Sensur av hovedoppgaver

Høgskolen i Sørøst-Norge
Fakultet for teknologi og maritime fag

Prosjektnummer: **2016-16**
For studieåret: **2015/2016**
Emnekode: **SFHO3201**

Prosjektnavn
Poleringsmaskin for kompaktflenser.
Polishing machine for compact flanges.

Utført i samarbeid med: Freudenberg Oil & Gas Technologies.

Ekstern veileder: David Robertson.

Sammendrag: We have developed a polishing machine for Freudenberg Oil & Gas Technologies' compact flanges. The machine is pneumatically driven and it fits the 14'', 16'' and 18'' flanges.

Stikkord:
- Polishing
- Offshore
- Mechanical

Tilgjengelig: JA

Prosjekt deltagere og karakter:

Navn	Karakter
Arian Krasniqi	
Richelieu Dahn	
Odd Eirik Hardem	
Morten Grøsfjeld	

Dato: 9. Juni 2016

____
Kjell Enger
Intern Veileder

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Karoline Moholth
Intern Sensor

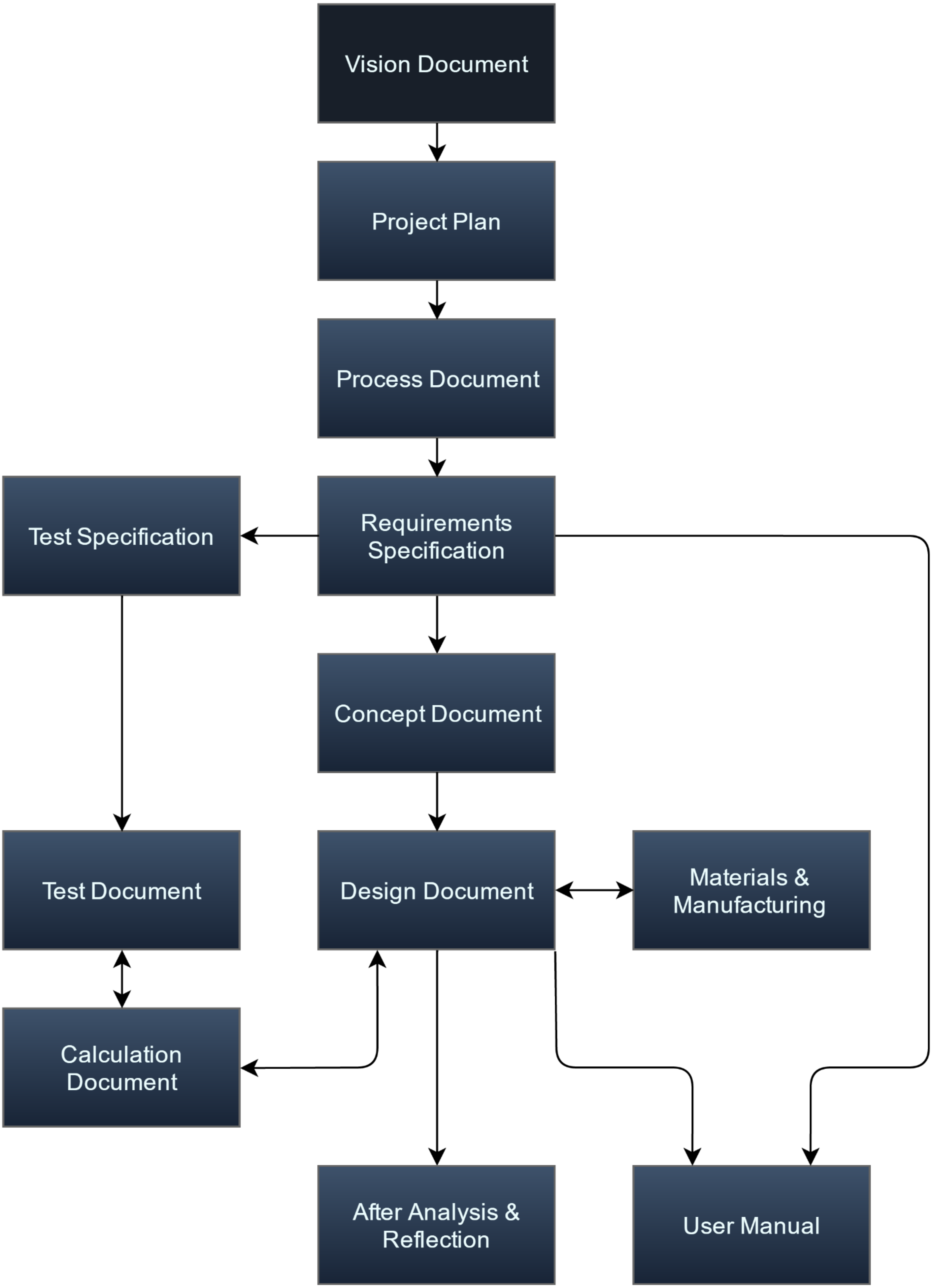
____
Przemyslaw Lutkiewicz
Ekstern Sensor

POLISHING MACHINE FOR COMPACT FLANGES

Freudenberg Bachelor 2016

SPO CF Seat polishing tool

Arian Krasniqi, Richelieu Dahn, Odd Eirik Hardem, Morten Grøsfjeld


Vision Document
Project Plan
Process Document
Test Specification
Requirements Specification
Concept Document
Test Document
Design Document
Materials & Manufacturing
Calculation Document
After Analysis & Reflection
User Manual

Vision document

Freudenberg Bachelor 2016

SPO CF Seat polishing tool

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Version	Document number	Date	Responsible	Status
5.0	001	22.05.2016	All	Finalized

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1.0 Document

1.1 Document history

Version	Date	Changes
0.1	12.01.2016	Document created
0.2	13.01.2016	Minor changes
0.3	13.01.2016	Restructure to IBM format
0.4	14.01.2016	Minor changes
0.9	14.01.2016	Restructured to own format
1.0	20.01.2016	Finalized
2.0	27.01.2016	• Restructured 4.0 • Spelling correction
2.1	28.01.2016	• Added list of tables • Changed product name • Remade figure 1 • Added abbreviations in 1.2 • Corrected formatting errors
2.2	01.02.2016	• Added abbreviations
2.3	05.02.2016	• Updated figure 1 and FO&GT logo
3.0	07.02.2016	• Reviewed
4.0	14.03.2016	• Updated table 4
5.0	22.05.2016	• Finalized

Table 1 - Document history

1.2 Definition of abbreviations

Abbreviation	Definition
A.K.	Arian Krasniqi
BL	Blind flange
CF	Compact Flange
EF	End fitting flange
FO&GT	Freudenberg Oil & Gas Technologies
HX	H-profile seal ring for SPO CF
IF	Integral flange
IX	I-profile seal ring for SPO CF
M.G.	Morten Grøsfjeld
O.E.H.	Odd Eirik Hardem
R.D.	Richelieu Dahn
SPO	FO&GT brand name for compact flanges (Steel Products Offshore)
SW	Swivel flange
WN	Weld Neck type of flange
WT	Wall Thickness

Table 2 - Abbreviations

1.3 Introduction

The vision document will serve as a preliminary study and a basis for the decision-making of our final year bachelor project within product development at the University College of Southeast Norway.

The purpose of this document is first and foremost to provide a common and unambiguous understanding of the assignment that has been given to us by FO&GT. This will develop the basics for a mutual understanding among our stakeholders (our team, HSN & FO&GT). The details of this document will serve as a basic for future development of our project.

The content of the document also gives brief description of all examiners and supervisors.

1.4 Scope

The scope of this document is to provide necessary background information related to the project. It will contain the following information:

- Background information of the product.
- The purpose of why this project needs to be done.
- A problem description that describes the problem clearly and unambiguously.
- A brief list and description of stakeholders.
- The overall goals of the project.

2.0 SYSTEM OVERVIEW

2.1 BACKGROUND

FO&GT have decided to invest some of their resources in a possible solution for a maintenance tool, in this case a polishing tool for their 16" SPO CF WN CL600 IX16. This solution would equip FO&GT with a tool that would satisfy their customer maintenance needs.

A successful solution would provide:

- Increased efficiency.
- Increased safety precautions.
- Increased revenue.
- Increased longevity of the flange.
- Dimensional control.

2.2 PROBLEM STATEMENT

The problem with the current method of maintenance used by the support engineers at FO&GT is that they have to either manually polish by hand the small damages to the seat and heel face of the SPO CF flange or bring in site machining tools. These options are costly and time consuming because of an inefficient use of man-hours & equipment, which in turn leads to unnecessary loss of revenue.

2.3 SYSTEM SUMMARY

FO&GT wants a polishing tool for their 16" SPO CF WN CL600 IX16 flange that will:

- Be mounted on the flange.
- Polish three distinct surfaces of the flange, shown in figure 1.
- Polish the flange for rust, minor damages and scratches.
- Be mechanically sound, and give sufficient angular control of polishing head.
- Have a total maximum weight no more than 25 kg.

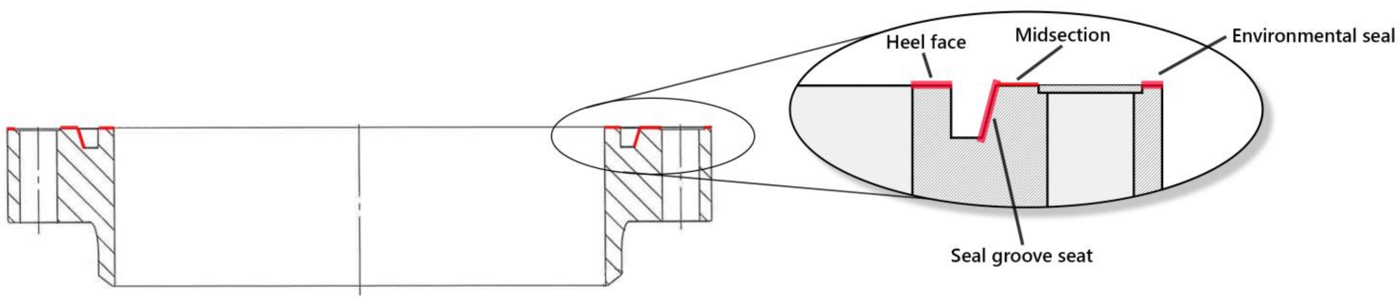


Figure 1 - Showing the affected flange faces marked in red.

3.0 STAKEHOLDERS

A stakeholder is anyone that has an interest in our project. For this project, we have decided to divide these stakeholders into primary and secondary. The primary stakeholders are those that have a direct interest in the growth and success of our project as they can be affected by the results, while the secondary stakeholders are anyone who are indirectly affected by the outcome of the project.

PRIMARY STAKEHOLDERS	SECONDARY STAKEHOLDERS
Employer	Customer
Our team	End users (Industry)
HSN	

Table 3 - Stakeholders

3.1 PRIMARY STAKEHOLDERS

FO&GT is the employer of our project, and is represented by Mr. David Robertson. Their responsibilities include to assist us with technical advises, join meetings, discuss how the project is going and to assist us financially.

HSN is our university college and is represented by our project`s internal examiner and supervisor whose roles are listed in table 2 and further elaborated in the project plan document. All of our listed primary stakeholders will have an overall insight on the process and progress of the entire project as they are monitoring. They will therefore be present at all scheduled presentations.

This is an overview of our primary stakeholders from FO&GT and HSN.

NAME	ROLE	CONTACT
Kjell Enger	Internal Supervisor	Kjell.enger@hbv.no
Karoline Moholth	Internal Examiner	Karoline.moholth@hbv.no
David Robertson	External Supervisor	David.robertson@fogt.com
Przemyslaw Lutkiewicz	External Examiner	Przemyslaw.utkiewicz@fogt.com

Table 4 - Primary stakeholders

3.2 SECONDARY STAKEHOLDERS

FO&GT is also our customer in terms of end users. To be more specific, their support engineers will be the ones using the product and possibly maintaining it after use. It is therefore our job to design a product that is easily driven in terms of functions. When this product is successful, the future plan of FO&GT is to rent it out to other companies that are in need of such tools. Therefore, end users from the industry will primarily be the mechanics and other professionals that will perform the polishing.

4.0 Project goals

In order for our team to complete a successful bachelor thesis, the project goals must be defined as they can be used as a form of evaluation as to whether or not we have succeeded with the project.

4.1 Team goals

Up to this point in our mechanical engineering bachelor's degree, we have studied technical courses along with theoretical courses. This has given us the fundamental knowledge we will need in order to learn how to solve the challenges associated with a project of this size; a project that will familiarize us with how product development projects are done in a professional setting. Therefore; our team goals are to:

- Improve our technical & theoretical knowledge and abilities.
- Obtain the necessary skills and experience to ensure efficient teamwork.
- Get an insight into how real engineering companies carry out projects.
- Obtain a high and well-deserved grade.

4.2 Result goals

FO&GT expects us to develop a concept for the polishing tool that satisfies their requirements.

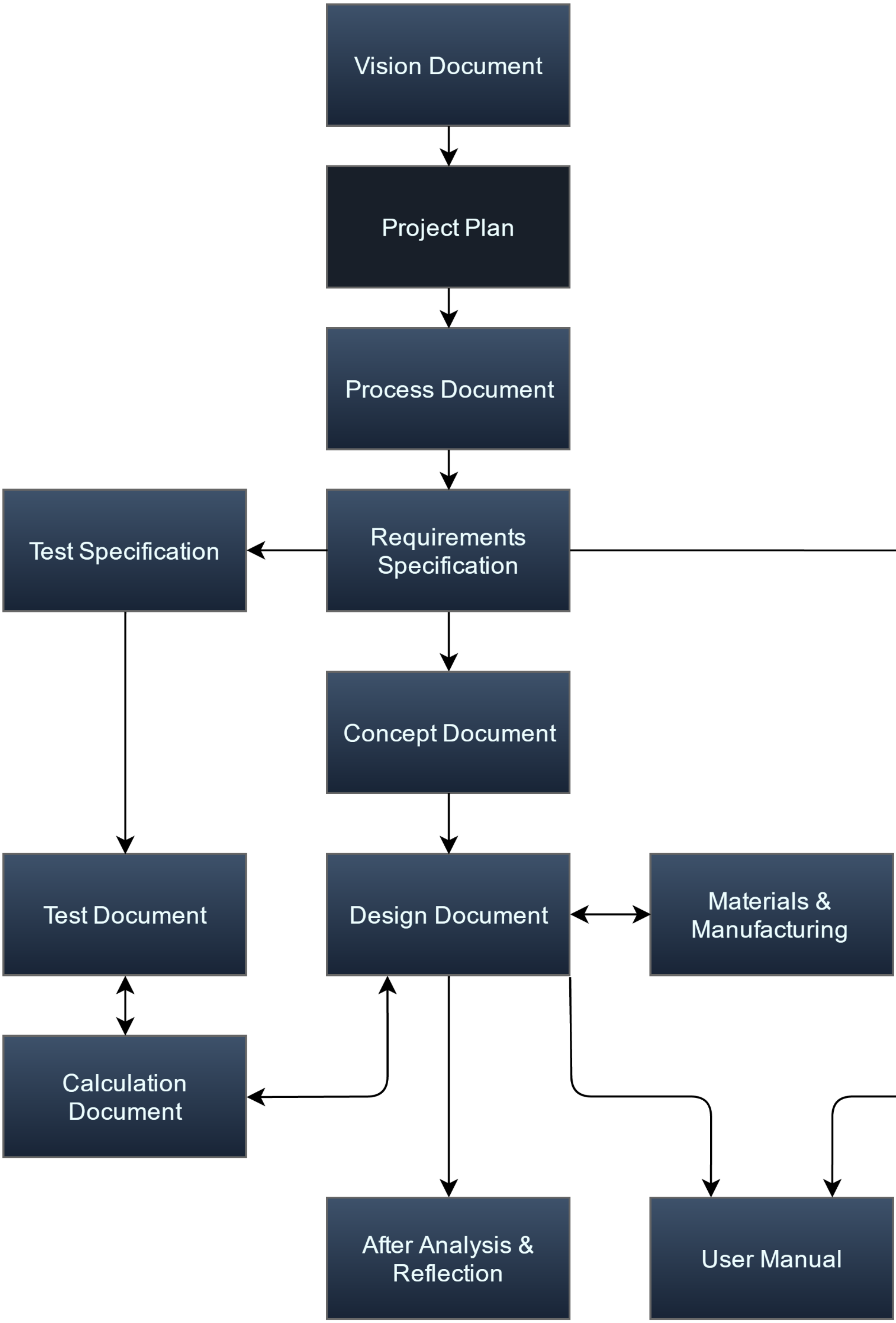
The result goals of this project have been divided into two; the primary and secondary goals. The primary goals are those that are to be done in other to cover up the expectations that our customer have, while the secondary goals are those we hope to fulfil if there is additional time available after the completion of the primary goals. The purpose of the secondary goals is to exceed our employer's expectations.

4.2.1 Primary goals

- Develop a solution that fulfils all high priority requirements.
- Complete detailed CAD drawings of the design.
- Animation that demonstrates the functionality of the design.
- Test results to prove requirement fulfilment of the design.

4.2.2 Secondary goals

- Make the solution compatible with a wider range of flanges.
- Create a prototype if time presents itself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Project Plan

Freudenberg Bachelor 2016

SPO CF Seat polishing tool

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1.0 Document

1.1 Document history

Version	Date	Changes
0.1	25.01.2016	Document created
0.2	28.01.2016	• Added 2.0 Organization • Added 3.0 Time management • Added 4.0 Tools and resources • Added 6.0 Project model • Added 7.0 Documentation
0.3	29.01.2016	• Added 9.0 Risk management • Added 2.2, 3.1
0.4	02.02.2016	• Updated 3.2, 5.0, 5.1, 5.2, 6.1, 6.2, 6.3,
0.5	03.02.2016	• Updated 9.0, 3.0
0.6	03.02.2016	• Added 3.3 Activity plan • Added 3.2 Schedule • Added 4.2 Software tools
0.7	03.02.2016	• Reviewed 1.0 through 8.0
1.0	04.02.2016	• Final review, added references
1.01	05.02.2016	• Corrected spelling and typing errors • Updated FO&GT logo
2.0	07.02.2016	• Reviewed
3.0	14.03.2016	• Updated 3.4 Activity plan • Updated photographs on chapter 2.1 • Updated table 9 with external examiner • Updated figure 2 • Added link to website in 8.3 • Updated burn
4.0	22.05.2016	• Finalized

Table 1 - Document history

1.2 Definition of abbreviations

Abbreviation	Definition
FO&GT	Freudenberg Oil & Gas Technologies
SPO	FO&GT brand name for compact flanges (Steel Products Offshore)
CF	Compact Flange
IX	I-profile seal ring for SPO CF
HX	H-profile seal ring for SPO CF
WN	Weld Neck type of flange
WT	Wall Thickness
IF	Integral flange
EF	End fitting flange
SW	Swivel flange

BL	Blind flange
M.G.	Morten Grøsfjeld
A.K.	Arian Krasniqi
O.E.H.	Odd Eirik Hardem
R.D.	Richelieu Dahn
GTD	Getting Things Done (method)
ECTS	European Credit Transfer and Accumulation System

Table 2 - Definition of abbreviations

1.3 INTRODUCTION

The purpose of this document is to clearly define the framework of our bachelor´s thesis. The intention of this project plan is to explain how we plan to execute the development stages necessary to complete FO&GT´s requirements for their product.

In order to work within the framework, it is important to list the boundaries associated towards the completion of this product.

It has been mentioned by our employer that the polishing tool should be designed in a way that it can easily be taken offshore by their support engineers as weight is a key factor.

The product is to be designed such that it is driven by non-electric means.

Given that this is a bachelor´s thesis; there is a limited amount of time that we are able to devote to this project, i.e. 2500 in total. If we estimate that every member of the group is able to devote as mandated by HSN's estimation that 20 ECTS equals to at least 600 working hours during the project.

The project plan will give a clear insight on how the progression that is made on the bachelor´s thesis is conducted.

1.4 SCOPE

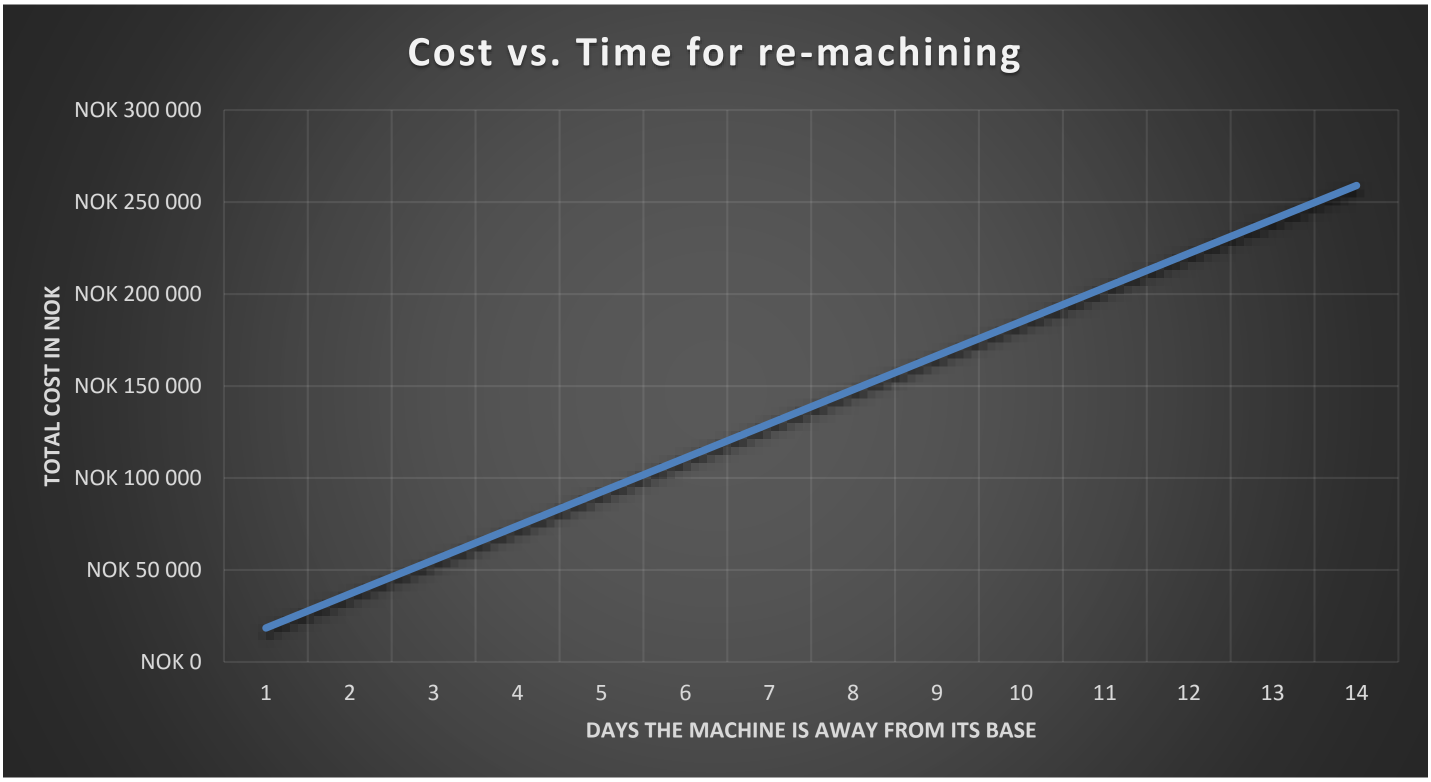
The scope of this document is the project plan. The document will contain the following information:

- How we plan to achieve our goals.
- Structure of the project team.
- The project lifecycle.

1.5 Marketing

The primary reasons FO&GT wants to have this machine designed is to make it easier and safer for their operators and to save money. The methods they use today are very time consuming, costly and tiring.

The only option they have today if hand polishing is not an option is to re-machine the flanges. This is very costly for FO&GT because they have to rent the machines and operators with it. When re-machining; FO&GT gets invoiced approximately 20.000 NOK in average for each flange. (Mikkelsen, 2016)



Hand polishing is often an option and it is done regularly. This process is very time consuming and can take anywhere from a few minutes to a few days depending on the magnitude of the damage. Hand polishing is also very tiring for the mechanic and can be damaging on the mechanic's wrist and thumbs. In many cases, the mechanic has to be in an awkward position when polishing which makes the process even more tiring and damaging.

If we reach our goal and develop a tool that can easily be installed onto the flange, the need for re-machining will decrease and in return; increase revenue for FO&GT.

The polishing tool will also be faster and more accurate than today's hand-polishing method. The machine will ensure that the mechanic will have an easier and safer workday when a flange has to be polished.

2.0 ORGANIZATION

2.1 TEAM MEMBERS

NAME	ROLES AND RESPONSIBILITIES	BACKGROUND
 Arian Krasniqi	• Project leader • Requirements	**Education:** Mechanical engineer. **Experience:** 5 years in service, mechanical trade school. **Interests:** Hiking, sports, cooking. **PHONE** 99294286 **EMAIL** arian.krs@gmail.com
 Richelieu Dahn	• Test • Materials	**Education:** Mechanical engineer. **Experience:** Served as a summer intern during the summer of 2015. Contributed as a junior safety engineer towards the Johan Sverdrup project for Statoil. **Interests:** 3D, Mixed Martial Arts, football. **PHONE** 90823212 **EMAIL** richelieudahn@gmail.com
 Morten Grøsfjeld	• Documentation • Design	**Education:** Mechanical engineer. **Experience:** 4 years of 3D design. **Interests:** Design, travel, squash. **PHONE** 91347388 **EMAIL** mgrosfjeld@gmail.com
 Odd Eirik Hardem	• Systems engineering • Force calculations	**Education:** Mechanical engineer. **Experience:** Plumbing and welding. **Interests:** Hiking, fishing and reading. **PHONE** 92113474 **EMAIL** oehardem@gmail.com

Table 3 - Team members

2.2 Roles and responsibilities

2.2.1 Project leader

- Communication with stakeholders
- Oversee progress
- Lead and organization

2.2.2 Requirements

- Identify stakeholder and product requirements

2.2.3 Test

- Supervise testing
- Survey test documents
- Select resources

2.2.4 Materials

- Ensure materials meet requirements

2.2.5 Documentation

- Make sure documentation follow set guidelines.
- MIM
- Backup
- Document templates

2.2.6 Design

- CAD modeling

2.2.7 Systems engineering

- Systems engineering tools implementation
- Time management
- Phase supervision

2.2.8 Force calculations

- Ensure calculations are correct in all means

2.3 Team Methodology

The team will work in such a way that maximizes creativity and discussion in order to explore possible solutions to the problems that exists or may occur, this will be done by the use of the agile method which states that the bachelor´s thesis will be completed by continuous evaluations and brainstorming sessions.

This leads up to the GTD method of effective individual problem solving, in order to complete the iterations, there is a need for organized and individual work that is productive. The GTD method is a problem solving routine that is implemented into daily life which will make the individual work more productive and less stressful. This is done by putting reminders about the task that is to be completed within the timeframe into a structured matter, such that there are no distractions for finding a solution for the task ahead. After a task is completed it will be reviewed by a team member, who will offer constructive criticism and praise where it's due.

2.4 Budget

Throughout the project, there will be several expenses that the project team will have to pay for. Table 4 lists all the costs that have occurred so far, as well as those that have yet to occur.

Item	Cost
Project poster	245 NOK
Printing final report (350 pages)	2000 NOK
6-point extension cord	109 NOK
Extension cord	159 NOK
Duct tape	60 NOK
Paymo subscription (5 months)	860 NOK (99 USD)
Total	**3 374 NOK**
Total per member	**845 NOK**

Table 4 – Budget

3.0 Time management

3.1 Milestones

Our team decided to utilize the milestones as a form of help where it marks and gives an overview of specific points/stages of our project along its timeline. Each stage in the milestones does not explain in detail how they have been completed, but rather when they are expected to be completed. Table 5 shows an overview of milestones.

ID	Date	Milestone
I	11.01.2016	Start of project
II	10.02.2016	First presentation
III	17.03.2016	Second presentation
IV	20.05.2016	Hand in of documentation
V	02.06.2016	Third presentation

Table 5 – Milestones

3.2 Schedule

The progression made is based on the schedules assigned during a limited timeframe. These schedules will work as the basis for the project planning as it will give an estimation on the total amount of hours available throughout the different phases.

The scheduled estimation of hours required is always higher than the actual time estimated, this because there is a high risk that there will be ongoing delays as we progress through the different phases, allowing the flexibility of allocating time to critical tasks that interfere with further development of the iteration.

We have defined our time schedule such as there is 6 hours of core time that is to be completed each day on the project, this leaves us with about 624 working core-hours throughout the 104 days, to work on the project before hand in is due.

As there is a need for time allocation when it may be needed the team has agreed to work an extra 2 hours each day, if the task assigned is not completed within the timeframe. This leaves us with a total amount of 8 hours of work consisting of 6 core hours + 2 flexible hours.

Phase	Scheduled time	Estimated time	Real time
Planning and Requirements	454.4 Hours [20%]	340.8 Hours [20%]	337.6 Hours [20%]
Analysis and Design	908.8 Hours [40%]	681.6 Hours [40%]	675.2 Hours [40%]
Test	568 Hours [25%]	426 Hours [25%]	422 Hours [25%]
Evaluation	340.8 Hours [15%]	255.6 Hours [15%]	253,2 Hours [15%]
Total	2272 Hours [100%]	1704 Hours [100%]	1688 Hours [100%]

Table 6 – Phase schedule

STAGE	DURATION	SCHEDULED TIME	ESTIMATED TIME	REAL TIME
Initial planning	**Start:** 11.01.2016 **End:** 10.02.2016	736 Hours [22%]	552 Hours [22%]	558 hours [24%]
Elaboration	**Start:** 10.02.2016 **End:** 18.03.2016	864 Hours [26%]	648 Hours [26%]	630 hours [27%]
Construction	**Start:** 18.03.2016 **End:** 18.05.2016	992 Hours [30%]	744 Hours [30%]	1058 hours [45%]
Deployment	**Start:** 02.05.2016 **End:** 02.06.2016	736 Hours [22%]	552 Hours [22%]	192 hours [8%]
Total		3328 Hours [100%]	2496 Hours [100%]	2324,5 hours [100%]

Table 7 – Stage schedule

The stages define the start of the project until the final presentation, and will be further elaborated in chapter 7.2.

3.3 BURN DIAGRAM

Figure 1 – Burn diagram

Information extracted from the weekly iteration reports and table 7. The diagram shows the difference between the actual time used and what we have scheduled and estimated.

3.4 Activity plan

Activity ID	Description
A.0	**Administrative**
A.01	Paymo and time sheets
A.02	Write MIM
A.03	Data storage maintenance
A.04	Write Follow-up document
A.05	Document Templates
A.06	Updating Webpage
A.07	Project management
A.08	Miscellaneous
M.0	**Meetings**
M.01	Internal group meeting
M.02	External supervisor meeting
M.03	Internal supervisor meeting
M.04	SCRUM meeting
P.0	**Presentations**
P.01	1st Presentation preparation
P.02	1st Presentation PowerPoint
P.03	2nd Presentation preparation
P.04	2nd Presentation PowerPoint
P.05	3rd Presentation preparation
P.06	3rd Presentation PowerPoint
I.0	**Initial Planning**
I.01	Vision Document
I.02	Project plan Document
I.03	Requirement Specification Document
I.04	Test Specification Document
I.05	Research
R.0	**Requirements and Planning**
R.01	Update Requirement Specification Document
R.02	Update Activity List and Gantt chart
R.03	Detail planning of new iteration
R.04	Update Project Plan Document
R.05	Brainstorming
R.06	Risk Analysis
R.07	Update Vision Document
T.0	**Testing**
T.01	Define test methods
T.02	Update Test Specification Document
T.03	Requirement testing
T.04	FEM analysis
T.05	Concept Validation
D.0	**Analysis and Design Implementation**

D.01	Concept brainstorming
D.02	Concept evaluation and selection
D.03	Concept elaboration
D.04	Concept Documentation
D.05	SolidWorks 3D drawing
D.06	SolidWorks 2D drawing
D.07	Calculation
D.08	Material research
D.09	Material evaluation and selection
D.10	Design documentation
D.11	Concept Research
E.0	**EVALUATION**
E.01	Review iteration
E.02	Review time usage
E.03	Update Process Document
F.0	**DEPLOYMENT**
F.01	Write user manual
F.02	Write after-analysis report
F.03	Design project poster

Table 8 – Activity list

4.0 Tools and resources

All projects depend on reliable tools and resources to achieve success. The two most important tools and resources in our project is primarily computer software and human resources. Computer software, because it simplifies every single task we need to do and human resources because we can't achieve success alone. We need advisors in both technical and theoretical knowledge and we need guidance in our progression.

4.1 Advisors

Advisor	Organisation
Jamal Safi	HSN
Mehdi Mousavi	HSN
Kjell Enger	HSN
Amin Hossein Zavieh	HSN
David Robertson	FO&GT
Morten Hartmann	FO&GT
Bjørn Mikkelsen	FO&GT
Ingar Hellingsrud	FO&GT
Przemyslaw Lutkiewicz	FO&GT

Table 9 - Advisors

4.2 Software Tools

For a successful project and result, we are dependent on good software that can assist us. Almost everything we do in this project can be connected to software.

Name	Type of software	Applied
MS Word	Text editing	All of our documents will be written and edited in Microsoft Word.
MS Excel	Spreadsheet	We use Excel to create graphs used in our reports and our presentation.
MS Projects	Projects Management	Our projects lifecycle (Gantt chart) is displayed in Microsoft Projects. An alternative was Excel, but MS project is more advanced and collaborate better with our Project model.
MS Power Point	Presentation	For our three major presentations we will use Microsoft Power Point as our presentation tool.
MS OneDrive	Cloud	We use Microsoft OneDrive as our online working platform. This is where we share files with each other and where the latest versions of documents can be found.
Solid Works	3D modelling	Our 3D modelling will be done in Solid Works.
Solid Works simulations	Simulation	All our simulations (See "Tests" document) will be done in Solid Works Simulations.
Photoshop	Photo Editing	Photo editing will be done in Photoshop.
Google Drive	Cloud	We use Google drive as a backup platform. We backup our work at least once every 24 hours.
Facebook	Social media	We use Facebook for quick chats and minor decisions.
Skype	Video chat	When one or more of our team members is unable to attend a meeting we use Skype to make the most out of it.
Paymo	Time management	Paymo is a software that logs hours and represent hours in spreadsheets and visual graphs. This software makes it easy to keep track of where we spend our time.
Mathcad	Math Software	We plan to use Mathcad to assist us with mathematical calculations.

Table 10 - Software tools

(Downloads, 16)

5.0 Meetings

Meetings are very important for a project of this kind where multiple parties are involved; as they set a guideline by ensuring us that the project is being carried out properly and in the right direction. We will therefore have several kinds of meetings throughout the project. Most will be internally amongst the project team members, and some will be with our internal and external supervisors. These meetings will give us the opportunity to:

- Raise question and concerns.
- Resolve disagreements.
- Make sure everybody is on the same page.
- Discuss and share knowledge on different topics.

This chapter will elaborate on the different types of meetings we will have.

5.1 Internal meetings

The project members will have a large number of meetings amongst ourselves. The purpose of these meetings is largely to get everyone up to speed with the status of the project, as well as to commit our shared knowledge into encountered obstacles. A MIM report is made when needed.

5.1.1 Morning meeting

This is a meeting we have at the start of every workday. In this meeting, we:

- Review the status of the different activities that are assigned to each member.
- Bring up any problems or obstacles we may have encountered in our work.
- Review the plan for each member and delegate work if necessary.
- Write a short meeting summary and publish to OneDrive.

5.1.2 Scrum meeting

SCRUM meetings are intended to be highly efficient meetings; they stem from the Agile development process. SCRUM meetings stand out from regular meetings primarily because we stand for the duration of the meeting. This is to encourage a quick progression of the meeting. In these meetings we typically ask ourselves:

- What has been done?
- What needs to be done now?
- Are there any obstacles for further progress?

5.1.3 End of day meeting

This is a meeting similar to the morning meeting where we discuss the status of the current tasks. New tasks are assigned when necessary.

5.2 EXTERNAL MEETINGS

These are the meetings we have with third-parties such as our internal and external supervisors. The purpose of these meetings are primarily to get counsel, and to keep FO&GT and HSN updated on our project.

5.2.1 INTERNAL SUPERVISOR MEETING

This is a weekly meeting we have with our internal supervisor Kjell Enger. 24 hours before this meeting, we have to submit a follow-up document. It is our responsibility to arrange such meetings with a set agenda of what is to be discussed. The purpose of this meeting is to:

- Keep him updated on the current status of the project.
- Ask questions about project management.
- Receive feedback.

5.2.2 EXTERNAL SUPERVISOR MEETING

This is a meeting that will not be held regularly, but when either party (FO&GT or the project team) deems it necessary. In situations where our external supervisor isn't available, it is also possible to contact him through other means when important matters are to be discussed. In these meetings we will:

- Ask technical questions related to our project and their product.
- Check and confirm various documents done by our team when needed.
- Keep them updated and discuss our progression.
- Receive feedback.

6.0 Presentations

The presentations are one of the most critical elements of the bachelor thesis, and 25% of the final grade depends on them.

The presentations will be attended by:

- The internal and external examiner
- The internal and external supervisor
- Anyone else that wishes to be present

(The internal and external examiner and the internal and external supervisor: Henceforth referred to as the critical parties.)

This is a summary of our responsibilities in relation to all the presentations:

- Book a room for the presentation.
- Arrange the presentation at a time and date where all critical parties are available.
- Organize a 30-minute meeting for the critical parties directly before the presentation.
- Deliver all required documentation sufficiently in advance.
- Prepare refreshments and snacks.

6.1 1st Presentation

During the first presentation, we will first talk about the problem description that was given to us by FO&GT, then later talk about what plans we have for the project during its period. We will also discuss what we need to do, and how we plan to do it. Finally, we will talk about the current status of the project, and what lies ahead.

Before this presentation, the following documents will be delivered:

- Project plan and vision document.
- Requirement specification.
- Test specification.

The presentation will last for up to 20 minutes. After this there may be an oral examination that will last no more than 15 minutes for each team member.

6.2 2nd Presentation

This presentation will largely be similar to the first presentation, but we will instead talk about possible solutions for the problem. We will also talk about our chosen concept for the product, design and the different test procedures. If any changes have been made on our first draft of project plan and the other documents, this will also be mentioned in the second presentation with good reason. Updates and plans for further development will be discussed as well. The length of this presentation will also be 20 minutes.

6.3 Final presentation

The final presentation is the most important of all three presentations and by the time it arrives, the project has reached its final stage and all documents have been delivered. This presentation will consist of three 20-minute parts:

- **Sales pitch**
  This is a non-technical part of the presentation, one intended to be understood by the average person. We will talk about the advantages of the product and compare it with competitors.

- **Technical presentation**
  In this part we will describe our solution in technical terms. We will also talk about our development process and what we have learned throughout the project.

- **Oral examination**
  Questions will be posed to the team, parts of the team, or towards individual members.

7.0 Agile Incremental Iterative Project Model

Our project is considered a medium size project (TenStep, 2016) (estimated to ~2500 hours) and we are only four team members. It will be easy for us to have face-to-face communication with each other and to have a lot of small meeting with our customer and other major stakeholders.

The model we have chosen to use is a hybrid model based on the incremental and iterative model. The model was originally constructed out of two non-repeating phases; initial planning and deployment, respectively at the start and end of the project.

The repeating ones can remind one of the waterfall model. But instead of only doing it once, we repeat the cycle until we are satisfied with our product. The repeating phases consists of:

- Planning and Requirements
- Analysis and Design
- Test
- Evaluation

This model is based on time and not tasks. So, we plan out in advance how much time we will be using on each task in each phase. If it occurs that we finish our work earlier, we will continue with something new and relevant to the same phase and not move on to the next phase. If the task is not finished on time, we still have to move forward to the next phase, and pick it up on the next iteration.

However, we have chosen to modify the model in the following ways:

- Redefined the two non-repeating phases to stages (initial planning, deployment)
- Group all the iterations into stages (elaboration, construction)

The reasoning behind these changes are that we felt the need to make the model provide us with a better overview of the project development lifecycle.

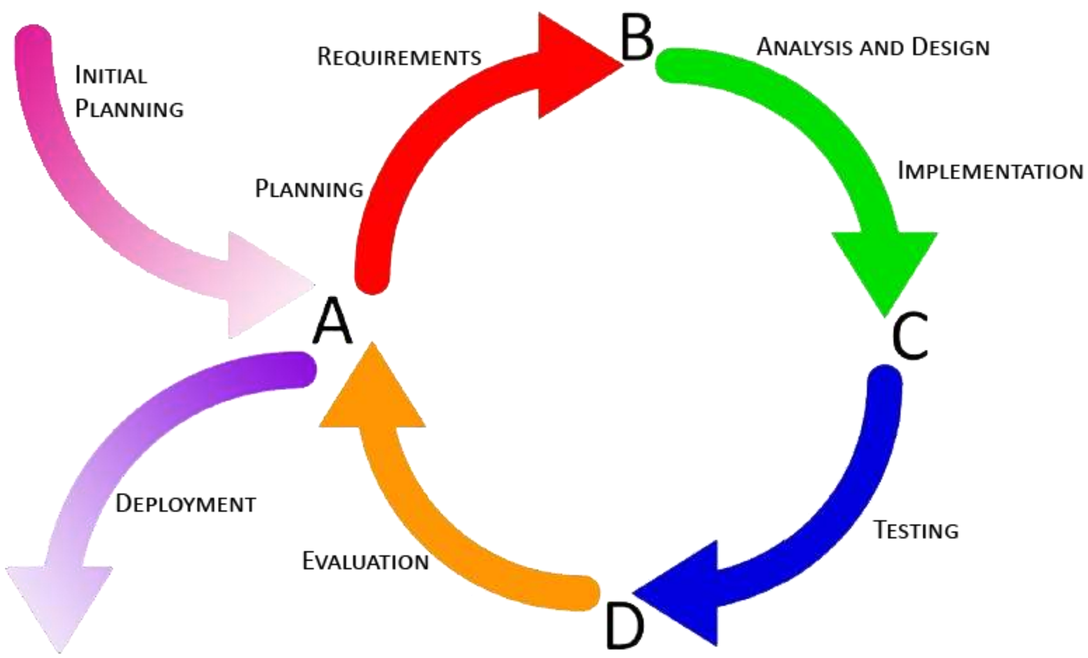


Figure 2 - Our project model

Between every phase (A, B, C and D) a phase report will be written. This report should be as short and concise as possible and it will be published for our stakeholders to read. We will also arrange for short meetings with FO&GT between phases if possible.

7.1 FURTHER EXPLANATION

As we can see in these figures, our model is a hybrid. In the beginning, it will be more Iterative than Incremental. We will as soon as possible establish roughly what the machine will look like and make the biggest decisions in our design (External or internal body for example). As we move on in our lifecycle, we will work more with the incremental model. We will start focusing on the individual parts and complete them one by one. However, we will still have in mind that everything has to fit together.

Figure 3 - Iterative

Figure 4 - Incremental

Figure 5 - Hybrid

7.1.1 Example

This is an example on how our first of many iterations will go. We will plan iterations such as this one in the Requirement and Planning phase, see chapter 7.3.1.

We plan early how much time we will use on what phase and who will perform the tasks:

Iteration 1			
Phase	**Task**	**Responsible**	**Tot. Hours**
Req. Planning	Reflect on presentation 1 and feedback Identify System requirements	All A.K. and M.G.	12 hours 6 hours
Design	Chose a concept Chose materials	All All	12 hours 8 hours
Test	Test work done in design and cross-reference with requirements	O.E.H. and R.D.	8 hours
Evaluation	Evaluate work	All	12 hours

Table 11 - Cycle example

7.2 Stages

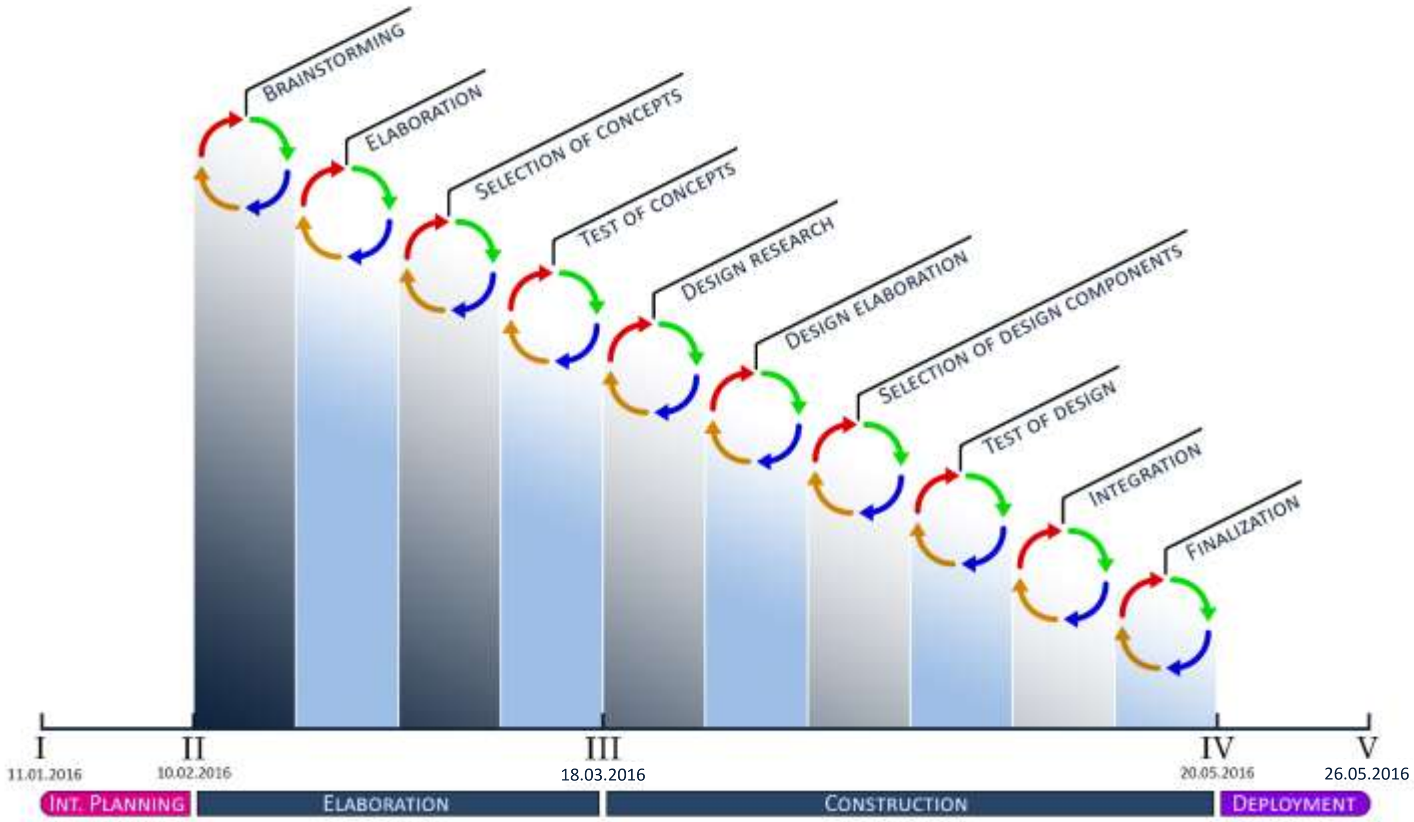


Figure 6 - Overview of project lifecycle

7.2.1 Initial planning

This is the first step and it is not a repeating one. This is where we do all the planning needed to start the project itself. In this phase, we have meetings to establish the customers' requirements, desires and other formalities. We write a vision document and a project plan and plan our first presentation. This phase last from the very start of the project until our first milestone; presentation 1. Overall tasks in this phase are:

- Create Vision document
- Create Requirement Specification document
- Create Test plan- and test requirements document
- Create Project plan
- Prepare presentation 1

7.2.2 Elaboration

Elaboration is the second stage in our projects lifecycle and we intend to finish four iterations in this stage. It is mainly concept research-, brainstorming- and high level design- tasks that we will work with in this stage. Before the stage is done we aim to have a concept and CAD-drawing ready to display at 2nd presentation.

7.2.3 Construction

As the concept is already selected and tested in the previous stage, we will in this stage define the sub - components in detail and test them such that we may select the correct sub -component functionality for implementation onto the system interface.

7.2.4 Deployment

At this stage of the project we will ensure that FO&GT has a system user manual in place so that they may develop the abilities necessary to use the SPO CF seat polishing tool. After that is complete we will start preparing the final presentation and hand over the project to FO&GT.

7.3 Phases

7.3.1 Requirements and Planning

This is the first of the four repeating phases. The very first thing we do in this phase is to analyse the [A] report which is the summary for the previous iteration. We use this information to plan the amount of time and resources we will spend on the iteration we just started. Tasks will be delegated between the team members at this point.

The second thing we do is to make changes (if necessary) to our requirements. We know from the [A] report and our meeting with FO&GT about possible changes to the requirements.

Overall tasks in this phase are:

- Schedule time and delegate iteration tasks
- Change requirements.

7.3.2 Analysis and Design Implementation

With the requirements in our mind, we start this phase. Overall tasks in this phase are:

- Brainstorm solutions.
- Chose solutions.
- Calculate.
- Draw and model.

7.3.3 Testing

In this phase, we test the work we have done so far throughout the iteration. This includes crosschecking our solutions with our requirements to see if they are fulfilled. We will also test any calculations we have done in our design phase. We will check if the formulas we have used are correct and correctly applied and we will check the mathematical outcomes of the calculations.

All 3D work will be run through FEM-analysis to identify any mechanical mistakes and to identify any unforeseen force concentrations that has to be dealt with. Motion tests will be done on the system and sub-systems to identify any design flaws, like colliding parts.

- Crosscheck our solutions with requirements.
- Test our calculations.
- Do FEM-tests.
- Physical tests to see how things fit together.
- Update test specification.

7.3.4 Evaluation

In this phase, we look at the work we have done so far and review it. We analyse our progression and determine if we are on the right track. It is in this phase that we see if we can continue on a concept or if we have to start over again. If we agree that we can continue with it, we will find out if we need to do any major or minor changes on what we have done so far or if we are on the right track. The overall tasks in this phase are:

- Evaluate our work and our reports.
- Determine if product is ready for deployment.
- Determine if changes are needed.
- Determine what has to be change.

8.0 DOCUMENTATION

Documentation is the most important aspect of this project. HSN demands more documentation than most employers, and 50% of the final grade depends on the documentation. The documentation is evaluated on three criteria; Layout, readability and completeness.

8.1 GUIDELINES

This chapter will detail the guidelines we will use throughout all documentation in the project. This is to ensure that all team members are aware of how the documentation should be presented and written so that we all follow the same rules and standards that are set by the group as a whole.

8.1.1 LAYOUT AND DESIGN

As early as the inception phase of the project, we agreed on the importance of quickly determining a standard design to use in all the documents throughout in the project. This decision, as well as real time editing in Word through OneDrive ensured that we would avoid wasting time formatting and merging the documentation.

The criteria we used to choose the design was:

- Complementary colors.
- Distinct look of different levels of titles.
- A clear and easy to read layout.

Taking these criteria into consideration, we made several templates of varying design, and then voted on which to go forward with.

Furthermore, we sought to present information in figures and illustrations over text as much as possible.

8.1.2 STRUCTURE

In a chapter that has several subchapters, we will place information that is common for all subchapters under the main chapter. Each chapter will also contain a small introduction when necessary.

8.1.3 VERSION AND DOCUMENT HISTORY

When making changes to a document, the changes shall be specified in the document history, and the document will be saved with a new version number.

The following changes will result in a 0.1 incremental increase in the version number:

- Additions of content.
- Restructuring.
- Removal of content.
- Spelling correction.
- Formatting correction.
- Improved wording of sentences.

The changes shall be specified categorically and refer to the relevant chapter. For example; if you write more information under chapter 5.1, the change will be specified as “5.1 – Added content”. If you move content from one chapter to another, the change will be specified as “Moved content from 5.1 to 3.4”.

8.3 WEB PAGE

During the time frame of this bachelor project, we are required by our university college to create a website. This will be an easy and reliable way to communicate with our external supervisor as it will contain updates and information about the project`s progress.

The web page will give information about our project, the team members and the future presentations that will be held, and will be updated as the project progress until its end.

The website can be found here: **https://home.usn.no/web-gr16-2016/**

9.0 Risk Management

9.1 Background

A part of our project is to do risk analysis. A risk analysis tells us the likelihood, and the magnitude of the impact of all potential risks associated with the project.
We do these analyses because a risk assessment is a great tool to help us figure out what the most crucial risks are. With the results from the assessments we will know where we should add resources and in what order we should deal with risks.

9.2 Preliminary risk assessment form

Preliminary Risk Assessment (PRA) Form							
Project	*xxxxx*						
Risk Question:	*What is the risk question?*						
	Step 1	Step 2	Step 3	Step 4a	Step 4b	Step 4c	Step 5
Risk ID:	*Hazard / Unwanted event*	*Harm / Consequence*	*Potential causes*	*Likelihood of occurrence [L]*	*Impact [I]*	*Risk Score (L x I) + Heat score*	*Possible additional controls / Actions*
	What could go wrong?	*What might be the potential impact*	*How might the hazard occur?*	*What is the likelihood that the hazard will occur? (Hazard Scale)*	*How significant is the impact? (rating scale)*	*Calculated*	*What might help control and/or mitigate the hazard?*

Table 12 - PRA form

For the project risk assessments, we have chosen to use a preliminary risk assessment (PRA) method to help us map out the risks.
The first thing we do in this assessment is to ask our self the Risk Question. The risk questions are the question we ask our self and then answer in the form. It should cover only one category of our project. For example, the system or the moral of the team.

We then start filling out a PRA form as seen above for each Risk Question.

- **Step 1:** Identify anything that can go wrong and Fill it into the form. Remember to stay on topic. If we identify a risk that does not fit this for we will start another form.
- **Step 2:** Here we write down the consequence of the hazard we wrote down earlier. This is what happens if the scenario occurs.
- **Step 3:** In the third column we write down potential causes. Note that there might be more than one potential cause for a scenario. We use this information later if we need to deal with the risk. The possible causes are a necessity to know if we want to reduce the risk in a project.

- **Step 4a:** The likelihood of occurrence is the chance for the hazard to occur. We rate this factor from 1-5 where:

Likelihood	Description
1	Rarely happens
2	May Happen
3	Likely to happen
4	High chance of happening
5	Almost always happen

Table 13 - Likelihood

- **Step 4b:** We now rate the magnitude of the impact of the risk. This factor also rated with a scale from 1-5 where:

#	Impact	Description
1	None or close to no impact	The scenario can easily be handled and/or will not affect the project in any significant way,
2	Some impact	The scenario will demand some resources and/or will negatively affect the project
3	Medium Impact	The scenario will demand significant resources and/or negatively affect in a significant degree
4	High impact	The scenario will demand a lot of resources and/or will seriously damage the project
5	Very high impact	The scenario will demand very high amounts of resources and/or might ruin the whole project.

Table 14 - Impact

- **Step 4c:** We now use the factors from step 4a and 4b to calculate the risk score. The risk score is given by this formula:

$$Risk\ Score = Likelyhood\ of\ occurance * \ Impact$$

$$R = L * I$$

These numbers let us know the risk of a scenario. They tell us that one risk is worse than another and needs more attention and resources. We use a heat map to help us categorize our risks.

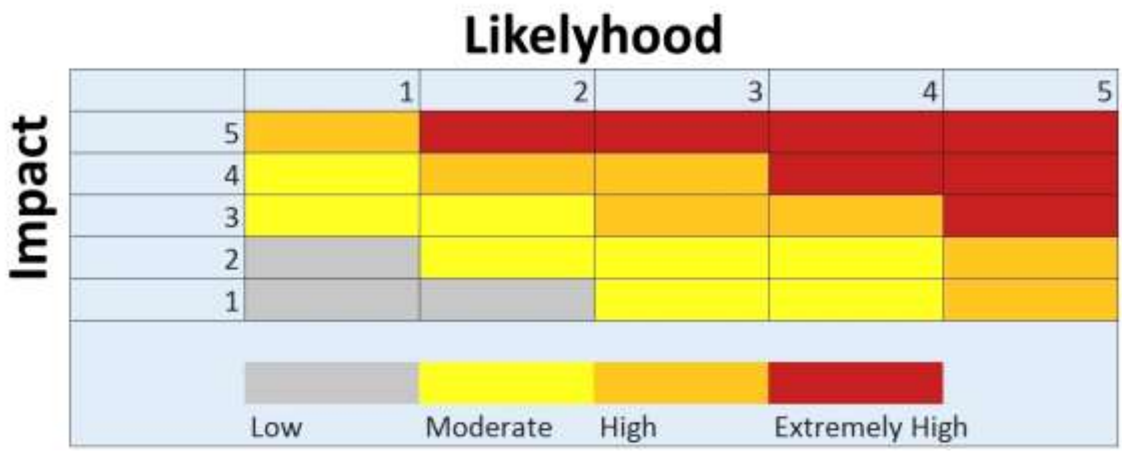


Figure 7 - Risk heat map

- ○ **Low Risk:** This risk is low in both likelihood and impact. Very little time and recourses should be spent on these risks.
- ○ **Moderate:** This risk can have significant consequences for the project and should be dealt with
- ○ **High:** High risks can jeopardise the entire project and should be dealt with as soon as possible
- ○ **Extremely high:** High chance of ruining the entire project. These risks MUST be dealt with immediately after identifying it. If possible the risk should be removed as soon as possible.

- **Step 5:** This is where to write down any measures that we think might lower the severity of occurrence or mitigate the impact.

(Vesper, 2014)

10.0 References

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Mikkelsen, B. (2016).

TenStep. (2016, Feb 03). Retrieved from http://www.lifecyclestep.com/open/406.0DetermineProjSize.htm

Vesper, J. (2014). Risk Assessment Methods.

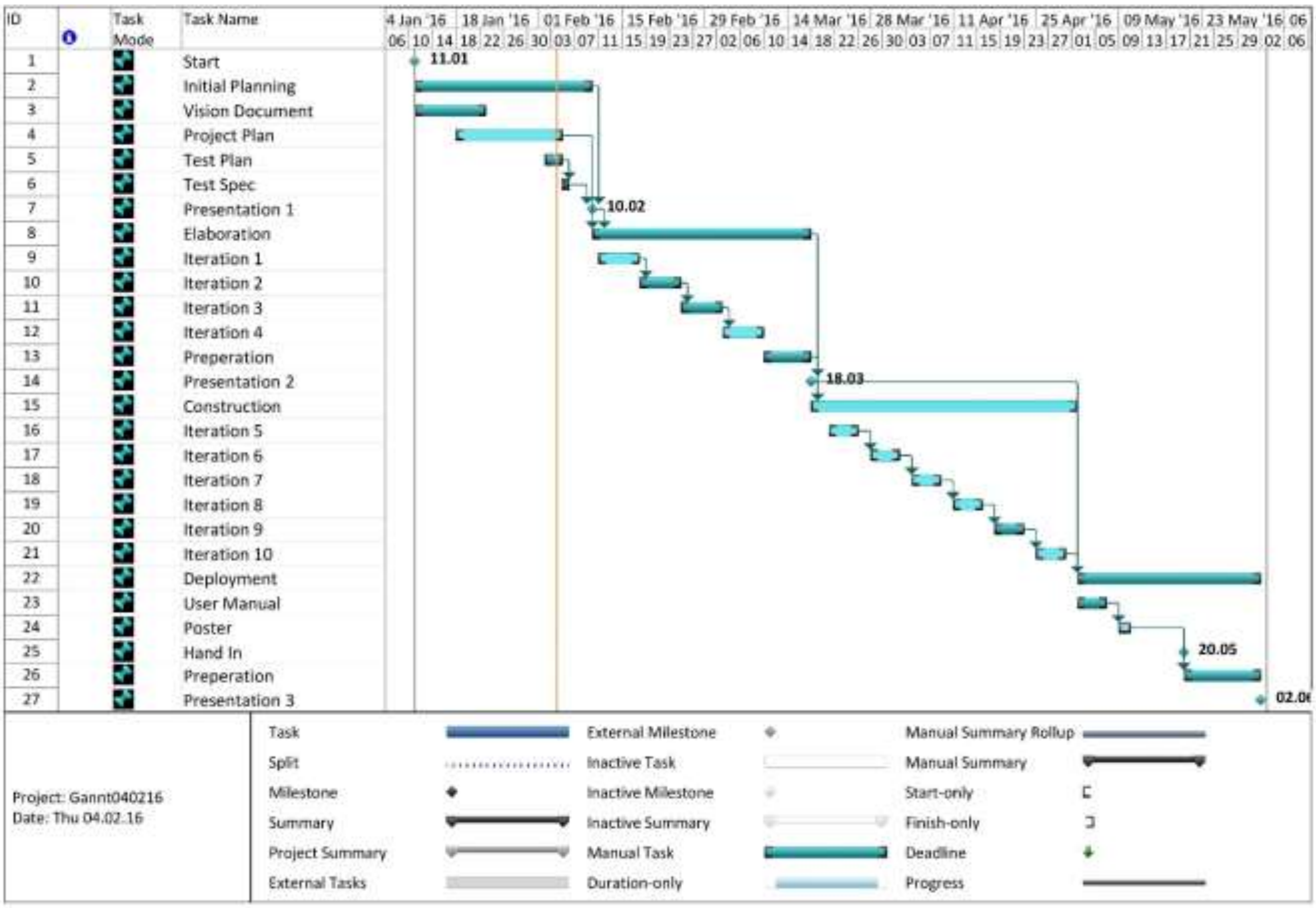
Attachments

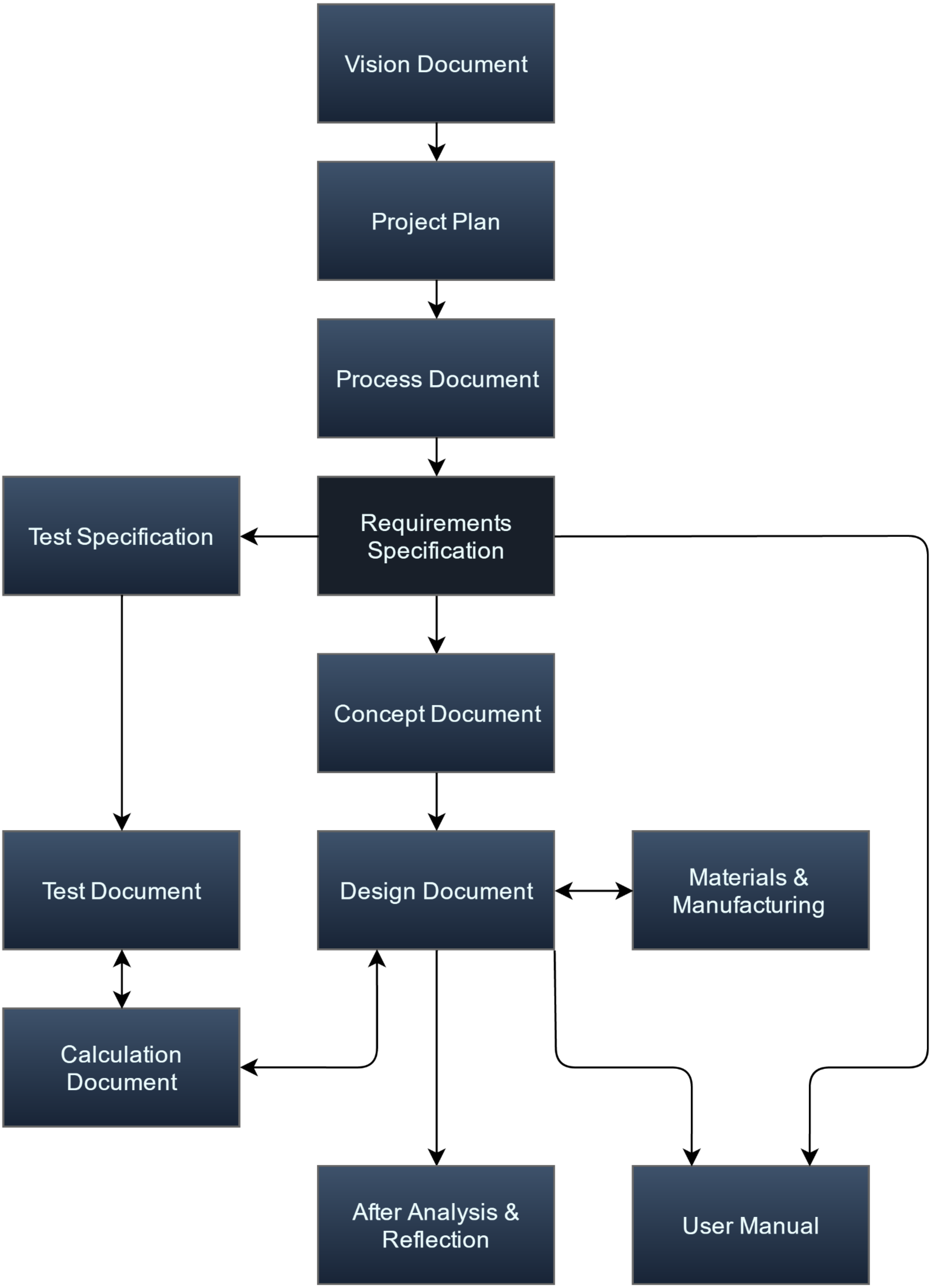
A.1 Risk Assessments

Preliminary Risk Assessment (PRA) Form								
Project	*Seat Polishing Tool*							
Risk Question:	*What are the risks that can negatively affect the moral and the motivation of the Team and its members*							
	Step 1	**Step 2**	**Step 3**	**Step 4a**	**Step 4b**	**Step 4c**		**Step 5**
Risk ID:	*Hazard / Unwanted event*	*Harm / Consequence*	*Potential causes*	*Likelihood of occurrence [L]*	*Impact [I]*	*Risk Score (L x I)*		*Possible additional controls / Actions*
	What could go wrong?	*What might be the potential impact*	*How might the hazard occur?*	*What is the likelihood that the hazard will occur? (Hazard Scale)*	*How significant is the impact? (rating scale)*	*Calculated*		*What might help control and/or mitigate the hazard?*
1	*Minor data loss*	*Redo work*	*Software crash* *Power loss* *Malware*	*4*	*2*	*8*		*Updated software* *Battery backup* *Regular saving*
2	*Major data loss*	*Redo work*	*Lost/Stolen PC*	*1*	*5*	*5*		*Backup on different server*
3	*Minor sickness*	*Get behind schedule*		*3*	*2*	*6*		
4	*Serious sickness*	*Loss of team member*		*2*	*3*	*6*		
5	*Avoidance*	*Lack of motivation*		*2*	*3*	*6*		*Regular check up on each other*
6	*Behind Schedule*	*Multiple*		*4*	*3*	*12*		*Stick to the Project Plan* *Burn time*
7	*Stuck*	*Get behind schedule*	*Not good enough team work*	*2*	*3*	*6*		*Regular internal meetings*
8	*Lack of external guidance*	• *Waste of time* • *Bad decisions*		*2*	*3*	*6*		*Call meetings well in advance*
9	*Lack of motivation*	*Bad moral*		*3*	*5*	*15*		*Personal update in meetings*
10	*Pull out from FO&GT*	• *No founding* • *No external examiner*	*Bankruptcy*	*1*	*5*	*5*		

A.2 GANTT CHART

A Gantt chart was made early in the project to help us with planning. We have used the Gantt to some degree, but we have not used it to its fullest. All the team members agree that a detailed Gantt chart does not comprehend with our project model since we make plans for small periods rather than long periods. However, it has been handy when working towards deadlines and milestones. The time for our iterations match the plan well and the stages too.




Vision Document
Project Plan
Process Document
Test Specification
Requirements Specification
Concept Document
Test Document
Design Document
Materials & Manufacturing
Calculation Document
After Analysis & Reflection
User Manual

Requirement Specification

Freudenberg Bachelor 2016

SPO CF Seat polishing tool

Arian Krasniqi, Richelieu Dahn, Odd Eirik Hardem, Morten Grøsfjeld

Version	Document number	Date	Responsible	Status
3.0	003	22.05.2016	All	Finalized

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1.0 Document

1.1 Document history

Version	Date	Changes
0.1	28.01.2016	• Document created • Added requirement template
0.2	29.01.2016	• Added 1.3, 1.4, 2.0
0.3	01.02.2016	• Added abbreviations. • Added background to 2.0
0.4	02.02.2016	• Added requirements 1.01 to 1.16 • Added requirements 2.01 to 2.05 • Added requirement 3.01
0.5	06.02.2016	• Updated all requirements • Changed ID for all requirements • Added 2.2.9 • Alphabetical order for 1.2 • Reviewed
0.6	07.02.2016	• Added related tests to requirements
1.0	07.02.2016	• Reviewed
2.0	15.03.2016	• Added requirement 1.21 and 1.22
2.1	22.03.2016	• Removed "authors" column from table 1 • Updated requirement 3.03
2.2	31.03.2016	• Updated requirement 1.13, 1.14 • Added requirement tables to list of tables
3.0	22.05.2016	• Finalized

Table 1 - Document history

1.2 Definition of abbreviations

Abbreviation	Definition
BL	Blind flange
CF	Compact Flange
EF	End fitting flange
FO&GT	Freudenberg Oil & Gas Technologies
HX	H-profile seal ring for SPO CF
IF	Integral flange
IX	I-profile seal ring for SPO CF
Req	Requirement
SPO	FO&GT brand name for compact flanges (Steel Products Offshore)
SW	Swivel flange
WN	Weld Neck type of flange
WT	Wall Thickness

Table 2 - Definition of abbreviations

1.3 Introduction

The requirement specification will detail the functionality and properties that the system will possess. Most of the requirements in this document are from FO&GT, but some are created by the project team as a result of elaboration of the existing requirements from FO&GT. The requirements will be divided into the following categories:

- System requirements
- User requirements.
- Constraining requirements

1.4 Scope

The scope of this document is to provide the foundation that is needed for further development of the SPO CF Seat Polishing Tool. It will include the following information:

- Criteria we use to write good requirements.
- Description of prioritization levels.
- All requirements for the system.

2.0 Requirement criteria

2.1 Background

In order for the system to function within the boundaries set by FO&GT it is needed to define the system such that there is clarity on how the requirements describe the need in question. This is done by having an efficient & systematic list of priorities on the different requirements evaluated by the team. The quality of these requirements will give a clear traceability on how the system requirements affect the user

2.2 Criteria

2.2.1 Unambiguity

There shall be only one way to interpret the requirement. Everybody that reads the requirement must have the same interpretation of it. In order to attain this, formal language is preferred. Disambiguation is often done subconsciously, therefore it is advisable to ask others to read them and ask how they interpret it.

2.2.2 Design independent

The requirement cannot constrain the solution in any way. It shall specify what a system needs to do, not how to do it.

2.2.3 Traceable

The requirement shall be traceable to the following:

- Source
- Higher level requirements
- Lower level requirements
- Related test

This is important if we later have to change the requirement. We will then know which of the related requirements that may be affected by the change, and subsequently need to be reviewed.

2.2.4 Concise

The requirement must be stated in the simplest manner possible. No unnecessary information must be included.

2.2.5 Unique

No requirement shall overlap or be made obsolete by one another.

2.2.7 Verifiable

All requirements must be verifiable through some form of testing, be it analysis, examination, test or demonstration. To achieve this, it is often wise to state the requirement with measurable quantities instead of ambiguous terms like “sufficient”, “strong”, “fast”.

2.2.7 Attainable

The requirement must be technically feasible, and fit within the constraints for the project like budget, schedule and weight.

2.2.8 Understandable

The requirements must be written in a way that makes them understandable for everyone involved with the requirements. This means that they have to be written in a non-technical manner where possible without sacrificing accuracy.

2.2.9 Priority

The requirements must be prioritized. Table 3 describe the different prioritization levels:

Priority	Description
A	Fulfilling these requirements can be seen as the absolute minimum that must be accomplished in order for the system to work. They are critical for the success of the system.
B	Although not as important as “A” level requirements, these requirements should be met. They are not critical for the system to work.
C	Requirements that are not necessary to fulfil in order for the system to be regarded as complete, but who would make it slightly better.

Table 3 - Requirement prioritization levels

3.0 Requirements

3.1 System requirements

Date created:	01.02.2016	Test:	TS-1.01	Higher req:	
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	1.02, 1.03, 1.04, 1.05
ID	**Description:**				Priority
1.01	The system shall be compatible with the 16’’ SPO CF WN CL600 flange.				A

Table 4 - Requirement 1.01

Date created:	01.02.2016	Test:	TS-1.02	Higher req:	1.01
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	1.12
ID	**Description:**				Priority
1.02	The system shall polish the seal groove.				A

Table 5 - Requirement 1.02

Date created:	01.02.2016	Test:	TS-1.02	Higher req:	1.01
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.03	The system shall polish the heel face.				A

Table 6 - Requirement 1.03

Date created:	01.02.2016	Test:	TS-1.03	Higher req:	1.01
Last changed:	06.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.04	The system shall polish the environmental seal.				B

Table 7 - Requirement 1.04

Date created:	01.02.2016	Test:	TS-1.03	Higher req:	1.01
Last changed:	06.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.05	The system shall polish the midsection face.				B

Table 8 - Requirement 1.05

Date created:	01.02.2016	Test:	TS-1.05	Higher req:	
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	1.11
ID	**Description:**				Priority
1.06	The system shall be rigid enough to handle the vibrations caused by the surface pressure onto the flange.				A

Table 9 - Requirement 1.06

Date created:	01.02.2016	Test:	TS-1.09	Higher req:	1.13
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.07	The system shall polish off surface rust.				A

Table 10 - Requirement 1.07

Date created:	01.02.2016	Test:	TS-1.09	Higher req:	
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	1.13
ID	**Description:**				Priority
1.08	The system shall polish off surface scratches.				A

Table 11 - Requirement 1.08

Date created:	01.02.2016	Test:	TS-1.09	Higher req:	
Last changed:	06.02.2016	Source:	FO&GT	Lower req:	1.13
ID	**Description:**				Priority
1.09	The system shall polish surface indentations to an acceptable standard.				A

Table 12 - Requirement 1.09

Date created:	01.02.2016	Test:	TS-1.01	Higher req:	
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	2.01
ID	**Description:**				Priority
1.10	The system shall be mountable on the flange.				A

Table 13 - Requirement 1.10

Date created:	01.02.2016	Test:	TS-1.06	Higher req:	1.06
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.11	The system shall provide an even surface pressure throughout the surface geometry of the flange.				A

Table 14 - Requirement 1.11

Date created:	01.02.2016	Test:	TS-1.04	Higher req:	1.02
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.12	The system shall be adjustable to angular differences in the seal groove.				A

Table 15 - Requirement 1.12

Date created:	01.02.2016	Test:	TS-1.09	Higher req:	
Last changed:	31.03.2016	Source:	FO&GT	Lower req:	1.14, 1.07, 1.08, 1.09
ID	**Description:**				Priority
1.13	The system will polish the flange sealing surfaces to a surface finish of minimum of Ra 1.0 µm.				A

Table 16 - Requirement 1.13

Date created:	06.02.2016	Test:	TS-1.09	Higher req:	1.13
Last changed:	31.03.2016	Source:	Norsok L-005	Lower req:	
ID	**Description:**				Priority
1.14	The system will polish the flange sealing surfaces to a surface finish of maximum Ra 0.8 µm.				B

Table 17 - Requirement 1.14

Date created:	01.02.2016	Test:	N/A	Higher req:	
Last changed:	06.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.15	The system shall not alter the functionality of the flange.				A

Table 18 - Requirement 1.15

Date created:	01.02.2016	Test:	TS-1.01	Higher req:	
Last changed:	06.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.16	The system should be adjustable to different flange sizes.				C

Table 19 - Requirement 1.16

Date created:	01.02.2016	Test:	TS-1.10	Higher req:	
Last changed:	06.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.17	The system shall cover the maintenance need before re-machining is required.				A

Table 20 - Requirement 1.17

Date created:	01.02.2016	Test:	TS-1.11	Higher req:	
Last changed:	06.02.2016	Source:	FO&GT	Lower req:	1.19, 1.20, 3.02,3.03
ID	**Description:**				Priority
1.18	The system shall be compliant with off-shore regulations where the FO&GT flanges are in use.				A

Table 21 - Requirement 1.18

Date created:	01.02.2016	Test:	TS-1.07	Higher req:	1.17
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.19	The total mass of the system shall not exceed 25 kg.				B

Table 22 - Requirement 1.19

Date created:	02.02.2016	Test:	TS-1.07	Higher req:	1.17
Last changed:	02.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.20	Each system component shall not exceed a mass of 12 kg.				B

Table 23 - Requirement 1.20

Date created:	02.02.2016	Test:	N/A	Higher req:	1.10, 2.01
Last changed:	02.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.21	The system shall be mountable on the flange, indifferent to flange position.				A

Table 24 - Requirement 1.21

Date created:	15.03.2016	Test:	N/A	Higher req:	
Last changed:	15.03.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.22	The system should allow the use of an alternative power supply				C

Table 25 - Requirement 1.22

Date created:	15.03.2016	Test:	N/A	Higher req:	
Last changed:	15.03.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
1.23	The system shall be resistant to corrosive environment.				A

Table 26 - Requirement 1.23

3.2 User requirements

Date created:	01.02.2016	Test:	TS-1.12	Higher req:	1.10
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
2.01	The user shall be able to manually mount the system onto the flange.				A

Table 27 - Requirement 2.01

Date created:	01.02.2016	Test:	N/A	Higher req:	3.01
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	2.03
ID	**Description:**				Priority
2.02	The user shall be able to adjust the system interface.				A

Table 28 - Requirement 2.02

Date created:	01.02.2016	Test:	TS-1.12	Higher req:	2.02
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	
ID	**Description:**				Priority
2.03	The system shall be operated by a qualified user.				B

Table 29 - Requirement 2.03

Date created:	01.02.2016	Test:	TS-1.12	Higher req:	1.18
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	2.05
ID	**Description:**				Priority
2.04	Another person shall be present while the machine is in use.				A

Table 30 - Requirement 2.04

Date created:	02.02.2016	Test:	TS-1.12	Higher req:	1.18, 2.04
Last changed:	02.02.2016	Source:	FO&GT	Lower req:	2.02, 2.03
ID	**Description:**				Priority
2.05	The person shall be able to shut down the system.				A

Table 31 - Requirement 2.05

3.3 Constraining requirements

Date created:	01.02.2016	Test:	TS-1.12	Higher req:		
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	2.02	
ID	**Description:**					Priority
3.01	The system shall accommodate safe assembly onto the flange.					A

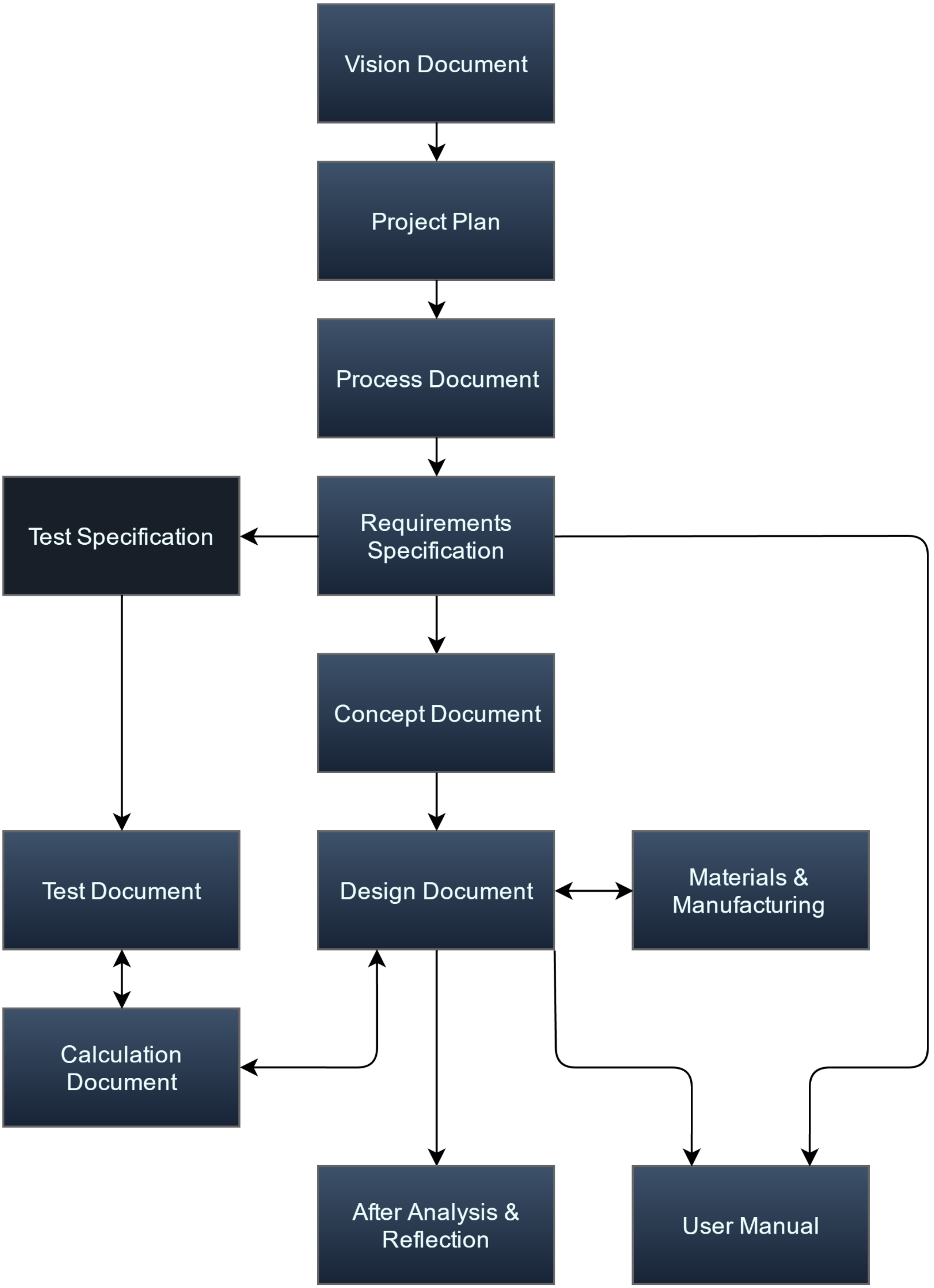
Table 32 - Requirement 3.01

Date created:	01.02.2016	Test:	TS-1.12	Higher req:		
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	1.18	
ID	**Description:**					Priority
3.02	The system shall not consist of any electronic components.					A

Table 33 - Requirement 3.02

Date created:	01.02.2016	Test:	TS-1.12	Higher req:	1.18	
Last changed:	01.02.2016	Source:	FO&GT	Lower req:	3.02	
ID	**Description:**					Priority
3.03	The system shall be driven by a power source that will not create sparks in operation.					A

Table 34 - Requirement 3.03



Vision Document
Project Plan
Process Document
Test Specification
Requirements Specification
Concept Document
Test Document
Design Document
Materials & Manufacturing
Calculation Document
After Analysis & Reflection
User Manual

TEST SPECIFICATION

Freudenberg Bachelor 2016

SPO CF Seat polishing tool

Arian Krasniqi, Richelieu Dahn, Odd Eirik Hardem, Morten Grøsfjeld

VERSION	DOCUMENT NUMBER	DATE	RESPONSIBLE	STATUS
2.0	004	22.05.2016	R.D and O.E.H	Finalized

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FIGURE 1 - LEVELS OF TESTING 6

1.0 Document

1.1 Document history

Version	Date	Changes
0.1	05.02.2016	Document created
0.2	07.02.2016	Added Test plan Added 8.0 Test specification
1.0	07.02.2016	Reviewed
2.0	22.05.2016	Finalized

Table 1 - Document history

1.2 Definition of abbreviations

Abbreviation	Definition
A.K.	Arian Krasniqi
BL	Blind flange
CF	Compact Flange
EF	End fitting flange
FO&GT	Freudenberg Oil & Gas Technologies
HX	H-profile seal ring for SPO CF
IF	Integral flange
IX	I-profile seal ring for SPO CF
M.G.	Morten Grøsfjeld
O.E.H.	Odd Eirik Hardem
PRA	Preliminary Risk Assessment
R.D.	Richelieu Dahn
SPO	FO&GT brand name for compact flanges (Steel Products Offshore)
SW	Swivel flange
WN	Weld Neck type of flange
WT	Wall Thickness

Table 2 - Definition of abbreviations

1.3 Introduction

Testing is one of the most important stages in the development process of a product. It sets a guideline for exposing weaknesses, faults and defects that may occur in our system. After these tests are conducted and faults detected, the chances of achieving a high quality on the final product increases.

The purpose of the test plan document is to give a framework of how we plan to test our product and all of the different test methods that are required. Most of the testing done in this project will be purely analytical tests done with SolidWorks Simulations. This because our primary goal is to first and foremost provide a 3D model in CAD to FO&GT, with our secondary goal being to provide them with a prototype.

2.0 Traceability

The process of tracing requirements is where individual requirements are linked up with each other. In connection with our project, the traceability of requirements is where a cross reference is created. This is done in order to trace the requirements that are to be tested in the testing phase of our project lifecycle. This is done in table 3, where both the requirement specification- and test specification ID are given.

Requirement ID	Test ID
1.01	TS-1.01
1.02	TS-1.02
1.03	TS-1.02
1.04	TS-1.02
1.05	TS-1.02
1.06	TS-1.05
1.07	TS-1.08
1.08	TS-1.08
1.09	TS-1.08
1.10	TS-1.01
1.11	TS-1.06
1.12	TS-1.04
1.13	TS-1.08
1.14	TS-1.08
1.16	TS-1.01
1.17	TS-1.10
1.18	TS-1.09
1.19	TS-1.07
1.20	TS-1.07
2.01	TS-1.10
2.03	TS-1.10
2.04	TS-1.10
2.05	TS-1.10
3.01	TS-1.10
3.02	TS-1.10

Table 3 - Requirement and test relationship

3.0 Verification

During the testing phase of our product, we have decided to make use of the verification method of testing. The term verification involves checking products against their specifications, and determines whether the system meets its original specifications (1). In other words, verification sets the blueprint for all activities that are associated with the production of a product with high quality, making sure that the project is on the right track in terms of production, and that they are being done according to plan. This evaluation phase will control that our entire system and components are being developed in accordance with our requirement specifications, which brings into light the question whether; we are building the product right? There are four fundamental methods for verifying a requirement, which will be explained below in detail (2); inspection, analysis, test, demonstration.

3.1 Inspection

This is the first of the four methods for verifying a requirement and is when a system is visually examined through drawings and data, as it determines the conformance to requirements. These inspections can be executed by the use of standard quality control method, without the use of special laboratory procedures or equipment (2). It includes the examination of a direct physical attribute such as, dimensions, weight, physical characteristics (2).

3.2 Analysis

Analysis is the act of verifying a product by using models, calculations and test equipment. To be more precise, data are evaluated by analytical techniques to make sure that items meet specified requirements (2). With this method we will be able to predict the breaking point or failure of our product with the help of different tests that we will run. One of the most important analysis that will be done on our system will be the FEM – analysis.

3.3 Test

Test is a verification method which involves the use of established principles and procedures to ensure evaluation of the system quality complies with the requirements set by the stakeholders. These tests differ from analysis as they produce more comprehensive results since the tests require use of more specialized equipment in order to measure its qualities. Verification by test is usually done on requirements with the word “shall” in it.

3.4 Demonstration

The demonstration method is a way in which the system is manipulated with the intention of being used to verify that the results are in accordance with the expectations. In other words, it gives the conformance that a system requirement needs through operation, as it shows the functions of a system in terms of its abilities. It mainly depends on the observation of the product and taking notes of its functional operations. Due to the limitation of time that we have on this project, we do not plan on producing an actual product. But being that one of our team`s secondary goals is possibly producing a prototype, we will have a 3D printed model where some of the product`s mechanical functions will be demonstrated and components will be observed.

4.0 TEST STRATEGY

The test strategy can be viewed as the general approach we have for testing. It is what guides us to how we design and plan testing.

In our case, we have found that a requirement-based bottom-up testing strategy suits our needs optimally.

In this strategy, the requirement specification forms the basis for test design. The testing will first be done on the smallest components, and as components are integrated to sub-assemblies, we will perform tests on the subsystems. This process is repeated until the complete system is tested.

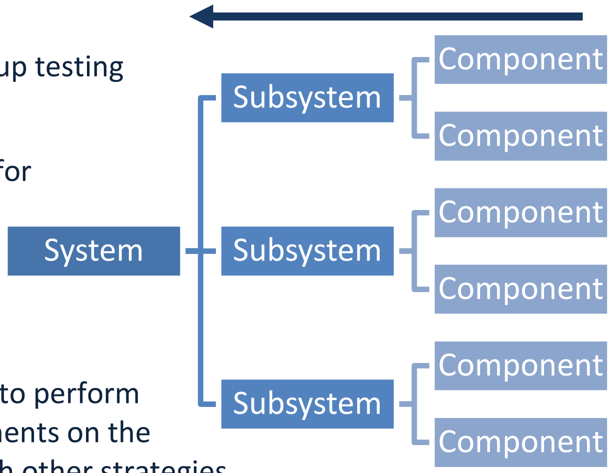


Figure 1 - Levels of testing

We have chosen this strategy as it will give us the opportunity to perform tests early in the development lifecycle; by testing the components on the smallest level we will be able to uncover faults earlier than with other strategies. By analyzing the requirements and risks associated with the product, we will have a preventative approach to testing, rather than a corrective one.

5.0 Methods and application

5.1 System

Tests have to be compatible throughout the projects lifecycle such that the goals set by the team are achievable. This is because before any physical system or component is made there is limited amount of methods we are able to apply. Our system will be subjected to more analysis and inspection than actual testing.

Mostly our analysis will be theoretical, done with simulation software. For our system, sub systems and components, analysis will primarily be:

- Force concentrations
- Frequency
- Vibrations studies
- Interfering parts/components

5.2 Proto type

If it happens that we reach our secondary goal which is to produce a working prototype we can apply more tests, but we are still pretty limited. A prototype will in many cases be made out of cheap materials like wood and other cheap "off the shelf" components. Tests results from a prototype can only tell you on what level your system will work independent of its performance during testing. Not how it behaves in different environments and conditions like extreme weather or in unwanted scenarios like a fire.

5.3 Other

It is not only the system that has to be tested. Our project result will consist of more than just a system. Other things that have to be tested are:

- Requirements has to be crosschecked with the system and its documentations and be verified to make sure they actually have been fulfilled.
- The contract has to be checked to make sure that there won't be (or has been) deviation from it.
- Compliance testing has to be done. This covers health and safety regulations, legal and government (all secondary stakeholders in pretty much all projects)

6.0 Risk in testing

The risk management is needed to ensure that all risks are taken into account when running tests on the system. This is because there is a probability of something going wrong in the test system or environment.

A risk assessment should be done before doing any testing, and for this we can use a normal PRA form. With a properly filled out PRA it will be easier to prove that the tests we have done are correct and incase of errors, the error management will be less time.

Preliminary Risk Assessment (PRA) Form							
Project	*xxxxx*						
Risk Question:	*What is the risk question?*						
	Step 1	**Step 2**	**Step 3**	**Step 4a**	**Step 4b**	**Step 4c**	**Step 5**
Risk ID:	*Hazard / Unwanted event*	*Harm / Consequence*	*Potential causes*	*Likelihood of occurrence [L]*	*Impact [I]*	*Risk Score (L x I)*	*Possible additional controls / Actions*
	What could go wrong?	*What might be the potential impact*	*How might the hazard occur?*	*What is the likelihood that the hazard will occur? (Hazard Scale)*	*How significant is the impact? (rating scale)*	*Calculated*	*What might help control and/or mitigate the hazard?*

7.0 Error management

In case of any errors during testing, we should look back on our Test PRA form to see what we have written down under column 5 "*What might help control and/or mitigate the hazard?" If this is not sufficient, we should ask for external guidance to minimize the time wasted on managing the error.*

If the error is directly connected to a design flaw, this will be written down in the phase report and processed in phase 4 "Evaluation". Here we will determine what we have to deal with and how we will deal with it.

8.0 Test specification

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.01	1.01, 1.10, 1.16	07.02.16	Analysis and inspection	A, A, C
Description: We will assemble our product onto a model of the flange(s) in 3D CAD and then run interference tests and inspect the results.				

Table 4 - TS-1.01.

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.02	1.02, 1.03, 1.04, 1.05	07.02.16	Analysis and inspection	A
Description: We will run a 3D animation to show how the system has contact with the faces that are to be polished The animation will reveal any colliding parts and other design flaws.				

Table 5 - TS-1.02.

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.04	1.12	07.02.16	Analysis and demonstration	A
Description: We will run an animation to show how the system follows the differences in the seal grooves angular geometry. The animation will reveal any colliding parts and other design flaws.				

Table 6 - TS-1.04.

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.05	1.06	07.02.16	Analysis	A
Description: • We will run FEM stress analysis to make sure no components will yield during installation and/or polishing. • We will run a frequency analysis in SolidWorks.				

Table 7 - TS-1.05.

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.06	1.11	07.02.16	Analysis and demonstration	A
Description: We will analyze the physical properties of the subcomponents that provide the surface pressure between the system and the flange faces that will be polished. The analysis depends on the component we chose but could for example be spring constant, stiffness, strength etc. This will later be demonstrated in CAD 3D animation.				

Table 8 - TS-1.06.

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.07	1.19, 1.20	07.02.16	Analysis	A
Description: FEM analysis will be done to check the mass of the system and sub systems with the selected materials.				

Table 9 - TS-1.07.

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.08	1.07, 1.08, 1,09 1.13, 1.14	07.02.16	Inspection	-
Description: An operational scenario study on the system will be done instead of testing, because no physical system that can provide sufficient information will be made, and because the requirement depends on external components. Make sure that the sub component (sand paper, grinding stone..) that does the polishing can provide wanted surface roughness by analyzing the sub component data plan. This is because physical test are the only tests that can give us useful information. Neither a CAD 3D drawing nor an early prototype can give us the needed information and therefore tests will only be a waste of time.				

Table 10 - TS-1.08.

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.09	1.18	07.02.16	Inspection	A
Description: Our team will ask FO&GT if the system has been designed in accordance with the offshore regulations. Inspections will be done by our team and FO&GT employees.				

Table 11 - TS-1.09.

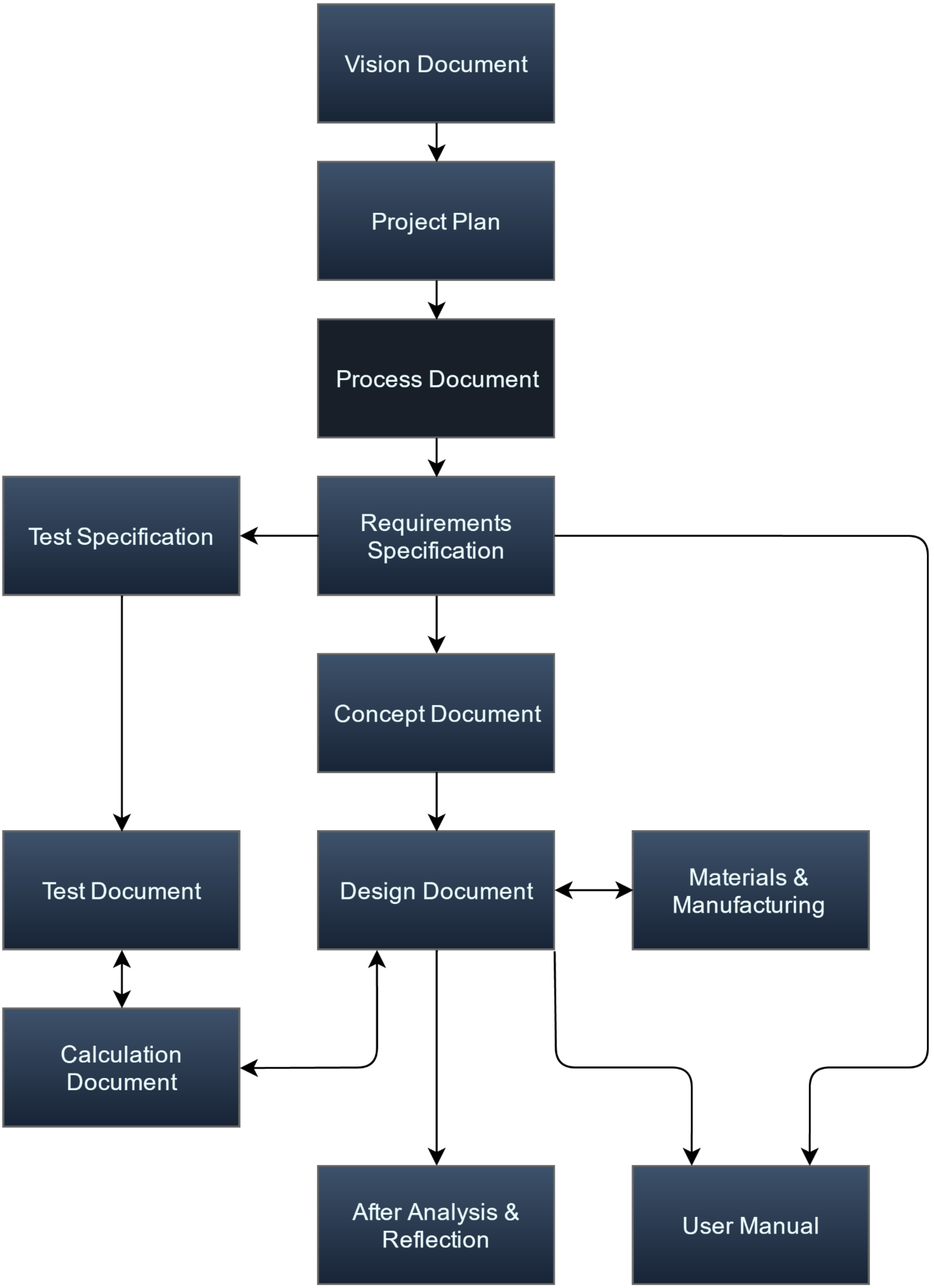
Test ID	Requirement ID	Date	Test Type	Priority
TS-1.10	2.01, 2.03, 2.04 2.05, 3.01, 3,02	07.02.16	Analysis	A
Description: An operational scenario study on the system will be done instead of testing, because no physical system that can provide sufficient information will be made. This is because physical test are the only tests that can give us useful information. Neither a CAD 3D drawing nor an early prototype can give us the needed information and therefore tests will only be a waste of time.				

Table 12 - TS-1.10.

References

1. **Stevens, Brook, Jackson and Arnold.** *Systems Engineering - Coping With Complexity.*

2. **Safi, Jamal.** *System engineering lecutre: Module 10 Verification & Validation and risk assesment.* 2014.


Vision Document
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Test Specification
Requirements Specification
Concept Document
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Design Document
Materials & Manufacturing
Calculation Document
After Analysis & Reflection
User Manual

PROCESS DOCUMENT

Freudenberg Bachelor 2016

SPO CF Seat polishing tool

Arian Krasniqi, Richelieu Dahn, Odd Eirik Hardem, Morten Grøsfjeld

VERSION	DOCUMENT NUMBER	DATE	RESPONSIBLE	STATUS
2.0	005	22.05.2016	All	Finalized

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1.0 Document

1.1 Document history

Version	Date	Changes
0.1	22.02.2016	• Document created
0.2	14.03.2016	• Updated first iteration.
0.3	14.03.2016	• Updated second iteration.
0.4	14.03.2016	• Updated third iteration. • Added the organization process. • Added Pugh matrices.
1.0	14.03.2016	• Updated fourth iteration. • Reviewed and finalized.
1.1	22.03.2016	• Small corrections
2.0	22.05.2016	• Finalized

Table 1 - Document history

1.2 Definition of abbreviations

Abbreviation	Definition
FO&GT	Freudenberg Oil & Gas Technologies
SPO	FO&GT brand name for compact flanges (Steel Products Offshore)
CF	Compact Flange
HSE	Health, Safety and Environment

Table 2 - Definition of abbreviations

1.3 Introduction

This document covers iteration reports that show how the team has worked together and used our project model. In every iteration report, details about our plans for the iterations and details on what actually happened are documented. Work-methods shown in flow-charts describes how the team attack problems and how we work with ideas towards the development of concepts.

1.4 Application of the Project Model

So far in the project we have worked in a more iterative way. Now that we have reached a new milestone and have completed our goal for stage two that was to find the “skeleton” of our system, it is time to change strategy and work in more of an incremental way. We will now start focusing on the different sub-systems and work on them one by one until they are ready for deployment. The iterations are still a mixture of both methods but the mixing ratio is different.

2.0 THE ORGANIZATION PROCESS

The process in which the operational and administrative tasks are carried out, are linked together during the duration of the bachelor´s thesis. For these to be efficient and implemented into the team, they have to be defined in such a way that in the face of uncertainty there is a general guideline on how progression is made and measured throughout the project lifecycle.

As we progress through the different phases it´s important to look at the patterns of the previous weeks on what has actually been achieved in terms of efficiency and organization. The way in which the process of the different team activities unfold, is what sets the foundation for questioning on how the team vision of the future progression of this project is to be.

2.1 THE OPERATIONAL PROCESS

The operational process is defined by the team to be any activity that contributes to fulfillment of the customer needs, because these activities are specifically designed to only focus on the customer requirements.

2.1.1 THE OPERATIONAL ACTIVITIES

The team discusses and works together on firstly expressing our individual vision for the concept/product. Afterwards, we elaborate on these individual ideas together as a team. We do this in order to evoke possible solutions, since it's easier for someone else to take an impartial stance on an idea rather than the mind behind it. An idea for a possible solution can be as simple as a small 2D drawing on a piece of paper.

After the team feels satisfied with the elaborated concepts, the question is then asked if there is a need to test the concept versus requirements, or if it is already being established by the elaboration session.

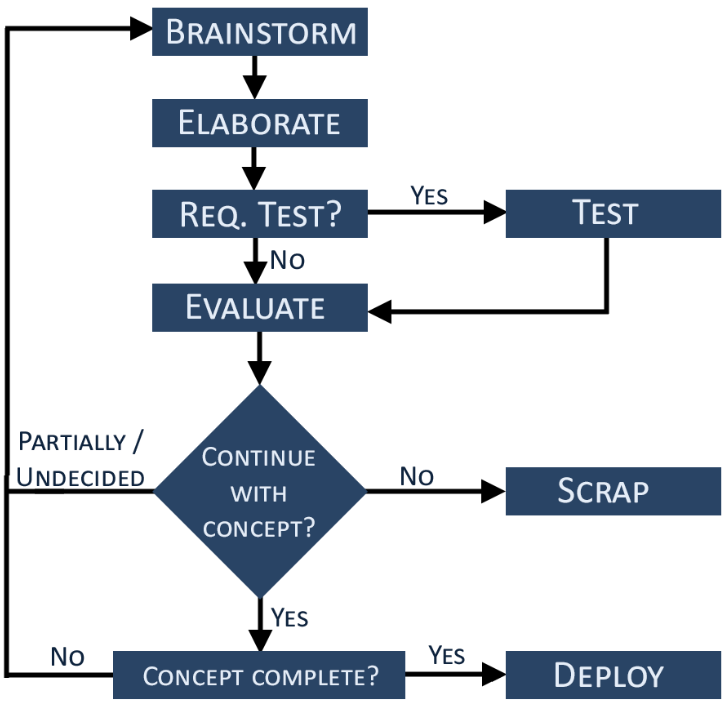

Figure 1 - Operational process flowchart

We evaluate the concept with the help of PUGH – matrices and general discussions as this gives us more insight of what is actually required of the concept in question. We then compare the idea with similar ideas and concepts in the same class. After these evaluations, we can decide to discontinue, partially use or select the concept. Undecided concepts can be further elaborated for improvement. If the concept is not completed, we will then repeat the process as shown in figure 1.

2.2 Monitoring process

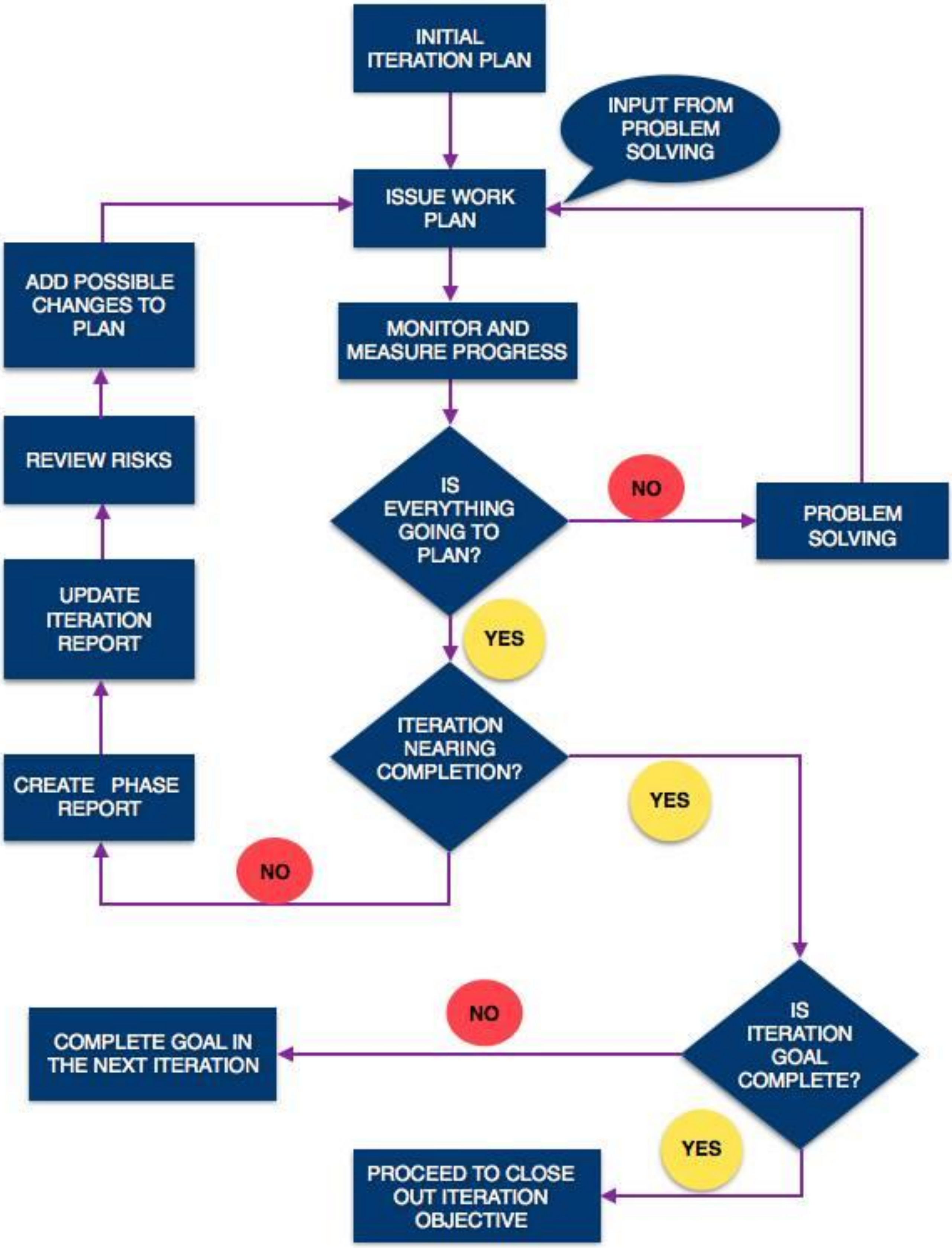

Figure 2 - The monitoring process flowchart (1).

2.0 Iteration 1

Iteration 1 - Brainstorming	Duration: Monday 15th February - Friday 19th February.	
Phases	**Activities**	**Objective**
Planning & Requirement	Detail planning of new iteration.	• Estimate time for this iteration. • Discuss possible team challenges for this week. • Plan team tasks.
Design & analysis	Concept brainstorming.	• Discuss team members vision for the product. • Collaborate on triggering of ideas for concepts.
Test	Concept validation.	Test concept vs requirements.
Evaluation	Review Iteration.	Evaluation of iteration outcome.

Table 3 - Iteration 1.

Hours estimated	Hours used
52 hours	63 hours

Table 4 - Time used on iteration 1.

2.1 Assessment

The iteration was initiated with time estimation and discussion about what possible challenges could be ahead. This worked great for our goal for this objective which essentially was to come up with as many possible concepts for primarily the mounting of system, and other needed system components to make the SPO CF polishing tool a reality.

We accumulated a good quantity of concepts that we decided to run some validation tests to see whether we were on the right track with the solutions. The team decided early on in the project that were going to be open minded about concepts in the initial iterations because it is important not to constrain ourselves to conventional ideas and solutions.

We also concluded that according to the hours used and hours estimated that the administrative task time estimation could improve, but we enjoyed this way of estimating time on each phase.

3.0 Iteration 2

Iteration 2 - Elaboration	Duration: Monday 22nd February - Friday 26th February.	
Phases	**Activities**	**Objective**
Planning & Requirement	• Detail planning of new iteration.	• Estimate time for this iteration. • Discuss possible team challenges for this week. • Plan team tasks.
Design & analysis	• Concept brainstorming. • Concept elaboration.	• Discuss possible improvement on existing concepts. • Collaborate on more detailed design of the concepts.
Test	• Concept validation.	• Test concept vs requirements.
Evaluation	• Concept evaluation & selection. • Review Iteration.	• PUGH matrix on C_Mount concepts.

Table 5 - Iteration 2.

Hours estimated	Hours used
96 hours	62.5 hours

Table 6 - Time used on iteration 2.

3.1 Assessment

The iteration was initiated with a team discussion on what our evaluation of the previous week concluded, this was seen as a reason to overestimate the hours needed, because we were preparing for the concept presentation with FO&GT the following week.

We worked on a good quantity of concepts to present for FO&GT that took into consideration the information that FO&GT had given us the previous meetings in relation to the user & system requirements of the product. This presentation consisted of sharing ideas where the concepts could improve and elaborate on these concepts.

We now have a number of concepts for the:

- Mounting of the system.
- Polishing of the seal groove seat.
- Heel face, midsection face and environmental seal.

We evaluated these concepts using the PUGH matrix, this was seen as a good way to judge the concepts available since we needed to start elaborating further on one concept for that particular system function. In this case; the mounting of the system.

The PUGH matrix worked well, since it sparked discussion that lead to ideas on how we could improve further on the concepts that scored low or even high on the outcome. This gave us a clear indication that the PUGH matrix is merely a tool that is used to judge if we are on the right track or not.

We also agreed on what the documents for this hand -in should contain, but this discussion was not completed because there was still more useful information missing that will be needed in these documents.

We may conclude that the iteration time estimation was overestimated. However, this is not a bad thing as we will hopefully learn from our mistakes, and estimate time more accurately for the next iteration. We are now ready to show our concepts so far to FO&GT.

4.0 Iteration 3

Iteration 3 – Concept selection	Duration: Monday 29th February - Friday 4th March.	
Phases	**Activities**	**Objective**
Planning & Requirement	• Detail planning of new iteration. • Update requirements.	• Estimate time for this iteration. • Discuss possible team challenges for this week. • Plan team tasks.
Design & analysis	• Concept brainstorming. • Concept elaboration.	• Discuss possible improvement on existing concepts. • Collaborate on more detailed design of the concepts.
Test	• Concept validation.	• Test concept vs requirements.
Evaluation	• Concept evaluation & selection. • Meeting with FO&GT. • Review Iteration.	• Evaluation of the concepts so far. • Evaluation of the project progression.

Table 7 - Iteration 3.

Hours estimated	Hours used
96 Hours	95,5 Hours

Table 8 - Time used on iteration 3.

4.1 Assessment

We initiated this iteration at FO&GT, with a presentation of the concepts for the mounting of the system, polishing of the seal groove seat, polishing for the heel face, midsection face and environmental seal. This presentation consisted of them sharing and discussing their vision for the product with us.

We started further elaborating on the other sub-systems concepts that we have, since we agreed on the concept that we should go ahead with concerning the mounting of the system onto the flange. This was an easy decision to make since the feedback from FO&GT matched our thoughts on this concept.

Concerning the feedback from FO&GT on the other concepts; they disliked some because of the impractical parts that these concepts contained concerning the environment in which they are going to be affected by. This is what led to some new requirements concerning the dust, sand and varying temperature.

The outcome of this meeting was great as it helped us verify whether or not we are on the right track. We have some good concepts for the remaining system components needed, in particular; the polishing fingers.

We may conclude that:

- We now have to select the polishing finger concept for the heel face, midsection face and environmental seal.
- We now have to select the polishing finger concept for the seal groove seat.
- Brainstorm concepts of how the motor is going to be connected with the system.

5.0 Iteration 4

Iteration 4 – Test of concepts	Duration: Monday 7th march - Tuesday 15th March.	
Phases	**Activities**	**Objective**
Planning & Requirement	• Detail planning of new iteration. • Risk analysis. • Concept documentation. • Process documentation	• Estimate time for this iteration. • Discuss possible team challenges for this week. • Plan team tasks.
Design & analysis	• Concept Research • Concept brainstorming. • Concept elaboration.	• Gather source material for pneumatic motor. • Discuss possible improvement on existing concepts. • Collaborate on more detailed design of the concept.
Test	• Concept validation.	• Test concept vs requirements.
Evaluation	• Concept evaluation & selection.	• Evaluation of the concepts so far.

Table 9 – Iteration 4.

Hours estimated	Hours used
172	183,5

Table 10 - Time used on iteration 4.

5.1 Assessment

This iteration was initiated with a discussion on what our time and energy should be focused on, because the deadline of the documents hand in and presentation were approaching. It was concluded that we should focus on finding a solution for the motor placement onto the system.

The concept research focused on gathering source material for the pneumatic motor since this is what the team has decided that the system should be driven by. This led to some more sketching and discussion of concepts for the pneumatic motor connection onto the system.

We also had a meeting with FO&GT where we presented the concepts for the motor to system connection. We were very delighted with the meeting as it confirmed that we were on the right track and that progression so far concerning the product development is good. After the meeting with FO&GT we started elaborating on the concepts we presented based on their feedback and our thoughts on how the concept would be further improved.

We then began finalizing the concept document and proceess document.

We may conclude that:

- We now have a solution for connecting the motor to the system.
- Documentation is being finalized.

6.0 Iteration 5

Iteration 5 – Detailed design	Duration: Monday 28th march – Friday 1st of April	
Phases	**Activities**	**Objective**
Planning & Requirement	• Documentation • Status discussion • Delegation of technical responsibilities.	• Technical references to be discussed such that everybody is on the same page. • Stakeholder insight on our product.
Design & analysis	• Concept Research • Technical Documentation	• Gather source material for individual technical responsibilities. • Discuss possible improvements on existing concepts. • Collaborate on more detailed design of the concept.
Test	• Test of springs	• Gather technical insight about our possibilities with off –the shelf components.
Evaluation	• Evaluation of team status and progression. • Evaluation of time.	• Evaluation of the technical advancements. • Stakeholder insight on progression and approval.

Table 11 - Iteration 5.

Hours estimated	Hours used
120	104

Table 12 - Time used on iteration 5.

6.1 Assessment

The iteration was initiated with a discussion on what the stakeholders required of us, and what we should do presently and in the future in order to be more synchronized with our stakeholders. This led to a follow –up discussion about the stakeholder meetings that occurred just before Easter.

Since then we decided to divide the technical responsibilities the following way:

A.K = Arm

M.G = Neck

R.D = Base

O.E.H = Legs

We then began working on these responsibilities individually and in pair, and when needed we discussed as a team. The work completed so far is that we now have run some tests on the springs, and made technical calculations on the legs, base and neck.

We may conclude that:

- Detailed responsibilities were assigned.

7.0 Iteration 6

Iteration 6 – Design Elaboration	Duration: Monday 4th of April – Friday 8th of April.	
Phases	**Activities**	**Objective**
Planning & Requirement	• Documentation • Product Risk analysis	• Find out what concepts we are going to elaborate further on, i.e for arm & polishing finger.
Design & analysis	• Detail design elaboration	• Elaborations and Improvements of chosen concepts for detail design.
Test	• Verify against requirements	• Assure ourselves that the concepts that we have chosen comply with the requirements that we have set.
Evaluation	• Evaluation • Detailed iteration plan.	• Evaluation of risk analysis • Evaluation of present iteration progression. • Planning of new iteration

Table 13 - Iteration 6.

Hours estimated	Hours used
160	95,5

Table 14 - Time used on iteration 6.

7.1 Assessment

The iteration was initiated with planning and requirement, where we discussed our thoughts on the work ahead. Possible ideas for improving the progress that is made were also discussed such that the work breakdown could be more efficient.

We continued with the work to develop concepts for arm and finger. Documenting was a key part of this iteration as we now have worked on what our documentation will look like in this stage, and what this will be compiled of.

We may conclude that:

- PUGH matrix for the arm & finger are to be developed.
- We will begin with more document writing now that we have the table of content in place.

8.0 Iteration 7

Iteration 7- Selection of Design components	Duration: Monday 11th of April – Sunday 17th of April.	
Phases	**Activities**	**Objective**
Planning & Requirement	• Documentation of new documents. • Requirement status. • Process documentation.	• Complete documents that are to be delivered for first draft. • Check if requirements need to be updated.
Design & analysis	• Design elaboration.	• Elaborations and Improvements of chosen concepts for detail design.
Test	• Verify requirements.	• The status of the requirements.
Evaluation	• Selection of polishing finger. • Evaluation.	• Suggestion on how to improve progression. • End week with selected polishing finger.

Table 15 - Iteration 7.

Hours estimated	Hours used
128	146

Table 16 - Time used on iteration 7.

8.1 Assessment

The week began with each team discussion about progression that is to be made and further improvements on how we could write the upcoming documents. The reason for this is to ensure ourselves that everything is detailed and structured in a manner that best reflects what we are creating and the process in which this performed. We did this by risk analysis and team discussion where we decided the goal for this iteration.

The goal for this iteration was to finish a first draft of the documents that we are about to deliver, but this process has stagnated a bit because of illness within the group caused by the flue. This means that we have to delay the deadline we have already set for ourselves that we were going to have a first draft in place by the end of the design elaboration iteration. Instead we are to complete a first draft of the documents this Thursday [17.04.2016] which marks the end of the selection of design components in accordance with the project plan and we may then evaluate on Friday at FO&GT.

This iteration was used to elaborate on the designs and the documentation of these. We did this at FO&GT in Drammen. This was good as we had the opportunity to communicate with the different stakeholders such that we may in more detail tailor to their needs and concerns.

With design elaboration in mind we laid heavy focus of material selection in this iteration as it became prevalent that the materials that we were about to use played a significant part when it came to further detail design of the SPO CF seat polishing tool.

We may conclude that:

- Stainless steel is the preferred material choice for the team, and that we will use the same material throughout in the system. This material being super duplex stainless steel.
- Status of requirements have been detailed.
- The workload will increase as the project lifecycle approaches the end.
- Time estimation for this week was off, because of illness within our team.

9.0 Iteration 8

Iteration 8- Selection of Design components	Duration: Monday 18th of April – Friday 22th of April.	
Phases	**Activities**	**Objective**
Planning & Requirement	• Documentation of Design. • Review requirements	• Complete documents that are to be delivered for first draft. • Check if requirements need to be updated.
Design & analysis	• Detail design brainstorming • Detail design elaboration • Individual Design	• SG Design • Arm finalized design. • Sliding connector finalized design. • Lid finalized design
Test	• Verify requirements	• We checked the status of the requirements.
Evaluation	• Evaluation.	• Suggestion on how to improve progression. • End week with selected polishing finger.

Table 17 - Iteration 8.

Hours estimated	Hours used
160	100

Table 18 - Time used on iteration 8.

9.1 Assessment

This iteration has been plagued by sickness within the team which has meant that we haven't gotten to work a lot together these two past weeks, but progress has been made by individual team work connected via Skype and team activities where we worked in groups.

The goal for this iteration was to complete a selection of components such that we were able to determine what kind of tests we needed to perform when we finalize a CAD design. This selection process was a success as we have now selected the arm, sliding connector, Lid, and Polishing finger for the heal face and midsection.

We are currently working on a solution for the seal groove-polishing finger, and are on good way, as we will determine which concept we will go ahead with. Our documentation progress has increased as we now see fit to hand -in the first draft of documents on Monday [24.04.2016] for a first draft review.

We all have worked this weekend and the weekends to come will be available to work as the project lifecycle approaches the end.

We may conclude that:

- Arm design is finalized for now.
- Sliding connector design is finalized.
- Heel face design is about to be finalized.

10.0 Iteration 9

Iteration 9 – Test of Design	Duration: Monday 25th of April – Friday 29th of April.	
Phases	**Activities**	**Objective**
Planning & Requirement	• Work with SG polishing finger. • Review and Document writing.	• Complete documents that are to be delivered for first draft. • Write documentation of design document.
Design & analysis	• Work with SG polishing finger. • Check of test plan for the sub –systems.	• SG finalized Design • Verify Requirements
Test	• Test of sub –system against requirements.	• We checked the status of the requirements.
Evaluation	• Evaluation of SG • Evaluation of Gears • Evaluation of Arm sub-system • Evaluation of System.	• Complete testing of the system. • Selection

Table 19 - Iteration 9.

Hours estimated	Hours used
168	170,5

Table 20 - Time used on iteration 9.

10.1 Assessment

We started the week with the goal of testing the components that we have so far, and this was done by verifying the requirements towards the status of the components. We concluded that there was still work to be done on several of the components before they were to be seen as completed.

This action delayed further testing of these components since our discussion with FO&GT also concluded that there was still work to be done with some of the components.

Our review session with Kjell also took place as we discussed what our progression is to be in the coming weeks, and what we are to focus on when writing the documents.

This meant that we had to spend further time on working with these components as this was needed in order to perform the components, sub-systems and system analysis. Our goal for this iteration is to complete the testing of components and finish documentation about the materials, and sub - systems.

We may conclude that:

- Our previous iteration goal «testing of components» is still to be completed.
- There is work to be done on the documentation.

11.0 Iteration 10

Iteration 10 – Integration of system	Duration: Monday 2th of May – Friday 6th of May	
Phases	**Activities**	**Objective**
Planning & Requirement	• Check Requirements • Test Document writing. • Material Research	• Get started with test documentation for all components. • Get done with finishing touches on the <<To do list>>
Design & analysis	• Document writing of calculations • Static analysis	• Calculations for FEM static analysis in place. • Start with bottom up testing and documentation. • Static analysis
Test	• Test of sub –system against requirements. • Standards component validation.	• We checked the status of the requirements. • To verify that our design is up to standards.
Evaluation	• Evaluation	• Evaluate components and sub-systems that have been analyzed.

Table 21 - Iteration 10.

Hours estimated	Hours used
172	211,5

Table 22 - Time used on iteration 10.

11.1 Assessment

We initiated the iteration with the finalization of the «to do» list that we had set up before starting the week, and afterwards we began with FEM analysis of most of the sub -systems. We also finalized and documented the changes that was done to the components that were in need of change. The manufacturing and materials document was elaborated on, and is on good progress to be completed this week, along side the design document.

We have also done testing this week to verify the requirements and quality assure the materials that are to be used for polishing.

We may conclude that:

- Documentation progress is good.
- FEM analysis was elaborated on.
- Verifying design is on good progress with completing requirements.

12.0 Iteration 11

Iteration 11 – finalization	Duration: Monday 9th of May – Sunday 15th of May.	
Phases	**Activities**	**Objective**
Planning & Requirement	• Control of fixtures and applied forces on existing tests & documents. • Friction coefficient test and friction forces.	• Status of requirements
Design & analysis	• FEM analysis • Documentation	• Frequency analysis and documentation • Design documentation
Test	• Test of polishing fingers. • Test of body. • Test of arm. • Test documentation	• We checked the status of the requirements. • Documentation for testing requirements • All sub-system requirements verified.
Evaluation	• Evaluation of SG • Evaluation of Gears • Evaluation of Arm – components. • Evaluation of System.	• Complete testing and system evaluation. • Finalize system.

Table 23 - Iteration 11.

Hours estimated	Hours used
160	232,5

Table 24 - Time used on iteration 11.

12.1 Assessment

We started off this iteration with the intent on finalizing all of the tasks that were listed for completion. This went according to the plan with most of the tasks except the materials and manufacturing document which remains to be worked on before final hand –in.

We still have work remaining with documentation of stage 3 documents, and updating previous documents. The team has extended this iteration objective to 09.05.2016 -16.05.2016 because we still have documentation remaining that is in need of final review.

We may conclude that:

- Documentation needs to be finalized.
- Review of calculation.
- Review of FEM analysis documents.

13. Deployment

Iteration 12 – Deployment	Duration: Wednesday 18th of May – Sunday 22nd of May.	
Phases	**Activities**	**Objective**
Planning & Requirement	• Requirement documentation update • Review Vision document • Review plan document.	• Finalize Requirement document for hand –in. • Finalize Vision Document for hand –in • Finalize Project plan for hand –in
Design & analysis	• Review Design document • Review Calculation Document	• Finalize Design document. • Finalize Calculation Document.
Test	• Review Test specification. • Review Test document.	• Finalize Test specification. • Finalize Test document
Evaluation	• Review Process document	• Finalize Process document

Hours estimated	Hours used
No time estimation was done for this iteration.	192 hours

At this stage of the project, we have ensured that FO&GT has a system user manual in place so that they may develop the abilities necessary to use the SPO CF seat-polishing tool. What`s important in this stage is the finalization of all documents that are to be handed in. When the documents are handed in, we will now start preparing for the final presentation and thus concluding this Bachelor thesis.

References

1. **Young, Trevor L.** Succesfull project management. London : Kogan Page, 2000, p. 134.

2. **MIT.** MIT. [Online] 1998. [Cited: 14 March 2016.] http://sloanreview.mit.edu/article/the-processes-of-organization-and-management/.

Pugh matrix template taken from Juran.com at 02.03.2016

Attachments

A.0 Pugh matrix criteria description

Criteria	Description
Mass	The total mass of the object.
Ease of mounting	The ability to mount the polishing tool onto the flange.
Balanced	The ease of the concept to be parallel with the heel face.
Time for setup	The total time required to assemble the tool onto the flange, ready to polish.
Rigid	How solid is the body?
Impact	Soundness against impact.
Mechanical Soundness	How solid is the body?
Complexity	Does the concept consist of several parts that make it more complicated?
Expected life	The life time expectancy of the concept
Mobility	How is to travel with the concept?
Flexibility	The ability for the concept to suit different flange sizes.
HSE	The safety for the environment surrounding the concept.
Limitations	The difficulty to implement the needed system functions onto the concept.

Table 25 - Pugh matrix criteria

A.1 Pugh Matrix for Mount

Pugh Selection Matrix

		Alternative Concepts							
Criteria	**Rating (1-10)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mass	**6**	-	S	S	S	-	+	+	+
Ease of mounting	**7**	-	S	S	S	+	-	+	+
Balanced	**6**	+	-	S	+	+	-	+	-
Time for setup	**3**	+	+	+	+	-	S	+	+
Rigid	**4**	+	S	S	S	+	-	+	-
Impact	**7**	S	-	-	-	+	S	+	-
Comlexity	**4**	S	-	-	S	+	+	+	-
Expected life	**2**	+	+	+	+	+	S	+	-
Mobility	**8**	+	+	+	+	-	+	+	+
Flexibility	**6**	-	+	+	+	-	-	-	S
HSE	**10**	+	+	+	+	+	+	+	-
Limitations	**6**	+	+	+	+	-	S	S	-
Sum of Positives		**7**	**6**	**6**	**7**	**7**	**4**	**10**	**1**
Sum of Negatives		**3**	**3**	**2**	**1**	**5**	**4**	**1**	**1**
Sum of Sames		**2**	**3**	**4**	**4**	**0**	**4**	**1**	**57**
Weighted Sum of Positives		**39**	**35**	**35**	**41**	**40**	**28**	**57**	**6**
Weighted Sum of Negatives		**19**	**17**	**11**	**7**	**29**	**23**	**6**	**0**
		20	18	24	34	11	5	51	6

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A.2 PUGH MATRIX FOR FACES

Pugh Selection Matrix

		Alternative Concepts		
Criteria	**Rating (1-10)**	**1**	**2**	**3**
Mass	**2**	-	+	s
Rigid	**9**	-	+	+
Impact	**6**	-	s	-
Complexity	**6**	s	+	-
Expected Life	**2**	s	+	s
Mobility	**2**	+	+	+
HSE	**6**	+	+	+
Limitations	**5**	-	-	+
Sum of Positives		**2**	**6**	**4**
Sum of Negatives		**4**	**1**	**2**
Sum of Sames		**2**	**1**	**2**
Weighted Sum of Positives		**8**	**27**	**22**
Weighted Sum of Negatives		**22**	**5**	**12**
		-14	22	10

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A.3 Pugh Matrix for Seal Groove

Pugh Selection Matrix

		Alternative Concepts			
Criteria	**Rating (1-10)**	**1**	**2**	**3**	**4**
Mass	**2**	s	+	s	+
Rigid	**9**	+	-	+	s
Impact	**6**	+	+	+	+
Complexity	**6**	s	+	-	+
Expected Life	**2**	+	-	s	+
Mobility	**2**	+	+	+	+
HSE	**6**	+	+	+	+
Limitations	**5**	+	-	s	s
Sum of Positives		**6**	**5**	**4**	**6**
Sum of Negatives		**0**	**3**	**1**	**0**
Sum of Sames		**2**	**0**	**3**	**2**
Weighted Sum of Positives		**30**	**22**	**23**	**24**
Weighted Sum of Negatives		**0**	**16**	**6**	**0**
		30	6	17	24

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A.4 Pugh Matrix for Neck

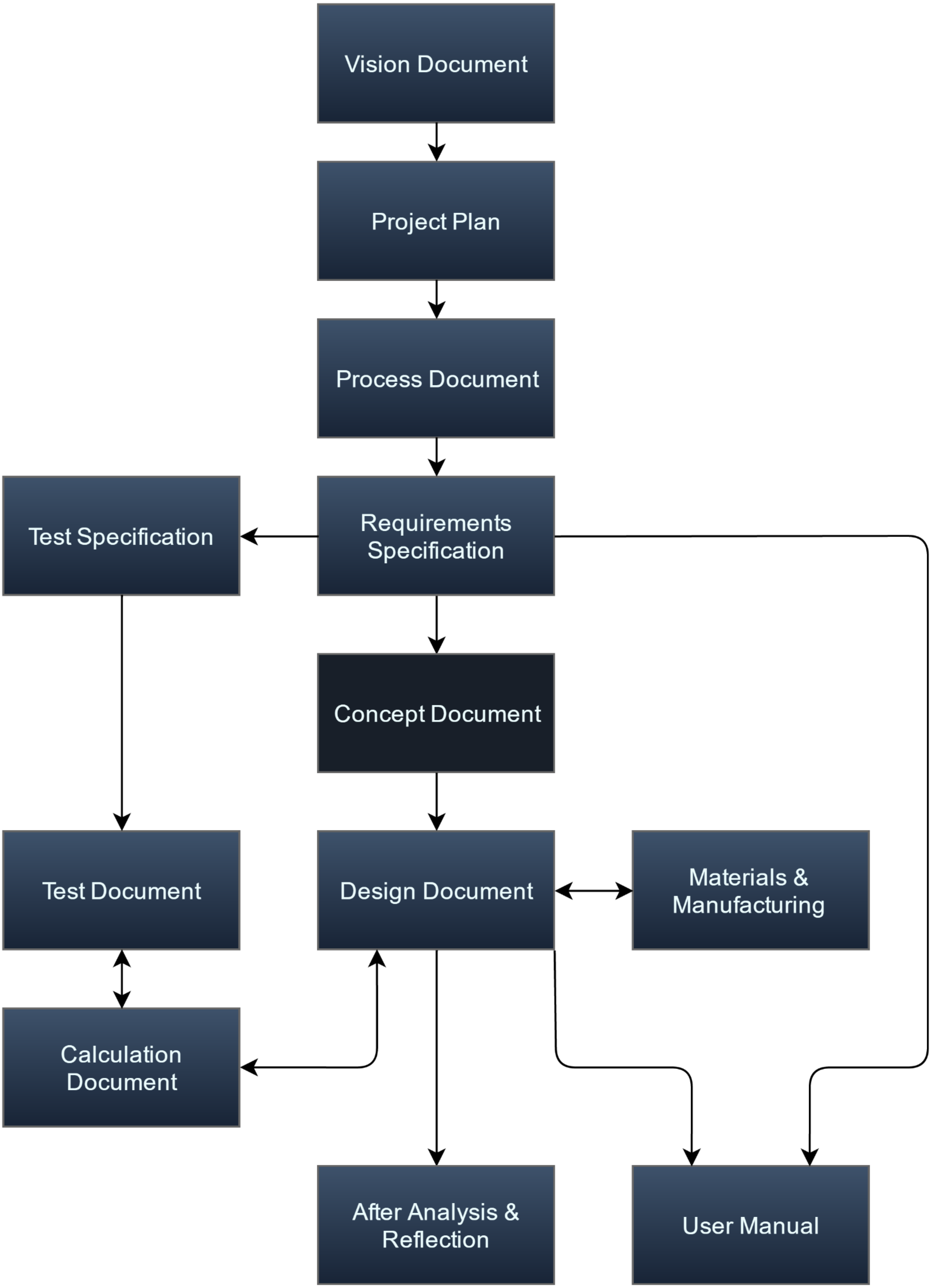
Pugh Selection Matrix

		Alternative Concepts			
Criteria	**Rating (1-10)**	**1**	**2**	**3**	**4**
Mass	**4**	-	+	S	-
Comlexity	**9**	-	-	+	+
Clean Ability	**8**	S	S	+	+
Rigid	**10**	+	+	-	+
Ease of mount	**3**	S	S	+	+
fail safe	**9**	-	-	+	+
time for setup	**4**	-	-	+	+
impact	**6**	-	S	+	+
life expectency	**5**	-	-	+	+
flexibility	**10**	+	S	-	+
HSE	**10**	+	+	+	+
Limitations	**7**	-	+	-	S
mobiliy	**8**	+	+	S	S
Environmental Interference	**8**	S	+	-	-

Sum of Positives		**4**	**6**	**8**	**10**
Sum of Negatives		**7**	**4**	**4**	**2**
Sum of Sames		**3**	**4**	**2**	**2**
Weighted Sum of Positives		**38**	**47**	**54**	**74**
Weighted Sum of Negatives		**44**	**27**	**35**	**12**
		-6	20	19	62

JURAN

http://www.juran.com


Vision Document
Project Plan
Process Document
Test Specification
Requirements Specification
Concept Document
Test Document
Design Document
Materials & Manufacturing
Calculation Document
After Analysis & Reflection
User Manual

CONCEPT DOCUMENT

Freudenberg Bachelor 2016

SPO CF Seat polishing tool

Arian Krasniqi, Richelieu Dahn, Odd Eirik Hardem, Morten Grøsfjeld

Version	Document number	Date	Responsible	Status
2.0	006	22.05.2016	All	Finalized

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1.0 Document

1.1 Document history

Version	Date	Changes
0.1	22.02.2016	• Document created
0.2	29.02.2016	• Added concepts and descriptions
0.3	02.03.2016	• Added additional concepts and descriptions
0.4	09.03.2016	• Restructured document
0.5	11.03.2016	• Added technical descriptions
0.6	12.03.2016	• Changed design layout • Elaborated technical description • Added figures
0.7	13.03.2016	• Reviewed document
1.0	14.03.2016	• Finalized
1.1	22.03.2016	• Corrections to list of tables
1.2	30.03.2016	• Rearranged concepts • Added “source” to concepts
2.0	22.05.2016	• Finalized

Table 1 - Document history

1.2 Definition of abbreviations

Abbreviation	Definition
FO&GT	Freudenberg Oil & Gas Technologies
SPO	FO&GT brand name for compact flanges (Steel Products Offshore)
CF	Compact Flange
HS	Heel seal
MS	Midsection seal
ES	Environmental seal
SG	Seal groove
SWS	SolidWorks Simulation

Table 2 - Definition of abbreviations

1.3 Related documents

- 001 Vision Document
- 002 Project Plan
- 003 Requirement Specification Document
- 005 Process Document

1.4 Introduction

The purpose of this document is to give a brief overview of the different concepts that we have come up with for the polishing tool. This involves concepts of the various sub-systems that are required to build a full system. This document will also contain the functionality that each of the concepts has in relation to the flange, and the illustrations of how the different base concepts can be mounted onto the flange. It will also give the necessary reasoning for the different concepts (ex: pros & cons), enabling us to conclude on the decision making for the final components that are to be integrated into the final product.

1.5 Scope

The scope of this document is the following:

- Classification of sub-systems
- Description of concepts
- Selection of sub-systems

1.6 Disclaimer

These concepts do not cover a detailed design of the product, as this will be covered in the construction stage of our project.

2.0 SYSTEM CLASSIFICATION

The SPO CF Seat Polishing Tool is as the name suggests a polishing tool (1). The only tool that exists today that it can be compared to is a re-machining tool. The big difference here is that our tools purpose is to polish which is a far simpler and less energy consuming process than the re-machining (2).

The machine is intended to be used when the polishing process is enough to make the flange function to an acceptable standard. The user will evaluate the state of the flange to determine whether to polish by hand, use the polishing tool or re-machine.

3.0 SYSTEM INTEGRATION

The term system integration in engineering is basically the process of gathering all of the different components and sub-systems as a complete functional system. It is therefore important that all of the different integrated components and subsystems relate to each other in terms of functionality, and they also have to work properly together as a system. (3)

In connection with our project, we came up with as many concepts as possible, did some reasoning and evaluations on them individually. This enabled us to come up with individual final concepts for some of the system components. Our system integration will therefore be an overview of some of the concepts that we have chosen to move forward with for the different components that are required to have a completed system. In the situations where improvements were made on a concept, an updated version of the existing version will be listed beside it.

Please be aware that our integrated system is still missing some sub-systems like the polishing finger and other components that are required to complete the system. The reason for this is that, there has been elaborated multiple versions of these individual components that haven't been selected yet. This will be done in the construction stage of the project as we will begin with detailed design of concepts and components.

3.1 Sub-system relationship

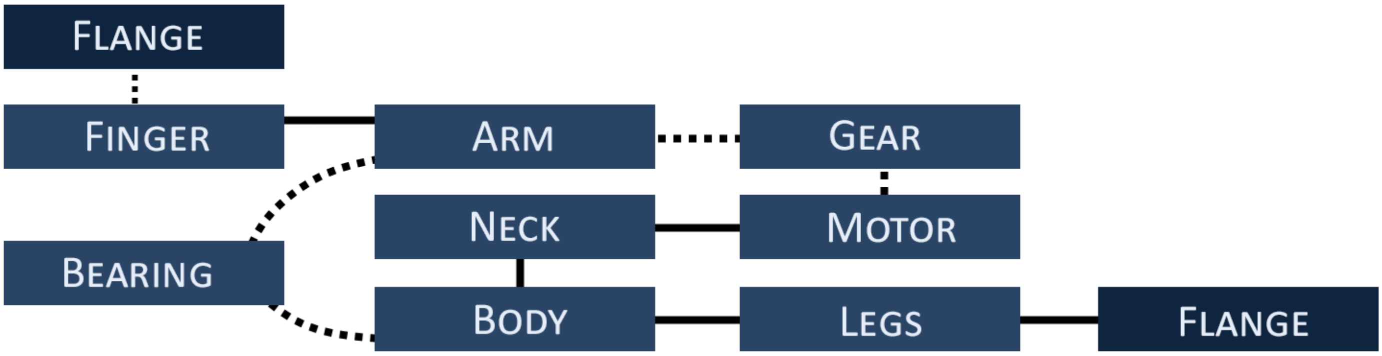


Figure 1 - Component diagram

The component diagram (fig. 1) is used to illustrate the structure and the relationship among the different sub-systems and components in the system (4 p. 229) and the layouts inspiration is taken from (5 p. 22).

- The solid lines represent a relationship where the objects are fixed together (i.e. bolted, clamped).
- The dotted lines represent a relationship where two objects are attached together, but can move independent of each other in one or more dimensions.

3.2 Motor

The main purpose of the motor is to supply a rotary force to the arm.

3.2.1 Description

The motor is to be installed and fixed inside the arms centre. Main reasons for this is because we want to save space wherever we can and because the arm can act as a protective cover for the motor.

We have chosen a motor that runs on compressed air in our system. This is because of requirement 3.02, which states that none of the systems sub-components can be electric. A pneumatic motor is a safer choice when it requires work in zones and areas with strict fire regulations (6)

After some rough calculations (7 p. C_1) and research (8), we know that we will need approximately 285 Watts effect and at least 110 Nm of torque, and pneumatic vane motor in this class has the dimensions: H≈269mm, D≈70mm and has a mass of 2.9 kilograms.

Our temporary motor selection is the 67-373 HTM from Deprag.

The motor will have an option to be removed from the system and be replaced with an option that will only require hand power to polish. This is an “emergency” solution.

3.2.2 Improvement

The motor is an off the shelf product and we will not alter the functionality of it in any way.

3.3 Body

The main purpose of the base is to act as a base that other sub-systems can be connected and/or fixed to.

3.3.1 Description

The body is shaped in such a way that it will be stiff, rigid and at the same time not take up too much of the precious space inside the flange.

The shape and design of the body will most definitely be changed over time since there are many parts that are directly or indirectly connected to it. It will have to be shaped around all the other sub-systems and components that have a more crucial and advanced design limits.

3.3.2 Improvement

Our initial idea for this concept was to have the outer framework curved as seen in figure 3. As of now we will go for a design with more straight parts (figure 4). This will be cheaper to manufacture. However, we suspect that the force distribution will be better in the second version (figure 3). We will do a FEM-analysis later to find out.

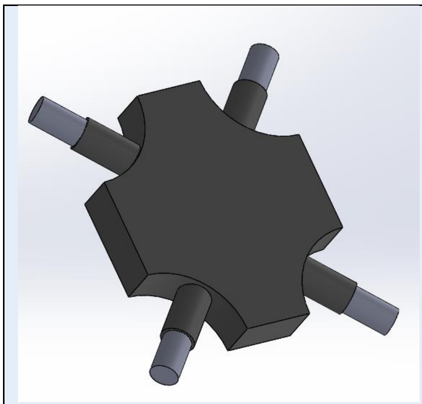


Figure 2 - C_Mount_01 V1

Version 1

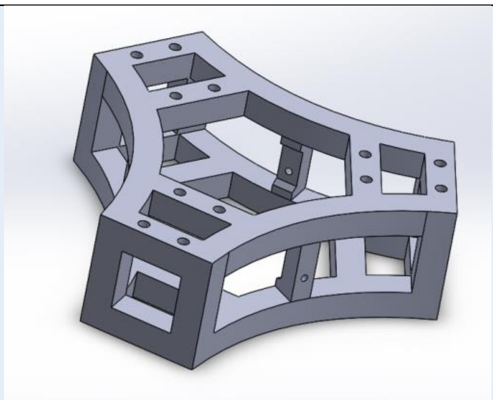


Figure 3 - C_Mount_01 V2

Version 2

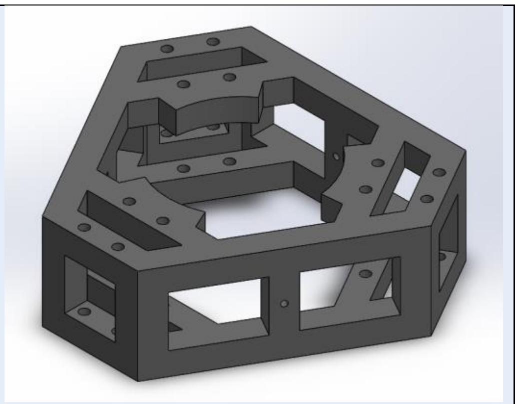


Figure 4 - C_Mount_01 V3

Version 3

3.4 Legs

The main purpose of the legs is to fix the system to the flange.

3.4.1 Description

In our concept, there are three legs that all consist of two main parts each; the bushing and the power screw. The power screw is the component that is in contact with the inner wall of the flange to apply a preload to the flange. The support engineer manually tightens it with a wrench and the length of this screw is one of the systems components that determines the size range of different flanges the system can support.

The bushing is the component that transfers the forces from the power screw to the body. The reason why the bushing is not a part of the body is because the bushing and the body will have different requirements when it comes to material properties (9).

3.4.2 Improvement

We want to change the tip of the power screw to be blunt instead of sharp. This is because it will damage the inner wall less and keep its original shape for a longer period of time.

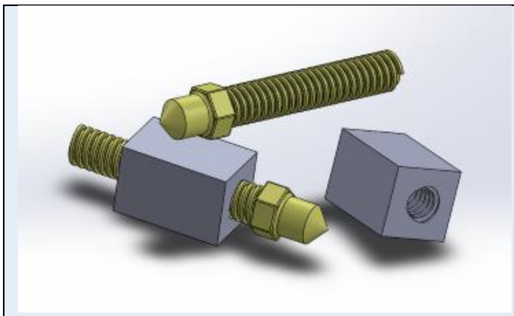


Figure 5 – Sharp power screw

Version 1

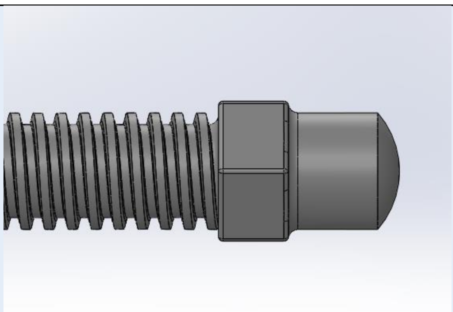


Figure 6 – Blunt power screw

Version 2

3.5 Neck

3.5.1 Description

The motor is not that powerful (8)(285 Watts), but it still has to be fixed such that it doesn't rotate around its own axis. Since the motor is relatively weak we don't need a big and solid component to fix it, and since space is very limited around the motor we will have a space efficient neck with a high quality material.

We also have to design it in such a way that it will not damage the motor when it is clamped on.

3.5.2 Improvement

From the meeting with FO&GT, we elaborated on C_Neck_01. Based on the feedback and brainstorming session with David Robertson and Przemyslaw Lutkiewicz, we found a solution that allowed the motor to be placed in the centre of the arm.

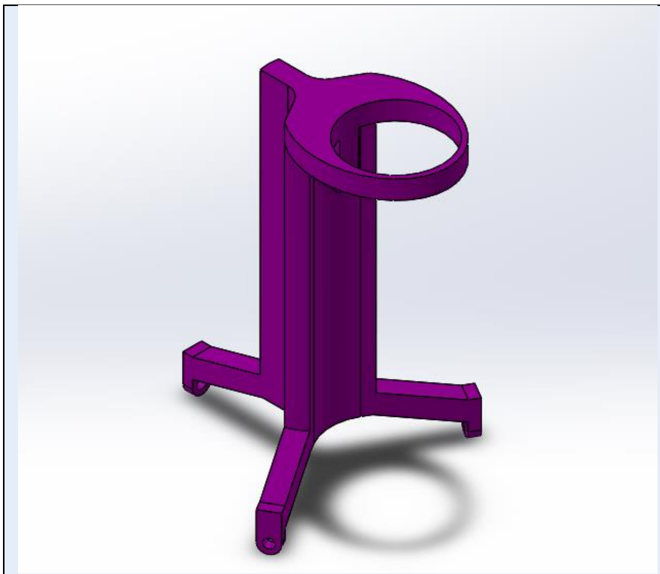


Figure 7 – Initial idea of neck

Version 1

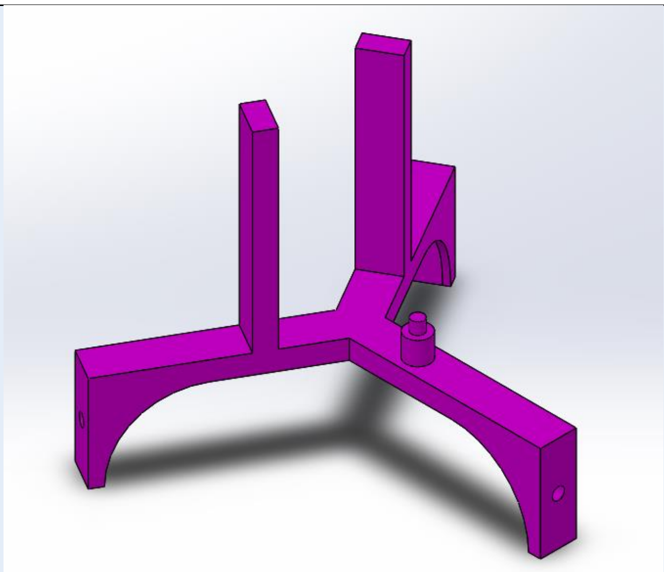


Figure 8 – Improved version of neck

Version 2

3.6 Arm

The main purpose of the arm is to link the rotary force from the motor to the fingers.

3.6.1 Description

The design of the arm is not yet complete because it depends greatly on how the other sub-systems will work. It is also a fairly simple task to design it because it is after all only a mechanical link from one point to another.

We do however plan to make the arm in multiple modules, so by combining the right modules we will make an arm that will fit the desired flange. This will make the arm heavier because of the additional parts required.

We also suspect that the arm is a sub-system that will be easily optimized to limit mass and volume.

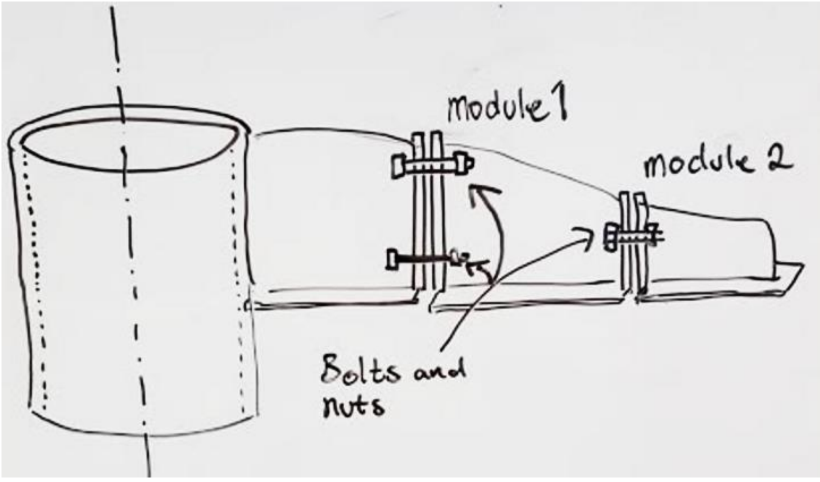


Figure 9 – Sketch visualizing arm modularity

3.6.2 Improvement

As of now, we only know that there will be an arm in the system and not what it will look like.

3.7 Fingers

The main purpose of the fingers is to polish the flange sealing surfaces with the energy from the motor.

3.7.1 Description

To apply a steady and correct force from the arm we have chosen to use springs to apply a load. The spring will apply a steady force and it will allow the sub-system to bend a small amount. The bending is necessary since the flanges are not 100% horizontal.

As mentioned in other documents (See vision doc and Project Plan doc), the fingers are split into two categories; Faces and Seal groove, and as of now we have multiple concepts for both categories that we believe will work. We plan to work further on the concepts before deciding which one(s) we will use and then have them prototyped for testing.

Testing will be a very efficient way to find out what the best option is and it will be fairly cheap to do as well since the parts are small and can easily be constructed in a workshop. A prototype is helpful to show if the product is sensible and if the design approach will work (4 p. 248).

3.7.2 Improvement

We plan to fit the fingers with Velcro for quick and easy replacement of the sandpaper.

3.8 Selected concept assembled

In this chapter we have assembled some of our chosen concepts with the help of SWS to see an overview of the system as a whole. Note that this assembly contains mainly the principle/fundamental components that decisions have been made on to move forward with for further development on the completed system. An exploded view of the assembly is also added as it will give an illustration of how the different components are installed.

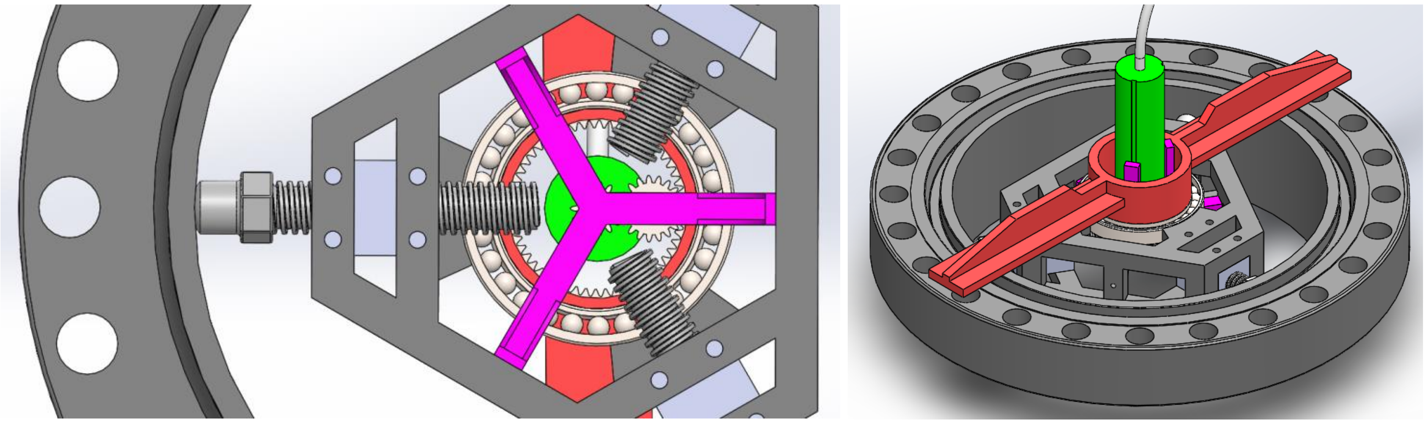


Figure 10 - Assembled concept

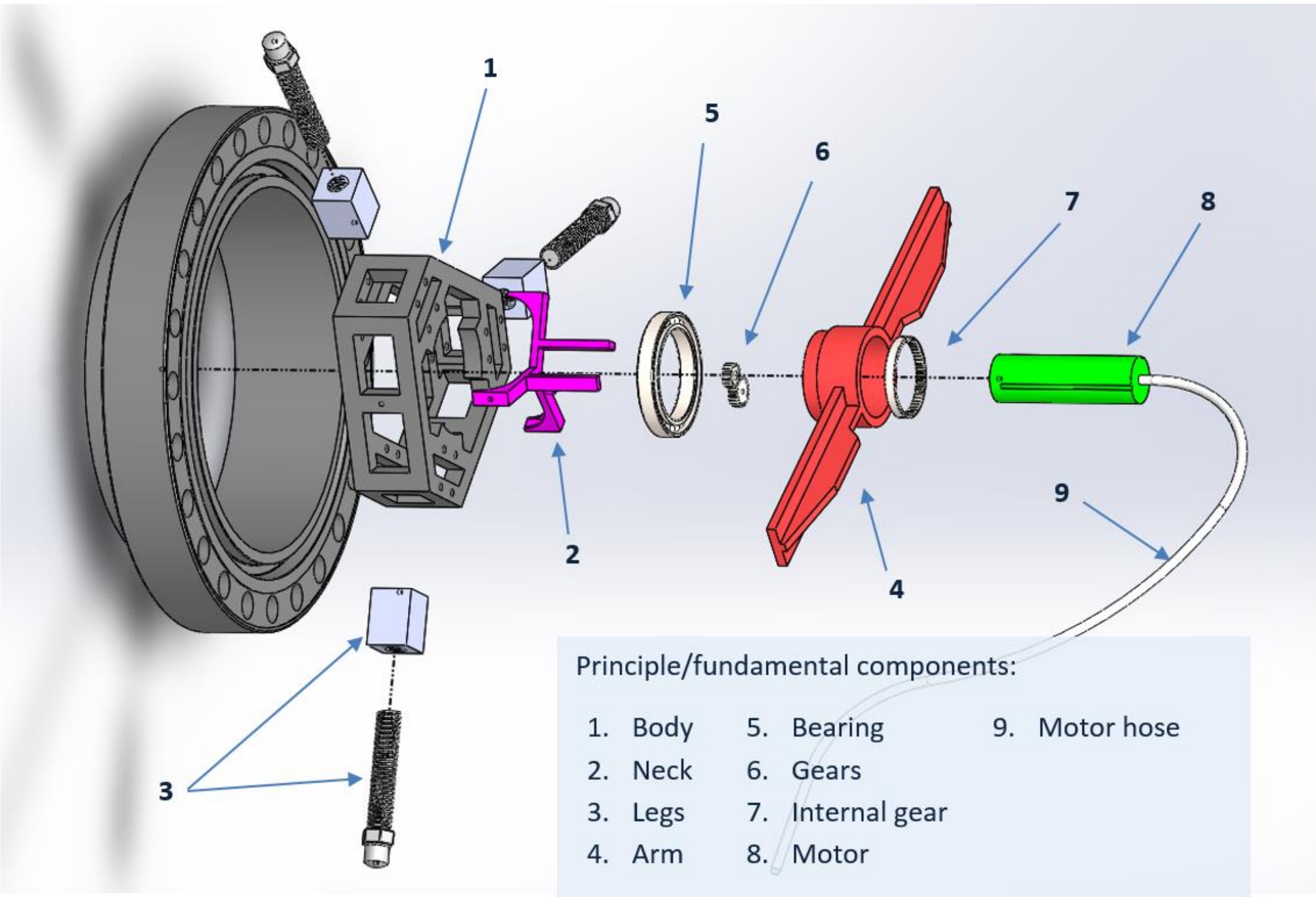


Figure 11 - Exploded view of concept

4.0 Concepts

This chapter will contain a list of all concepts developed.

4.1 Mounting concepts

Name/ID	C_Mount_01	Mounting	Motor	Arm	Polishing	Neck
		Yes	No	No	No	No
Source						
Main components	Base, bolts, bolt housings					
Description	The base is attached to the flange by turning four bolts such that they exert a pressure on the inner wall of the flange.					
Advantages	• Simple design. • Mechanically sound. • Fits several flange sizes.					
Disadvantages	• Limits application for the smaller flange sizes.					
Status	**Selected**	Partially used	Undecided	Discontinued		
Justification	Selected because of the advantages.					

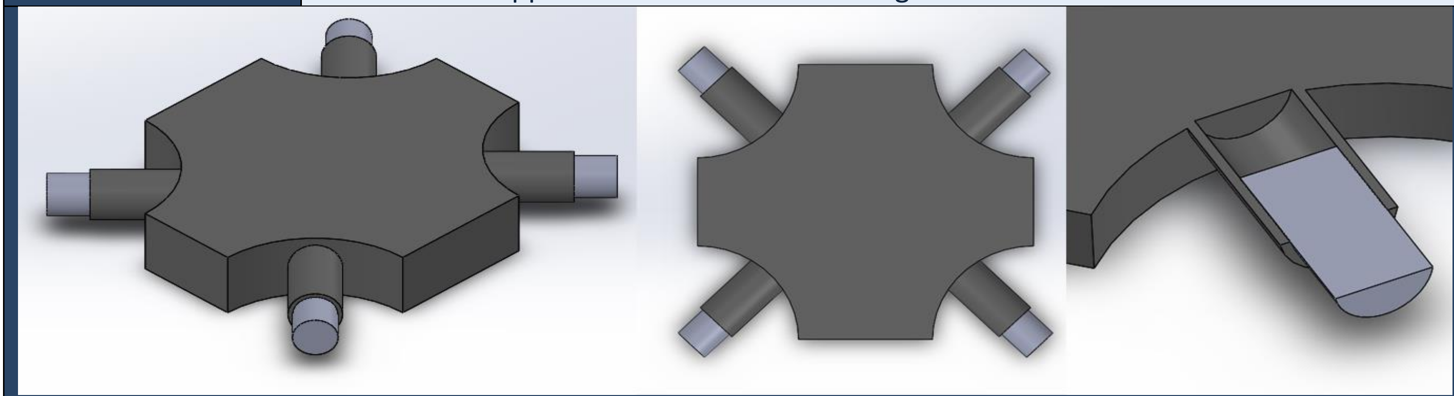


Figure 12 – C_Mount_01

Table 3 - C_Mount_01

NAME/ID	C_MOUNT_02	MOUNTING	MOTOR	ARM	POLISHING	NECK
		Yes	No	No	No	No
SOURCE						
MAIN COMPONENTS	Varying number of legs, keys (purple) and grippers (black). Cylindrical base.					
DESCRIPTION	Three very similar concepts who all share some similar disadvantages. Functions by extending three or four legs towards the inner wall of the flange. This is done by the keyway mechanism that pushes the keys towards each other on each respective leg, causing the grippers to move outwards perpendicular to the cylindrical base.					
ADVANTAGES	• Fits several flange sizes. • Can be easy to mount.					
DISADVANTAGES	• Require at least four legs in order to attain stability. Having four legs is a disadvantage in itself as the construction needs to have low tolerances, or you risk having less pressure on one of the legs which in turn makes the construction unstable. • Will be placed relatively far down into the borehole, which makes the concept impossible to use on flanges with a bend or joint directly beneath it. • There is some uncertainty on how to design this concept further in such a way that every pair of legs moves outwards at the same time and with the same force. It is safe to say that however way we solve it; it will increase the complexity of this already complex system.					

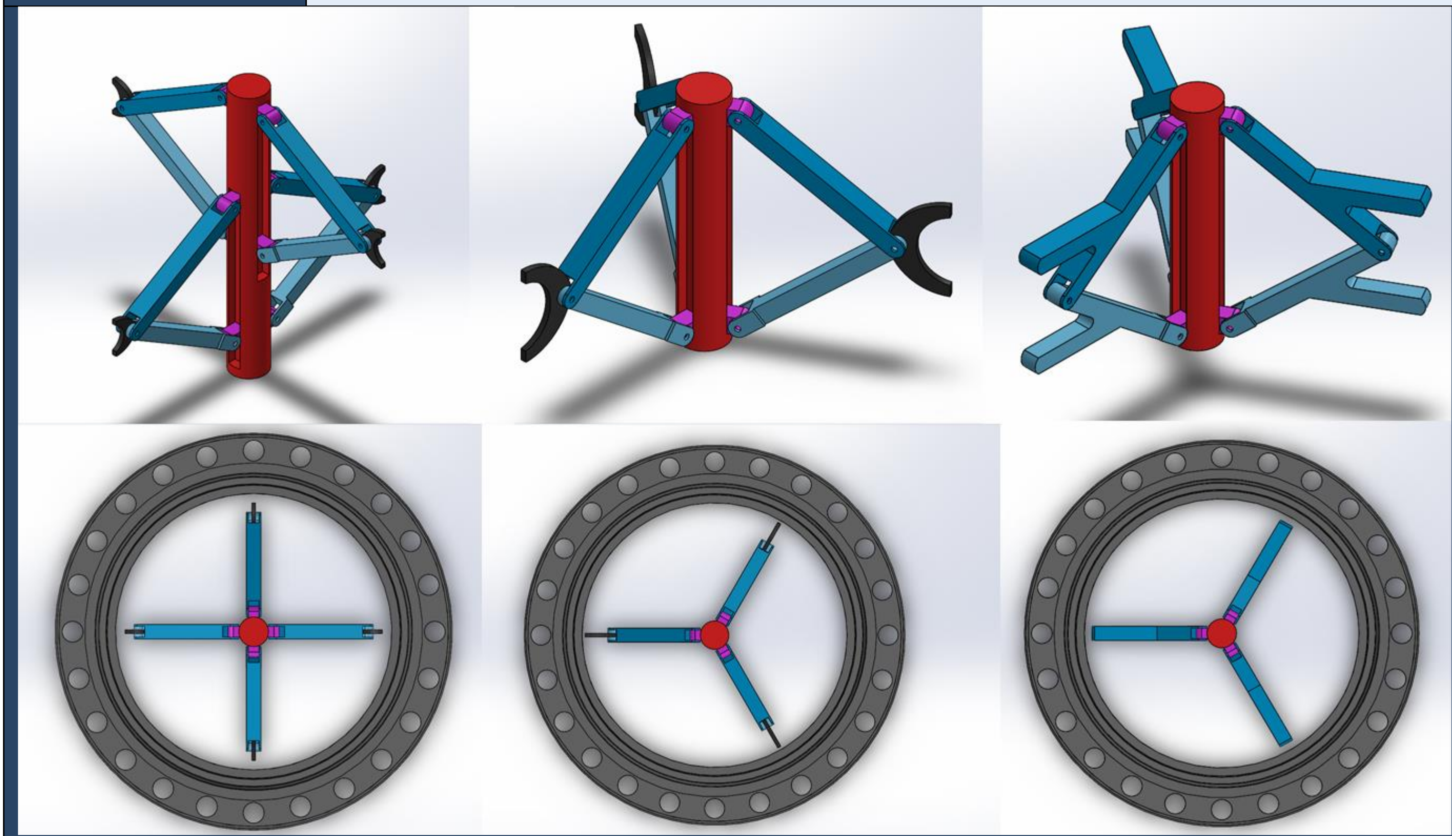


Figure 13 – C_Mount_02

STATUS	Used	Partially used	Undecided	**Discontinued**
JUSTIFICATION	Discontinued because of the disadvantages.			

Table 4 - C_Mount_02

Name/ID	**C_Mount_05**	**Mounting**	**Motor**	**Arm**	**Polishing**	**Neck**
		Yes	No	No	No	No
Source	Rollercoaster					
Main components	Frame with internal gear (blue), arm (red), two spur gears, nuts, motor, belt.					
Description	This concept functions by inserting the frame into the flange using the bolt holes. Nuts are used to secure the frame in place. The motor will be firmly secured to the arm and will drive the two gear by the use of a belt.					
Advantages	• Mechanically sound					
Disadvantages	• Only compatible with one flange size. • Gears that are open to the environment. • Limits the design of the component that polish the environmental seal face.					

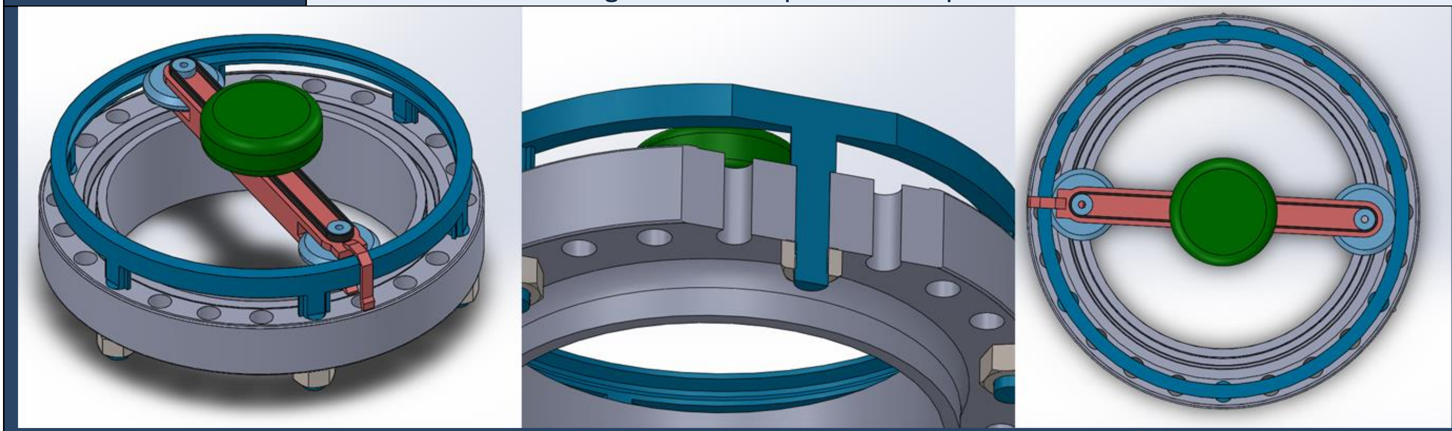


Figure 14 – C_Mount_05

Status	Used	Partially used	Undecided	**Discontinued**
Justification	Discontinued because of the disadvantages.			

Table 5 - C_Mount_05

NAME/ID	C_MOUNT_06	MOUNTING	MOTOR	ARM	POLISHING	NECK
		Yes	No	No	No	No
SOURCE	C_Mount_05					
MAIN COMPONENTS	Ring frame with internal gear (green), three clips (black)					
DESCRIPTION	This concept consists of a ring with an outer diameter that is slightly smaller than the diameter of the inner wall of the flange. The ring will be placed inside the flange and will be made level by using the three clips as shown in the figure. The frame will be attached to the flange using the four bolt holes, where screws will be tightened such that they exert a pressure to the flange. There will be internal gears on the inside of the frame.					
ADVANTAGES	• Very simple • Low weight					
DISADVANTAGES	• Minor deformation of the frame as a result of tightening the bolts, which may result in an uneven polishing of the seal groove. • Gears that are open to the environment. • The clips may damage the heel face.					

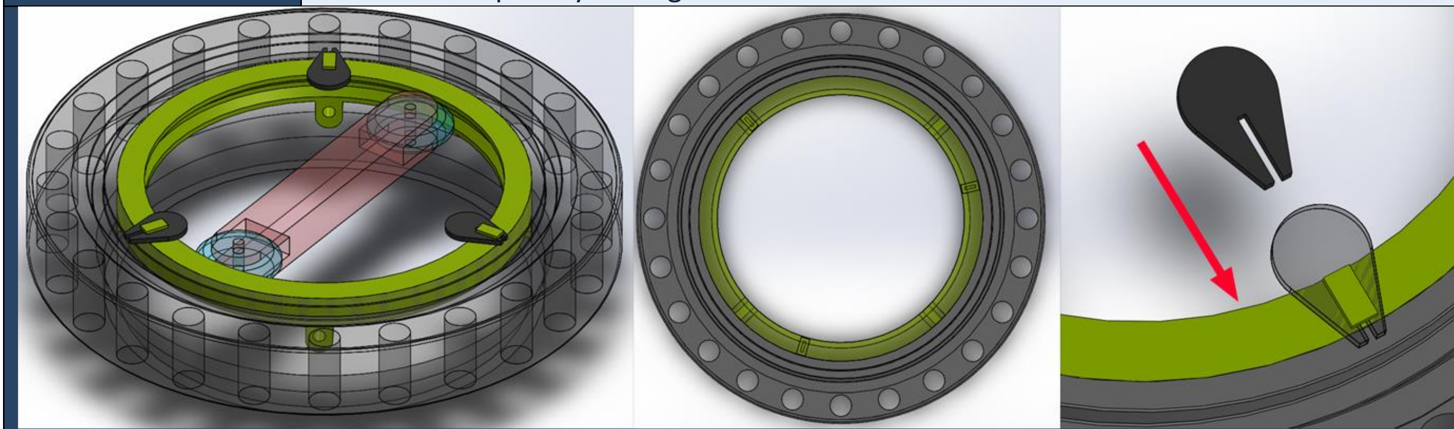


Figure 15 – C_Mount_06

STATUS	Used	Partially used	Undecided	**Discontinued**
JUSTIFICATION	Discontinued because of the disadvantages.			

Table 6 - C_Mount_06

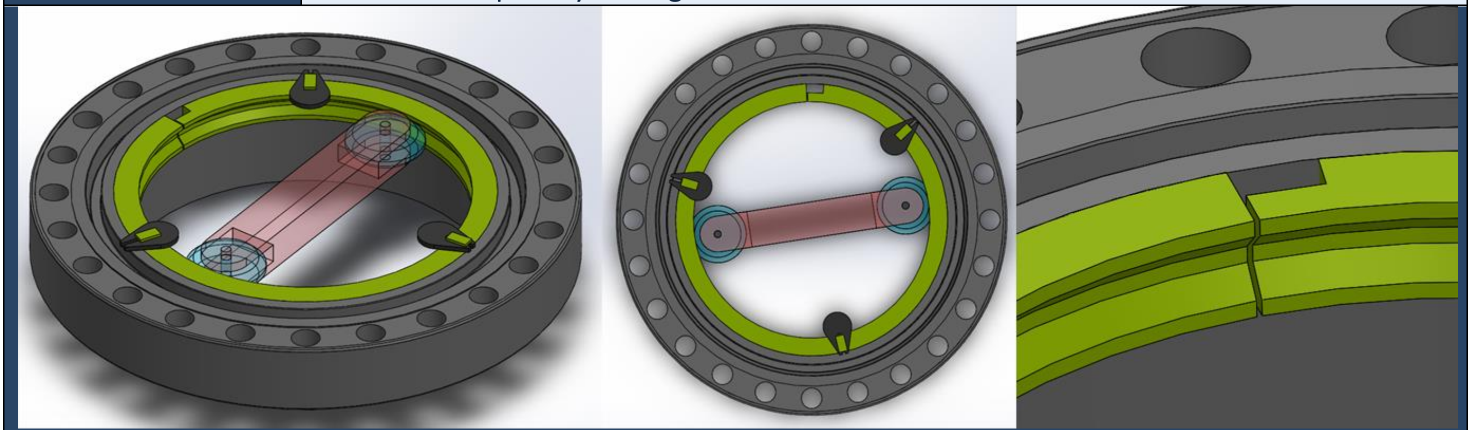
NAME/ID	C_MOUNT_07	MOUNTING	MOTOR	ARM	POLISHING	NECK
		Yes	No	No	No	No
SOURCE	C_Mount_06					
MAIN COMPONENTS	Ring with internal gear (green), three clips (black)					
DESCRIPTION	Functions similar to C_Mount_06. The difference being that the ring is attached to the flange by increasing the gap in the ring through hand threads.					
ADVANTAGES	• Simple • Low weight					
DISADVANTAGES	• Deformation of the ring as a result of the tightening of the bolts, which may result in an uneven polishing of the seal groove. • The gap in the ring will cause issues with the gear mechanism. • Gears that are open to the environment. • The clips may damage the heel face.					
 *Figure 16 – C_Mount_07*						
STATUS	Used	Partially used	Undecided	**Discontinued**		
JUSTIFICATION	Discontinued because of the disadvantages.					

Table 7 - C_Mount_07

NAME/ID	**C_MOUNT_08**	**MOUNTING**	**MOTOR**	**ARM**	**POLISHING**	**NECK**
		Yes	No	Yes	No	No
SOURCE						
MAIN COMPONENTS	Two wheels (black), two solid arms (red), two springs, two rods					
DESCRIPTION	This concept consists of two identical sub-assemblies that each contains a base and a wheel. These two sub-assemblies have a spring between them that exerts a force outward such that pressure is attained between the wheels and the inner flange wall. There are also two rods between them to ensure stiffness. The wheels have a slight angle to provide pressure for the flange sealing surfaces.					
ADVANTAGES	• Easy to mount.					
DISADVANTAGES	• It will be complicated to transfer power from the motor to the wheels. • The wheels may wear down quickly. • Compatible with a limited range of flange sizes.					

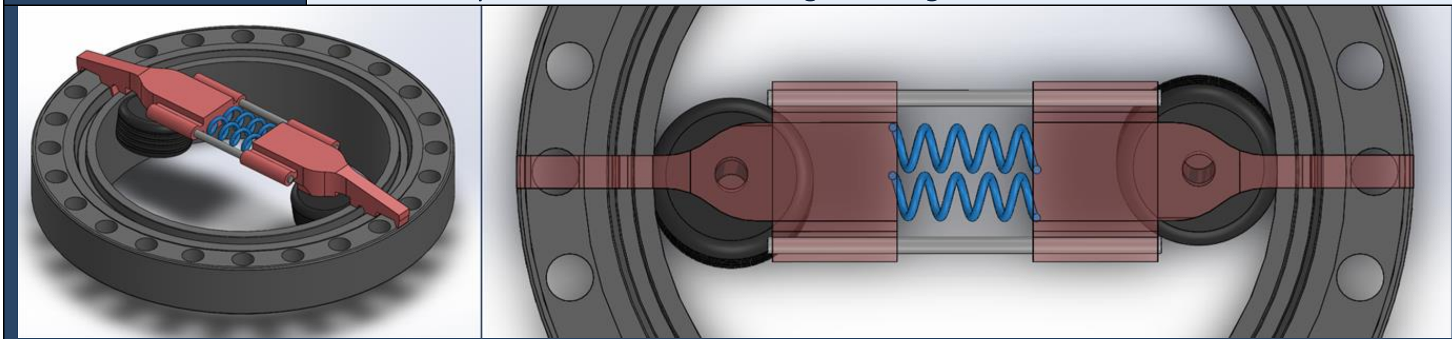


Figure 17 – C_Mount_08

STATUS	Used	Partially used	Undecided	**Discontinued**		
JUSTIFICATION	Discontinued because of the disadvantages.					

Table 8 - C_Mount_08

NAME/ID	C_MOUNT_09	MOUNTING	MOTOR	ARM	POLISHING	NECK
		Yes	No	No	No	No
SOURCE	C_Mount_01					
MAIN COMPONENTS	Four bolts, face gear, four clips (black), casing around gear mechanism (red).					
DESCRIPTION	Similar to C_Mount_01. The difference being that the four legs are connected to a single gear. When the gear is rotated by turning a bolt under the flange base, the four screws will move outwards simultaneously. The clips on the top are used when mounting the tool; to ensure that it is level in relation to the flange.					
ADVANTAGES	• Will fit a certain size range of flanges, and if the screws are made interchangeable; will fit an even larger size range of flanges. • Very easy to mount. Simply by turning a single bolt, the system will automatically become concentric to the flange.					
DISADVANTAGES	• The four bolts need low tolerances lengthwise. • The face gear will be expensive to manufacture.					

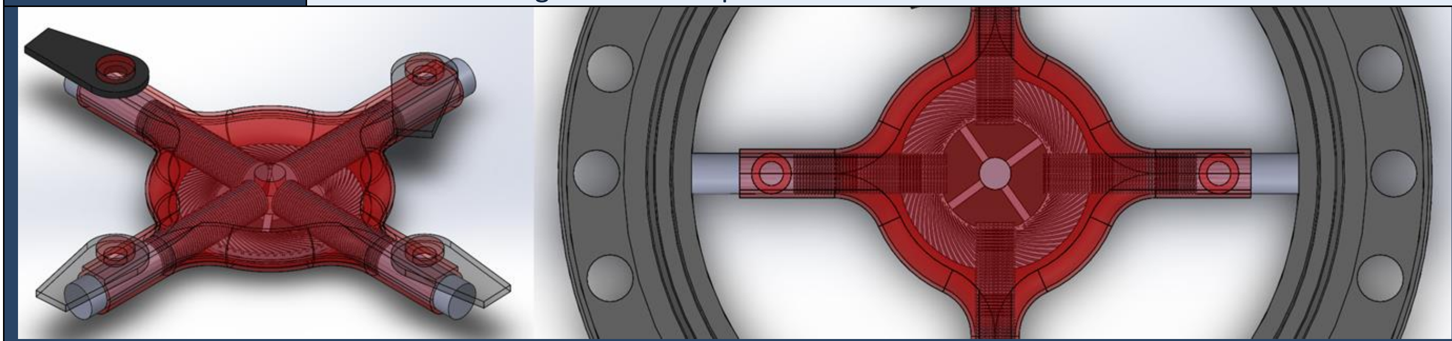


Figure 18 – C_Mount_09

STATUS	Used	Partially used	Undecided	**Discontinued**
JUSTIFICATION	Discontinued because of the disadvantages.			

Table 9 - C_Mount_09

4.2 Neck concepts

Name/ID	C_Neck_01	Mounting	Motor	Arm	Polishing	Neck
		No	No	No	No	Yes
Source						
Main components	Motor mount (purple)					
Description	In this concept, we have a motor mount between the base and the motor that provides it with a resistance point. There is no contact between the arm and the motor mount. The arm is mounted on a roller bearing which is attached to the base. Power is transmitted from the motor to the arm through a gear mechanism.					
Advantages	• The motor is kept stationary, which will simplify the connection with the air hose. • Does not limit the length of the three bolts.					
Disadvantages	• The motor mount is difficult to transport. • Motor is fixed with the motor mount with frictional forces. • Motor is not mounted in the centre.					
Status	Used	Partially used	Undecided	Discontinued		
Justification	We redesigned the concept to fit the motor in the centre of the arm.					

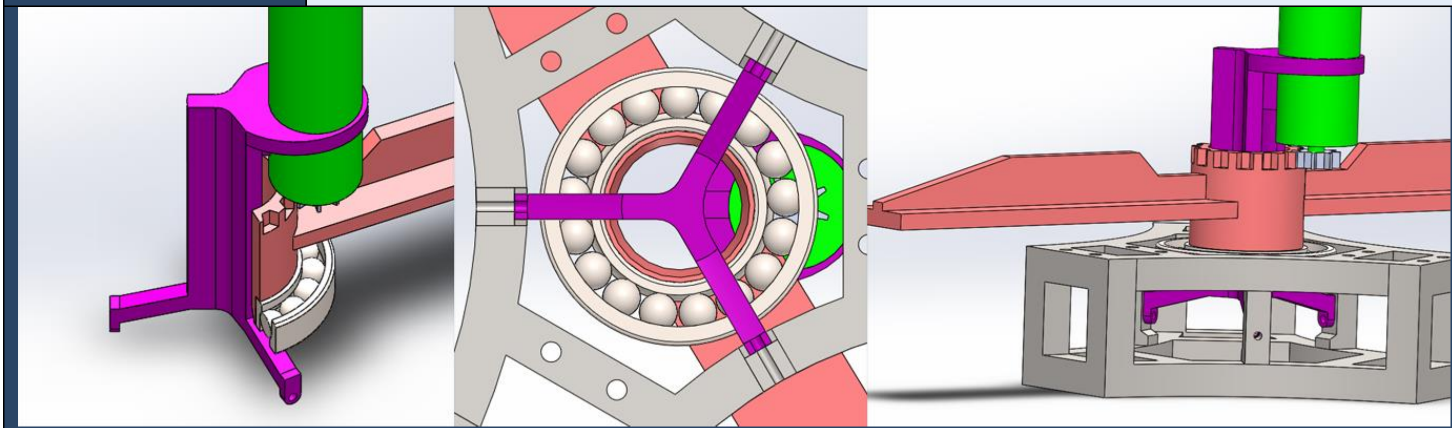


Figure 19 – C_Neck_01

Table 9 - C_Neck_01

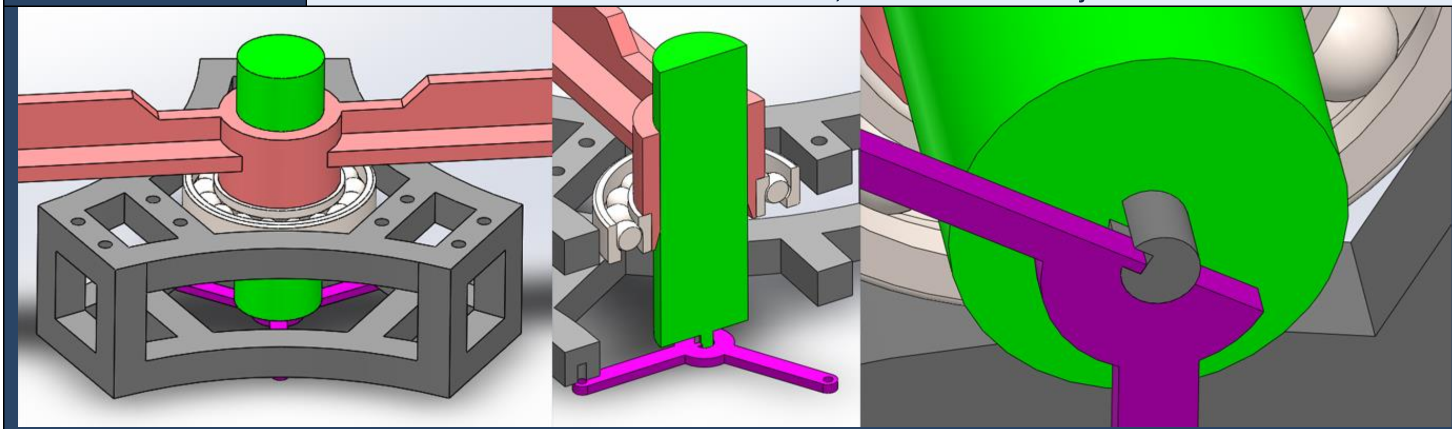
<table>
<tr><td rowspan="2">NAME/ID</td><td rowspan="2">C_NECK_02</td><td>MOUNTING</td><td>MOTOR</td><td>ARM</td><td>POLISHING</td><td>NECK</td></tr>
<tr><td>No</td><td>No</td><td>No</td><td>No</td><td>Yes</td></tr>
<tr><td>SOURCE</td><td colspan="6"></td></tr>
<tr><td>MAIN COMPONENTS</td><td colspan="6">Fixed keyhole for shaft (purple)</td></tr>
<tr><td>DESCRIPTION</td><td colspan="6">In this concept, the arm and the motor shaft are fixed firmly together. The motor shaft is secured on the fixed keyhole component below the base to provide a resistance point for the motor. The arm is attached to a roller bearing which is attached to the base.</td></tr>
<tr><td>ADVANTAGES</td><td colspan="6">Simple solution with few parts. We use the motor itself to give structural stability to the arm.
As the motor is mounted inside the base, we minimize the space used above and around the flange.</td></tr>
<tr><td>DISADVANTAGES</td><td colspan="6">Depending on the diameter of the motor, the length of the bolts will be limited by a certain amount, which means we need a larger number of bolt sizes to accommodate the different flange sizes.
Unconventional use of the motor; the shaft will be stationary while the motor itself rotates.
Since the motor itself will rotate, we need a swivel joint for the air hose.</td></tr>
<tr><td colspan="7">
Figure 20 – C_Neck_02</td></tr>
<tr><td>STATUS</td><td>Used</td><td>Partially used</td><td>Undecided</td><td colspan="3">Discontinued</td></tr>
<tr><td>JUSTIFICATION</td><td colspan="6">Discontinued because of the disadvantages.</td></tr>
</table>

Table 10 - C_Neck_02

NAME/ID	C_NECK_03	MOUNTING	MOTOR	ARM	POLISHING	NECK
		No	No	No	No	Yes
SOURCE						
MAIN COMPONENTS	Fixed motor mounting arm (yellow), two bolts, double washer					
DESCRIPTION	The fixed motor mounting arm is attached through the bolt holes on the flange. Rotation of the motor is halted through frictional resistance with the mounting arm.					
ADVANTAGES	• Simple design					
DISADVANTAGES	• Uses space outside the flange • Arrests rotational motion of the motor by frictional means.					

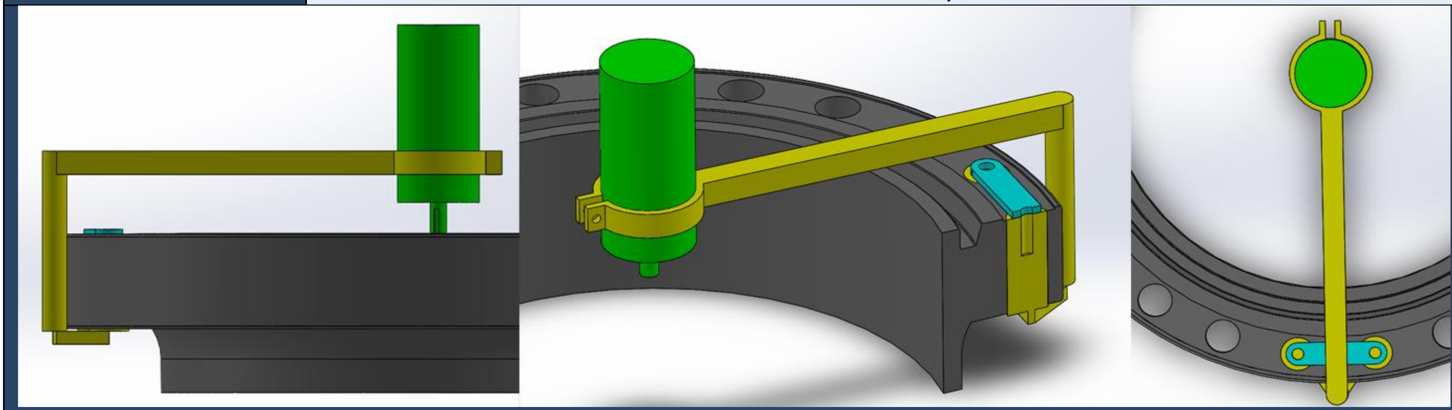


Figure 21 – C_Neck_03

STATUS	Used	Partially used	Undecided	**Discontinued**
JUSTIFICATION	Discontinued because of the disadvantages.			

Table 11 - C_Neck_03

NAME/ID	C_NECK_05	MOUNTING	MOTOR	ARM	POLISHING	NECK
		No	No	No	No	Yes
SOURCE						
MAIN COMPONENTS	Motor mount (purple), two spur gears, internal gear.					
DESCRIPTION	The motor is fastened to the motor mount which itself is fastened to the base. Power is transmitted from the motor to the arm through two spur gears and an internal gear which is fastened to the arm.					
ADVANTAGES	• Fail-safe; hand drill can be used instead of the pneumatic vane motor. • The motor is placed concentric inside the arm allowing greater stability. • Minimizes the amount of space required above the flange. • Gear mechanism allows us to control the speed ratio.					
DISADVANTAGES	• Fragile components are open to the environment.					
STATUS	**Selected**	Partially used	Undecided	Discontinued		
JUSTIFICATION	Selected because of the advantages.					

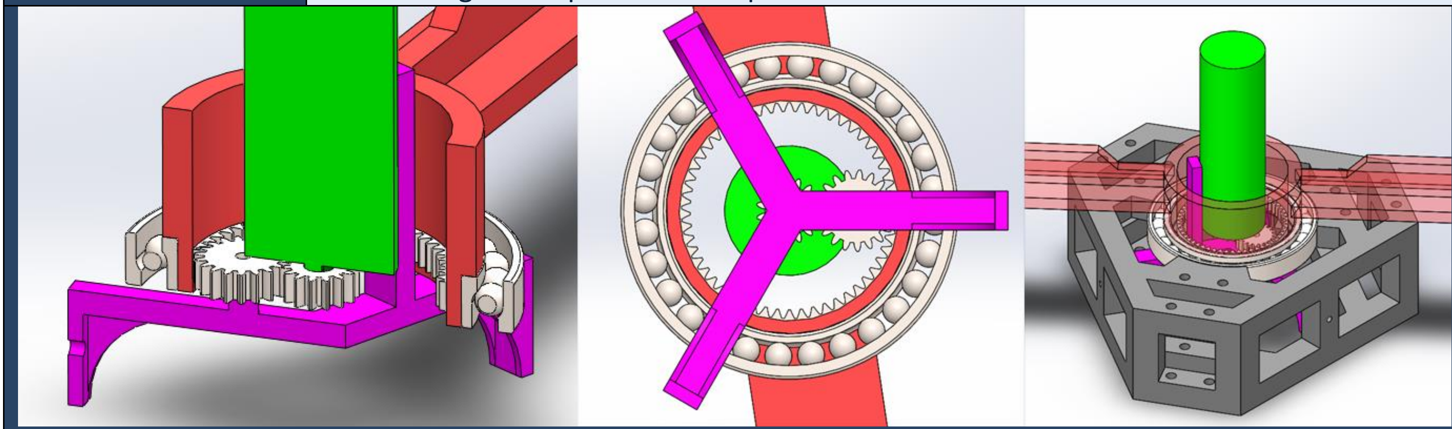


Figure 22 – C_Neck_05

Table 12 - C_Neck_05

4.3 FINGERS FOR SEAL GROOVE

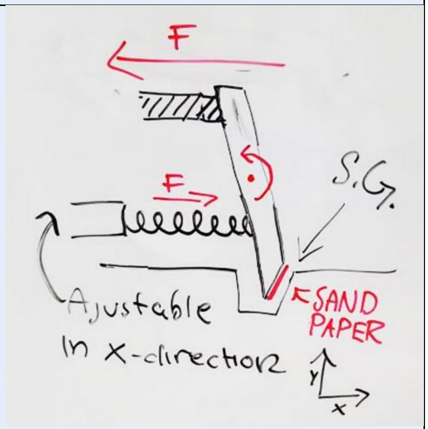
NAME/ID	C_GROOVE_01	MOUNTING	MOTOR	ARM	POLISHING	NECK
		No	No	No	SG	Yes
SOURCE						
MAIN COMPONENTS	Arm, plate head, screws					
DESCRIPTION	The polishing head would be a plate that is connected to the arm - this polishing head would be adjusted by the user, with the help of a screw that is connected to the upper side of the polishing head. When the user decides to adjust the screw, he would then push the lower side of the polishing head to the opposite direction which in turn would be stopped by the spring that is connected to the lower side. This would cause the polishing head to be fixed onto the seal groove seat.	 *Figure 23 – C_Groove_01*				
ADVANTAGES	• Rigid.					
DISADVANTAGES	• Complex.					
STATUS	Selected	**Partially used**	Undecided	Discontinued		
JUSTIFICATION	Morten Hartman (FO&GT) told us something we had discussed earlier that day, which was that this design would be great if we fitted the screw with a spring that would in turn make sure the polishing head would have a better connection with the seal groove seat. Refer to					

Table 13 - C_Groove_01

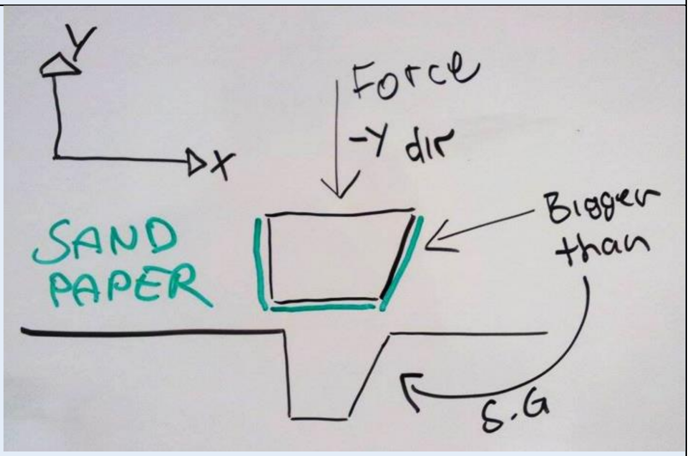
NAME/ID	C_GROOVE_02	MOUNTING	MOTOR	ARM	POLISHING	NECK
		No	No	No	SG	No
SOURCE						
MAIN COMPONENTS	Elastic material, spring, velcro					
DESCRIPTION	The polishing finger is made out of an elastic material covered with a velcro that the sandpaper is attached to. The shape of the head is the same as the trench where the seal groove is located, but slightly bigger. When it is pushed down with a force, it will distribute the force evenly through all of the faces in the groove.  *Figure 24 – C_Groove_02*					
ADVANTAGES	• Cheap					
DISADVANTAGES	• Uncertainty about functionality in reality.					
STATUS	Used	Partially used	**Undecided**	Discontinued		
JUSTIFICATION	If we choose to move forward with this concept we will have to do some 3D-printing and some testing to see if it can work.					

Table 14 - C_Groove_02

NAME/ID	C_GROOVE_03	MOUNTING	MOTOR	ARM	POLISHING	NECK
		No	No	No	SG	No
SOURCE						
MAIN COMPONENTS	Arm, finger, spring, finger holder, hinge (purple)					
DESCRIPTION	In this concept, the finger is part of the arm. The spring applies a force onto the flanges seal groove. The hinge is self-aligned, so in theory it will adjust itself to the correct angle.					
ADVANTAGES	• Ease of force measurement.					
DISADVANTAGES	• Limitations to arm functionalities & dimensions/ dependant of arm. • Occupy space required by heel face finger. • Functional uncertainty to smaller parts in harsh environments.					

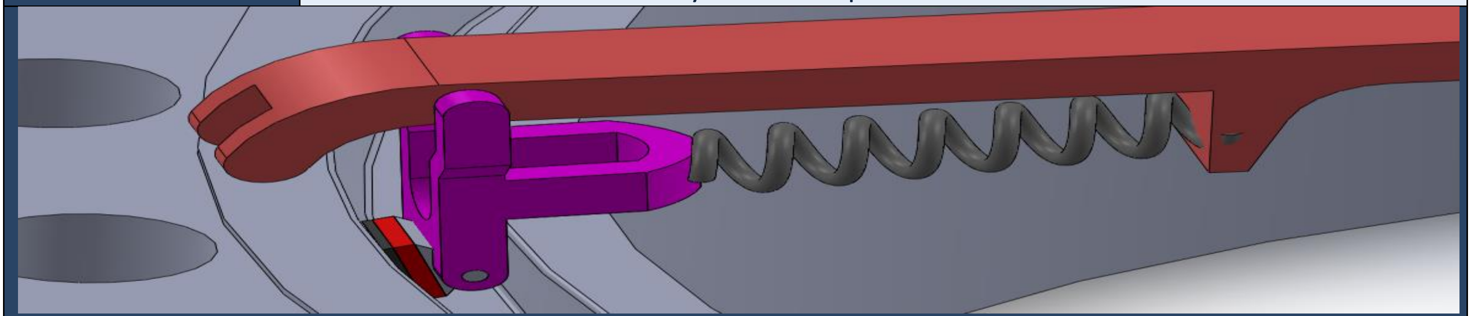


Figure 25 – C_Groove_03

STATUS	Used	Partially used	**Undecided**	Discontinued
JUSTIFICATION	Requires further detail elaboration to make an accurate assessment.			

Table 15 - C_Groove_03

NAME/ID	C_GROOVE_04	MOUNTING	MOTOR	ARM	POLISHING	NECK
		No	No	No	SG	No
SOURCE	Clothespin					
MAIN COMPONENTS	Torque spring, polishing finger					
DESCRIPTION	The idea here is to use a torque spring which is connected to a polishing finger in one end, and the arm in the other. This will apply a force onto the seal groove.					
ADVANTAGES	• Cheap. • Simple. • Independent of arm.					
DISADVANTAGES	• Surface pressure. • Cannot measure force. • The lifespan of this solution might be short • The force distribution will not be even on the surface if the alignment is incorrect.					

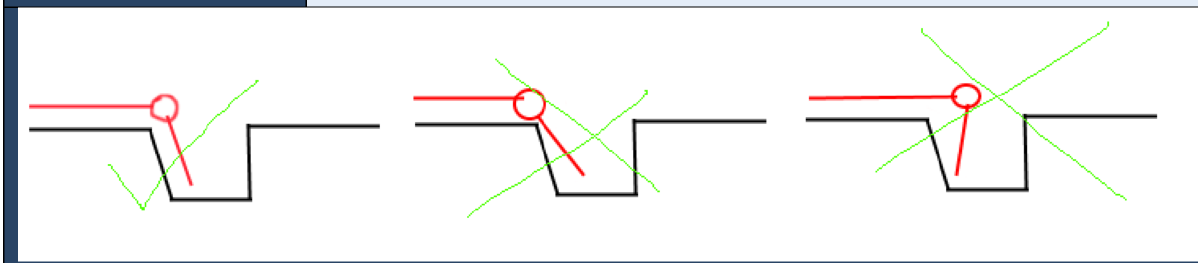


Figure 27 – Consequences of incorrect alignment of torque spring

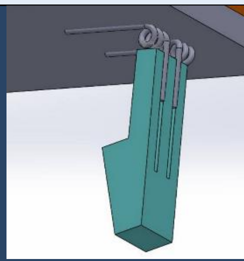


Figure 26 – C_Groove_04

STATUS	Used	Partially used	**Undecided**	Discontinued
JUSTIFICATION	Requires further elaboration and testing.			

Table 16 - C_Groove_04

4.4 Flange face concepts

Name/ID	C_Face_01	Mounting	Motor	Arm	Polishing	Neck
		No	No	No	HS, MS, ES	No
Source	Spider					
Main components	Finger (black), spring, arm (red), finger arm (blue)					
Description	This concept is part of a rigid/stiff arm, and consists of 3 identical twin finger arms for each surface. When polishing each surface, the spring that is connected between each twin finger arm will then make sure that the right pressure is being applied, causing an even polish of the surfaces.					
Advantages	• Rigid. • Faster polishing as there are two polishing fingers for each surface. • Polishes three surfaces simultaneously and independently.					
Disadvantages	• Complex. • Multiple moving parts. • Not user friendly. • Higher maintenance requirements. • Springs limit integration with seal groove finger on the same side of the arm.					

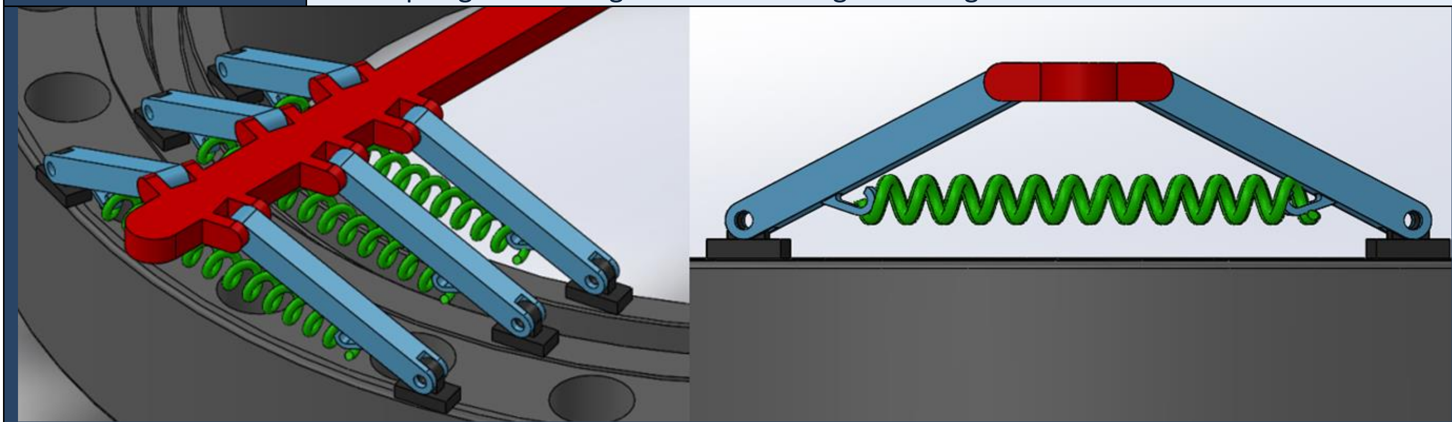


Figure 28 – C_Face_01

Status	Used	Partially used	Undecided	**Discontinued**		
Justification	Discontinued because of the disadvantages.					

Table 17 - C_Face_01

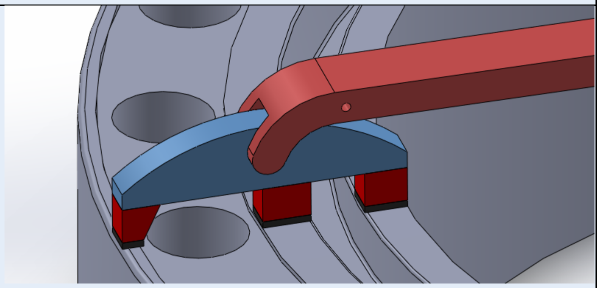
NAME/ID	C_FACE_02	MOUNTING	MOTOR	ARM	POLISHING	NECK
		No	No	Yes	HS, MS, ES	No
SOURCE	Washing mop					
MAIN COMPONENTS	Polishing fingers, arm					
DESCRIPTION	The polishing will be performed by having the different polishing fingers for the flange sealing surfaces connected to one part which will exert a downward force onto the fingers.	 *Figure 29 – C_Face_02*				
ADVANTAGES	• Rigid.					
DISADVANTAGES	• Uneven surface pressure. • Issues with dimensional control.					
STATUS	Used	Partially used	**Undecided**	Discontinued		
JUSTIFICATION	Requires further elaboration and testing.					

Table 19 - C_Face_02

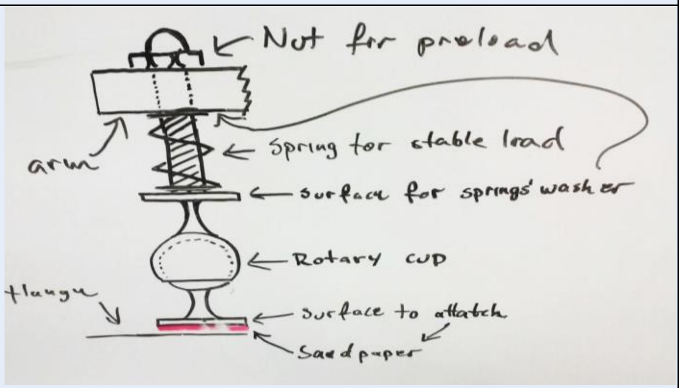
NAME/ID	C_FACE_03	MOUNTING	MOTOR	ARM	POLISHING	NECK
		No	No	No	HS, MS, ES	No
SOURCE						
MAIN COMPONENTS	Gimbal, spring, piston					
DESCRIPTION	This is a concept for the polishing finger for the three faces. The way it works is that a pin with a shell is attached through and has a spring that applies a force from the sub-system to the flanges' face. The rotary cup is for achieving a self-adjustable and even surface pressure between the sandpaper and the face.	 *Figure 30 – C_Face_03*				
ADVANTAGES	• Self-aligning. • Easy to measure force. • Even surface pressure.					
DISADVANTAGES	• Complex. • Not environmentally friendly (with the thought of dusts). • Fragile components are open to the environment.					
STATUS	Used	Partially used	Undecided	**Discontinued**		
JUSTIFICATION	The reason why we have chosen not to move forward with this concept is because it is not suitable for harsh working environments.					

Table 18 - C_Face_03

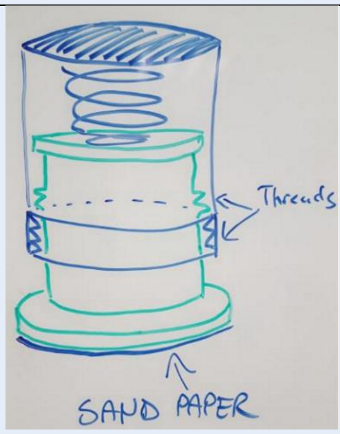
NAME/ID	C_FACE_04	MOUNTING	MOTOR	ARM	POLISHING	NECK
		No	No	No	HS, MS, ES	No
SOURCE						
MAIN COMPONENTS	Spring, polishing finger, bushing					
DESCRIPTION	The flange sealing surfaces will be polished by the use of a spring that has an attached polishing finger which will be fastened by the bushing. The placement of this polishing finger for the flange sealing surfaces would be on the arm socket, where it would be screwed into place. The polishing finger will exhibit a linear downward force onto the sealing surface.	 *Figure 31 – C_Face_04*				
ADVANTAGES	• Allows the force to be modified. • Does not restrict design of arm. • Sufficient and even surface pressure applied to the sealing surfaces. • Easy to dismount.					
DISADVANTAGES	• None identified so far.					
STATUS	Used	Partially used	**Undecided**	Discontinued		
JUSTIFICATION	Requires further elaboration and testing.					

Table 19 - C_Face_04

5.0 CONCLUSION

The tool we have designed is made with respect to flexibility. This means that we have designed it in such a way that it will be compatible with a wide range of SPO CF flanges, and not only the 16'' that we were assigned to design for. It is an internal machine that is to be installed inside the flange in such a way that it does not take up more space than it actually needs.

We have chosen to drive the system with compressed air, with a hand-driven option in case of emergencies such as malfunctioning of the pneumatic motor. The tool is design such that it is easy to clean and maintain as well. We have also used as few fragile parts as possible. The few fragile parts we have used will be “off the shelf” and physically small, therefore, it will be easy to bring an extra set of spares.

It is also designed in such a way that it can easily be assembled and disassembled from the flange.

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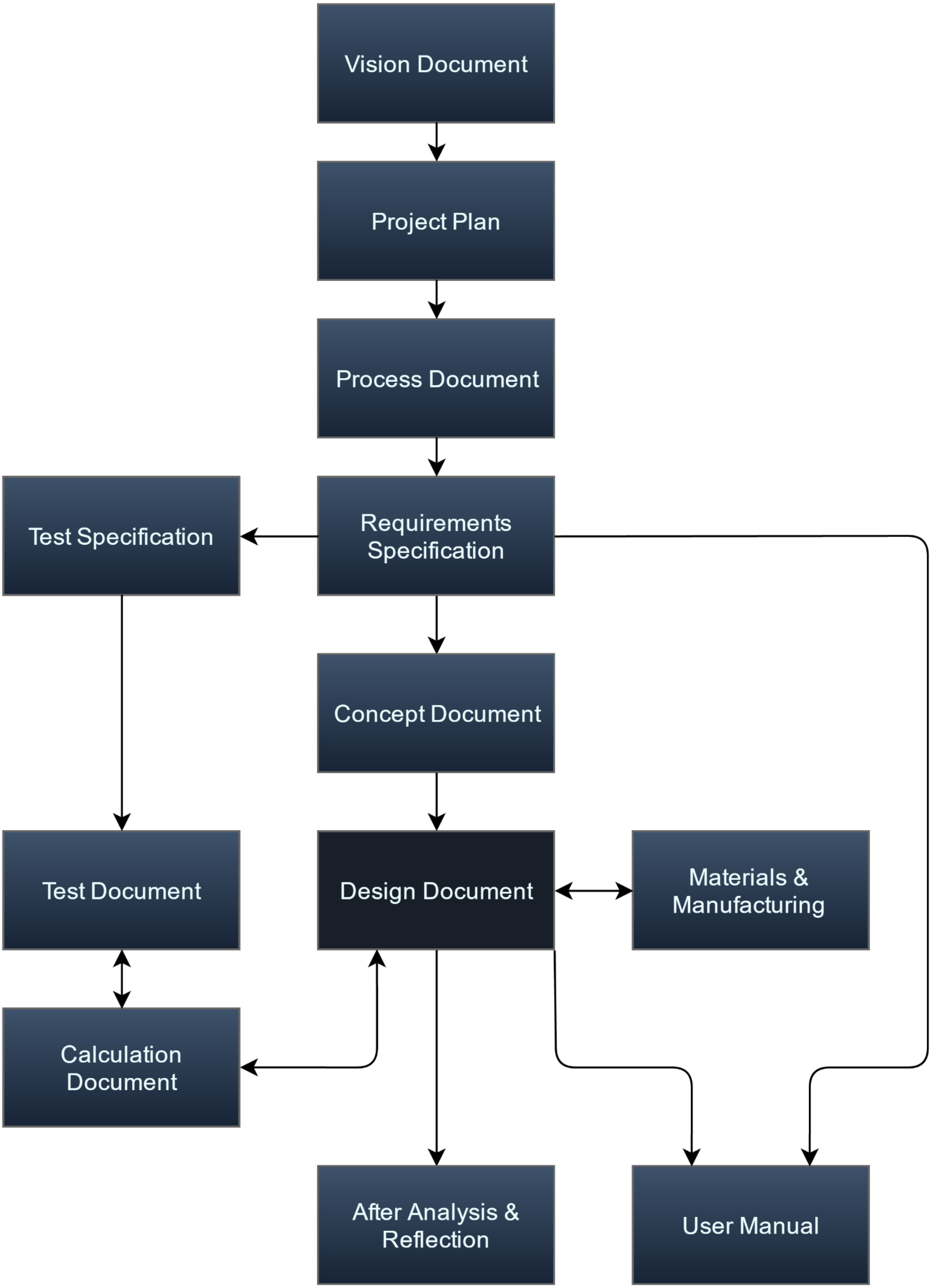
Vision Document
Project Plan
Process Document
Test Specification
Requirements Specification
Concept Document
Test Document
Design Document
Materials & Manufacturing
Calculation Document
After Analysis & Reflection
User Manual

Design Document

Freudenberg Bachelor 2016

SPO CF Seat polishing tool

Arian Krasniqi, Richelieu Dahn, Odd Eirik Hardem, Morten Grøsfjeld

Version	Document number	Date	Responsible	Status
1.0	007	22.05.2016	All	Finalized

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1.0 Document

1.1 Document history

Version	Date	Changes
0.1	31.03.2016	Document created
0.2	08.04.2016	• Document content outline defined • Added 5.2 *"Friction"* • Added 3.2 *"Legs"* • Added 3.3 *"Neck"*
0.3	12.04.2016	• Added 3.1 *"Body"* • Added 4.3 *"Bearing"*
0.4	16.04.2016	• Added 4.1 *"Motor"* • Added 3.4 *"Arm"*
0.5	25.04.2016	• Reviewed
1.0	22.05.2016	• Finalized

Table 1 - Document history

1.2 Definition of abbreviations

Abbreviation	Definition
ATEX	ATmosphères EXplosibles
CF	Compact Flange
CNC	Computer Numerically Controlled
DSS	Duplex Stainless Steel
Env.	Environmental
FHCS	Flat Head Cap Screws
FO&GT	Freudenberg Oil & Gas Technologies
HM	Heel and Midsection
HME	Heel, Midsection and Environmental
NA	Not Applicable
OTSC	Off The Shelf Components
RPM	Revolutions Per Minute
SG	Seal Groove
SHCS	Socket Head Cap Screw
SHSS	Socket Head Shoulder Screw
SKF	Svenske KullagerFabriken (Swedish Bearing Manufacturer)
SPO	FO&GT brand name for compact flanges (Steel Products Offshore)

Table 2 - Definition of abbreviations

1.3 Introduction

The design of our system has changed with a varying degree almost every day. Our agile project model allows frequent changes during the design process and instead of looking at changes because of poor planning; we look at changes as step-by-step improvement of the product.

Our design consists of multiple smart solutions that the team has come up with during the design stage. All these solutions have been approved by FO&GT. It has been very important for the team to constantly update FO&GT with our solutions. This is because the feedback we get from FO&GT is the best feedback we can get. Another reason is that FO&GT is our customer and we want our customer to be satisfied with the product. With the constant communication with FO&GT, we know if we are on the right track or not.

1.4 Scope

This document covers every detail of the design process and the design outcome. Development paths with illustrations shows how different components have evolved from the initial concept to its final design. Every selection and decision about the machine is justified, and every single component has been through FEM-analysis and/or hand calculations to assure their accordance to relevant regulations.

2.0 SPO CF SEAT POLISHING TOOL

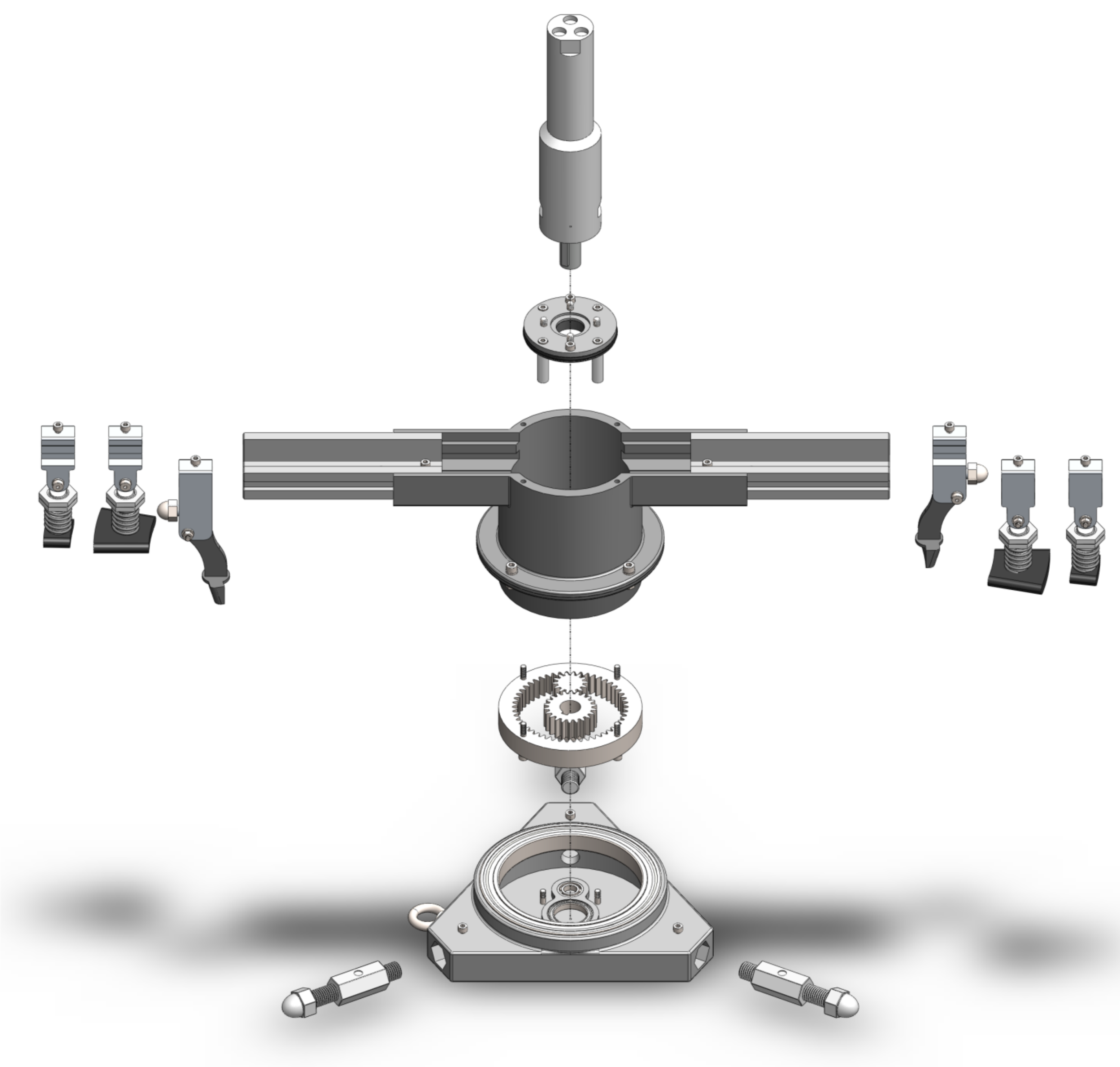

Figure 1 - Exploded view of system.

2.2 PROPERTIES OF SYSTEM

The system makes it possible to polish three different flange sizes; 14”, 16” and 18” CF. All four sealing surfaces can be polished simultaneously, and with two polishing heads for each surface, the process will be both quick and accurate. To ensure a long service life, all parts in the system are made out of high quality corrosion resistant materials. And even though most of the machine is made out of steel, it is still light enough to be checked into a normal commercial airline for easy transportation.

2.1 List of system components

ID	Name	Standard	N	Dim	Material	OTSC
L	Leg sub-system					
L-01	Cap nut	DIN 917	3	M16	F53	No
L-02	Threaded Rod	DIN 975	3	M16	F53	No
L-03	Joining nut	DIN 926	3	M16	F53	No
B	Body sub-system					
B-02	Eye bolt	ISO 3266	1	M8	A2-70	Yes
N	Neck sub-system					
N-01	Motor flange	-	1	-	F53	No
N-02	Gear cover	-	1	-	F53	No
N-03	Pillar	-	4	-	F53	No
A	Arm sub-system					
A-01	Inner arm	-	2	-	F53	No
A-02	Outer arm	-	2	-	F53	No
A-02-01	Outer arm side	-	4	-	F53	No
A-02-02	Outer arm bottom	-	2	-	F53	No
A-03	Top cylinder	-	1	-	F53	No
A-04	Arm flange	-	2	-	F53	No
A-05	Lower cylinder	-	1	-	F53	No
A-06	Arm cap	-	1	-	F53	No
F	Finger sub-system					
F-SG-01	SG Polishing finger	-	2	-	F53	No
F-SG-02	SG Spring	-	2		SS 302	Yes
F-SG-03	SG Sliding connector	-	2	-	F53	No
F-HM-01	HM Bracket	-	2	-	F53	No
F-HME-01	HME Finger rod	-	4	-	F53	No
F-HME-02	HME Sliding connector	-	4	-	F53	No
F-E-01	Env. Bracket	-	2	-	F53	No
D	Mounting dolly					
D-01	Handle	-	1	-	F53	No
D-02	Sliding rod	-	2	-	F53	No
D-03	Expansion sleeve		2	-	F53	Yes
M	Miscellaneous					
M-01	Motor	-	1	-	Stainless	Yes
M-02	Valve	-	1	-	Stainless	Yes
O-S	OTSC Seals					
O-S-01	O-Ring	ISO 3601	1	-	N70/6052	Yes
O-S-02	V-Ring	-	1	-	Nitrite Rubber	Yes
O-B	OTSC Bearings					
O-B-01	Driver	ISO 281	1	-	683-17	Yes
O-B-02	Idler	ISO 281	1	-	683-17	Yes
O-B-03	Inner	ISO 281	1	-	683-17	Yes
O-B-04	Outer	ISO 281	1	-	683-17	Yes

O-N	**OTSC Nuts**					
O-N-01	Hex for SHSS	ISO 4762	6	M5	A2-70	Yes
O-N-02	Hex for HME Finger rod	ISO 4762	8	M10	A2-70	Yes
O-N-03	SG Cap nut	DIN 917	2	M10	A2-70	Yes
O-W	**OTSC Washers**					
O-W-01	Flat washer	ISO 7089	6	M5	A2-70	Yes
O-W-02	Flat washer	ISO 7089	33	M6	A2-70	Yes
O-G	**OTSC Gears**					
O-G-01	Driver	DIN 3962	1	-	SS 304	Yes
O-G-02	Idler	DIN 3962	1	-	SS 304	Yes
O-G-03	Internal	JIS B1702-1	1	-	SS 304	Yes
O-Z	**OTSC Springs**					
O-Z-01	SG	ISO 11891:2012	2	-	SS 302	Yes
O-Z-02	HM	ISO 11891:2012	2	-	SS 302	Yes
O-Z-03	Env.	ISO 11891:2012	2	-	SS 302	Yes
O-F	**OTSC Bolts**					
O-F-01	SHSS	ISO 7379	6	M5	A2-70	Yes
O-F-02	LHCS	ISO 262	4	M5	A2-70	Yes
O-F-03	SHCS	ISO 4762	33	M5	A2-70	Yes
O-F-04	DEPRAG	-	4	M6	A2-70	Yes
O-F-05	SHCS	ISO 4762	2	M20	A2-70	Yes

Table 3 - List of system components.

3.0 Sub-systems of the SPO CF seat polishing tool

The process of technical product design involves developing it from the requirements and specifications from FO&GT. The feedback received from stakeholder meetings with FO&GT have been very useful to us throughout the development of the system. The following points must be followed, regardless of what is to be developed, these points state that (1 p. 1.2):

- You must be able to talk with the stakeholders, listen, perceive the problems and see technical solutions
- You must be able to sketch, know the rules for technical drawing, and be able to use digital modelling tools
- You must have good knowledge about materials and the production processes that are used in the industry
- You must be able to do strength calculation on constructions and machine components
- You must have knowledge about common machine parts such as screws, nuts, shafts, bearings, springs and seals
- You must be able to construct safe and reliable control systems
- You must be academically sufficient so that you can communicate with other professionals and associate you with expertise when necessary
- You must be able to document your work

However, as constructors when designing a product (whether completely new or an updated version), a lot of things have to be taken into consideration. One of these things require that the product has to be designed such that it can withstand all of the forces that are exerted on it. Therefore, all components in our system have to be designed in such a way that plastic deformation or fracture is avoided (1 p. 1.3).

- Which loads will the system be exposed to?
- What is the load impact on each part of the system?
- Which stresses it causes in each part?
- How much stresses can the chosen material withstand before it is deformed?

To answer all of these questions, we would then need to use our knowledge gained within the most important fundamental for construction and strength calculations; mechanics, which is all about static and strength of material. The "*static*" section of mechanic focuses on the external forces that are acting on each component, and the impact that these forces have on it (1 p. 1.3).

3.1 Body

The primary function of the body sub-system is to act as a foundation to mount all other sub-systems and components. As a result of this, its shape is greatly influenced by the rest of the system, while retaining sufficient strength and rigidity.

3.1.1 Design

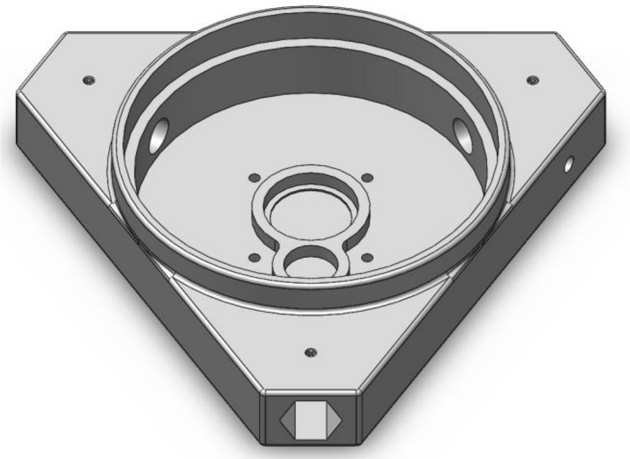

Figure 2 - Isometric view of body.

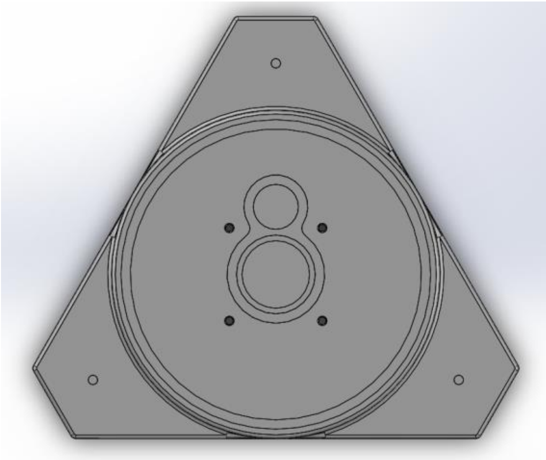

Figure 3 - Top view of body.

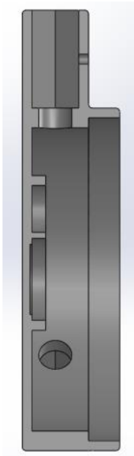

Figure 4 - Section view of body.

#	Description
1	Screw hole (1) for securing the leg sub-system
2	Screw hole (2) for securing the neck sub-system
3	Bearing seat driver
4	Bearing seat idler
5	Bearing seat outer
6	Leg socket
7	Leg borehole
8	Screw hole (3) for eye bolt

Table 4 - Description for Figure X

The body is designed with a triangular shape to serve its purpose optimally, given the number of legs used in the system. The cylindrical cut in the centre contain the bearings, gear train and the neck sub-system.

In order to easily place the body concentrically inside the flange, the polishing tool is designed to have three anchoring points rather than four, which was in our initial design. Three anchoring points serve the same purpose as four, while also decreasing the mass of the system, and making installation easier.

The body contain three sockets for the legs M16 joining nuts, following with leg borehole of the inner wall of the body`s cylindrical cut. The leg sockets allow the M16 joining nuts to be inserted into the body before they are mounted onto it. However, the diameters of the *leg borehole* are larger than that of the actual legs diameters (M16 screws). These *leg sockets* are not meant to serve as a grip point for the legs, but rather enable them to move freely along the radial direction, while not interfering with other components like the bearings that will be placed into the cylindrical cut.

3.2 Legs

3.2.1 Assembly

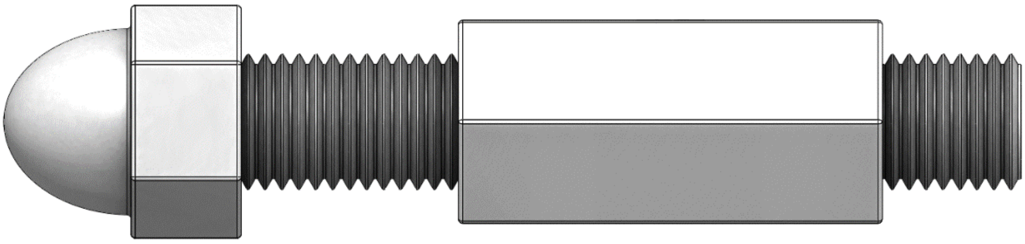

Figure 5 - Side view of leg sub-system.

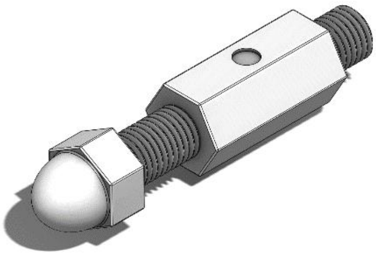

Figure 6 - Isometric view of leg sub-system.

Name	ID	Standard	Material	Dimension	OTSC
Cap Nut	L-01	DIN 917	Super DSS F53	M16	No
Threaded Rod	L-02	DIN 975	Super DSS F53	M16x110mm	No
Joining Nut	L-03	DIN 926	Super DSS F53	M16x50mm	No

Table 5 - List of components of leg sub-system.

We have chosen to use the same material for all three components of the legs. Keeping in mind that it is desired that the tools is functional with a range of flanges, we have designed them such as one trio of legs can be used for multiple flanges.

3.2.3 Cap Nut

Function: Contact point for the leg to the inner wall of the flange. In addition, this part will be in contact with a wrench when the system is attached to the flange.

We chose to use a blunt shape rather than a pointed edge on the cap nut. The blunt shape will have a longer life than a pointy one because the material will not wear out as fast. This is proved in a FEM-analysis that show that the stress concentration is higher on the pointed shape than it is on the blunt.

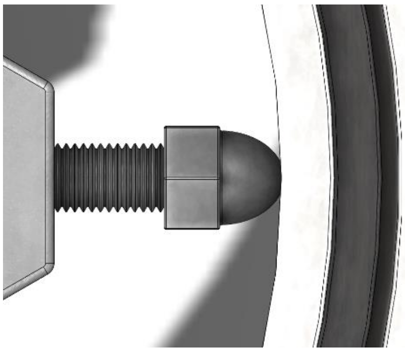

Figure 7 - Cap nut in contact with the inner wall of the flange.

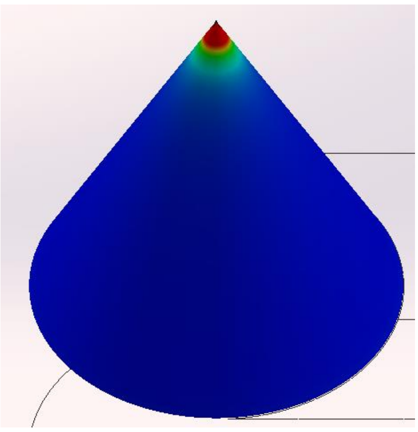

Figure 8 – Pointed edge.

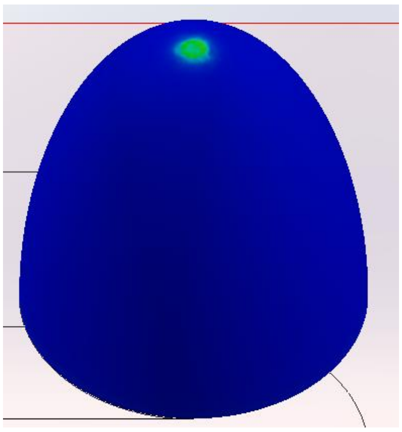

Figure 9 – Blunt edge.

Surface roughness

The cap nut will be in direct contact with the inner wall of the flange. Therefore, the surface roughness is important because we want a high coefficient of friction µ between the two faces.

It is a standard procedure for FO&GT to clean the inside of the flanges before refurbishing them (2). We can therefore assume that both surfaces are clean, and use the coefficient of friction µ for dry condition, which in most cases are higher than wet conditions. The µ for steel in dry, clean conditions is 0.5 µ - 0.8 µ according to The Engineering Toolbox (3)

The calculation of this preload can be viewed in detail in the calculation document (4 pp. C-16). In this document you can see that the necessary tension between the two surfaces is 410 N. Corresponding torque is 6.6Nm

3.2.4 Threaded Rod

Function: Adjust the working diameter of the system

Material Quality

The yield strength is not the dimensioning factor for this part since the average shear force on the rod has been calculated to be 0.99 MPa (4 pp. C-21). Therefore, we may conclude that there is no danger for any plastic deformation because of the share force in the rod.

In theory, the steel quality is irrelevant. However, we still recommend a high quality steel. This is because the rod will be used and worn. The threads are the most fragile part of the rod and can easily be damaged which can cause a sub-system malfunction. This is another reason why we have selected F53 as material.

However, the system has to be rigid and therefore we need to calculate for displacement. We have allowed ourselves a displacement of maximum 1 mm (2) when the total applied force in the axial direction of the flange is 300 N.

M:	Displacement
14	0,611 mm
16	0,358 mm
18	0,224 mm

Table 6 - Displacement of different rod dimensions.

Calculations show that with a 16mm F53 rod we will achieve a displacement of 0,358mm (4 pp. C-16) which is acceptable. Other dimension of the steel rod and the corresponding displacement with the given load can be seen in Table 6.

3.2.5 Joining Nut

Function: Act as a contact point for the threaded rod. The joining nut will be fixed in the body.

The joining nut is inserted into the frame and secured by a case to prevent it sliding in a radial direction. The hexagon shape ensures a good distribution of the forces from the screw onto the body.

The joining nut is fitted with a small borehole in order to avoid problems caused by plastic deformation from the hole 1 (Figure 2)

3.3 Neck

The primary function of the neck is to act as a platform in which the motor can be mounted and dismounted, without compromising the sealed gear train area. It must be rigid enough to provide a reaction point for the torque of the motor, and it cannot obstruct the gear train.

3.3.1 Development


Figure 10 - Threaded bolt holes around motor

Most pneumatic vane motors contain threaded bolt holes at the bottom of the motor, around the motor shaft (Figure 10). This simplified the design of the neck a great deal, as we now would not need to fix the motor through frictional means; i.e.: a clamp around the motor.

Our first idea was a relatively simple. It consisted of a hollow cylinder with 6 bolt holes drilled through it, and a gap (Figure 11). The purpose of the gap in the cylinder is to allow room for the gears to pass unhindered. However, we could not move forward with this concept because of the subsequent problematic mounting process.

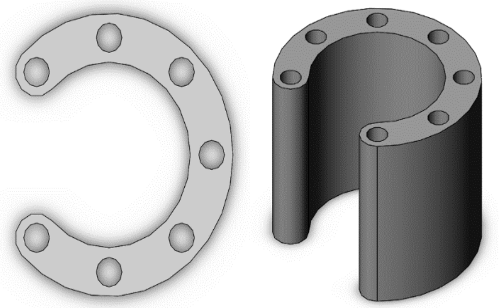
Figure 11 - First concept, top view and isometric

The entire system, minus the motor, will be mounted inside the flange first, followed by mounting the motor onto the tool. With the concept shown in Figure 11, it would require the user to screw the bolts in from beneath the tool, *after* the tool was mounted. Doing so would be very difficult for the user, with regards to the small space, and would risk losing bolts into the depth of the pipe.

We solved the aforementioned problem in our next concept, where the neck would be divided into two unique components; motor flange and pillar (Figure 12).

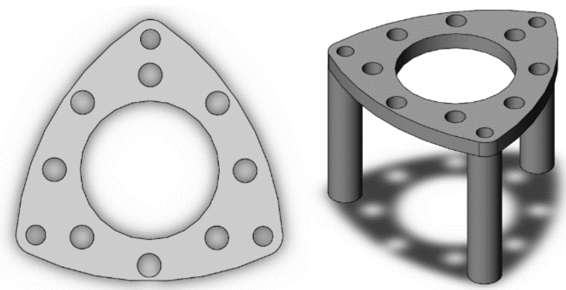
Figure 12 - Second concept, top view and isometric view.

The idea here is that the pillars would be bolted to the base prior to mounting the system inside the flange. The motor flange attached to the motor is then screwed onto the pillars after the tool is mounted. This means that the pillar will have bolts coming in from both ends.

After a meeting with FO&GT, a request was made for the neck to be compatible with several motors. The aforementioned design was therefore changed to accommodate that request (Figure 13) while otherwise remaining as the second concept. This involved modifying the inner bolt holes to be elongated such that the neck would be compatible with a range of motors where the centre distance of the motor bolt holes ranged from 22.5 mm to 32.5 mm. This range was a compromise between the overall size of the neck sub-system, and the number of applicable motors that could potentially be used. The elongated holes were arranged in such a way as to allow mounting motors with a configuration of 2, 3, 4, 6 or 8 threaded holes around the motor shaft.

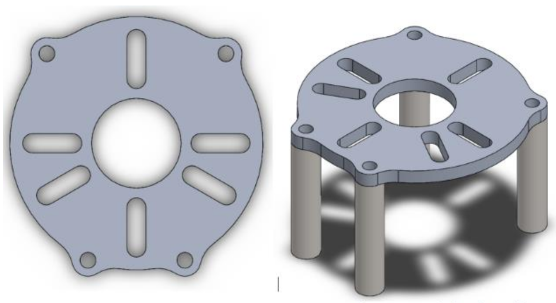
Figure 13 - Third concept, top view and isometric view.

An issue that was later discovered was that it would be impractical or excessively difficult to seal the gear train from the environment with the third concept. The unused elongated bolt holes of the motor flange could simply be sealed using a rubber insert, however, no satisfactory solution for the elongated bolt holes that was used to fix the motor could be found.

Therefore, compatibility with several motors was abandoned in favour of a solution that made sealing the gear train possible.

3.3.2 Assembly

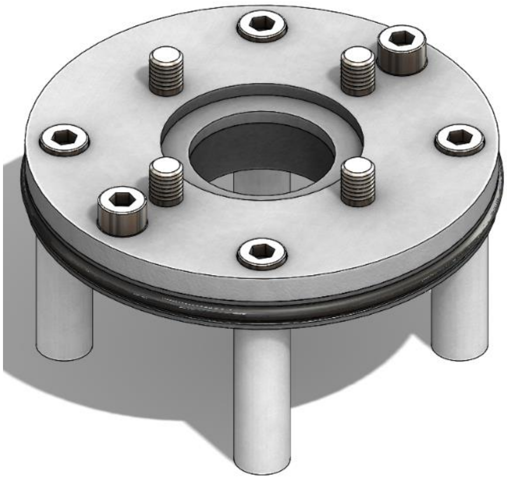

Figure 14 - Isometric view of neck assembly.

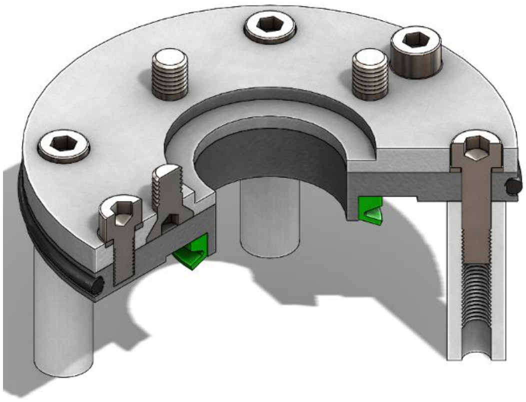

Figure 15 - Section view of neck assembly.

Figure 16 - Separation of motor flange and gear cover.

The pillars are fastened securely to the body prior to mounting the system to the flange. The V-ring seal is stretched onto the short shaft of the gear cover, before fastening the gear cover to the pillars.

The motor flange, fixed to the motor is then inserted on top of the gear cover and fastened with two M5x10 screws after the system has been mounted inside the flange.

Name	ID	Standard	Material	N	Dimension	OTSC
Motor flange	N-01	N/A	Super DSS F53	1	N/A	No
Gear cover	N-02	N/A	Super DSS F53	1	N/A	No
Pillar	N-03	N/A	Super DSS F53	4	N/A	No
SHCS	O-F-03	ISO 4762	A2-70	4	M5x20	Yes
SHCS	O-F-03	ISO 4762	A2-70	2	M5x10	Yes
HCHS	O-F-04	ISO 10642	A2-70	4	M6x12	Yes
Washer	O-W-01	ISO 7092	Stainless steel	6	M5	Yes
SKF V-ring seal (30 VA V)	O-S-02	N/A	SKF Duralife (5 p. 32)	1	(5 p. 401)	Yes
O-ring seal (OR 79.5x3.0-N70)	O-S-01	ISO 3601	N70/6052 (6 p. 27)	1	(6 p. 307)	Yes

Table 7 - List of components of neck sub-system.

3.3.3 Motor flange

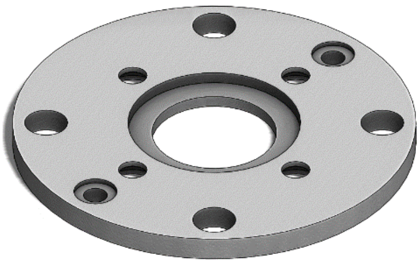

Figure 17 - Motor flange.

The motor flange serves as a platform to mount and secure the Deprag 67-373 pneumatic vane motor. It contains four inner M6 bolt holes to secure the motor, and two outer M5 bolt holes to secure the neck to the pillars. The inner and outer diameter of the component has a clearance of 1mm between the motor shaft and bearing respectively, to avoid interference and allow high dimensional tolerances.

The four outermost holes are intended only to make room for the heads of the M5x20 screws that attach the gear cover to the pillar

3.3.4 Gear cover

Figure 18 - Gear cover.

The function of the gear cover is to partly seal the gear train, and allow fastening of the motor flange without breaking the aforementioned seal. It contains four M5 bolt holes for the pillars and two M5 bolt holes for the motor flange. Around the perimeter of the gear cover lies a groove for the O-ring.

3.3.5 Pillar

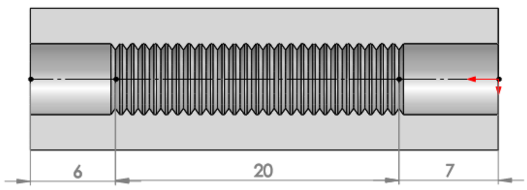

Figure 19 – Section view of pillar.

The function of the pillar is to act as a mechanical link between the gear cover component and the base sub-system, while not obstructing the gear train. The pillar has internal threads as shown in Figure 19. M5x20 bolts will be screwed into both ends.

3.3.6 V-ring seal

Figure 20 - V-ring seal.

The primary function of the V-ring seal is to retain gear lubricant and exclude contaminants from the environment. The criteria for its selection was the following:

- The ability to seal in the axial direction as opposed to the radial direction.
- Good wear characteristics.
- Resistance to oil based lubricants.
- Minimized dimensions.

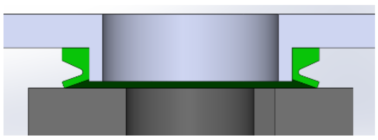

Figure 21 - V-ring seal in contact with the driving gear.

A V-ring seal fulfils all of the above criteria. The seal is stretched and fitted to the gear cover component (5 p. 399), making the seal lip come into contact with the driving gear (Figure 21). In order to obtain a satisfactory seal, the contacting surface of the driving gear must have a surface roughness below 2.5 µm (5 p. 394).

The seal ring is made of a proprietary material called SKF Duralife (5 p. 32). This material is a fluoro rubber that has good wear characteristics, and is resistant to oil based lubricants. The designation of the selected V-ring seal is 30 VA V.

3.3.7 O-ring seal

The criteria used to select the O-ring where similar to those for the V-ring seal, however, no relative motion occur between the gear cover and the 61817-2RS1 bearing. In addition, it must seal radially rather than axially. An O-ring is a cheap and easily available solution to those criteria, it is made of a nitrile rubber material, which is resistant to oil and hydraulic fluids (7 p. 2).

3.4 Arm

The function of the arm sub-system is to act as a rotating platform in which the polishing fingers can be mounted to, and allow their radial position to be adjusted.

3.4.1 Development

Our initial concept for the arm was based on modules. This concept made it possible for the machine to fit multiple flanges. The modular design is assembled much like building blocks where the arm is assembled piece by piece and bolted together. However, a new, more flexible concept was developed which consist of fewer parts and lower mass.

3.4.2 Selected

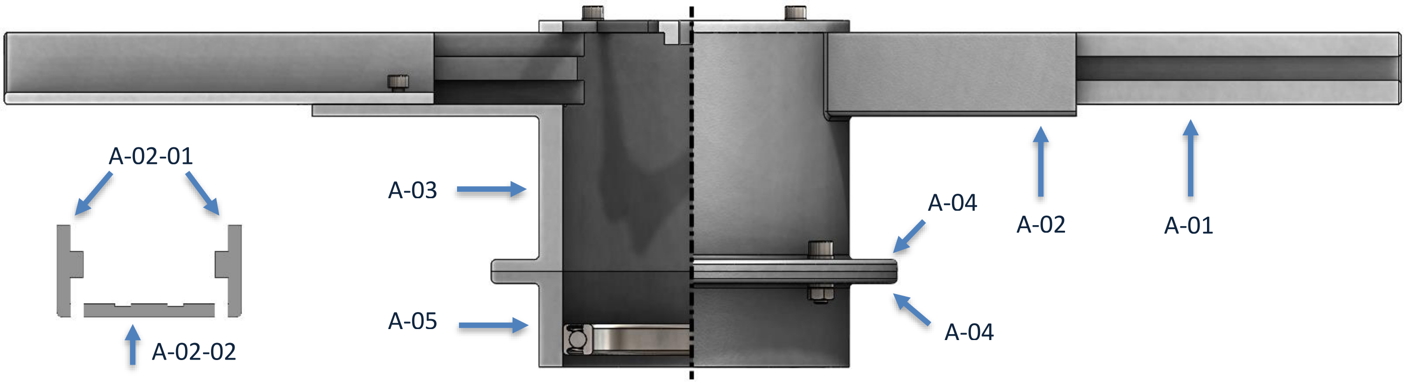

Figure 22 – Half cutaway view of arm sub-system with marked components.

Name	ID	Standard	Material	N	Dimension	OTSC
Inner arm	A-01	N/A	F53	2	N/A	No
Outer arm	A-02	N/A	F53	2	N/A	No
Outer arm side	A-02-01	N/A	F53	4	N/A	No
Outer arm bottom	A-02-02	N/A	F53	2	N/A	No
Top cylinder	A-03	N/A	F53	1	N/A	No
Arm flange	A-04	N/A	F53	2	N/A	No
Lower cylinder	A-05	N/A	F53	1	N/A	No
Arm cap	A-06	N/A	F53	1	N/A	No
SHCS	O-F-03	ISO 4762	A2-70	12	M5	Yes
Washer	O-W-01	ISO 7089	A2-70	16	M5	Yes
Inner bearing	O-B-03	ISO 281	683-17	1	N/A	

Table 8 - List of components for arm sub-system.

The final design selected is of a modified U-shape profile with keyways that allow for the sliding connector to be fastened independently of location.

With this design in place we are able to fasten the sliding inner arm with SCHC screws onto the slotted keyway which is located in the outer arm. The slotted keyway has a coarse surface finish for a better connection when in contact with the screw.

The top cylinder contains 4 bolt holes on top which allows for the arm cap to be jointed onto place. It is in the connection between the top cylinder and the outer arm.

The lower cylinder is to be mounted on the gear before the tool is in operation, such that a connection between the lower flange and top flange is made possible thus allowing the arm to be mounted onto the body.

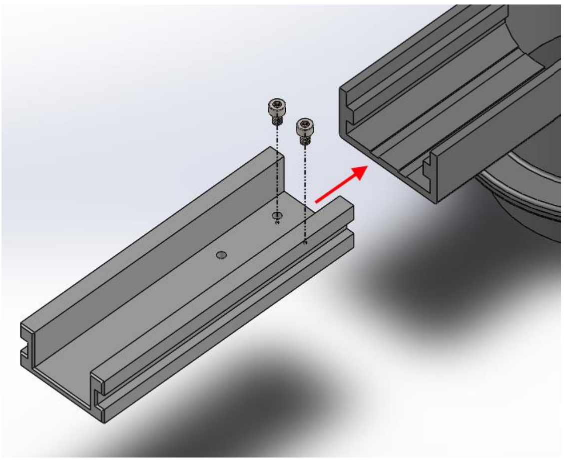

Figure 23 – Outer arm inserted into inner arm.

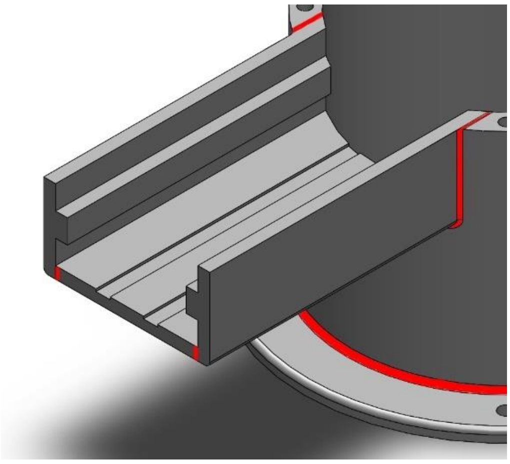

Figure 24 - Welded connection between the top cylinder and outer arm.

3.4.2 Sliding Connector

Once the length of the arm is set, the operator assembles the sliding connector onto the keyway allowing for the connector of the polishing finger to be moved to the location of the surface that will be polished. This gives us the option to polish all faces independent of location of the flange surfaces in need of polishing.

This sliding connector will allow rotation around the shaft axis of the polishing finger if needed onto the desired angle and lock it into place with that angle. Since the sliding connector is allowed to move in radial direction with the keyway.

3.4.5 Arm cap

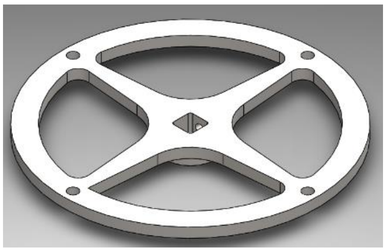

Figure 25 - Isometric view of arm cap.

The arm cap is intended to be used in cases where the pneumatic vane motor is for various reasons not used. Its main function is to act as an interface between the arm and alternate power sources, such as mechanical and electric drills.

The centre of the arm cap contains a socket for a standard 3/8-inch square drive (Figure 26).

Figure 26 - Square drive drill bit.

This component is dimensioned for a torque of 60 Nm acting in the centre; which is the torque required to polish all the sealing surfaces simultaneously. It will be mounted at the top of the centre tube of the arm using four M5x20 screws.

The spokes are wider near the centre than they are near the bolt holes; this is because the magnitude of the shear stress at any one given circular section is inversely proportional to the radius.

3.5 Heel face, midsection and environmental finger

The heel face and midsection face are to be polished simultaneously as they are co-linear with each other, and need to remain so in order to avoid compromising the sealing properties of the flange. The two surfaces lie at a small angle in relation to the X-axis.

It is important that the two faces will keep this relationship after the polishing is done so that the flange can function optimally. Among factors that can provoke such imperfections are:

- Different polishing material applied to the two faces.
- Different surface pressure on the two faces.

3.5.1 Assembly

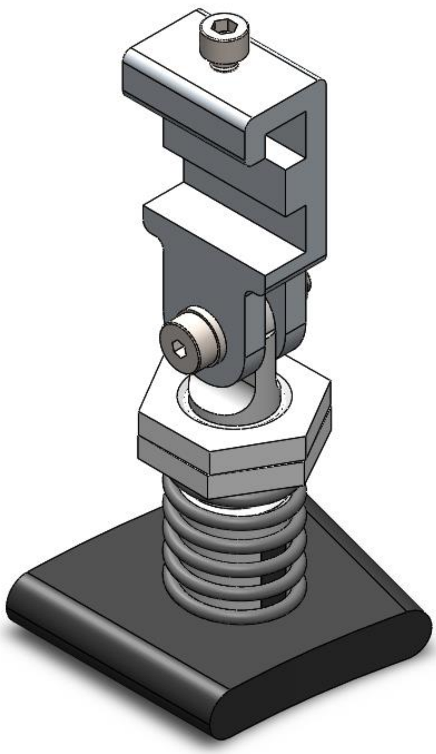

Figure 27 - Isometric view of HS finger.

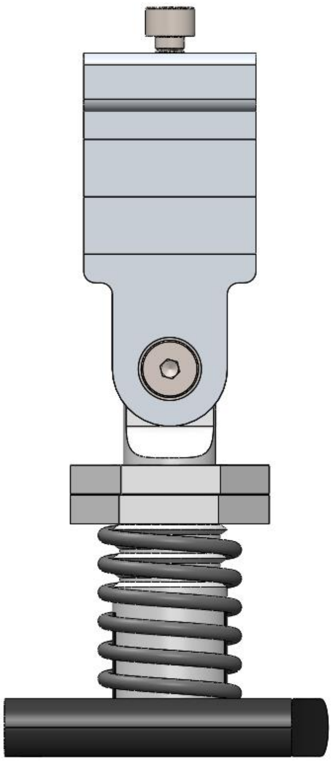

Figure 28 - Left view of HS finger.

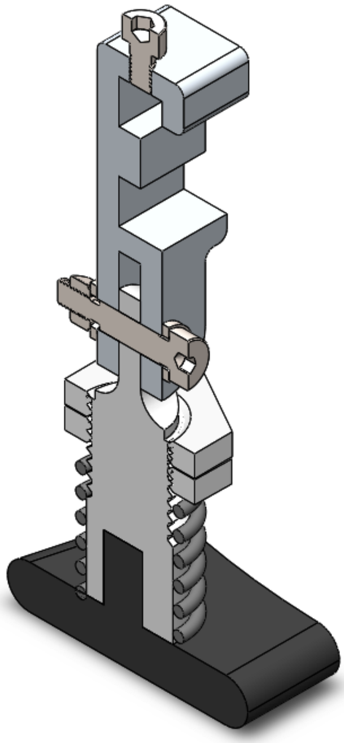

Figure 29 - Section view of HS finger.

The primary function of the HM polishing finger is to ensure an accurate polishing of the heel face and the midsection face. To accomplish this job properly we have designed the sub-system with a keyed connection between the bracket and the finger rod. This connection prevents the finger from rotating around its own axis and lets it move freely up and down so it will always be it contact with the flange.

Name	ID	Standard	Material	Dimension	OTSC
HM Bracket	F-HM-01	N/A	F53	N/A	No
HME Finger rod	F-HME-01	N/A	F53	N/A	No
HME Sliding connector	F-HME-02	N/A	F53	N/A	No
HM Spring	O-Z-02	ISO 11891:2012	SS 302	N/A	Yes
Hex nut	O-N-01	ISO 4762	A2-70	M20	Yes
Hex nut	O-N-02	ISO 4762	A2-70	M20	Yes
SHSS	O-F-01	ISO 7379	A2-70	M5	Yes

SHCS	O-F-03	ISO 4762	A2-70	M5	Yes
Washer	O-W-01	ISO 7089	A2-70	M5	Yes
Washer	O-W-02	ISO 7089	A2-70	M6	Yes

Table 9 - List of components for HM finger sub-system.

To adjust the pressure between the bracket and the flange, the operator can either tighten or loosen the nut that secures the spring.

The polishing finger for the environmental seal works in the exact same way. The only difference between the two sub-systems is the size and shape of the bracket.

3.6 Seal Groove Polishing Finger

The primary function of the SG finger is to polish the seal groove. It is mounted on the inner arm component.

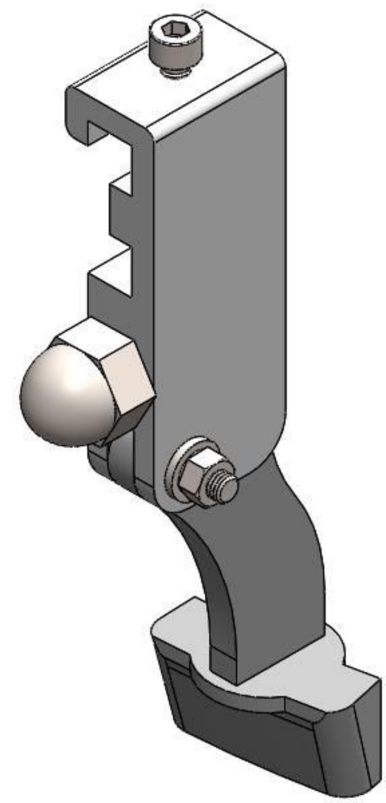

Figure 30 - Isometric View of SG Finger

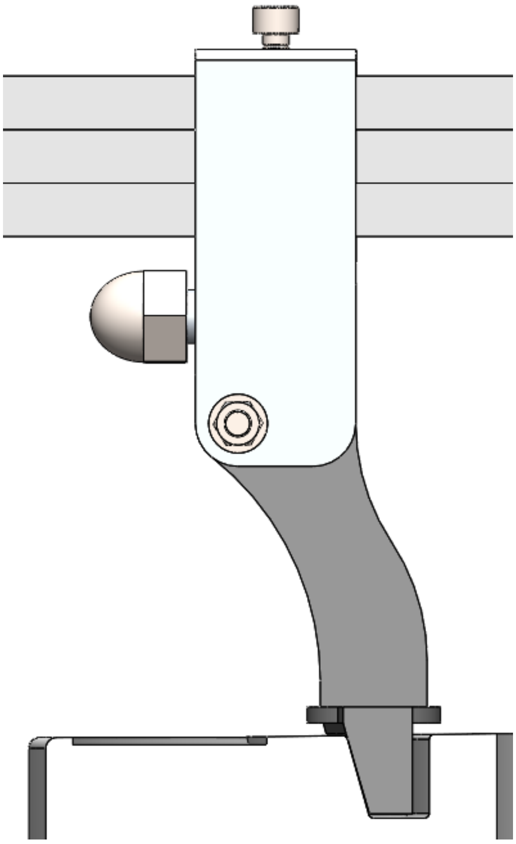

Figure 31 - Mounted SG finger.

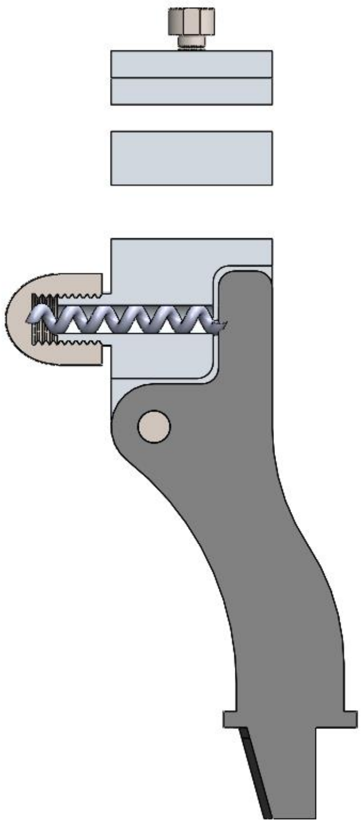

Figure 32 - Section view of SG finger.

Name	ID	Standard	Material	Dimension	OTSC
SG Polishing Finger	F-SG-01	N/A	Super Duplex F53	N/A	No
SG Spring	F-SG-02	N/A	SS 302	N/A	Yes
SG Sliding Connector	F-SG-03	N/A	Super Duplex F53	N/A	No
SHSS	O-B-01	ISO 7379	A2-70	M5	Yes
Washer	O-W-01	ISO 7089	A2-70	M5	Yes
Washer	O-W-02	ISO 7089	A2-70	M6	Yes
Hex Nut	O-N-01	ISO 4032	A2-70	M5	Yes
Cap Nut	O-N-03	DIN 917	A2-70	M10	Yes
SHCS	O-B-03	ISO 4762	A2-70	M5	Yes

Table 10 - List of components for SG finger sub-system.

The sub-system works by converting the linear load applied from the spring to a moment around the shaft. When the system is installed, the SG will act as the reaction point and a controlled frictional load between the two surfaces will occur. The spring will ensure a continuous load under the whole operation process.

By turning the cap nut the operator can adjust the desired load applied from the spring.

The finger is shaped in such a way that it will always follow the curvature of the seal groove. This will ensure that the force distribution from the finger to the seal will be better.

For the SPO 16'' CF, a load of 147N is required for optimal performance (4 pp. C-06 and C-09).

3.7 Mounting dolly

The purpose of the mounting dolly is to provide a way to safely and accurately mount the system onto the flange. The mounting dolly is intended to be used only during the mounting of the tool. This sub-system is created to fulfil requirement 2.01 and 3.01.

3.7.1 Assembly

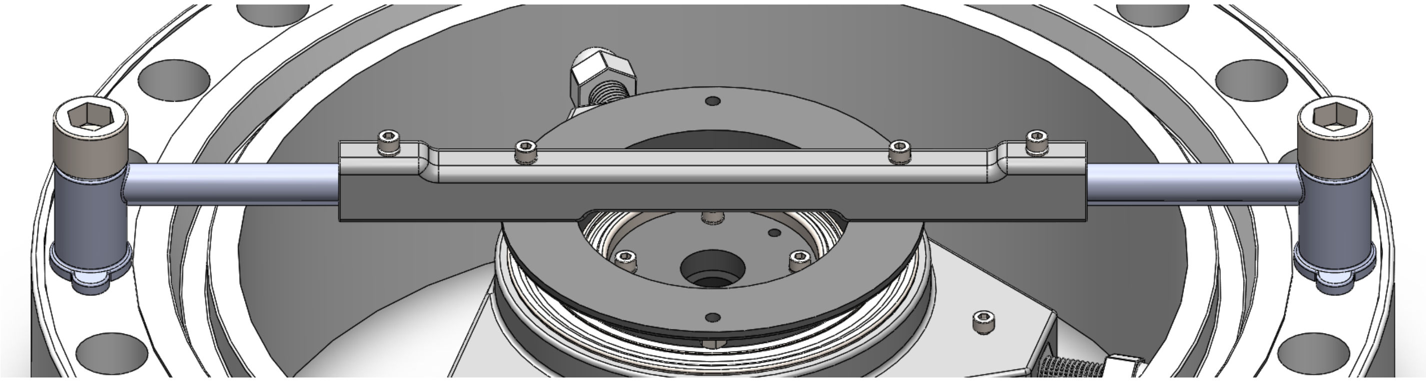

Figure 33 - Mounting dolly used to mount the sub-assembly.

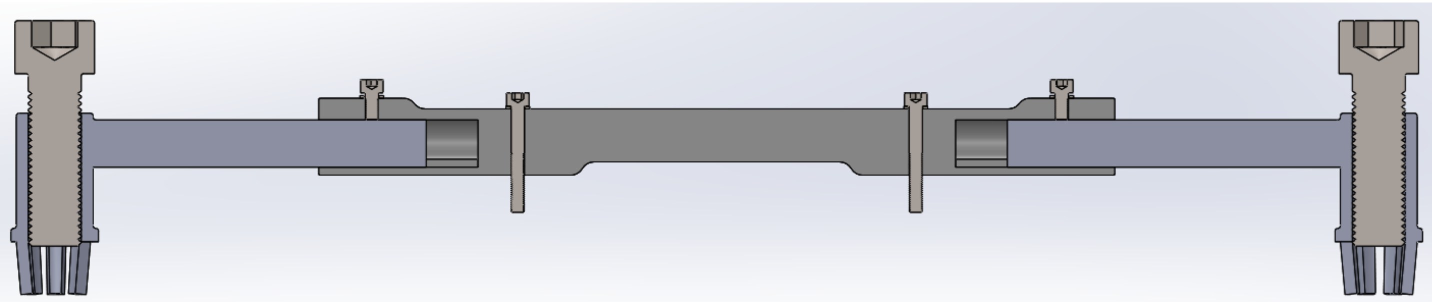

Figure 34- Section view of mounting dolly.

As a result of the system assembly procedure, where the body, legs, neck, gear train and the arm flange need to be assembled before flange mounting, the mass of this sub-assembly is too great for the user to mount it. It would also be difficult for the user to mount the system in the correct alignment to the flange due to the weight of the system.

The mounting dolly provides a way to easily and accurately mount the sub-assembly to the flange. The mounting dolly is first fixed to the arm flange through two M5x35 bolts. The sub-assembly is then mounted to the flange by inserting the two expansion sleeves into two opposing bolt holes on the flange as shown in Figure 33, while a second user fasten the M20x65 screws. By tightening the M20x65 screws, the split sleeve expands to create a tight grip with the flange bolt holes. The user then slides the sub-assembly to be concentric to the flange before tightening the M5x10 screws to lock the sub-assembly in place.

Name	ID	Standard	Material	N	Dimension	OTSC
Handle	D-01	N/A	Super DSS F53	1	N/A	No
Sliding rod	D-02	N/A	Super DSS F53	2	N/A	No
Expansion sleeve	D-03	N/A	Super DSS F53	2	N/A	No
SHCS	O-F-05	ISO 4762	A2-70	2	M20x65	Yes
SHCS	O-F-03	ISO 4762	A2-70	4	M5x40	Yes
Washer	O-W-01	ISO 7092	A2-70	4	M5	Yes

Table 11 - List of components for mounting dolly sub-system.

3.7.2 Mounting base

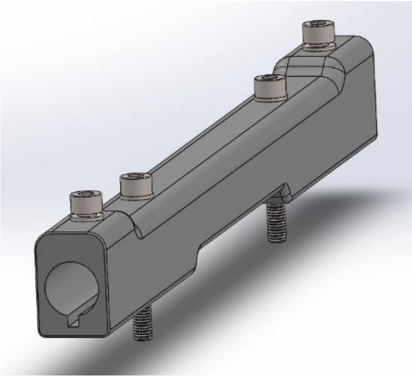

Figure 35 - Mounting base.

The function of the mounting base is to act as a mechanical link between the arm flange and the expansion bolt. It is fastened to the arm flange using two M5x35 bolts, and contain sockets with keyways for the expansion sleeve components. Axial movement of the expansion sleeve is halted through an M5x10 screw, when correct position have been achieved.

3.7.3 Expansion sleeve

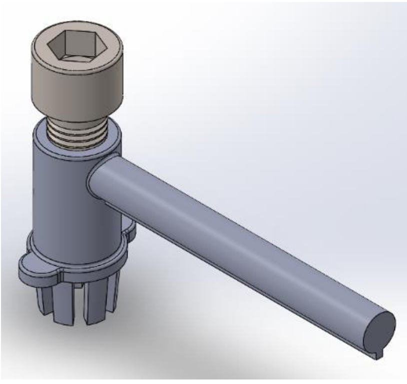

Figure 36 – Expansion sleeve.

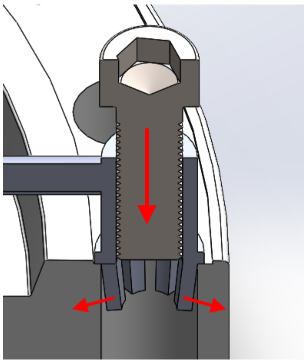

Figure 37 - Function of the expansion sleeve.

This component serves to fix the sub-assembly to the flange using an M20 screw to expand the split sleeve outwards to create a pressure towards the bolt holes of the flange (Figure 37), thereby locking the mounting dolly in place through friction.

4.0 Components

4.1 Motor

The motor is the source of power for the rotational motion of the arm.

As mentioned in the Concept document, we had temporarily selected a pneumatic vane motor from Deprag. At that time, we had only rough calculations to estimate the required torque and power of the motor, and had not gone sufficiently in depth to justify the choice.

4.1.1 Criteria for selection.

The most important criteria for the selection of the motor is as follows:

- Sufficient torque output at the specified surface pressure.
- Sufficient power at the specified angular velocity.
- Certified to use in an environment with an explosive atmosphere.
- Operate on a readily available power source.
- Resistance to corrosion.

It has been calculated that the motor requires at least 14.3 Nm of torque and 28 W of power to drive two arms, assuming all surfaces are polishing simultaneously with a rotational speed of 15 RPM and a surface pressure of 0.06 MPa (4 pp. C-06).

As the tool will be used in offshore environments; an environment where all machinery cannot pose an ignition risk in the event of for example a gas leak, the motor must be certified for use in explosive environments. For the same reason, it must be resistant to corrosion.

4.1.2 Selected motor

The motor we have selected is from the advanced line high torque motors from Deprag, series 67-373.

As can be seen from the torque diagram (Figure 39), the motor can deliver 140 Nm of torque at 15 RPM (Figure 39), which will require an operating pressure of approximately 3.6 bar.

The motor is ATEX certified, which is part of two EU directives that among other things, describes what equipment can be used in environments with an explosive atmosphere.

Motor size 3 with high torque		reversible
Series 67- Ex II 2 GD c IIC T6 (80°C)	Type Part no.	67-373 444560 M
Nominal-Power	W / HP	280 / 0.37
Nominal-Speed	rpm	25
Speed (idling)	rpm	50
Nominal-Torque	Nm / in.lbs	110 / 973.5
Start torque min.	Nm / in.lbs	162 / 1433.7
Air consumption	m^3/min / cfm	0.47 / 16.6
Weight	kg / lbs	2.9 / 6.4
Hose I.D.	mm / in.	10 / 3/8

Figure 38 - Data for the Deprag series 67-373 pneumatic vane motor.

The motor is corrosion resistant and made of stainless steel.

Other motors can also be used, as long as the bolt holes around the shaft have M6 dimensions, and are located 24mm from the centre. However, because of time limitations for this project, we will not spend resources on making the tool compatible with additional motors.

It was originally believed the required torque and power of the motor would be far higher, as our calculations where built upon the wrong assumptions, namely the surface pressure and the frictional coefficient between the sealing surface and the polishing material. Therefore, our selected motor is over dimensioned in terms of the required torque and power, however, it still satisfies the criteria for selection. Had we identified and corrected the errors in our calculation sooner, we would likely have changed the motor.

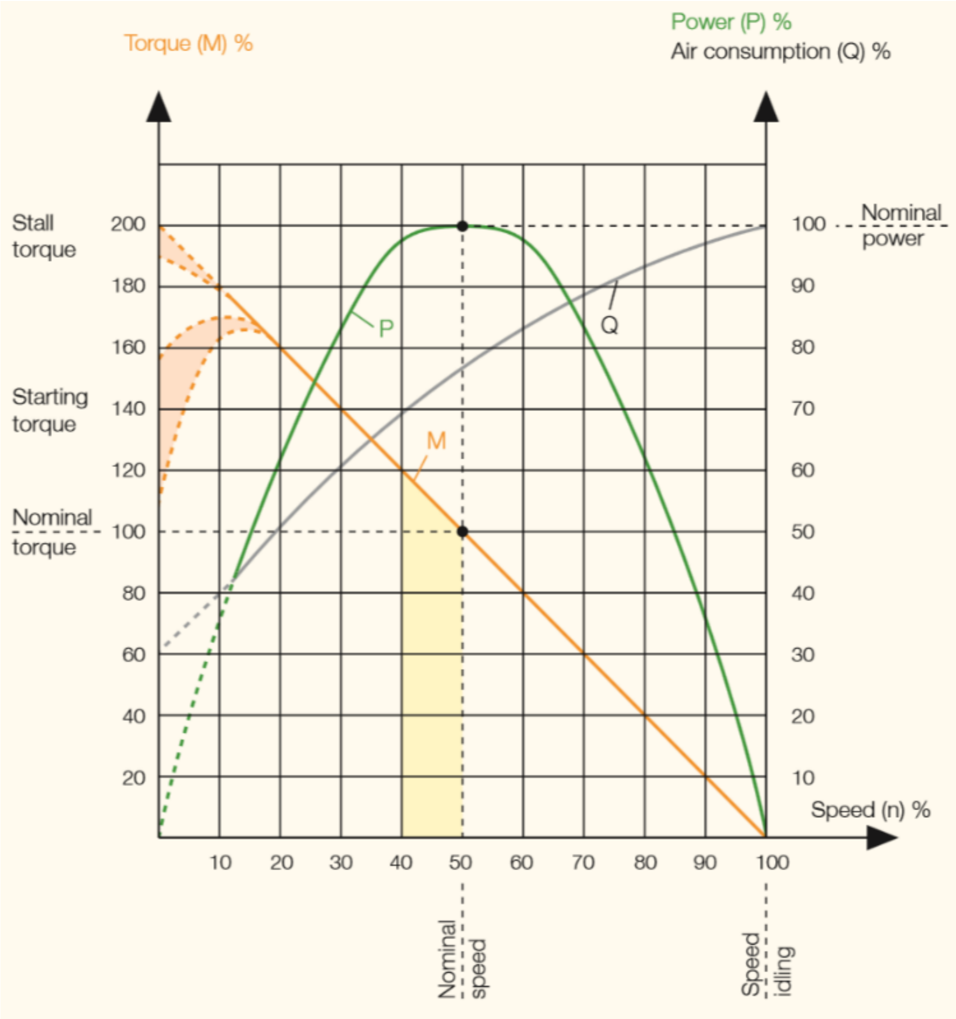

Figure 39 - Torque diagram of pneumatic vane motors from Deprag.

4.1.3 Speed control

To ensure safe operation the system, we have integrated a speed control valve on the system. We have selected a one-way flow control valve from FESTO.

Figure 40 - CGRLA-1/4-B

One-way flow control valves work with the principle that air only flows in one direction (directly through the hoses and the motor). The valve is to be connected on the exhaust of the motor and can therefore control the amount of air that exits the motor, which is the same amount as the input air. The valve increases the amount of resistance the exhaust will have and therefore the speed is reduced as well (8).

Simply by turning a knob, the speed can be accurately controlled by the operator.

We have selected the CGRLA-1/4-B type valve from FESTO for our system. This is because this is a small and easily operated valve with a slotted controller screw. The dimensions correspond with the dimensions of the selected motor and it is corrosion resistant (9).

4.2 Gear train

The gear train is located under the neck at the bottom of the central cut of the body. The function of the gear train is to transfer torque and power from the motor to the arm.

The shaft axis of the motor and the arm is collinear with each other, therefore, an internal gear system with spur gears will be used. The gear train consists of a driving gear, an idling gear and an internal gear as seen on Figure 42.

4.2.1 Design factors and constraints

There is a number of aspects that govern the design of the gear train. They are as follows:

- The gear train must possess the necessary mechanical properties to handle the specified loads from the motor, both static and dynamic.
- The driving gear must contain a keyway for the motor shaft.
- The output rotational speed should be within 5 - 11 RPM.
- The module must be equal for all gears to ensure correct meshing between gears (10 p. 1025).

Because the dimensions of the neck, motor, body and arm sub-systems is already defined, the gear train is constrained by the geometry of the pre-existing sub-systems. Therefore:

- The dedendum circle diameter of the internal gear is limited by the internal diameter of 110mm by the central arm tube.
- The addendum circle diameters of the driving gear must be smaller than 60mm to avoid interference with the pillars of the neck.
- The face width is limited as there needs to be room for bearings and other components needed to seal the gear train from the environment.

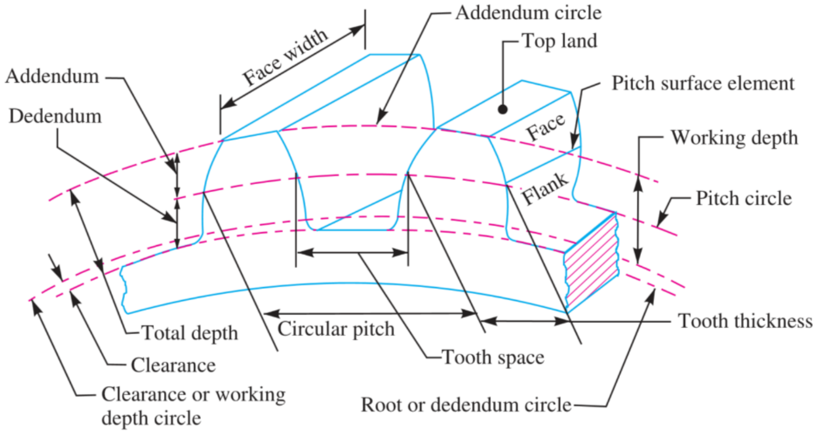

Figure 41 - Terms used to describe the geometry of gears. (13 p. 676)

4.2.2 Design procedure

An involute tooth profile with a pressure angle of 20° will be used, as it allows for some variation of centre distance between gears, and gives constant velocity throughout the engagement of the teeth (10 p. 1031).

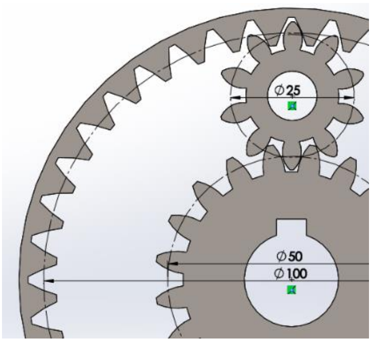

Figure 42 - Trial pitch circle diameters.

There are several interdependent variables that need to be determined to dimension the gear train, such as the pitch circle diameters, gear module, the number of teeth for each gear and the face width.

Gear size is determined by two variables, where the third variable is determined by the first two. The module is the metric size index of the teeth, and is the circular pitch divided by π. The module, in conjunction with the number of teeth, determine the pitch circle diameter of the gears. This relationship is given as:

$$N = \frac{d_p}{m} \text{ (11 p. 656).}$$

Where N is the number of teeth, d_p is pitch circle diameter, and m is the module.

As a result of the many interdependent variables, a trail was first performed where the pitch circle diameters was defined as seen in Figure 42. It was found that regardless of module, we would either get too few teeth on the idler gear, or teeth too small to withstand the forces subjected to them. Therefore, the pitch circle diameters needed to be altered.

4.2.3 Selected gears

Name	ID	Standard	D_P	N_{TEETH}	Material	OTSC
Driving gear	O-G-01	DIN 6962	44 mm	22	BS 970	Yes (12 s. 38)
Idler gear	O-G-02	DIN 6962	28 mm	14	BS 970	Yes (12 s. 38)
Internal gear	O-G-03	JIS B1702-1	100 mm	50	BS 970	Yes (13 p. 149)

Table 12 - List of gear components.

With the help of Mathcad, the optimal gear dimensions were found to be as seen in Figure 43. With a module of 2mm, a sufficient number of teeth was attained, and with a face width of 20 mm, the teeth are calculated to be strong enough to withstand the motor torque (14). The gear ratio is independent of the idler gear (11 p. 677) and is calculated to be 0.44 (4 pp. C-04).

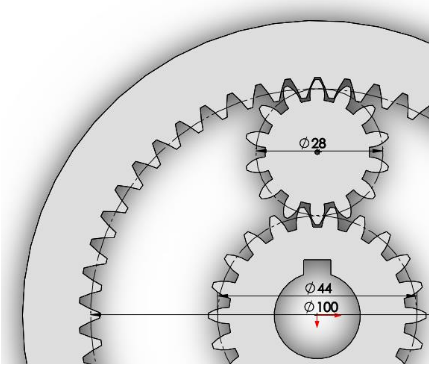

Figure 43 - Final pitch circle diameters.

4.2.3.1 Driving gear

The driving gear contains a socket compatible with the motor shaft of the Deprag 67-373 pneumatic vane motor. The gear is fixed in the bearing O-B-01. The reason this bearing is capped is to prevent the lubrication to leak out through the gear socket.

The top surface of the driving gear must be polished such that a surface finish of minimum 2.5 µm is attained (5 p. 397).

4.2.3.2 Idler gear

The idler gear is axially fixed through a single row deep groove ball bearing, designation 61901 from SKF. This bearing does not contain seals as it is fully within the sealed gear train area.

4.2.3.3 Internal gear

The internal gear is fixed to the lower arm flange through four M5 screws. It is an OTSC from KHK Stock Gears with designation SI2-50 that originally possess an outside diameter of 150 mm (13). However, the outer diameter has to be reduced to 130mm in order to fit inside the body.

4.3 Bearings

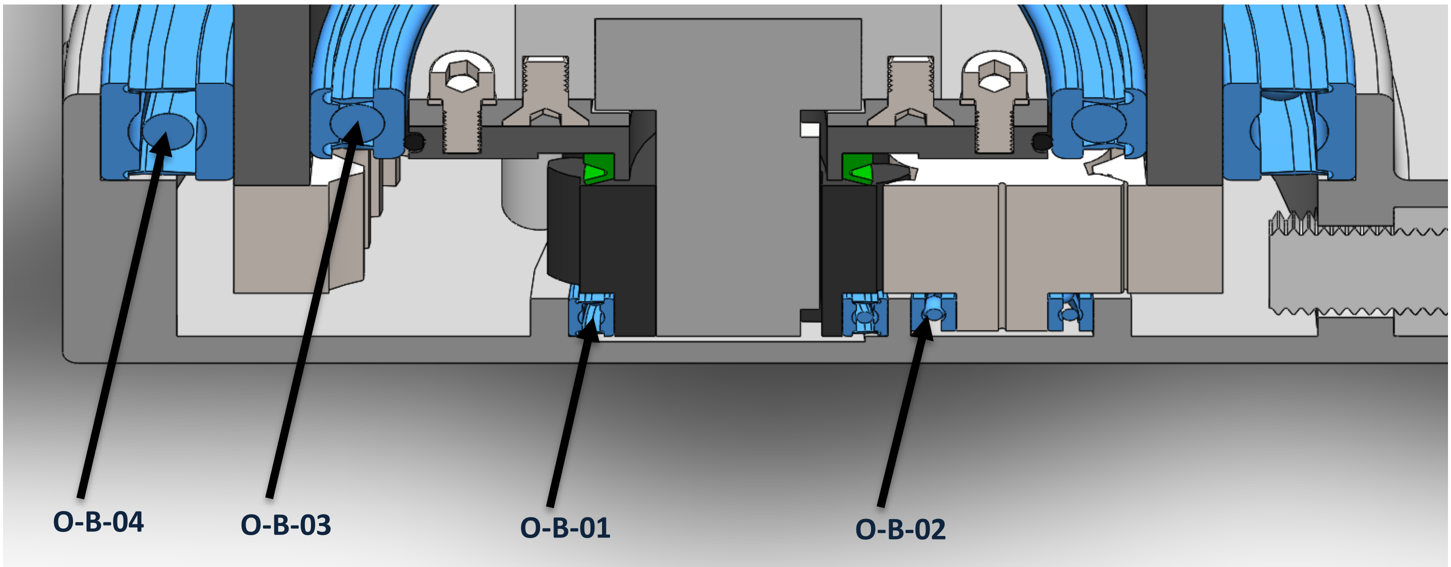

Figure 44 – Section view of system assembly displaying bearings highlighted in blue.

The bearings used in the system have two purposes:

- Act as a low frictional intermediary between two components with a relative difference in angular motion.
- Act as a sealing barrier between the external environment and the gear train.

4.3.1 Criteria for selection

The most important factors that determine the kind of bearings used are the following:

- Minimized dimensions.
- Accuracy of the shafts alignment to the central axis.
- Ability to handle axial loads in both directions.
- Sealing.
- Minimized mass.

Figure 45 - Radial length of system.

The bearings should ideally have as small overall dimensions as possible. The smallest flange size the system is compatible with depend on the radial length (R in Figure 45), which is furthermore dependent upon the dimensions of the bearings. The total mass of the system is likewise reduced with minimized dimensions.

The bearings should not compromise the shafts alignment to their respective central axis, as this may cause stress concentrations if the shafts wobble back and forth angularly.

The bearings in contact with the lower arm flange (O-B-03 and O-B-04 in Figure 44) will primarily be subjected to axial loads and moment loads depending on the orientation of the system, however the moment loads can be neglected as they would only stem from the weight of the arm and fingers.

The bearings attached to the gears (O-B-01 and O-B-02) will primarily be subjected to radial loads that stem from the gears. These loads are however well within the rated load capacity of the gears (15).

All bearing, with the exception of O-B-02 must be sealed, in order to keep contaminants out of both the bearing and the gear train area, and to retain lubrication.

4.3.2 Selected bearings

Designation	ID	Capped	Mass	Dimensions(d·D·B)	Static load	Reference
61826-2RS1	O-B-04	Yes	0.93 kg	130mm·165mm·18mm	28 kN	(16 p. 372)
61817-2RS1	O-B-03	Yes	0.27 kg	85mm·110mm·13mm	20.8 kN	(16 p. 368)
61806-2RS1	O-B-01	Yes	0.025 kg	30mm·42mm·7mm	2.9 kN	(16 p. 358)
61901	O-B-02	No	0.011 kg	12mm·24mm·6mm	1.46 kN	(16 p. 324)

Table 13 - List of selected bearings.

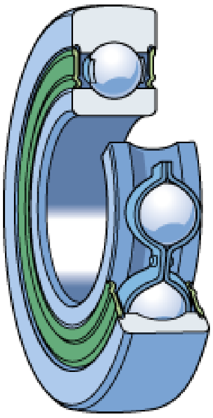

Figure 46 - Capped single row deep groove ball bearing.

With the criteria in mind, there were only on viable option, single row deep groove ball bearings from SKF.

This type of bearing provides a good accuracy for the shafts alignment to the central axis, and can handle both axial and radial loads in both directions (10).

These are the smallest standard bearings attainable from SKF with the given forces and dimensional parameters from the other sub-systems. All bearings have a rated load capacity far exceeding the actual forces that occur (4).

In addition, the bearings can be delivered with seals on both ends. These seals are contact based and have good oil and wear resistance (16 p. 300).

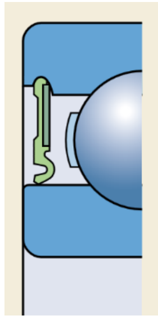

Figure 47 - 2RS1 seal

4.3.3 Mounting of bearing

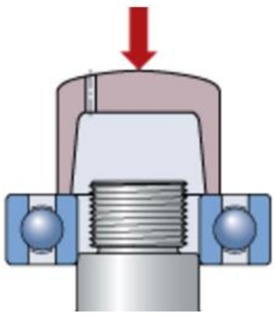

Figure 48 - Cold mounting using a mounting tool.

The bearings will be mounted to the system through a press fit.

Normally, a press fit does not allow dismounting of the fitted component, however, since the axial load applied to the bearing is so low compared to its rated load, it can. After all, there is no need to dimension the fit to handle larger loads than necessary. See the calculation document for further details (17).

In order to avoid a skewed mounting, a mounting tool or hydraulic press should be used as this will distribute the force evenly throughout the side face of the outer or inner race. This operation should be done in accordance to SKF regulations.

The dimensional tolerances for the outer diameter of the bearing is already given (16 p. 137), therefore, a fitting tolerance for the corresponding diameter of the contacting surfaces on the system needs to be defined to ensure a reliable press fit, even in the worst case scenarios. For example, if the tolerances of the outside diameter of a bearing is given as $150mm^{0\ \mu m}_{-15\ \mu m}$, the press fit need to be dimensioned with the assumption that the outside diameter of the bearing lies at the minimum.

4.4 Fasteners in system

To ensure a user friendly and easy system, we are designing with as many similar fasteners as possible. This means that some fasteners are over-dimensioned so we can stick to as few different fasteners as possible. We have chosen to use Unbrako fasteners in our system. Unbrako is a well-known manufacturer and the unique shape of the fasteners head makes them resistant to wear when re-using them. To be able to re-use bolts in our system is important because many of the sub systems and components has to be disassembled after use.

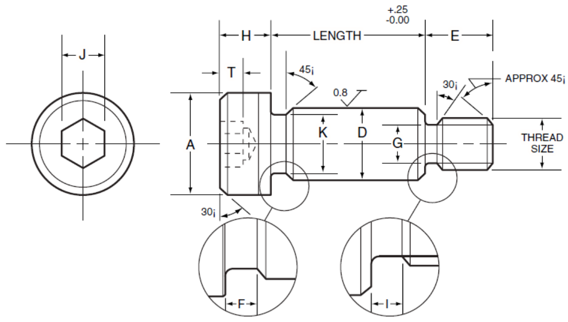

Figure 49 - Socket head shoulder screw.

Unbrako fasteners comes in many different materials, but we have chosen only to use the A2-70 series. A2-70 is a stainless steel material; more about A2-70 can be read about in the materials document.

We have used two types of Unbrako fasteners in our system. These two are Socket Head Cap Screw (SHCS) and Socket Head Shoulder Screw (SHSS). In addition to this we are using cylinder screws from Deprag.

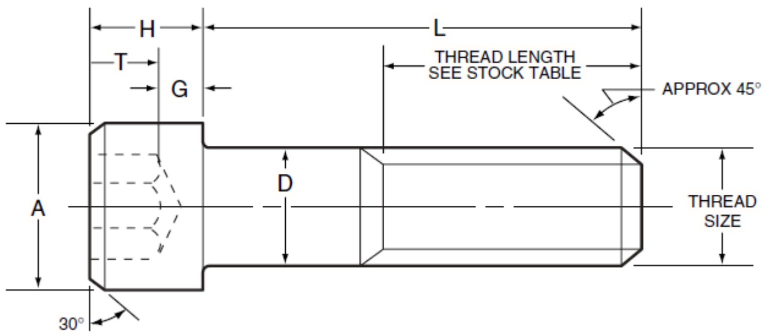

Figure 50 - Socket head cap screw.

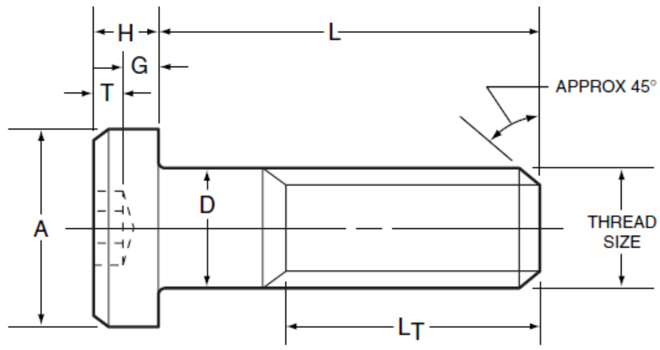

Figure 51 - Low head cap screw.

For all polishing fingers, the SHSS are used. This is because the bolt will work as a shaft, and will reduce wear between the inner hole of the fingers and the bolt itself. The bolts are installed with two washers and a hexagon nut for securing.

The connection between the motor flange and gear cover requires a short screw. The best option here is Low Head Cap Screws (LHCS). This is because the shoulder length on LHCS is short.

For other connections, the SHCS are used. All the bolts are off the shelf but some of them has to be cut achieve a suitable length.

For the connection between the motor flange and the motor, special fasteners from Deprag are required. The dimensions of these bolts are not published for the public.

4.4 Springs

Springs are in a state of controlled deflection which is why dimensions and material selection is important. The springs are classified by direction and the nature of the force that is exerted when they are deflected, in our case compressional forces.

The function of the springs is to provide controlled application of force towards the polishing surfaces. The springs will be fitted either inside a hole or outside a shaft, this support will prevent buckling to be of great concern.

4.4.1 Designing factors and constraints

There are many different design strategies that can be used when dimensioning springs, in this case the factors and constraints are as follow:

The spring index determines the strength of the spring, the stress induced on the spring, and the manufacturability of the spring. The preferred values for the spring index are between $4 < C < 12$, this is because a spring with an index of less than 4 are difficult to manufacture and a spring with an index greater than 12 will be prone to buckling. (11 p. 231)

- Pre - stressing of the spring is to be used to improve the spring´s ability to withstand stress, increasing its load -carrying capability and fatigue resistance. This is done in the manufacturing process where the spring is induced to residual stresses. (11 p. 521)
- The springs will be of squared and ground ends, as this will allow for a better transfer of the load that is obtained from force applied. (11 p. 520)
- The number of active coils in the spring need to be equal to or greater than 3 or equal to or less than 15. (11 p. 528)
- The safety factor for the spring at closure (solid height) has to be greater than or equal to 1.2 (11 p. 528)

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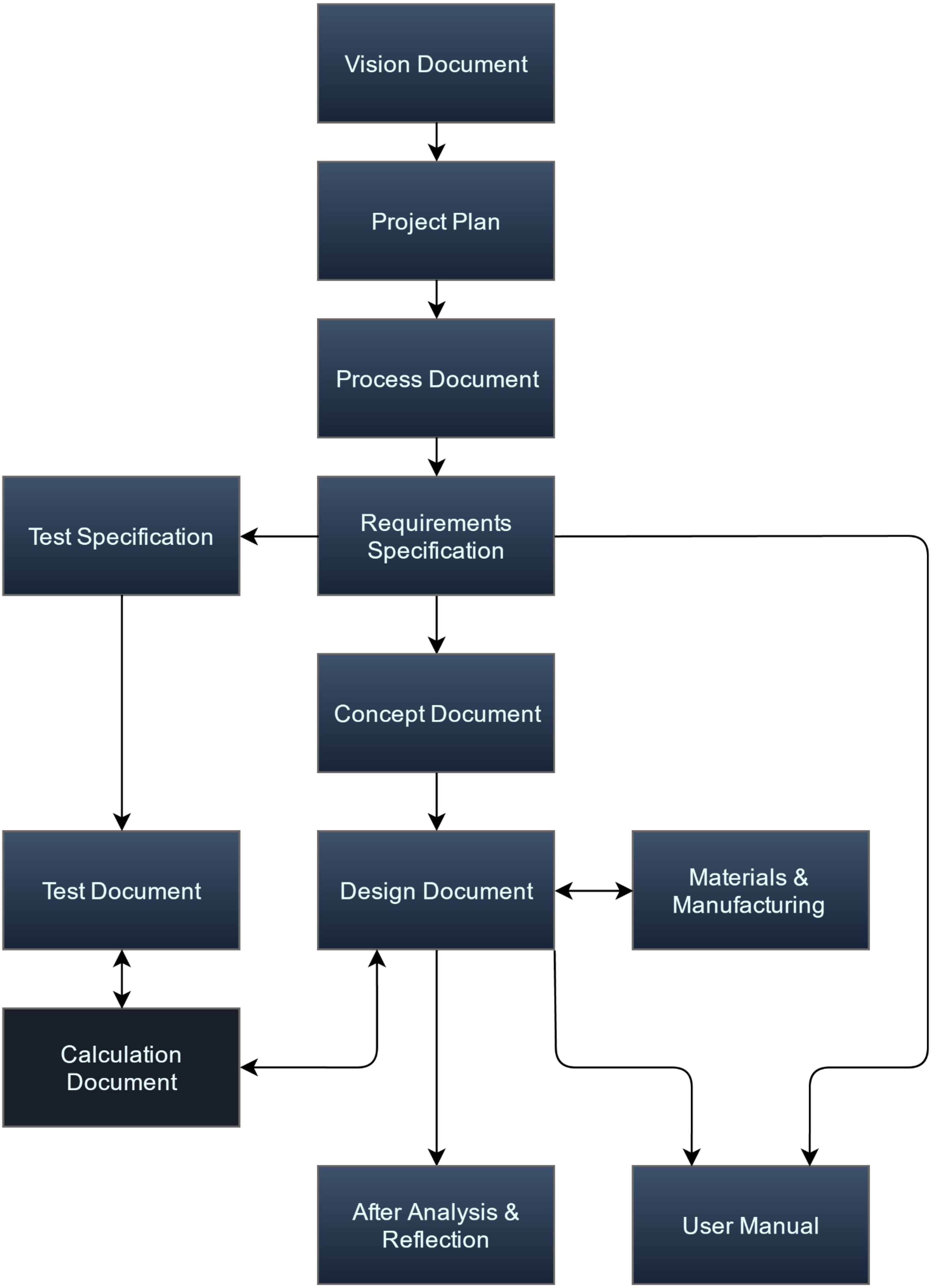
Vision Document
Project Plan
Process Document
Test Specification
Requirements Specification
Concept Document
Test Document
Design Document
Materials & Manufacturing
Calculation Document
After Analysis & Reflection
User Manual

Calculation Document

Freudenberg Bachelor 2016

SPO CF Seat polishing tool

Arian Krasniqi, Richelieu Dahn, Odd Eirik Hardem, Morten Grøsfjeld

Version	Document number	Date	Responsible	Status
1.0	008	22.05.2016	All	Finalized

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1.0 Document

1.1 Document history

Version	Date	Changes
0.1	22.03.2016	Document created
1.0	22.05.2016	Finalized

Table 1 - Document history

1.2 Definition of abbreviations

Abbreviation	Definition
FO&GT	Freudenberg Oil & Gas Technologies
SPO	FO&GT brand name for compact flanges (Steel Products Offshore)
CF	Compact Flange

Table 2 - Definition of abbreviations

1.3 Introduction

In some cases, hand calculations are more suitable than FEM analysis. Therefore, the team has done multiple hand calculations, all done with Mathcad.

1.4 Scope

This document will consist of all hand calculations done by the team in for of a screenshot from Mathcad-files (.PCT). The reason being that Mathcad do not have an “export to PDF” option. A consequence of this is that a small loss of image quality. Therefore, we recommend to look open the files in Mathcad when reviewing.

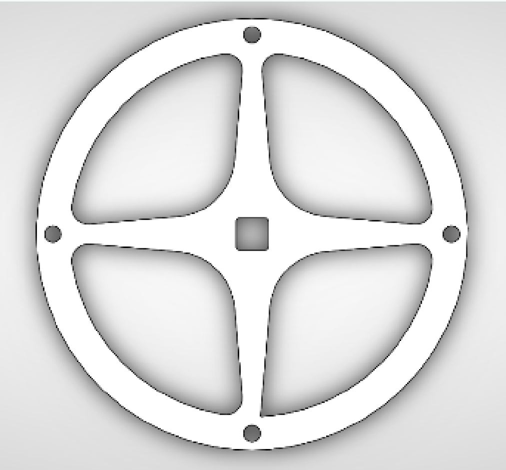
All our Mathcad files have a unique ID, so if the reader want to inspect the files more closely it will be easy to find the correct PCT-file.

It is important to note that all calculation documents are independent of each other. A consequence of this is that one parameter in one document can mean something else in another.

C.0 Calculation Documents

C-01 Arm cap

Arm cap calculation



In this calculation, shear stress on the four bolt holes will be calculated.

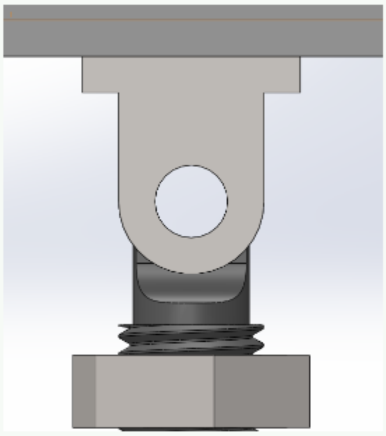
$T := 60\ N \cdot m$	Maximal torque	
$R := 60\ mm$	Center distance of bolts	
$d := 5\ mm$	Diameter of bolts	
$r := \frac{d}{2} = 2.5\ mm$	Radius of bolts	[1]
$N := 4$	Number of bolts	

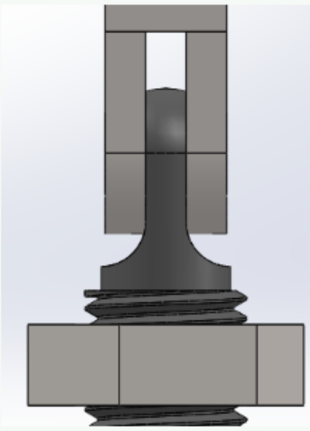
$F := \frac{T}{R \cdot N} = 250\ N$	Force acting on each bolt	[1]
$A := \pi \cdot r^2 = 19.635\ mm^2$	Area of shear plane in each bolt	[1]
$\tau := \frac{F}{A} = 12.732\ MPa$	Shear stress on each bolt	[1]

[1] - First principles

2.2 C-03 Bolted connection between arm and finger

Calculation for bolted connection between arm and finger





In this calculation, the bolted connection betwen the arm and the finger will be dimensioned. The connection will be dimensioned for the finger of the heel and midsection seal faces, as the loads are greatest on this finger.

$r_{in} := 5\ mm$ *Radius of bolt hole*

$r_{out} := 10\ mm$ *Radius of hinge*

From the motor calculation C-06, the normal forces for the different sealing surfaces has been calculated to be:

$F_h := 34.5\ N$ *Force on heel face*

$F_m := 42\ N$ *Force on midsection face*

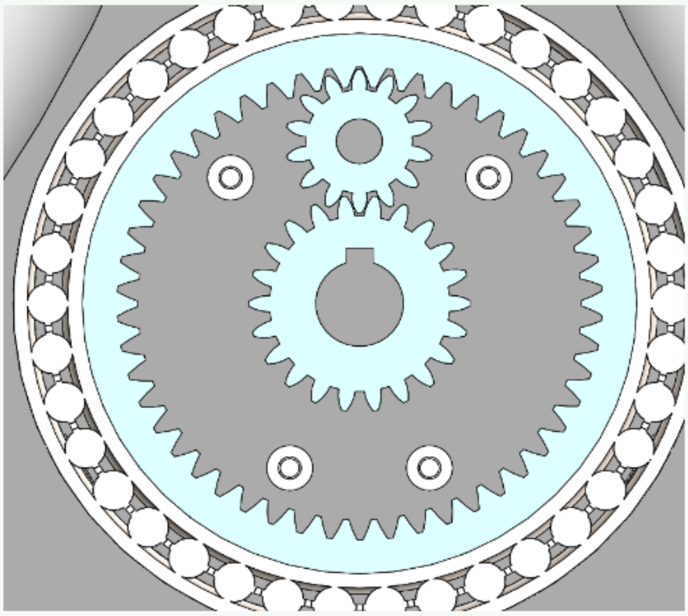
$F_T := F_h + F_m = 76.5\ N$ *Total force*

$A_b := \pi \cdot {r_{in}}^2 = 78.54\ mm^2$ *Area of bolt*

$\tau_b := \dfrac{F_T}{A_b} = 0.974\ MPa$ *Shear stress of bolt*

2.3 C-04 Gear train

Dimensioning of gear train



The gear train will consist of a driving gear, an idle gear and an internal gear. In this calculation, we will determine the optimal gear ratio, and the subsequent dimensions of the gears.

We are constrained by the internal diameter of the arm, the diamterer of the motor shaft and the support bushings for the neck.

We define the subscripts of driving gear, idler gear and internal gear as A, B and C respectively.

The train ratio is independent of the number of teeth on gear B, as the linear velocity on the contacting tangent point between A-B and B-C is equal.

$n_A := 15\ rpm$ *Rotational speed of gear A*

Trail run with predefined pitch circle diameters and module:

$d_{p\_a} := 44\ mm$ *Pitch circle diameter of the driving gear*

$d_{p\_c} := 100\ mm$ *Pitch circle diameter of the idler gear*

$d_{p\_b} := \frac{d_{p\_c}}{2} - \frac{d_{p\_a}}{2} = 28\ mm$ *Pitch circle diameter of the internal gear*

$TR := \frac{d_{p\_a}}{d_{p\_c}} = 0.44$ *Gear ratio*

Given the above dimensions, there is only a few preferred modules that can be used that will give natural numbers for N_a, N_b and N_c while also resulting in gears that are small enough not to interfere with the other sub-systems; these are 1, 1.25 and 2.5.

$m := 2\ mm$ *Selected module for all gears*

$m_{nu} := \frac{m}{mm} = 2$ *Module without unit*

$\phi := 20\ deg$ *Pressure angle of teeth*

$k := 1$ *Full depth teeth*

Minimum number of teeth on idler gear without interference:

$$N_b := \frac{2 \cdot k}{(1 + 2 \cdot m_{nu}) \cdot \sin(\phi)^2} \cdot \left(m_{nu} + \sqrt{m_{nu}^2 + (1 + 2\ m_{nu}) \cdot \sin(\phi)^2} \right) = 14$$

The circular pitch/module must be equal for all gears to ensure correct meshing of gears, therefore:

$N_a := \frac{d_{p\_a}}{m} = 22$ $\quad N_b := \frac{d_{p\_b}}{m} = 14$ $\quad N_c := \frac{d_{p\_c}}{m} = 50$ *Number of teeth*

The resulting tooth dimension will then be as follows:

$a := m = 2\ mm$ *Height of addendum*

$c := 0.25 \cdot m = 0.5\ mm$ *Clearance*

$b := 1.25 \cdot m = 2.5\ mm$ *Height of dedendum*

$h_k := 2 \cdot m = 4\ mm$ *Working depth*

$p_c := \pi \cdot m = 6.283\ mm$ *Circular pitch*

$h_t := 2.25 \cdot m = 4.5\ mm$ *Total depth*

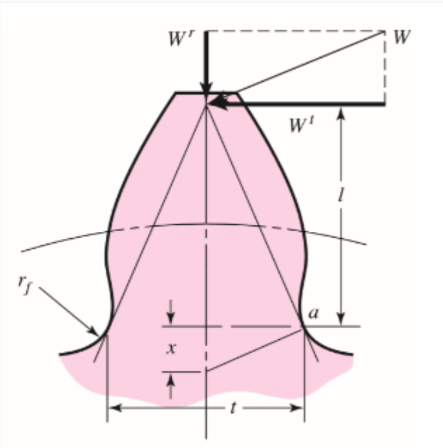
$t := \frac{p_c}{2} = 3.142\ mm$ *Thickness of tooth*

$t_c := 0.25 \cdot m = 0.5\ mm$ *Width of top land*

$F := 20\ mm$ *Face width*

Force analysis of gear train

The force acting on the gears is shown in the figure below.



Number of Teeth	Y	Number of Teeth	Y
12	0.245	28	0.353
13	0.261	30	0.359
14	0.277	34	0.371
15	0.290	38	0.384
16	0.296	43	0.397
17	0.303	50	0.409
18	0.309	60	0.422
19	0.314	75	0.435
20	0.322	100	0.447
21	0.328	150	0.460
22	0.331	300	0.472
24	0.337	400	0.480
26	0.346	Rack	0.485

The output torque from the motor is given as $T := 14.333\ N \cdot m$

$W_t := \frac{2 \cdot T}{d_{p\_a}} = 651.5\ N$ *Tangential force*

$W_r := W_t \cdot \tan(20\ deg) = 237.127\ N$ *Radial force*

The bending stress is calculated with the assumption that the maximal bending stress occurs at point A, and that the force acts on the tip of the tooth.

$Y := 0.322$ *Lewis form factor from table*

$y := \frac{Y}{\pi} = 0.102$ *Lewis form factor, metric conversion*

$\sigma_b := \frac{W_t}{F \cdot p_c \cdot y} = 50.582\ MPa$ *Maximal bending stress*

From this, we can conclude that the gears selected are suitable for use on the SPO Seat polishing tool.

Formulas taken from Budynas–Nisbett: Shigley's Mechanical Engineering Design, Eighth Edition, pp. 714-723.

2.4 C-05 Mass of system

Mass of SPO Seat polishing tool

$m_1 := 0.93\ kg$	Mass of 61826-2RZ bearing
$m_2 := 0.27\ kg$	Mass of 61817-2RZ bearing
$m_3 := 0.025\ kg$	Mass of 61806-2RZbearing
$m_4 := 0.011\ kg$	Mass of 61901 bearing
$m_{motor} := 2.9\ kg$	Mass of motor
$V_{system} := 0.0023799\ m^3$	Volume of entire system, excluding bearings
$P_{F53} := 7810\ \frac{kg}{m^3}$	Density of F53 DSS
$r := 77.5\ mm$	Radius of central hole in base
$V_{ch} := r^2 \cdot \pi \cdot 38\ mm = \left(7.17 \cdot 10^5\right)\ mm^3$	Volume of central hole in base
$V_{gear} := 145472.67\ mm^3$	Volume of gears
$P_{oil} := 0.870\ \frac{kg}{l} = 870\ \frac{kg}{m^3}$	Density of gear oil
$m_{oil} := \left(V_{ch} - V_{gear}\right) \cdot P_{oil} = 0.497\ kg$	Approximate mass of oil

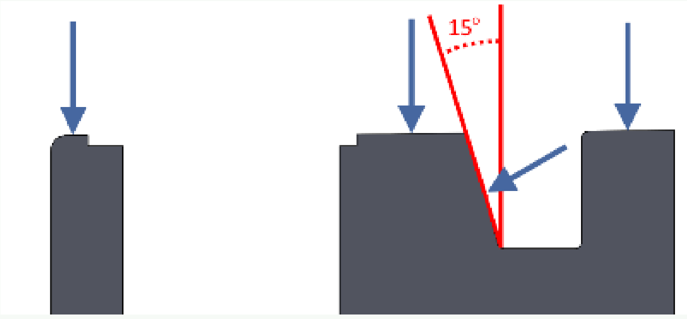
$$m_{total} := m_1 + m_2 + m_3 + m_4 + m_{motor} + m_{oil} + V_{system} \cdot P_{F53} = 23.22\ kg$$

The total mass is therefore:

$$m_{total} = 23.2\ kg$$

2.5 C-06 Motor

Calculation of required motor power and torque



In this calculation, we make the following simplifications/assumptions:

- Force is applied in the negative y-direction towards all sealing surfaces.

Sealing surface	Subscript:
Heel face	h
Seal groove	sg
Midsection face	m
Environmental seal	es

$B := 50\ mm$ *Width of polishing area*

$RPM := 15$ *Rotational speed*

$p := 0.06\ MPa$ *Polishing pressure applied to surface*

$N_{arm} := 2$ *Number of arms*

$\mu := 0.256$ *Frictional coefficient between flange and sandpaper*

Length of face	Midpoint distance from centre	Surface area
$L_h := 11.5\ mm$	$D_h := 196\ mm$	$A_h := L_h \cdot B = 575\ mm^2$
$L_{sg} := 14.5\ mm$	$D_{sg} := 215\ mm$	$A_{sg} := L_{sg} \cdot B = 725\ mm^2$
$L_m := 14\ mm$	$D_m := 225\ mm$	$A_m := L_m \cdot B = 700\ mm^2$
$L_{es} := 3\ mm$	$D_{es} := 270\ mm$	$A_{es} := L_{es} \cdot B = 150\ mm^2$
Frictional forces:	**Normal forces:**	**Torque:**
$F_h := p \cdot A_h \cdot \mu = 8.832\ N$	$N_h := p \cdot A_h = 34.5\ N$	$T_h := F_h \cdot D_h = 1.731\ N \cdot m$
$F_{sg} := p \cdot A_{sg} \cdot \mu = 11.136\ N$	$N_{sg} := p \cdot A_{sg} = 43.5\ N$	$T_{sg} := F_{sg} \cdot D_{sg} = 2.394\ N \cdot m$
$F_m := p \cdot A_m \cdot \mu = 10.752\ N$	$N_m := p \cdot A_m = 42\ N$	$T_m := F_m \cdot D_m = 2.419\ N \cdot m$
$F_{es} := p \cdot A_{es} \cdot \mu = 2.304\ N$	$N_{es} := p \cdot A_{es} = 9\ N$	$T_{es} := F_{es} \cdot D_{es} = 0.622\ N \cdot m$

$F_T := F_h + F_{sg} + F_m + F_{es} = 33.024\ N$ *Total frictional force per arm*

$N_T := N_h + N_{sg} + N_m + N_{es} = 129\ N$ *Total normal force per arm*

$T_T := T_h + T_{sg} + T_m + T_{es} = 7.167\ N \cdot m$ *Total torque per arm*

$L_c := 2 \cdot D_{es} \cdot \pi \cdot RPM = 25.447\ m$ *Length traveled around flange at the specified RPM*

$P := \frac{F_T \cdot L_c}{60 \cdot s} \cdot N_{arm} = 28.012\ W$ *Minimum power required of motor*

$T := T_T \cdot N_{arm} = 14.333\ N \cdot m$ *Minimum torque required of motor*

Forces on heel and midsection finger

$N_{hm} := N_h + N_m = 76.5\ N$ *Normal force*

$F_{hm} := F_h + F_m = 19.584\ N$ *Frictional force*

Forces on seal groove finger

$N_{sg} = 43.5\ N$ *Normal force*

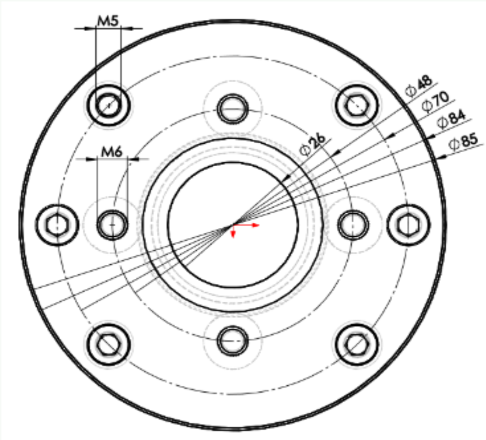
$F_{sg} = 11.136\ N$ *Frictional force*

Forces on environmental seal finger

$N_{es} = 9\ N$ *Normal force*

$F_{es} = 2.304\ N$ *Frictional force*

2.6 C-07 Neck



$T_M := 60\ N \cdot m$ *Torque of motor*

$R_{mf\_out} := 42\ mm$ *Outside radius of motor flange and gear cover*

$R_{mf\_in} := 13\ mm$ *Inside radius of motor flange and gear cover*

$CD_{ibh} := 24\ mm$ *Centre distance of inner bolt holes*

$CD_{obh} := 35\ mm$ *Centre distance of outer bolt holes*

$r_{ibh} := 3\ mm$ *Radius of inner bolt holes (M6)*

$r_{obh} := 2.5\ mm$ *Radius of outer bolt holes (M5)*

$N_{ibh} := 4$ *Number of inner bolt holes*

$N_{obh} := 2$ *Number of outer bolt holes*

$N_{sb} := 4$ *Number of support bushings*

$r_{sb} := 5\ mm$ *Radius of support bushing*

$r_{sb\_bh} := r_{obh} = 2.5\ mm$ *Inner radius of support bushing*

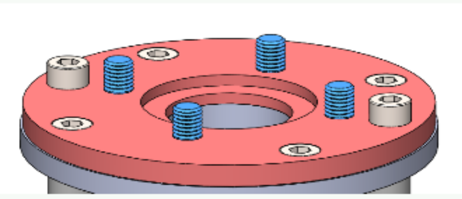
$L_{sb} := 33\ mm$ *Length of support bushing*

Material data for F53 DSS

$\sigma_{max} := 332.6\ MPa$ *Allowable stress*

$E_{sb} := 199956\ \frac{N}{mm^2}$ *Elastic modulus at room temperature*

Shear stress in inner bolt holes (marked in blue)



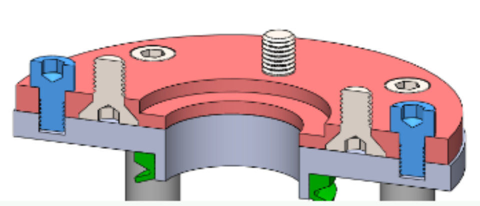
It is assumed that all torque is absorbed through the four bolts

$F_{ibh} := \frac{T_M}{CD_{ibh} \cdot N_{ibh}} = 625\ N$ *Axial force on inner bolts (per bolt)*

$A_{ibh} := \pi \cdot r_{ibh}^2 = 28.274\ mm^2$ *Stress area of inner bolt (M6)*

$\tau_{ibh} := \frac{F_{ibh}}{A_{ibh}} = 22.105\ MPa$ *Shear stress on inner bolts*

Shear stress in outer bolt holes (marked in blue)



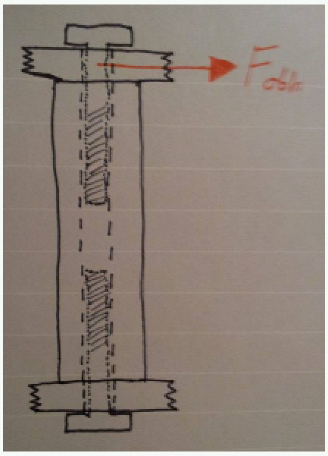
It is assumed that all torque is absorbed through the two bolts

$F_{obh} := \frac{T_M}{CD_{obh} \cdot N_{obh}} = 857.143\ N$ *Axial force on inner bolts (per bolt)*

$A_{obh} := \pi \cdot r_{obh}^2 = 19.635\ mm^2$ *Stress area of inner bolt (M6)*

$\tau_{ibh} := \frac{F_{obh}}{A_{obh}} = 43.654\ MPa$ *Shear stress on inner bolts*

Deflection of support bushing in axial direction:



The support bushing can be imagined to be a cantilever beam being fixed in one end, and subjected to a force at the other. The bolts are disregarded in this calculation.

$A_{sb} := \pi \cdot r_{sb}^2 - A_{obh} = 58.905\ mm^2$ *Area of support bushing*

$M := F_{obh} \cdot L_{sb} = 28.286\ N \cdot m$ *Moment around bottom*

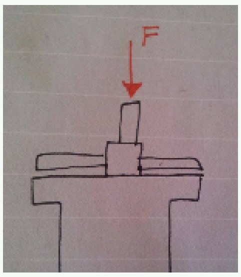
$I_{sb} := \frac{\pi}{2} \cdot \left(r_{sb}^4 - r_{sb\_bh}^4\right) = 920.388\ mm^4$ *Second area of inertia for a hollow cylinder along neutral axis*

$\sigma_b := \frac{M \cdot r_{obh}}{I_{sb}} = 76.831\ MPa$ *Maximal bending stress*

$x_{max} := \frac{F_{obh} \cdot L_{sb}^3}{3 \cdot E_{sb} \cdot I_{sb}} = 55.792\ \mu m$ *Maximal deflection in tangential direction*

Stresses caused by unexpected loads:

If the user leans against the motor, what kind of forces and stresses will the neck be subjected to? In this scenario, it is assumed that the tool is in a vertical position.

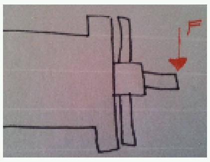


$m_{extra} := 15\ kg$ Assumed mass placed on motor

$F_w := m_{extra} \cdot g = 147.1\ N$ Force on inner bolts

$\sigma_w := \frac{F_w}{A_{ibh} \cdot N_{ibh}} = 1.301\ MPa$ Tensile stress per inner bolt

In this scenario, the motor is in a horizontal position:



$H_{motor} := 150\ mm$ Height of motor, we assume the force is applied to the far end

$F_{ibh\_w} := \frac{F_w \cdot H_{motor}}{N_{ibh} \cdot CD_{ibh}} = 229.843\ N$ Force on each screw, one will be in tension while the other in compression

Dimensioning of inner screws to attach motor:

The screws will be dimensioned to the shear stress caused by the torque of the motor, and tensile stress caused by unexpected loads when the motor is placed in a horizontal position.

Maximal shear stress on inner screws: $\tau_{ibh} = 43.654\ MPa$

Maximal tensile stress on inner screws: $\sigma_{ibh\_w} := \frac{F_{ibh\_w}}{A_{ibh}} = 8.129\ MPa$

Maximal Von Mises stress: $\sigma_{ibh\_vm} := \sqrt{\sigma_{ibh\_w}^2 + \tau_{ibh}^2} = 44.404\ MPa$

From this, we can conclude that M6 screws will be sufficient.

2.7 C-08 Screws between internal gear and arm flange

Amount of screws and their dimensions to fix the internal gear to the arm.

$Pm := 60\ N \cdot m$ Max power output from the motor.

$Db := 6\ mm$ The diameter of the bolts

$L := 0.0575\ m$ Length from center of arm to centre of bolt holes

$a := \pi \cdot \left(\frac{Db}{2}\right)^2 = \left(2.827 \cdot 10^{-5}\right)\ m^2$ Area of 6mm bolt

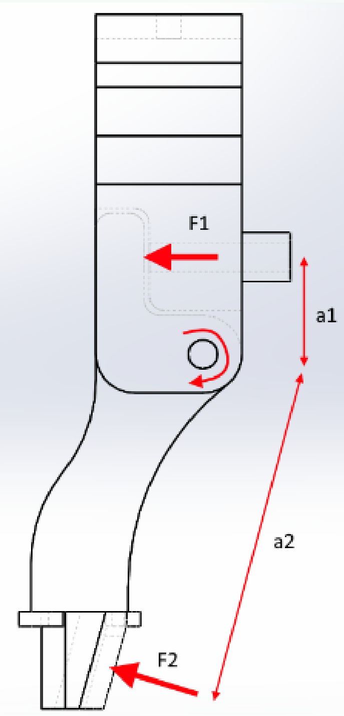
$n := 1$ Number of bolts

$\tau n := \frac{Pm}{L \cdot a \cdot n} = 36.905\ MPa$ Shear stress in each of the n bolts

$\tau n = 36.905\ MPa$

We will design with 4 bolts even though 1 is theoretically enough

2.8 C-09 SG FEM FORCES



$$F_2 := 43.5\ N$$

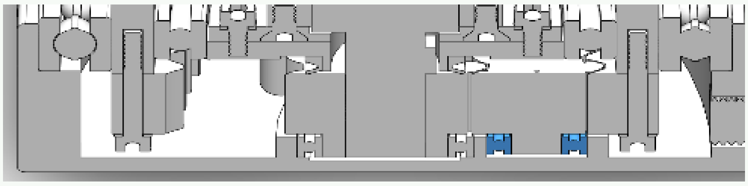
$$a_1 := 20\ mm$$

$$a_2 := 68\ mm$$

$$F_1 := \frac{F_2 \cdot a_2}{a_1} = 147.9\ N$$

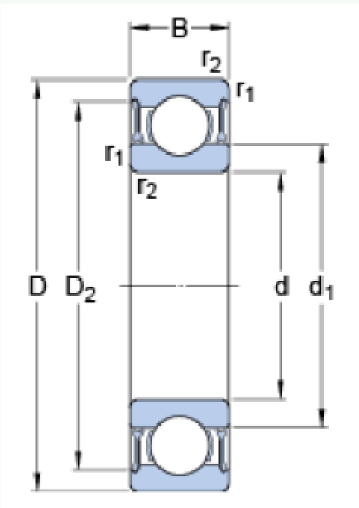
2.9 C-10 PRESS FIT FOR BEARING 61901 TO THE BASE

Press fit for 61901 to the base



In this calculation, we make the following simplifications/assumptions:

- The bearing and the base is considered to be hollow cylinders with the dimensions as shown below.



Bearing dimensions:

$$D := 24\ mm$$

$$d := 12\ mm$$

$$B := 6\ mm$$

Tolerance of D:

$$T_{D\_max} := 0\ \mu m$$

$$T_{D\_min} := -9\ \mu m$$

Base dimensions:

$D_{base} := 34\ mm$ Outer diameter of base slot

$d_{base} := 24\ mm$ Inner diameter of slot, the contact point between bearing and base

$B_{base} := 6\ mm$ Heigth of the wall where the bearing is fitted

Bearing material data:

$E_1 := 210000\ MPa$ Elastic modulus of bearing material (SKF catalogue)

$v_1 := 0.3$ Poisson Ratio of bearing material (SKF catalogue)

Base material data:

$E_2 := 1999956\ MPa$ Elastic modulus of F53 (FO&GT, Material document)

$v_2 := 0.31$ Poisson Ratio of F53 (FO&GT, Material document)

To define the required radial interference, we must first find the required radial stress to hold the bearing in place inside the base. This depend on the axial force and the torque applied to the bearing.

The torque can be neglected because the outer race of the bearing will react to close to no torque. The axial force is in reallity low as well. However, we want to bearing to withstand a pull of 100 Newtons as a safety procaution

$F_{axial} := 100\ N$ Applied force in axial direction to the bearing

$A := \frac{D}{2} \cdot \pi \cdot B = 226.195\ mm^2$ Contact area between bearing and base

$\mu := 0.10$ Fiction Coeffisiant for static contact, (Konstruksjonselementer, 2 edt PP. 168

$n := 4$ Reccomended safety Factor (A textbook of Machine Design, PP 101-102)

The frictional force between the bearing and the body must be greater than the axial load ($F_{axial} = 100\ N$).

Required frictional force: $F_f := F_{axial} \cdot n = 400\ \boldsymbol{N}$

Therefore:
Equation taken from Konstruksjonselementer 2edt, PP 171-172

$$x_2 := \frac{d_{base}}{D_{base}} = 0.706$$

$$x_1 := \frac{d}{D} = 0.5$$

$$p := \frac{F_f}{\mu \cdot A} = 17.684\ \boldsymbol{MPa}$$

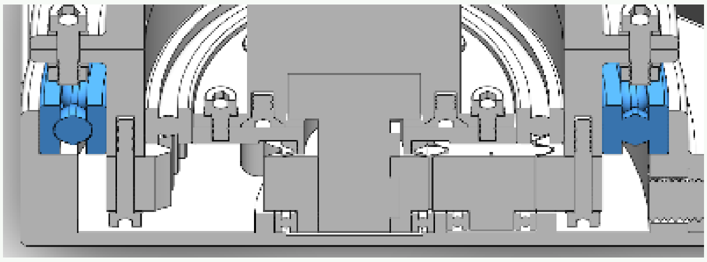
Required radial interference:

$$\Delta d := D \cdot p \cdot \left(\frac{1}{E_2} \cdot \left(\frac{1 + {x_2}^2}{1 - {x_2}^2} + v_2 \right) + \frac{1}{E_1} \cdot \left(\frac{1 + {x_1}^2}{1 - {x_1}^2} - v_1 \right) \right) = 3.462\ \mu m$$

MIT reccomends H7, p6 for guaranteed interference for cold pressed interference fit.
http://www.mitcalc.com/doc/tolerances/help/en/tolerances.htm (05.05.16)

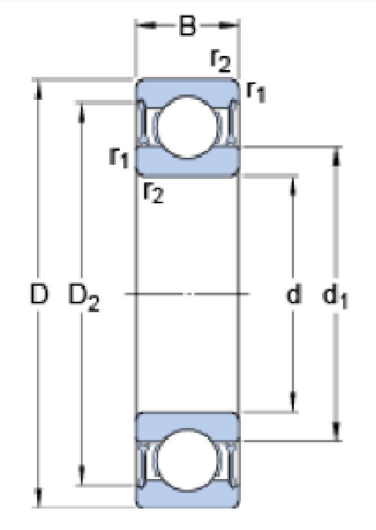
2.10 C-11 Press fit for bearing 61826-2RS1 to the body

Press fit for 61826-2RS1 to the body



In this calculation, we make the following simplifications/assumptions:

- The bearing and the body is considered to be hollow cylinders with the dimensions as shown below.



Bearing dimensions:

$D := 165\ mm$

$d := 130\ mm$

$B := 18\ mm$

Tolerance of D:
$T_{D\_max} := 0\ \mu m$
$T_{D\_min} := -25\ \mu m$

Body dimensions:

$D_{base} := 175\ mm$ Outer diameter of base slot

$d_{base} := 165\ mm$ Inner diameter of slot, the contact point between bearing and base

$B_{base} := 16\ mm$ Heigth of the wall where the bearing is fitted

Bearing material data:

$E_1 := 210000\ MPa$ Elastic modulus of bearing material (SKF catalogue)

$\upsilon_1 := 0.3$ Poisson Ratio of bearing material (SKF catalogue)

Base material data:

$E_2 := 1999956\ MPa$ Elastic modulus of F53 (FO&GT, Material document)

$\upsilon_2 := 0.31$ Poisson Ratio of F53 (FO&GT, Material document)

To define the required radial interference, we must first find the required radial stress to hold the bearing in place inside the base. This depend on the axial force and the torque applied to the bearing.

The torque can be neglected because the outer race of the bearing will react to close to no torque. The axial force is the force that the fingers of two arms will exert onto the arm.

$F_{axial} := 500\ N$ Applied force in axial direction to the bearing

$A := \frac{D}{2} \cdot \pi \cdot B = 4665.265\ mm^2$ Contact area between bearing and base

$\mu := 0.10$ Fiction Coeffisiant for static contact, (Konstruksjonselementer, 2 edt PP. 168

$n := 4$ Reccomended safety Factor (A textbook of Machine Design, PP 101-102)

The frictional force between the bearing and the body must be greater than the axial load ($F_{axial} := 300\ N$).

Required frictional force: $F_f := F_{axial} \cdot n = 1200\ N$

Therefore:
Equation taken from Konstruksjonselementer 2edt, PP 171-172

$$x_2 := \frac{d_{base}}{D_{base}} = 0.943$$

$$x_1 := \frac{d}{D} = 0.788$$

$$p := \frac{F_f}{\mu \cdot A} = 2.572\ MPa$$

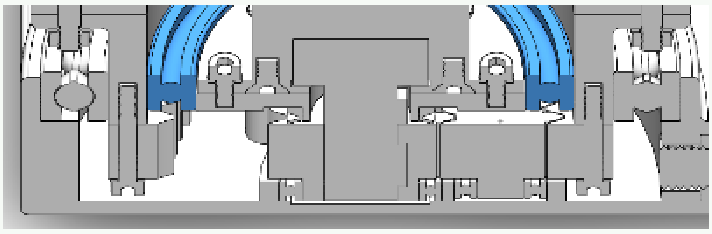
Required radial interference:

$$\Delta d := D \cdot p \cdot \left(\frac{1}{E_2} \cdot \left(\frac{1 + {x_2}^2}{1 - {x_2}^2} + \upsilon_2 \right) + \frac{1}{E_1} \cdot \left(\frac{1 + {x_1}^2}{1 - {x_1}^2} - \upsilon_1 \right) \right) = 11.707\ \mu m$$

MIT reccomends H7, p6 for guaranteed interference for cold pressed interference fit.
http://www.mitcalc.com/doc/tolerances/help/en/tolerances.htm (05.05.16)

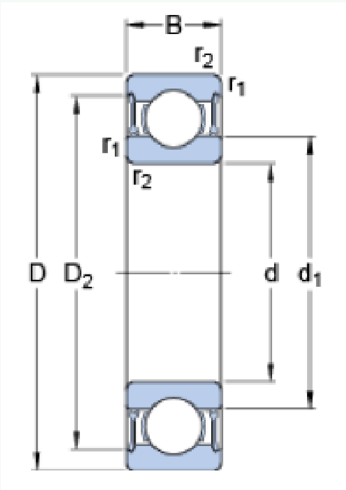
2.11 C-12 Press fit for bearing 61817-2RS1 to the arm flange

Press fit for 61817-2RS1 to the arm flange



In this calculation, we make the following simplifications/assumptions:

- The bearing and the arm flange is considered to be hollow cylinders with the dimensions as shown below.



Bearing dimensions:

$D := 110\ mm$

$d := 85\ mm$

$B := 13\ mm$

Tolerance of D:

$T_{D\_max} := 0\ \mu m$

$T_{D\_min} := -20\ \mu m$

Arm flange dimensions:

$D_{arm} := 130\ mm$ Outer diameter of arm flange

$d_{arm} := 110\ mm$ Inner diameter of arm flange, the contact point between bearing and the arm flange

$B_{arm} := 13\ mm$ Heigth of the wall where the bearing is fitted

Bearing material data:

$E_1 := 210000\ MPa$ Elastic modulus of bearing material (SKF catalogue)

$\upsilon_1 := 0.3$ Poisson Ratio of bearing material (SKF catalogue)

Arm flange material data:

$E_2 := 1999956\ MPa$ Elastic modulus of F53 (FO&GT, Material document)

$\upsilon_2 := 0.31$ Poisson Ratio of F53 (FO&GT, Material document)

To define the required radial interference, we must first find the required radial stress to hold the bearing in place inside the arm flange. This depend on the axial force and the torque applied to the bearing.

The torque can be neglected because the outer race of the bearing will react to close to no torque. The axial force is in reallity low as well. However, we want to bearing to withstand a pull of 300 Newtons as a safety procaution

$F_{axial} := 300\ N$ — Applied force in axial direction to the bearing

$A := \frac{D}{2} \cdot \pi \cdot B = 2246.239\ mm^2$ — Contact area between bearing and base

$\mu := 0.10$ — Fiction Coeffisiant for static contact, (Konstruksjonselementer, 2 edt PP. 168

$n := 4$ — Reccomended safety Factor (A textbook of Machine Design, PP 101-102)

The frictional force between the bearing and the arm flange must be greater than the axial load ($F_{axial} := 300\ N$).

Required frictional force: $F_f := F_{axial} \cdot n = 1200\ N$

Therefore:
Equation taken from Konstruksjonselementer 2edt, PP 171-172

$$x_2 := \frac{d_{arm}}{D_{arm}} = 0.846$$

$$x_1 := \frac{d}{D} = 0.773$$

$$p := \frac{F_f}{\mu \cdot A} = 5.342\ MPa$$

Required radial interference:

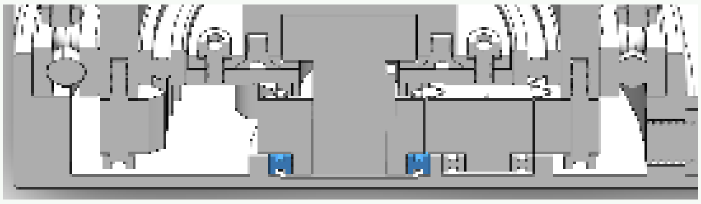
$$\Delta d := D \cdot p \cdot \left(\frac{1}{E_2} \cdot \left(\frac{1+{x_2}^2}{1-{x_2}^2} + v_2 \right) + \frac{1}{E_1} \cdot \left(\frac{1+{x_1}^2}{1-{x_1}^2} - v_1 \right) \right) = 12.12\ \mu m$$

MIT reccomends H7, p6 for guaranteed interference for cold pressed interference fit.
http://www.mitcalc.com/doc/tolerances/help/en/tolerances.htm (05.05.16)

2.12 C-13 Press fit for bearing 61806-2RS1 to the body

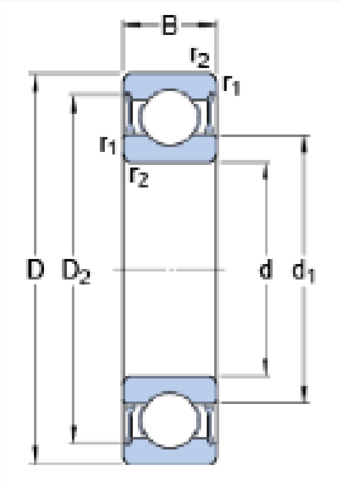
C-13

Press fit for 61806-2RS1 to the base



In this calculation, we make the following simplifications/assumptions:

- The bearing and the base is considered to be hollow cylinders with the dimensions as shown below.



Bearing dimensions:

$D := 42\ mm$

$d := 30\ mm$

$B := 7\ mm$

Tolerance of D:
$T_{D\_max} := 0\ \mu m$
$T_{D\_min} := -11\ \mu m$

Base dimensions:

$D_{base} := 40\ mm$ Outer diameter of base slot

$d_{base} := 30\ mm$ Inner diameter of slot, the contact point between bearing and base

$B_{base} := 7\ mm$ Heigth of the wall where the bearing is fitted

Bearing material data:

$E_1 := 210000\ MPa$ Elastic modulus of bearing material (SKF catalogue)

$\upsilon_1 := 0.3$ Poisson Ratio of bearing material (SKF catalogue)

Base material data:

$E_2 := 1999956\ MPa$ Elastic modulus of F53 (FO&GT, Material document)

$\upsilon_2 := 0.31$ Poisson Ratio of F53 (FO&GT, Material document)

To define the required radial interference, we must first find the required radial stress to hold the bearing in place inside the base. This depend on the axial force and the torque applied to the bearing.
The torque can be neglected because the bearing outer ring of the bearing will react to close to no torque
The axial force is in reallity low as well. However, we want to bearing to withstand a pull of 100 Newtons as a safety procaution

$F_{axial} := 100\ N$ Appliedforce in axial direction to the bearing

$A := \frac{D}{2} \cdot \pi \cdot B = 461.814\ mm^2$ Contact area between bearing and base

$\mu := 0.10$ Fiction Coeffisiant for static contact, (Konstruksjonselementer, 2 edt PP. 168

$n := 4$ Reccomended safety Factor (A textbook of Machine Design, PP 101-102)

The frictional force between the bearing and the body must be greater than the axial load ($F_{axial} = 100\ N$).

Required frictional force: $F_f := F_{axial} \cdot n = 400\ N$

Therefore:
Equation taken from Konstruksjonselementer 2edt, PP 171-172

$$x_2 := \frac{d_{base}}{D_{base}} = 0.75$$

$$x_1 := \frac{d}{D} = 0.714$$

$$p := \frac{F_f}{\mu \cdot A} = 8.661\ MPa$$

Required radial interference:

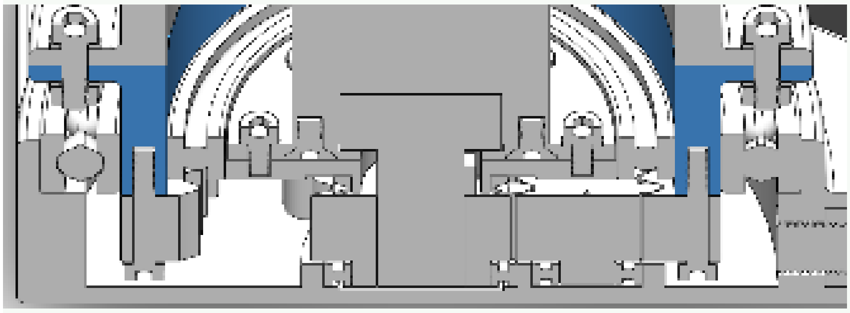
$$\Delta d := D \cdot p \cdot \left(\frac{1}{E_2} \cdot \left(\frac{1 + x_2^{\,2}}{1 - x_2^{\,2}} + v_2 \right) + \frac{1}{E_1} \cdot \left(\frac{1 + x_1^{\,2}}{1 - x_1^{\,2}} - v_1 \right) \right) = 5.528\ \mu m$$

MIT reccomends H7, p6 for guaranteed interference for cold pressed interference fit.
http://www.mitcalc.com/doc/tolerances/help/en/tolerances.htm (05.05.16)

2.13 C-14 Press fit for arm flange on bearing 61826-2RS1

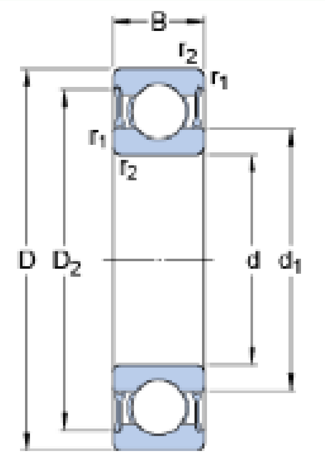
C-14

Press fit for arm flange on 61826-2RS1 outer bearing



In this calculation, we make the following simplifications/ assumptions:

- The bearing and the arm is considered to be hollow cylinders with the dimensions as shown below.



Bearing dimensions:

$D := 165\ mm$

$d := 130\ mm$

$B := 18\ mm$

Tolerance of D:

$T_{D\_max} := 0\ \mu m$

$T_{D\_min} := -25\ \mu m$

Arm dimensions:

$D_{arm} := 130\ mm$ Outer diameter of arm cylinder

$d_{arm} := 110\ mm$ Inner diameter of arm cylinder, the contact point between bearing and arm

$B_{arm} := B = 18\ mm$ Heigth of the wall where the bearing is fitted

Bearing material data:

$E_1 := 210000\ MPa$ Elastic modulus of bearing material (SKF catalogue)

$\upsilon_1 := 0.3$ Poisson Ratio of bearing material (SKF catalogue)

Base material data:

$E_2 := 1999956\ MPa$ Elastic modulus of F53 (FO&GT, Material document)

$\upsilon_2 := 0.31$ Poisson Ratio of F53 (FO&GT, Material document)

To define the required radial interference, we must first find the required radial stress to hold the bearing in place inside the base. This depend on the axial force and the torque applied to the bearing.

The torque can be neglected because the bearing outer ring of the bearing will react to close to no torque. The axial force is the force that the fingers of two arms will exert onto the arm.

$F_{axial} := 500\ N$ — Appliedforce in axial direction to the bearing

$A := \frac{d}{2} \cdot \pi \cdot B = 3675.663\ mm^2$ — Contact area between bearing and base

$\mu := 0.10$ — Fiction Coeffisiant for static contact, (Konstruksjonselementer, 2 edt PP. 168

$n := 4$ — Reccomended safety Factor (A textbook of Machine Design, PP 101-102)

The frictional force between the bearing and the body must be greater than the axial load ($F_{axial} = 500\ N$).

Required frictional force: $F_f := F_{axial} \cdot n = 2000\ N$

Therefore:
Equation taken from Konstruksjonselementer 2edt, PP 171-172

$$x_1 := \frac{d_{arm}}{D_{arm}} = 0.846$$

$$x_2 := \frac{d}{D} = 0.788$$

$$p := \frac{F_f}{\mu \cdot A} = 5.441\ MPa$$

Required radial interference:

$$\Delta d := D \cdot p \cdot \left(\frac{1}{E_2} \cdot \left(\frac{1 + x_2^{\ 2}}{1 - x_2^{\ 2}} + v_2 \right) + \frac{1}{E_1} \cdot \left(\frac{1 + x_1^{\ 2}}{1 - x_1^{\ 2}} - v_1 \right) \right) = 26.605\ \mu m$$

MIT reccomends H7, p6 for guaranteed interference for cold pressed interference fit.
http://www.mitcalc.com/doc/tolerances/help/en/tolerances.htm (05.05.16)

2.14 C-16 Preload on legs threaded rods

Preload on legs threaded rods.

C-16

Forces acting in x-direction:

$Fhm := 19.584\ N$

$Fsg := 11.136\ N$

$Fes := 2.304\ N$

$TOTx := (Fhm + Fsg + Fes) \cdot A = 66.048\ N$

Parameters taken from C-06

$A := 2$ Amount of arms

$L := 3$ Amount of legs

$S := 2$ Safety factor

$d := 16\ mm$ diameter of bolt

$\mu := 0.5$ Steel-Steel under dry conditions

Forces acting in y-direction:

$M := 300\ N$ Weight of machine

$TOTy := M = 300\ N$

$Resultant := \sqrt{TOTx^2 + TOTy^2} = 307.185\ N$

Force from the legs has to excert the resultant

$P := \frac{Resultant \cdot S}{L \cdot \mu} = 409.579\ N$ The force each leg has to exert onto the flanges inner wall.

Necessery torque:

$T := P \cdot d = 6.553\ N \cdot m$ [1]

[1] EFUNDA, 2016, http://www.efunda.com/designstandards/screws/fasteners_intro.cfm

2.15 C-17 SPRINGS FOR HEEL AND MIDSECTION FINGER

C-17

Springs for heel and mid-section finger

Selected material is A313-SS

All equations are taken from Shigley's Mechanical Engineering Design 9th edition by Budynas and Nisbet, Chapter 10 PP 517-560 unless otherwise refered

$E := 1930000\ MPa$ Elastic Modulus of A313-SS
$G := 69000\ MPa$ Shear Modulus
$UTS := 1622.7\ MPa$ Ultimate Tensile Strength [1]
$SY := 1054\ MPa$ Yield Strength [1]

Predefined dimentions and parameters:

$Di := 20\ mm$ Inner diameter of spring
$F := 76.5\ N$ Force to be applied to the faces [2]
$Lf := 40\ mm$ Free length of spring
$Ymax := 0.001\ m$ Shrink Length
$d := 2.5\ mm$ Coil diameter
$\alpha := 0.5$ End condition factor [3]

$Dm := Di + d = 22.5\ mm$ Mid-diameter of spring

Spring index is found by:

$$Ci := \frac{Dm}{d} = 9$$ Is between 4 and 12 which is OK

$\zeta := 0.15$ Fractural overrun to closure

The correction factor is found by:

$$Kb := \frac{4 \cdot Ci + 2}{4 \cdot Ci - 3} = 1.152$$

The largest shear stress is found by:

$$\tau := Kb \cdot \frac{8 \cdot (1 - \zeta) \cdot F \cdot Dm}{\pi \cdot d^3} = 274.57\ MPa$$

$$ns := \frac{SY}{\tau} = 3.839$$ Safety Factor

2.16 C-18 Springs for seal groove finger

C-18

Springs for Seal Groove

Selected material is A313-SS

All equations are taken from Shigley's Mechanical Engineering Design 9th edition by Budynas and Nisbet, Chapter 10 PP 517-560 unless otherwise refered

$E := 1930000\ MPa$ Elastic Modulus of A313-SS

$G := 69000\ MPa$ Shear Modulus

$UTS := 1622.7\ MPa$ Ultimate Tensile Strength [1]

$SY := 1054\ MPa$ Yield Strength [1]

Predefined dimentions and parameters:

$Do := 6\ mm$ Outer diameter of spring

$F := 43.5\ N$ Force to be applied to the faces [2]

$Lf := 37\ mm$ Free length of spring

$Ymax := 7\ mm$ Shrink Length

$d := 2.5\ mm$ Coil diameter

$\alpha := 0.5$ End condition factor [3]

$Dm := Do - d = 3.5\ mm$ Mid-diameter of spring

Spring index is found by:

$Ci := \frac{Dm}{d} = 1.4$ Is between 4 and 12 which is OK

$\zeta := 0.15$ Fractural overrun to closure

The correction factor is found by:

$$Kb := \frac{4 \cdot Ci + 2}{4 \cdot Ci - 3} = 2.923$$

The largest shear stress is found by:

$$\tau := Kb \cdot \frac{8 \cdot (1 - \zeta) \cdot F \cdot Dm}{\pi \cdot d^3} = 61.65\ MPa$$

$ns := \frac{SY}{\tau} = 17.096$ Safety Factor

Number of active coils:

$$Nae := \frac{G \cdot d^4 \cdot Ymax}{8 \cdot Dm^3 \cdot F} = 0.387$$ Na is between 3 and 15, OK $Na := 4$

$Nt := Na + 2 = 6$ Total number of coils

$Ls := d \cdot Nt = 15\ mm$

The spring rate is given by:

$$k := \frac{d^4 \cdot G}{8 \cdot Dm^3 \cdot Na} = 7394.547\ \frac{N}{m}$$

The deflection is given by:

$$\delta := \frac{8 \cdot F \cdot Dm^3 \cdot Na}{d^4 \cdot G} = 0.01\ m$$

The initial force is found by:

$Fi := F - k \cdot \delta = -1.421 \cdot 10^{-14}\ N$

To check for absolute stability:

$$Lo := \frac{\pi \cdot Dm}{\alpha} \left(\frac{2 \cdot (E - G)}{2 \cdot (G + E)} \right)^{0.5} = 0.136\ m$$

Has to be larger than Lo for absolute stability

[1] Childs, Mechanical DESIGN, 2nd edt, 2004, PP 234

[2] Team16 Calculation Document C-06

[3] Budynas and Nisbet, Shigley's Mechanical Engineering Design 9th edt, 2011, PP 522

2.17 C-19 Springs for environmental seal finger

C-19

Springs for environmental seal finger

Selected material is A313-SS

All equations are taken from Shigley's Mechanical Engineering Design 9th edition by Budynas and Nisbet, Chapter 10 PP 517-560 unless otherwise refered

$E := 1930000\ MPa$ Elastic Modulus of A313-SS
$G := 69000\ MPa$ Shear Modulus
$UTS := 1622.7\ MPa$ Ultimate Tensile Strength [1]
$SY := 1054\ MPa$ Yield Strength [1]

Predefined dimentions and parameters:

$Di := 20\ mm$ Inner diameter of spring
$F := 9\ N$ Force to be applied to the faces [2]
$Lf := 40\ mm$ Free length of spring
$Ymax := 0.001\ m$ Shrink Length
$d := 2.5\ mm$ Coil diameter
$\alpha := 0.5$ End condition factor [3]

$Dm := Di + d = 22.5\ mm$ Mid-diameter of spring

Spring index is found by:

$Ci := \frac{Dm}{d} = 9$ Is between 4 and 12 which is OK

$\zeta := 0.15$ Fractural overrun to closure

The correction factor is found by:

$$Kb := \frac{4 \cdot Ci + 2}{4 \cdot Ci - 3} = 1.152$$

The largest shear stress is found by:

$$\tau := Kb \cdot \frac{8 \cdot (1 - \zeta) \cdot F \cdot Dm}{\pi \cdot d^3} = 32.302\ MPa$$

$ns := \frac{SY}{\tau} = 32.629$ Safety Factor

Number of active coils:

$$Nae := \frac{G \cdot d^4 \cdot Ymax}{8 \cdot Dm^3 \cdot F} = 3.286$$ Na is between 3 and 15, OK $Na := 4$

$Nt := Na + 2 = 6$ Total number of coils

$Ls := d \cdot Nt = 15\ mm$

The spring rate is given by:

$$k := \frac{d^4 \cdot G}{8 \cdot Dm^3 \cdot Na} = 7394.547\ \frac{N}{m}$$

The deflection is given by:

$$\delta := \frac{8 \cdot F \cdot Dm^3 \cdot Na}{d^4 \cdot G} = 0.001\ m$$

The initial force is found by:

$Fi := F - k \cdot \delta = 0\ N$

To check for absolute stability:

$$Lo := \frac{\pi \cdot Dm}{\alpha} \left(\frac{2 \cdot (E - G)}{2 \cdot (G + E)} \right)^{0.5} = 136.405\ mm$$

Has to be larger than Lo for absolute stability, in this case the spring will be stabillised within the hole it is contained.

[1] Childs, Mechanical DESIGN, 2nd edt, 2004, PP 234

[2] Team16 Calculation Document C-06

[3] Budynas and Nisbet, Shigley's Mechanical Engineering Design 9th edt, 2011, PP 522

2.18 C-20 GEAR BOLTS

C-20

$Pmax := 60\ N \cdot m$ Max torque output from the motor.

$Pavg := 54\ N \cdot m$ Average torque output from the motor

$Db := 5\ mm$ The diameter of the bolts

$L := 0.0575\ m$ Length from center of arm to centre of bolt holes

$Sut := 798.4\ MPa$ UTS of f45

$a := \pi \cdot \left(\frac{Db}{2}\right)^2 = 19.635\ mm^2$ Area of 6mm bolt

$A := 2$ Amount of arms

We can now calculate the amount of bolts we need if design with the endurance strength Se of the material. This is found by using Marin's method taken from Shigley's 9th edt pp. 287 .

$Ka := 4.51 \cdot 798.4^{-0.265} = 0.768$ Surface factor, Machined

$Kb := 1.24 \cdot 6^{-0.107} = 1.024$ Size factor

$Kc := 1$ Loading factor, bending

$Kd := 1$ Temp. factor 20 celcius

$Ke := 0.62$ 99.9999 % Relability

$Se' := 0.5 \cdot Sut$

$Se := Ka \cdot Kb \cdot Kc \cdot Kd \cdot Ke \cdot Se' = 194.46\ MPa$

Amount of bolts:

$n1 := \frac{Pmax}{L \cdot a \cdot Se} = 0.273$ 1 bolt is needed

However. This calculation does does not consider that the maximum fluxuation is 22 MPa. According to DNV, the maximum Δ for 10^7 cycles is 22 MPa. This means that the max stress in each bolt can be 22 MPa, because τmin will be 0 (full stop of machine)

With x bolts the fluxuation will be: $x := 6$

$Fmax := \frac{Pmax}{L} = 1.043\ kN$ $\tau max := \frac{Fmax}{x \cdot a} = 8.857\ MPa$

$Favg := \frac{Pavg}{L} = 939.13\ N$ $\tau avg := \frac{Favg}{x \cdot a}$

Stress Concentration Factor, taken from Shigley's 9th edt PP.
equation 3-48

$SCF := \frac{\tau max}{\tau avg} = 1.111$ $SCF2 := 2$

SCF2 is the Stress Concentration Factor with a safety factor

$\Delta \cdot SCF2 = 17.715\ MPa$ Is lower that our allowed stress, so we can conclude that three bolts are enogh.

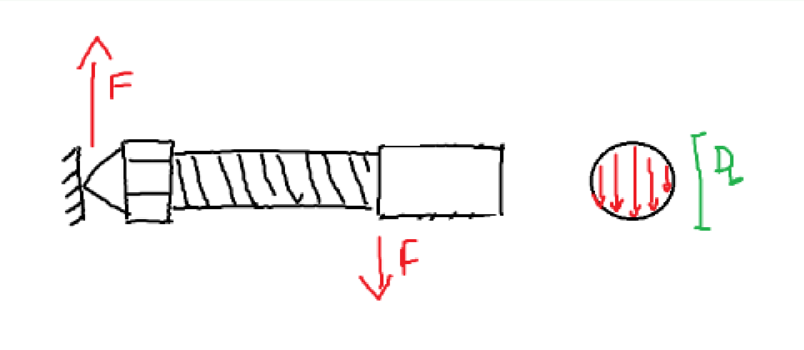
We use this factor to find out the number of bolts we need to prevent fatigue

$x = 6$

2.19 C-21 Shear in leg

C-21

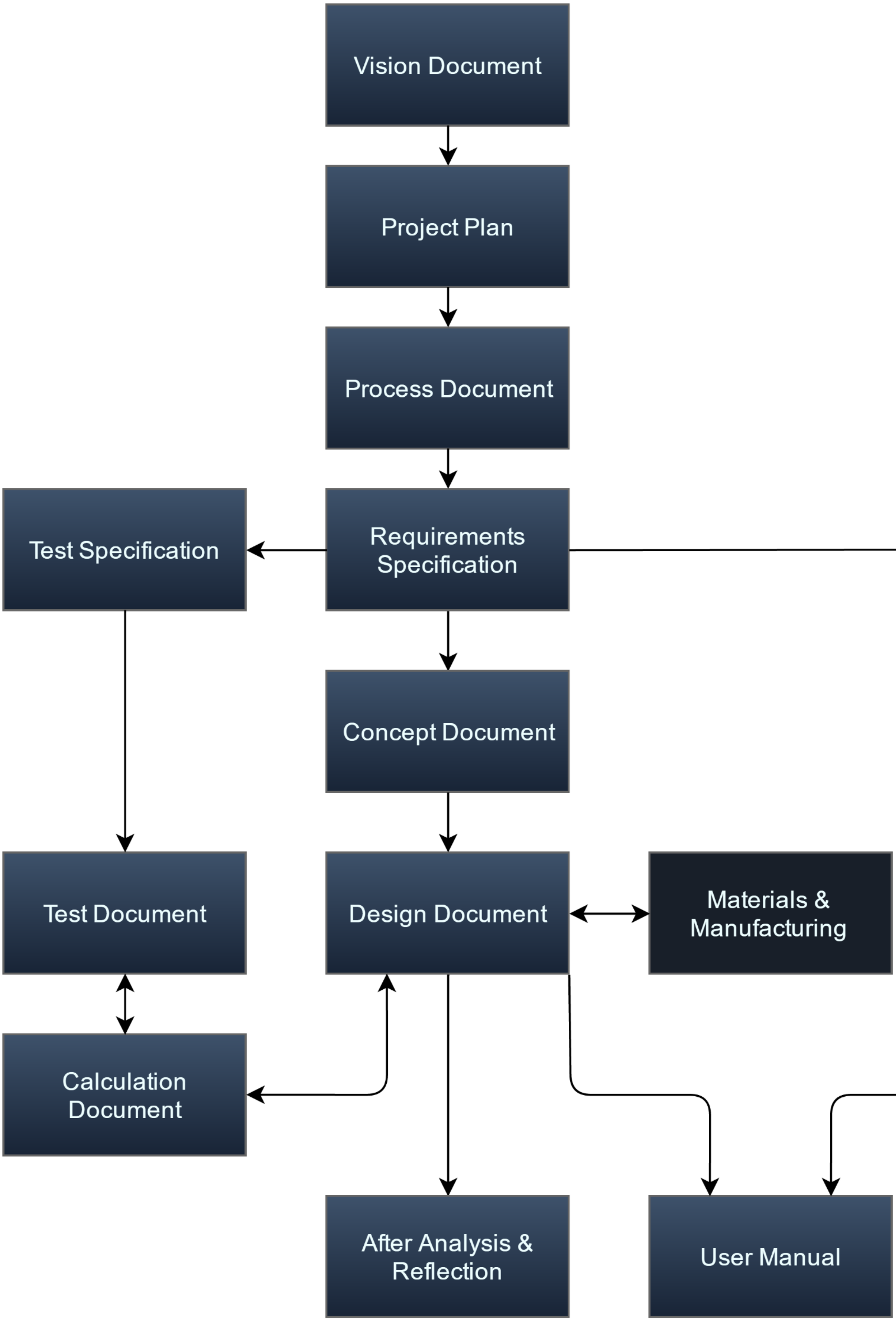
Average shear in the threaded rod



$$Wm := 250\ N$$
$$Wa := 50\ N$$
$$F := \frac{2 \cdot (Wm + Wa)}{3} = 200\ N$$
$$Db := 16\ mm$$

The average shear τavg of the screw: $$\tau avg := \frac{F}{\left(\frac{\pi \cdot Db^2}{4}\right)} = 0.995\ MPa$$

Note that the Yield strength for shear is 1/3 of the yield strength of the same material in tension/compression


Vision Document
Project Plan
Process Document
Requirements Specification
Test Specification
Concept Document
Test Document
Design Document
Materials & Manufacturing
Calculation Document
After Analysis & Reflection
User Manual

MATERIAL & MANUFACTURING DOCUMENT

Freudenberg Bachelor 2016

SPO CF Seat polishing tool

Arian Krasniqi, Richelieu Dahn, Odd Eirik Hardem, Morten Grøsfjeld

VERSION	DOCUMENT NUMBER	DATE	RESPONSIBLE	STATUS
1.0	009	22.05.2016	All	Finalized

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1.0 Document

1.1 Document history

Version	Date	Changes
0.1	08.05.2016	Document created
1.0	22.05.2016	Finalized

Table 1 - Document history

1.2 Definition of abbreviations

Abbreviation	Definition
CAD	Computer Assisted Design
CF	Compact Flange
DSS	Duplex Stainless Steel
FEA	Finite Element Analysis
FEM	Finite Element Method
FO&GT	Freudenberg Oil & Gas Technologies
HV	Hardness Vickers (22)
OTSC	Off The Shelf Components
SCC	Stress Corrosion Cracking
SPO	FO&GT brand name for compact flanges (Steel Products Offshore)
USD	United States Dollar

Table 2 - Definition of abbreviations

1.3 Introduction

The purpose of this document is to prove that the materials used in our system fulfills the requirements set by the stakeholders.

When designing a mechanical system, it is crucial to choose suitable materials for all components and parts. Wrong or poor material selection can cause failures that in the worst case can jeopardize the health and safety of the operator. It is important to respect passive stakeholders when selecting materials. We have chosen to follow the codes and guidelines from NORSOK when selecting material for our system. This is because the machine will be used in off shore environments, and strict rules and regulations apply there.

Corrosion is a big concern when designing systems for use in offshore environments. Therefore, we have looked closely into the types of corrosion that we believe can occur on the system.

Different components also require different manufacturing methods. The method depends highly on the material itself, the shape and function.

1.4 Scope

The document contains information about metal alloys used in the system. This information includes but are not limited to mechanical properties, chemical composition and corrosion resistance. All selected materials are justified and backed up with reliable sources.

We have also dedicated a whole chapter to corrosion where we look into the different types that can affect our system and precautions taken to avoid them.

For all components that has to be manufactured we have selected one or more manufacturing method. All the components and methods can be viewed in Table 8.

Lastly, we have included a cost breakdown study that gives an insight of the total price of the system.

2.0 SELECTED MATERIALS

2.1 MATERIAL SELECTION PATH

During the elaboration stage of the project lifecycle, we decided that the leg sub-systems were to consist of a galvanized steel alloy, while the body sub-system were to have an aluminium alloy.

The reason for this is that the body and the legs were judged to have the highest influence on the overall weight and strength of the system. Research and discussion about the leg sub-systems led us to the conclusion that the hardness and mechanical properties of the galvanized steel alloy was adequate. Given the specified loads, keeping stress levels and elastic deformation is important to keep within acceptable limits.

An aluminium alloy was originally chosen for the body as weight was to be minimized while retaining relatively high strength and rigidness. An advantage of aluminium is its very high resistance of corrosion as a result of the oxide layer on surfaces exposed to oxygen (1 p. 152). However, when in contact with other materials such as galvanized steel, galvanic corrosion occurs (2 p. 14). This led to the decision of applying one type of material to all components in the system; to be more specific the stainless steel (3). After research on the stainless steel materials, our team concluded that the super duplex stainless steel (*super DSS*) (3) was suitable.

2.2 F53 SUPER DSS

Among others, the super DSS is a type of stainless steel that has a two-phase microstructure, which has grains that consist of ferritic and austenitic stainless steel (4). The duplex family consists of grades that are designed to have a microstructure in the annealed condition, which consists of equal proportion of ferrite and austenite (4) (5).

Figure 1 below displays how both the austenitic (yellow) and ferritic (blue) phases are mixed in relation to each other (4). As you can see, the austenitic phase has the form of an "island" that is surrounded by the ferritic phase. So when the DSS is melted, it solidifies from a liquid phase to a structure that is more ferritic (4). Nevertheless, as the DSS cools down to room temperature, approximately half of the ferritic grains change its form to grains that are more austenitic, causing about the same amount of microstructure in each phase as stated above (4). This type of stainless steel provides the perfect combination of economy, weldability and toughness. Furthermore, they are selected for use in situations where the properties of both strength and corrosion are crucial (5).

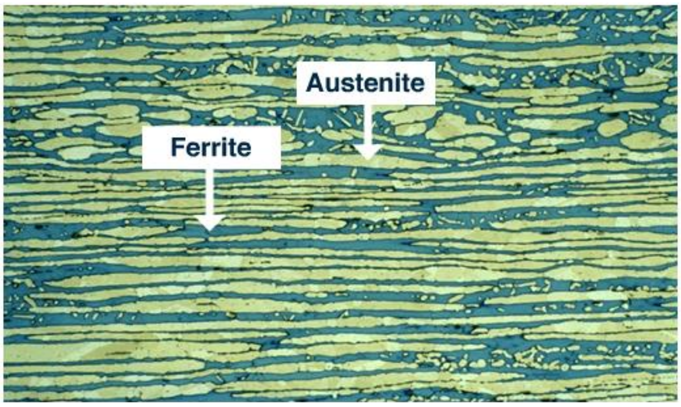

Figure 1 – Microstructure of DSS (4).

Generally, the mechanical properties of the DSS include the same properties of the austenite and ferrite stainless steel. This means the yield strength of the DSS is normally higher than the yield strength of the austenitic stainless steels. The main reason for this is the fact that the ferritic stainless contributes to the high strength as its yield strength is higher than those of the austenitic stainless steels. When added to the austenite stainless steel, the strength of DSS increases. Meanwhile, the DSS have a high level of ultimate tensile strengths, which is usually between 600 MPa – 800 MPa (3), (5), (6).

The grade of super DSS our team decided to go for is the F53 material (Also referred to as Duplex *2507).* This grade of material is designed to be used in applications that require and demand an exceptional amount of strength and corrosion resistance (7). More specifically, two of the most important characteristics of this grade are its very good resistance to chloride corrosion, and its mechanical strength. The use of this F53 material is suitable for environments that are extremely aggressive to vulnerable materials with low corrosion resistance. These environments include warm chlorinated seawater and acidic chloride containing media (8).

For a further justification of the decision to use this material on our system, it is only right to present a list of the suitable environments and field of technology/engineering that the material is generally applied to. However, below is a list of some of the areas that our chosen material can be applied to in Table 3*:*

#	APPLICATIONS
1	*Desalination equipment*
2	*Chemical process pressure vessels, piping & heat exchangers*
3	*Marine industry and shipbuilding* Some examples are: valves, propellers & shafts, oil & chemical tankers
4	*Offshore oil production/technology*
5	*Oil & gas industry equipment* Some examples are: pumps, valves, pipes, vessels, wellhead & subsea equipment
6	*Civil engineering* Example: sewage treatment

Table 3 - Applications of F53 DSS (7).

Among the list of applications for the "F53" material, it is obvious that *#4 and #5* on Table 3 will best suit the conditions of our system, as it will on multiple occasions be used in an offshore environment among others. Research also shows that this material is highly used within the oil & gas industry. We may conclude from the information above that we have chosen a suitable material.

The characteristics of the "F53" material include (8), (7):

- Very high resistance to pitting and crevice corrosion
- Very High mechanical strength
- Excellent resistance to chloride stress corrosion cracking
- Good general corrosion resistance in acids
- Excellent resistance to erosion corrosion
- Excellent resistance to corrosion fatigue
- Low rate thermal expansion
- Combination of properties given by austenitic and ferritic structure
- Good weld- and workability

2.1.1 F53 PROPERTIES

Table 4 shows all relevant properties of the F53 material. The content of this table is in accordance with FO&GT regulations when designing for their different products that require material of this kind. We will therefore make use of this data.

Data table generated using the Material Toolkit rev.L by PLU. date: 14.04.2016

Tem. [°C]	E [MPa] data up to 426.7 °C	ν [] data at RT	S [MPa] data up to 200 °C	1.5 x S [MPa] data up to 200 °C	SMYS [MPa] data up to 200 °C	UTS [MPa] data up to 200 °C	α_L [m/m°C] data up to 815.6 °C	κ [W/mm°C] data up to 815.6 °C	C_p [J/kg°C] data up to 815.6 °C	ρ [kg/mm3] data at RT
21.1	199956	0.31	332.6	499.0	550.1	798.4	1.2600E-05	0.014192	510.0	7.81E-06
30.5	199238	0.31	327.4	491.1	537.6	785.8	1.2701E-05	0.014290	511.4	7.81E-06
39.9	198520	0.31	322.2	483.3	525.1	773.3	1.2794E-05	0.014405	513.4	7.81E-06
49.3	197802	0.31	317.0	475.5	512.5	760.8	1.2855E-05	0.014580	517.1	7.81E-06
58.8	197076	0.31	312.9	469.4	502.8	751.0	1.2916E-05	0.014758	520.9	7.81E-06

Material name: **SA-182 F53 23Cr-7Ni-4Mo-N DNV derating**

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Young Modulus E	ASME 2013, Section II, Part D, Table TM-1, Material group H
Poisson ratio ν	ASME 2013, Section II, Part D, Table PRD (Poissons ratio), High alloy steels (duplex / austenitic-ferritic)
Density ρ	ASME 2013, Section II, Part D, Table PRD (Density), High alloy steels (duplex / austenitic-ferritic)
Allowable Stress S	ASME 2013, Section II, Part D, Appendix 10, Table 10-100, page 943, S = min (SMYS/1.5;UTS/2.4)
Specified Minimum Yield Strength SMYS	80 ksi derated according to DNV-OS-F101 2012, section 5, C304, Figure 2 22Cr-25Cr
Ultimate Tensile Strength UTS	116 ksi derated according to DNV-OS-F101 2012, section 5, C304, Figure 2 22Cr-25Cr
Linear Thermal Expansion α_L	ASME 2013, Section II, PartD, Table TE-1, Other Low Alloy Steels Group 2
Thermal Conductivity κ	ASME 2013, Section II, PartD, Table TDC (TC), Material group K
Specific Heat C_p	ASME 2013, Section II, PartD, Table TCD, General note A (Cp=TC/(Dens*TD)
Material type	Duplex material

Table 4 - F53 material properties.

2.1.2 CHEMICAL COMPOSITION

Generally, the contents within this grade of the duplex material includes 25% chromium, 4% molybdenum and 7% nickel. These extremely high contents of specifically the molybdenum, chromium and nitrogen contribute towards the excellent resistance to chloride pitting & crevice corrosion attack, the duplex structure provides the F53 material with an exceptional resistance to chloride stress corrosion cracking (7). Figure 2 below shows an overview of the chemical composition (in percentage) that our chosen material contains.

Chemical Composition, %

Cr	Ni	Mo	C	N	Mn
24.0-26.0	6.0-8.0	3.0-5.0	0.030 Max	.24-.32	1.20 Max
Si	**Cu**	**P**	**S**	**Fe**	
0.80 Max	0.50 Max	0.035 Max	0.020 Max	Balance	

Figure 2 - Chemical composition of F53.

2.3 302 Stainless steel

The criteria for the selection of materials for the spring is that it should have suitable mechanical properties such as modulus of rigidity and elasticity. These properties are directly correlated with the dimensions of the spring and the amount of applied force the spring is able to exhibit. (9 p. 233).

The 302 stainless steel ASTM no. A313 is part of the family of stainless steels (301,302, 303,304,316,347); it has good corrosion resistance due to the addition of nickel and chromium (10). The 302 stainless steel type and super duplex are close to each other in the galvanic series (chapter 3.1), such that this corrosion is negligible.

Chemical Composition			Specifications	Designations
Element	Min %	Max %		
C	-	0.12	AMS 5688	W.Nr 1.4310
Mn	-	2.00	ASTM A313	UNS 30200
P	-	0.045	ASTM A580	AWS 160
S	-	0.03	BS 970	
Si	-	1.00	BS 2056	
Cr	17.00	19.00		
Ni	8.00	10.00		

Mechanical Properties

Density	8.0 g/cm^3
Melting Point	1420°C
Coefficient of Expansion	17.6 µm/m °C (20 - 100°C)
Modulus of Rigidity	70.3 kN/mm^2
Modulus of Elasticity	187.5 kN/mm^2

Figure 3 - Material Composition and Mechanical Properties (28).

2.4 A2-70

A2-70 is an austenitic stainless steel that is used in some of our OTSC. The material is sometimes referred to as ASTM 304 and it follows the ISO 3506 standard.

When selecting materials for offshore use, it is important to follow the guidelines from Norsok. In the Norsok guidelines, it is mentioned that materials with good availability is preferred (13 p. 6).

A2-70 is a widely used material for fasteners and is more common than sister alloys like A2-50 and A2-80 (14). This is why we have selected A2-70 as our material for OTSC.

Some of the selected A2-70 OTSC have to be machined to fit in our system. These operations include drilling and cutting. The material does not have great machinability properties (15). However, keeping in mind that the parts of the components that are to be machined are not under any high stresses, we have concluded that the operations are acceptable.

The tables below show the properties of A2-70 along with the chemical composition.

		Bolts, Screws and Studs (Part 1)			Nuts (Part 2)
Property Class	Diameter Range	Tensile Strength R_m (Nmm^{-2})	0.2% Proof Stress $R_{p0.2}$ (Nmm^{-2})	Elongation A (mm)	Stress under Proof Load S_p (Nmm^{-2})
50	≤M39	500	210	0.6*d*	500
70	≤M24	700	450	0.4*d*	700
80	≤M24	800	600	0.3*d*	800

Table 5 - Properties of A2-70.

Grade	Chemical Composition (% maxima unless stated)									Types Included
	C	Si	Mn	S	P	Cr	Mo	Ni	Cu	
A1	0.12	1	6.5	0.15-0.35	0.20	16-19	0.7	5-10	1.75-2.25	303, 1.4305
A2	0.1	1	2	0.03	0.05	15-20	-	8-19	4	304,349S17 (BS3111) 1.4567
A4	0.08	1	2	0.03	0.045	16-18.5	2-3	10-15	1	316,396S17 (BS3111)

Table 6 - Chemical composition of A2-70.

2.5 683-17

All bearings in our system are made out of ISO 683-17. All stainless steel bearings from SKF comes in this ISO standardized material. The material is similar to SS-304, and will therefore not cause any galvanic corrosion to other components they are in contact with.

The steel is austenitic and has a Cr content of 18%. More accurate information about the material composition is unavailable for us (16).

2.2 Polishing material

2.2.1 Selection criteria

When we elaborated on which polishing material we wanted to use for the machine, we consulted with FO&GT to find out what properties they found important. We also discussed internally about this and concluded that the material criteria should be:

- Cheap - To reduce costs of each operation
- Effective - To ensure a good result
- Accessible – To make sure that the material is available in other locations.
- Fast and easy to replace

From a practical view, we concluded that we mainly had three options.

- Hard grindstone
- Soft grindstone
- Sandpaper

All three options were tested on a SPO CF and we got good results that helped us decide which material to use (17 p. 3.0). It appears that the hard grindstone wears out very fast and is therefore not a good option. The soft grindstone on the other hand is excellent against wear, but will be difficult to align evenly on the seal surfaces. The reason being because the flange surfaces have an angular difference throughout the circumference of the flange.

2.2.2 Emery sandpaper

The sandpaper self-aligned very good and provided an even polish. However, as mentioned in the test report, we recommend a finer grit than 240 for the final polishing. BOSCH, among other manufacturers can deliver emery sandpaper with grit sizes 180, 240, 320 and others (not finer, only coarser) (17). Sandpaper is therefore very accessible.

With these test-results and the experience from FO&GT who can confirm that sandpaper is good enough even for hand-polishing (18), we decided to use emery sandpaper as our material for polishing.

We recommend emery sandpaper, because it meets all the requirements set for the polishing materials/process (18 pp. R1.07, R1.08, R1.09, R1.11). Emery is a material that consist of crystalline aluminium oxide, which is an incredibly hard material. The average hardness is measured to approximately 1000HV (19). Compared to the DSS that the flanges are made of which is around 300HV (20), it is more than three times as hard.

Many of the flanges that FO&GT have to refurbish are covered by rust or paint, and the hard aluminium oxide is well suited for these operations (21 p. 5).

However, a drawback with sandpaper is that from experience it will easily get clogged up with debris (18), which reduces the performance of the paper. We therefore recommend that the operator apply a form of lubrication to the paper and the flange surface before initiating the polishing process. The lubricant will increase the service life of the sandpaper. This is mostly because it will bind the debris together such that they do not clog the sandpaper (22 pp. 966-969). The lubrication may be water, oil, grease or similar. Whichever form of lubrication the operator chooses to use; we do however recommend a green[1] product. The first reason being the most obvious one is that the less damage you do to the environment the better, and second one being that more countries and companies now have strict regulations about hazardous fluids (22 p. 969).

3.0 Corrosion

Corrosion is an important factor while designing a product such as ours. All metals are in one way or another subjected to corrosion, and it is only a matter of time before they are discovered. As the polishing tool will be used in different environments, the chances of corrosion attacks are likely to occur. An example of this it the offshore environment that the tool will be exposed to. Such environments contain electrolytes such as salt water that could easily damage the tool if the right material is not chosen.

Our chosen material gives a security for the polishing tool against different forms of corrosion that have been mentioned above. Details about these corrosions that are going to act on the system and how to mitigate the risk of these attacks can be found below.

3.1 Galvanic corrosion

Galvanic corrosion is defined as being the effect resulting from contact between two different metals or alloys with different electrode potential. Greater difference in electrode potential will increase the speed of the corrosion. By using materials that have similar electrode potential, this can be prevented. We have used the galvanic series table and identified the materials that have been selected for the system, and made sure that they have similar electrode potential. Another way to prevent this type of corrosion is to isolate components by using a non-conductive material, such as paint or gaskets (23 p. 2).

Material	Electrode Potential in Volts
F53	Approximately 0 (23)
A2-70	-0,05 to -0,1 HBV
SS 302	-0,05 to -0,1 HBV
BS970	-0,05 to 0,05 HBV
683-17	-0,05 to -0,1 HBV

Table 7 - Our selected materials and their electrode potential.

3.2 Pitting corrosion

Pitting is an extremely localized form of corrosion that occurs in metals, leading to the creation of small holes within them.

This type of corrosion take place as the presence of an oxidizing cation, which enables the formation of pits, including when oxygen is not available. Nevertheless, even when oxygen is available, all chlorides turn out to be dangerously reactive. This also happens in the presence of hydrogen peroxide. Pitting corrosion is especially active in stainless steels as the cause of pitting is when inclusions emerge through the passive film in stainless steel. Galvanic coupling is then established between the discontinuous zones, which form small anodes where metal dissolution occurs and the remainder of the surface where the cathodic reaction takes place. It is also active in other metals such as aluminium, passive iron, and copper, just to mention a few (23 p. 4).

One can reduce pitting corrosion by using materials that are appropriate for the environments they are to be used in. It is also advisable that one uses cathodic protection like a sacrificial zinc anode.

3.3 Crevice corrosion

Crevice corrosion occurs when part of a metal surface is shielded from the environment and the rest is in exposed to an electrolyte. Oxygen will start to diffuse out from the crevice because oxygen is used on the surface. This will eventually cause the crevice to become an anode that will corrode. This type of corrosion is avoided by the use of welds in affected areas rather than bolts or riveted joints where it is necessary. Also in the case where two surfaces are in contact we will grease all of the seals and seal- planes, by using only solid and non-porous seals. (23 p. 3).

3.4 Fretting Corrosion

Fretting corrosion is a combined damage mechanism involving corrosion at points where two moving metal surfaces make rubbing contact. This occurs when the system is subjected to vibrations, caused by the relative movement of the contacting surfaces and to compressive loads. When the frictional movement in a corrosive medium is continuous, the resulting process is termed tribocorrosion. The sliding connector, springs, HM/E finger can be affected by fretting corrosion.

We prevent this type of corrosion by using:

- Lubrication with oils or greases; this to reduce friction and exclude oxygen from the interface.
- Increase in the hardness of one or both materials in contact. Certain material combination shows better friction behavior then others. Surface hardening treatments can be beneficial.
- Use of seals to absorb vibrations and exclude oxygen, and/ or moisture.
- Reduction of the frictional loads in certain cases, or on the contrary increase the frictional loads to attenuate vibrations.
- Modification of the amplitude of the relative movement between the two contacting surfaces (25 p. 8).

4.0 Manufacturing process

Our system consists of multiple parts and components that have to be manufactured from raw material. When manufacturing something it is important to use the best possible manufacturing method. A good selection of processes can both reduce total cost of the process and increase the quality of the product.

Dimensional tolerance is important because we are creating a polishing tool that is going to operate on a workpiece that is highly sensitive to geometrical changes. This will require of the SPO CF seat polishing tool; close dimensional tolerances for when the different components are assembled and mated together. The dimensional tolerances will also affect the total cost of the manufacturing process. Although this affects the cost of the product, it is necessary to make it function properly (22 p. 1013).

Information about surface finishes from different methods are taken from *Mechanical DESIGN 2nd edt. By Peter R. N. Childs, table 15, 4 pp 307* (9).

4.1 Method

Component	ID	Method
M16 Cap Nut		Off The Shelf
M16 Threaded Rod		Off The Shelf – Cut to desired length
M16 Joining Nut		Off The Shelf – drill hole on top
Bearing Idler		Off The Shelf
Bearing Pinion		Off The Shelf
Bearing Inner		Off The Shelf
Bearing Outer		Off The Shelf
Spur Gear Idler		Off The Shelf
Spur Gear Pinion		Off The Shelf
Spur Gear Internal		Off The Shelf – Drill holes
Pillars		Rods – Turn to correct thickness, Cut, Drill holes, Thread
V-ring Seal		Off The Shelf
Gear Cover		Cut from sheet - CNC
Arm Flange Pipe*		Open Die Forge from pipe, weld
Arm Flange Plate*		CNC, weld
Arm cylinder Pipe*		Open Die Forge, weld
Arm cylinder arm*		CNC one long profile, then cut into four pieces, weld
Arm*		CNC one long profile, then cut into four pieces, weld
HM&E slider connector		CNC
HS Bracket		CNC
SG Slider Connector		CNC
SG finger		CNC
Cap Nut SG		Off The Shelf
Body		CNC from forged billet
HEX jam nut		Off The Shelf
Comp. Spring HM		Off The Shelf
Comp. Spring E		Off The Shelf
Comp. Spring SG		Off The Shelf
Motor Flange		Cut from sheet - CNC

Table 8 - Manufacturing of components.

- The components designated with this star (*) are to be welded.

Milling

For the removal or material in order to achieve straight edges, we will use peripheral milling. Peripheral milling is an excellent manufacturing method when material has to be removed in straight lines. However, the surface finish from milling is not excellent (averaging from R_a $6{,}3 - 0{,}8$). Although 0.8 is a good surface finish, it is far from guaranteed.

The absolute best surface finish one can achieve from milling is R_a $0{,}2$. Therefore, milling can be used even where tolerances are strict, as long as the right cutting tool is selected. The CNC machine should perform this process.

Turning

Turning is a process where a piece is attached to a lathe and turned with a high speed. In turning the operator can remove material, cut and polish the surface of the material. Hole drilling can also be done on the end of the material. The operation speed on the lathe depends on the material and the process.

Only a few components in our system will be turned. It is however the best process when working on cylindrical workpieces and one can also achieve an excellent surface finish down to R_a $0{,}05$

Forging

Forging is a manufacturing method that offers many advantages. Fairly complex designs can be forged out from rods or billets. The consequence of this process is often increased stiffness and strength in the material, as a result of the cold work that is done.

For the pipes of the arms, open die forging will be used to reduce the thickness of the material. This will be forged with the impression die forging method and later be machined in a CNC.

Numerous parts in the system will be forged. Some of these parts will require machining afterwards to achieve the desired tolerances. Parts like the arm-cylinder-pipe that does not depend on a strict tolerance will not require any treatment after the forging.

Welding

We will use welding to manufacture some of the parts that are not suitable to manufacture in one piece. For the parts that are to be welded.

4.2 Cost breakdown

For a cost estimation of the system, it is important to consider which material is selected. A cheap material will reduce the cost of the manufacturing but increase the level of maintenance required. More expensive materials like the F53 that we have selected will increase the total cost of the production, but the material properties ensure that minimum maintenance is required and long lifespan of the product.

Activity	Cost breakdown
Design	5 %
Materials	50 %
Direct labour	15 %
Indirect labour	30 %

Table 9 - Cost breakdown.

The total cost breakdown of the manufacturing process listed in Table 9 is a typical breakdown of costs in modern manufacturing. The percentages indicated can however vary significantly depending on product type (1 pp. 32-33).

Direct labour concerns the labour that is directly involved in manufacturing the product. Indirect labour cost pertains to the service of the total manufacturing operation; also called the overhead (22 p. 33).

4.3 Arm manufacture

The arm sub-system consists of components that require multiple manufacturing and requires strict tolerances to work properly. The figures (5,6,7) below show the welds marked with green.

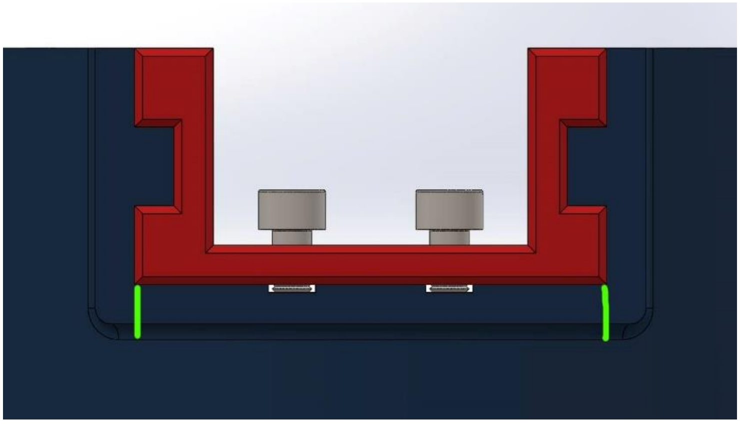

Figure 4 - Direct view on the arm system with emphasized welds.

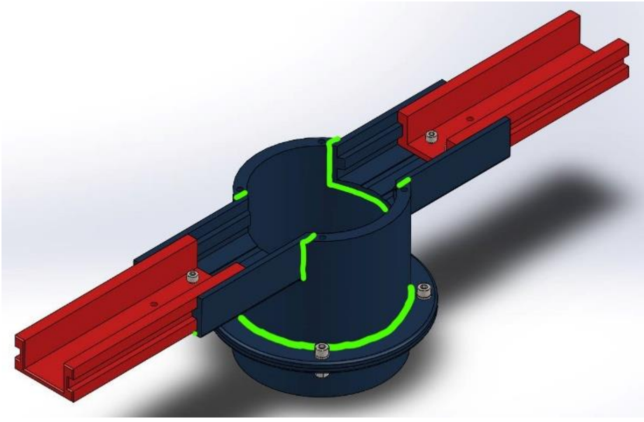

Figure 5 - Isometric view on the arm system with emphasized welds.

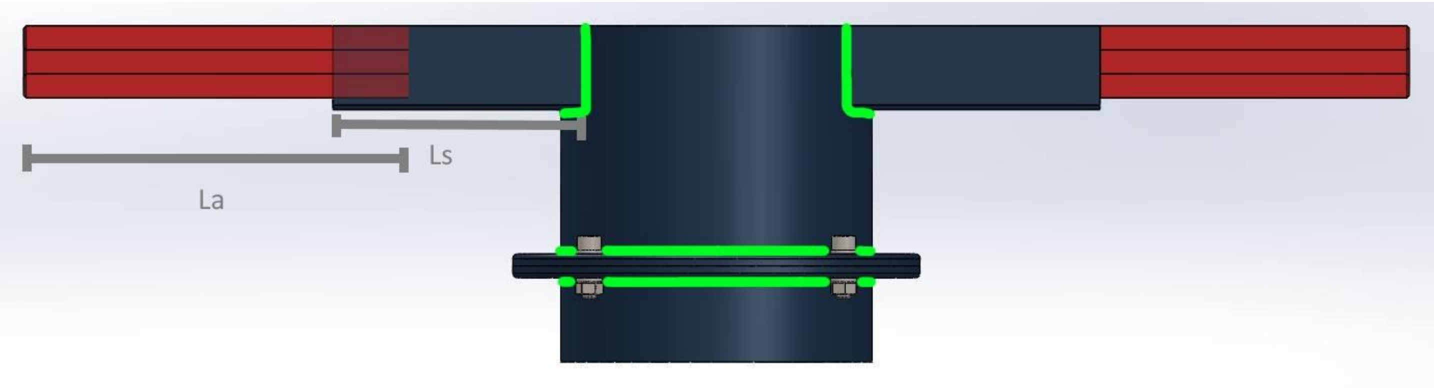

Figure 6 - Side view on the arm system with emphasized welds.

4.3.1 Arm

As seen on the figures (5,6,7), the inner arm does not consist of any welds. This component is designed to be impression die forged from a billet. After the forging is completed, it will be inserted into a CNC machine for finishing. The finishing process consists of milling to get a better surface finish and achieve the correct tolerances. Drilling and threading will be done where the bolts are located.

We recommend that both inner arms are manufactured at the same time and with a length $> 2L_a$, and later cut into two pieces. This will save time while manufacturing the piece and reduce the cost.

4.3.2 Cylinder

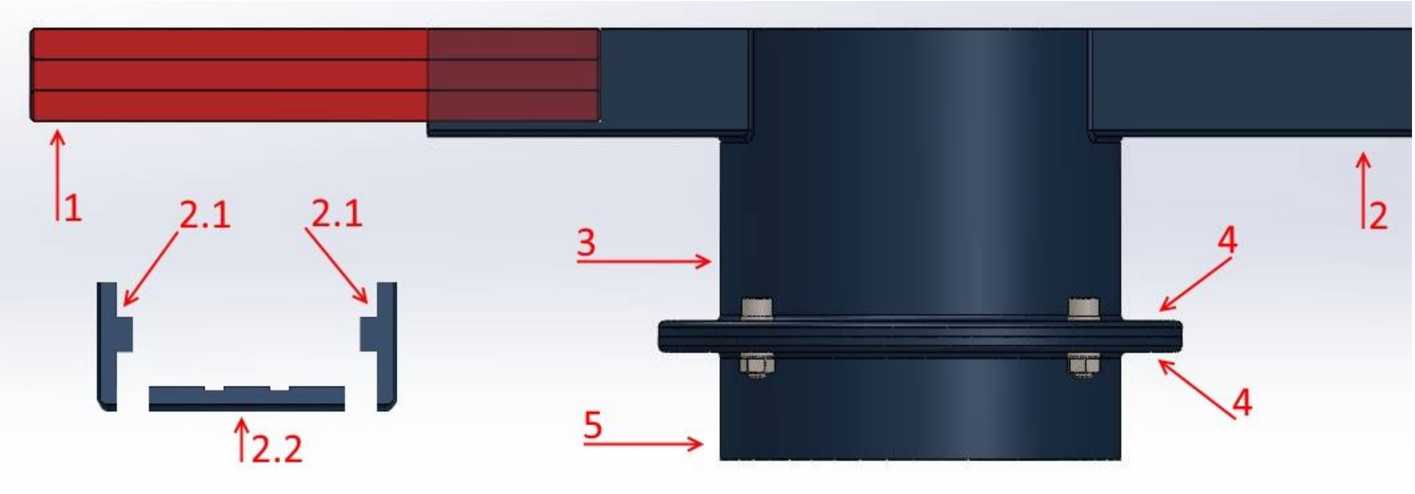

Figure 7 - Arm sub-system with numbers.

The rest of the parts in the arm sub-system is to be welded together. All the names of the sub-system are listed in Figure 7.

#	Name
1	Inner arm
2	Outer Arm
2.1	Outer Side
2.2	Outer Bottom
3	Top Cylinder
4	Lower Flange
4	Top Flange
5	Lower Cylinder

Table 10 - Arm sub-system names.

Lower- and Top Cylinder

Both of the cylinders have the same dimension, and should therefore be manufactured parallel with each other. The cylinders will be open die forged from a pipe and later cut. The Top Cylinder have to be cut in so that the outer arm can be welded to it and the inner arm can slide smoothly over it.

Lower- and Top Flange

Both of the cylinders are to be welded to a flange. These two flanges are identical and will be cut out in a CNC machine from sheet metal. On Figure 5, Figure 6, Figure 6; you can see where the welds are located.

Outer arm

The outer arm will be welded together from three parts where two of them are identical. When they are welded together with the outer bottom piece (5.2), the inner arm should be used as a dolly to ensure the correct measurements. The identical parts should be manufactured at the same time to save time and costs.

4.4 Spring manufacture

The spring material that is to be used for the springs in our system is 302 stainless wire – ASTM No. A313. The dimensioned spring (11 pp. 17, 18, 19) is an OTSC with this material. After enquiring with a spring manufacturer through customer service (12) about the possibility to manufacture the spring with custom material, we learned that it costs 300 USD to manufacture 25 pieces. Other options include changing the dimensions of the shaft that the spring is to be attached to by +3 mm in diameter and decreasing the free length of the spring by 2mm.

Select.		Price	TSS Part#	Outer Diameter (mm.)	Inner Diameter (mm.)	Free Length (mm.)	Rate (N./mm.)	Sugg. Max. Deflection (mm.)	Sugg. Max. Load. (N.)	Solid Height (mm.)	Wire Dia. (mm.)	Total Coils	Material Type	End Type	Finish
		$9.28	PC2700-27790-5.500-SST-38.100-CG-N-MM	27.7876	22.4536	38.1	7.880707575	18.288	142.3430912	14.732	2.667	5.500	SST-Stainless Steel	CG	N
		$27.76	PC2700-27940-5.500-SST-38.100-CG-N-MM	27.94	22.606	38.1	7.530453905	19.05	142.3430912	14.732	2.667	5.500	SST-Stainless Steel	CG	N

End Type: **C** = Closed Ends, **CG** = Closed and Ground Ends, **O** = Open Ends
Finish: **BO** = Black Oxide, **GI** = Gold Irridite, **N** = None, **Z** = Zinc

Figure 8 - Off the shelf components.

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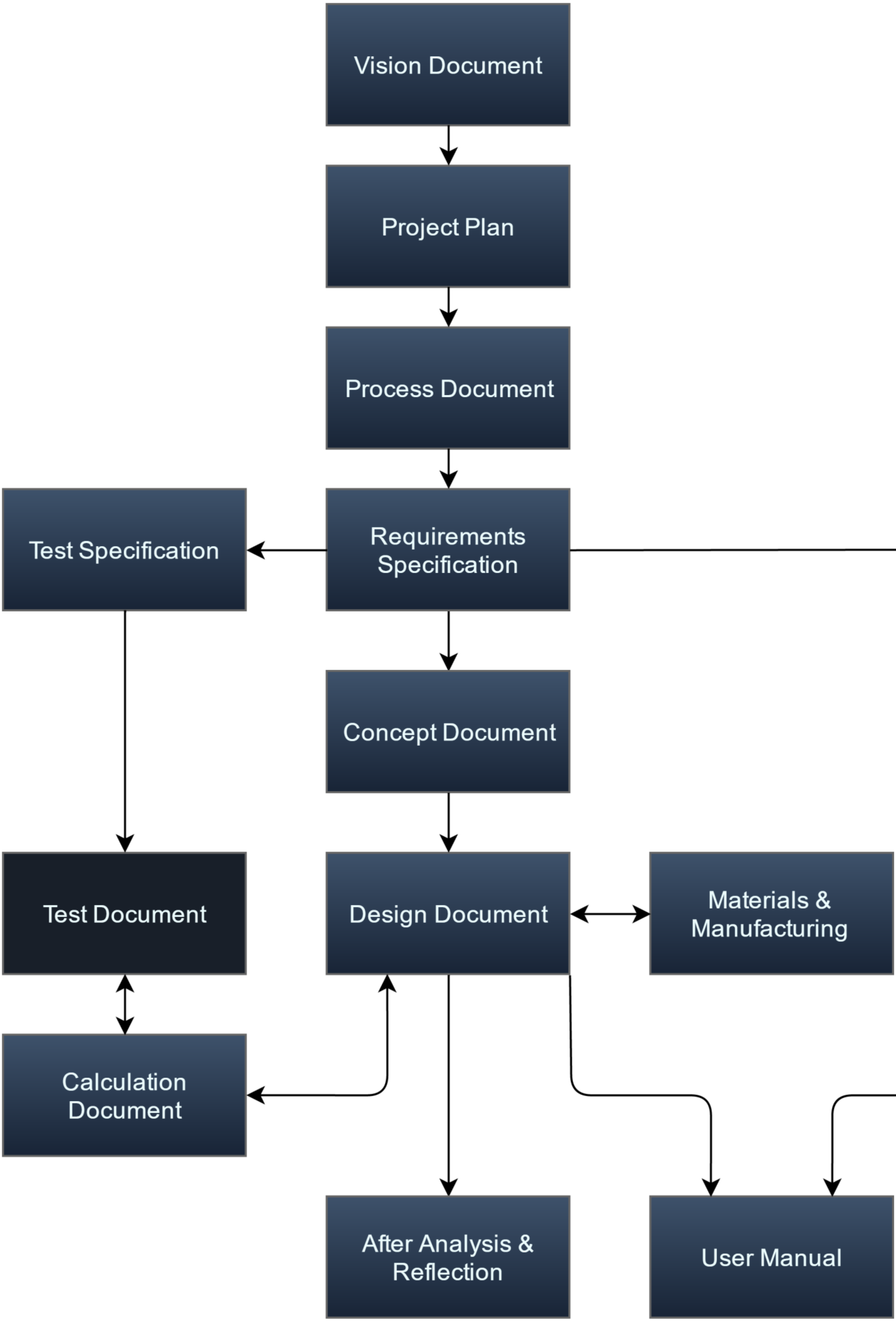
Vision Document
Project Plan
Process Document
Test Specification
Requirements Specification
Concept Document
Test Document
Design Document
Materials & Manufacturing
Calculation Document
After Analysis & Reflection
User Manual

TEST DOCUMENT

Freudenberg Bachelor 2016

SPO CF Seat polishing tool

Arian Krasniqi, Richelieu Dahn, Odd Eirik Hardem, Morten Grøsfjeld

VERSION	DOCUMENT NUMBER	DATE	RESPONSIBLE	STATUS
1.0	010	22.05.2016	All	Finalized

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1.0 Document

1.1 Document history

Version	Date	Changes
0.1	08.05.2016	Document created
1.0	22.05.2016	Document finalized

Table 1 - Document history

1.2 Definition of abbreviations

Abbreviation	Definition
CAD	Computer Assisted Design
CF	Compact Flange
DOF	Degree Of Freedom
FEA	Finite Element Analysis
FEM	Finite Element Method
FO&GT	Freudenberg Oil & Gas Technologies
OTSC	Off The Shelf Components
SPO	FO&GT brand name for compact flanges (Steel Products Offshore)
SWS	SolidWorks Simulation

Table 2 - Definition of abbreviations

1.3 Introduction

The purpose of the test document is to validate all of our system requirements, making sure they are met. The requirements are tested from the existing test specification, assuring ourselves that we have a functional system. Please note that the tests are performed on a CAD 3D model and not a physically constructed product. Requirements that are dependent of a physical product are tested by some case studies where all necessary information is given for justification. This document will also give an overview of how the bottom up method of testing is conducted in order to verify our system and discover possible defects within it. The document will include a full finite element analysis (FEM) with results of our components, sub-systems and entire system that are conducted in SWS. It also contains results of some physical tests that were performed for the decision making of a suitable polishing head for our system.

1.4 Scope

The scope of the Test Document is the following:

- FEM tests
- Requirements validation
- Physical tests on different polishing heads

1.5 Related documents

- Requirement specification
- Test specification
- Calculation

2.0 FEM Test

2.1 Legs

2.1.1 Test procedure

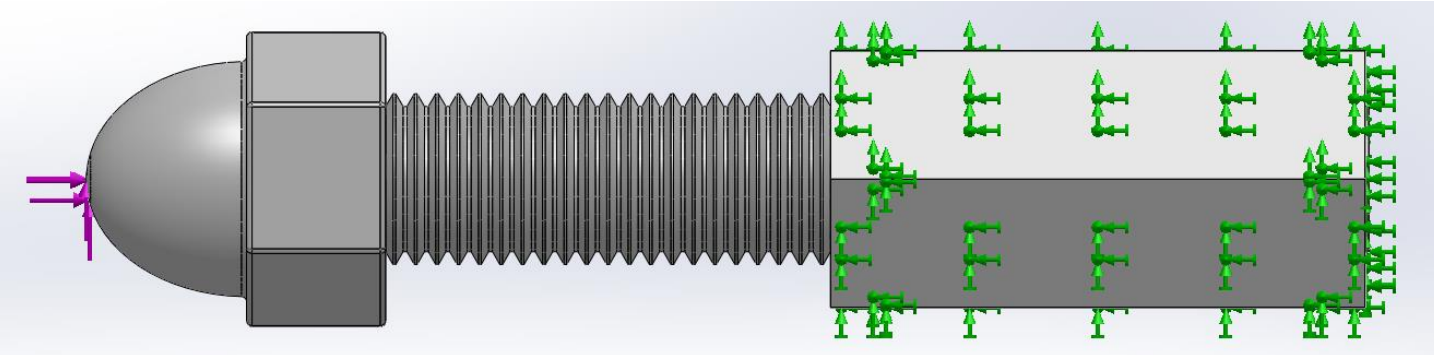

Figure 1 - Forces and fixtures on leg sub-system.

Assumptions and simplifications

For the testing of this sub-system, some simplifications and assumptions had to be made. One of these is related to the cap nut. For the preload force to be placed on the tip of the cap nut that is in contact with the inner wall of the flange, a simplification had to be done where we had to model a split line in SW. This simplification allows us to apply the force properly, making it close to reality (Figure 2). Another simplification is the fillets being neglected on the joining nut.

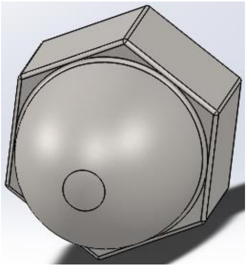

Figure 2 - Split line on cap nut.

Fixtures

While testing a sub-system such as the legs, some predictions (Figure 3) have to be in terms of how the deformation will occur (1). Therefore, the fixture on a single leg will be completely different from that of the ones on the entire system. We have predicted that each leg will be deformed as displayed in Figure 3, and have therefore applied the forces to each leg as described in the "forces" section of this chapter to achieve these results.

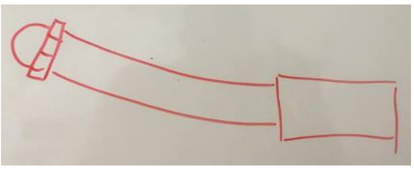

Figure 3 - Predicted deformation.

The legs are components that are placed into the body sub-system, therefore when testing the strength of a single leg, it has to be fixed in such a way that the right results are generated. However, the fixture is a normal one that is placed around the joining nuts as seen on figure 1 above.

Forces

The applied forces on this component are the preload and the weight force of the system. As each leg is fastened on the inner wall of the flange, a preload of 200 N (2 pp. C-16) will be applied on the cap nut component of this component as shown in Figure 4. This force is therefore exerted in the axial direction of the leg.

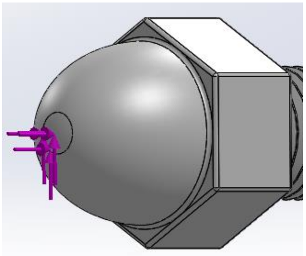

Figure 4 - Forces on cap nut.

A mass force of the system is also applied on the tip of the cap nut for each leg, but in a vertical direction. This illustrates that, as each leg is fastened into the inner wall of the flange (in contact with the tip of the cap nut), a vertical force will be exerted on it in form of the system`s weight. The value of this force per leg is 98.1 N, and is also applied as shown in Figure 4.

2.1.2 Result

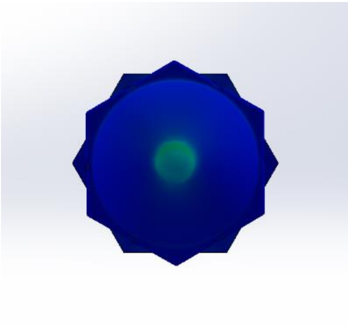

Figure 5 - Stress distribution, front view.

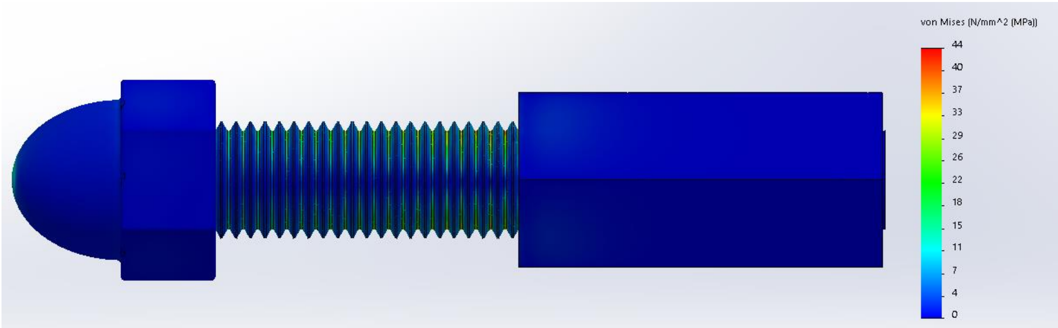

Figure 6 - Stress distribution, left view.

Stresses

The result shows that the highest stress that each leg has when forces are applied is 44 MPA. These stresses can mostly be seen in the threaded rod, and are very low compared to our chosen materials yield strength and allowable stress (3). The stresses will therefore not cause any damages or have any kind of effect on the legs.

Deformation

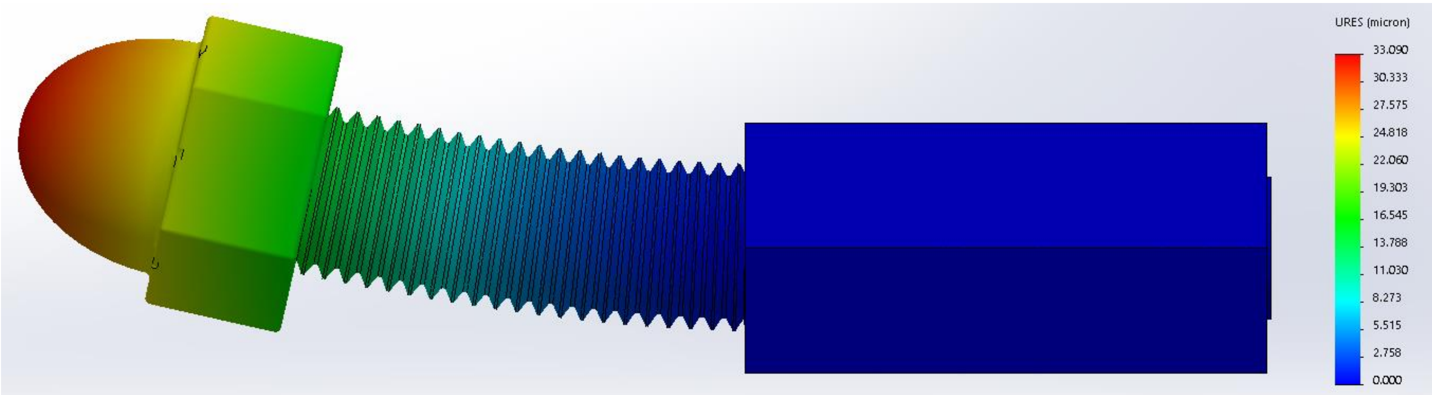

Figure 7 - Deformation of leg, viewed from the left.

As seen on Figure 7 above, the displacement of the leg is at a value of 33.090 µm. In reality, this value is very low and would therefore cause no defects or damages on the system. The visual displacement shown in Figure 7 is greatly exaggerated.

2.1.3 Conclusion

To conclude with this FEA test, we can see that each leg on our system will be able to withstand all of the necessary applied forces. The stresses will therefore not cause any damages or have any kind of effect on the legs, and they are ready for deployment.

2.2 Neck

Two static tests have been performed for the neck sub-system, one with only the motor flange, and one with the gear cover along with the pillars. The purpose of these tests is to prove the mechanical soundness of the neck sub-system, both in terms of stress and elastic deformation.

2.2.1 Test procedure of gear cover and pillars

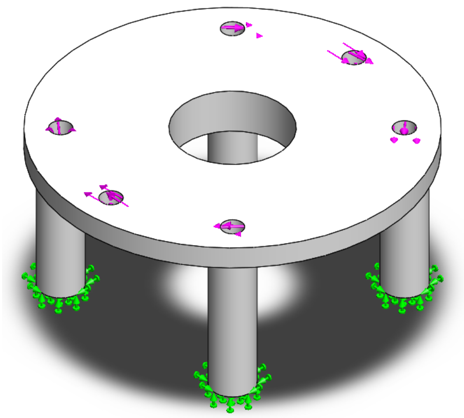

Figure 8 - Forces and fixtures on gear cover and pillars.

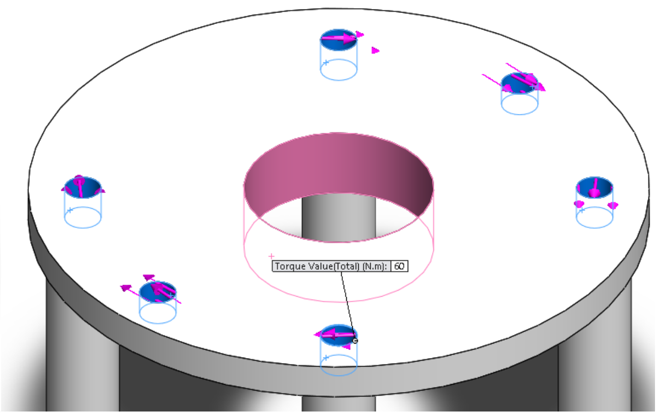

Figure 9 - Definition of torque on gear cover.

Assumptions and simplifications

An assumption made is that the entire torque of the motor is absorbed through the six boltholes of the gear cover. This is not accurate, as most of the motor torque will be absorbed through frictional contact with the sealing surfaces. However, if the motion of the arm is somehow fully resisted, the neck will be subjected to the full reaction torque from the motor.

The V-ring seal attached to the gear cover is disregarded in this test, as the frictional forces that would stem from its contact with the driving gear are negligible.

Fixtures

The assembly has been fixed on the bottom of all four pillars, as they themselves will be fixed in the body sub-system.

The gear cover and the pillars have been bonded, meaning they are regarded as a single component for the test. This is a simplification of the bolted connection between the gear cover and the pillars. The shear stresses in the bolts have been calculated by hand (2 pp. C-07).

Forces

The torque has been defined in the boltholes as seen in Figure 9. The value of this torque is 60 Nm, and is equally divided into all boltholes.

2.2.2 Results of gear cover and pillars

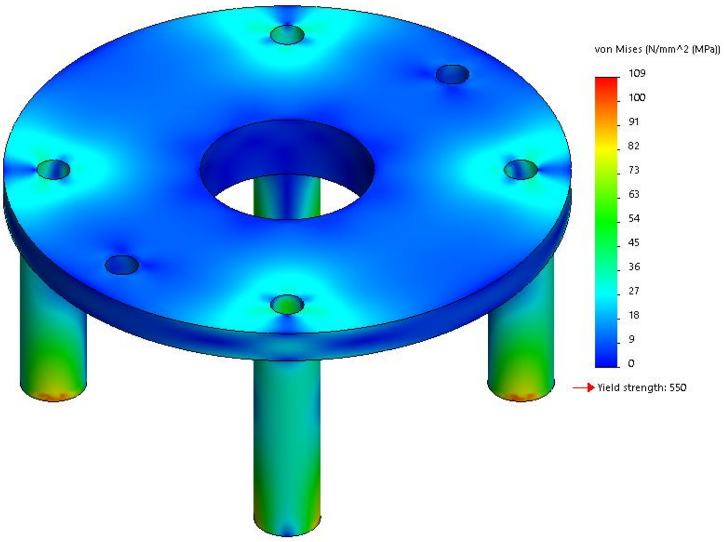

Figure 10 - Stress concentrations on support bushings.

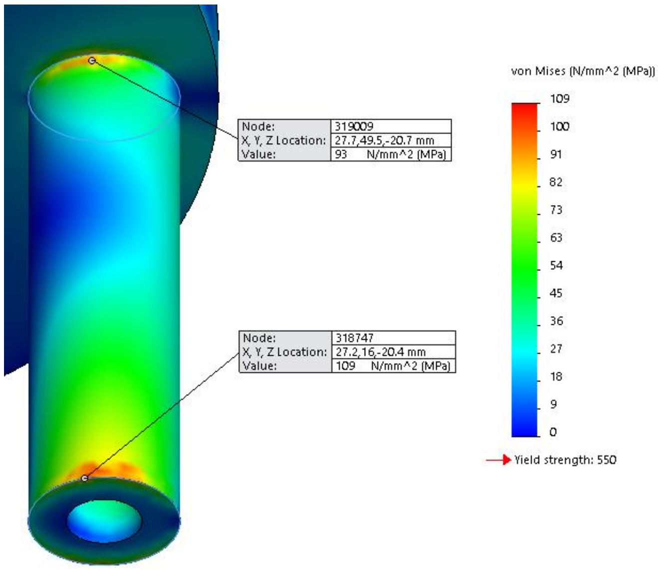

Figure 11 - Stress distribution of gear cover and support bushings.

Stresses

The results display very low stresses occurring throughout the sub-assembly, with the exception of the top and bottom of the support bushings. The value of the maximal stress that arises in this sub-assembly is therefore 109 MPA. These stresses arise as a result of the sharp geometric transitions between the pillars and the gear cover, and the fixtures at the bottom.

It is evident that the thickness of the gear cover could be greatly reduced, however, since the mass of this component is so low, any mass savings as a result of lower dimensioning will be rather insignificant.

Deformation

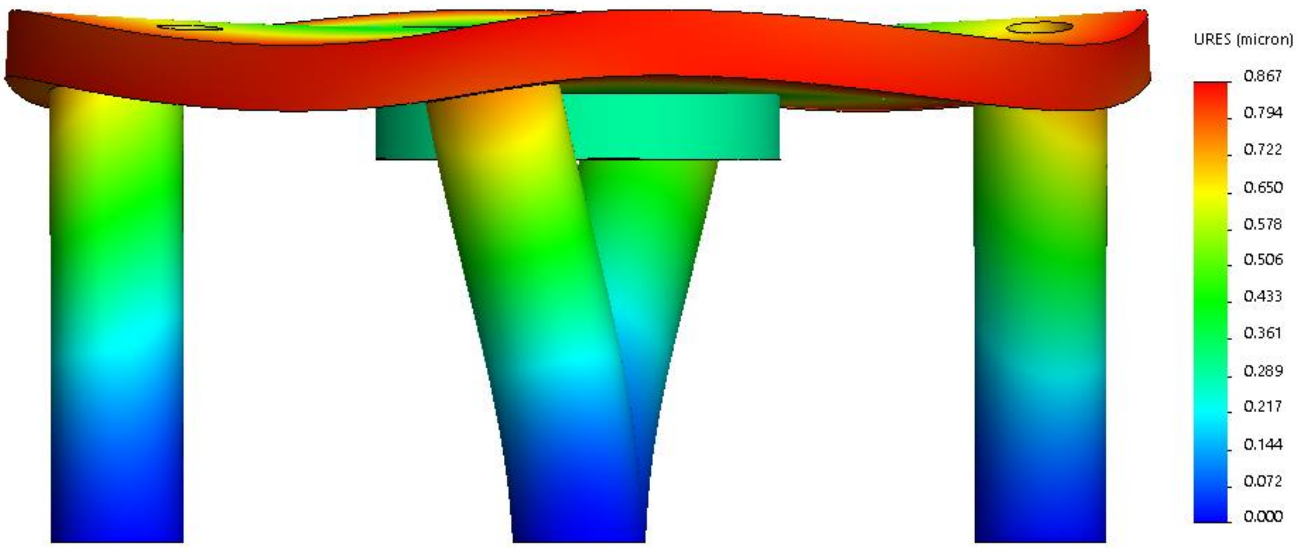

Figure 12 - Displacement of gear cover and support bushings.

The maximal displacement is 0.867 µm as shown in figure 12. The displacement of the support bushings will be lower in reality as the bolts screwed into both ends of the support bushing will make them more rigid. In any case, the displacement is sufficiently low to be neglected.

2.2.3 Test procedure of motor flange

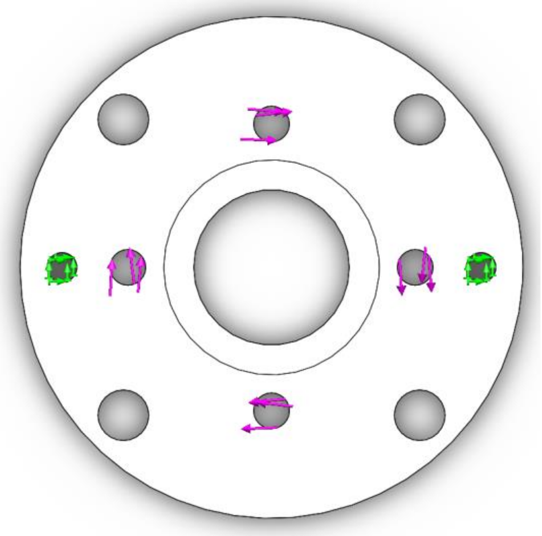

Figure 13 - Forces and fixtures on motor flange.

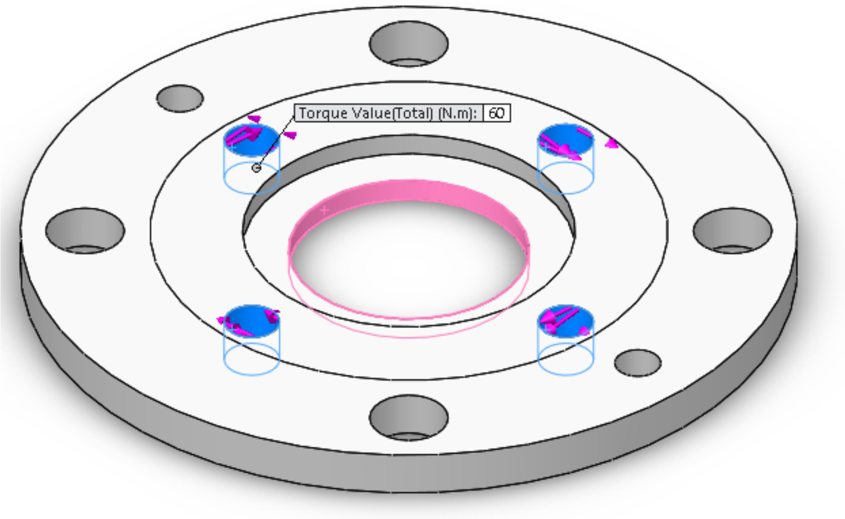

Figure 14 - Definition of torque on motor flange.

Assumptions and simplifications

As with the test for the gear cover and pillars, we assume the motion of the arm is fully resisted. This would cause the neck to be subjected to the full reaction torque from the motor.

Fixtures

The motor flange is fixed through the two boltholes that fasten it to the gear cover (Figure 13).

Forces

The total torque of 60 Nm is defined in the four boltholes used to fasten the motor to the motor flange Figure 14).

2.2.4 Results of motor flange

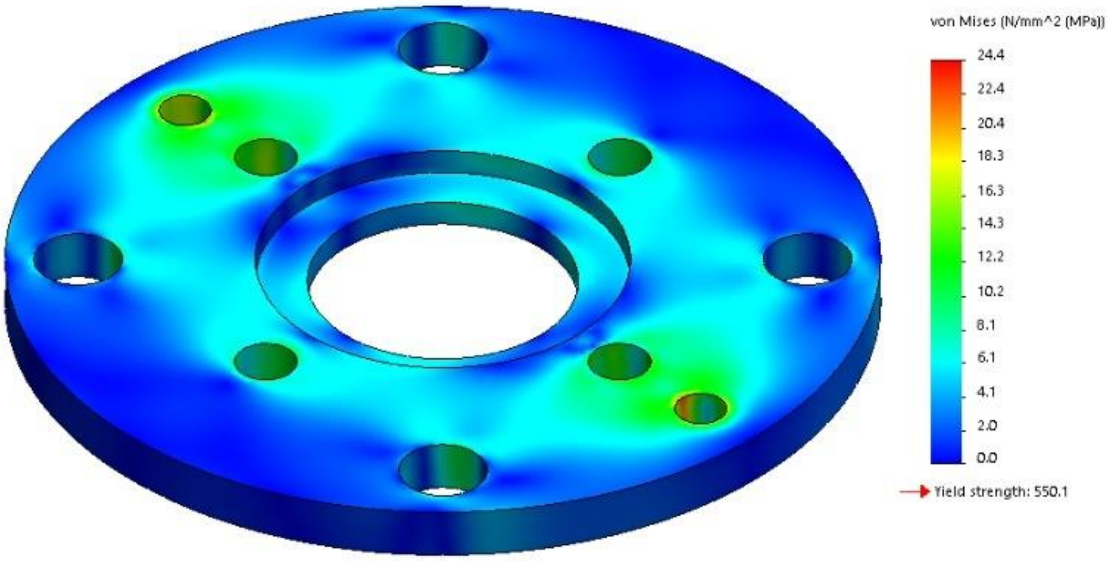

Figure 15 - Stress results on motor flange.

Stresses

The maximal occurring stress is 24.4 MPa, located in the two fixed bolt holes (figure 15). This is to be expected as the reactional torque of the motor is concentrated in those two bolt holes alone, as they alone are fixed. From a pure stress perspective, the dimensions and mass of this component could certainly be reduced.

Deformation

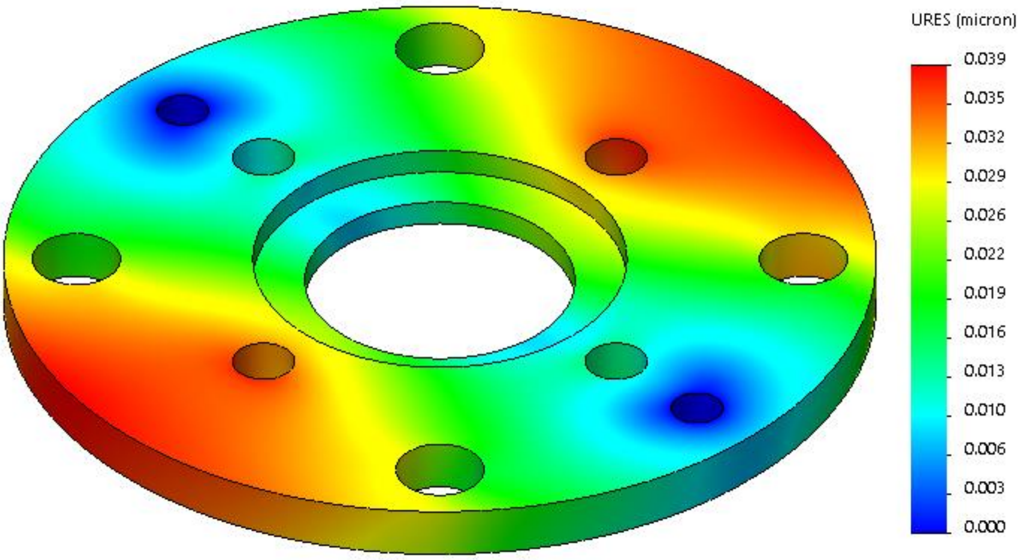

Figure 16 - Deformation of motor flange.

No discernible deformation occurs, as the value of the maximal displacement is at 0.039 microns.

2.2.5 Conclusion

We can conclude that the neck sub-system possesses sufficient mechanical strength and rigidity for the application of the polishing tool, and is ready for deployment.

2.3 Body

2.3.1 Test procedure

Assumptions and simplifications

A simplification made for this test is the removal of all threads. The threads on the body and the legs will not in any way vital or have an impact on the results. This would furthermore require a much lower mesh element size which for an assembly of this volume; would require an extremely long time to compute.

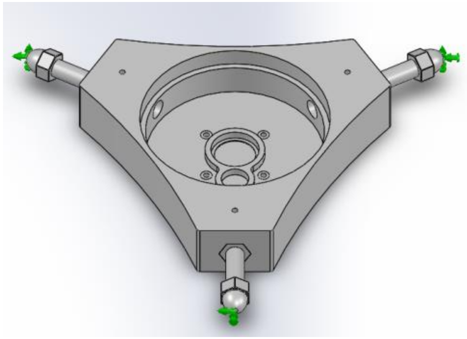

Figure 17 - Fixtures on body.

Fixtures

The body has been fixed through the legs (Figure 17), as they are assembled together. This has been done, as there is no reasonable way to fix the body sub-system without the legs.

Forces

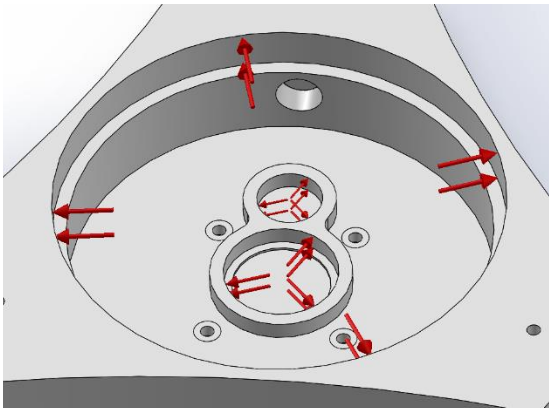

Figure 18 - Pressure from bearings.

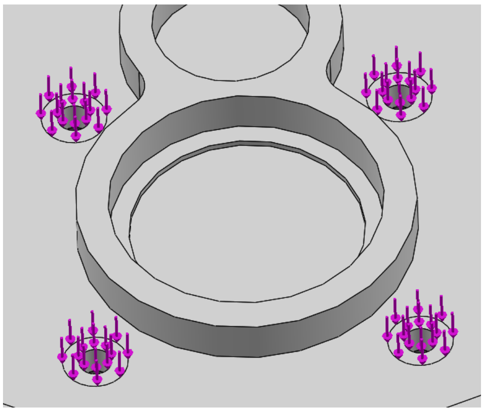

Figure 19 - Force from weight of neck and motor.

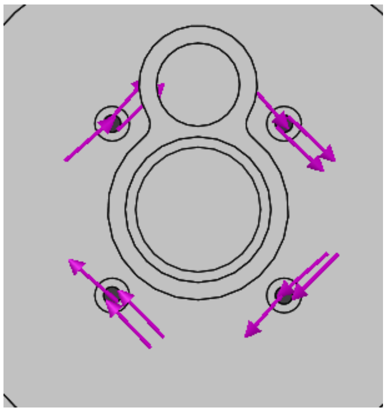

Figure 20 - Torque from motor.

The press fit of the bearings results in an outwards radial pressure towards their mated surfaces (Figure 18). For the 61826-2RS1 bearing, a pressure of 2.572 MPa is defined (2 pp. C-11). For the 61901 bearing, 17.684 MPa is defined (2 pp. C-10), and for the 61806-2RS1 bearing, 8.661 MPa is defined (2 pp. C-13).

The masses of the neck and motor have also been defined as the force acting on the contacting surfaces between the body and the support bushings (Figure 19). This force has been defined as 33.38 N. Being that the force is so low; it will have negligible impact on the results.

A total torque of 60 Nm has been defined to the four boltholes (Figure 20) at the bottom of the body to simulate the reaction forces from the motor through the neck sub-system.

2.3.2 Results

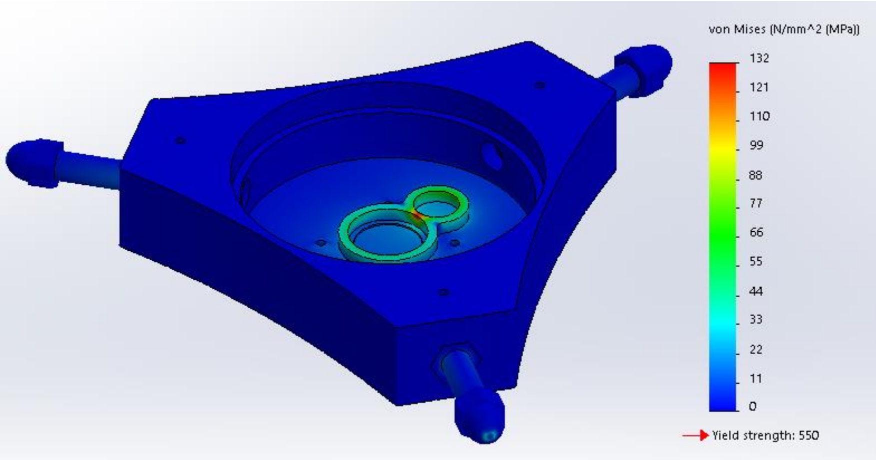

Figure 21 - Stress distribution of body.

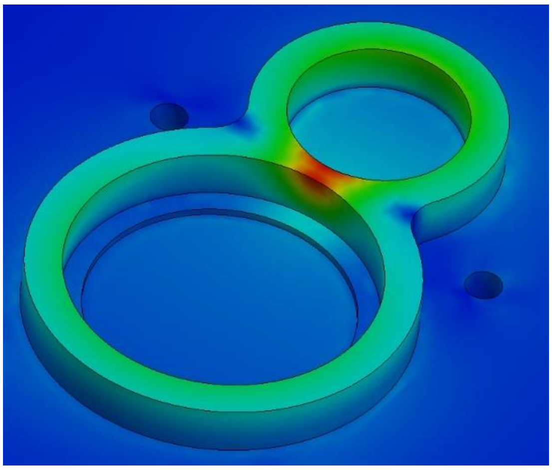

Figure 22 - Closer view of bearing housings.

Stresses

There are practically no significant stresses on the body, with the exception of the area between the two gear bearings where high compressive stresses occur (Figure 22 & 24). The reason the forces are so high is that the press fit has been calculated with a relatively high safety factor (2 pp. C-13, C-10). The dimensions cannot be changed to attain a better stress distribution unfortunately, as they depend on the gears and their associated bearings. Changing the gear cannot easily be done at this stage, as it would require alteration on the body, arm and all bearings.

There is a high potential for mass reduction as the body is not subjected to any significant stresses (Figure 21). Large parts of the solid areas around the legs can likely be removed with negligible consequence of the mechanical strength of the body.

Deformation

The most significant deformation occurs in the innermost two bearing housings, with a maximal deformation of 17.743 µm. Furthermore, the entire body is deformed approximately 10 µm (Figure 23).

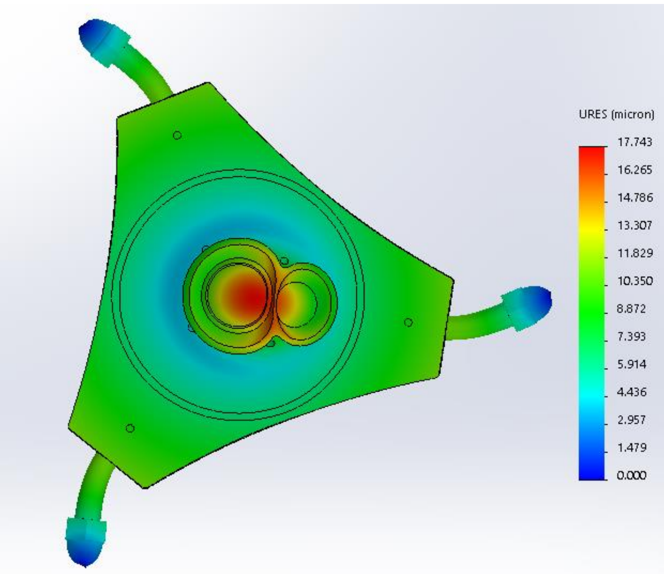

Figure 23 - Deformation of body.

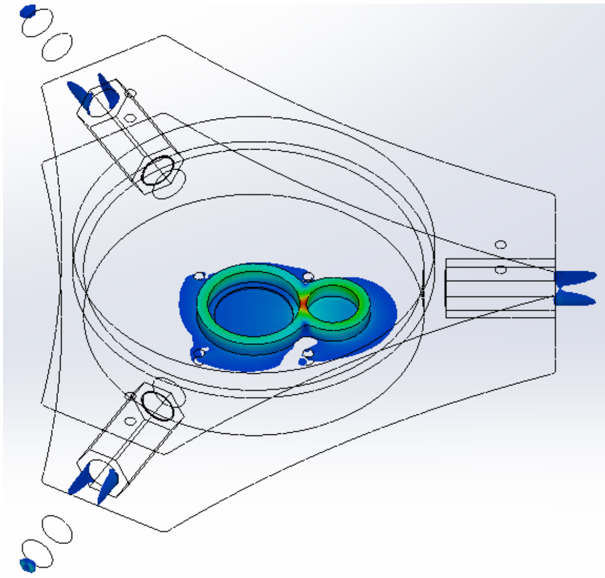

Figure 24 - Iso clipping where elements with stresses under 10 MPa are hidden.

2.3.3 Conclusion

We can conclude that the body sub-system possesses sufficient mechanical strength and rigidity for the application of the polishing tool, furthermore, the mass can be reduced greatly by optimization.

2.3.4 Optimization

As the stresses induced throughout the majority of the body are of a very low magnitude (see Figure 24), a high amount of mass could be removed from the body. In addition, the total mass of the system prior to optimization of the base was too high to fulfil requirement 1.19 (4 p. 11).

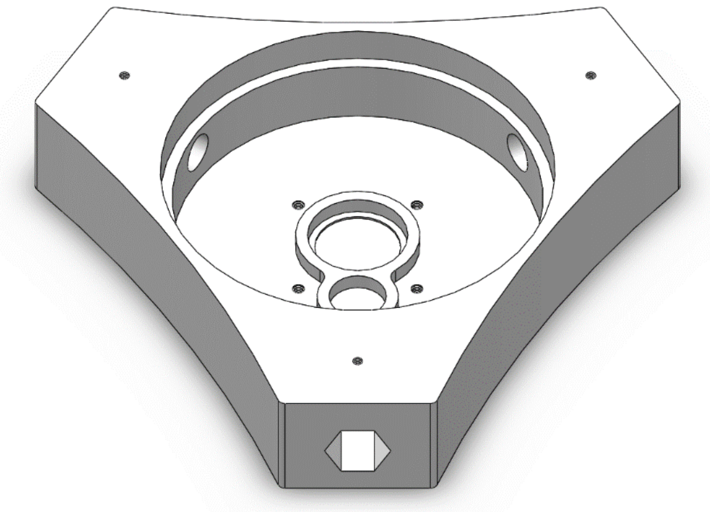

Figure 25 - Body before optimization

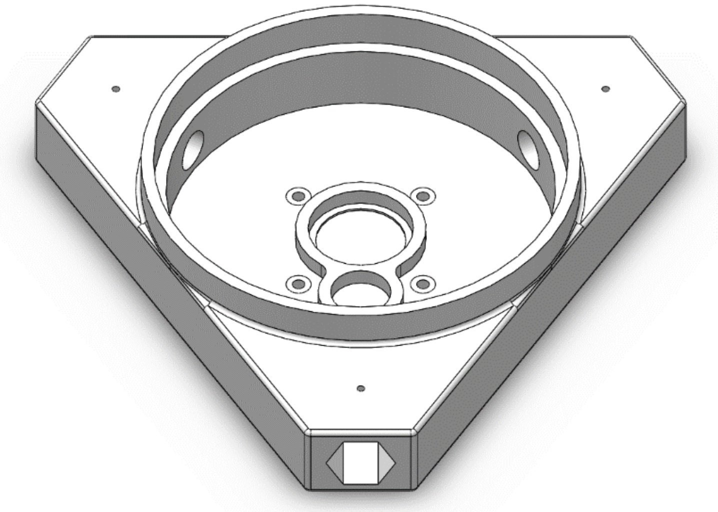

Figure 26 - Body after optimization.

The following changes to the body were made:

- The leg sockets were moved 5mm further down.
- The outer curvature of the body was removed.
- The height of the base, with the exception of the 61826-2RS1 bearing housing was reduced by 16mm.

With these changes, the mass of the body is reduced from 7.9 kg to 5.4 kg. This reduction is more than sufficient in order to fulfil requirement 1.19.

2.3.5 Results after optimization

A second analysis with a test procedure identical to the one discussed in chapter 2.3.1 Test was executed. The objective of this test is to verify whether or not the stresses and deformations occurring are still within accepted limits after the optimization of the body.

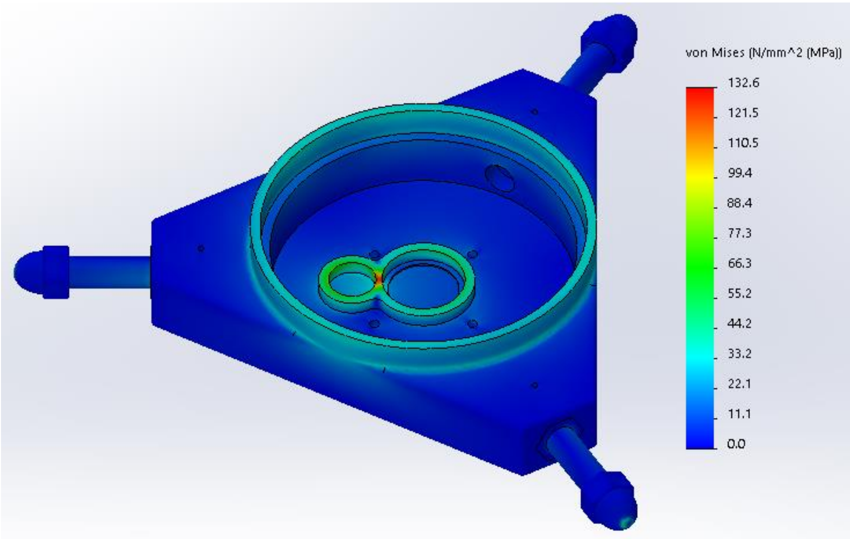

Figure 27 - Stress distribution after optimization.

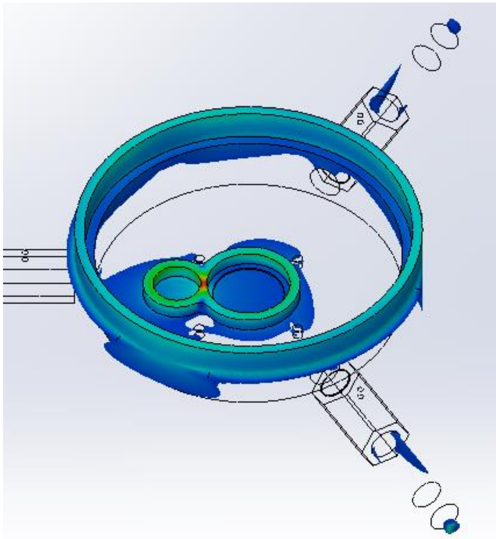

Figure 28 - Iso clipping where elements with stresses under 10 MPa are hidden.

Stresses

The stress concentrations in the area shared between the two bearing housings remain unchanged. The most noticeable difference lies in the stress of the 61826-2RS1 bearing housing which has a stress of approximately 30 MPa.

Deformation

Again, the difference lies primarily in the 61826-2RS1 bearing housing which have a displacement of approximately 20 µm.

The displacement of the inner bearing housing has also increased. This value However, this will not cause any actual damage in reality.

The visual displacement shown in Figure 29 is however greatly exaggerated.

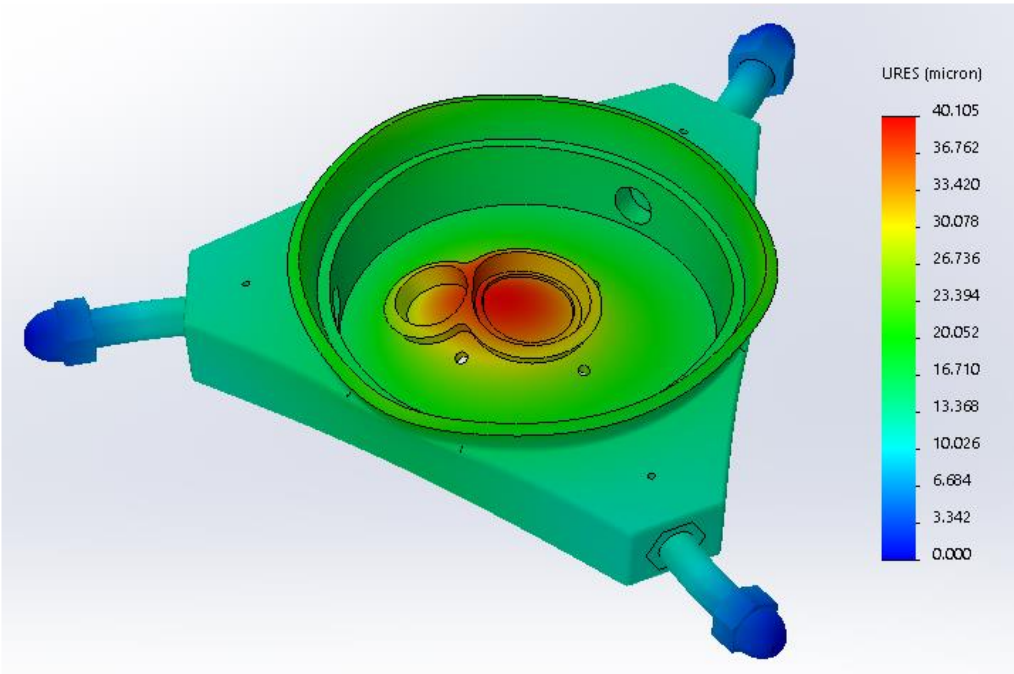

Figure 29 - Deformation after optimization.

2.3.6 Conclusion of optimization

The optimization of the body is satisfactory and has not increased the magnitude of stress and deformation within the sub-system.

2.4 ARM

Two tests are performed on the arm sub-system. One for the arm flange component and another is for the rest of the arm sub-system.

2.4.1 TEST PROCEDURE FOR ARM FLANGE

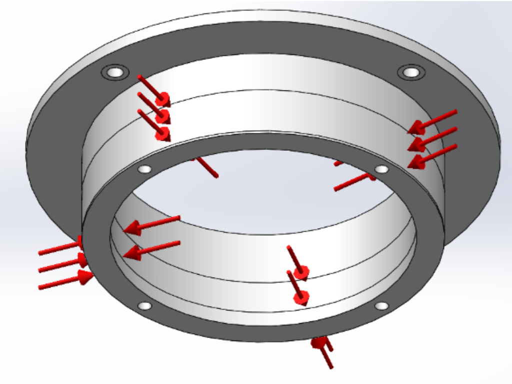

Figure 30 - Pressure from bearings.

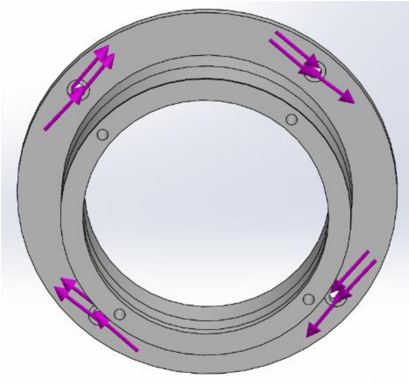

Figure 31 - Torque acting in bolt holes.

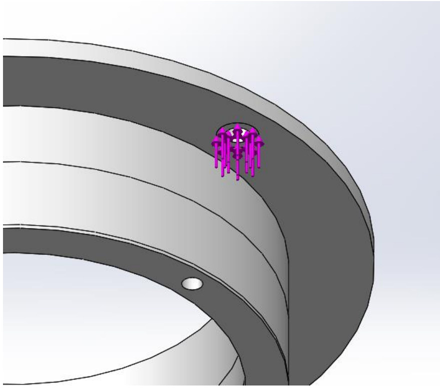

Figure 32 - Reaction force from the polishing fingers.

ASSUMPTIONS AND SIMPLIFICATIONS

A 3D model of our system shows that two bearings are pressed against the arm flange component. As a result of this, they are therefore exposed to some pressure forces. For these forces to be applied properly, a simplification had to be done where the exact surfaces that the bearings would be pressed on, had to be split up in SW as shown in Figure 30.

An assumption made here is that a worst-case scenario has been made in terms of the reaction forces from the polishing heads on the different surfaces. Since these forces are extremely high compared to the mass forces (72 N), they have been used while the mass forces have been neglected. The reason for this decision is that if the maximum stresses gained in the worst-case condition are acceptable, the stresses generated for the mass force will also give no harm to the component.

FIXTURES

The bottom of this component is mounted to a gear in order to function. We have therefore placed a normal fixture on the bottom surface of this component while testing it separately from the entire arm sub-system.

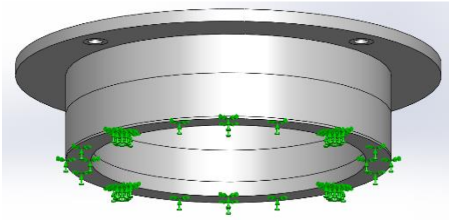

Figure 33 - Fixture on arm flange.

FORCES

As the bearings are pressed around the inner and outer diameter of the arm flange components, they are exposed to some compressive forces (pressure) on both surfaces as shown in Figure 30. The values of these compressive forces are (5.342 MPa) for the inner diameter, and (5.441 MPa) for the outer diameter.

A total torque of 60 Nm has also been applied into the flange boltholes of this component as shown in Figure 31.

An upper reaction force is also exerted on the flange of this component as the same forces are exerted on all polishing surfaces by the polishing heads. More specifically, the forces are applied such that when the bolts are fastened with nuts, a reaction force is exerted on the flange surfaces of this component that these nuts cover. The value of these reaction forces is 496 N (2 pp. C-06), and Figure 32 shows how they have been applied.

2.4.2 Results for arm flange

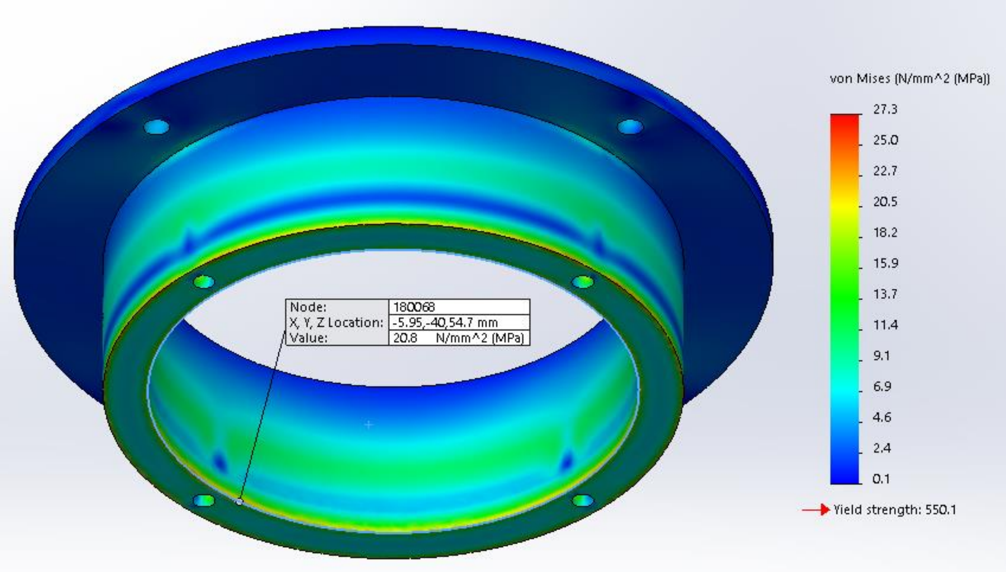

Figure 34 - Stress distribution of arm flange.

Stresses

The results are as expected. There are no significant displacement or stress concentrations. The biggest concentration of stresses is on the lower outer edge, where the stresses are maximized to 27.3 MPa. This value is well within the allowable stress limit.

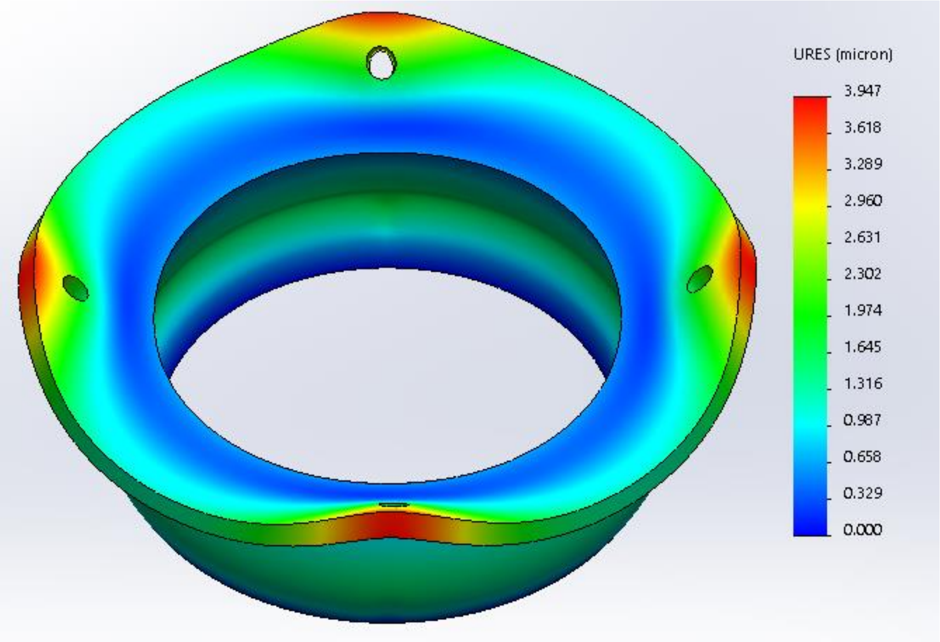

Figure 35 - Deformation of arm flange.

Deformation

As seen on Figure 35, the displacement is the highest around the boltholes area, but this displacement is less than 4/1000th of one millimetre and will not cause any problems.

2.4.3 Conclusion of arm flange

The results propose that there can be some material removed on the part to reduce mass. We however do not want to remove so much that might alter the component`s physical function.

2.4.3 Test procedure for arm sub-assembly

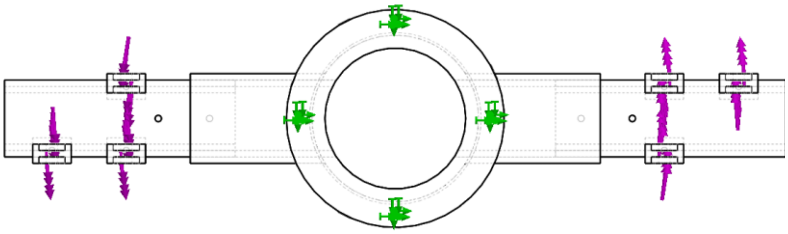

Figure 36 - Tangential forces and fixtures to arm, seen from above.

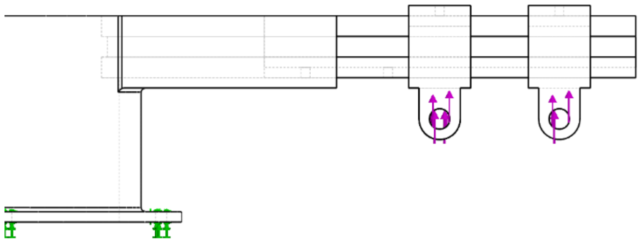

Figure 37 - Normal forces acting in the bolt holes of the finger sliding connectors.

Assumptions and simplifications

An assumption made is that the torque is resisted only through the bolts of the arm flange, rather than the frictional contact across the contacting arm flange surfaces. This is to simulate the worst-case scenario where the bolts are not sufficiently tightened.

Nevertheless, a simplification is the forces that are distributed on the surfaces of the inner boltholes, while in reality; the frictional forces would act on the side surfaces of the finger sliding connector.

Forces

For each finger sliding connector, a normal and frictional force from the corresponding finger is defined. The normal forces are directed upwards, while the frictional forces are directed tangential around the arm cylinder.

Fixtures

The assembly has been fixed through the four boltholes in the bottom of the arm cylinder.

2.4.4 Results for arm sub-assembly

Stresses

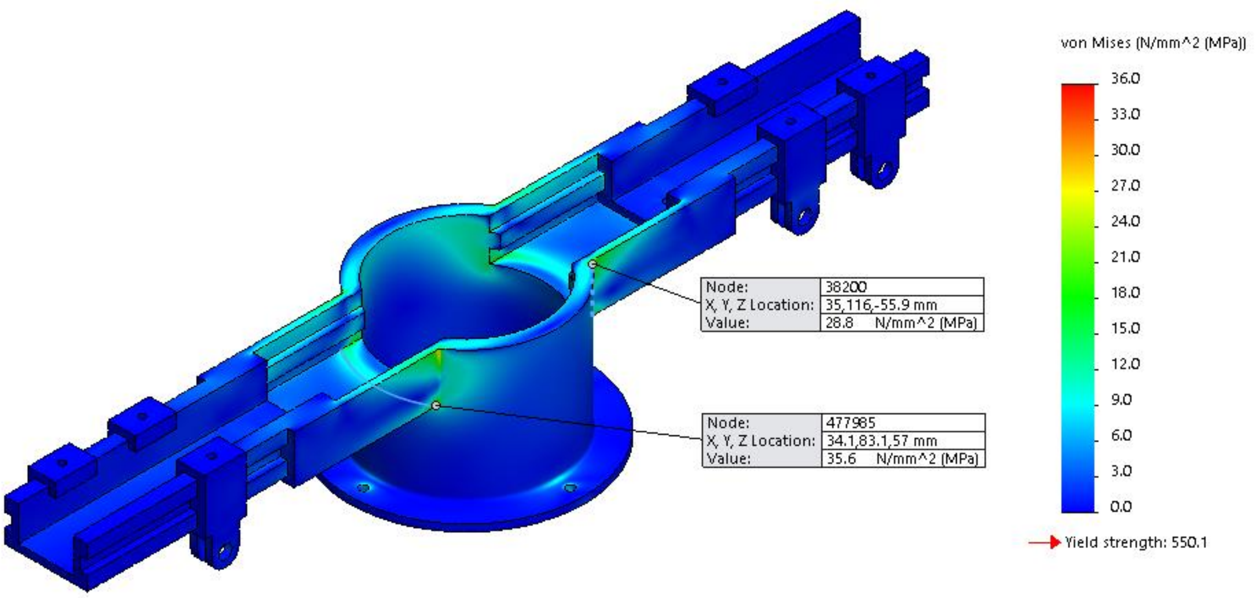

Figure 38 - Stress distribution of arm assembly.

The highest stress concentration occurs in the transitional areas between the central arm cylinder and the protruding telescopic elements. The maximal stress is therefore 36 MPa.

Deformation

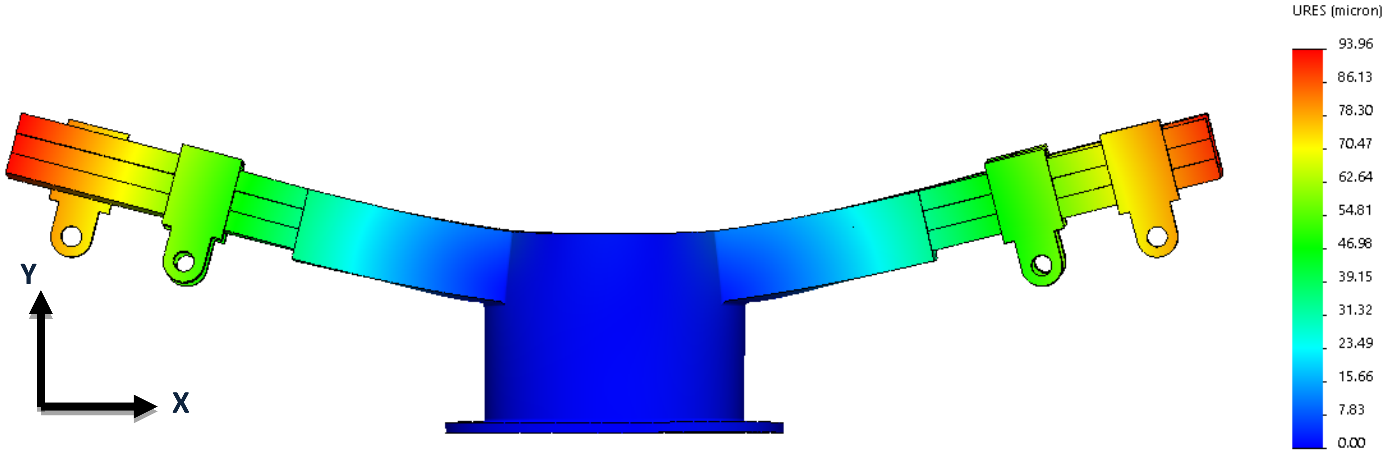

Figure 39 - Deformation of arm assembly.

The maximal deformation is 93.96 µm; this will not affect the functionality of the arm in any discernible way.

2.4.5 Conclusion for arm sub-assembly

We can conclude that the arm sub-system possesses sufficient mechanical strength and rigidity for the application of the polishing tool. Furthermore, the mass can potentially be reduced by optimization, if needed.

2.5 SEAL GROOVE FINGER

2.5.1 TEST PROCEDURE

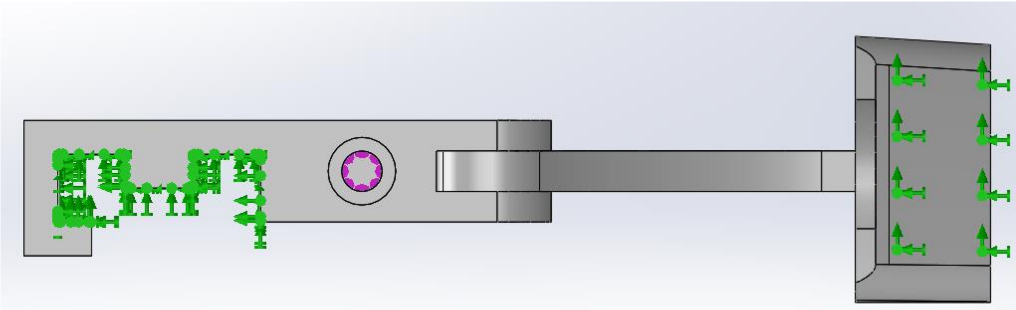

Figure 40 - Fixtures and forces on SG finger.

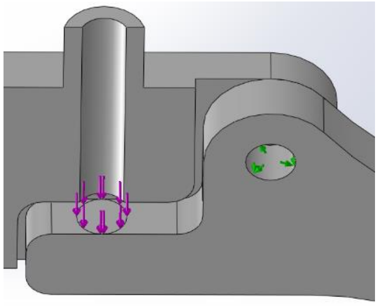

Figure 41 – Force acting on split line.

ASSUMPTIONS AND SIMPLIFICATIONS

A simplification made is that the SG finger is fixed on the contact that is in contact with the seal groove, rather than a split line. In doing so, the frictional forces from the seal groove are neglected. The value of these forces is calculated to be approximately 11 N and will therefore not alter the results in a discernible way.

FORCES

A force of 147.9 N is defined acting on a circular split line as seen in Figure 41. This force is required in order to deliver a force of 43.5 N on the seal groove surface (Figure 42). The circular split line is an approximation of the contact area made with the compressive spring.

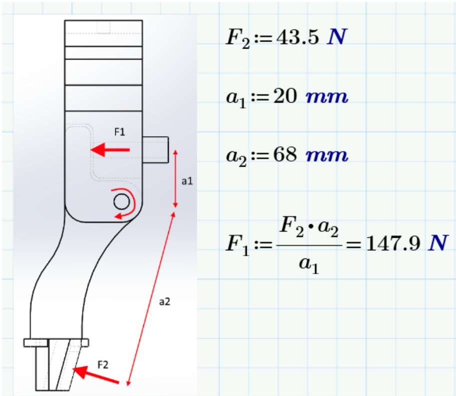

Figure 42 - Force calculation of SG.

FIXTURES

The SG sliding connector is fixed on the surfaces that are in contact with the arm component. The SG finger is fixed through a hinge fixture in the bolthole that connects it to the SG sliding connector. It is also fixed through a normal fixture on the surface in contact with the seal groove. The assembly has been defined with no penetration contact in order to more accurately simulate the interaction between the SG sliding connector and the SG bracket.

2.5.2 Results

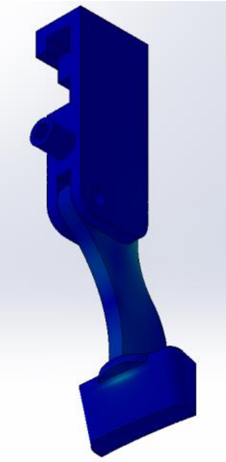

Figure 43 - Stress distribution of SG.

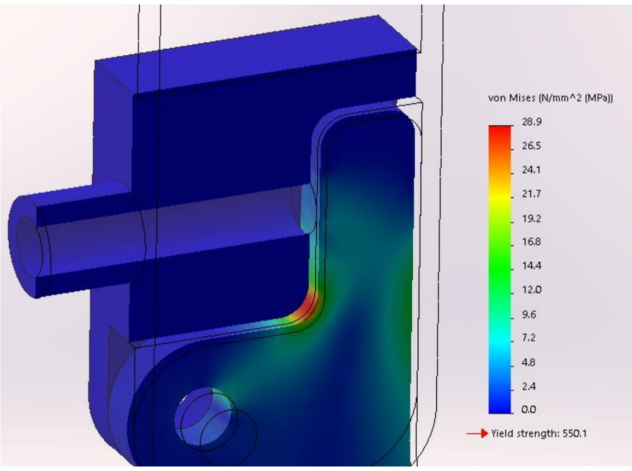

Figure 44 - Stress concentration of SG finger.

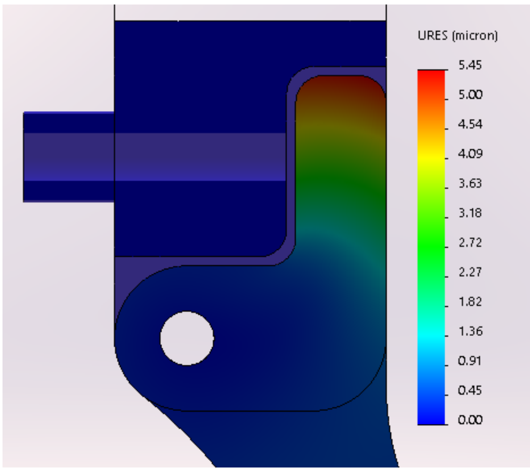

Figure 45 - Deformation of SG finger.

Stresses

There are no significant stresses within the SG assembly. The highest stresses occur on the fillet of the SG finger as seen in Figure 44. This result was expected as the force is applied directly above it.

Deformation

The highest deformation occurs on the top of the SG bracket as seen in Figure 45. The maximal deformation is 5.45 µm.

2.5.3 Conclusion

We can conclude that the seal groove finger sub-system possesses sufficient mechanical strength and rigidity for the application of the polishing tool.

2.6 Heel and midsection finger

2.6.1 Test procedure

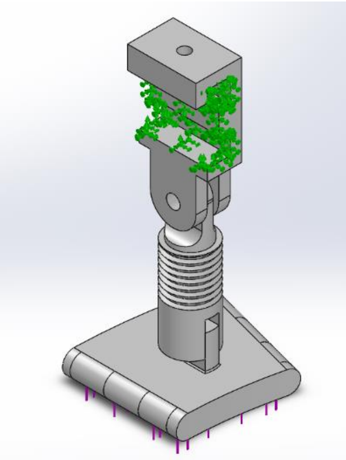

Figure 46 - Forces and fixtures of H/MS assembly.

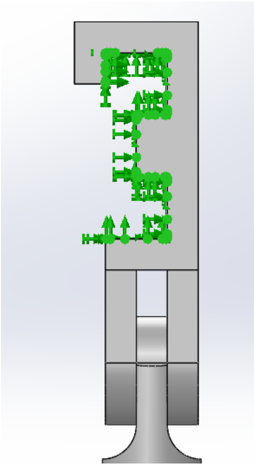

Figure 47 - Fixtures.

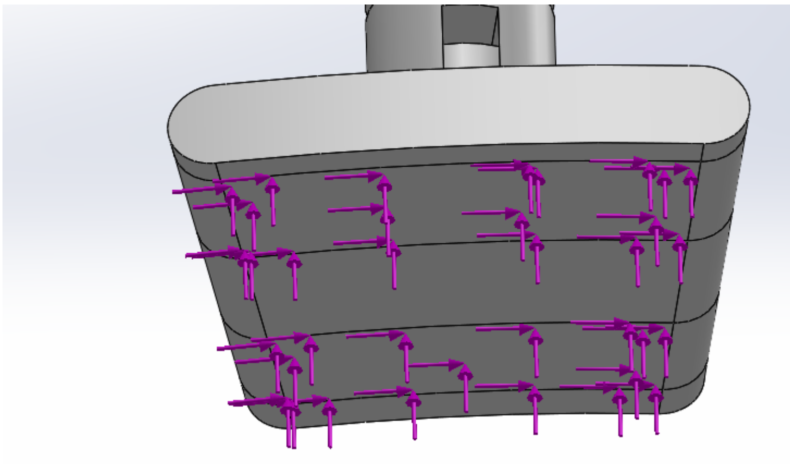

Figure 48 - Tangential and axial forces on H/MS finger.

Assumptions and simplifications

A series of split lines (Figure 48) have been made for the lower surface of the H/MS finger in order to apply the forces to the correct areas where the H/MS finger is in contact with the heel and midsection sealing surfaces. The compressive spring responsible for the force against the sealing surfaces is neglected for this test.

Fixtures

The H/MS sliding connector is fixed on the surfaces that are in contact with the arm component. The assembly has been defined as bonded for this test (Figure 47).

Forces

Two forces are defined for the test: One is a force of 76.5 N that is acting normal to the surface of the H/MS finger to simulate the normal force. Meanwhile another is a frictional force of 19.6 N acting tangential to the surface. These forces are displayed in Figure 46.

2.6.2 Results

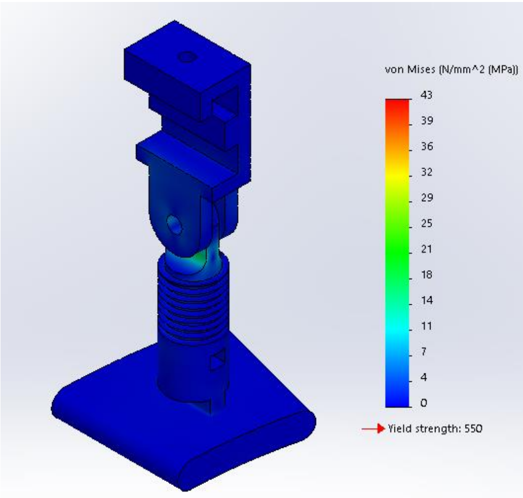

Figure 49 - Stress distribution of H/MS finger.

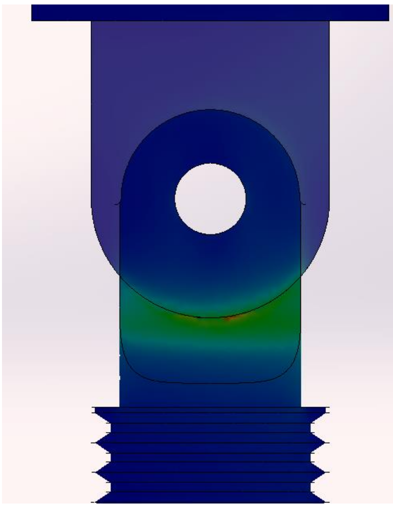

Figure 50 - Section view displaying area of maximal stress.

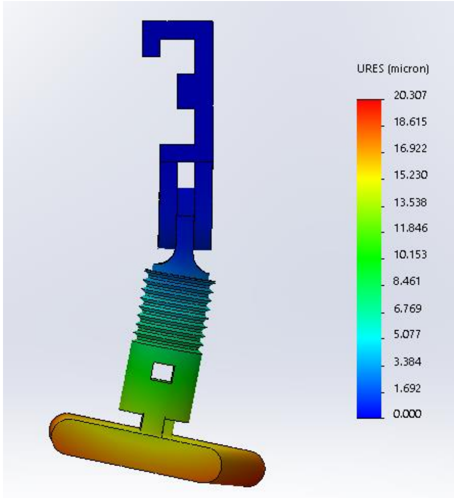

Figure 51 - Deformation of H/MS finger.

Stresses

Maximal stress occurs near the joint area of the H/MS sliding connector and the H/MS finger rod. This is the weakest area of the sub-system, and is therefore expected to harbour the highest stress concentrations. It is primarily caused by the frictional force, which leads to a bending stress at the weak point. Figure 49 shows that the highest stress concentration is at 43 MPa.

Deformation

The maximal deformation is 20.307 µm. This result is not entirely accurate, as the angular movement of the H/MS bracket will be resisted through its contact with the heel and midsection sealing surfaces. However, it is safe to conclude that the deformation would be lower in reality because of the aforementioned statement.

2.6.3 Conclusion

We can conclude that the H/MS finger sub-system possesses sufficient mechanical strength and rigidity for the application of the polishing tool.

2.7 Mounting dolly

The purpose of this test is to measure the vertical displacement of the mounting dolly as a result of the attached assembly mass.

2.7.1 Test setup

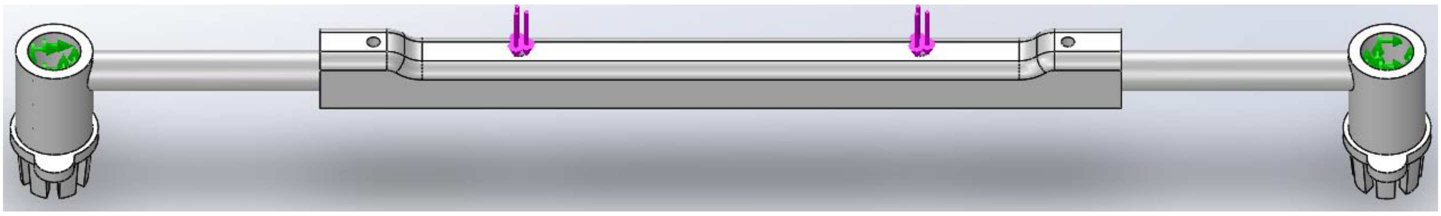

Figure 52 - Forces and fixtures on mounting dolly.

Assumptions and simplifications

We have simplified this test by defining the fixtures at the outer M20 boltholes. This is adequate for the goal of this test as we are only interested in the vertical displacement. The assembly has been defined as bonded.

Forces

A total force of 120 N is defined acting in the two M5 boltholes in the centre. This force stems from the mass of the body, legs, neck, gear train and arm flange.

Fixtures

The assembly has been fixed inside of the M20 boltholes as shown in Figure 52.

2.7.2 Results

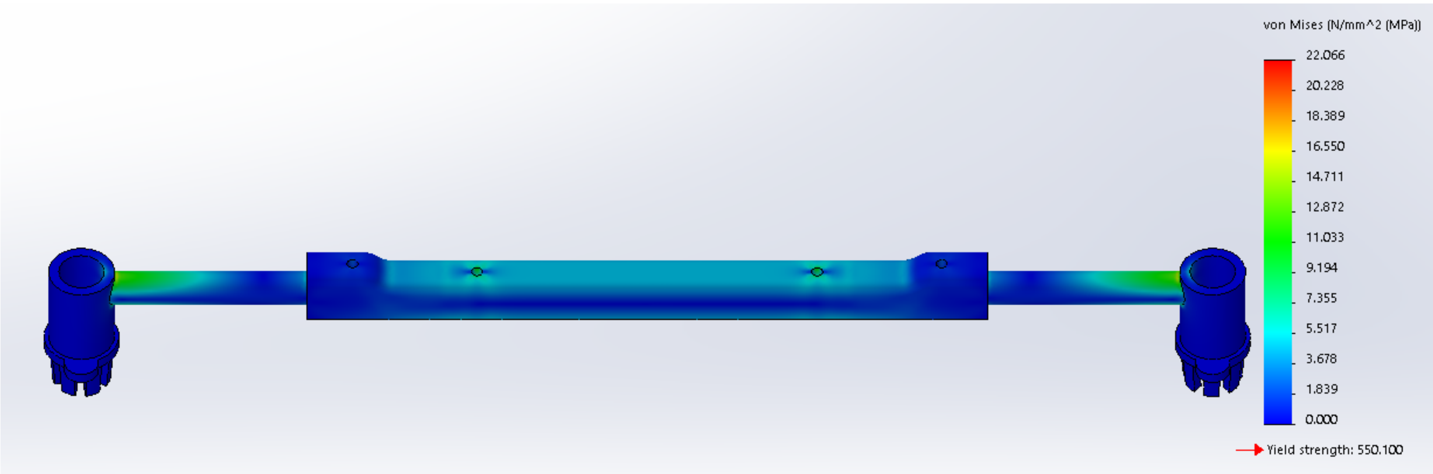

Figure 53 - Stress distribution of mounting dolly.

Stresses

No significant stress levels occur. The maximal stress is 22 MPa and is located in the expanding screw anchor at the transition between the telescopic element and the M20 bolt housing. Fillets would reduce the stresses at this area.

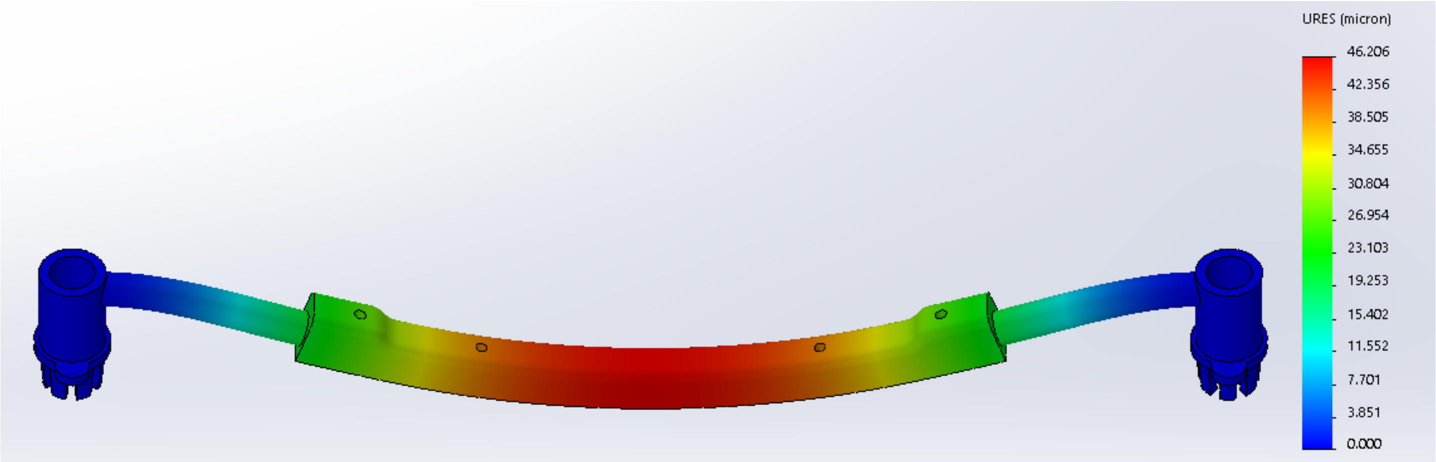

Figure 54 - Deformation of mounting dolly.

Deformation

The mounting base is pulled down 46.2 µm by the weight of the system. This displacement will not have any discernible consequences on the functionality of the mounting dolly. Figure 54 shows that this displacement occurs in the middle of the component. The visual displacement shown in Figure 54 is greatly exaggerated.

2.7.3 Conclusion

We can conclude that the mounting dolly sub-system possesses sufficient mechanical strength and rigidity for mounting the system to the vertically positioned flange.

2.8 SYSTEM INTERFERENCE TEST

This test was performed using the SW “Interference detection” function, with the following simplifications:

- All fasteners and washers are disregarded for this test. This has been done as the internal threads on their corresponding components have been drawn either for cosmetic reasons, or not at all. Furthermore, it is not intended to draw exact threads in the 3D CAD model, as they are normally specified in 2D drawings.
- The springs located in the fingers have been disregarded, as they will cause some interference problems when assembled into SW.

Result from this test however shows that there is no form of interference within the system. A visual figure can be viewed in the appendix.

2.9 FREQUENCY ANALYSIS

The reason why we are doing a simulation to find the natural frequency of the system is that resonance is a well know problem in machines. The natural frequency is however an important factor in a mechanical system that says a lot about the frequency and shape of the vibration in which the system wants to move (5 p. 1). Resonance is a result of an external force to the system that vibrates in the same frequency as the system natural frequency (6). This phenomenon can cause serious system malfunctions and has to be taken into consideration.

For a 1 DOF system, the equation below is used to calculate the natural frequency ω_n in radians/second, where k is a function of the systems stiffness and m is the mass (5 p. 19). If it occurs that we have to alter the natural frequency of the system, we can change the stiffness of the system and/or the mass.

$$\omega_n = \sqrt{\frac{k}{m}} \quad \left[\frac{rad}{sec}\right]$$

For complicated systems such as our polishing tool, one can use FEM in SW to generate all necessary natural frequencies that a system possesses (5 p. 19). Nevertheless, without manually calculating the natural frequency, one can easily assume the frequencies in a simple system by looking at the formula (5 p. 19). The reason is, the formula states that the higher the stiffness, the higher natural frequency is, and this applies to any kind of system (5 p. 19). The formula also states that the higher the mass of the system is, the lower the natural frequency will be (5 p. 19).

ASSUMPTIONS AND SIMPLIFICATIONS

As mentioned multiple of times, our system consists of few OTSC. Instead of running the test without the OTSC (to be more specific; the bearings), we decided to include some of them into the system. The reason for this decision is to have the masses of these OTSC as a contribution for the results. Knowing that these OTSC already have a set amount of masses individually, we applied our chosen material to them hoping to achieve these existing masses. Things did not work as planned, as the individual masses of the OTSC in SW were a little bit lower than the actual masses. We however decided to accept these mass values as a form of simplification to run the frequency analysis, concluding that the results would not be largely affected. The springs on the polishing heads and all screws within the system were neglected in order to avoid complications while running the test (especially the springs, which cause interference in SW).

For the fixtures to be placed properly on the cap nut, a split function in SW has been used such that the leg is fixed in the section of the cap nut that`s in contact with the flange inner wall (ref: leg FEM).

FIXTURES

For running this analysis, a normal restraint was applied to the cap nuts of the three legs while the entire system is assembled. This fixture covers the section of the cap nut that is in contact with the inner wall of the flange, causing the entire system to be fixed when mounted to the flange.

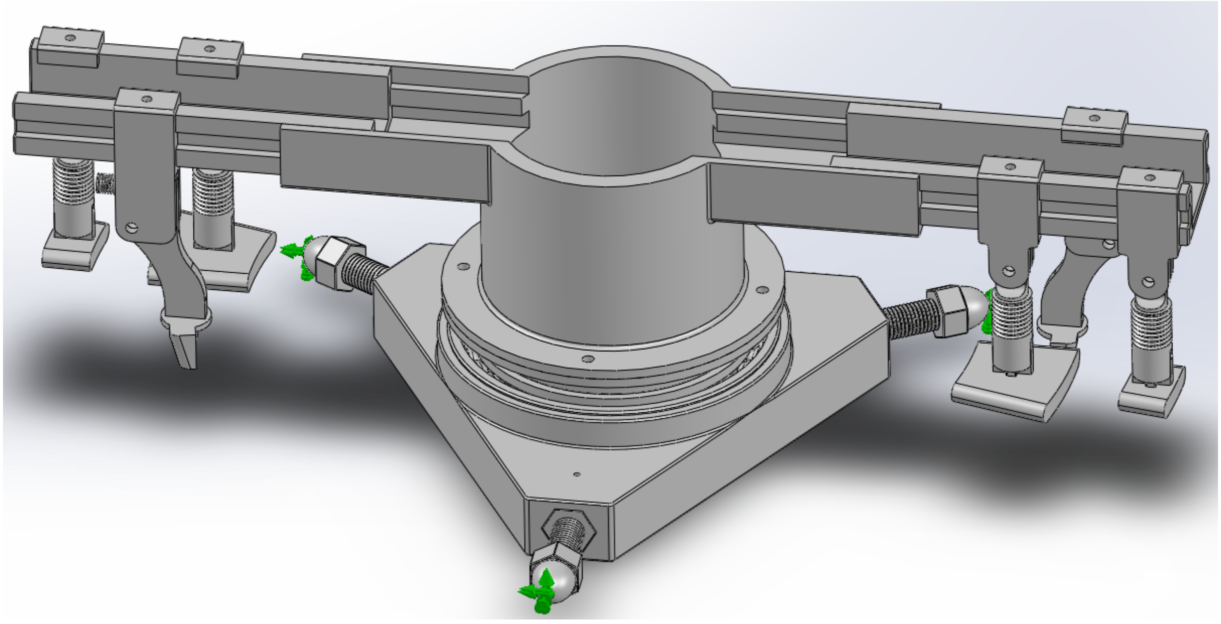

Figure 55 - Fixtures on the system.

Process

In order to run an analysis on our system against the danger of resonance, we will make use of a rule that was introduced during our academic years when working with frequency analysis. This rule states that the applied frequency (f_{motor}) should not have a natural frequency value that is within the range of half of this applied frequency to double of it (5 p. 20). For this machine, it will mean that the rotational speed should not be within this range as shown below, so:

$$\frac{1}{2} f_{motor} \leq \overline{\omega_n}_{System} \leq 2 f_{motor}$$

For our polishing tool, which has a chosen motor that operates at a speed of 15 RPM, the frequency is calculated as follows:

$$f_{motor} = \frac{Motor\ speed}{60\ Seconds}\ x\ 2\pi\ = \frac{15}{60}\ x\ 2\pi\ = 1.57\ \frac{rad}{sec}$$

The natural frequency values that are generated from the frequency analysis in SW should therefore not be within the range of these values:

$$\frac{1.57}{2} = 0.785\ \frac{rad}{sec} \qquad \text{and} \qquad 1.57 * 2 = 3.14\ \frac{rad}{sec}$$

Results and conclusion

The results in Table 3 show that the natural frequency values are higher than the double frequency value of an external force ($3.14\ \frac{rad}{sec}$). The table however shows results of the five lowest frequencies within the system. For an example, “Mode No.1” in the table gives a value that`s far above the upper natural frequency. We have therefore theoretically concluded that the polishing tool will not be affected because of these results.

Mode No.	Frequency(Rad/sec)	Frequency(Hertz)	Period(Seconds)
1	777.33	123.72	0.008083
2	922.16	146.77	0.0068136
3	1036.3	164.93	0.0060632
4	1260.3	200.59	0.0049853
5	1373.4	218.58	0.004575

Table 3 - Natural frequency.

3.0 TEST

3.1 240 Grit sandpaper on environmental seal

3.1.1 Tools

- Grid 240 emery sandpaper
- Polishing test rig
- Permanent marker
- Oil
- 2,5'' SPO IX Blind Flange
- Carl Zeiss CITOVAL 2 microscope

3.1.2 Goal

To determine whether the grid 240 emery sandpaper is suitable as a polishing material for the environmental seal.

3.1.3 Method

1. With the permanent marker, mark radial stripes on the of the environmental seal face.
2. Insert the polishing finger to the test rig and measure
3. Oil the surface
4. Rotate the polishing finger in and even pace 10 times and document the results
5. Repeat step 4 until the marks made from step 1 are vanished.
6. Make 1000 rotations.
7. Disassemble the finger and photograph the environmental seal and the sand paper.
8. Inspect results under a microscope.

3.1.4 Results

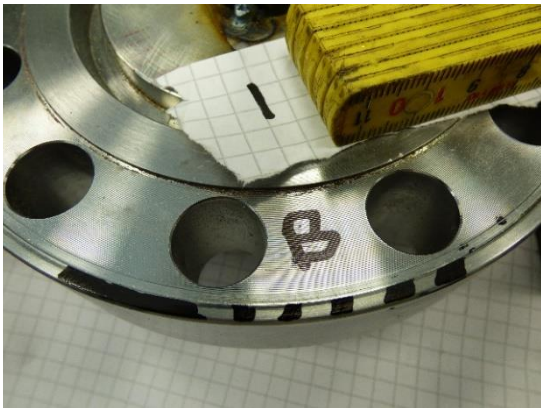

Figure 56 – Environment seal after 0 rotations

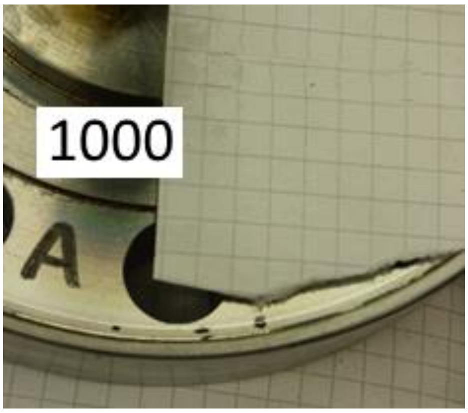

Figure 57 - Environment seal after 1000 Rotations

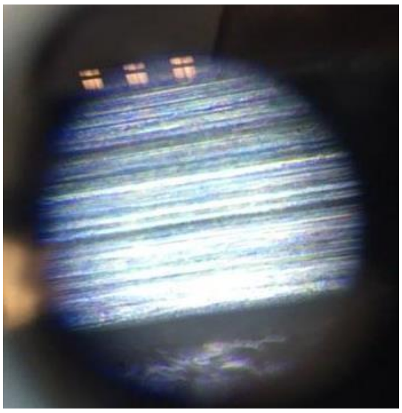

Figure 58 - Microscopic view of the environment seal after 1000 rotations

After only 10 rotations the permanent marks were completely erased from the surface. This proves that the sandpaper evenly polishes the surface, which is good. We then went ahead and did 1000 rotations to see what the surface will look like under a microscope. The microscopic view mainly tells us two things:

- The curvature is almost perfectly homogeneous.
- The surface finish is bit coarse with three deep grooves.

The sandpaper shapes itself sufficiently to the surface and distributes the forces evenly throughout the surface. We could barely see any wear on the paper after 1000 rotations.

3.1.5 Discussion

Keeping in mind that the test rig is not perfectly accurate the sand paper still polishes well and evenly. We believe that a similar test with a sand paper of a higher grid would provide better results

Since we could barely see any wear on the paper after 1000 rotations, we believe that the sandpaper might hold up for one job. Figure 59 shows how the sand paper will look after 1000 rotations.

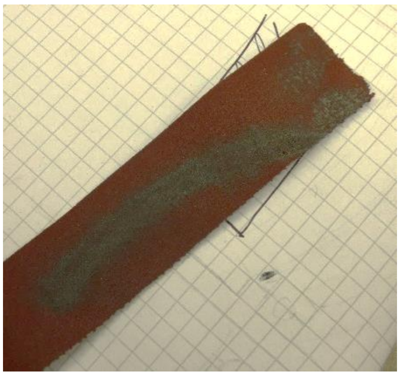

Figure 59 - Sand paper after 1000 rotations.

3.1.6 Conclusion

Sand paper is a good option for polishing, but we would recommend a higher grit than 240.

3.2 Grindstone on environmental seal

3.2.1 Tools

- Grid 220 stone set from Lisle, art. No. 23520
- Polishing test rig
- Permanent marker
- Oil
- 2,5'' SPO IX Blind Flange
- Carl Zeiss CITOVAL 2 microscope

3.2.2 Goal

To determine whether a grid 220 grind stone is a suitable option for polishing material for the environmental seal.

3.2.3 Method

9. With the permanent marker, mark radial stripes on the of the environmental seal face.
10. Insert the polishing finger to the test rig and measure
11. Oil the surface
12. Rotate the polishing finger in and even pace 10 times and document the results
13. Repeat step 4 until the marks made from step 1 are vanished.
14. Make 1000 rotations.
15. Disassemble the finger and photograph the environmental seal and the grindstone.
16. Inspect results under a microscope.

3.2.4 Results

The grindstone removed the permanent marker marks. As seen on the figures below, the marks are almost completely vanished after only 20 rotations.

Figure 60 - Environmental seal after 0 rotations.

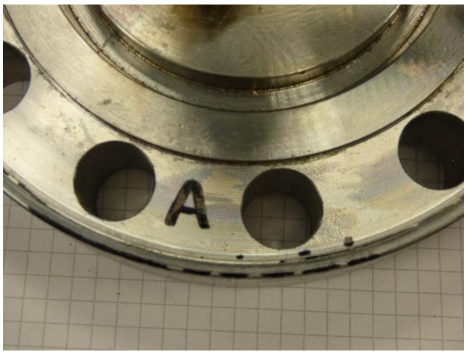

Figure 61 – Environmental seal after after 10 rotations. Marks are still clear

Figure 62 – Environmental seal after 30 rotations. Marks are still clear on the outer edge.

Figure 63 – Environmental seal after 40 rotations. No difference from Figure 62

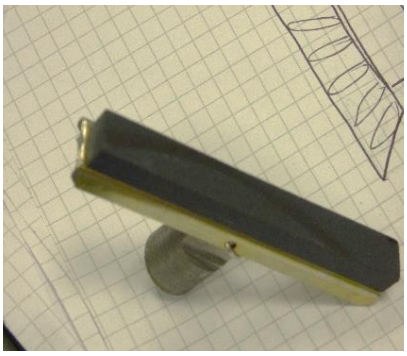

Figure 64 – Grind stone after 1000 rotations. No signs of wear.

The results indicate that the stone does not distribute an even load to the flange surface. However, this was investigated further by doing more rotations.

After 1000 rotations, the environmental seal seemed polished on a macroscopic level. However, after closer inspections with a microscope, we could see clear undesired scratches on the surface. The grindstone also has no sign at all of any wear after 1000 rotations.

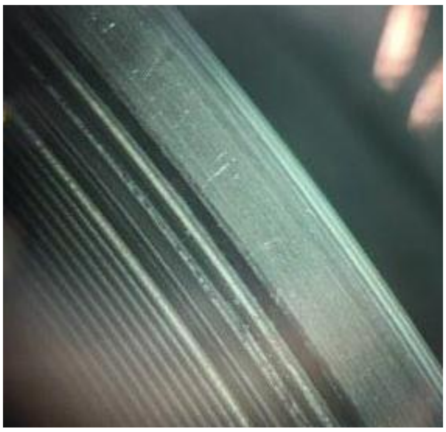

Figure 65 – Environmental seal after 1000 rotations

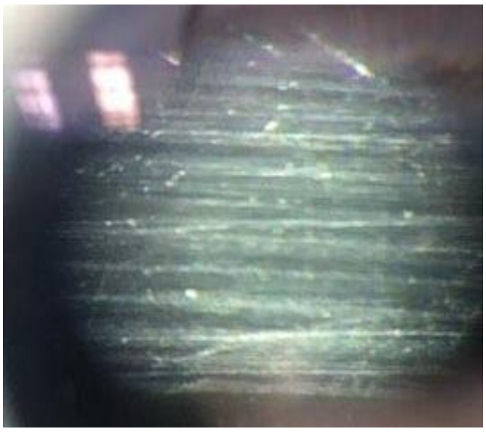

Figure 66 - Microscopic view of environmental seal after 1000 rotations

The pictures from the microscope show clear non-uniform scratches. However, on the bottom of Figure 65 and Figure 66. The inner part of the environmental seal) a small area is clear and well-polished.

3.2.5 Discussion

The small portion that gets polished really well shows that the setup might not have been perfect, and taking in regard that the test rig is made mostly by scrap metal there is a really high chance that this is true.

This shows that the correct setup is important when polishing with a grindstone. The particular type we used has a good resistant to wear as seen on Figure 64.

We believe that a better and more precise setup and more rotations will provide better results. This is because the surface finish is very good where the grindstone actually polished.

3.2.6 Conclusion

The grindstone does not easily apply an even pressure to the surface. However, it has a good resistance to wear and polishes with a high quality finish.

4.0 Requirement test

4.1 TS-1.02

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.02	1.02, 1.03, 1.04, 1.05	07.02.16	Analysis and inspection	A
Description: We will run a 3D animation to show how the system has contact with the faces that are to be polished The animation will reveal any colliding parts and other design flaws.				

Table 4 - TS-1.02 from Test Specification.

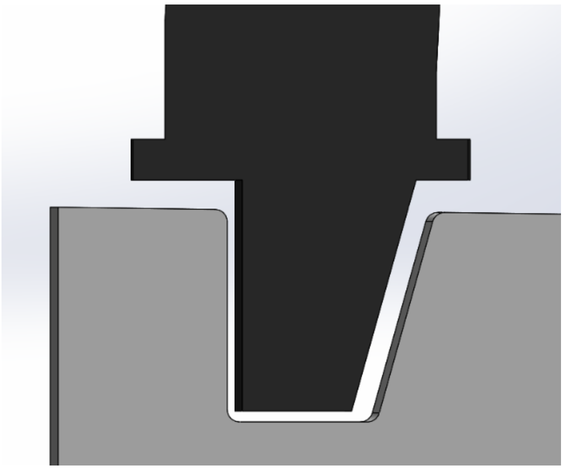

Figure 67 - Section slice view of SG finger

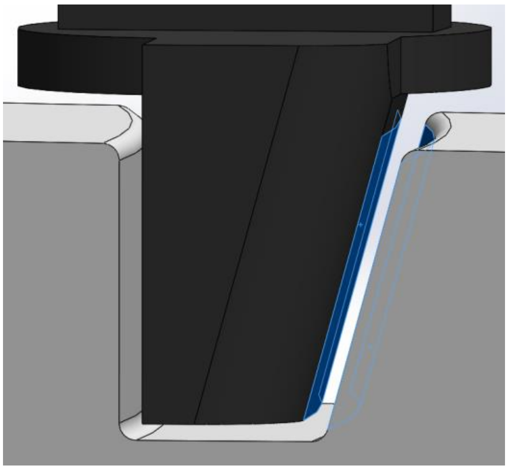

Figure 68 - Section slice view of SG finger

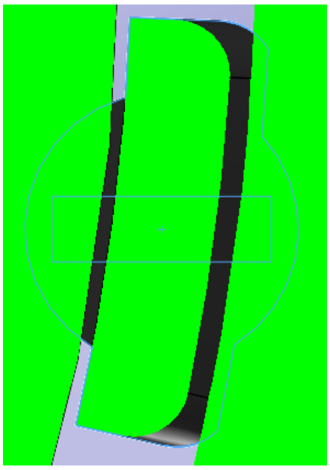

Figure 69 - Section slice view of SG finger from bottom

An animation has not been performed as first planned, as it has later been regarded as unnecessary and would furthermore require too much time to perform. Instead, a visual inspection of the SW assembly has been performed. The SG finger has been designed such that its curvature is identical to that of the SG exactly, given its offset from the centre plane. The H/MS and Environmental seal fingers are merely flat.

All fingers will have their polishing papers attached by Velcro, which will absorb some angular misalignment.

Therefore, assuming that the polishing surfaces of the fingers are manufactured with sufficiently low tolerances, we can conclude that the associated requirements for this test have been fulfilled.

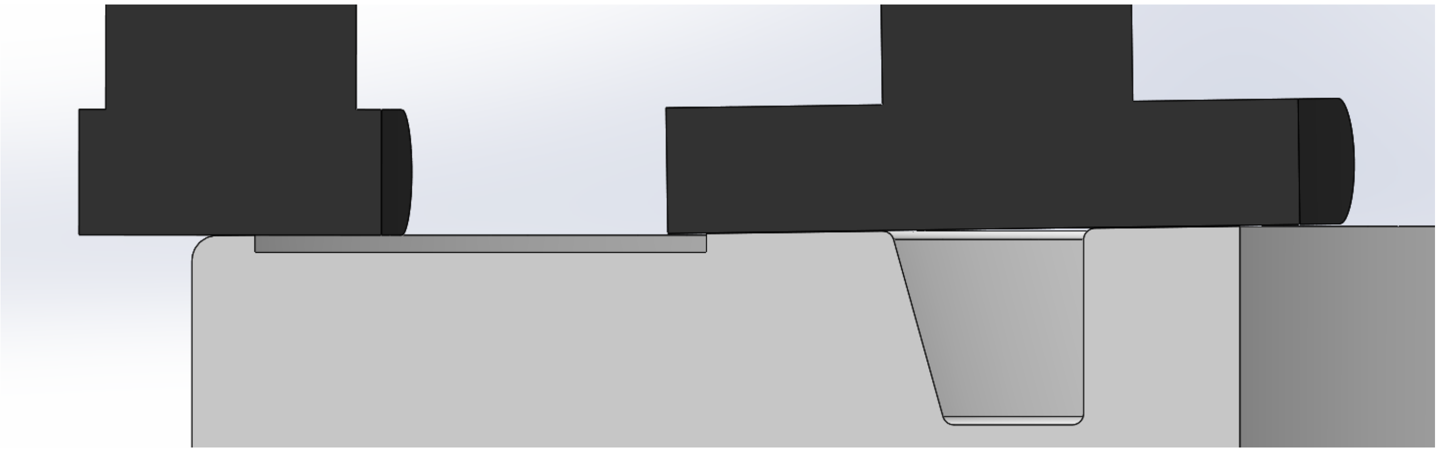

Figure 70 - Section view of H/MS finger and environmental seal finger.

4.2 TS-1.04

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.04	1.12	07.02.16	Analysis and demonstration	A
Description: We will run an animation to show how the system follows the differences in the seal grooves angular geometry. The animation will reveal any colliding parts and other design flaws.				

Table 5 - TS-1.04 from Test Specification.

As with TS-1.02, an animation has later been deemed unnecessary. Below are two figures that show how the angle of the seal groove finger can be adjusted by using the cap nut. A red scribble in these figures represents the spring.

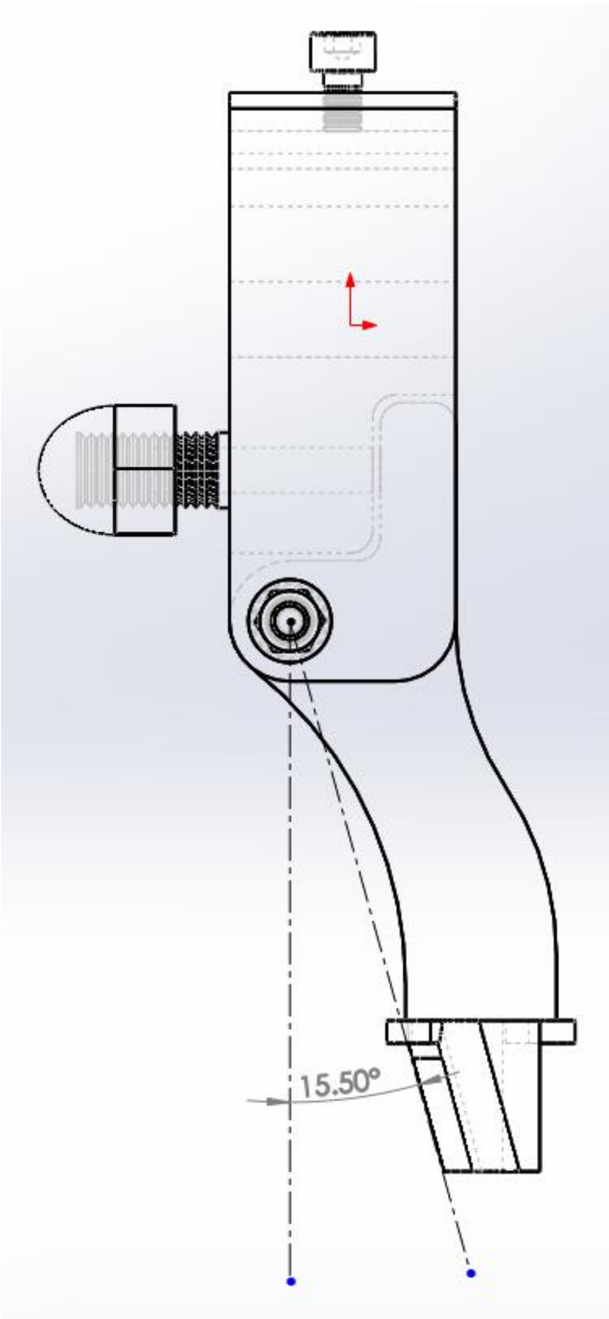

Figure 71 - Seal groove finger in correct position.

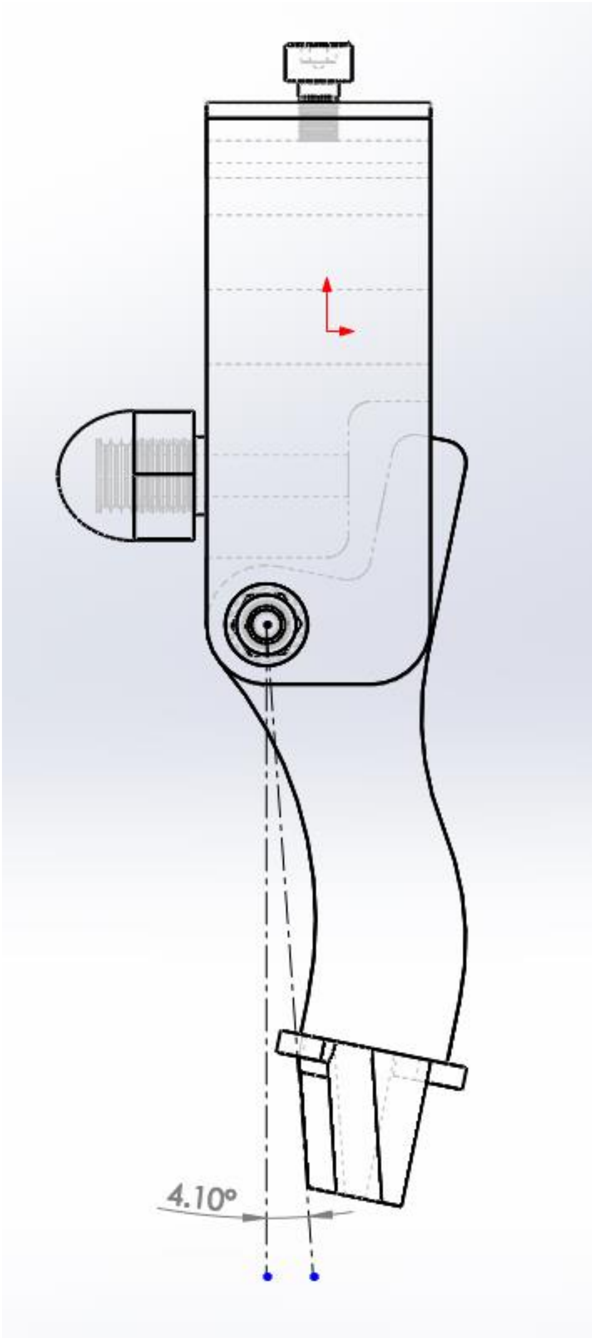

Figure 72 - Seal groove finger in incorrect position.

4.3 TS-1.05

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.05	1.06	07.02.16	Analysis	A

Description:

- We will run FEM stress analysis to make sure no components will yield during installation and/or polishing.
- We will run a frequency analysis in SolidWorks.

Table 6 - TS-1.05 from Test Specification.

The results shown in chapter 2.0 of this document cover this requirement. These results cover the linear elastic and frequency analysis that have been done on our system. The analysis results will therefore show that the system will not be easily destroyed, as it is one of FO&GTs top priorities.

4.4 TS-1.06

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.06	1.11	07.02.16	Analysis and demonstration	A
Description: We will analyse the physical properties of the subcomponents that provide the surface pressure between the system and the flange faces that will be polished. The analysis depends on the component we chose but could for example be spring constant, stiffness, strength etc. This will later be demonstrated in CAD 3D animation.				

Table 7 - TS-1.06 from Test Specification.

It is impossible to get good results from simulation for requirement 1.11. Therefore, the team has instead elaborated on what can cause uneven pressure and developed solutions to prevent this.

The even surface pressure depends mainly on the spring, the tolerance of the parts in the finger and the height deviation of the legs. The spring is double secured by two nuts to prevent it from creeping under operation. Creeping under operation will cause an uneven pressure and must be avoided. Components used in the polishing fingers have been designed with low tolerances.

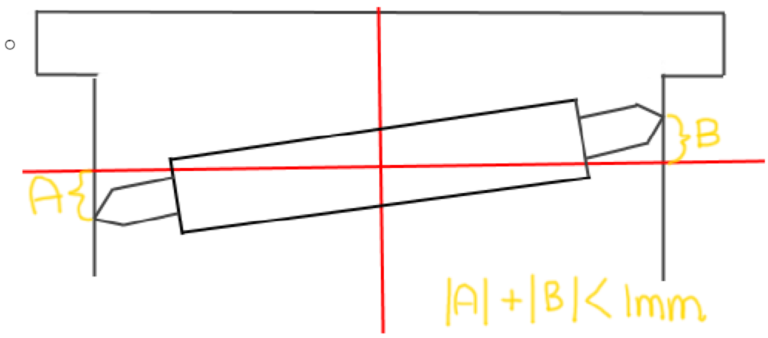

Figure 73 - Allowable height deviation.

We have allowed a height deviation of maximum 1mm (1). So, as figure 30 implies:

$$|A| + |B| < 1mm$$

The height deviation will evoke uneven surface pressure. This is because as the arm rotates it will always be 90⁰ to the central axis of the system. As a result of this, the length between the arm and the flange surface will not be constant, but rather change depending on the angular location of the arm. When the height changes, the forces applied to the flange will also change and cause un-even surface pressure.

4.5 TS-1.07

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.07	**1.19, 1.20**	**07.02.16**	**Analysis**	**A**
Description: FEM analysis will be done to check the mass of the system and sub systems with the selected materials.				

Table 8 - TS-1.07 from Test Specification.

In order to attain an accurate estimation of the total mass of the system, the entire SW CAD assembly needs to be finalized.

There is a number of OTSC such as bearings, screws and gears used for the SPO CF polishing tool. Most of these components are placeholders in the CAD model gained through SW Toolbox. However, while the principal dimensions of these components are correct, the exact geometry is not.

Therefore, when calculating the total mass of the system, the OTSC are suppressed in SW. The volume is then found from the use of SW “Mass properties” function and then multiplied with the density of F53 DSS.

The masses of these components are then acquired from the manufactures product catalogues and added to the sum (2 pp. C-05). Smaller bolts, screws and nuts have been neglected because of their insignificant mass.

ID	Name	Mass	N	Total Mass
L	**Leg sub-system**			
L-01	Joining nut	0.127 kg	3	0.381 kg
L-02	Rod	0.147 kg	3	0.441 kg
L-03	Cap nut	0.056 kg	3	0.168 kg
B	**Body sub-system**			
B-01	Body	5.4 kg	1	5.4 kg
N	**Neck sub-system**			
N-01	Motor flange	0.166 kg	1	0.166 kg
N-02	Gear cover	0.203 kg	1	0.203 kg
N-03	Pillars	0.001 kg	4	0.004 kg
A	**Arm sub-system**			
A-01	Inner arm	0.980 kg	2	1.960 kg
A-02	Outer arm	-	2	With A-03
A-02-01	Outer arm side	-	4	With A-03
A-02-02	Outer arm bottom	-	2	With A-03
A-03	Top cylinder	4.180 kg	1	4.180 kg
A-04	Arm flange	-	2	With A-03 and A-05
A-05	Lower cylinder	1,531 kg	1	1,531 kg
A-06	Arm cap	0.240 kg	1	0,240 kg
F	**Finger sub-system**			
F-SG-01	SG Polishing finger	0.140 kg	2	0.280 kg
F-SG-03	SG Sliding connector	0.186 kg	2	0.372 kg
F-HM-01	HM Bracket	0.222 kg	2	0.444 kg
F-HME-02	HME Finger rod	0.091 kg	4	0.364 kg
F-HME-03	HME Sliding connector	0.125 kg	4	0.5 kg
F-E-01	Env. Bracket	0.083 kg	2	0.166 kg
D	**Mounting dolly**			

D-01	Handle	0.923 kg	1	0.923 kg
D-02	Sliding rod	0.361 kg	2	0.722 kg
D-03	Expansion sleeve	-	2	With D-02
O-B	**OTSC BEARINGS**			
O-B-01	Driver	0.025 kg	1	0.025 kg
O-B-02	Idler	0.011 kg	1	0.011 kg
O-B-03	Inner	0.27 kg	1	0.27 kg
O-B-04	Outer	0.93 kg	1	0.93 kg
O-G	**OTSC GEARS**			
O-G-01	Driver	0.208 kg	1	0.208 kg
O-G-02	Idler	0.097 kg	1	0.097 kg
O-G-03	Internal	0.818 kg	1	0.818 kg
O-B-04	DEPRAG	2.9 kg	1	2.9 kg
TOTAL MASS OF SYSTEM				**23.7 Kg**

Table 9 - Mass of components.

4.6 TS-1.08

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.08	1.07, 1.08, 1,09 1.13, 1.14	07.02.16	Inspection	-
Description: An operational scenario study on the system will be done instead of testing, because no physical system that can provide sufficient information will be made, and because the requirement depends on external components. Make sure that the sub component (sand paper, grinding stone..) that does the polishing can provide wanted surface roughness by analysing the sub component data plan. This is because physical test are the only tests that can give us useful information. Neither a CAD 3D drawing nor an early prototype can give us the needed information and therefore tests will only be a waste of time.				

Table 10 - TS-1.08 from Test Specification.

Requirement 1.07, 1.08, 1.09, 1.13 and 1.15 are among those that are either impossible, or impractical to physically test in this stage of the lifecycle. Therefore, theoretical analysis and scenarios will supplement the test.

Requirement 1.13 and 1,14 use R_a as surface roughness. $1R_a = 1\mu m$.

1.07; The system shall polish off surface rust.

Aluminium Oxide Emery sandpaper used in our system is effective against rust. This is covered under "Polishing Material"

1.08; The system shall polish off surface scratches.

Aluminium Oxide Emery sandpaper used in our system is documented to be effective for metal material removal. This is covered under "Polishing Material"

1.09; The system shall polish surface indentations to an acceptable standard.

Surface indentations will in many cases mean that the flange has either to be replaced or re-machined. In the cases where only polishing is required, the Aluminium Oxide Emery sandpaper used in our system will polish them off. More about this can be read about under "Polishing material"

1.13; The system will polish the 16'' SPO CF WN CL600 flange to a surface finish of minimum $1R_a$

As of today, FO&GT uses Aluminium Oxide Emery sandpaper grit 240 for the last polishing, and according to them, this results in an acceptable surface roughness. (1)

1.14; The system will polish the 16'' SPO CF WN CL600 flange to a surface finish of maximum $0.8R_a$

As of today, FO&GT uses Aluminium Oxide Emery sandpaper grit 240 for the last polishing, and according to them, this results in an acceptable surface roughness. (1)

4.7 TS-1.09

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.09	1.18	07.02.16	Inspection	A
Description: Our team will ask FO&GT if the system has been designed in accordance with the offshore regulations. Inspections will be done by our team and FO&GT employees.				

Table 11 - TS-1.09 from Test Specification.

The requirement could not be tested because it required personnel with expertise within rotating machinery.

4.8 TS-1.10

Test ID	Requirement ID	Date	Test Type	Priority
TS-1.10	2.01, 2.03, 2.04 2.05, 3.01, 3,02	07.02.16	Analysis	A
Description: An operational scenario study on the system will be done instead of testing, because no physical system that can provide sufficient information will be made. This is because physical test are the only tests that can give us useful information. Neither a CAD 3D drawing nor an early prototype can give us the needed information and therefore tests will only be a waste of time.				

Table 12 - TS-1.10 from Test Specification.

2.01; The user shall be able to manually mount the system onto the flange.

In SW, the machine will be assembled per component. This way we can identify possible "setup-errors" and/or possible impractical solutions.

2.03; The system shall be operated by a qualified user.

The user manual and warning labels will clearly notify users that they have to be qualified to use the machine.

2.04; Another person shall be present while the machine is in use.

The user manual and warning labels will clearly notify users that they have to be in a team of two when operating the machine.

2.05; The person shall be able to shut down the system.

The system will be delivered with a valve that the operator can use to manually shut down the system. The frictional force between the fingers and the flange will ensure a shutdown of under 1 second (See calculations document: Breaking).

3.01; The system shall accommodate safe assembly onto the flange.

We have ensured that no components are heavier than 12.5 kg. At the same time, we inspect for setup errors, hazardous operations the users have to follow to properly set up the machine.

3.02; The system shall not consist of any electronic subcomponents.

A pneumatic motor drives the system and no other components are electric.

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1. **FO&GT.** *Conversation.* Drammen, 2016.

2. **Team16.** *Calculation Document.* Kongsberg : s.n., 2016.

3. **FO&GT.** *F53 Material Properties.* Drammen : FO&GT, 2016.

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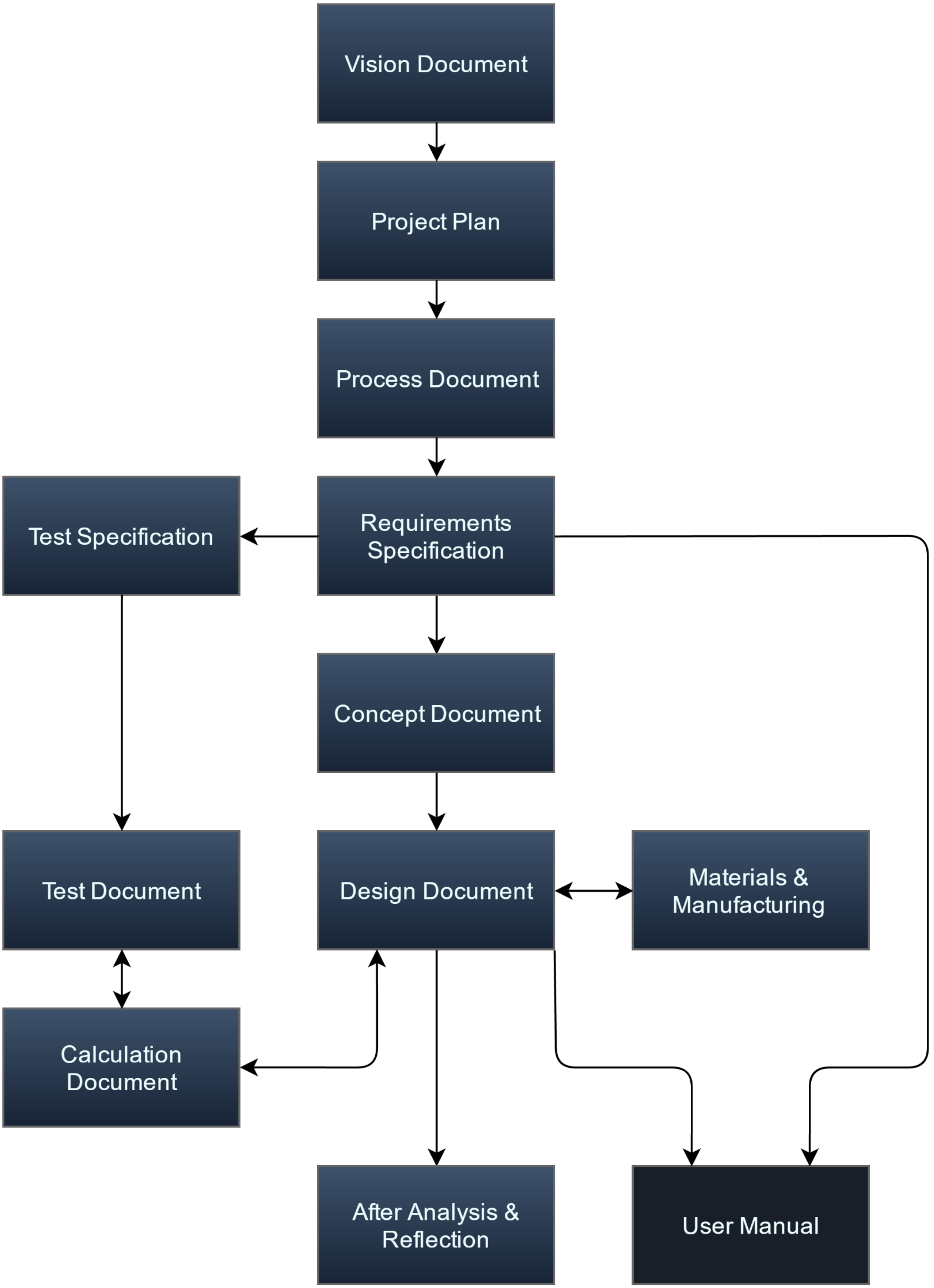
6. **Pellegrino, Alain.** 2016.


Vision Document
Project Plan
Process Document
Test Specification
Requirements Specification
Concept Document
Test Document
Design Document
Materials & Manufacturing
Calculation Document
After Analysis & Reflection
User Manual

USER MANUAL

Freudenberg Bachelor 2016

SPO CF Seat polishing tool

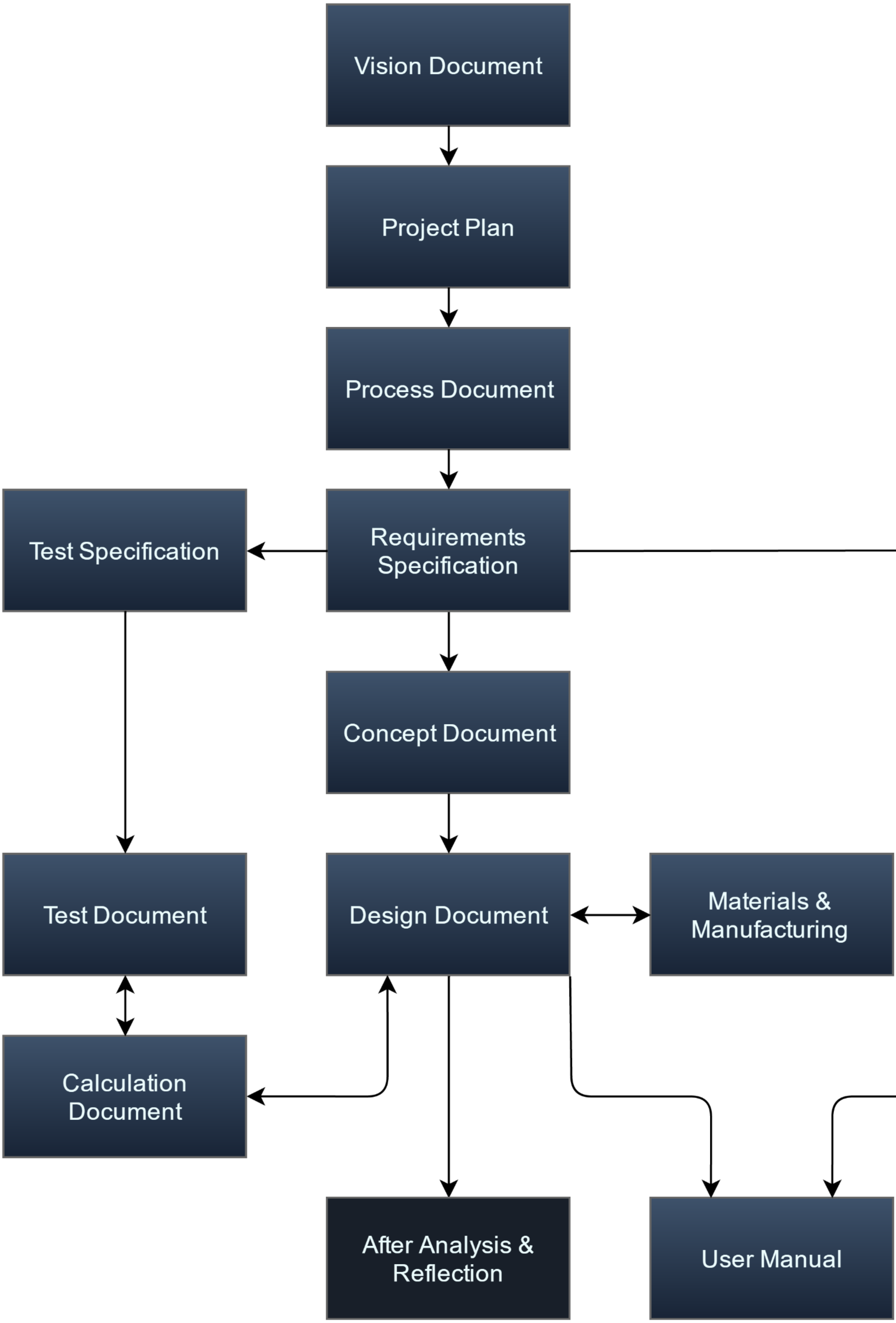
Arian Krasniqi, Richelieu Dahn, Odd Eirik Hardem, Morten Grøsfjeld

VERSION	DOCUMENT NUMBER	DATE	RESPONSIBLE	STATUS
1.0	011	22.05.2016	All	Finalized

Mounting procedure

HSE rules and regulations may vary from one work site to another. Therefore, it is important to review these regulations and see if there are any conflicts between them and the safety regulations set for this machine. The safety regulations for this machine is meant only for guidance, and local HSE regulations will always overrule the regulations set for the machine.

- Properly clean the inside of the flange according to FO&GT rules and regulations.
- Exert the legs out so that they are almost touch the inner wall of the flange.
- Attach the mounting dolly onto the base and secure the bolts.
- Carefully insert the body inside the flange and secure the mounting dolly.
- Exert the legs until they hit the inner wall of the flange and start calibrating.
- With the body calibrated, detach the mounting dolly.
- Attach the arm and then the fingers.
- Carefully place the fingers in the right place and measure out the wanted force.
- Oil the surfaces that are to be polished.
- Attach the motor and connect the hose.
- Open the flow control valve carefully and check for any deviations.
- Open valve until the wanted operation speed is achieved.


Vision Document
Project Plan
Process Document
Test Specification
Requirements Specification
Concept Document
Test Document
Design Document
Materials & Manufacturing
Calculation Document
After Analysis & Reflection
User Manual

After analysis document

Freudenberg Bachelor 2016

SPO CF Seat polishing tool

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1.0	011	22.05.2016	All	Finalized

1.0 Document

1.1 Document history

Version	Date	Changes
0.1	22.03.2016	Document created
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Table 1 - Document history

1.2 Definition of abbreviations

Abbreviation	Definition
FO&GT	Freudenberg Oil & Gas Technologies
SPO	FO&GT brand name for compact flanges (Steel Products Offshore)
CF	Compact Flange

Table 2 - Definition of abbreviations

1.3 Introduction

The purpose of this document is to give a total evaluation of what has been accomplished during the period of this project, and in addition to that the challenges that have occurred. The document contains a reflection from each team member where our experiences and challenges are expressed.

2.0 After analysis

Why did we choose this assignment?

We chose this assignment because it was quite extensive and gave us the opportunity to practice all of our skills we were taught at HSN. This was important to us because we envisioned this assignment to be a platform in which we could experience the growth and realization of a functional product.

What has been challenging with this assignment?

The challenges associated with this bachelor thesis has been lack of experience when it comes to team work of this magnitude and design of a complete system from scratch. As we progressed through the different stages we also made sure to notice the challenges that became prevalent along the way; these being the operational processes that the university requires of us.

As we have used the Agile iterative and incremental project model we have also gone through all of the different phases. We have relied on constant communication and concurrent team work, even though this at times has been demanding.

Time estimation has been a challenge throughout the project. However, our project model allowed us to make frequent changes in both design and time allocation, independent of where we were in the project lifecycle.

What is the assessment of the project goals?

We believe that we have produced feasible solutions for the SPO CF seat polishing tool that cover the primary and secondary goals the team set in stage 1 quite well, except that we have not had the time to create the prototype. All of the high priority requirements have been covered and tested. We have relied on standards and guidance from FO&GT to let us know if we were on the right direction with the design of this product.

What is the end product?

The tool consists of several sub -systems that are all connected in order to achieve the end -goal which is a polishing tool that will be used in an off -shore / on site environment with the intent of polishing the surfaces of the 14”, 16” and 18” CF. The SPO CF seat polishing tool will be driven either by pneumatically, by drill or mechanically by hand, when in operation it will be able to polish all of the surfaces that are of maintenance concern for FO&GT. It will achieve this by being mounted onto the flange and locked into alignment such that all of the surfaces are even with the polishing.

3.0 REFLECTIONS

3.1 Odd Eirik Hardem

This bachelor thesis has been the greatest academically challenge and academically experience of my life. I now feel more confident with my knowledge and skills as an engineer and I am ready to start working as one.

I personally believe that the project was a success. Obviously not everything went as planned and the team hit a few speed bumps during the project. I think a few of these problems could have been avoided with a bit more and careful planning, which leads us to the most important lesson I learned in this project.

My greatest lesson in this project is to never underestimate the importance good planning. Both personally planning and team planning. If I was better with planning from the very beginning, I am sure that I could have put less hours into this project and still come out with the same result, or even better.

Another thing I learned is that it is important to separate the project from personal life. Internally in the team, we have had a great many heated discussions. Some very unprofessional ones. Despite this, we are all still good friends when two minutes after when we go for a break. This proves to me that the people you work with and how you deal with them and respect them is very important.

Academically I believe that our group worked very well. No one knows everything, and therefore the diversity in a group is very important. My teammates and I all have different skills and I believe that the skills I contributed with was creative thinking, technical solutions and document writing. Personally, we also get along very well even though no one knew each other before the project. Good luck or good social skills? I do not know.

As a conclusion, I would like to say that I am very happy with the result. Not everything went as planned but that was expected. The project was like the Lord of the Rings extended edition. Exciting, fun, and memorable. Nevertheless… When Sam closes the door to his hole, you are glad it is finally over.

3.1 Richelieu Dahn

Already in autumn of 2015 Arian and Morten were introduced to me by our internal supervisor kjell Enger create to form a group. Without any previous working experience with neither one of them, I was fortunate enough to work with Arian on a school project during the autumn of 2015 in order to build a good working dynamic before our bachelor project get started.

We then started to do some researches about different firms and contacted them during this same period (autumn 2015). Fortunately for us, we came across FO&GT (Drammen) and saw that their field of engineering was very interesting as it strictly deals with what we have studied during our years of studying. We were anxious to contact them and were invited to have a meeting with them where it was confirmed that we are going to be writing our bachelor thesis for their firm. I have ever since been looking forward to get started with this project once it guaranteed that FO&GT had given us this opportunity.

However, during all of my bachelor years of studies, this project has been the most challenging that I have ever come across. One of the reasons for this is the fact that I have very little experiences working within an engineering firm as I have not really worked in such places before. The closest I have come with working on engineering projects was during the summer of 2015 while working as a summer interim for a private firm that`s presently collaborating with Statoil on the Johan Sverdrup project. I was very fortunate to be a part of this project. On the other hand, the working process (steps) of producing a machine of this kind was always very challenging as everything was completely new to me, and had to be learned from scratch.

A rough patch for me during this project was during the first stage (at the end of January) when I was informed that my uncle was brutally murdered. Getting such news one week into the first presentation was very heartbreaking, but I was determined to continue with the project. I however kept this to myself and continued working with the project because I did not want to let that interfere with the teamwork. Generally, my motivation during this project has always been high as I was very anxious to be part of a project of this kind where I am able to actually contribute towards the development of a completely new product. This experience has been very interesting and exciting to me.

The process in which we have used in working with the project has contributed to a great learning benefit for me. It has given me an insight of the daily challenges that engineers go through, and the solution alternatives or decisions that one has to take. I have also learned that it takes researches and integrated resources to actually generate a solution, and that, solutions can be discovered from the simplest things around you to be integrated into a functional system.

Working in a group that consists of individuals that I have never worked with previously has been challenging, but I have learned the importance of it, and how it`s like to work with other engineers. This I believe is one of the most important lessons I believe that I can take with me while I start my career as a mechanical engineers, as I am very convinced that I will come across people of different backgrounds. Sharing ideas during my years of studies was very normal to me, but the unusual to me was the idea of being dependent of the approvals of my team members' thoughts, criticism and comments on the tasks that were done by me. Unusual but not a problem for me as taking in constructive criticisms give me the chance to learn and develop myself on another level.

Before the project, I was pretty convinced that my planning skills were at a high level. I however learned that there is always a room for self improvement, and therefore gained more knowledge on how to plan and work systematically after the created plan even though it is sometimes challenging. My experiences from this semester have proven me that a more reasonable and logical way of thinking will simplify many complexities. To conclude, I would say that as much as there were multiple of challenges, working with this project has given me some experiences as there are more to gain later in the future. It has taught me an important lesson, that is, not to ever give up, but keep pushing as this is the key to success. I have also learned a lot of things during this experience that I can take further with when the project is all set and done.

I would love to take this time to thank all of our advisors who have contributed and supported us during this experience. From our internal supervisor (*Kjell Enger*) to external supervisor (*David Robertson and Bjørn Mikkelsen*) and all of the brilliant employees at FO&GT, I have learned a lot from everyone of them during this project. They have guided us every step of this experience and I highly appreciate this.

3.1 Arian Krasniqi

The assignment that we were given by FO&GT, involved creating something that was just an idea to something which has grown into a functional product with a purpose. With this assignment, I have gained clarity in what my strengths and weakness are in the product development stages. The biggest learning outcome I have gotten throughout all of this is that communication is key.

The process of understanding the project lifecycle has been important for me, because I feel that it is within the process that the knowledge on how to become a better engineer is gained. During my role as the project leader of the team I have been actively involved in trying to get everyone to participate in the discussions and tasks at hand. I did this because I see communication as the most important tool that we have as a team. and once communication breaks down so does progression and eventually the team. Which is why throughout the project lifecycle I have tried to ensure that everyone is on the same page when it comes to how the team should move forward.

Our external supervisors David Robertson and Björn Mikkelsen along with Przemyslaw Lutkiewicz our sensor, have been very helpful in the discussions that I have had with them, they have also shown great interest in the product that we have designed. The experience that I have had with FO&GT personnel and advisors has been fulfilling, they have been very helpful with information and guidance.

Our internal supervisor from HSN; Kjell Enger has been very helpful with his constructive criticism and knowledge that he has shared with me. I have also used other advisors from HSN such as Mehdi Mousavi, Jamal Safi and Amin Hossein Zavieh all of whom have been helpful in the technical and theoretical challenges that I have faced.

This has been a beautiful and pressurized process in which I will take with me towards the next chapter of my life. As time changes so does human, but how we react to those changes is what enables us to move forward.

3.1 Morten Grøsfjeld

This project has certainly been an extraordinary learning experience, although largely in unexpected ways.

I had a series of preconceptions about how the bachelor thesis would play out, most of whom in retrospect have been proven wrong.

As someone who prefers to write as concise as possible, I thought it impossible to write hundreds of pages of documentation, yet here we are; with hundreds of pages. I though the technical aspect of the thesis would pose the greatest challenge, while teamwork and the art of thinking simple has been the greatest. I thought my academic skillset was insufficient to be a valuable member of the team, but have proven otherwise. I thought I would not drink ridiculous amounts of coffee, but I did.

Overall, I think the project has gone much better than expected, given the circumstances.

Ideally, you want to make sure you get along, and more importantly; work well with someone prior to such an important group project like this. I was originally supposed to be part of a group with people I got along and worked well with, but was unfortunately not allowed to take part in the bachelor thesis that year as I failed an exam. As a result of this, I ended up in a group with people I had never met before. Our group consisted of members with very different personalities, ways of thinking, strengths and weaknesses, which has proven challenging at times. I was quite unaccustomed to being depended upon, and depending on other people for a serious project I was very motivated for.

If I had to do the project again, I doubt I would do even a single thing the same as before. Perhaps that tells you how much I have learned? There is no denying that many mistakes have been made, but I have learned from every single one of them.

As for my own contribution to the project, I can with confidence say I have done my fair share. I have worked harder than ever before in my life, and have surprised myself with what I have been capable of.

I have nothing but praise and gratitude for our internal supervisor Kjell Enger, who have during the course of the project given wise counsel, both technical expertise and advice regarding teamwork. FO&GT have also been very helpful in this project, and have given us valuable input in our design. There have been quite a few occasions where we have struggled with a technical problem, and have elaborated an overly complex solution, and when presenting it to FO&GT, been informed that a single bolt would do the trick. There is truth to the saying “Keep it simple”, but it is an art in itself to actually do it.