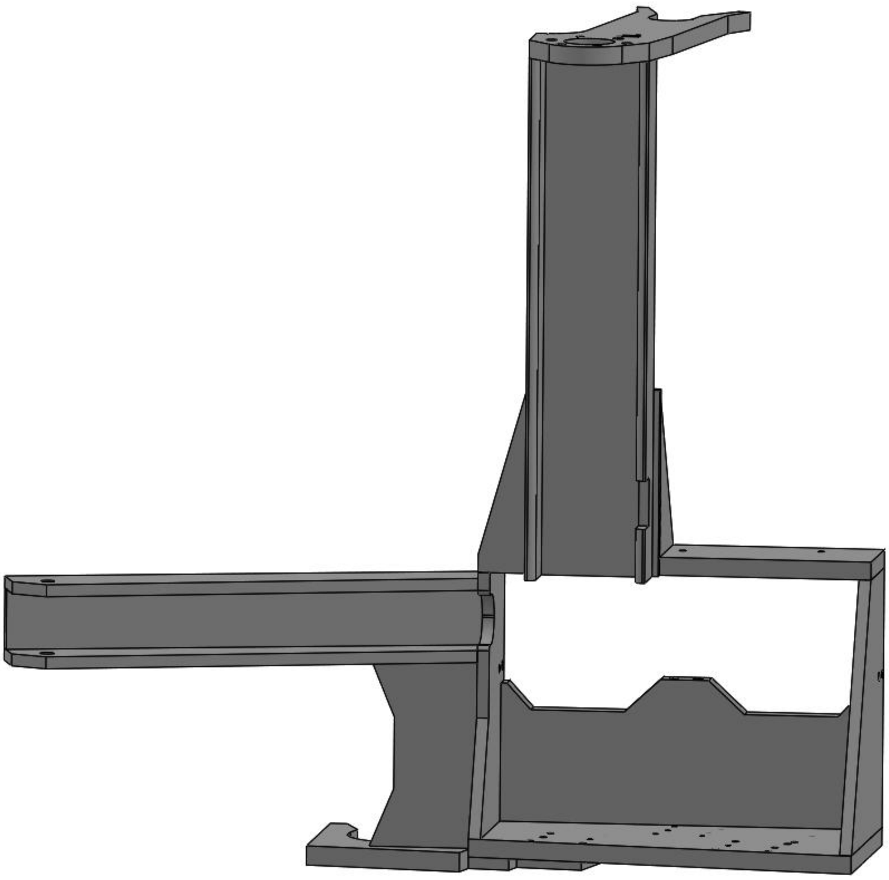
| | |
|---|---|
| 6 |   Left picture: Weld the pusher bracket (part 36) on top of the channel steel with cutaway (part 34).<br>Right picture: Ensure the slots with high tolerances in the pusher bracket (part 36) evelopes the channel steel (part 34) at the right spot. Use pression tools for this operation. |
| 7 |  Weld the assembly from step 6 onto the momentum bracket (part 41). |

*Table 48 continues.*

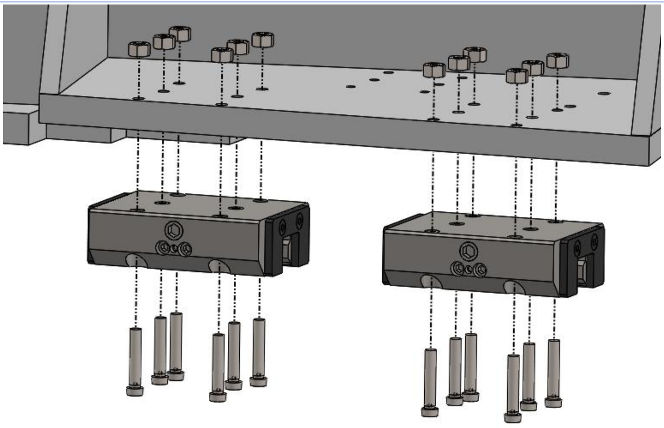
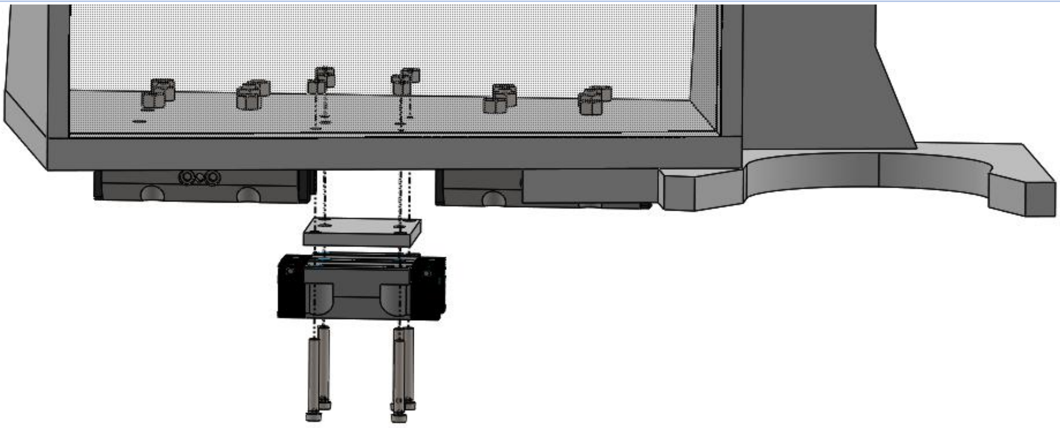
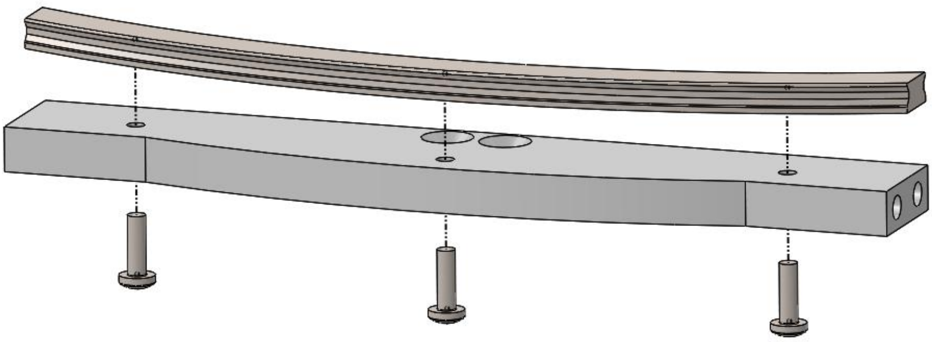
| | |
|---|---|
| 8 |  Fasten 2x Linear Roller 23 mm (part 37-39) to the frame using 12xM6 screws (part 26) and 12xM6 nuts (part 27) |
| 9 |  Fasten Linear Roller 20 mm (part 11-13), adding a spacer (part 40) using 6xM6 screws (part 26) and 6xM6 nuts (part 27). Stiffener (part 45) is transparent for visuality. |
| 10 |  Assembly the Curved rail (part 29) with the Radii bracket (part 42) using 3xM6 screws (part 53). |

*Table 48 continues.*

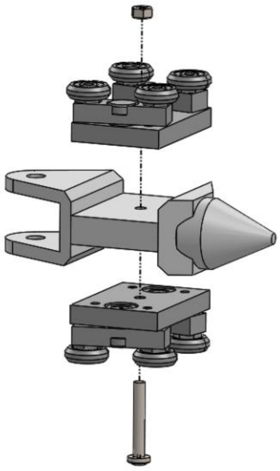
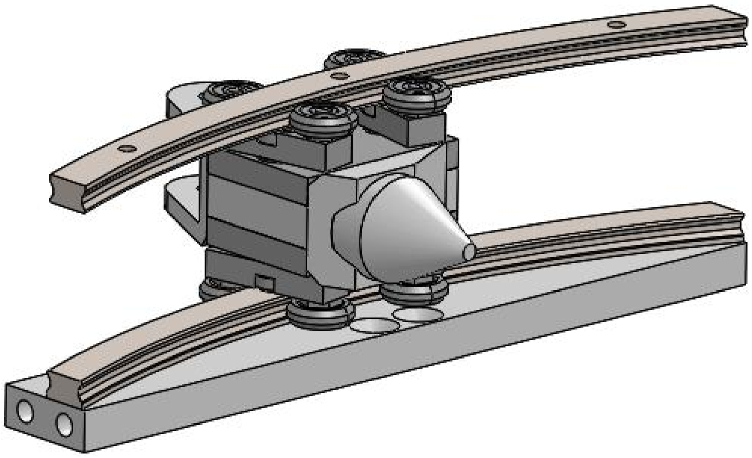
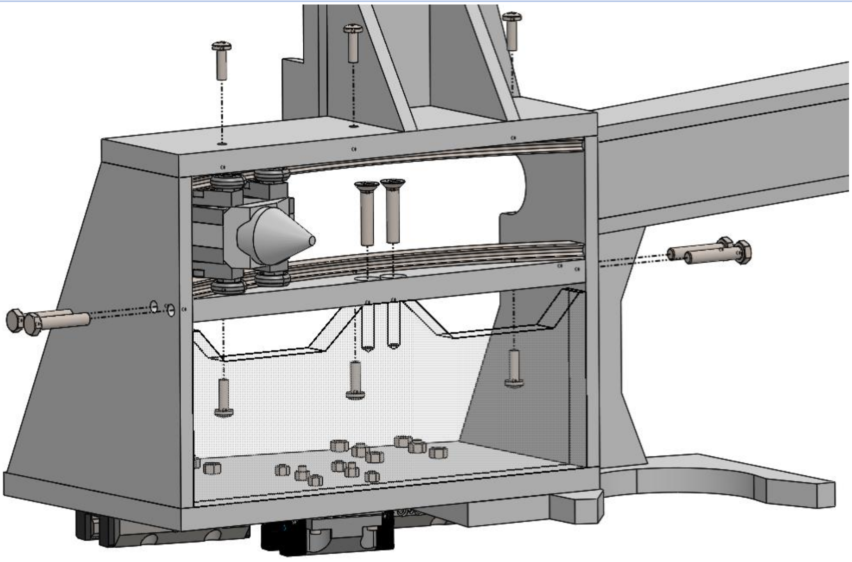
| | |
|---|---|
| 11 |  Assembly the cavity pin (part 56) with the rollers (part 54 and 55) using a M6 screw and bolt (part 58 and 59). |
| 12 |  Combine step 10 and 11 into the assembly above. Include another curved rail (part 29) before installing in frame. |
| 13 |  Fasten the assembly from step 12 using 6xM6 bolts (part 53), 2xM8 bolts (part 52) and 4xM8 Hexbolts (part 51). Stiffener (part 45) is transparent for visuality. |

*Table 48 continues.*

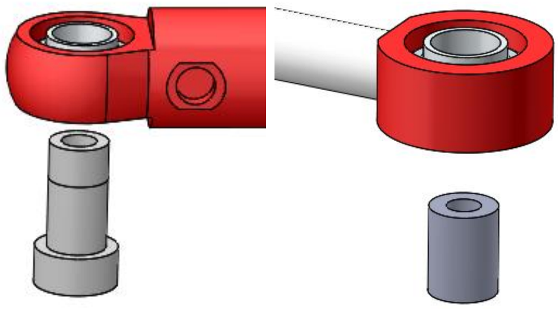
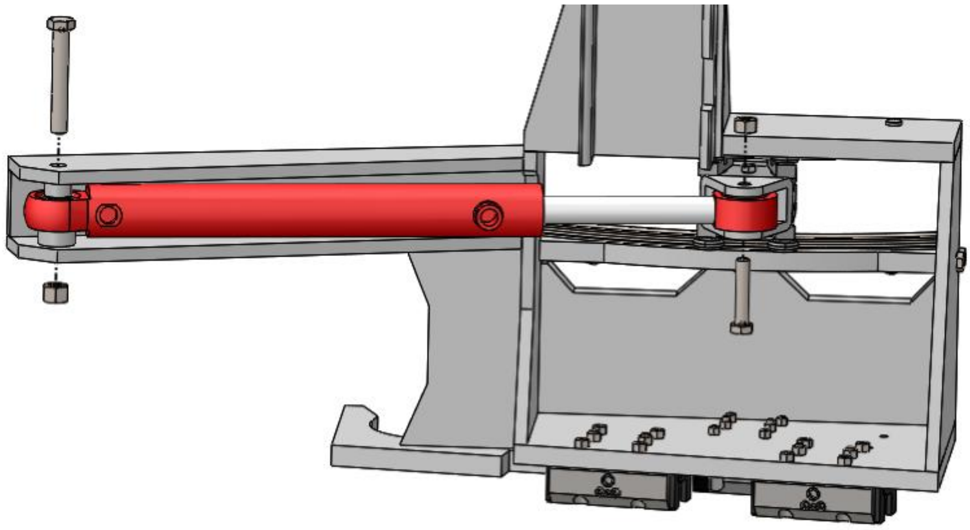
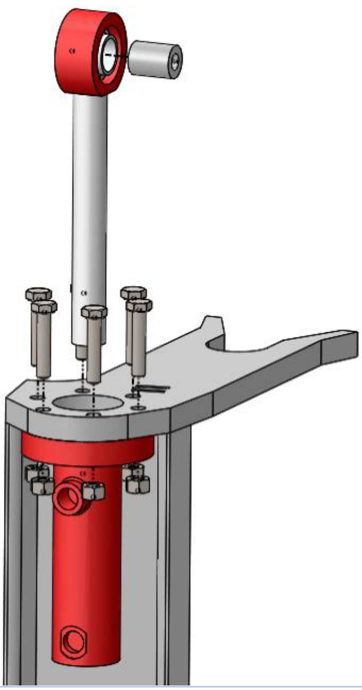
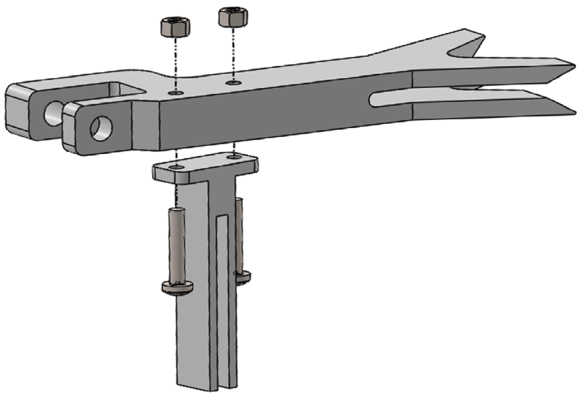
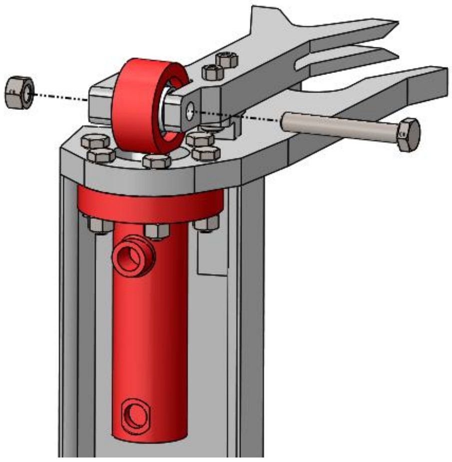
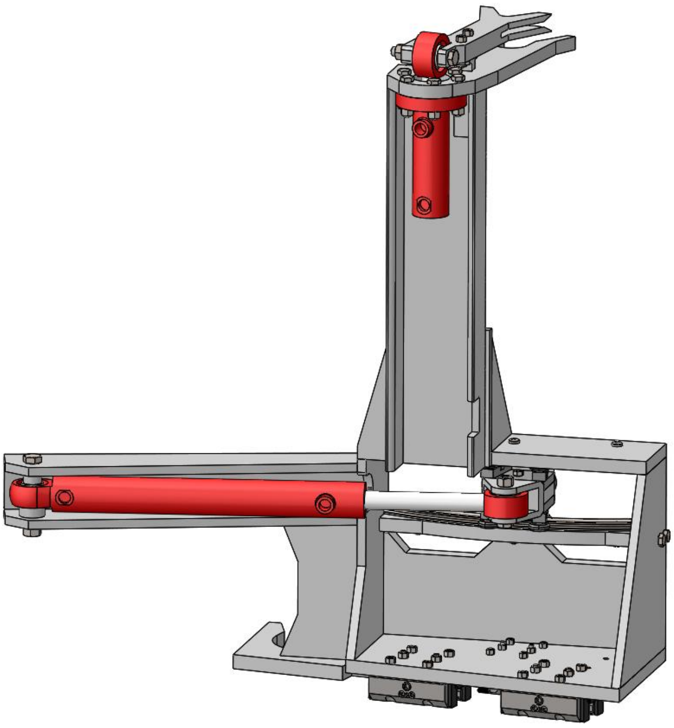
| | |
|---|---|
| 14 |  Insert hydraulic pin (part 47) on the cylinder side of the actuator (part 64-68). Insert pin (part 57) on the rod side of cylinder.  Fasten actuator (part 64-68) using M12 bolt and nut (part 23 and 24) on the cylinder side and M10 bolt and nut (part 60 and 61) on the rod side. |
| 15 |  Assemble cylinder (part 81) onto the pusher bracket (part 36) using 6xM8 bolt and nut (part 51 and 81). Insert pin (part 57) into cylinder bearing, and assemble the cylinder rod (part 70-73) into the cylinder (part 81). |

*Table 48 continues.*

| | |
|---|---|
| 16 |  Assemble the lifting bracket (part 62) with the non momentum pin (part 63) using 2xM6 bolts and nuts (part 27 and 82). |
| 17 |  Fasten the assembly from step 16 to the actuator, using M10 bolt and nut (part 61 and 80) |
| 18 |  The full Frame assembly is shown above. |

## 14.4 Assembly procedure for Automated Rotator

*Table 49 - Assembly procedure for Automated Rotator.*

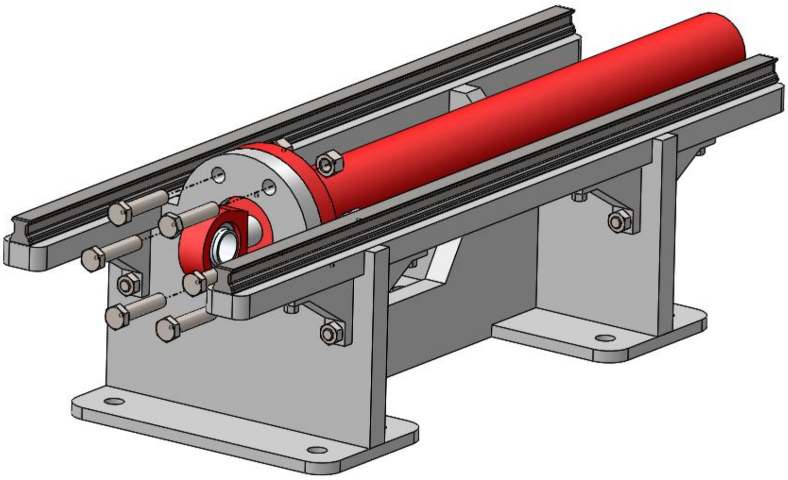
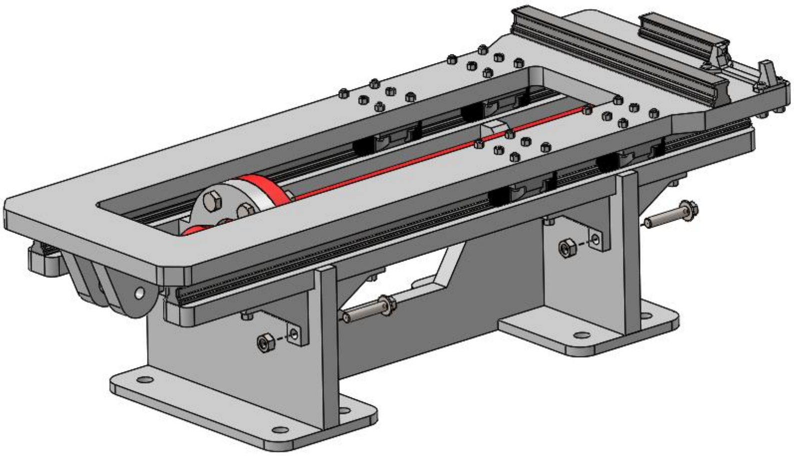
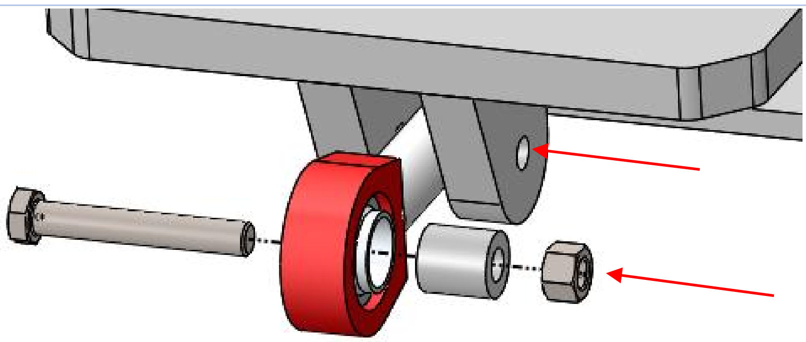
| Step | Description |
|---|---|
| 1 |  Fasten cylinder (part 75-78) to the floor mounting assembly using 6xM12 bolts (part 79) and 6xM12 nuts (part 24). |
| 2 |  Slide on the slider. For this to be possible, the screws and nuts (part 9 and 10) must be loosened, and then put together. |
| 3 |  Couple the hydraulic brackets (2xpart 16) on the slider together with the hydraulic cylinder (part 75-78) using a pin (part 17) and one set of M12 bolt + screw (part 23+24). The red arrows must be concentric. |

*Table 49 continues.*

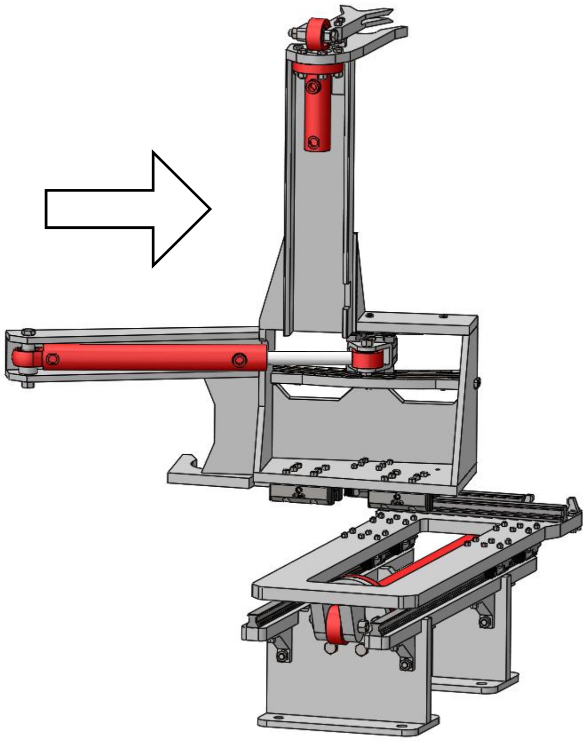
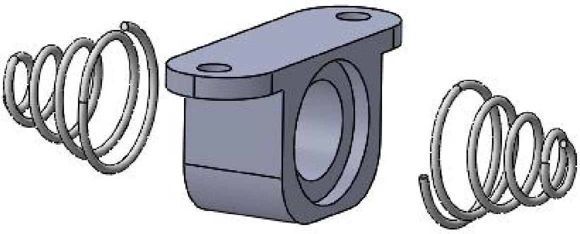
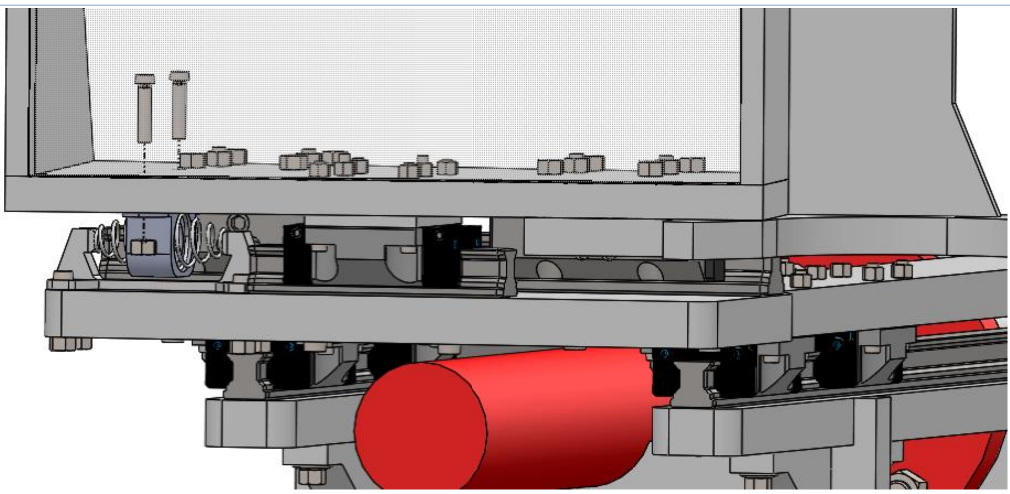
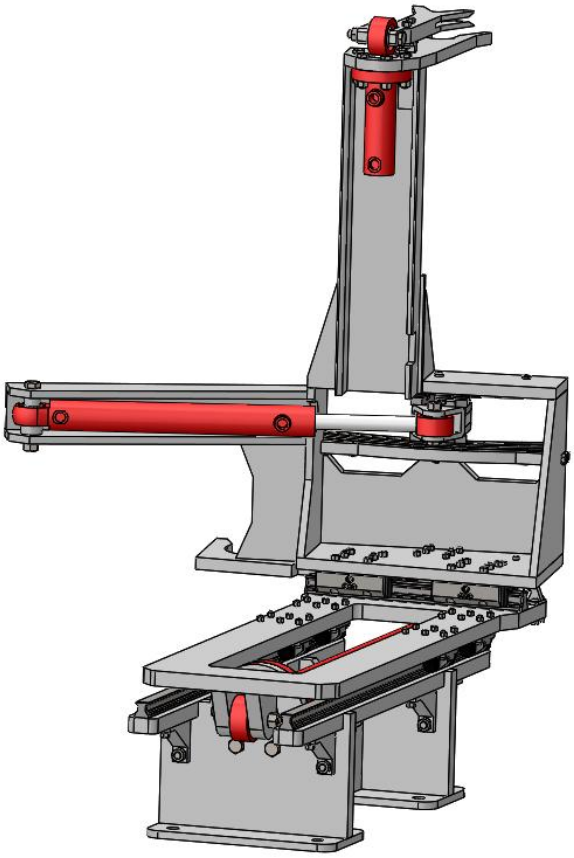
| | |
|---|---|
| 4 |  Slide the frame onto the slider as shown above. |
| 5 |  Assemble the 2xsprings (part 48) and the spring fastener (part 49) by pressing the springs inside the slots. |
| 6 |  Fasten the spring assembly in the spring clamp (part 25) as shown above using 2xM6 bolt and nuts (part 50 and 27). Stiffener (part 45) is transparent for visuality. |

*Table 49 continues.*

| | |
|---|---|
| 7 |  Above, the finshed Automated Rotator is shown. |

## 14.5 Assembly procedure for Index pin Assembly

*Table 50 - Assembly procedure for Index pin assembly.*

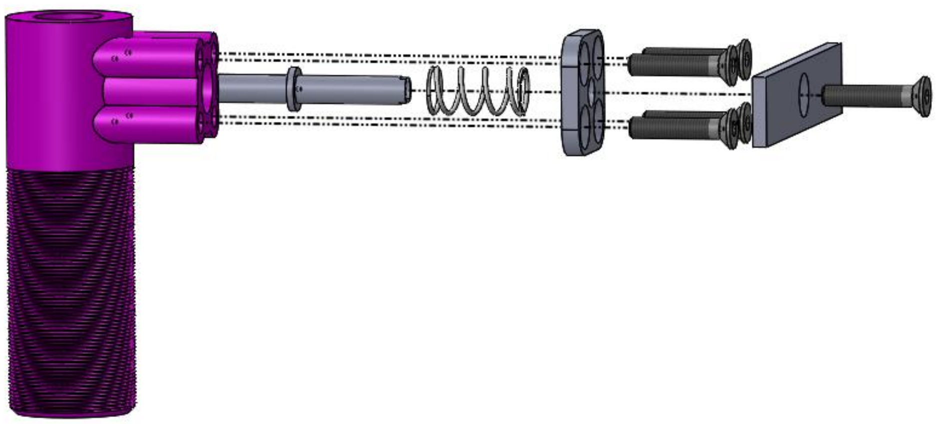
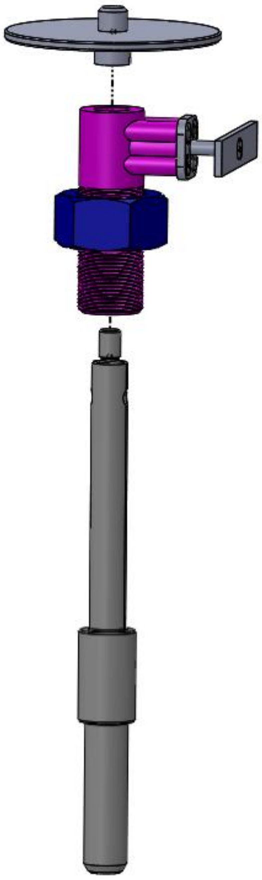
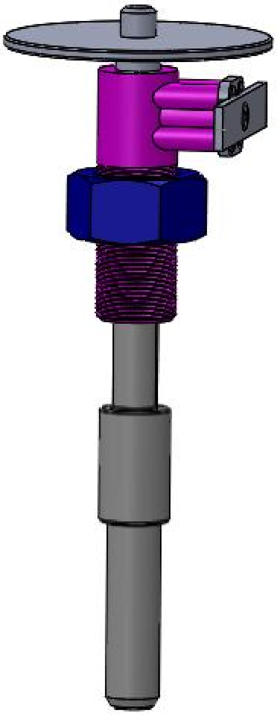
| Step | Description |
|---|---|
| 1 |  Assemble the locking pin (part 3) and the spring (part 9) into the two armed sleeve (part 1). Put on the spring cover (part 4) and fasten with 4xM6 bolts (part 6). Fasten the press plate (part 2) to the locking pin (part 3) using 1xM6 bolt (part 6). |

*Table 50 continues.*

| | | |
|---|---|---|
| 2 |  | Open the press plate, and screw the index pin (part 7) into the top hat (part 5). Put on the nut (part 8) used for implementation. |
| 3 |  | To the left the finished index pin assembly is shown. |

## 14.6 Package and transport of the Automated Rotator

After the Automated Rotator has been assembled, it is placed on a pallet for transportation. This pallet is placed in a container for shipping to the rig. When transported, the AR is put in the withdrawn position due to this configuration's center of gravity. The floor mounting of the AR is 530 mm x 260 mm fitting on a EUR-pallet, which is 1200 mm x 800 mm. To secure the AR, straps are used. In addition, screws could be used to fasten the AR to the pallet.

*Figure 116 - withdrawn position for transportation*

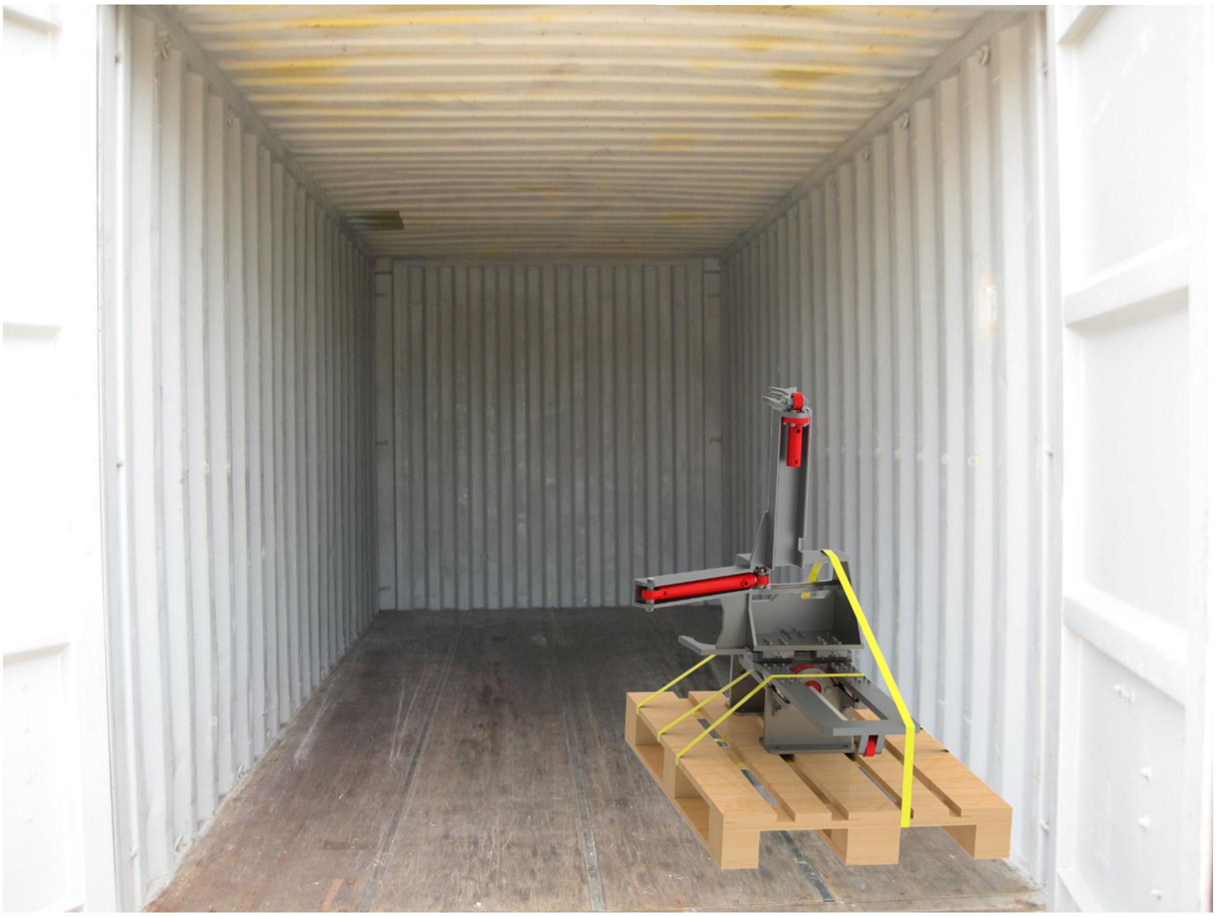


*Figure 117 - Transportation of the Automated Rotator*

# 15 Evaluation of development process and discussion

In this chapter, the process of making the Automated Rotator will be discussed. The step wise process used in this thesis consists of four different main parts: Definitions and methodology, concept development, construction and design and product realization. The evaluation regarding each part of the process will be examined below.

## 15.1 Concept development and improvements

### Definitions and methodology

- The time management plan was very successful, with no overdues.
- The use of different methodology became important as I mostly sat in a working environment surrounded by experienced engineers with different specialties. Especially IPD was important.
- The quality chapter was investigated thoroughly as many different standards and recommendations applied to it.
- The theory chapter mostly included elements from MHWirth's portfolio as well as hydraulic and electric systems. This gave deep insight into MHWirth's product, which is relevant to me as an employee.
- IPD methodology could have been involved at an earlier stage to ensure quality in the electrical and hydraulic system because I as a student has limited competence in these areas.

### Concept development

- It was hard to formulate the best-suited objectives for the thesis. After some thought, the objectives neatly separated into two groups. Main objectives, regarding functionality, and property objectives, regarding wanted properties independent of the functionality. This way the objectives could add guidelines for both the functionality of the concept as well as the size, costs etc.
- The available space for the automated rotator was mapped, yielding the volume of the concept. This was done by putting riser joints and handling tools in different positions while measuring in CAD.
- A large amount of time was spent drawing different concepts by hand and colorizing them in Photoshop. This could have been done in less time, but I found it so rewarding that I just could not stop.
- As a part of the process making the AR, competence was always nearby. Because of the close dialogue with colleagues, there was less room for an expert survey when this happened on a daily basis. This was considered an advantage.

### Construction and design

- Because of the preparatory study, it was possible to get deep into engineering problems. This has made this thesis comprehensive.

- The FEA in the deformation studies could have been done more thoroughly using welds between parts instead of rigid connections. The FEA could also have used maximum stress with a safety factor, not the yield strength directly. However, all FEAs were collision loads, not regular loads.
- The rendering of pictures was time-consuming, and not representative for MHWirth. MHWirth only uses screenshots from Solidworks in their own presentations. However, I wanted the report to yield a impression of quality.
- The electrical system could probably have been improved by an expert. IPD should have been implemented earlier in this stage.
- The design of index pin assembly with moving parts is not tested. It could be that 5 – 10 years of subsea use will make the spring a pressure plate brittle and vulnerable (this assembly is submerged in the water while the AR is always onboard the rig). However, no standard or recommendations prohibits this design, and experienced colleagues have approved the design.
- The parts are mostly constructed with standard plates or profiles in mind.
- Some parts have complex shapes, radii and other unnecessary complex aspects. The design of these could be improved.
- A design without guide rails and runner blocks would have made the design less vulnerable for dirt and pollution.

#### Product realization

- The cost estimate for prototyping was very rough, and based upon qualified guesses. In addition, the time spent on assembling was guesswork.
- Maintenance recommendations are based on the guide rail and runner block system. Other parts could need maintenance more often, but may have been overlooked.
- To be able to build a prototype, more detailed technical drawings for all original parts must be made. Only exploded views and outer dimensions have been completed. This was not done due to time constraints.

## 15.2 Design revision

The design of the AR has been a comprehensive job, working with both mechanical and FEA design of the AR simultaneously as the design of the index pin assembly. In addition, a hydraulic system has been schematically designed, but not thoroughly calculated. Furthermore an electrical relay based control system has been made with corresponding proximity sensor placement suggestion. All these different designs and different areas of expertise creates a potential risk in an overall lack of quality.

The design of the AR could have been investigated more thoroughly, adding topology for making the design lighter and smaller. Fewer parts and a reduction in screws and nuts could have been applied.

# 16 Conclusion

In this project an investigation, a development and a design of an automated rotator that is able to make a secure coupling between MHWirth's marine risers has been made. This secure coupling is done by opening the locking pin, lifting the index pin, and turning the lock ring without human interaction.

All generated concepts were screened against the product objectives, resulting in the most feasible concept for each function. These concepts were then assembled into one complete concept, the Automated Rotator. The Automated Rotator was designed using Solidworks and was analyzed using the FEA/FEM-solver in Solidworks.

The development has resulted in both an Automated Rotator as well as a compatible index pin assembly. This means that every joint's index pin in a riser system needs to be changed to be compatible with the Automated Rotator.

## 16.1 Product objectives, achievements and Results

Results
Below, all results and designs are listed:

- Functionality
    - Concept is able to grip the lock ring using the lock ring cavity.
    - Concept is able to rotate the lock ring within 6 seconds.
    - Concept is able to open and close locking ring.
    - Concept is able to lift and close index pin.
    - Concept controls itself, but does not give feedback to operator (see further work).
    - Concept handles delivery variance.

- Dimensions and complexity
    - Weight of AR: 111,6 kg.
    - Small size compared to competitors.
    - 301 individual parts.

- Schematics and control system
    - Hydraulic system.
    - Relay based electronic control system.

- Materials and strength
    - S355J2 is used for all original parts.
    - All stresses from the FEA are lower than the yield strength.

- Economy
    - Price for a prototype is estimated to: 1.130.500 NOK.

- Post Production
    - Maintenance: The guide rails needs cleaning every eight hours.
    - HSSE: Safety routines are part of further work.
    - The ecological footprint is 3250 MJ if the EoL potential is reached.

The results are connected to the project and product objective. For the full list of results with referrals, see appendix II.

## 16.2 Recommendations and further work:

The product needs to be further developed with regard to the following aspects:

- The control panel (Flagging system) used by the operator for monitoring the process is yet to be made.

- If the locking pin does not lock the index pin, there are no system to register this potential error. When the AR is deactivated, the system does not register whether or not the locking pin is locked.

- The electric system is not compatible with both assembling and disassembling the riser string. This could easily be achieved by introducing an additional proximity sensor number 3b, that are coupled in parallel and are switchable. Proximity sensor 3b must be mounted on the opposite side of the frame.

- The proximity sensors must be implemented in the design of the components on the AR.

- The hydraulic system should be developed and explored in CAD, not only schematically.

- A thorough FEA/FEM should be executed on the AR, using welds and on the index pin assembly.

- Around the AR, there is a risk of trapping. Therefore, a certain area must be shielded for workers. This has not been investigated in this project. A HSSE plan for this must be made.

- Comprehensive calculations of hydraulic and electric system should also be executed.

- Two of the linear guides (part 37-39) have built in hydraulic brakes. The use of these brakes has not been investigated in this project put could be looked into as further work.

- In order to validate the functionality, a prototype is required.

# 17 References

## Literature references

1. Andersen, Erling *et.al.*, *Goal Directed Project Management (Effective Techniques and Strategies).* London, UK: Kogan Page Ltd, 2009, 272 pp.
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# 18 Appendix

# Appendix I

## BoM for Automated Rotator with production methods

This appendix shows the bill of materials with corresponding Production methods. The yellow fields represent retail parts that consist of multiple parts in Solidworks.

| ITEM NO. | PART NUMBER | QTY. | Production |
|---|---|---|---|
| 1 | Floor Weldment 1 | 1 | Cuts from Steel Plate (SP) |
| 2 | Floor Weldment 2 | 1 | Cuts from SP |
| 3 | Floor Bracket | 4 | Cut from SP |
| 4 | Rotating rail component | 2 | Cut from SP |
| 5 | Jack | 1 | Cut from SP |
| 6 | KUGELSCHIENE_NR_RAIL1 740 | 2 | Retailer (RT) |
| 7 | ISO 7045 - M5 x 25 - Z --- 25N | 22 | RT |
| 8 | ISO 4162 - M8 x 25 x 25-N | 8 | RT |
| 9 | ISO 4162 - M10 x 50 x 26-N | 4 | RT |
| 10 | Hexagon Nut ISO - 7413 - M10 - W - N | 4 | RT |
| 11 to 13 | Linear Roller 20 mm | | RT |
| 11 | R200180131 | 5 | |
| 12 | R200180102 | 10 | |
| 13 | R343706101_Z | 20 | |
| 14 | Flat steel | 1 | Cut from SP |
| 15 | KUGELSCHIENE_NR_RAIL1_1 | 1 | RT |
| 16 | Hydraulic bracket radial | 2 | Cut from SP |
| 17 | Pin | 1 | Lathe |
| 18 | KUGELSCHIENE_NR_RAIL1 | 1 | RT |
| 19 | ISO 14580 - #6 x 30 x 28 - 4.8-N | 7 | RT |
| 20 | ISO 7045 - M5 x 30 - Z --- 30N | 8 | RT |
| 21 | ISO 14580 - #4 x 35 x 33.6 - 4.8-N | 22 | RT |
| 22 | Hexagon Nut ISO - 4034 - M5 - N | 30 | RT |
| 23 | ISO 4014 - M12 x 80 x 30-N | 2 | RT |
| 24 | Hexagon Nut ISO - 4034 - M12 - N | 8 | RT |
| 25 | Spring clamp | 1 | Milled |
| 26 | ISO 14580 - #5 x 30 x 28.4 - 4.8-N | 16 | RT |
| 27 | Hexagon Nut ISO - 4034 - M6 - N | 20 | RT |
| 28 | Frame | 1 | Cut from SP |
| 29 | _GCT0141045_3_2 - Curved Rail | 2 | RT |
| 30 | Frame Bracket 1 | 1 | Cut from SP |
| 31 | Frame Bracket 2 | 1 | Cut from SP |
| 32 | Guide bracket | 1 | Cut from SP |
| 33 | Top Bracket | 1 | Cut from SP |
| 34 | Channel steel with cutaway | 1 | Milled standard part |
| 35 | Support | 2 | Cut from SP |
| 36 | Pusher bracket | 1 | Cut from SP |
| 37 - 39 | Linear Roller 23 mm | | RT |
| 37 | 1 | 2 | |
| 38 | 2 | 2 | |
| 39 | 3 | 2 | |
| 40 | Spacer | 1 | Cut from SP |
| 41 | Moment Bracket | 1 | Cut from SP |
| 42 | Radii bracket | 1 | Cut from SP |
| 43 | Hydraulic Bracket 2 | 2 | Cut from SP |
| 44 | Hydraulic Bracket 3 | 1 | Cut from SP |
| 45 | Stiffener | 1 | Cut from SP |
| 46 | Stiffener 2 | 1 | Cut from SP |
| 47 | hydraulic pin | 1 | Lathe |

| | | | |
|---|---|---|---|
| 48 | 6701-Lesjofors - Spring | 2 | RT |
| 49 | spring fastener | 1 | Milled |
| 50 | hexalobular socket cheese head_iso | 2 | RT |
| 51 | ISO 4014 - M8 x 40 x 22-N | 10 | RT |
| 52 | ISO 7046-1 - M8 x 40 - Z --- 40N | 2 | RT |
| 53 | ISO 7045 - M6 x 20 - Z --- 20N | 6 | RT |
| 54 | _GCT01_1_4 | 2 | RT |
| 55 | _GCT01_180_45_2_6 | 4 | RT |
| 56 | Cavity pin | 1 | CNC Machined |
| 57 | Pin | 2 | Lathe |
| 58 | ISO 7045 - M6 x 40 - Z --- 40N | 1 | RT |
| 59 | Hexagon Nut ISO - 4032 - M6 - W - N | 1 | RT |
| 60 | ISO 4014 - M10 x 50 x 26-N | 1 | RT |
| 61 | Hexagon Nut ISO - 4034 - M10 - N | 2 | RT |
| 62 | Lifting bracket | 1 | CNC Machined |
| 63 | Non momentum pin | 1 | CNC Machined |
| 64-68 | Cylinder CD25 240 | | RT |
| 64 | cylinder-CD25-32_20x240-SS-HR-SSN-NNN-servi | 1 | |
| 65 | bearing-ring-CD25-32_20x240-SS-HR-SSN-NNN-servi | 2 | |
| 66 | bearing-ball-CD25-32_20x240-SS-HR-SSN-NNN-servi | 2 | |
| 67 | rod-CD25-32_20x240-SS-HR-SSN-NNN-servi | 1 | |
| 68 | rod-end-CD25-32_20x240-SS-HR-SSN-NNN-servi | 1 | |
| 69-73 | Cylinder CD25 40 | | RT |
| 69 | cylinder-CD25-32_20x40-AS-HR-SSN-NNN-servi | 1 | |
| 70 | rod-CD25-32_20x40-AS-HR-SSN-NNN-servi | 1 | |
| 71 | rod-end-CD25-32_20x40-AS-HR-SSN-NNN-servi | 1 | |
| 72 | bearing-ring-CD25-32_20x40-AS-HR-SSN-NNN-servi | 1 | |
| 73 | bearing-ball-CD25-32_20x40-AS-HR-SSN-NNN-servi | 1 | |
| 74-78 | Cylinder CD25 500 | | RT |
| 74 | cylinder-CD25-50_25x500-AE-HR-SSN-NNN-servi | 1 | |
| 75 | rod-CD25-50_25x500-AE-HR-SSN-NNN-servi | 1 | |
| 76 | rod-end-CD25-50_25x500-AE-HR-SSN-NNN-servi | 1 | |
| 77 | bearing-ring-CD25-50_25x500-AE-HR-SSN-NNN-servi | 1 | |
| 78 | bearing-ball-CD25-50_25x500-AE-HR-SSN-NNN-servi | 1 | |
| 79 | hex bolt gradeab_iso | 6 | RT |
| 80 | ISO 4014 - M10 x 70 x 26-N | 1 | RT |
| 81 | Hexagon Nut ISO - 4034 - M8 - N | 6 | RT |
| 82 | ISO 7045 - M6 x 30 - Z --- 30N | 2 | RT |
| Sum individual parts: | | 301 | |

# Appendix II

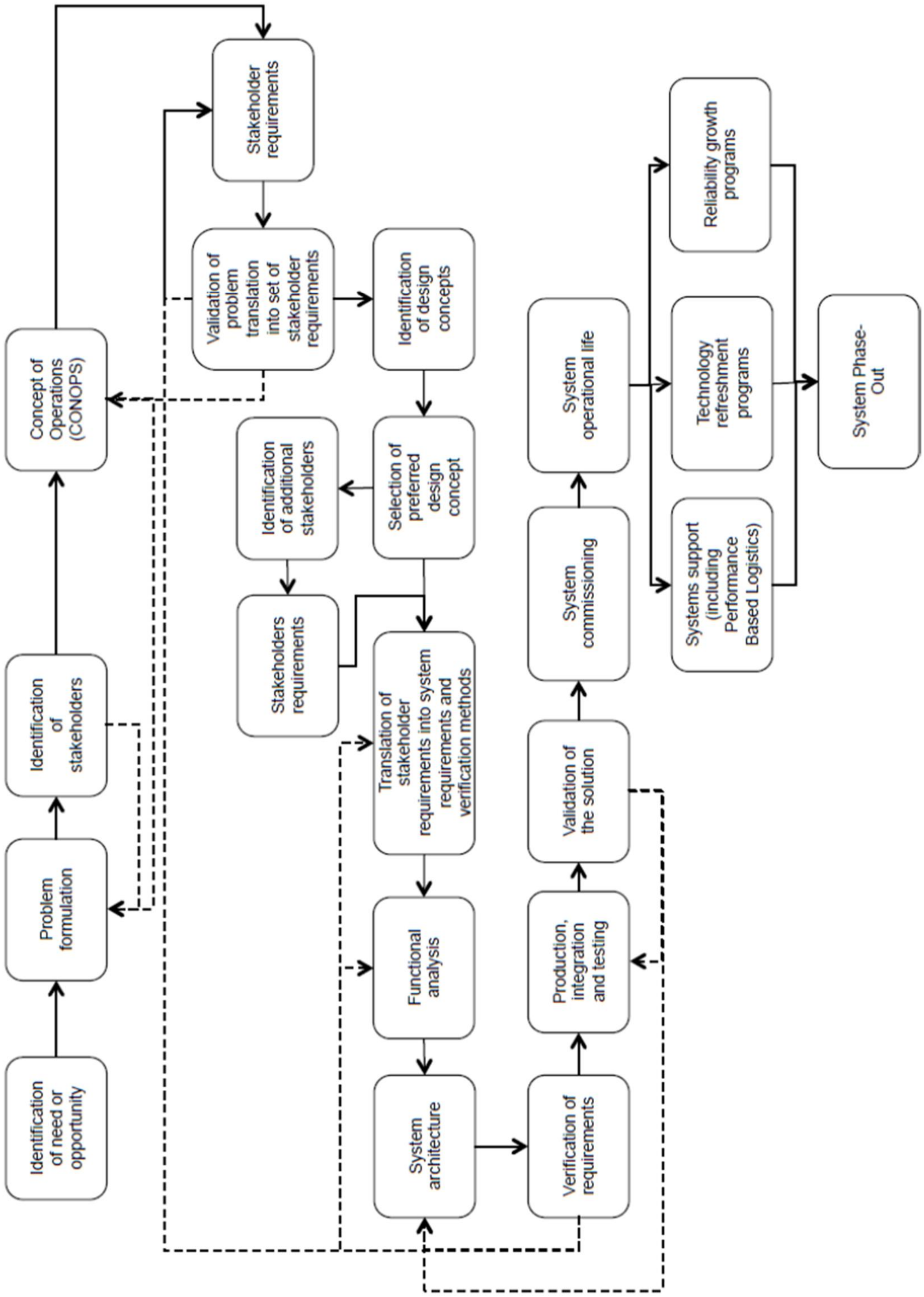
## Achieved objectives with chapter references

| | Main objectives | Verification/Results |
|---|---|---|
| *M1* | (M1) Grip of lock ring | Design of cavity pin, chapter 8.3.1.<br>Adding chamfers to existing lock rings, chapter 8.3.1. |
| *M2* | Rotate lock ring within 6 seconds | Design of Rotational system, chapter 8.3.2.<br>Design of Hydraulic system, chapter 10.1.<br>Flow calculations 10.2. |
| *M3* | Open and close locking pin | Design of pusher system, chapter 8.3.3.<br>Design of locking pin on index pin assembly, chapter 8.3.7.<br>Design of Hydraulic system, chapter 10.1. |
| *M4* | Lift and close index pin | Design of lifting system, chapter 8.3.4.<br>Design of index pin on index pin assembly, chapter 8.3.7.<br>Design of Hydraulic system, chapter 10.1. |
| *M5* | Verify coupling | Design of Hydraulic system, chapter 10.1.<br>Design of electric control system, chapter 10.2.<br>Further work: Flagging system and verification of locking pin withdrawal. |
| *M6* | Handle delivery variance | Design of guide bracket system, chapter 8.3.6.<br>Design of electric control and censor system, chapter 10.2. |

| | Property Objectives | Verification |
|---|---|---|
| *P1* | Low weight | Weight 111,6 kg, chapter 8.1.1.<br>Low compared to competitive products. |
| *P2* | Small size | Small compared to competitive products.<br>See appendix V.i. for outer dimensions:<br>$1225 \cdot 709{,}8 \cdot 990{,}6$ |
| *P3* | Low complexity | Low complexity compared to competitive products<br>301 individual parts, appendix I.<br>Electric relay system is not complex, chapter 10.3. |
| *P4* | Cheap prototyping and production | 1.130.500 NOK According to, chapter 13.2 |
| *P5* | Low maintenance | The linear equipment needs cleaning every 8 hours, chapter 12.3. |
| *P6* | Health, security, safety and environment | The AR pass all deformation test.<br>Further work: make safety routines |
| *P7* | Ecological footprint | 3250 MJ according to, chapter 12.4. |

# Appendix III

## Alberto Sols Original Flow Chart



# Appendix IV

## ECO Audit

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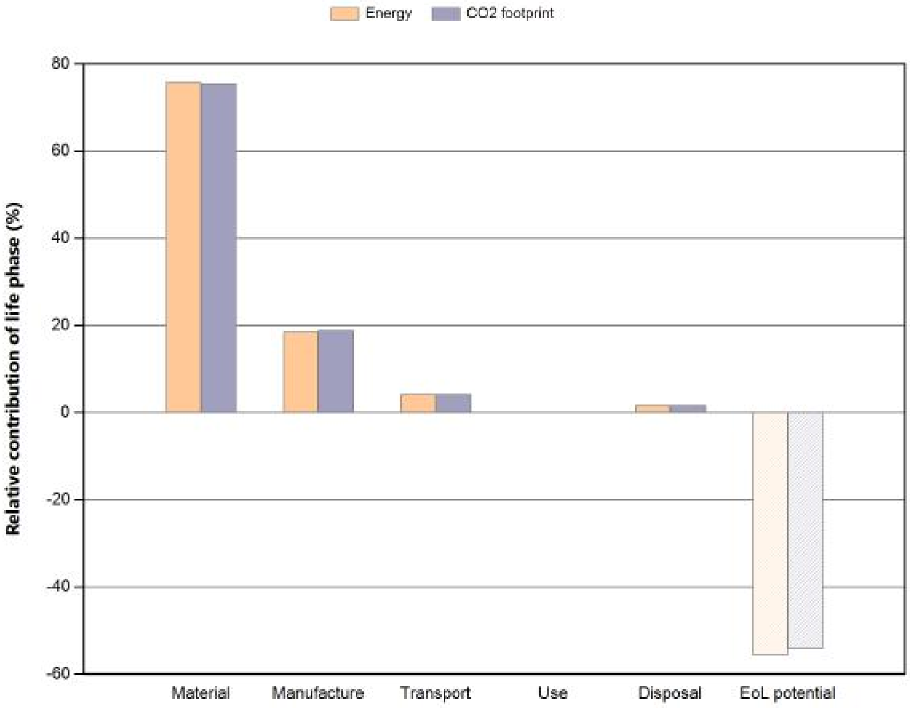
**Eco Audit Report**

| | |
|---|---|
| Product name | Automated Rotator |
| Country of use | World |
| Product life (years) | 10 |

**Summary:**




Energy details CO2 footprint details

| Phase | Energy (MJ) | Energy (%) | CO2 footprint (kg) | CO2 footprint (%) |
|---|---|---|---|---|
| **Material** | 5,54e+03 | 75,6 | 407 | 75,5 |
| **Manufacture** | 1,36e+03 | 18,5 | 102 | 18,9 |
| **Transport** | 309 | 4,2 | 22,2 | 4,1 |
| **Use** | 0 | 0,0 | 0 | 0,0 |
| **Disposal** | 120 | 1,6 | 8,41 | 1,6 |
| Total (for first life) | **7,33e+03** | **100** | **539** | **100** |
| **End of life potential** | -4,08e+03 | | -292 | |

NOTE: Differences of less than 20% are not usually significant.
See notes on precision and data sources.

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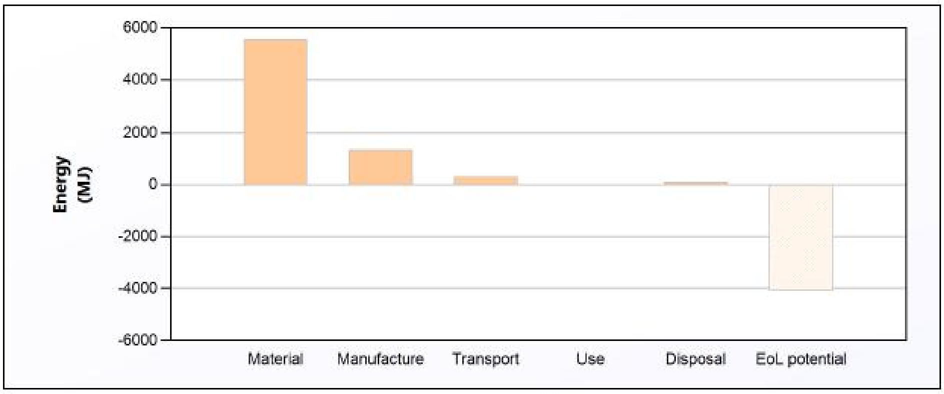
CES 2018 EDUPACK

# Eco Audit Report

## Energy Analysis

Summary




| | Energy (MJ/year) |
|---|---|
| Equivalent annual environmental burden (averaged over 10 year product life): | 733 |

## Detailed breakdown of individual life phases

### Material:

Summary

| Component | Material | Recycled content* (%) | Part mass (kg) | Qty. | Total mass (kg) | Energy (MJ) | % |
|---|---|---|---|---|---|---|---|
| Retail Parts | Low alloy steel | Virgin (0%) | 52 | 1 | 52 | 1,7e+03 | 30,1 |
| Original Parts | Low alloy steel | Virgin (0%) | 60 | 2 | 1,2e+02 | 3,9e+03 | 69,9 |
| Total | | | | 3 | 1,7e+02 | 5,5e+03 | 100 |

*Typical: Includes 'recycle fraction in current supply'

### Manufacture:

Summary

| Component | Process | Amount processed | Energy (MJ) | % |
|---|---|---|---|---|
| Retail Parts | Casting | 52 kg | 5,9e+02 | 43,7 |
| Original Parts | Extrusion, foil rolling | 1,2e+02 kg | 7,6e+02 | 56,3 |
| Total | | | 1,4e+03 | 100 |

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## Transport:

Summary

### Breakdown by transport stage

| Stage name | Transport type | Distance (km) | Energy (MJ) | % |
|---|---|---|---|---|
| Boat | Ocean freight | 1e+04 | 3,1e+02 | 100,0 |
| Total | | **1e+04** | **3,1e+02** | **100** |

### Breakdown by components

| Component | Mass (kg) | Energy (MJ) | % |
|---|---|---|---|
| Retail Parts | 52 | 93 | 30,1 |
| Original Parts | 1,2e+02 | 2,2e+02 | 69,9 |
| Total | **1,7e+02** | **3,1e+02** | **100** |

## Use:

Summary

### Relative contribution of static and mobile modes

| Mode | Energy (MJ) | % |
|---|---|---|
| **Static** | 0 | |
| **Mobile** | 0 | |
| Total | **0** | **100** |

## Disposal:

Summary

| Component | End of life option | Energy (MJ) | % |
|---|---|---|---|
| Retail Parts | Recycle | 36 | 30,1 |
| Original Parts | Recycle | 84 | 69,9 |
| Total | | **1,2e+02** | **100** |

## EoL potential:

| Component | End of life option | Energy (MJ) | % |
|---|---|---|---|
| Retail Parts | Recycle | -1,2e+03 | 30,1 |
| Original Parts | Recycle | -2,9e+03 | 69,9 |
| Total | | **-4,1e+03** | **100** |

## Notes:

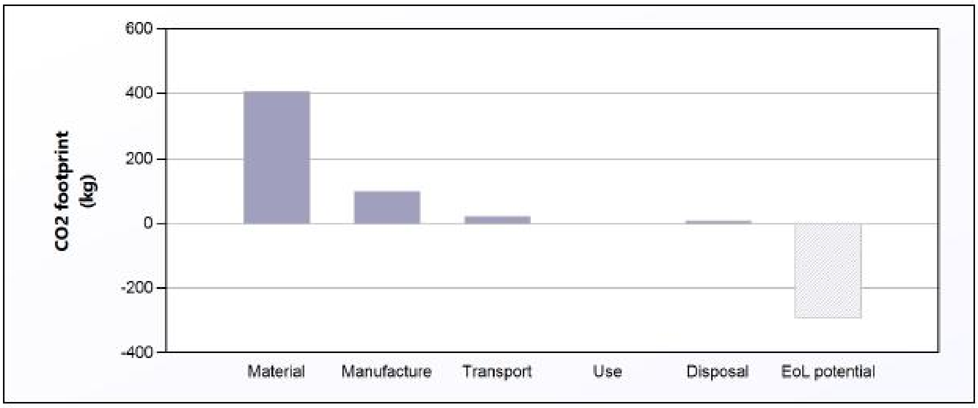
Summary

CES 2018 EDUPACK

**Eco Audit Report**

## CO2 Footprint Analysis

Summary




| | CO2 (kg/year) |
|---|---|
| Equivalent annual environmental burden (averaged over 10 year product life): | 53,9 |

## Detailed breakdown of individual life phases

### Material:

Summary

| Component | Material | Recycled content* (%) | Part mass (kg) | Qty. | Total mass (kg) | CO2 footprint (kg) | % |
|---|---|---|---|---|---|---|---|
| Retail Parts | Low alloy steel | Virgin (0%) | 52 | 1 | 52 | 1,2e+02 | 30,1 |
| Original Parts | Low alloy steel | Virgin (0%) | 60 | 2 | 1,2e+02 | 2,8e+02 | 69,9 |
| Total | | | | 3 | 1,7e+02 | 4,1e+02 | 100 |

*Typical: Includes 'recycle fraction in current supply'

### Manufacture:

Summary

| Component | Process | Amount processed | CO2 footprint (kg) | % |
|---|---|---|---|---|
| Retail Parts | Casting | 52 kg | 44 | 43,7 |
| Original Parts | Extrusion, foil rolling | 1,2e+02 kg | 57 | 56,3 |
| Total | | | 1e+02 | 100 |

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## Transport:

Summary

### Breakdown by transport stage

| Stage name | Transport type | Distance (km) | CO2 footprint (kg) | % |
|---|---|---|---|---|
| Boat | Ocean freight | 1e+04 | 22 | 100,0 |
| Total | | 1e+04 | 22 | 100 |

### Breakdown by components

| Component | Mass (kg) | CO2 footprint (kg) | % |
|---|---|---|---|
| Retail Parts | 52 | 6,7 | 30,1 |
| Original Parts | 1,2e+02 | 16 | 69,9 |
| Total | 1,7e+02 | 22 | 100 |

## Use:

Summary

### Relative contribution of static and mobile modes

| Mode | CO2 footprint (kg) | % |
|---|---|---|
| Static | 0 | |
| Mobile | 0 | |
| Total | 0 | 100 |

## Disposal:

Summary

| Component | End of life option | CO2 footprint (kg) | % |
|---|---|---|---|
| Retail Parts | Recycle | 2,5 | 30,1 |
| Original Parts | Recycle | 5,9 | 69,9 |
| Total | | 8,4 | 100 |

## EoL potential:

| Component | End of life option | CO2 footprint (kg) | % |
|---|---|---|---|
| Retail Parts | Recycle | -88 | 30,1 |
| Original Parts | Recycle | -2e+02 | 69,9 |
| Total | | -2,9e+02 | 100 |

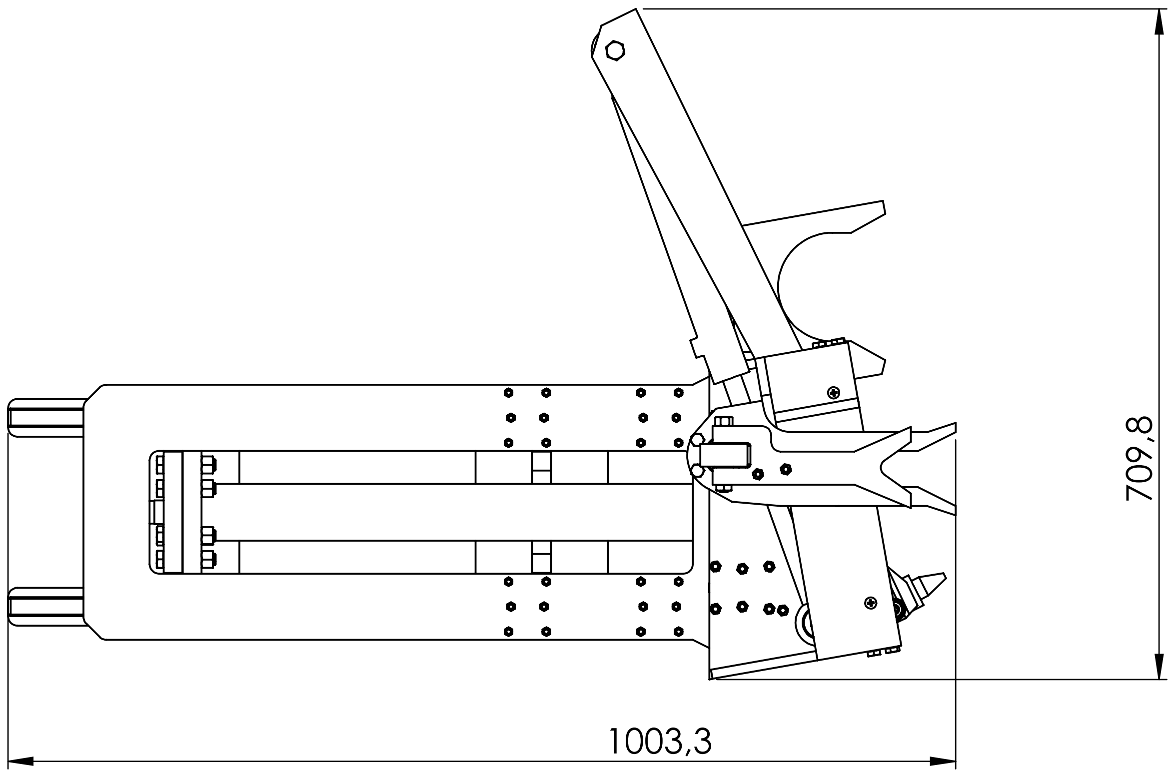
## Notes:

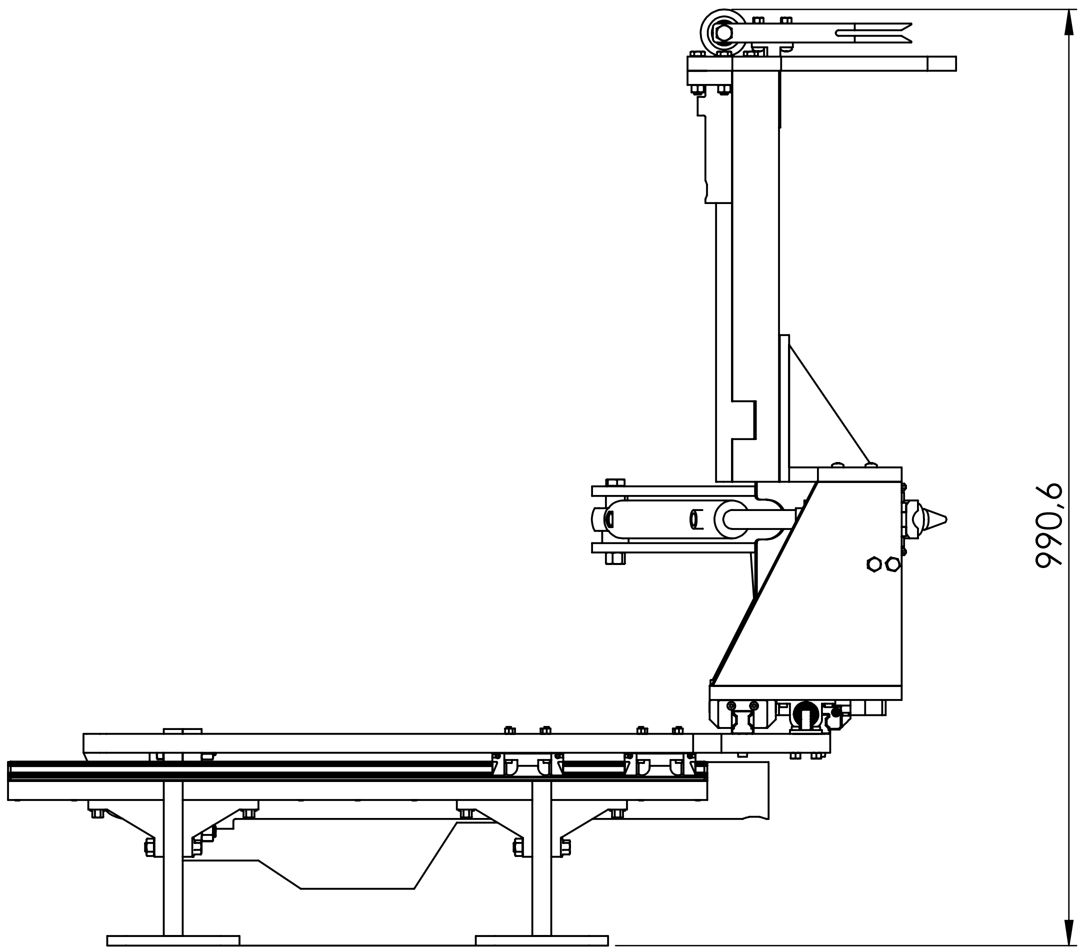
Summary

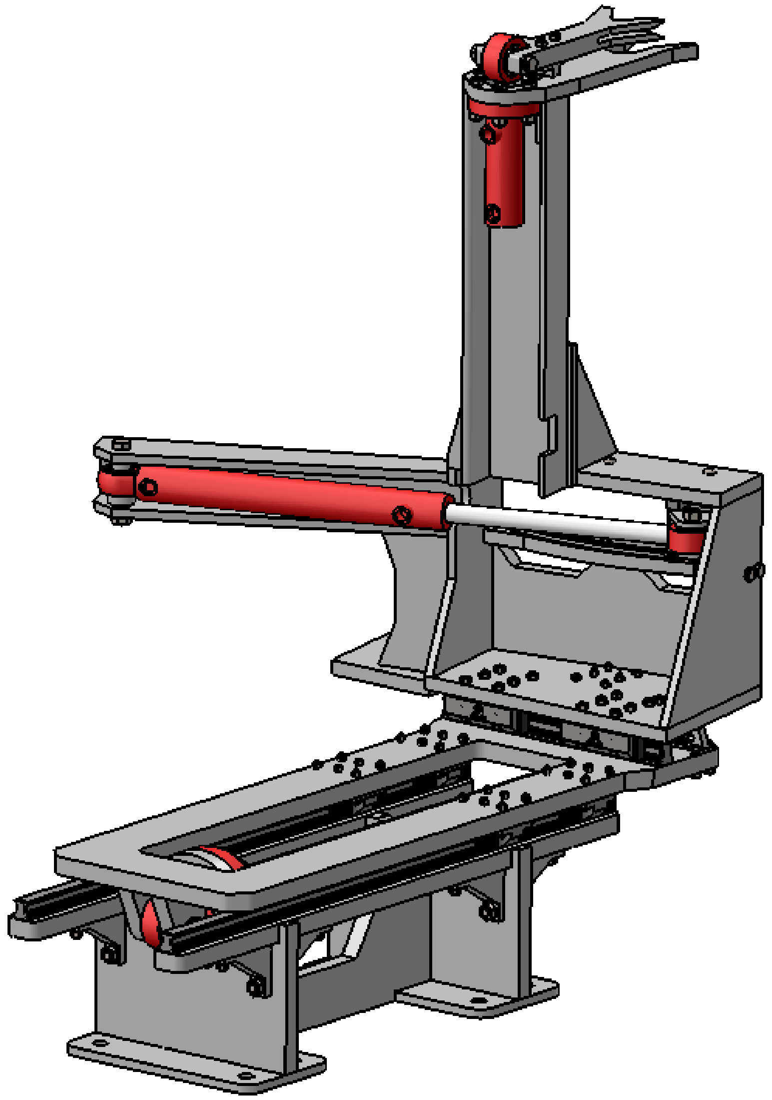
# Appendix V

## Technical Drawings

i. Automated Rotator – Outer Dimensions
ii. Automated Rotator – Main Assemblies – Exploded View
iii. Automated Rotator – Frame Assembly – Exploded View
iv. Automated Rotator – Slider Assembly – Exploded View
v. Automated Rotator – Floor Mounting – Exploded View
vi. Index Pin Assembly – Outer Dimensions
vii. Index Pin Assembly – Exploded View



ACTIVATED POSITION

| Responsible dept. | Created by | Checked by | Approved by |
|---|---|---|---|
| Drilling Risers | David R. K. Holm | Daniel Myrseth | Henrik Falstad |

Legal owner: mhwirth

Document types: General Assembly Drawing

Title: Automated Rotator Outer Dimensions

Institution: NMBU Norges miljø- og biovitenskapelige universitet

| Rev | Date of issue | Lang | Sheet |
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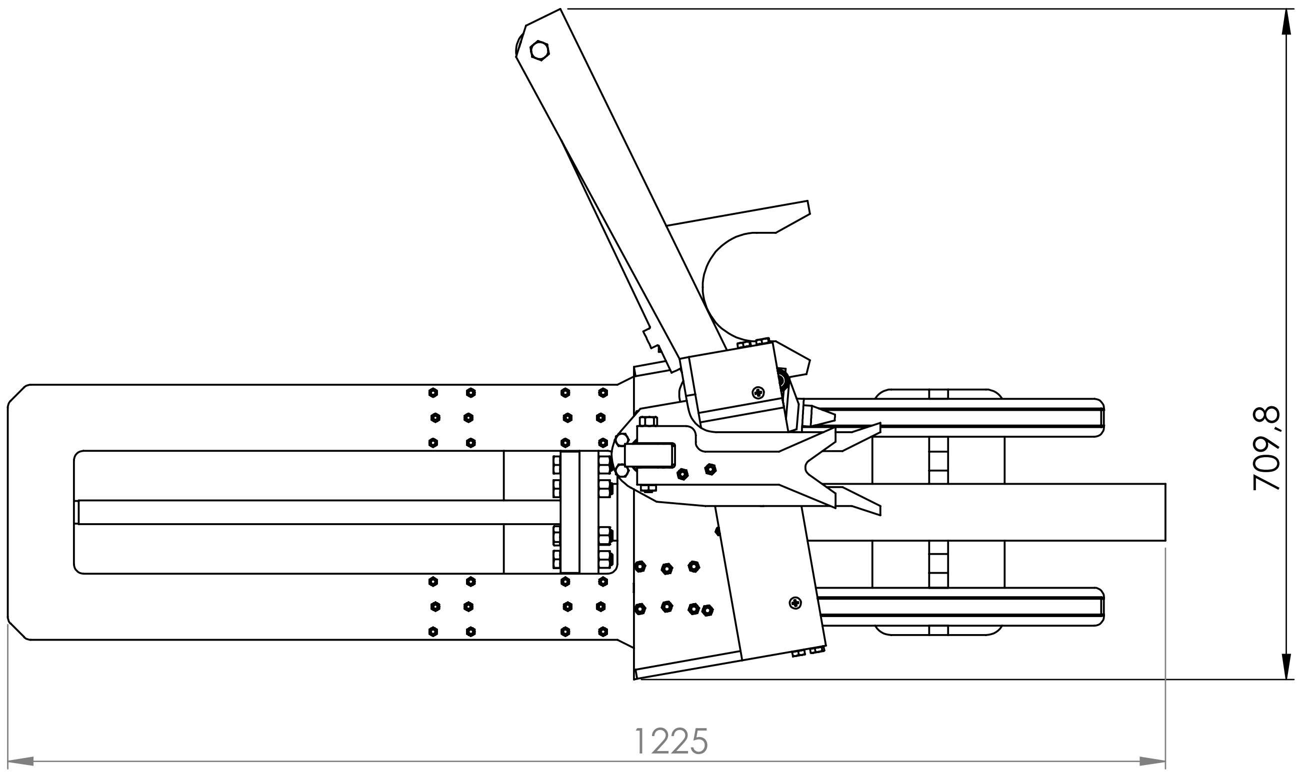


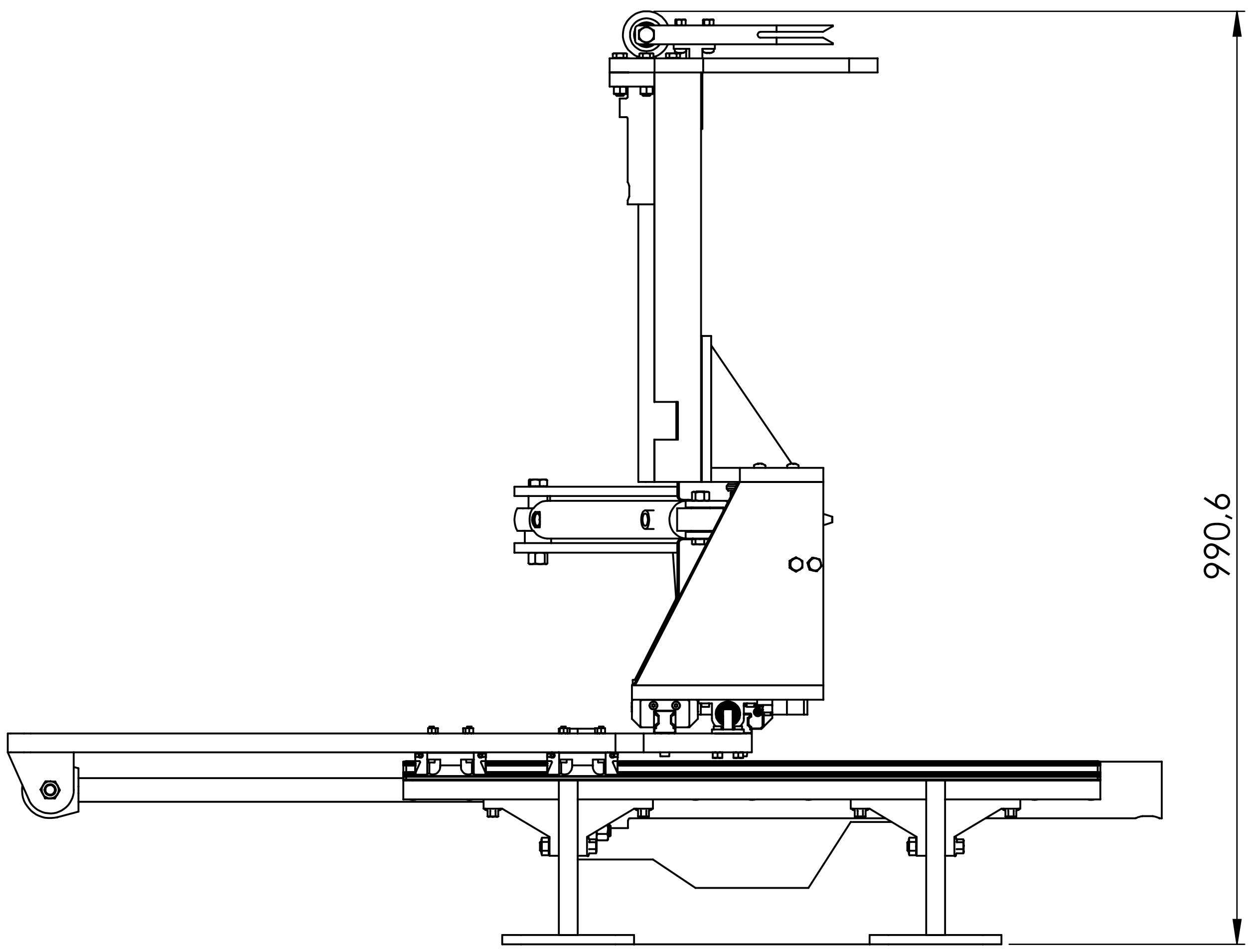


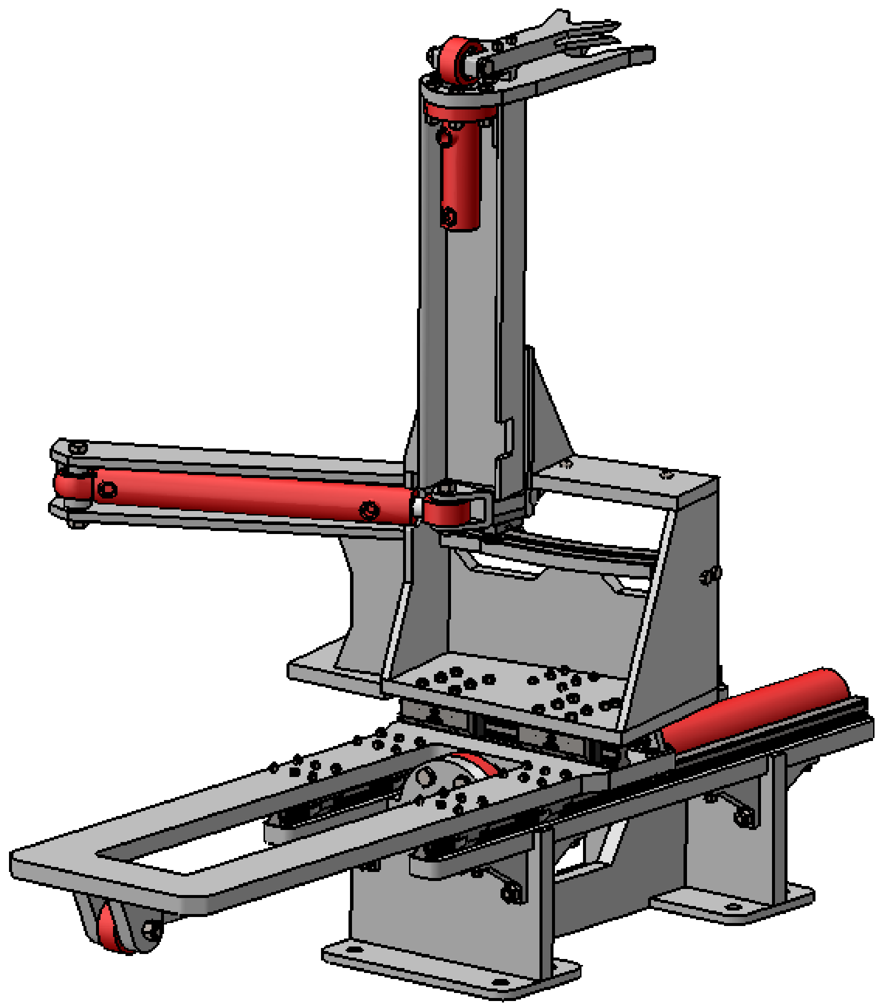

DEACTIVATED POSITION

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| Legal owner | Document types | Institution |
| --- | --- | --- |
| mhwirth | General Assembly Drawing | Norges miljø- og biovitenskapelige universitet |
| | Title: Automated Rotator Outer Dimensions | |

| Rev | Date of issue | Lang | Sheet |
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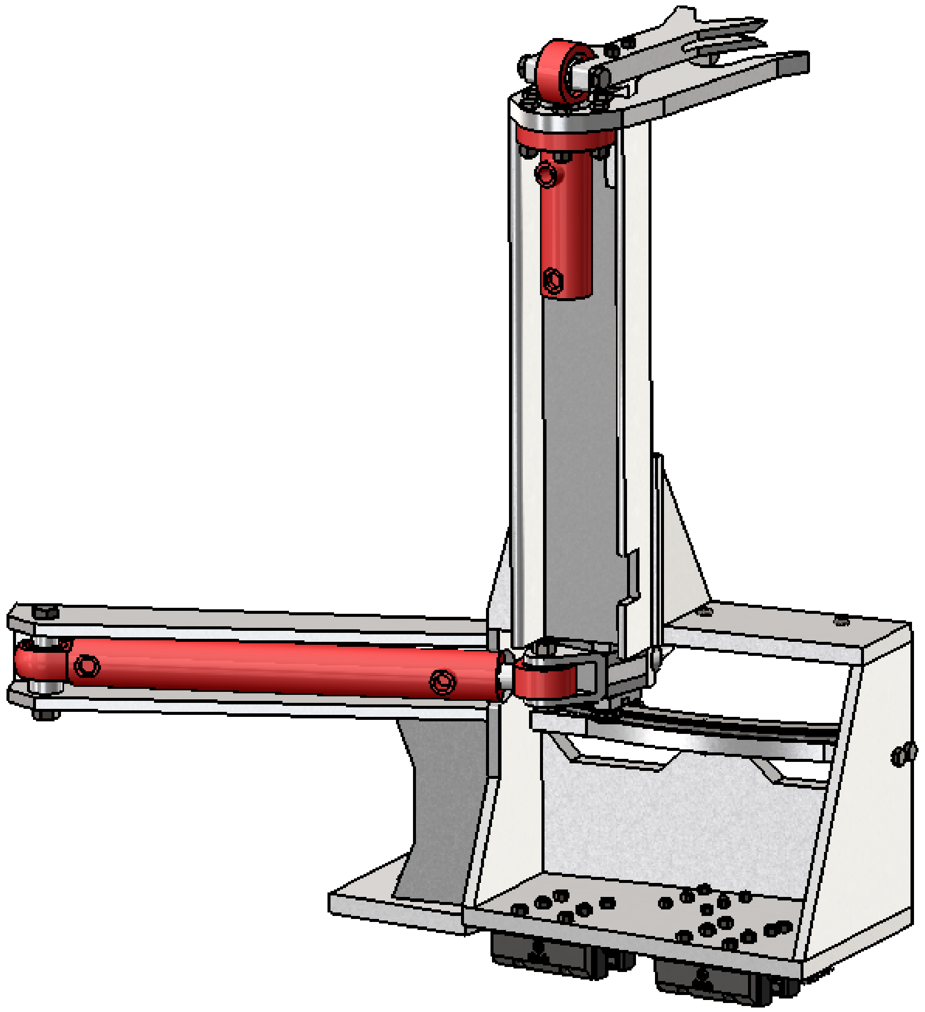
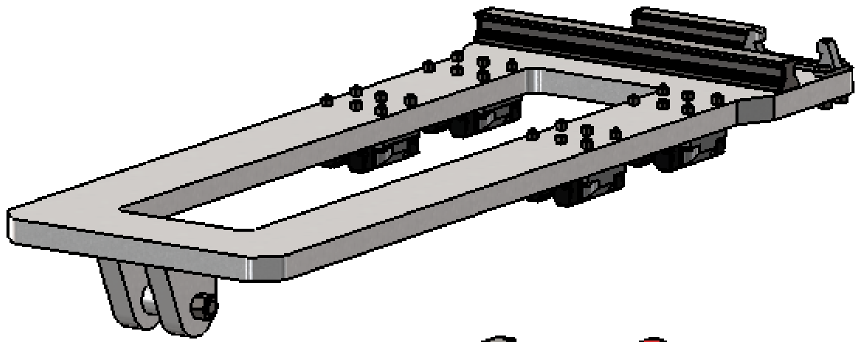
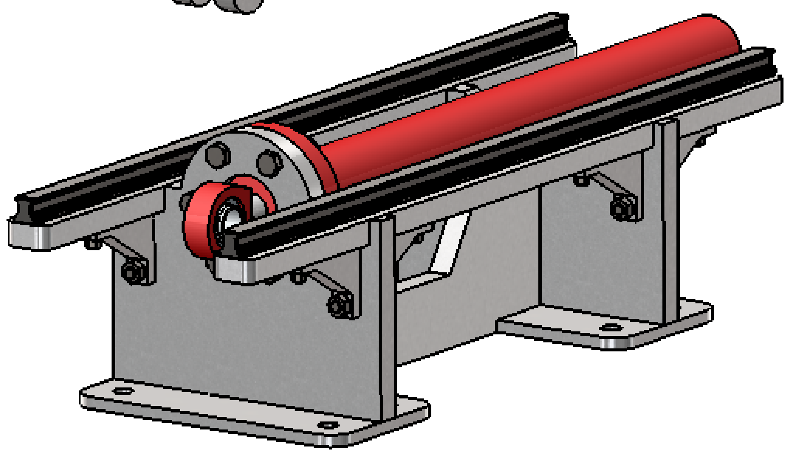


Frame



Slider



Floor Mounting

| Responsible dept. | Created by | Checked by | Approved by |
|---|---|---|---|
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| Legal owner | Document types / Title | Institution |
|---|---|---|
| mhwirth | Assembly Drawing | Norges miljø- og biovitenskapelige universitet |
| | Automated Rotator Main Assemblies Exploded View | |

| Rev | Date of issue | Lang | Sheet |
|---|---|---|---|
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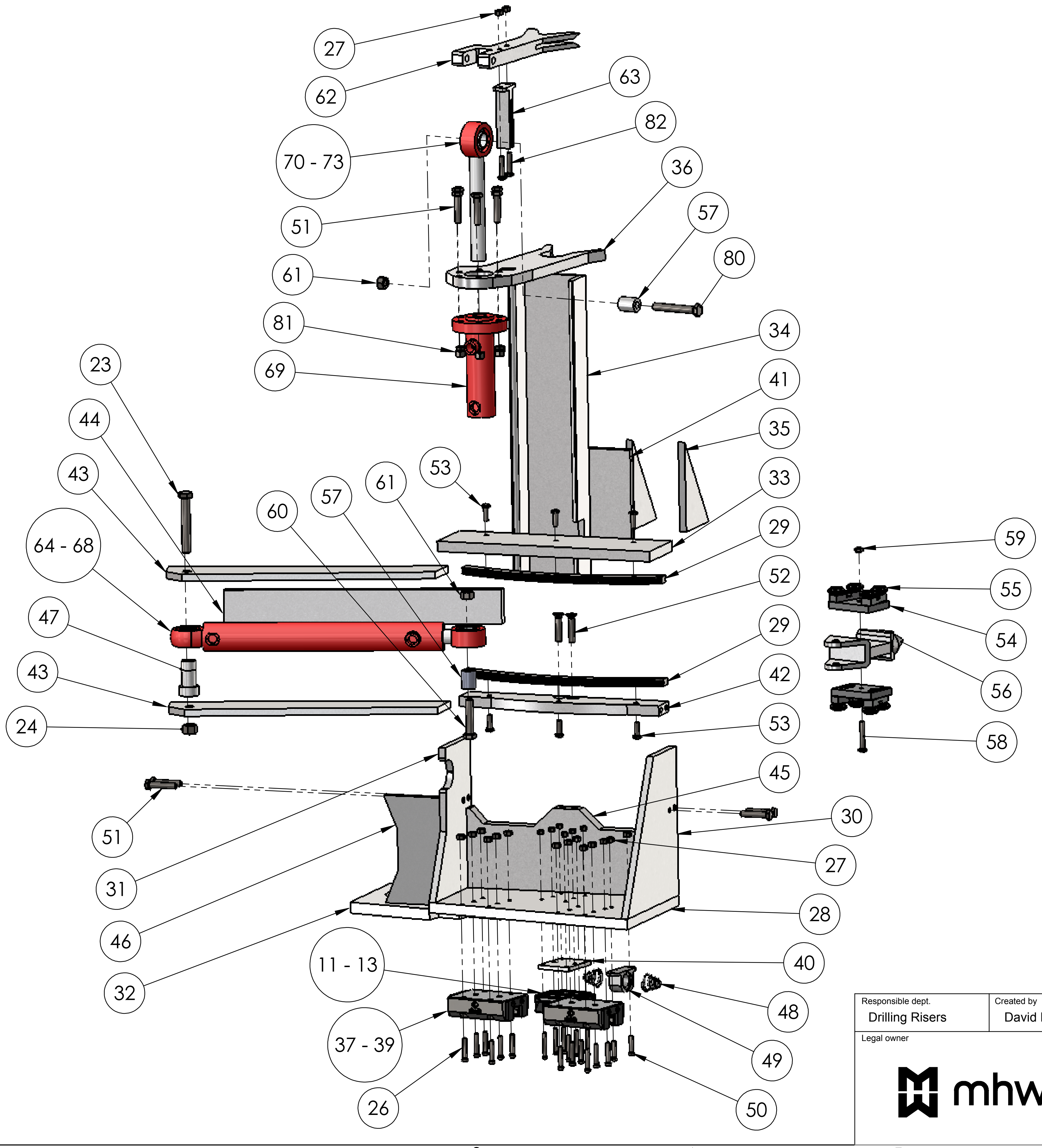


| Responsible dept. | Created by | Checked by | Approved by |
|---|---|---|---|
| Drilling Risers | David R. K. Holm | Daniel Myrseth | Henrik Falstad |

Legal owner

mhwirth

Document types
Assembly Drawing

Title
Automated Rotator
Frame Assembly
Exploded View

Institution
Norges miljø- og biovitenskapelige universitet

| Rev | Date of issue | Lang | Sheet |
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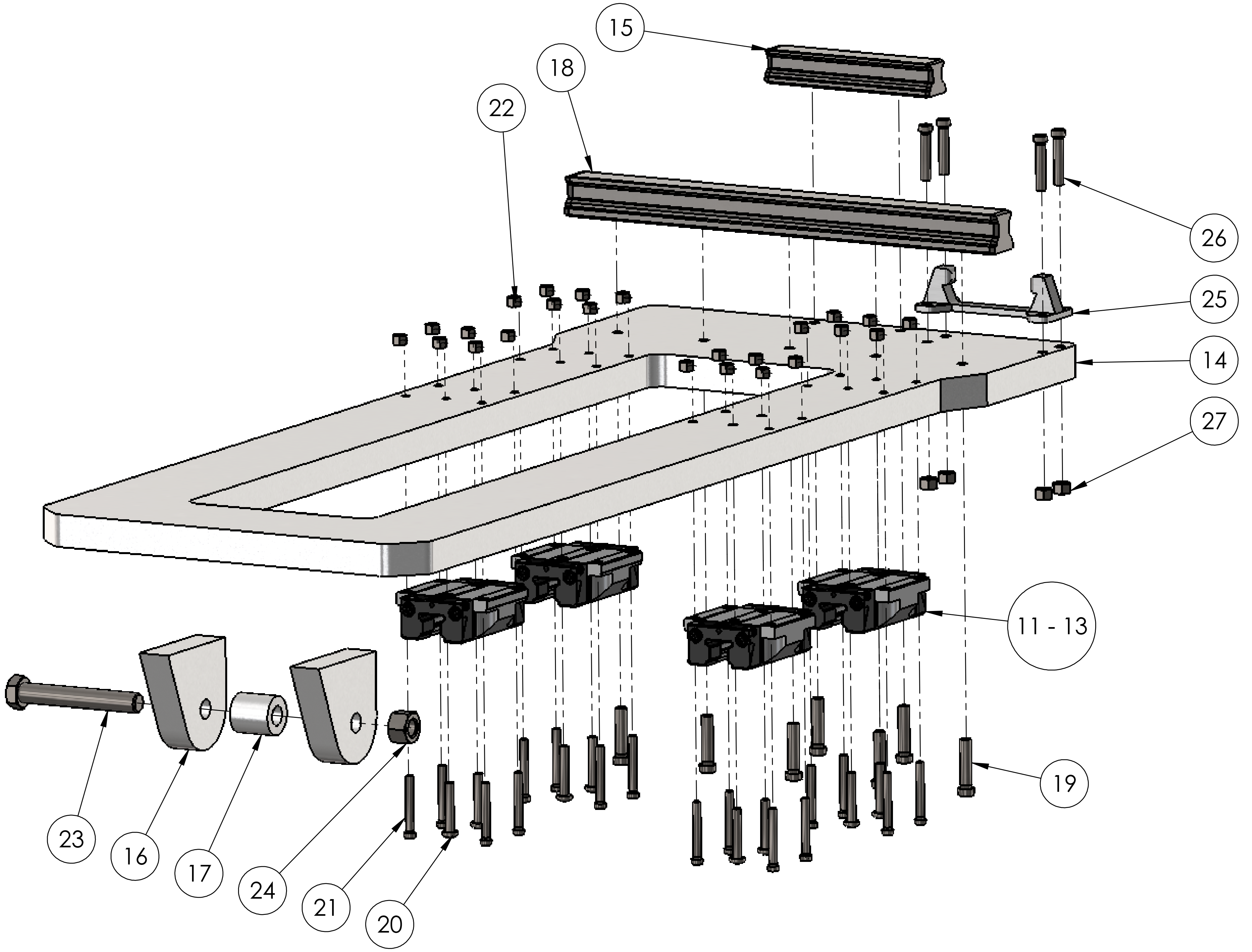


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| Legal owner | Document types | Institution |
|---|---|---|
| mhwirth | Assembly Drawing | NMBU Norges miljø- og biovitenskapelige universitet |
| | Title: Automated Rotator Slider Assembly Exploded View | |

| Rev | Date of issue | Lang | Sheet |
|---|---|---|---|
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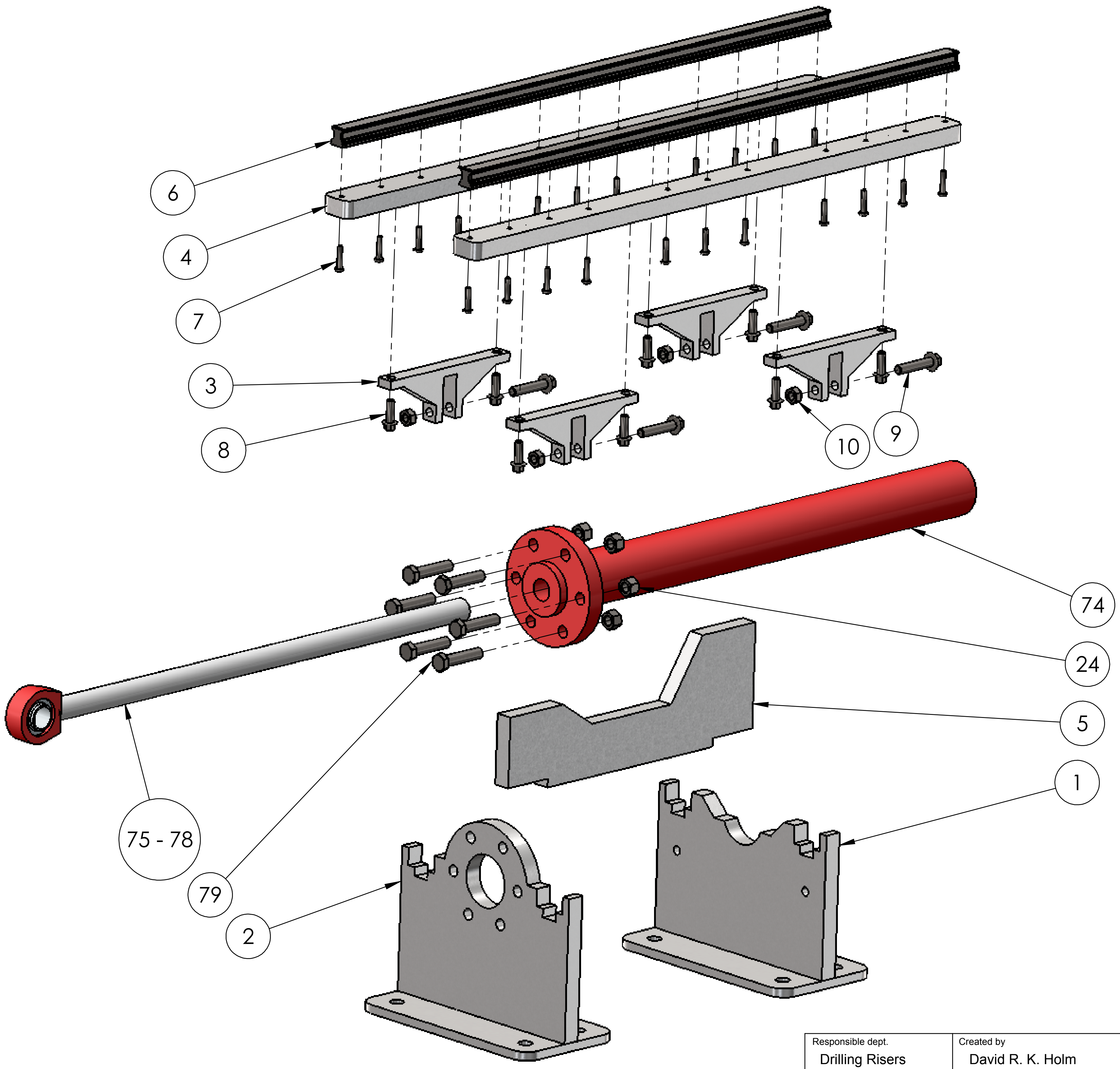


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|---|---|---|---|
| Drilling Risers | David R. K. Holm | Daniel Myrseth | Henrik Falstad |

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| | Title: Automated Rotator<br>Floor Mounting Assembly<br>Exploded View | |

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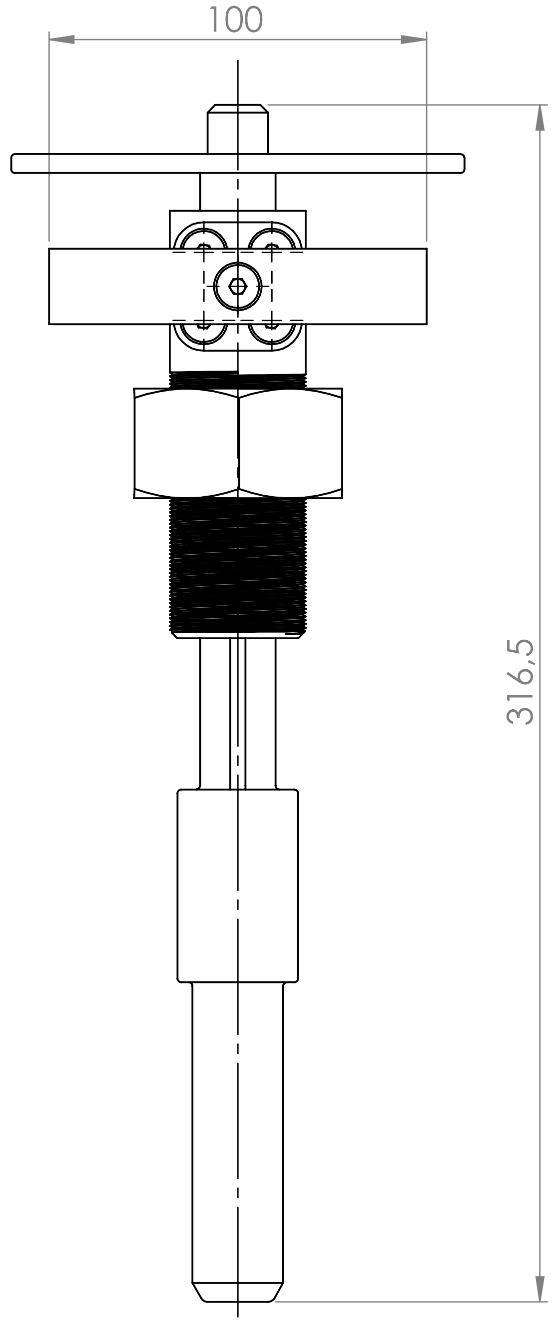
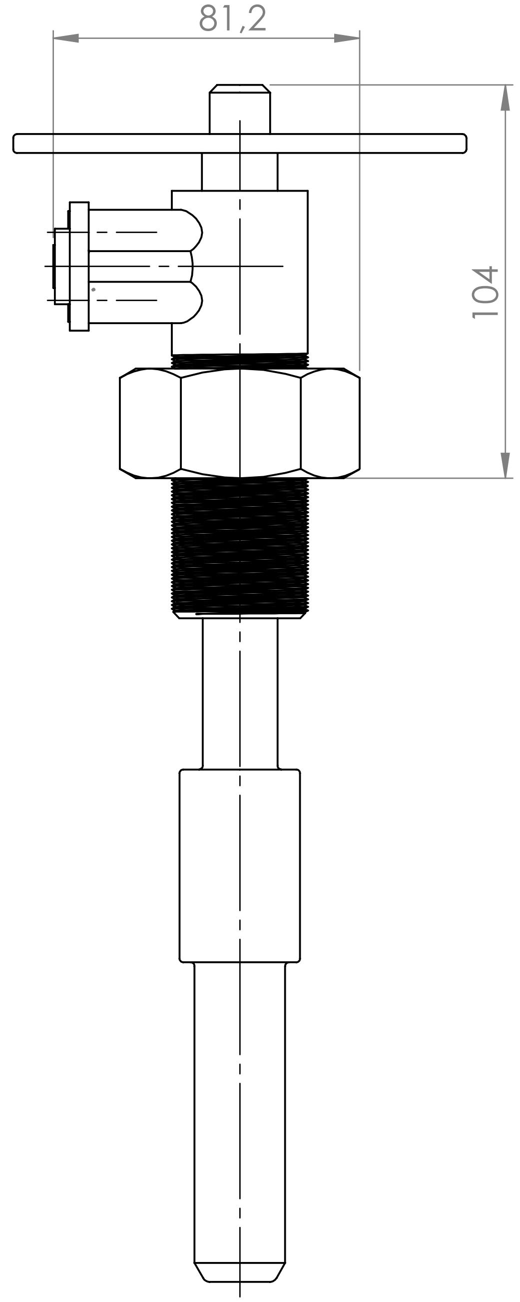
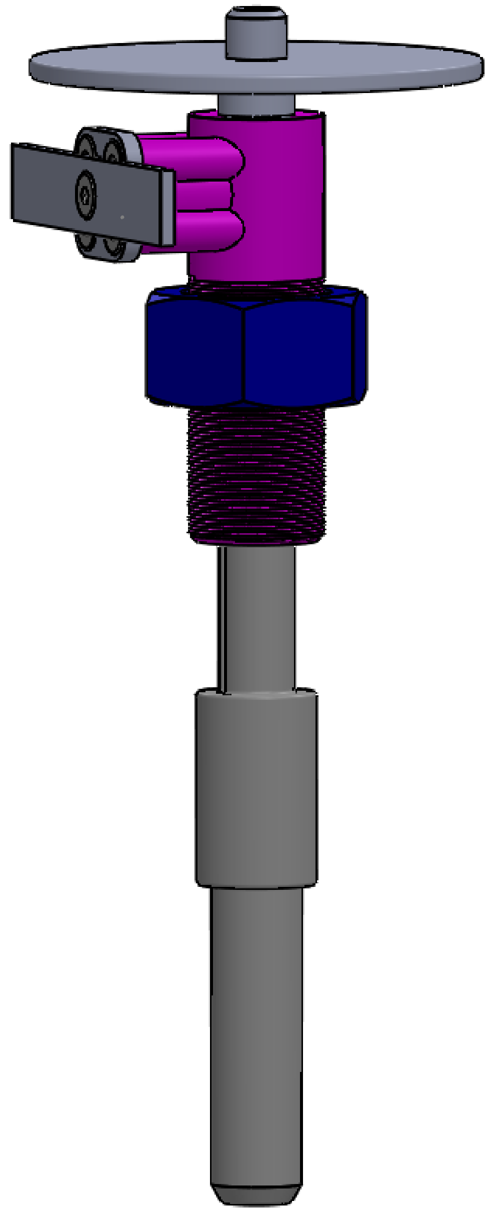
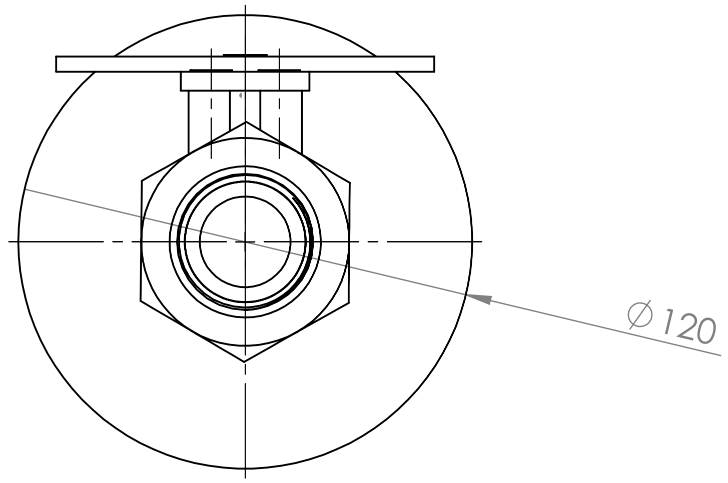


LOCKED POSITION

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| | Title: Index Pin Assembly, Closed Outer Dimensions | |

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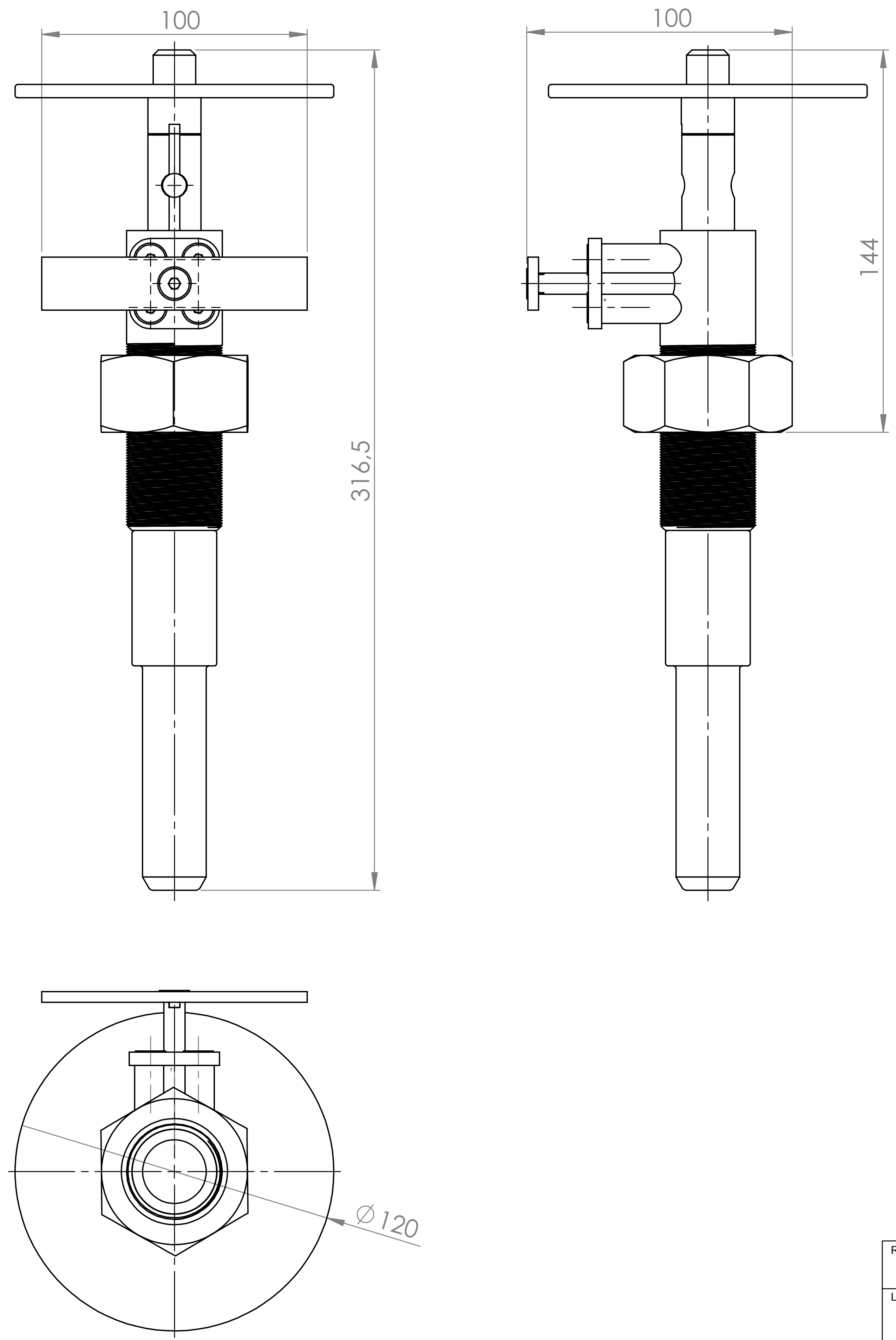


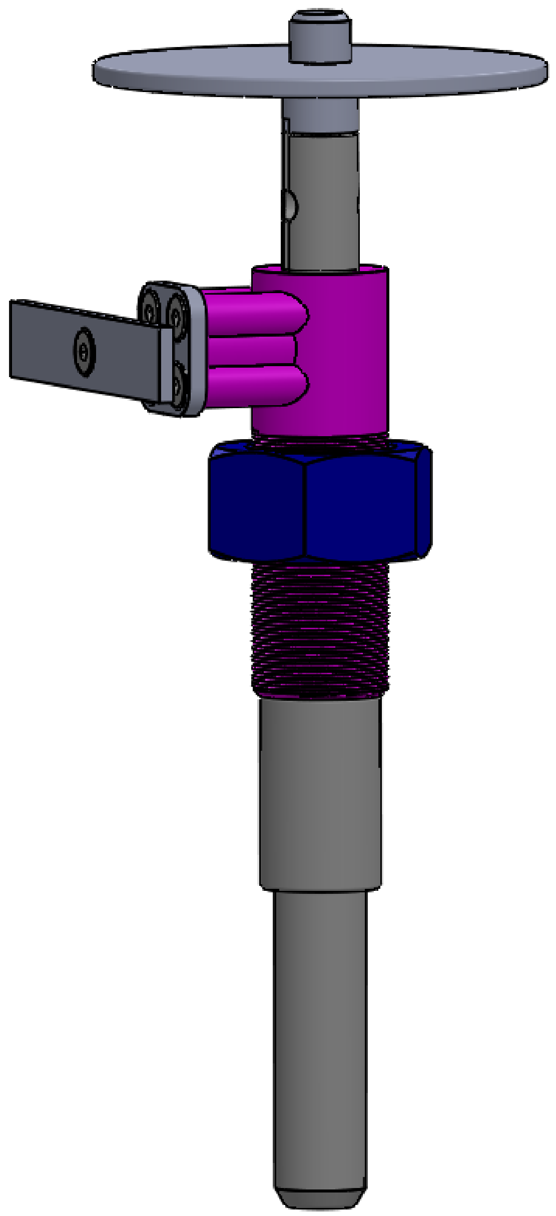

OPEN POSITION

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| | Title: Index Pin Assembly, Open Outer Dimensions | |

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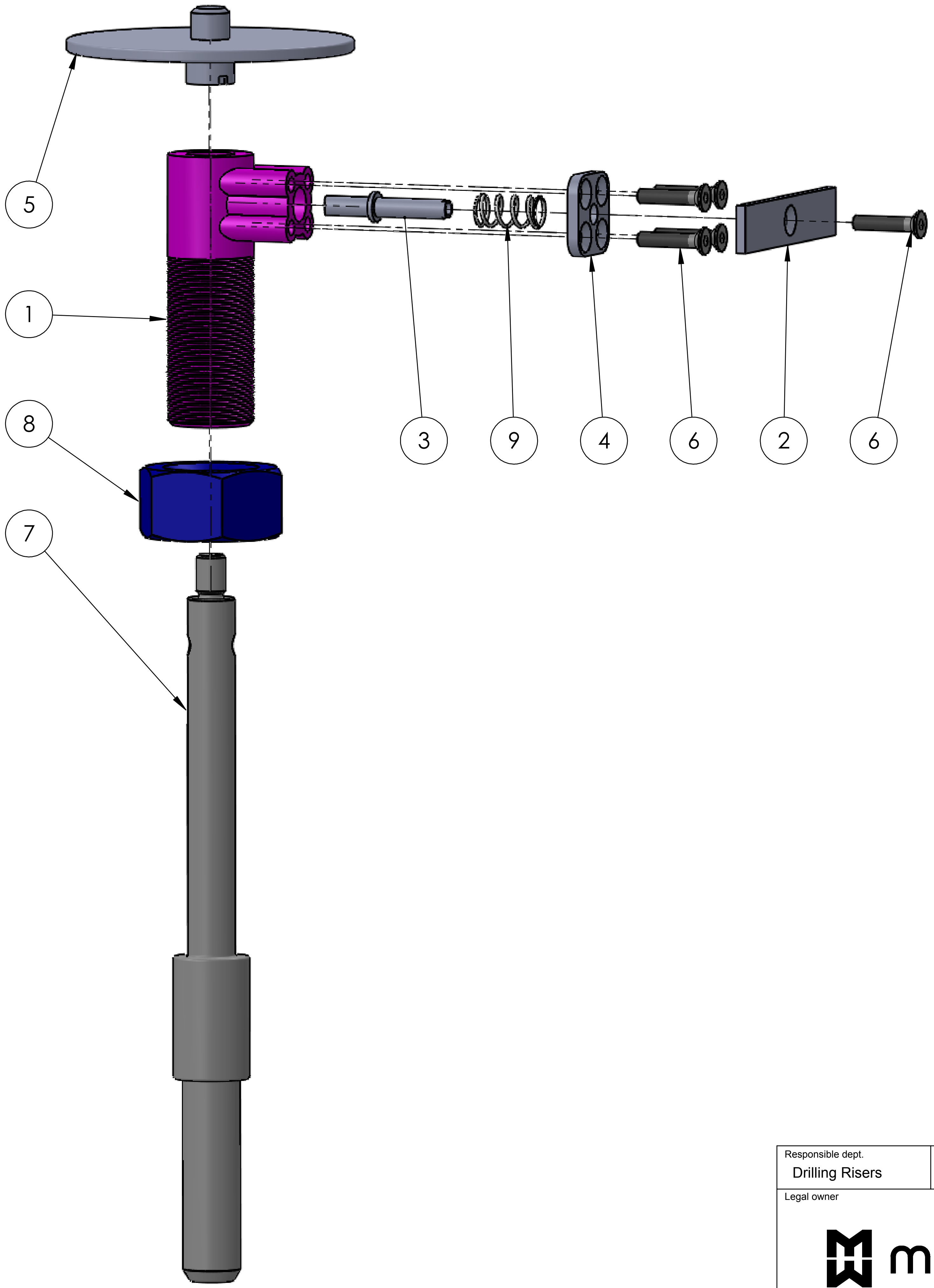
| 01 | 11/04/19 | en | 2/2 |

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| mhwirth | Assembly Drawing | Norges miljø- og biovitenskapelige universitet |
| | Title: Index Pin Assembly Exploded View | |

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