Sensur av hovedoppgaver
Høgskolen i Buskerud
Avdeling for Teknologi

Prosjektnummer: 2012-11
For studieåret: 2011/2012
Emnekode: SFHO-3200

Prosjektnavn
Testing av utmatting i stål og aluminium, Fatigue Test Rig
Fatigue testing of steel and aluminum, Fatigue Test Rig

Utført i samarbeid med: Høgskolen i Buskerud
Avdeling for Teknologi

Ekstern veileder: Kjell Enger

Sammendrag: Denne rapporten inneholder dokumentasjon av de ulike fasene i produktutviklingen. Oppgaven gikk ut på å designe en maskin for å teste utmatting i stål og aluminium. Det skulle designes en komplett test maskin med tilhørende teknisk løsning.

Stikkord:
- Utmatting
- Høgskolen i Buskerud
- Maskiningeniør/Produktutvikling

Tilgjengelig: JA

Prosjekt deltagere og karakter:

Navn	Karakter
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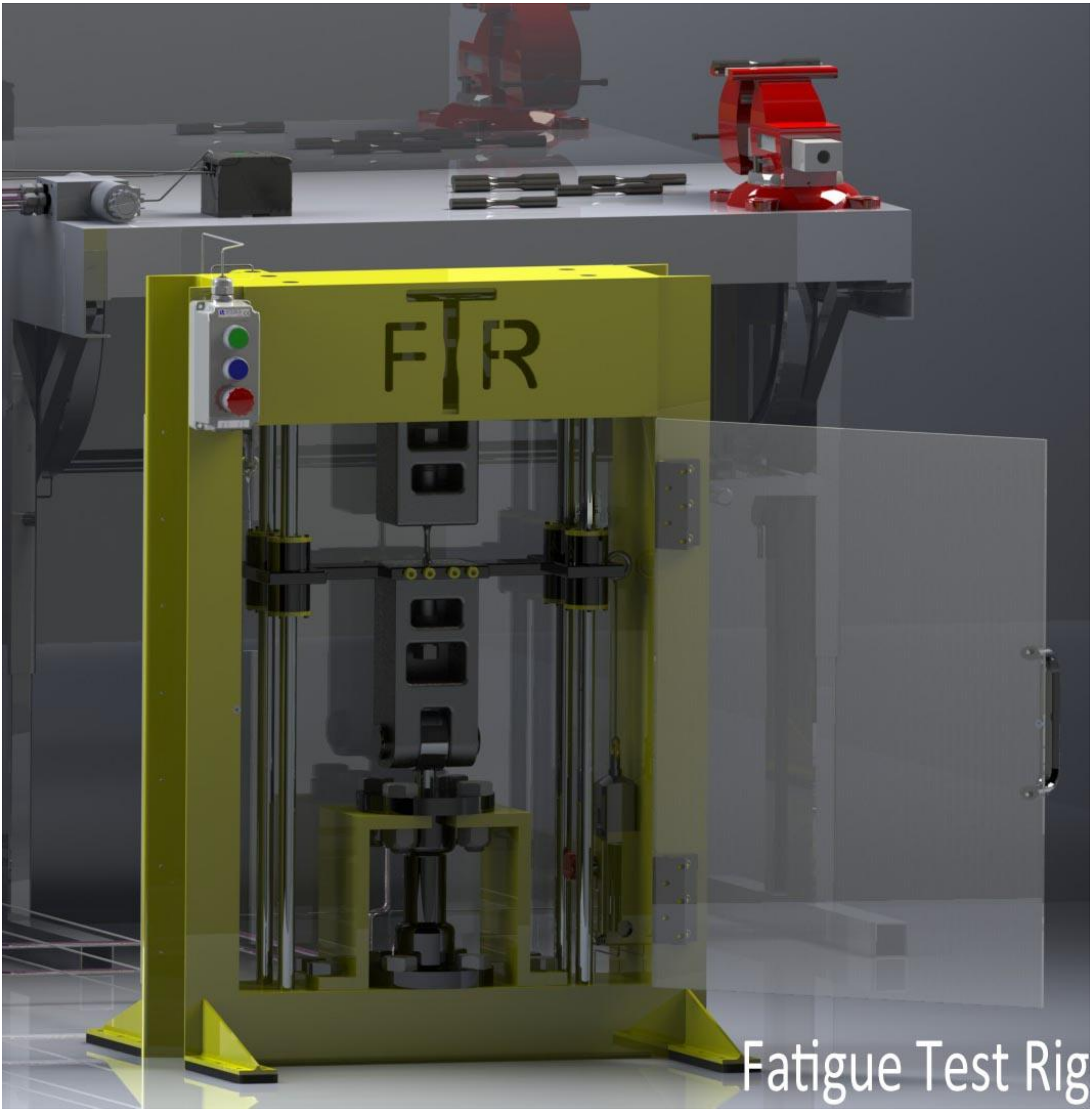
Espen Sætre Kolberg	

Dato: 30. mai 2012

Navn	Olaf Hallan Graven	Navn
Intern Veileder	Intern Sensor	Ekstern Sensor


FTR
Fatigue Test Rig

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HØGSKOLEN i Buskerud

Department of Technology
Kongsberg

Title of document: **Vision document, Version 2.0**
Course (code/name) SFHO3200 - H11 - Hovedoppgave med prosjektstyring
Group Members: Espen Sætre Kolberg Kjetil Haugmoen Kjøndal
Internal Supervisor: Jamal Safi
Date: 26.05.2012
We confirm that the submitted assignment is entirely our work   **Espen Kolberg** **Kjetil Kjøndal**

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Document history

Date:	**Version:**	**Changes:**	
20.12.2011	0.1	First draft	
08.01.2012	0.2	English check, spell check	
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23.03.2012	1.1	Change participants, change responsibilities	
09.05.2012	1.2	Spell and grammar check	
09.05.2012	1.3	Adding risk analysis and outcome 22.03.2012. Fatigue theory	
26.05.2012	2.0	Grammar and spell check Finalized document	

Table 1: Document history

Fatigue Test Rig

The name of the project is discussed and we concluded with "Fatigue Test Rig".
We find this name precise, clear and simple and that this name explains the design task.

Project group members

Name: Espen Sætre Kolberg, 24 years old from Kongsberg
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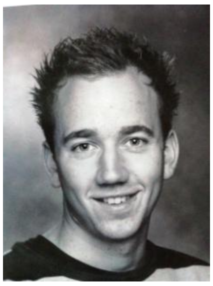

Name: Kjetil Haugmoen Kjøndal, 24 years old from Larvik
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Project Main Group E-mail: gruppe11ftr@gmail.com

Project organizing and responsibility

Espen S. Kolberg- Design and control responsible
- Responsible for design
- Responsible for the control system
- Responsible for manual calculations
- Responsible for the homepage

Kjetil H. Kjøndal – Project leader
- Responsible for documentation
- Responsible for disposal of time
- Contact person
- Report to and have contact with internal supervisor
- Coordinate testing
- Responsible for FEM analysis

The Client

BUC (Buskerud University College) is a University with different departments, which offer several subjects and professions. In the Department of Technology there are several bachelor degrees of engineering. The Department of Technology has a Laboratory to be used as a practical educational method and as laboratory during the process with the bachelor degree. As a supplement to the present instruments there was a demand for a renewal.

Our Contact at the University who has provided us with the project assignment is:

Name:	Kjell Enger
Phone number:	32869734
E-mail:	kjell.enger@hibu.no

The Assignment

Introduction

Our assignment is given by BUC (Buskerud University College). BUC have a laboratory department for showing and teaching the students more thoroughly what exactly the different practical methods are. The professors want to have instruments to show the students each method and have the possibilities of a practical approach in teaching. The instrument most wished for, is a fatigue test rig that can be operational and give reliable results. The University has asked for an update on old equipment for fatigue testing, that is; a new Fatigue Test Rig.

Situation today

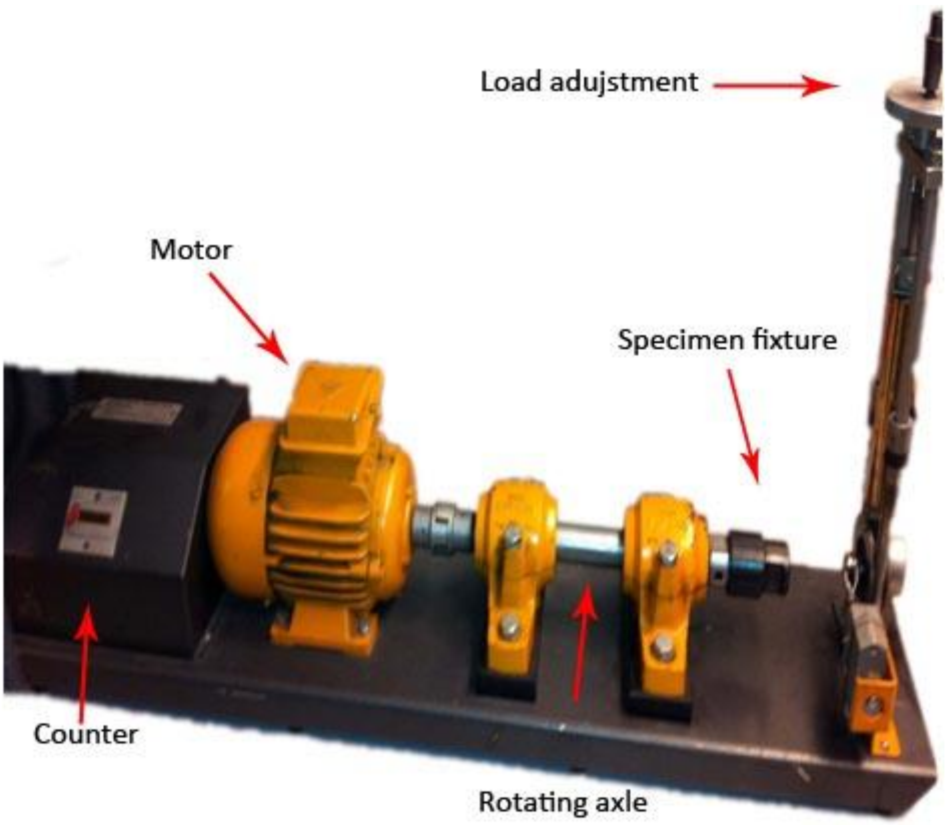

Figure 1: The old test rig

The Fatigue test rig, which is operational, now, does only test fatigue-bending stress on a circular test sample. This rig has been worn down and is not at its best condition.
It consists of an electromotor that delivers the power to rotate the test specimen. The specimen is held in place on the one side of the axle, while it is subjected to bending load on

the other side. This rotation is providing a reversible bending moment that eventually causes the specimen to fail.

Main objective of the project

The main objective of this project is producing a complete fatigue test rig.
We need to consider the concepts out on the market, find the best solutions, and then design a Fatigue Test Rig with axial force appliance. Since the most of the testing machinery and equipment on the market has more test options than we need, we have to withdraw solutions and ideas in terms of what our Fatigue test rig needs.

The group will have to model the whole test rig in Solid Works part by part. We do also need to do FEM (Finite element method) analysis on many, if not all parts of the test rig to get the best possible solution for the University and our project, but have in mind what the University actually has of parts and equipment.

After finishing the design and implementations we will need to go through a test period, where we test our equipment to be sure that we will get accurate results which can be trusted and used.

During the work on the project, the group realized that to manufacture and assemble a test rig would take more time than the project had. The group also realized that the University had not as much equipment and parts as anticipated. When discussing this with the client, a decision was made to produce a complete basis for production of the test rig.

This can be a fun and instructive project assignment, where we can get a deeper and broader understanding of what we have been taught by the University the last years.

Fatigue Theory

Fatigue is a damage condition, which appears when there is repeating fluctuations in a material. This result in forming cracks which wanders through the material for each cycle done. Fatigue is considered dangerous because it is hard to discover before the residual fracture occurs. This is a significant problem because fracture can happen with loads below the static yield strength, and can cause failure.

Wøhler first systematically studied fatigue around 1850 in relation to repeating axle fractures with the Prussian government railroads (Hærkegård. G 2004) Wøhler confirmed that fracture could appear after large amount of load cycles, and with no other understanding of this topic Wøhler meant that with a large number of cycles the material would get "tired" and this lead to the expression fatigue.

It was not before around 100 years past Wøhlers groundbreaking test the fatigue phenomenon were connected to physical metal explanation.

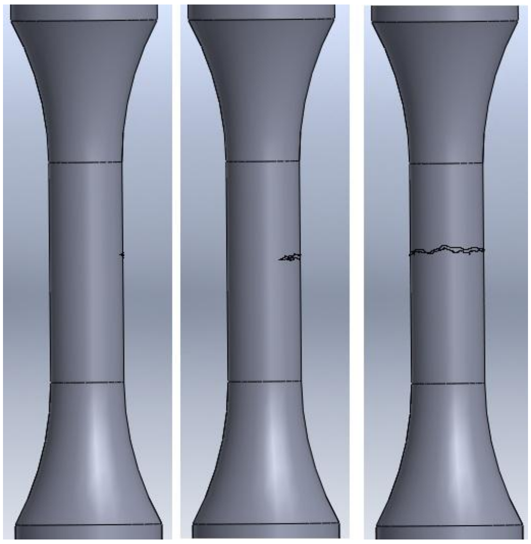
Figure 2: A test specimen shows fracture

The initiation of a crack appears when there are plastic deformations adding up causing shear instability, which leads to micro fractures. As the micro fractures increases the crack increases.

When manufacturing parts, it is normal with small amounts of irregularities like for example pores at the surface of the material. These structural abbreviations can cause the initiation of a crack. The crack growth occurs slowly at first, and as the crack grows into the material it occur faster until it has a critical size and a residual fracture occurs.

When testing for fatigue, it is usually used a standard test specimen. This is to examine and to collect data on material properties. The fatigue testing is important; when designing a construction or a machine the material fatigue data helps to choose the best possible material for the design. There are also a lot simpler to test a small test specimen to get material data, instead of a big construction with a weight of several tons.

When Wøhler conducted a fatigue test, he used rotating bending and the fatigue testing equipment consisted of a rotating chuck with a force perpendicular to the test specimen. (Similar to the old fatigue test rig the school has in its workshop today) Today, solution of a fatigue test rig consists of apply the forces pure axially on the test specimen. The experimentally determined Wøhler-curve / SN-curve are to be used as a basis for all fatigue dimensioning. This curve shows stress related to number of cycles until fracture giving a picture of the material lifetime at a given tension.

Material testing can be sorted into two categories: Nondestructive tests and Destructive tests. The use of nondestructive tests has increased in the industry because of the time spared. These tests can detect hidden failures or defects without destroying the material. Typical tests of nondestructive testing include x-ray, magnetic particle inspection, ultrasound etc.

Destructive testing gives an overview of the material properties. By using the destructive tests like tensile testing, hardness testing or fatigue testing, information as strength of material can be known. The testing our machine offers is fatigue testing, a destructive test where the test specimen breaks off to end the test.

HØGSKOLEN i Buskerud

Department of Technology

Kongsberg

Title of document: **Requirement specification, Version 2.0**
Course (code/name) SFHO3200 - H11 - Hovedoppgave med prosjektstyring
Group members: Espen Sætre Kolberg Kjetil Haugmoen Kjøndal
Internal Supervisor: Jamal Safi
Date: 29.05.12
We confirm that the submitted assignment is entirely our work **Espen Kolberg** **Kjetil Kjøndal**

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1.0 Document history

Date	Version	Changes
29.12.2011	0.1	Started and edited
03.01.2012	0.2	Written introduction
06.01.2012	0.3	Edited requirements
09.01.2012	0.4	Rewritten requirements, added table of contents
10.01.2012	1.0	Finalized document
28.12.2012	1.1	Edited requirements,
13.02.2012	1.1.1	Edited
26.02.2012	1.2	Added hierarchy
02.03.2012	1.3	Finalized document
23.04.2012	1.31	Added R28
10.05.2012	1.4	Grammar and spell check
24.05.2012	1.41	Read through and checked
29.05.2012	2.0	Spell check and layout. Finalized document

Table 1

2.0 Abbreviations

BUC- Buskerud University College

3.0 Introduction

This task is given by BUC which is located in Kongsberg.

The need for a replacement of a fatigue machine is the background for the project. The existing machine is old and does not fulfill the demands of a reliable machine to be used by the students. It consists of an electromotor which delivers the power to rotate the test specimen. The specimen is held in place on the one side of the axle, while it's subjected to bending load on the other side. This rotation is providing a reversible bending moment that eventually causes the specimen to fail.

The main goal of this project is to design a fatigue machine and eventually build an alpha prototype which uses linear forces instead of circular running with bending stresses. The machine is to be used by the students at BUC, where they can observe the behavior of metal when subjected to variable loadings.

This document contains the main requirements that are set for our design. It will be the guidelines for the group during the development of the testing machine system.

4.0 Requirement definitions

The requirements will be divided into groups to give a better overview and to ease tractability. There are requirements given by the client (BUC) and others are constructed by the group out of understanding the need. The different subdivisions of requirements are listed below:

- Functional requirements
- System requirements
- Result requirements
- Environmental requirements
- Other requirements

All of the requirements are also divided into different categories based on how important those requirements are to be met by the proposed design solution. These categories are as follows:

- A: Essential requirements
- B: Significant requirements
- C: Requirements that will be done if there is time

5.0 Requirements

5.1 Functional requirements

	Req. name	**Comment**	**Date**	**Req. ID**	**Req. origin**	**Priority**
5.1.1	Counter	The machine should give the number of cycles of tension and compression	29.12.2011	R1	BUC	**A**
5.1.2	User operated emergency stop	The machine should stop in case of emergency	06.01.2012	R2	BUC	**A**
5.1.3	Test specimen fixture	The machine should apply adequately gripping force to ensure tightness and avoid slack of the test specimen	06.01.2012	R3	BUC	**A**
5.1.4	Movement of test- rig	Linear movement	06.01.2012		BUC	
		The machine should apply the load axially		R4		**A**
		Test specimen must be exposed to an alternating tension-compression cycle		R5		**B**
5.1.5	Test stop	The machine must stop when test specimen breaks	06.01.2012	R6	BUC	**B**
5.1.6	Test time	The testing time for standard specimen should not exceed 24 hours	06.01.2012	R7	BUC	**B**

5.2 System requirements

	Req. name	Comment	Date	Req. ID	Req. origin	Priority
5.2.1	Vibrations	No resonance must be created, neither in machine nor in surrounding areas	06.01.2012	R8	BUC	**A**
5.2.2	Life cycle (durability)	The performance degradation should be a minimum of 7% of the delivered accuracy after 3 years of service.	06.01.2012	R9	BUC	**A**
5.2.3	Machine weight	The machine weight divided by the area it occupies should not exceed the floor carrying capacity. (NS 3473:2003)	06.01.2012	R10	BUC	**B**
5.2.4	Test material	The machine is primarily designed to test normal construction steel(E=200GPa) The machine should also be able to test aluminum (E=70GPa)	06.01.2012	R11 R12	BUC	**B** **B**
5.2.5	Machine dimensions	The machine must be transportable In/out of the hydraulics lab C151 at the university.	06.01.2012	R13	BUC	**B**
5.2.6	Power supply	The machine electricity connection should fit into the norwegian standard outlet.	06.01.2012	R14	BUC	**B**
5.2.7	Frame stiffness	The frame must have fatigue safety factor of at least 2.	06.01.2012	R15	BUC	**B**
5.2.8	Deflection	The maximum deflection in the frame has to be less than 0,5mm.	23.04.2012	R28	Group	**A**

5.3 Result requirements

	Req. name	Comment	Date	Req. ID	Req. origin	Priority
5.3.1	Measurement units	All results must be shown in SI – units	06.01.2012	R16	BUC	**C**
5.3.2	Results	Output data must show number of cycles until fracture._One cycle is from 0->tension->0->compression->0 The user should be able to read the load and number of cycles throughout the test.	06.01.2012	R26 R27	BUC	**A** **A**
5.3.3	Deviation	The machine should give results within a tolerance of double industry tolerance when delivered to the university (+-2%) ASTM E4-10	06.01.2012	R19	BUC	**B**
5.3.4	SN - Graph	The system shall produce an SN-graph on laptop after 10 tests are done.	06.01.2012	R17	BUC	**C**
5.3.5	Data log	Output data with all results must be saved on a device	06.01.2012	R18	BUC	**C**

5.4 Environmental requirements

	Req. name	Comment	Date	Req. ID	Req. origin	Priority
5.4.1	Testing conditions	Operating temperature range must be between 5-30 °C	06.01.2012	R20	BUC	**A**
5.4.2	Noise level	The rig has to operate at 90dB or less at a distance of 1 meter	29.12.2011	R21	Group	**B**

5.5 Other requirements

	Req. name	Comment	Date	Req. ID	Req. origin	Priority
5.5.1	Operator safety	Moving parts must be placed in a housing	06.01.2012	R22	BUC	**A**
5.5.2	User manual	The system must have a user manual in English	06.01.2012	R23	BUC	**A**
5.5.3	User friendly	The system must be operable by an engineer student after reading the manual	06.01.2012	R24	Group	**A**
5.5.4	Test specimens	There must be produced test specimens (6.35mm dia. , ASTM 606E)	06.01.2012	R25	BUC	**B**

HØGSKOLEN i Buskerud

Department of Technology
Kongsberg

Title of document: **Test specification, Version 2.0**
Course (code/name) SFHO3200 - H11 - Hovedoppgave med prosjektstyring
Group members: Espen Sætre Kolberg Kjetil Haugmoen Kjøndal
Internal Supervisor: Jamal Safi
Date: 29.05.12
We confirm that the submitted assignment is entirely our work **Espen Kolberg** **Kjetil Kjøndal**

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1.0 Document history

Date	Version	Changes
29.12.2011	0.1	Started and edited
03.01.2012	0.2	Edited hierarki
06.01.2012	0.3	Edited requirements
08.01.2012	0.4	Added Introduction and edited test specs
10.01.2012	1.0	Finalyzed document
23.03.2012	1.1	Edited requirements, layout and test strategies
29.05.2012	2.0	Finalized document

Chart 1

2.0 Abbreviations

BUC- Buskerud University College

3.0 Introduction

This task is given by BUC which is located in Kongsberg. The need for a replacement of a fatigue machine is the background for the project. The existing machine does not fulfill the demands of a reliable machine to be used by the students. It consists of an electromotor which delivers the power to rotate the test specimen. The specimen is held in place on the one side of the axle, while it's subjected to load on the other side. This circular type of motion will make the test specimen exposed to both tension and compression forces.
The main goal of this project is to make a prototype of a fatigue machine which uses linear forces instead of circular. The machine is to be used by the students at BUC, where they can observe the behavior of metal when subjected to variable loadings.

The test specification includes a description of how the requirements will be tested. The different tests will ensure that the machine is built and performs according to the requirements set in the project. All of the requirements have their own ID, which makes it easier to find a specific requirement. A number in the requirement specification corresponds with a similar number in the test specification. By using this method it is easy to track the different requirements and their functional tests.

4.0 Test strategies

During the design process of the project, all of the designs will be tested in SolidWorks with the Final Element Method (FEM). This software has the possibility to perform analysis of components and parts in our design. It is also possible to subject the components to different types of stresses. In doing this, it makes it possible to estimate approximately the dimensions needed in the design.
We test bottom up, there we start with the smallest components and then assemble these together afterwards.

5.0 Test specification

5.1 Test of functional requirements

	Req. name	Comment	Date	Req. ID	Req. origin	Priority
5.1.1	Counter	Visually inspect the counter to check if it's counting	29.12.2011	T1	BUC	**A**
5.1.2	User operated emergency stop	Turn on the machine; use the emergency mechanism to check if the machine stops.	06.01.2012	T2	BUC	**A**
5.1.3	Test specimen fixture	Ensure that the test specimen is held tight and inspect that the forces in the fixture is adequately.	06.01.2012	T3	BUC	**A**
5.1.4	Movement of test- rig	Perform measurement in SW and physically measurement on the machine. Visually check, and measure that the movement is from 0 to + to 0 to – to 0	06.01.2012	T4 T5	BUC	**A** **B**
5.1.5	Test stop	Be present during the testing to see if the machine stops when specimen breaks.	06.01.2012	T6	BUC	**B**
5.1.6	Test time	Use a timer to control if the system test time exceeds 24hrs	06.01.2012	T7	BUC	**B**

5.2 Test of system requirements

	Req. name	Comment	Date	Req. ID	Req. origin	Priority
5.2.1	Vibrations	Check the surroundings for vibrations and or resonance.	06.01.2012	T8	BUC	**A**
5.2.2	Life cycle (durability)	Simulation of a SW design for the fatigue test rig in a FEM analysis there we test that the non maintainable parts of the rig will hold for at least 3 years in a fatigue simulation.	06.01.2012	T9	BUC	**A**
5.2.3	Machine weight	Check and verify that the total weight of the Fatigue Test Rig does not exceed maximum of the floor capacity/2	06.01.2012	T10	BUC	**B**
5.2.4	Test material	Check the material data of the test specimen to ensure it`s construction steel with a modulus of elasticity of 200GPa. (E=200GPa)  Check the material data of the test specimen to ensure it`s aluminium with a modulus of elasticity of 70GPa. (E=70GPa)	06.01.2012	T11 T12	BUC	**B** **B**
5.2.5	Machine dimensions	Perform physical measurements of the machine and measurements in SW to make sure it`s able to go inside C151.	06.01.2012	T13	BUC	**B**
5.2.6	Power supply	Check that all electric systems is using 220V and attach it to an outlet of 220v to verify that everything works as it should.	06.01.2012	T14	BUC	**B**
5.2.7	Frame stiffness	Perform calculations to ensure the frame has a factor of safety of at least 2 against fatigue.	06.01.2012	T15	BUC	**B**
5.2.8	Deflection	Perform a FEM analysis on the frame to check the deflection.	23.04.2012	T28	Group	**A**

5.3 Test of result requirements

	Req. name	Comment	Date	Req. ID	Req. origin	Priority
5.3.1	Measurement units	Manually check if the output is using the SI- units	06.01.2012	T16	BUC	**C**
5.3.2	Results	Visually inspect output data to check if number of cycles until fracture is listed. Visually inspect the output data, then check for forces applied	06.01.2012	T26 T27	BUC	**A** **A**
5.3.3	Deviation	Perform a test with the same criteria at the HiG lab and check for deviation.	06.01.2012	T19	BUC	**B**
5.3.4	SN - Graph	Observe that the laptop is showing a SN curve after the 10 tests are done.	06.01.2012	T17	BUC	**C**
5.3.5	Data log	Try to access earlier test data and verify.	06.01.2012	T18	BUC	**C**

5.4 Test of environmental requirements

	Req. name	Comment	Date	Req. ID	Req. origin	Priority
5.4.1	Testing conditions	Verify that all components of the machine are designed to tolerate temperatures from 5-30°C with a FEM analyses and data sheets for the components.	06.01.2012	T20	BUC	**A**
5.4.2	Noise level	Test with a dB-meter at a distance of 1 meter and verify.	29.12.2011	T21	Group	**B**

5.5 Test of other requirements

	Req. name	Comment	Date	Req. ID	Req. origin	Priority
5.5.1	Operator safety	Check and verify that all personnel protection equipment is ready for usage and that all protection housing is functional.	06.01.2012	T22	BUC	**A**
5.5.2	User manual	Check and verify that all aspects of user functions is covered and explained in detail.	06.01.2012	T23	BUC	**A**
5.5.3	User friendly	Let an engineer student try to use the machine and confirm that he understands from the user manual how to use it.	06.01.2012	T24	Group	**A**
5.5.4	Test specimens	Manually inspect and measure the test specimens to ensure they are up to standard.	06.01.2012	T25	BUC	**B**

HØGSKOLEN
i Buskerud

Department of Technology

Kongsberg

Title of document: **Project plan, Version 2.0**
Course (code/name) SFHO3200 - H11 - Hovedoppgave med prosjektstyring
Group Members: Espen Sætre Kolberg Kjetil Haugmoen Kjøndal
Internal Supervisor: Jamal Safi
Date: 29.05.12
We confirm that the submitted assignment is entirely our work **Espen Kolberg** **Kjetil Kjøndal**

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1.0 Document history

Date:	Version:	Changes:	
30.12.11	0.1	Started and edited	
04.01.2012	0.2	Added activity plan and project plan	
08.01.2012	0.3	Added Risk analyses	
10.01.2012	0.4	Added project plan	
10.01.2012	1.0	Finalized document	
29.05.2012	2.0	Added Risk outcome, grammar and spell check. Finalized document	

2.0 Abbreviations

BUC -Buskerud University College

3.0 Introduction

This project has an objective and purpose to increase the students' knowledge and to give them an understanding of being an engineer. The students who participate in the project will learn to cooperate, execute and to lead through a project. It is important for the students to get to know how an engineer works and completes a project.

It is important to do a good job and to show that we can work effectively and efficiently in a group. This group aims at making a project worth using as a recommendation applying for a future job. A project could be just as important as a character chart to show future companies when applying for a job.

Every student needs to have a full understanding of all aspects of the project throughout, and therefore it is necessary to assign different work areas to every student. It is also important that the students plan the time ahead needed to complete the project.

4.0 Project model

There are many different project models; some models are made to cover special needs in a project. The project model is a very important tool in the working with a project and we need to choose the best-suited model for our project. The model shows the different phases the project would need to go trough to be successful. The model helps us through the project and points us in the right direction, without necessarily following it by every step.

Some of the most common models are:

- Waterfall
- Prototyping
- Evolutionary
- Incremental

4.1 Waterfall

The waterfall model is the most common model for development of bigger systems. The approach is based on a thoroughly analysis of the system before the design phase is started. It includes an in depth analysis of the previous phase. There are some pros and cons with this kind of approach. It is a simple model with clearly defined milestones. On the other hand this model is not very flexible and leads to an early fix of the requirement specification, which could lead to a poor outcome.

4.2 Prototyping

Prototyping model leads to a rapid development of the product. There are vague specifications and is not often used on larger projects. The model is based on an open dialog with the customer. The design and construction are made for the customer to test and then to have a feedback from the customer. This method is more appropriate for software based development. There are some pros and cons with this model as well. There are not much time for design and might lead to mistakes during the process.

4.3 Evolutionary

The evolutionary model includes the customer in the development process. There are several small waterfall models This leads to a common understanding of the product to be made. Working with this model makes it difficult to predict the time needed to finish the work.

4.4 Incremental

Incremental development allows the main goal of the project to be finished, even with a limited number of people. The product could operate with less functionality. Difficult parts that occurs during the project could be postponed to allow to start at the easier parts of the task.

[1]

5.0 Incremental development

The group have chosen a model that is an adapted version of the waterfall method. In this method we run trough the waterfall method faster than originally and then repeat the process. First the analysis is done and the requirement specifications are set. This will give us knowledge of what are the project-needs and a base from where we start further work with our project.

The project is divided into increments and we chose to start with the most demanding increments and do the easier increments at the end. We come up with a solution for each increment, evaluate the solution and work through it again and again until we are satisfied. By doing this we hope to see our flaws and correct our mistakes and also improve some aspects of the project.

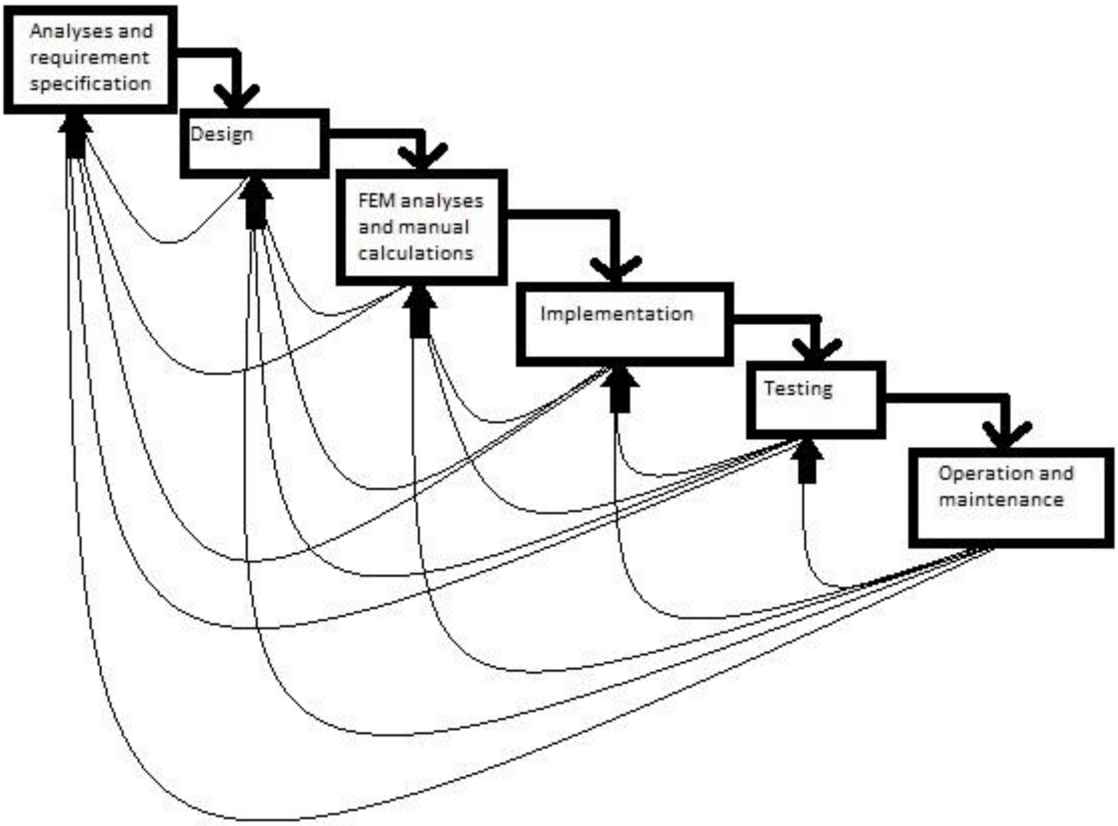


Figure 1: Incremental development

6.0 Risk analysis

In a project such as this, there are several factors that can jeopardize the progress of the project and the final product. It is important to know these factors, so that the effects of any risk can be reduced or avoided.

6.1 Fail in exams

As the project group consists of three students who not jet have passed the necessary exams, there is a possibility that one or more of the group members fail and they are not allowed to continue the project. If this occurs BUC must decide what action to take. Possible solutions may be that either the project can be scaled down to match the remaining group members, the project cannot be done, or project members have to be placed on other Bachelor projects.

High-risk High consequences

6.2 Loss of data

In a scenario there could be a crash in one of the group members computer or on the server, or there could be an infection with a virus. It is important to back up every document in at least 2 places. We use drop box folder that can be opened from the Internet by any member of the group. We need to back up our own work on our own computer and also back up the contents of the drop box folder and also take precautions against viruses.

Medium risk High consequences

6.3 Short term illness

Short-term illness is something that almost every project group is prone to suffer. If this happens, the other members on the group will have to take on some extra work in a short time period. Or in case this will not work the activity have to be postponed ahead.

High-risk Low consequences

6.4 Long term illness

If this occurs the project group will need to distribute the work on other members of the group. This can make it difficult to complete the project as planned, and a possibility will be that project will have to be scaled down from its original plan.

Low risk High consequences

6.5 Lack of components

If the University lacks some of the needed components or the delivery of a component is going slow, the production of a prototype can be in peril. The project group is bound by its deadline and has very limited economical resources. The group will need to either come up with a better solution for components, or have to wait for delivery of the component. This will delay the project.

Medium risk Medium consequences

6.6 Client changes

If the client changes the requirements or functions of the product, this will lead to reorganization and add to the work of the project group. Every member of the group will need to increase their work, and if the added workload is too extensive, a prototype may be too much to ask for.

Medium risk Medium consequences

6.7 Supervisor absence

If the supervisor is absent when the group needs advice, we will suffer a delay relative to the absence. If a longer absence of the supervisor should occur, it may be necessary to apply for a substitute supervisor.

Low risk High consequences

6.8 Lack of knowledge

Some of the purposes with this project are to increase the students' knowledge and competence in working with projects. It may very well be that some aspects of the project need a higher competence and knowledge than the group members can provide. The group will in addition to using literature on relevant topics, need to seek advice by the supervisor and also by other competent people. Failing to find necessary advice or data will of course influence the finished product and an extensive search for relevant help may delay the progress of the project.

Medium risk   Medium to high consequences

7.0 Risk outcome

7.1 Failing exams

After the exam results were clear, one of the group members had to withdraw from the project. After talking to the client and internal supervisor, the project was decided to continue with two members instead of three. The project group reorganized and divided responsibilities and task between them. The demands of the project were scaled down, but still a group of two instead of three may influence the final results.

7.2 Loss of data

In this project some challenges have occurred. There has been a computer crash, and a virus infection in both computers, which also infected the drop box. The virus was an encryption infection, which attacked one of the computers running an older java version. All files on two computers and the drop box were encrypted.

The group had taken precautions and had backed up the work on other devices. No documents were lost.

7.3 Illness

So far has no one in the group suffered neither short term nor long-term illness.

7.4 Lack of components

There have been difficulties in providing different components for the making of a prototype. The group has tried to collect and manufacture necessary parts both from BUC and from different firms and companies. After discussing with the supervisor in April, the project group realized that making a prototype would be too time-consuming. Instead the aim was to complete a thorough description of the prototype ready for manufacturing.

7.5 Client changes

There have been no major demands of alteration or changes except that of stated above.

7.6 Supervisor absence

The supervisor has been absent for 2 weeks. In this period the group was unable to contact the supervisor, but decided to work with subjects, in which they required no help or advice.

7.7 Lack of knowledge

During the project the group has had some challenges with some aspects of the project work. The group has had a challenge in finding the necessary force that had to be applied to the wedges, creating enough gripping force to hold the test specimen. There has also been a challenge for the group to acquire knowledge about the control system of the rig. During the work with the project, the group realized that the system had to have in some extent an electrical control system. This lead to a delay and caused the group to come behind schedule. The project plan was to some extent staggered.

8.0 Follow up

During the examination period the group was occupied with various subjects, which lead to less work with the project. The group was not as much in contact with the client as scheduled. This meant that the client did not get as much update on the project progress as intended in the requirements set by the client. The group was late to confront the client on the fact that building a prototype was put on hold.

During the project process the group has learned a lot about working together as a team to achieve a goal. There has been educational for each group member to work with this project. Each group member has acquired experience in planning a project from start to finish. The process has also involved consulting with several companies regarding components that have been relevant for use in the project.

At the very start of the project the group decided to write the report in English. There was some difficulties regarding the documentation in the beginning, but the group is overall pleased that this decision were taken. During the process each member of the group has increased their skills in writing a technical document in English.

9.0 Project plan

We have chosen the following milestones for our project:

- Milestone 1: Presentation 1, 13.01.2012.
- Milestone 2: Presentation 2, 27.03.2012.
- Milestone 3: Final submission of documents, 29.05.2012.
- Milestone 4: Presentation 3, 07.06.2012.

	Task Name	Duration	Start	Finish
1	Presentation 1	0 days	Fri 13.01.12	Fri 13.01.12
2	Develop web site	1 day	Mon 16.01.12	Mon 16.01.12
3	Arne Bjørnar Næss?	1 day	Fri 13.01.12	Fri 13.01.12
4	**Phase 1 Product development**	**42 days?**	**Tue 17.01.12**	**Wed 14.03.12**
5	**Coarse concept**	**23 days?**	**Tue 17.01.12**	**Thu 16.02.12**
6	Fixture design	4 days?	Tue 17.01.12	Fri 20.01.12
7	Test specimen design	2 days?	Thu 19.01.12	Sun 22.01.12
8	Chassis	3 days?	Fri 20.01.12	Tue 24.01.12
9	Drivetrain design	3 days?	Mon 23.01.12	Wed 25.01.12
10	Power supply	18 days?	Tue 24.01.12	Thu 16.02.12
11	Control system	2 days?	Fri 20.01.12	Thu 26.01.12
12	**Selection concept 1**	**1 day?**	**Fri 17.02.12**	**Fri 17.02.12**
13	Select concept	1 day?	Fri 17.02.12	Fri 17.02.12
14	**Design phase 1**	**16 days**	**Mon 20.02.12**	**Mon 12.03.12**
15	Design Solid works	3 days	Mon 20.02.12	Wed 22.02.12
16	FEM analysis	5 days	Thu 23.02.12	Wed 29.02.12
17	Manual calculation	8 days	Thu 01.03.12	Mon 12.03.12
18	Documenting Phase 1	2 days?	Tue 13.03.12	Wed 14.03.12
19	**Phase 2 Product development**	**15 days?**	**Thu 15.03.12**	**Wed 04.04.12**
34	**Easter holiday**	**3 days?**	**Thu 05.04.12**	**Mon 09.04.12**
36	Eksamenstid	11 days?	Thu 05.04.12	Thu 19.04.12
37	**Phase 3 last design**	**13 days?**	**Thu 19.04.12**	**Mon 07.05.12**
38	Last FEM analysis	12 days	Thu 19.04.12	Fri 04.05.12
39	Last calculation	3 days?	Thu 03.05.12	Mon 07.05.12
40	Last equipment choice	2 days?	Fri 04.05.12	Mon 07.05.12
41	**Phase 4 testing**	**8 days**	**Wed 09.05.12**	**Fri 18.05.12**
43	**Phase 5 Finalize documents**	**7 days**	**Mon 21.05.12**	**Tue 29.05.12**
45	**Final submission of documents**	0 days	Tue 29.05.12	Tue 29.05.12
46	Presentation 3	0 days	Thu 07.06.12	Thu 07.06.12

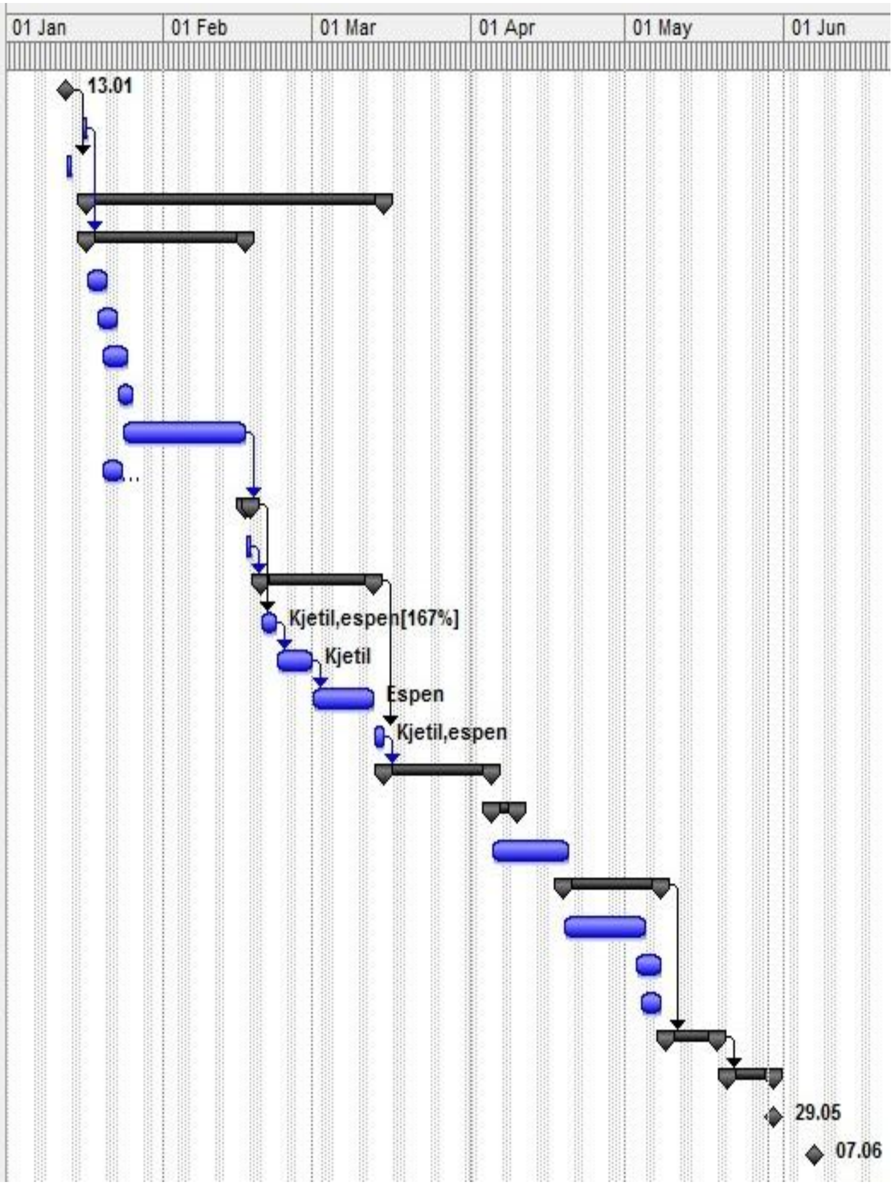


Figure 2: Project plan

10.0 Sources

[1]
http://www.uio.no/studier/emner/matnat/ifi/INF1050/v11/Prosesser.INF1050.24.1.2011_2pr_side.pdf (12.04.2012)

HØGSKOLEN
i Buskerud

Department of Technology
Kongsberg

Title of document: **Concept round 1, version 2.0**
Course (code/name) SFHO3200 - H11 - Hovedoppgave med prosjektstyring
Group Members: Espen Sætre Kolberg Kjetil Haugmoen Kjøndal
Internal Supervisor: Jamal Safi
Date: 29.05.2012
We confirm that the submitted assignment is entirely our work   **Espen Kolberg** **Kjetil Kjøndal**

Document history

Version	Date	Changes
0.1	29.02.2012	Added introduction, hydraulic
0.2	21.03.2012	Added fixture, test specimen dimension
1.0	23.03.2012	Changed font size, page layout
1.1	30.03.2012	Changed headlines, dates
1.2	14.05.2012	Grammar and spell check
2.0	29.05.2012	Finalized document

Table 1: Document history

1.0 Introduction

The document shows which concepts that are made in round 1 of the bachelor project, and has as intension to show what ideas that were considered and which ideas that were chosen as approved. It will show the decisions made and why they were made.

We will explain ideas, why they were considered and what made us either throw the idea away or choose one.

There are different solutions to choose from and every concept has something new about it. This is to know what is out there, and what ideas that could be possible. Every one with different up and downsides

In our work we wish to increase our knowledge within hydraulics, solidworks, and calculations and estimates. We will also explore possibilities for workshop willing to produce our test specimens, check out where we can get materials etc.

Our project plan is incremental and is based on several concept rounds where we discuss and improve our concept.

Table of contents

2.0 The Planning

In our project the group was attracted to jump on to the task at hand right away. And as the group already had a thought in mind for how the test rig would work, we would need to clear our heads, to think of different solutions which could work for the test rig. The group purpose is to be innovative, and to find the best solution.

When starting on our concepts we took 15minute of brainstorming on each of our components and on subsystems to make sure all components are the best and that subsystem are fit together.

The group wants to find good solutions and good ideas in each round, and the best ideas are taken into the next round. The solutions might be modified, but the best is brought on.

3.0 Abbreviations

BUC	-Buskerud University College
SW	-Solidworks
FEM	-Finite Element Method
FTR	-Fatigue Test Rig
F.S.	-Factor Of Safety

4.0 Test specimen Dimension

Concept 1

The test specimen dimension is important, and affects every aspect of our fatigue test rig. Because our test specimen defines how much force the test rig will have to withstand.

When searching for a dimension that is mostly used, we came over some sites on the internet and design books that mention that the dimension of the test specimen have to be 10mm when doing a fatigue test.[1] We chose to use 10mm. The forces needed to show the first point on the SN - graph would be right up to 2850kg

$$A = \pi \times r^2$$

$$A = \pi \times 0{,}005^2 = 0{,}00007853 mm^2$$

$$\sigma_{max} = \frac{P}{A}$$

$$355 MPa \times 0{,}00007853 mm^2 = 27878 N$$

5.0 The frame

In this section there are different concepts for how the frame of our FTR could look like. The different concepts came from idea rounds, there we sat down in 15 minutes each time and chose the best one from each idea round.

These concepts were the first ones to be considered and that we used to work further to find the best possible solution. The frame concepts were made out from our own ideas and from solutions taken out from industry used fatigue test machines.

5.1 Idea 1

Figure 1

Concept 1 was the first idea to make it to the drawing board. This concept came from own ideas from the group. The cylindrical rods are there to make sure that the test specimen at all times is straight like it is supposed to be.

This concept is built with two hydraulic cylinders, and two cylindrical guide rods.

It can be difficult to make sure the two hydraulic cylinders go parallel with each other.

Here there is the problem with guide rods on one axis; this could cause a crooked load on the test specimen. There would be more preferred with the four guide rods that cover both x-axis and y-axis.

There will also be an economical cost by having two hydraulic cylinders. Then we would need more oil, more hoses and a system to make sure the cylinders go parallel. There is also not needed more than one cylinder to apply the needed load.

5.2 Idea 2

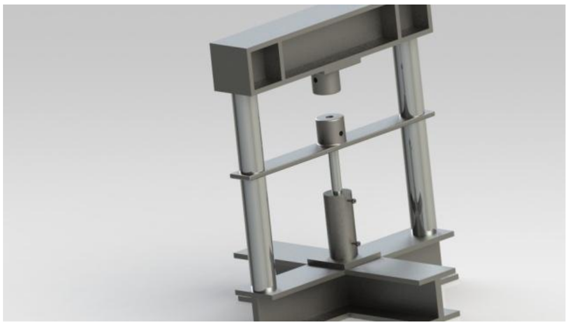


Figure 2

This concept consists of an axial tension/compression load appliance, but here with only two guidelines the danger of getting a crooked load appliance is there.

This has the same properties as idea1, only that here there is only one hydraulic cylinder, which makes this more economical.

The H-beams used as lower and upper frame, provides stiffness to the rig. The lower frame is big and stable, and the rig will withstand the forces applied.

5.2 Concept 1

Figure 3

This is very suitable for tension / compression loads, since there is a hydraulic cylinder in the middle of the specimen fixture.

There are four cylindrical guiding rods that assure that the load is applied axially. It is also difficult for the hydraulic cylinder to pull itself out of position with the 4 cylinder guiding rods.

The h – beam is only used to show how it could be solved, but this can be different. It all depends on how much force that is applied on the beam. But the h- beam is good to use in this case, because it will resist the forces applied axially and withheld stiffness in the beam.

5.3 The decision

Since the client is not interested in how the frame is designed, the group had a group meeting.

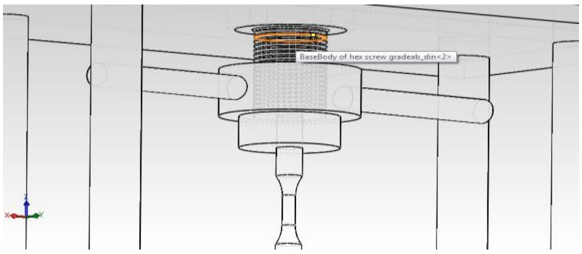
In this group meeting the concepts were discussed. With the qualifications that concept 4 holds, that it only uses only one cylinder, has the most stable axial loading and has a great amount of stiffness due to the H-beam, the group means this is the one to use as a basis point.

Concept 1 is used to develop further, since it has the best qualities of the four of them.

6.0 Test specimen fixture design

The test specimen fixture is an important part of the system, and there was researched for different types of fixture. The fixture that has to be decided will have to hold the specimen tight. It has to be a simple applicability, which is easy to understand and use. There were a lot of ideas floating both in our heads and from the industry. There was used time to consider industry fixtures, both from the use of internet, machine parts book, and standard ASTM e606standard and on a trip to Gjøvik where we saw some different fixture methods. The concepts we have been working on in concept round 1 is the first ideas that we came up with after going through idea rounds of 15 minutes each. There was discussed what was the best ideas to work with.

6.1 Idea 1a, Thread fixture design



M36 thread safety factor 5

$$\tau = \frac{K_d \times P_p}{\pi \times d_m \times h \times L_n} = \frac{S_y}{n}$$

$$L_n = \frac{3{,}5 \times 10450 \times 3 \times 5}{355 \times \pi \times 33{,}252 \times 2{,}7}$$

$$L_n = 5{,}48mm$$

M20 Thread safety factor 5

$$L_n = \frac{3{,}5 \times 10450 \times 1{,}25 \times 5}{355 \times \pi \times 12{,}912 \times 1{,}088}$$

$$L_n = 14{,}59mm$$

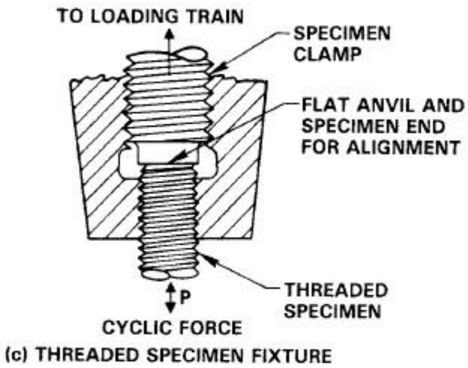


Figure 4

This concept was made out from a fixture design taken from ASTM e606standard which shows threads on the test specimen and a threaded bolt from the top. By turning on the fixture, it will screw itself on both fixture bolt and test specimen. This bolt you can tighten against the test specimen to make sure the test specimen is fastened properly.

On both concepts 1a and 1b there will only be needed 5,48mm threads (M36) on the tightening bolt and 14,59mm threads (M20) on test specimen with a safety factor of 5. This is not much and will not take up a lot of space.

This concept is made simple to use, easy to make and would spare materials as well as costs. But this type of fixture can in some cases shake loose and that could result in slack. The threads do also produce a threat of fracture points which could result in fracture at the wrong area.

6.2 Idea 1b, Thread fixture design

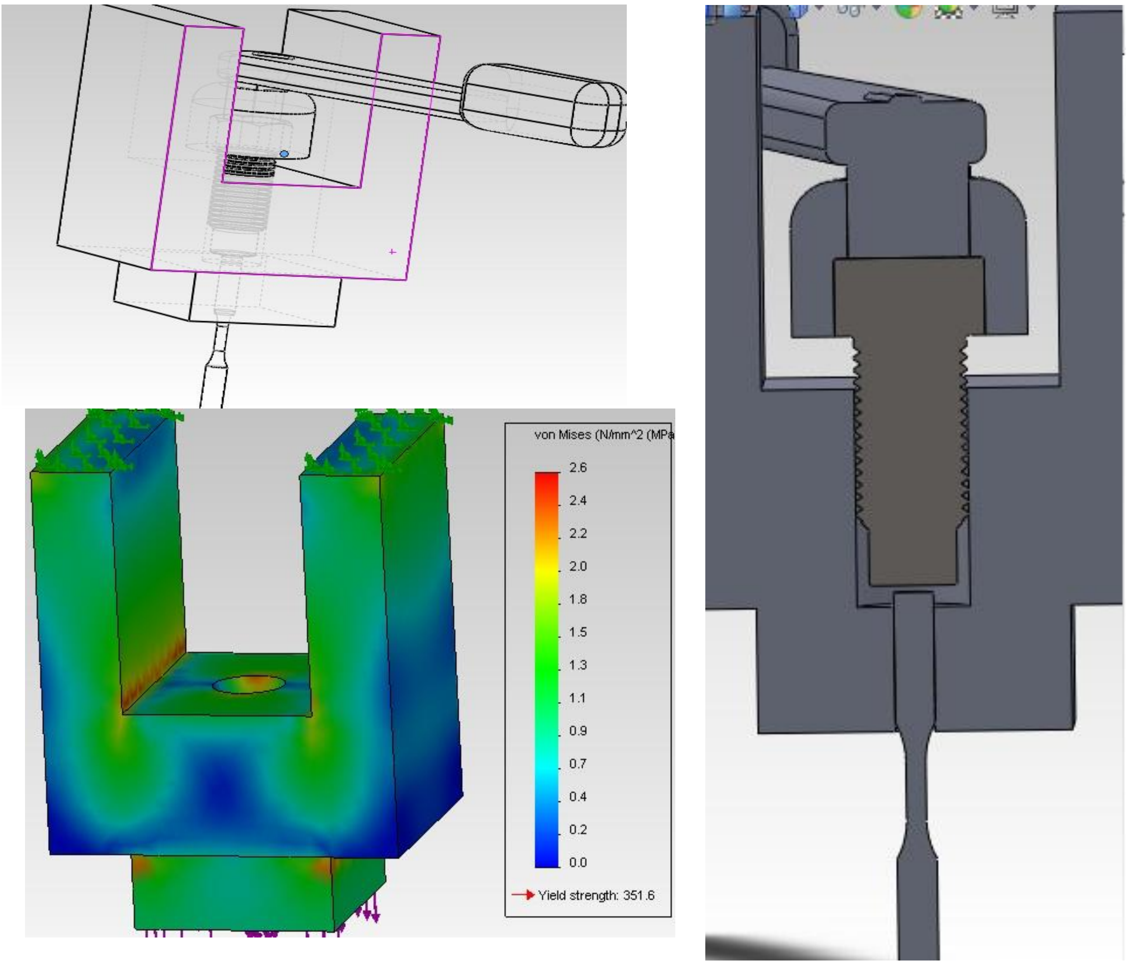


Figure 5

This concept did also follow ASTM e606 standard for test specimen fixture. This concept is only another version of concept 1a. This was a bigger version, and you would also need a ratchet wrench to tighten the bolt against test specimen. This concept would also need more material to produce.

With this fixture you would only need one tightening point. With left hand thread at the bottom and ordinary threads at the top of the test specimen, you would only need to screw the test specimen into the fixture and tighten with the tightening bolt at the top with the ratchet wrench.

This also have the disadvantage that the test specimen can shake loose, resulting slack. The threads can also here produce fracture points on the wrong area because of the threading.

6.3 Concept 1, Collar fastening

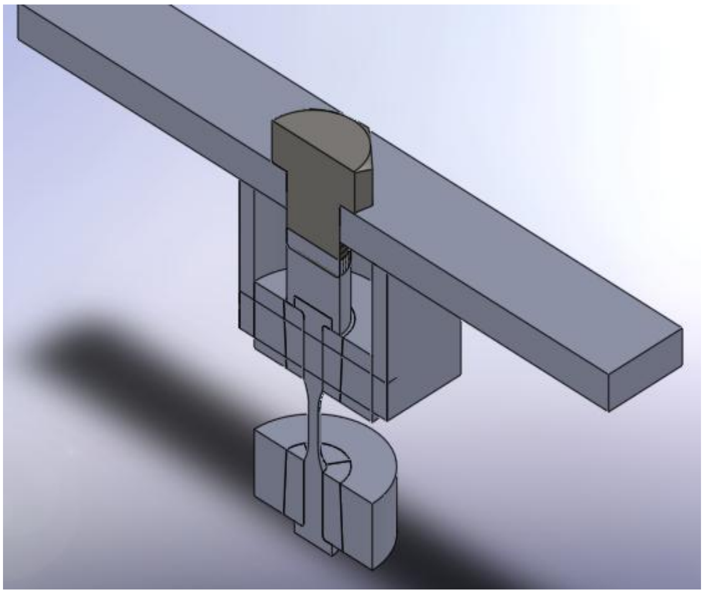
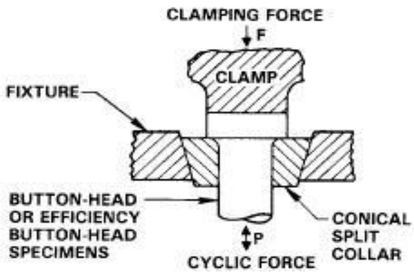



Figure 6 [4]

This Fixture is made out from a fixture method used in ASTM e606 standard. There is a conical split collar of 4 parts per fixture.

To fasten the test specimen the collars need to be taken out, the test specimen is placed in the fixture and the collars are placed around the test specimens' button head. Then there is a cup placed on the collars and test specimen. The clamping force will be made by a bolt screwed in from the top of the bottom head. This force on the test specimen and on the collars will make the collars grip the test specimen when exposed to tensile force and the force on the button head will make sure it stays in place when exposed to compression force.

This fixture will provide a good fastening of the test specimen, the coarse fine threaded bolt supports test specimen very good and the fixture is robust.

On the downside there will be some manufacturing with the collars in mind. There will possibly be used some time on the test specimen assembly. And there is a possibility that the bolt may shake loose after a period of time.

6.4 The decision

The group arranged a meeting with the client, to decide which specimen fixture that was the best solution. The client and the group went through the various concepts the group had come up with and it was determined what the client wanted to go for. There was also discussion around changes to the tightening of the specimen. The group came up with a couple of suggestions for possible changes. The internal supervisor asked us to investigate whether it was possible to make use of hydraulic attachments after the meeting.

When deciding there were made clear that threads on the test specimen were something that was not wanted. The choice from the client was concept 2, but he wanted to look for other tightening options than the screw clamping force.

7.0 Drive Medium

7.1 Idea 1, Hydraulic

Hydraulic is widely used in the industry because of its ability to apply large forces and to achieve a great accuracy in testing.

Use of the hydraulic system is suitable to achieve a soft startup of the system and will lead to a smooth transition when the machine alternates between tension and compression cycles. This will avoid “backlash” or sudden changes which can lead to deviation in the test results. Due to the drive medium of hydraulic, it is self lubricating and does not require any external maintenance as long as the oil is kept clean.

Advantages

- 3-5 Hz (up to 10-15Hz-depends on stroke/design/costs) [2] [3]
- Low maintenance
- Ability to regulate forces applied
- Smooth transitions between load cycles
- School has hydraulic pump to run the system

Disadvantages

- Low Hz leads to longer test times

7.2 Idea 2, Electro

The use of an electromotor as a power supply for the system is often used when there is a rotating system. This is an effective method to get a high amount of cycles and it is a cheap construction. The uses of electro in linear test rigs are often a servo electric solution which is complex systems.

Advantages

- High frequency
- Quiet system

Disadvantages

- Not suitable for applying large forces
- Not so good in terms of controlling forces applied

7.3 Concept, Pneumatic

Pneumatic systems are commonly used in tests which require a small amount of force. That is because air as a drive medium not provides a large amount of forces without having a very large cylinder, which also requires more room. Besides that, air as a drive medium is compressible; this could lead to deviation in the test results. A system driven on pneumatic requires a large amount of air supply which has to be delivered by a compressor and an external pressure vessel.

Advantages

- Possible to let excess pressure in the air
- No harmful vapors
- Not flammable
- Environmentally pleasant
- Ability to regulate forces applied.

Disadvantages

- Requires large equipment in terms of forces needed
- No expertise at school

7.4 Decision

The ideas were presented to the client. The electro motor based system was decided to be dropped, because of the many gearings that would occur by using it, which could lead to a lot of deviations in the results.

The hydraulic and pneumatic systems were decided to be done more research on, before making a decision for which system to choose. The client wanted to be absolutely certain, and the group agreed.

But there was chosen pneumatic as a starting point because of the cheap and small equipment to use.

8.0 Pneumatic system

The actual control system of the pneumatic system is not generated, and will have to be more specified and researched. Since the decision for drive medium not is set, there is not researched into the depth of using a pneumatic system. But some components were researched and the components further in this section, are the ones preferred to use at this point. To get the best as possible frequency the valve needs to be as close to the cylinder as possible, and a pressure reservoir is needed to always have pressure ready to control the cylinder.

SMC pneumatics Norway is the supplier for these components except for the compressor. After been in contact with a sales engineer at SMC the following components were chosen for the pneumatic system

8.1Valve

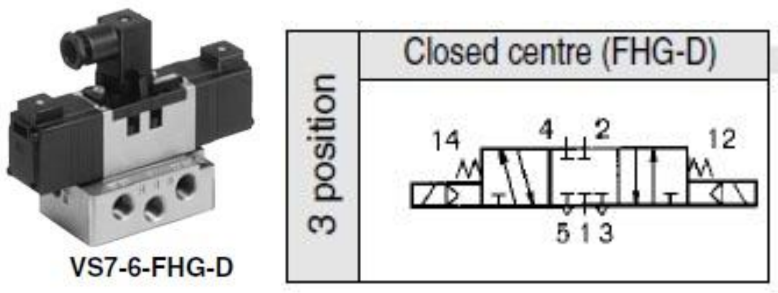


Figure 7

The valve thought of using is an ISO interface solenoid valve VS7-6-FHG-D with a closed centre. [6] The airflow to the cylinder controlled by this, when the valve initiates the different positions.

Figure 8

The sub plate [7] is a plate which has the airflow going through it. It has connections to the cylinder, to the pressure line from the compressor and to the air reservoir. This plate is attached underneath the solenoid valve.

8.2 Cylinder

Figure 9

The cylinder thought of using is a series CS1 non lube. The cylinder works between maximum 10bar pressure and 0.5bar pressure. [8] The piston speed is 50mm/s which create a great potential frequency in the system.

8.3 Tubes and fittings

Figure 10

The tubes and fitting thought of using is nylon tubing series T and the fittings is a one touch fittings series KQ2. The tube has a max operating pressure at 15 bar [9] and is adequate. The fittings can work with 30 bar [10] and is also adequate.

8.4 Compressor

Figure 11

The compressor is a two step pump housing and belt drive. The pump reservoir is 90 liter and has a power of 4kW. Maximum pressure given from the compressor is 10 bar. [11] This compressor will be adequate to run the pneumatic system.

9.0 Resources and references

[1]: Frank helgestads pdf. Copy from a design book

[2]: Test rig ved HIG(Kenneth Kalvåg)

[3]: http://fatigue.testresources.net/us/axial-fatigue-testers/104-810le516-modular-fatigue-tester-8500-lb-15-hz

[4]: Standard ASTM e606-04

[5]: http://www.coastpneumatics.com/metric/valves/EVS_Series_Valves.pdf

[6]: http://content2.smcetech.com/pdf/VS7_6_8_EU.pdf

[7]: http://content2.smcetech.com/pdf/VS7_6_8_EU.pdf

[8]: http://content2.smcetech.com/pdf/CS1_EU.pdf

[9]: http://content2.smcetech.com/pdf/T_EU.pdf

[10]: http://content2.smcetech.com/pdf/KQ2_EU.pdf

[11]: http://biltema.no/no/Verktoy/Trykkluft/Kompressorer/Kompressor-55B-90-17659/

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Title of document: **Concept round 2, version 2.0**
Course (code/name) SFHO3200 - H11 - Hovedoppgave med prosjektstyring
Group Members: Espen Sætre Kolberg Kjetil Haugmoen Kjøndal
Internal Supervisor: Jamal Safi
Date: 29.05.2012
We confirm that the submitted assignment is entirely our work   **Espen Kolberg** **Kjetil Kjøndal**

Table of contents

1.0 Document history

Version	Date	Changes
0.1	21.03.2012	Added fixture 1,2.introduction, test fixture dimension
1.0	23.03.2012	Added fixture 2,3, concept choice
1.1	30.03.2012	Changed headlines, dates
1.2	10.04.2012	Added calculation on specimen
1.3	09.05.2012	Grammar and spell check
1.4	14.05.2012	Added concept and idea layout
1.5	27.05.2012	Added Frame, hydraulic system, bearing of guide rods, counter and switches, machine control system, planning and theory, and done grammar and spell check
2.0	29.05.2012	Finalized document

Table1: Document history

2.0 Abbreviations

BUC -Buskerud University College

SW -Solidworks

FEM -Finite Element Method

FTR -Fatigue Test Rig

F.S. -Factor Of Safety

POM -Polyoxymethylen

PLC -Programmable Logic Controller

3.0 Designations

mm	-Millimeter
kN	-Kilo Newton
MPa	-Mega Pascal

4.0 Introduction

This document provides an insight of round 2. This round is more extensive than round 1 in terms of more details and work done regarding development of the product. The group of two people has been working together since the start of the semester and is working more efficient as a result.

The knowledge from last round and new ideas are the ground stone for round 2. This leads to better solutions and better execution of new designs. Knowledge in Solid Works and in the field of hydraulics is improving.

5.0 Ideas vs. Concepts

This document contains the different ideas and concepts of the second round of concepts. The best solutions from the first concept round, which the group decided to develop further is implemented in this second round of concepts.

The ideas presented in this document were the starting point of this round, the concepts presented is the final decisions made in this round.

6.0 Planning

The project model used by the group is based on incremental development. The project is divided into increments and we chose to start with the most demanding increments and do the easier increments at the end. We come up with a solution for each increment, evaluate the solution and work with it over and over until we are satisfied. By doing this we ensure that we get the best possible solution.

It is also important to bring on the useful information and solutions from the previous round to improve components. The previous concept and ideas let us think of new solutions based on the experiences that were achieved during the first round. When working with a project, it is easy to get stuck at one solution, so the group has to be innovative and look for alternative solutions.

There are limited amount of time and the group has to decide which solutions that should be further developed in the next round. To be able to achieve the goal set for the project, it is important to be rational with the disposal of time regarding what to work on and what to throw away.

To make sure the final product corresponds with the requirements set from the client, the group continuously work towards the requirements defined by both the group themselves and the client. This will also make sure the implementation of the various components is as smooth as possible.

To avoid getting a single-tracked mind and get stuck on a concept the group has been disregarding earlier ideas and thought of alternative solutions for the problem. The new ideas are discussed with the client and the best solutions will be analyzed further.

7.0 Theory and appropriation

The tools used and theories in round 2 of the project are:

- Solid Works
- FEM analysis
- Material technology and manufacturing techniques
- Construction technology
- Hydraulic constructions
- Digital technology

There are many challenges that need to be solved. Knowledge within digital technology, construction technology and hydraulic constructions need to be studied to acquire further knowledge.

The level of knowledge in the group is improving and the development of different components are increasing.

8.0 Final test specimen concept

8.1 6.35mm

The ASTM E606 standard operates with a minimum diameter of the test area on the test specimen of 6.35mm. By using this as a guideline for processing the test specimens, an estimation of the force needed for carrying out the test will only be around 11000N

Calculation:

10mm:

$A = \pi r^2$

$A = \pi * 0{,}005^2$

$A = 0{,}00007853 m^2$

$\sigma_{max} = \frac{P}{A}$

$P = 330 MPa * 0{,}00007853 m^2$

$P = 25914 N$

6,35mm:

$A = \pi r^2$

$A = \pi * 0{,}003175^2$

$A = 0{,}0000316 m^2$

$\sigma_{max} = \frac{P}{A}$

$P = 355 MPa * 0{,}0000316 m^2$

$P = 11218 N$

[1][3]

By reducing the diameter of the test specimen to 6.35mm, the project will end up with a more cost efficient solution compared to the larger more robust 10mm test piece. Due to the smaller diameter, the forces applied from the rig could be reduced significantly. These factors leads to that both the machine and the test specimen will be less expensive to produce. The group then decided that the smaller diameter specimen were the best solution to use for the project and will be used in the final design.

9.0 Frame design

9.1 Idea 1

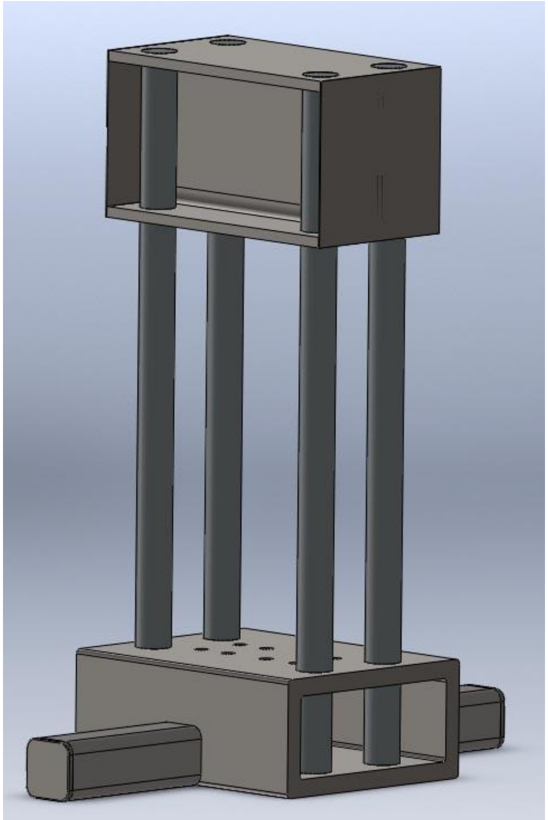

Figure 1: Idea frame

Based on the earlier design from the first round the group came up with a more compact design. The decision to utilize a center mounted cylinder made the group look at alternative solutions to the lower frame. The earlier H-profile used in round one would not be suitable for attachment of a double rod cylinder as it would lose its stiffness.

9.1.1 Upper frame

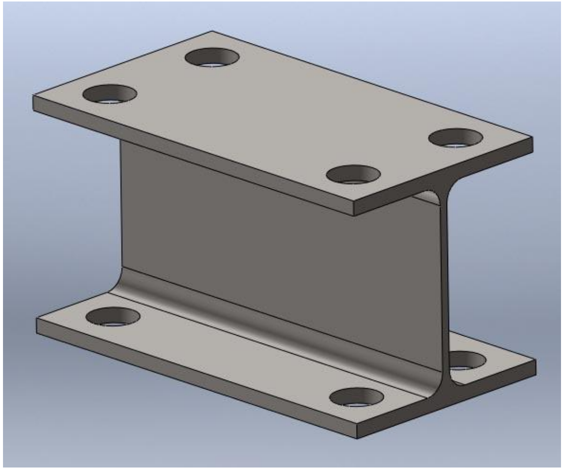

Figure 2: HE280B beam

The heavy duty H-beam upper frame used in the previous concept was quite over dimensioned and would withstand far more stresses than necessary. The dimensions of the beam is 500x280x280mm (length x width x height). To make the rig more compact and more suitable compared to the forces applied, the group came to the conclusion that the beam could be redesigned. The benefits of the H-beam profile to resist bending was desirable to bring further in the project process.

FEM analysis

Stress

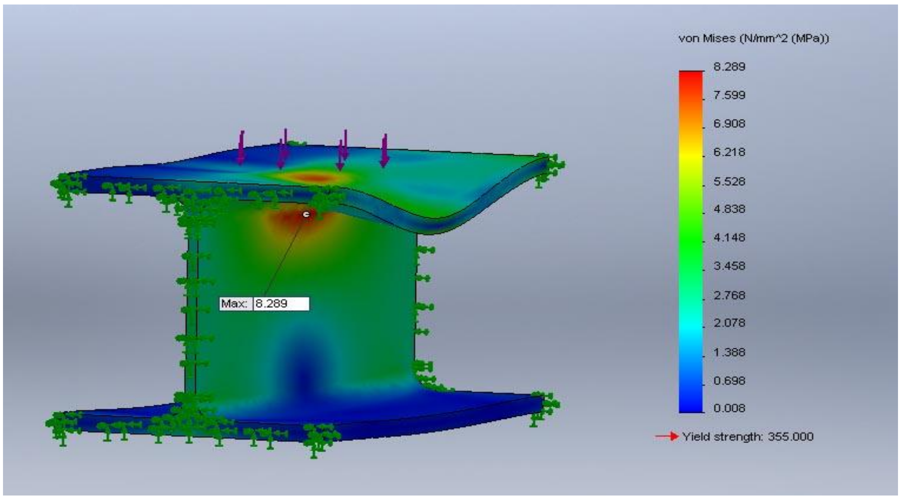

Figure 3: Stress analysis of the HE280B beam, 11kN applied normal to the beam.

The stress is located under the upper flange of the beam and has a maximum value of 8,2MPa.

Displacement

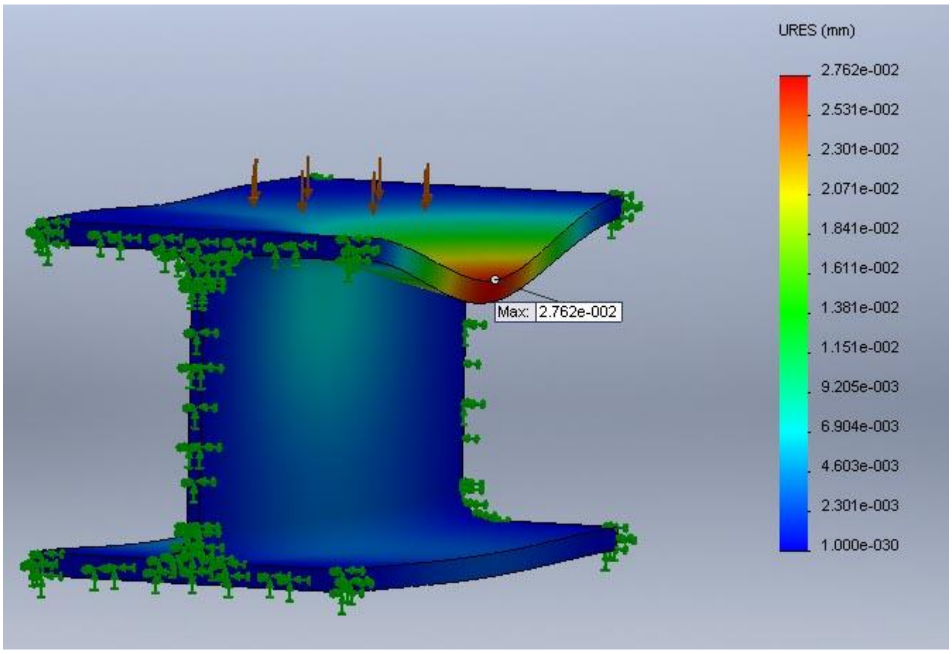

Figure 4: Displacement analysis of the HE280B beam.

The analysis of the upper frame show a maximum displacement of 0,0276mm. The maximum displacement is located at the edge on the upper flange.

9.1.2 Lower frame

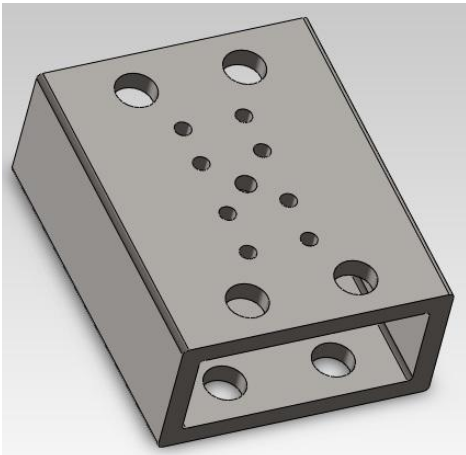

Figure 5: Square tube lower frame

The application of a double rod cylinder led to the desire for a more suitable design of the lower frame. The square tube design has a weakness towards bending in contrast to the H-profile, but makes it possible to mount a double rod cylinder. The dimensions of the lower frame is 500x400x200mm (length x width x height)

To make the rig more compact the group decided to go further with the square tube design of the lower frame, but redesign it to make it more suitable to handle.

FEM analysis

Stress

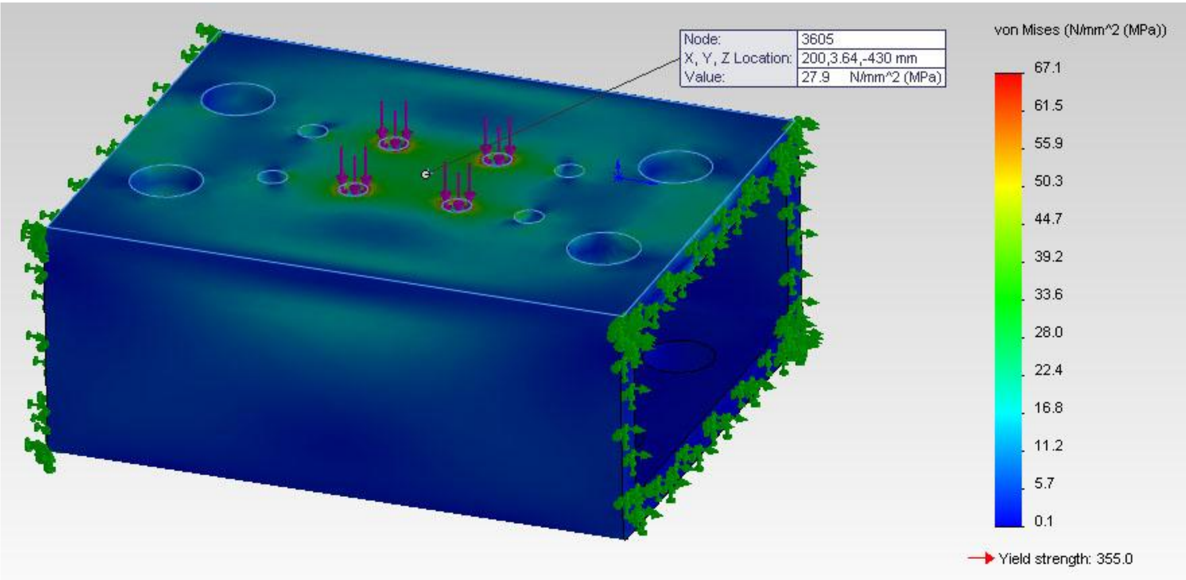

Figure 6: Stress in rectangular lower frame, 11kN

The software analysis of the lower frame show a maximum stress of 27,9kN at the very center of the square tube.

9.1.3 Cylindrical guide rods

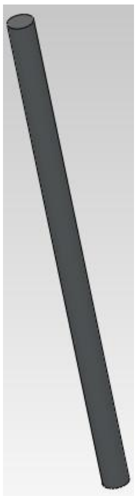

Figure 7: Guide rod

The cylindrical guide rods are supposed to ensure the axial appliance of the force on the test specimen. In this idea, the guide rods are also the bearing structure of the frame.

After doing research in the workshop at BUC, the rods available had a diameter of 60mm.

The rods will be subjected to a force of 1,428kN plus the weight of the upper frame.

Calculations:

105kg pr meter. [2]

105 kg*0,5 m=52,5kg

52, 5 kg*9, 81= 515N

10428N + 515N = 10943 N

The rod will then be subjected to a load of approximately 11kN divided on the four guide rods, which result in a force/rod of 2750N.

The cylindrical rod in this idea is 50mm in diameter and we wish to test if it is within the requirement of 2x fatigue F.S. (ref. R15, Requirement Specification rev. 1.4).

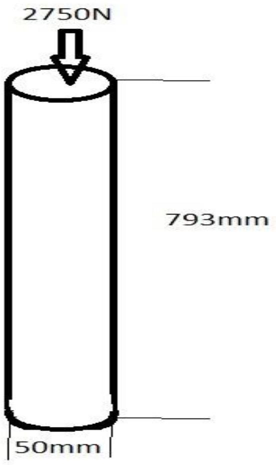

Figure 8: Force applied on guide rod and Stress in guide rod Ø50mm

Calculations:

$A = \pi r^2$

$A = \pi 25^2$

$A = 1963mm^2$

$\sigma = \frac{P}{A}$

$\sigma = \frac{2750}{1963}$

$\underline{\sigma = 1{,}4\ MPa}$

$\delta = \frac{PL}{AE}$

$\delta = \frac{2750N * 0{,}793m}{1963mm^2 * 200000}$

$\underline{\delta = 0{,}0055mm}$

[1][3]

F.S. =355/1,4=253

The calculations on the previous page show that the maximum stress in the material is 1,4MPa, which gives us a F.S of 253. From this calculation one can conclude that the guide rod and frame structure is rather oversized.

The displacement in the rod is a maximum of 0.0055mm.

FEM analysis

Stress

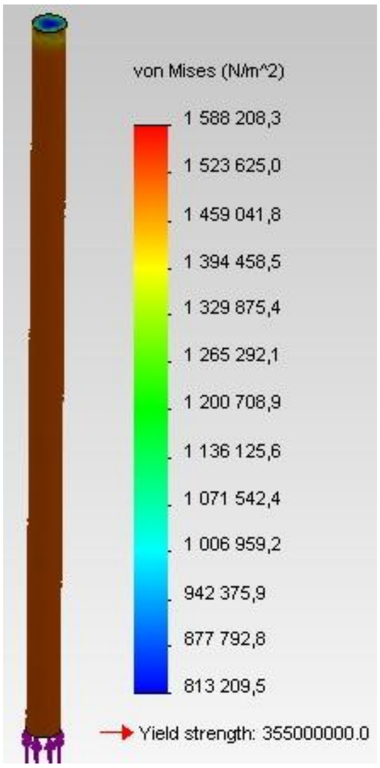

Figure 9: Stress analysis of the guide rod

The FEM analysis shows a max stress in the rod of 1,588MPa, which corresponds quite good with the manual calculations.

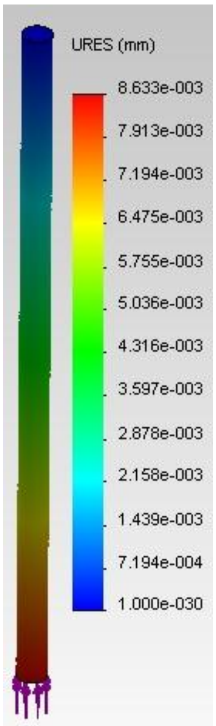

Figure 10: Displacement analysis of the guide rod

The analysis show a maximum displacement of 0,0086mm. At the analysis, the maximum displacement is located in the bottom of the rod, where the force is applied.

Calculations

To ensure the design of the rig is optimal regarding size and weight, the minimum allowed diameter of the guider rods are calculated.

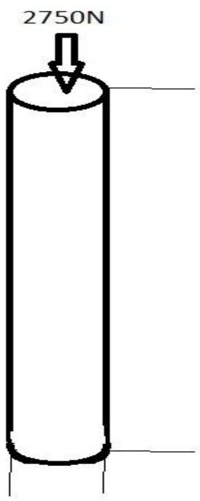

Figure 10: Force applied on guide rod

With F.S = 16

$$\sigma_{tillatt} = \frac{330}{16} = 20{,}625\ MPa$$

$$\sigma_{tillatt} = \frac{P}{A}$$

$$A = \frac{P}{\sigma_{tillatt}}$$

$$A = \frac{2750N}{20{,}625MPa}$$

$$A = 133.33mm^2$$

$$A = \pi r^2$$

$$r = 6{,}51mm$$

[1][3]

When looking at the dimension Ø13mm with a length of 1200mm, there is seen that there could be a possibility of buckling in each of the guide rods. The rods have to be designed to withstand buckling, and with these calculations, the diameter of the rods will have to be Ø13,06mm.

$$l = 1.2m$$

$$I_O = \frac{\pi d^4}{64} = I_O = \frac{\pi 9{,}212^4}{64} = 353{,}497mm^4$$

$$l_k = 0.5l = 0.5 * 1.2m = 0.6m$$

$$i = \frac{d}{4} = \frac{9.212}{4} = 2.303$$

$$\lambda = \frac{l_k}{i} = \frac{600mm}{2.303} = 260.53 > 105$$

$$F_k = \frac{\pi^2 * E * I_o}{l_k^2} = \frac{\pi^2 * 210000MPa * 353.497mm^4}{600mm^2}$$

$$F_k = 2{,}03kN$$

Force applied is 11kN.

The force is divided on 4 rods. One rod should resist 2750N without buckling

It should have a safety factor of around 3.

The rods should resist a load of 8250N

$$I_O = \frac{F_k * l_k^2}{E * \pi^2}$$

$$\frac{\pi d^4}{64} = \frac{F_k * l_k^2}{E * \pi^2}$$

$$\frac{\pi d^4}{64} = \frac{8250N * 600^2}{210000MPa * \pi^2}$$

$$\frac{\pi d^4}{64} = 1432$$

d =13,06mm

[4]

As seen in the calculations, the minimal diameter of the guide rods will be 13,6mm.

9.2 Support legs

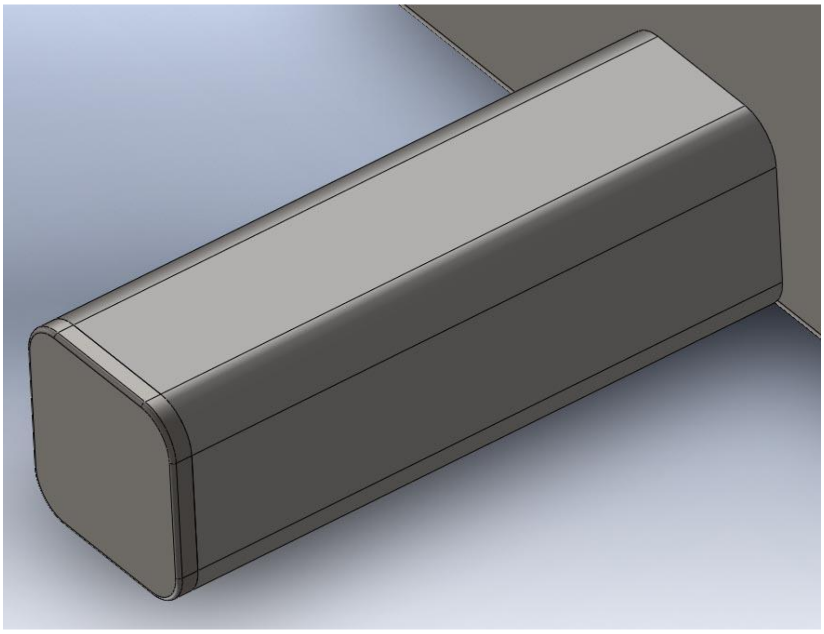

Figure 11: Support legs

The test rig need supporting legs to make sure it does not tip over when in use. The group added one square tube at each side of the lower frame. The support legs are welded on the side of the lower frame.

The legs has a outer dimension of 300x100x100mm (length x width x height)

9.3 Final frame concept

This is the last concept the group has made and a lot from previous ideas and concept are used further in this concept. The group has thought of dimensioning it to real dimensions, since the FTR is not going to be produced.

The group thought of a solution for the possibility to change parts quite easily. This was not considered that much in the previous concepts, but has been an important key in this new concept.

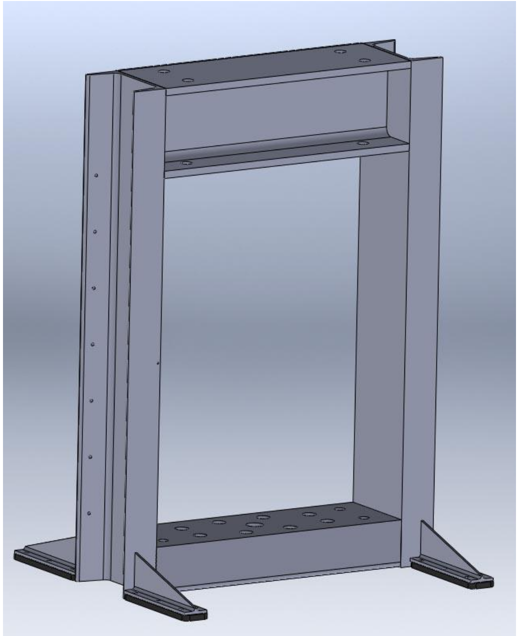

Figure 12: Final frame concept

9.3.1 Upper frame

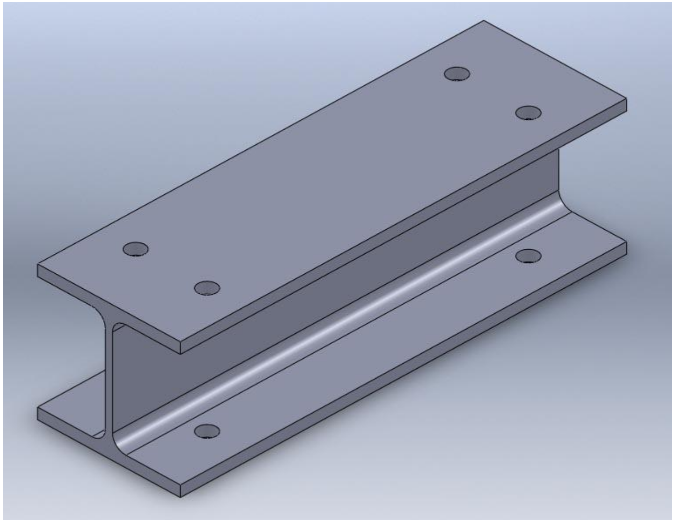

Figure 13: Upper frame HE160B

The final frame concept includes a much leaner H-beam profile as well as a much more compact lower frame. The redesigned upper frame consists of a HE160B profile beam.

9.3.2 Lower frame

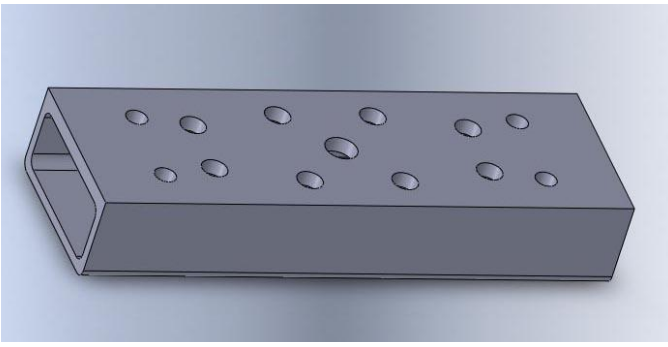

Figure 14: Lower frame Rectangular tube

Like the previous idea there is going to be used H-beam as upper frame and a rectangular beam as a lower frame. These comply with our need for stiffness and can be dimensioned for fatigue, with small modifications. The lower frame is reinforced with a thicker wall on top of it, to withstand the forces applied.

9.3.3 Cylindrical guide rods

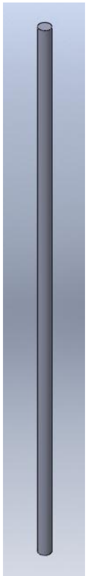

Figure 15: Guide rod

As a solution to make the rig more maintainable and to easily change parts, the cylindrical guide rods have now only one function. This function is to guide the stabilizer bar and make sure this is horizontal to apply forces directly axial. When giving the guide rods only one function, and using another bar set as a frame to hold upper and lower frame together, the guide rods can be taken out from the rig, which make changing parts much easier.

When using guide rods for one purpose, the rods can be dimensioned to a smaller diameter.

9.3.4 Channel bars

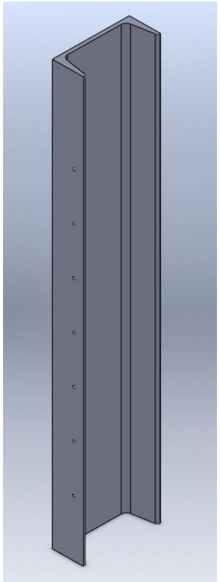

Figure 16: Channel bar

In this last concept there are used channel bars to hold the frame together. The channel bars are stiff and can be dimensioned for fatigue. The bars have one function. It has to withstand the forces applied and the weight of the upper frame.

The rig needs to have an easier solution to change parts if needed. The channel bars will replace the earlier function, to withstand forces, of the cylindrical guide rods. And the guide rods can be taken out and there will be easier to reach the other components.

9.3.5 Support legs

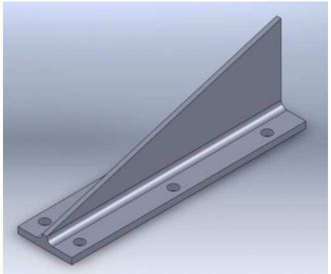

Figure 17: Support legs

The support legs in the earlier idea were not satisfying. It was over dimensioned and there was only one on each side. It was used a square beam in the last one, and was not needed.

The support legs which are used in this concept is small, takes little space and it is not in front of the operators work area. It is 4 support legs, each in a corner, which supports the rig from tilting.

10.0 Test specimen fixture design

10.1 Ideas

10.1.1 Idea: Quick lock device

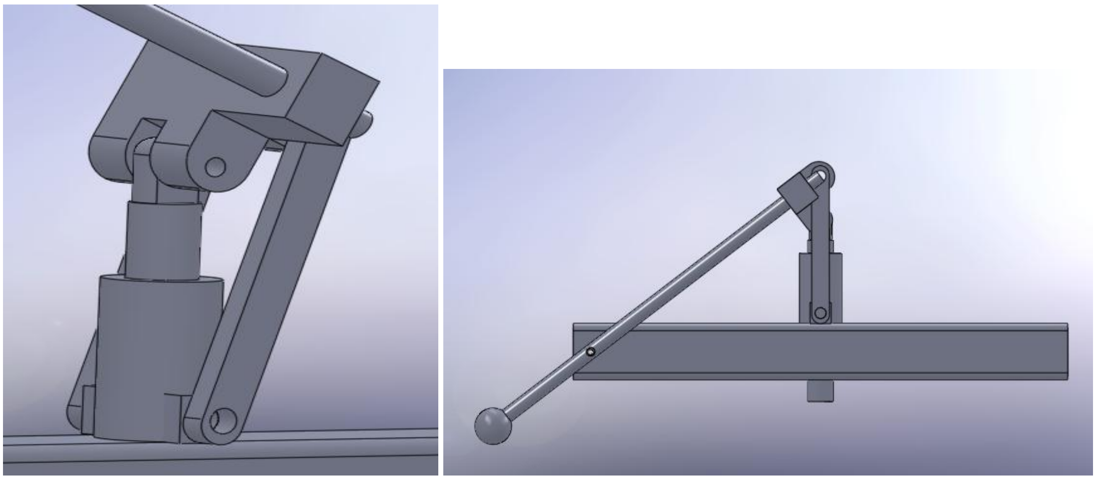

Figure 18: Quick locking device with handle

This concept came up as an idea from a cartridge reloading press. In this mechanism a simple coupling that makes it easy to fasten and unfasten the test specimen. What the press essentially does is to hold the specimen, and eventually reload the testing machine with a new specimen and at the same time provides the mechanical leverage that allows the operator to easily accomplish these tasks.

The major disadvantage of this mechanism is that it cannot be used on the bottom side fixture, and thus another solution has to be developed. On the other hand it is relatively complex structure with many moving parts that will be exposed to fatigue.

10.1.2 Idea: Hydraulic jack on top

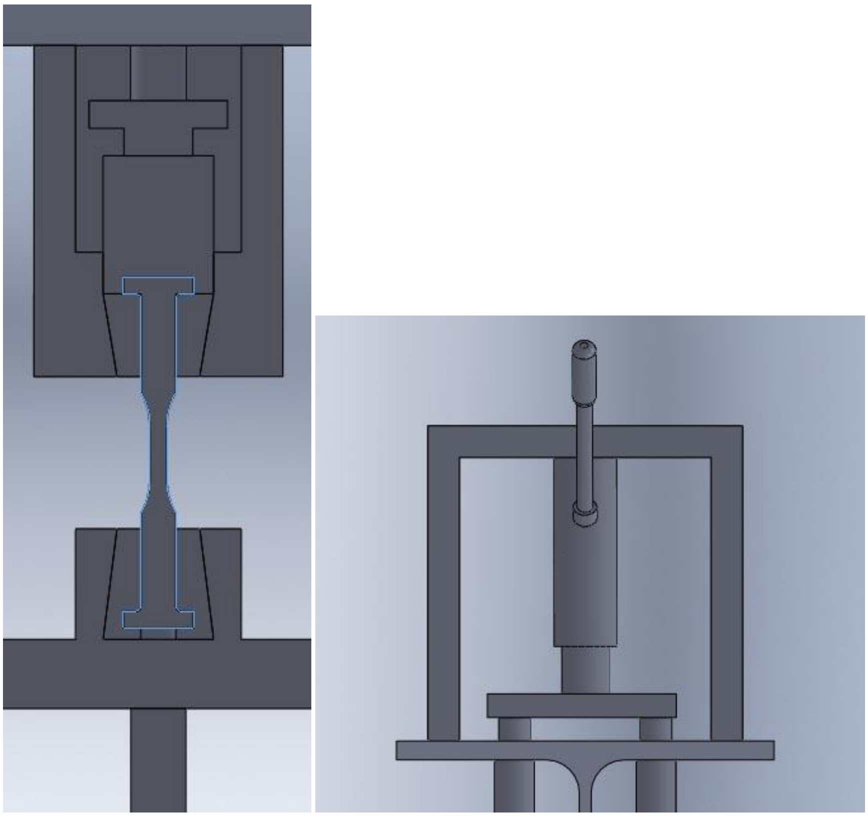

Figure 19: Hydraulic press at the top

In this concept, a hydraulic press fastened vertically at the top of the frame creating a vertical force downward on a bar which then presses on a cup as shown in the figure above. The cup is in contact with the wedge grips as well as with the specimen, and when in action this pressing force is holding both the specimen and the wedges in place.

As the cup presses on the wedges, the wedge acts to increase the squeezing pressure applied to the specimen, securing it from gliding upwards.

The major disadvantage of this solution is that it is costly as extra and relatively sized parts have to be manufactured to fasten the hydraulic press. In addition, specimen in this case will not by standard on the shelf product rather than specifically manufactured to be used on this machine. On the other hand, handling the specimen in and out of the testing machine is demanding. Furthermore, this structure cannot be used at the bottom side of the machine.

10.1.3 Idea: Hydraulic press from test specimen side

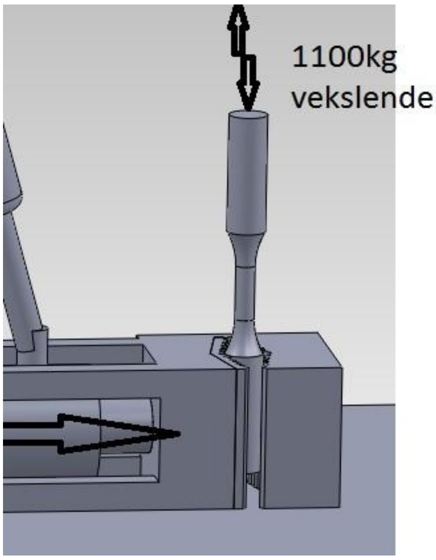

Figure 20: Hydraulic press from the side

Restricted by the low budget for the project, the group started to look for a very simple, cheaper and more user friendly fastening mechanism. The concept has been adopted from the most used fastening mechanism in fatigue testing that use a hydraulic cylinder. The structure contains a simple hydraulic press with a gripping clamp fixed to press cylinder. The press is handled manually though a lever that produces enough clamping force to grip and fix the specimen.

An advantage is that the jack is readily available and little manufacturing is needed for the clamps. It is also easy to handle manually.

However, this idea has some disadvantages concerning inability to control or adjust the applied clamping force.

10.2 Final concept test specimen fixture design

10.2.1 Collar fastening

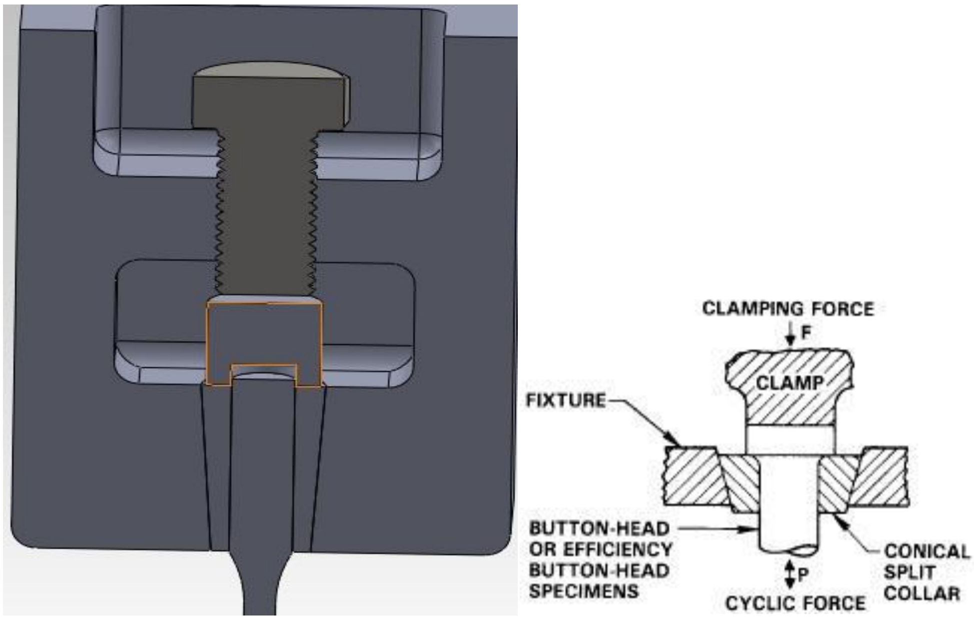

Figure 21: Collar fastening [6]

This Fixture is made out from a fixture method used in ASTM e606 standard. There is a conical split collar of 4 parts per fixture.

To fasten the test specimen, the collars need to be taken out, the test specimen is then placed in the fixture and the collars are placed around the test specimens' button head. On the top of the collars a cup is placed. A bolt screwed in from the top of the bottom head will make the clamping force. This force on the test specimen and on the collars will make the collars grip the test specimen when exposed to tensile force and the force on the button head will make sure it stays in place when exposed to compression force.

This fixture will provide a good fastening of the test specimen, the coarse fine threaded bolt is supporting tightly the test specimen and the fixture is robust.

On the bottom side, the solution is not as straightforward and some manufacturing and machining is needed to integrate the collars. In this case, more time will be used on assembling and disassembling of the specimen.

10.2.2 Concept choice

In case of idea 1 with the quick locking handle, both parties have agreed that though this concept will provide simple and quick loading of the specimen, it will be difficult to optimize, design and manufacture such many parts. Furthermore, many moving parts will increase possibility of fatigue failure mechanism.

With regard to idea 2, the client thought that this concept would become too difficult to use, there would be a lot of efforts in placing the test specimen. This will also get more complicated if one to use the same fastening concept on both bottom and top side

The group had a meeting with the client to discuss the four concepts. The client meant that idea 3 with horizontally mounted hydraulic would with time leads to oil leaks from the hydraulic press. This concept would also have too many heavy parts, which might affect the accuracy of the testing results. In consulting with the client, this concept has been frozen from further development.

Out of the four ideas presented, the concept using bolt and wedge grip has been chosen for further development. We found out that in case of using wedge grip it will be no need for applying horizontal force since wedges will work as self-locking mechanisms, increased by increasing the tension force. This will bring us back to use a standard manufactured specimen that is easier to produce.

11.0 Bearing of guide rods

11.1 Idea 1 Linear ball bearings

The bearing of guide rods is important. If there are not any bearings, the stabilizer bar can get lodged up against the guide rods. This can lead to serious consequences where components can get damaged. When there is used bearing, the stabilizer bar can travel freely on the guide rods. There are two options the group has looked at.

Figure 22: Linear ball bearings

The linear ball bearings provide an adequate sliding on the guide rods. It consists of a housing that is, in this case, press fitted on the stabilizer bar, and balls to roll on the guide rods. The lubrication used is grease lubrication for spindle bearing arrangements. There are only needed small amounts of grease to maintain the lifetime of the bearing. [7]

When the bearing is attached to the stabilizer bar, it can roll on the balls with little friction. Because the balls are rolling they have a much lower coefficient of friction than if two flat surfaces were sliding.

11.2 Final concept bearing of guide rods

11.2.1 POM

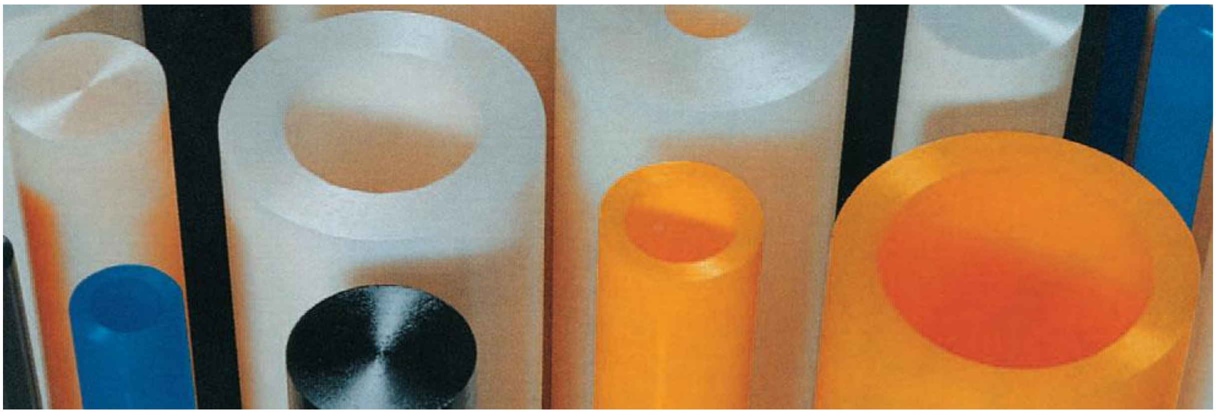

Figure 23: POM

The other guide bearing the group has gotten an interest in is POM – polyoxymethylen, which is widely technical used for production subjects or strong precision mechanics. POM is distinguished by a high degree of rigidity and mechanical strength, it is easy to manufacture and has outstanding resilience. Because of these properties, POM is often used for the manufacture of precision parts. (9)

The mechanical industry uses these for cogwheels, rollers, wheels, sliders and guide rails. It is used when it is desired a maintenance free function and dimensional stability.

The POM would secure an almost friction free movement between the stabilizer bar and the guide rods.

12.0 Drive Medium

12.1 Idea 1 Pneumatic

Pneumatic systems are commonly used in tests which require a small amount of force. That is because air as a drive medium not provides a large amount of forces without having a very large cylinder, which also requires more room. Besides that, air as a drive medium is compressible; this could lead to deviation in the test results. A system driven on pneumatic requires a large amount of air supply which has to be delivered by a compressor and an external pressure vessel.

Pros

- Possible to let excess pressure in the air
- No harmful vapors
- Not flammable
- Environmentally pleasant

Cons

- Requires large equipment in terms of forces needed
- No expertise at school

12.2 Final concept drive medium

12.2.1 Hydraulics

Hydraulic is widely used in the industry because of its ability to apply large forces and to achieve a greater accuracy in testing. The oil is not compressible and will not lead to deviations in relation to a pneumatic driven system, where the air has the possibility to be compressed. By operating the system using hydraulic, this will result in a precise and stable process. The use of hydraulic, requires a relatively small piston area to achieve large forces due to the system`s high pressure. Use of the hydraulic system is suitable to achieve a soft startup of the system and will lead to a smooth transition when the machine alternates between tension and compression cycles. This will avoid “backlash” or sudden changes, which can lead to deviation in the test results. Due to the large forces that can be achieved with a smaller diameter piston, it`s possible to make the system quite small. Due to the drive medium of hydraulic, it is self-lubricating and does not require any external maintenance as long as the oil is kept clean.

Pros

- 3-5 Hz (up to 10-15Hz-depends on stroke/design/costs) [11] [12]
- No compression of drive medium, greater accuracy
- Low maintenance
- Possibility to regulate frequency
- Ability to regulate forces applied
- Smooth transitions between load cycles
- School has hydraulic pump to run the system
- School has a resource person to ask for advice within hydraulic

Cons

- Low Hz leads to longer test times

17.2 Discussion

After having been in contact with several companies including SMC, Lautom and Bosch Rexroth we have come up with that we could be able to have a pneumatic system capable of carrying out 2-3 cycles per second with a max load of 20kN. That is in a total reversed load cycle. The air supply from a reasonable priced compressor like the model 55B-90N [13] at 490 ln/min is not sufficient. With the use of magnet valve EVS7-10-FG-D-3DOB-XSE647 [14] with a flow of 4905 ln/ min, it requires the use of an external pressure vessel. Using an electro-based system, will not meet the requirements of the forces needed to conduct a test.

By using an electromotor, there would be a need for having a form of gearing that is exposed to slack during a period of time.

Having made contact with several industrial hydraulic companies and BUC`s internal expert on hydraulic, the group has the perception that a hydraulic system would be the best solution regarding forces needed as well as getting as little deviation in the results as possible. This decision is also based on the fact that there is a goal to use as much equipment as possible from BUC, in that way the project costs will decrease.

17.3 The Decision

The group discussed the differences, both individually and with the supervisor forth and back. There was then held a meeting with our client where we went through the concepts for drive medium and the up and downsides of each drive medium.

It was made a decision to go for the hydraulic system. This was because it will provide enough force, as little deviation on the results, the compression of fluid and the fact that BUC can provide with a lot of equipment to hold the costs low.

13.0 Hydraulic valves

13.1 Idea 1 Olsen valve

The group has looked at different valves, which can provide the needed function. It has to have 3 positions; where position one has as function to provide pressure to lower end of the hydraulic cylinder and that fluid from upper end in the hydraulic cylinder goes into the reservoir. Position two contains a function that drains fluid from the hydraulic cylinder to the reservoir. And position three will provide a function that sends pressure into the upper end of the hydraulic cylinder while the lower end drains into the reservoir.

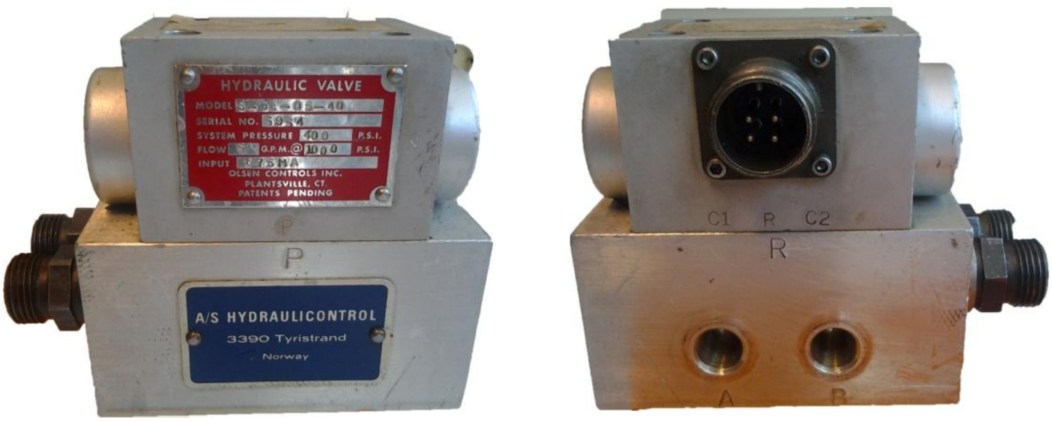

Figure 24: Olsen valve [15]

A valve at University premises is an Olsen Valve, which is a pre guided spool valve. A pre guided spool valve is a valve that contains a directional valve on top. The main component is hydraulically connected to a directional valve that controls the main valve. The valve controls the main component when the electro magnets on the directional valve activate the slide. When the slide is activated it sends directional pressure to the opposite site of the main slide and the main slide is pushed to the relevant side. [16] The Olsen valve does function with a closed centre. This is actually not wanted because of the need to bleed off the hydraulically cylinder to be able to retain the test specimen after a test is done.

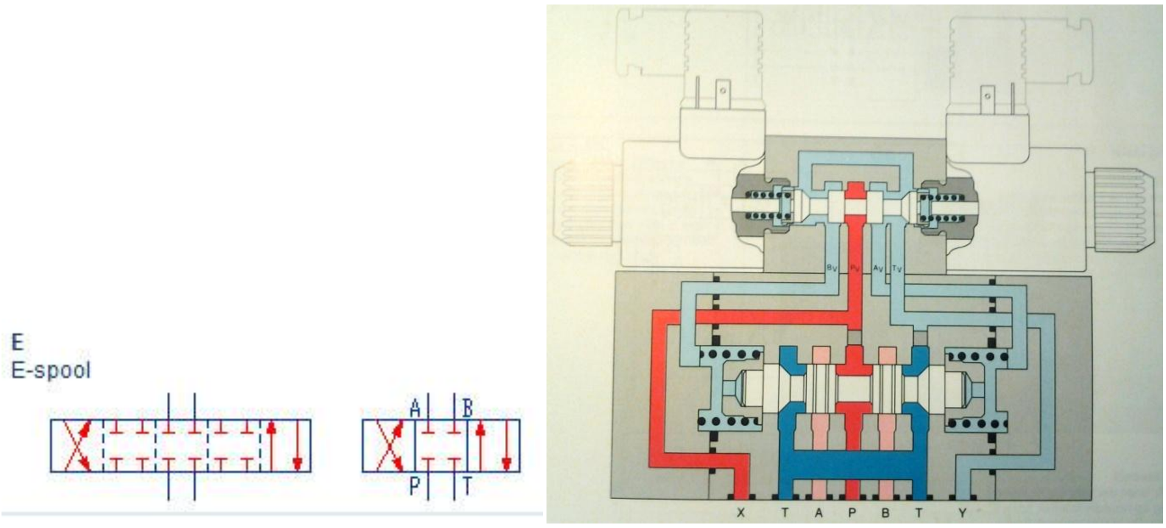

Figure 25: Function and inside of Olsen valve [16]

13.2 Final concept valve

13.2.1 Bosch Rexroth directional spool valve

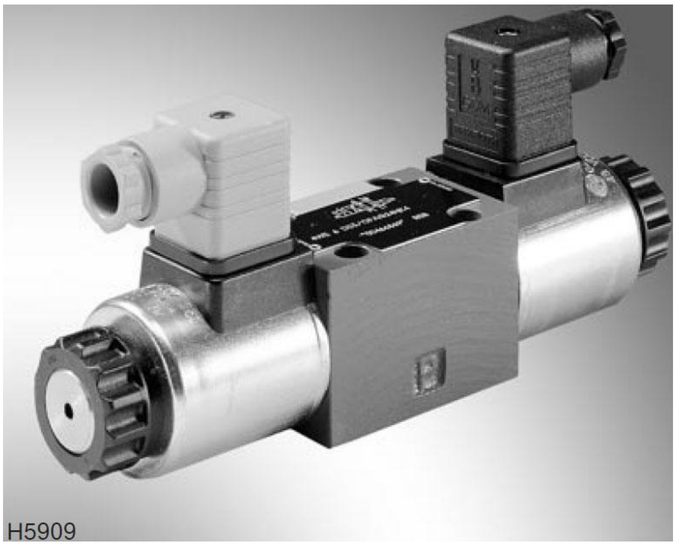

Figure 26: Direct directional spool valve

The direct directional spool valve has properties like the directional valve used on top of the Olsen valve, but in this case the valve directly controls the fluid. The magnets on each side react when it gets a signal of 24V and switch to the wanted position. If the magnet spool (a) on the left of the picture gets 24V voltage it switch the slide inside to open fluid output A, and opens fluid output B when magnet spool (b) on the right side of the picture gets 24V voltage. [17] The center position is open between the lines to the cylinder and to the reservoir, which is desirable.

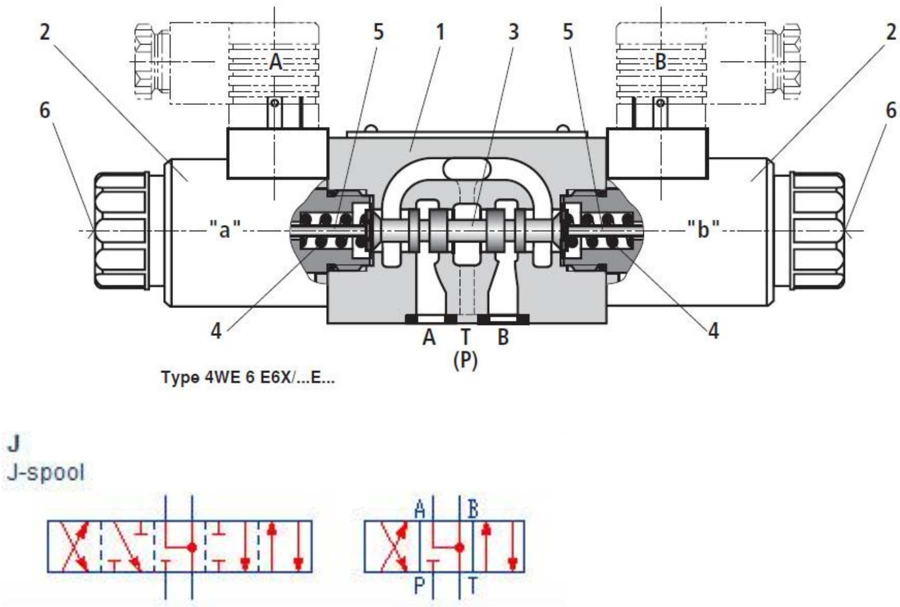

Figure 27: Function and inside of the directional spool valve [17]

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14.0 Choice of cylinder

14.1 Idea Single rod cylinder

The test rig will need to have a hydraulic cylinder to apply force on test specimen. It has to provide approx. 11000N and it should have as small dimensions as possible. There was also wanted to use as small pressure as possible in the system. There was looked at two types of cylinders, a single rod cylinder and a double rod cylinder.

Figure 28: Single rod cylinder [18]

The single rod cylinder would have the disadvantage to apply less force when the cylinder withdraws the piston rod, than it would when the piston rod is pushed out from the cylinder. This is because of the area the pressure works on each side of the piston. The single rod cylinder has one side which has a bigger area than the other, and the greater the area, greater the force.

Calculation:

This is illustrated in the following example: [18]

Diameter of the piston: D= 5cm

Diameter of the rod: d= 2,5cm

Work pressure ρ:60 bar

$$A = \frac{\pi * D^2}{4} = \frac{\pi * 5^2 cm}{4} = 19{,}63 cm^2$$

$$A = \frac{\pi * (D^2 - d^2)}{4} = \frac{\pi * (5^2 - 2{,}5^2) cm}{4} = 14{,}72 cm^2$$

Figure 29: Inside of a single rod cylinder

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FTR

$Piston\ force: F = A * \rho * 10$

$F^{+} = A * \rho * 10 = 19{,}63 * 60 * 10 = 11778N$

$F^{-} = A * \rho * 10 = 14{,}72 * 60 * 10 = 8832N$

$The\ cylinder\ has\ a\ plus\ stroke\ of\ 11778N\ and\ a\ minus\ stroke\ of\ 8832N$

As the calculation show, when the piston retracts it has a force that is 2946N less than when the piston is pushed out from the cylinder. This is because of the smaller area at the side with the piston rod

To make sure the specimen is subjected to equal forces in both cycles, there would be a need for an extra component to adjust the pressure. This can be solved by adding a pressure reducing valve to the system, which is placed on the piston side of the cylinder but would complicate the system and lead to higher costs.

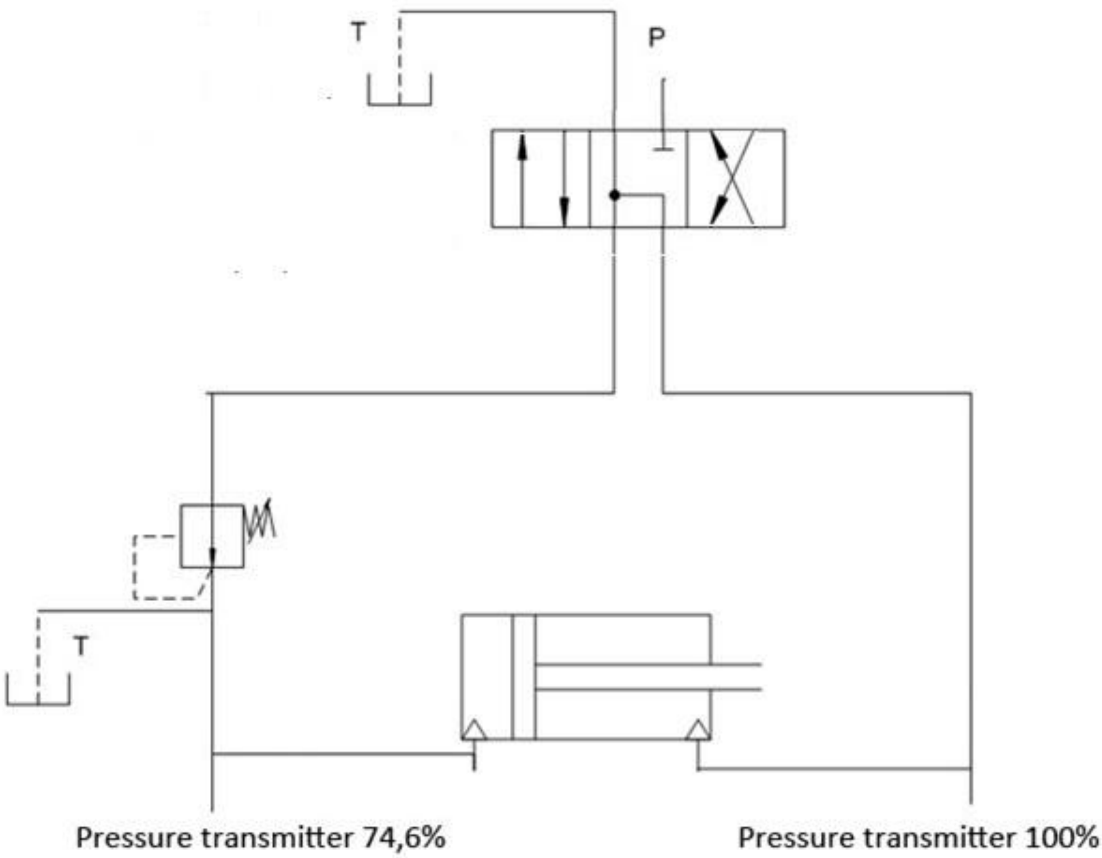


Figure 30: Function of hydraulics when using a single rod cylinder

14.2 Final concept cylinder

14.2.1 Double rod cylinder

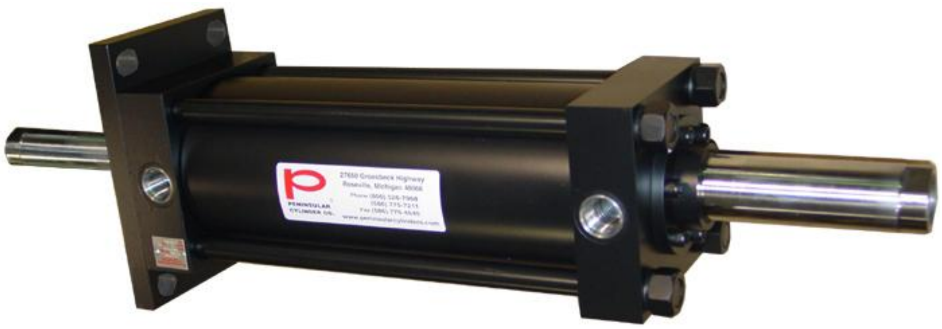
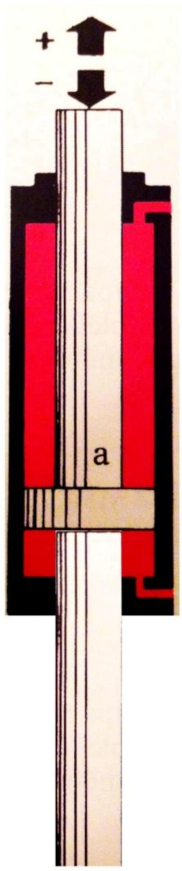


Figure 31: Double rod cylinder

In double rod-end cylinders, the actuator has a rod extending from both sides of the piston and out both ends of the barrel. This cylinder provides equal force on both tension and compressive cycles, because of the area on both sides of the piston is equal.

Calculation:



This is illustrated in the following example: [18]

Piston diameter D: 5cm

Bar diameter d: 2,8cm

Work pressure ρ:60 bar

$$a = \frac{\pi(D^2 - d^2)}{4} => \frac{\pi \times (5^2 - 2{,}8^2)cm^2}{4} = 13{,}5cm^2$$

$$a = \frac{\pi(D^2 - d^2)}{4} => \frac{\pi \times (5^2 - 2{,}8^2)cm^2}{4} = 13{,}5cm^2$$

Piston force: F= p x A x 10

$$F^+ = A \times \rho \times 10 = 13{,}5 \times 60 \times 10 = 8100N$$

$$F^- = A \times \rho \times 10 = 13{,}5 \times 60 \times 10 = 8100N$$

Figure 32: inside of a double rod cylinder

As shown in the calculations, the force is equal. If used, this double rod cylinder simplifies the hydraulic scheme and there will not be needed a pressure reducer.

15.0 Final concept manual switches

15.1 manual emergency stop button

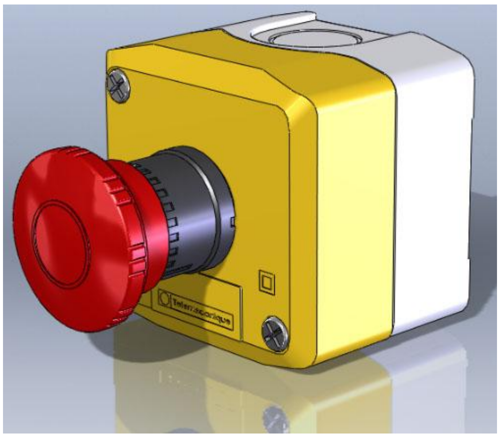


Figure 33: Manual emergency stop button [19]

The wanted solution for a manual emergency stop button is a standard push and hold button, which you turn to unleash. It is going to be used as a safety precaution if something happens and the rig needs to be manually stopped.

16.0 Automatic emergency trigger switch

The automatic emergency stop button is needed to ensure that when the test specimen breaks, the whole test rig and hydraulic pump stops. The group has looked at different solutions for a emergency stop for this occasion.

16.1 Idea, Automatic emergency trigger switch

Figure 32: automatic emergency trigger switch [21]

The automatic emergency trigger switch has as purpose to stop the hydraulic pump and rig. The switch is triggered when the stabilizer bar hits the trigger. It then cuts the power in the pump and stops the rig.

16.2 Concept, Automatic emergency rope pull

Figure 32: automatic emergency ropes pull [21]

This is placed on top and bottom of the rig, with a “rope” attached to the stabilizer bar, both “ropes” to each automatic emergency rope pull device. The device triggers when the displacement of the stabilizer bar is outside its work area. This occurs when the “rope” is pulled, and the emergency rope pull trigger the stop. The rope pull device automatically stops both the pump and rig.

17.0 Counter

To cover the requirement to count cycles, the group has looked at different counter types. It is looked at pure mechanical counters and other types of counters. When getting information about the material the cycles done before fracture is essential to get any usable information.

17.1 Idea, Mechanical counter

Figure 33: Mechanical counter

Before the electronic counters were used there was used mechanical counters, and in all mechanical machines. For our test rig, this could be an option.

Totalizes are used in a wide variety of applications where accurate totals are needed. Typical applications include counting the number of parts produced, amount of material used, or the number of machine cycles occurring. Totalizes are the simplest and most common type of counter. [22] The Mechanical totalize counter is in this case used to count every time the stabilizer bar push the count lever. The count is for every time the stabilizer bar is in compression mode.

17.2 Concept, Binary counter

In the project the group has considered using PLC in the control of the machine. If there is used PLC a digital counter can count every 1 signal given by SR flip flop, JK flip-flop or other logically devices. The use of a counter of this matter would work better and more reliable than a mechanical counter.

18.0 The machine control system

The system, which controls the Fatigue test rig, has to be reliable, and should have all commands covered. There is going to be used switches, buttons, counter and emergency stop devices.

The group wanted to look at 2 different types of controlling the machine, where in one control method there is only used mechanical components and in the second one, the controlling is done through PLC with different switches

18.1 Idea 1 Mechanical control of the system

If it is used mechanical controlling of the machine, every component used is mechanical and manual. The switches and counters will work with mechanical and manual labor.

To control the start and stop there is switches going directly to the hydraulic pump. To adjust the force on the test specimen, the operator has to adjust the pressure on output from the pump.

The emergency stop devices will also need to cut the power directly to the hydraulic pump.

The use of all mechanical and manual components would reduce the quality of our rig, and some components would be difficult to manage.

To switch from compression to tension in the cylinder would be hard to control and there would have to be used a timer to send signal to the correct end of the valve for controlling this. It may be unreliable because of the time used to fill up and press with one side of the cylinder.

18.2 Concept, Digital control of the system

If there are used digital controls in our system, some of the functions would function automatically, and it would help the automatic switch between compression and tension.

PLC- Programmable logic controller is an option. It is used in industry to automate tasks like production and control of e.g.: levels in a silo. The PLC has outperformed in tasks that a lot of relays has done in the past. The PLC has, as a computer, memory and processor which form the basis for all program execution. The PLC can be programmed to do different assignments, with programs used from a computer connected to the PLC.[23]

Different from a computer the PLC does not have a flat-screen and a keyboard. Instead it is used electrical inlets and outlets, and communicates with the system by electrical signals instead of a screen and keyboard.

This option would simplify a lot of the trouble with control of the rig. The Switches, buttons, emergency stop triggers and counter would all be included in this system.

18.2.1 The chosen PLC

Figure Eaton PLC EASY 819 at the left and Siemens PLC LOGO! 230RC to the right. [24] [25]

The PLC is a programmable logic controller and can manage the signals given to it. When programmed, it can logically control the signals with logical components.

When choosing a PLC for our control system the two different choices were Eaton PLC EASY 819 and Siemens PLC LOGO! 230RC.

Both of the PLCs have a display, which is needed for the cycle counter.

The Eaton PLC has 12 inputs and 6 outputs and the total cost for this PLC is:

Ant	Art.nr	El.nr	Type	Tekst	Pris/stk.	Netto/stk.	Beløp
1	256269	4520956	EASY819-DC-RC	12DI (4AI) 6DO RELE STD.24VDC	2 970,00	2 970,00	2 970,00
1	212319	4520907	EASY400-POW	POWERSUPPLAY 230VAC/24VDC1,25A	801,00	801,00	801,00
						Pris netto kr:	3 771,00

Table 2: The cost of Eaton PLC

The Siemens PLC has 8 inputs and 4outputs and the total cost for this PLC is:

Pos.nr	Artikkelnummer	Alternativer	El nr	Antall	Beskrivelse	Listepris (NOK)	Prisenhet	Rabatt (%)	Sum nettopris (NOK)
4	6ED1057-1AA01-0BA0		4504115	1	LOGO! USB PC CABLE FOR PROGRAM TRANSMITTING FROM PC TO LOGO! AND VICE VERSA DRIVER ON CD-ROM INCLUDED	685,00	1		685,00
3	6ED1058-0BA02-0YA1			1	LOGO! SOFT COMFORT V7, SINGLE LICENSE, 1 INSTALLATION E-SW,SW AND DOCU. ON DVD, 6-LANGUAGES, EXECUTABLE ON WIN98SE/ NT4.0/ME/2000/XP/VISTA/WIN7 MAC OS, SUSE LINUX, REFERENCE-HARDWARE:LOGO!	447,00	1		447,00
2	6ED1055-1MM00-0BA1		4540386	1	LOGO! AM2 AQ EXPAN. MODULE, PU: DC 24V, 0/4-20MA 2AQ, 0-10V	995,00	1		995,00
1	6ED1052-1FB00-0BA6		4510358	1	LOGO! 230RC,LOGIC MODULE,DISPL. PU/I/O: 115V/230V/RELAY, 8 DI/4 DO, MEM. 200 BLOCKS, EXPANDABLE WITH EXTRA MODULES 230V AC/DC	1080,00	1		1080,00
								Pris netto	3207,00

Table 3: The cost of Siemens PLC

The Siemens PLC is more cost efficient than the Eaton PLC, and the Siemens PLC comes with software to program the PLC. Since this project only requires a PLC with 5 inputs and 2 outputs, the Eaton PLC is superfluous with its 12 inputs and 6 outputs and the Siemens PLC will match better with the need.

The Siemens PLC LOGO! 230RC is chosen for this concept.

19.0 Resources and references

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HØGSKOLEN
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Department of Technology

Kongsberg

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Group members: Espen Sætre Kolberg Kjetil Haugmoen Kjøndal
Internal Supervisor: Jamal Safi
Date: 29.05.12
We confirm that the submitted assignment is entirely our work **Espen Kolberg** **Kjetil Kjøndal**

Table of Contents

1.0 Document history

Date	Version	Changes
04.04.2012	0,1	Created technical document
02.05.2012	0,2	Edited, added figures, calculations
26.05.2012	0.3	Added components, calculations and text
29.05.2012	1.0	Finalized document

Table 1: Document history

2.0 Intro

This document will cover the technical aspects of the different parts in our rig. The document will provide 3D models of the mechanical components used in the project. The Fatigue Test Rig is both hydraulically and electrically operated and the document will include schematics of both solutions.

3.0 Abbreviations

BUC - Buskerud University College

SW - Solid Works

FEM - Finite Element Method

FTR - Fatigue Test Rig

F.S. - Factor Of Safety

POM - Polyoxymethylene

PLC - Programmable Logic Controller

AC - Alternating Current

DC - Direct Current

PMMA - Polymetylmetakrylat

4.0 Designations

mm	- Millimeter
kN	- Kilo Newton
MPa	- Mega Pascal
bar	- Bar

5.0 Finite Element Method

The calculations vary slightly from the FEM analysis. However taking into account that FEM uses a material library to perform the calculations, the deviation is within an acceptable level. To ensure that the frame of the FTR is stiff enough, the project has come up with a maximum allowed displacement of 0,5mm for the frame.

6.0 Development process

In the very beginning of the project, the exact dimensions of the test specimen and the forces required to run a test were not completely figured out. This led to a slightly over-dimensioned frame which later was downsized to a more cost efficient and adequate rig design.

During the development process the project has come up with several frame designs. Discussion with the client and manual analyses led to a need for further development of the previous framework. The client has not set any specific requirements for the frame design, other than it should obtain a safety factor of 2 against fatigue. A typical requirement in designing for fatigue is a F.S. of 8. [1] In order to ensure the frame would withstand the fatigue stresses, the group has set the F.S. of the various parts of the frame to 16.

7.0 The Fatigue Test Rig

7.1 Test specimen

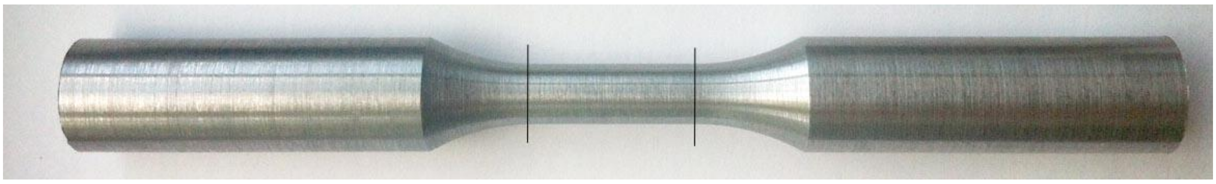


Figure 1: Test specimen

A test specimen with a straight sided collet grip was chosen for the project. The smooth finish surface is cost efficient to produce, making it possible for the client to obtain relatively inexpensive test specimens. This makes it possible to run multiple tests without excessive costs. The smooth finish and the design of the specimen include gradual size of the transitions. The test specimen also has no abrupt changes in the surface, which again could lead to stress concentrations known as the notch effect.

The project chose to go with a test specimen dimension, which are described in the ASTM e606 standard as the minimum for a test piece. The dimension of the test area has the dimensions of 6,35x19,05 mm (diameter x length) and may be seen in the figure above. [1] Processing the test specimen require high accuracy to avoid surface defects or a non uniform shape. The area of the test area is 31,6*10^{-6} m^2 and the material S355JO, which gives us the equation $\sigma_{max} = P/A$, P= $355MPa$ x $31{,}6x10^{-6}m^2 = 11218N$. This sets the upper limit for the force needed to conduct the testing.

7.2 Upper frame

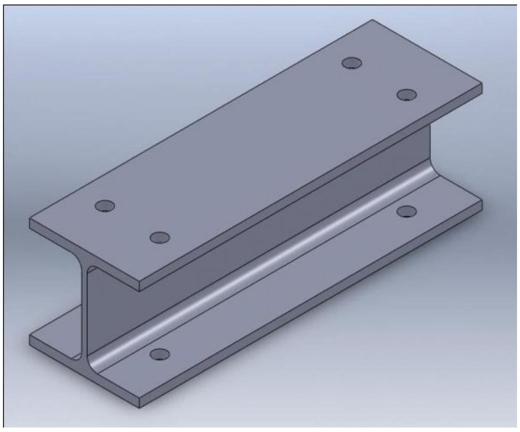


Figure 2: Upper frame

During the process of the project there has been made some changes to the different components of the frame. The final version of the upper frame consists of a single HE160B H-shaped beam with the dimensions of 160x160x500mm. The use of this profile ensures the rigidity in the frame as well as being small and compact. This leads to a smaller and more rigid setup, compared to the earlier versions of the upper frame, which is twice the size. The beam is made out of S355J2G3 construction steel and the preferred dimensions are chosen from a DIN standard. The reason this design was chosen is its ability to withstand large bending forces.

Calculations

Bending

HE160B

$I = 24{,}9 * 10^{-6} m^4$

$M = 1375 N * m$

$C = 0{,}08 m$

$$\sigma_{max} = \frac{M * C}{\mathrm{I}} \rightarrow \frac{1375 N * m * 0{,}08 m}{24{,}9 * 10^{-6} m^4} = 4{,}4 MPa$$

Max bending stress $=$ **4, 4MPa**

Deflection

$$\delta = \frac{F * L}{E * I * 48} = \frac{11000N * 500mm}{200000\frac{N}{mm^2} * 24900000mm^4 * 48} = 5{,}75 * 10^{-3}mm$$

Max deflection of the beam $= \mathbf{5,75 * 10^{-3}}\boldsymbol{mm}$

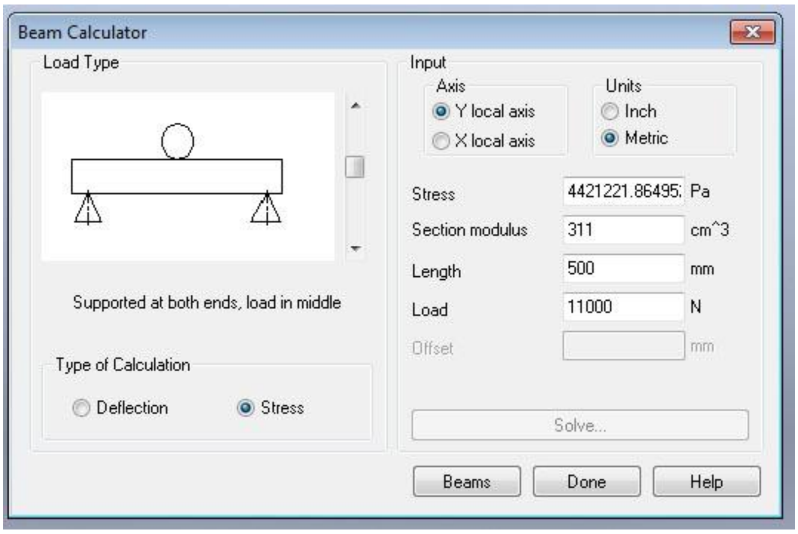


Figure 3: Software stress calculation

As can be seen at the figure above, the computer-analyzes software supports the results of the manual calculations regarding bending stress in the beam.

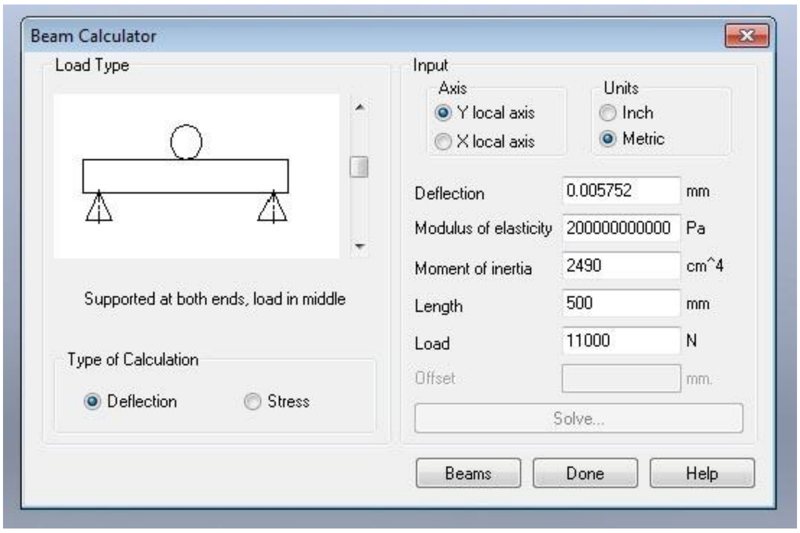


Figure 4: Software displacement calculation

The figure above show the computer based calculations of the deflection in the beam that concur with manual calculations. The FEM analysis has some deviation to these calculations which is caused by the fastening points of the beam in the computer simulation. The group chose to use fixed geometry to simulate the beam being welded together with the channel bars in the top of the frame. The application of the forces in the FEM analysis might also be a factor for the deviations.

FEM analysis

Stress

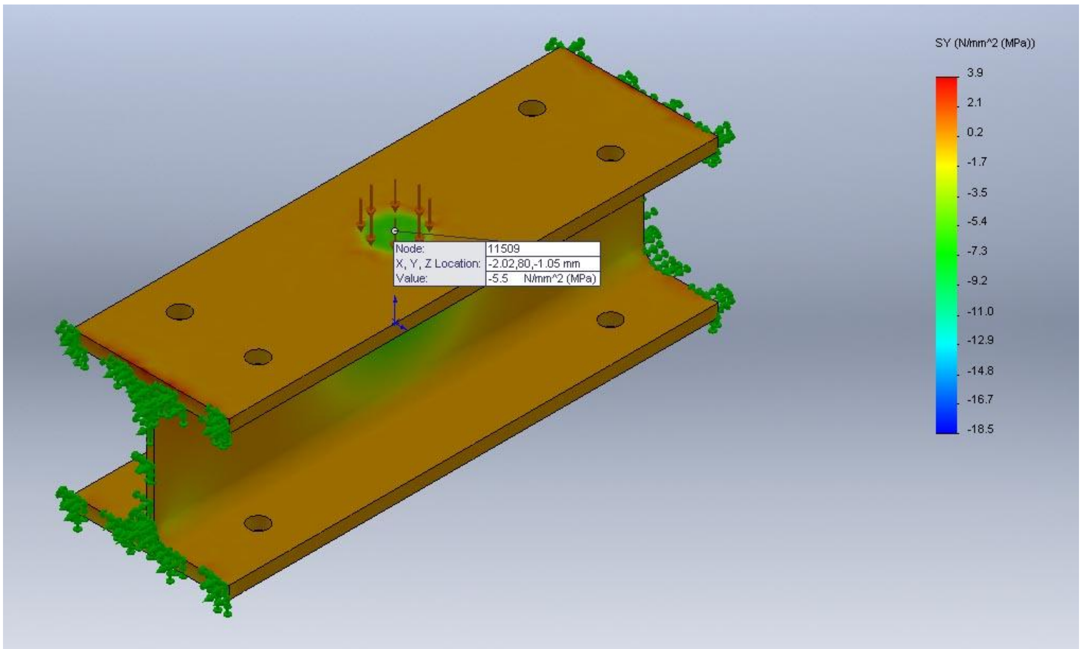


Figure 5: Stress analysis H-beam, 11kN

The stress analysis for the beam conducted in SW shows a maximum bending stress of 3.9 MPa on the edge of the beam. This corresponds with the theory that states that the highest level of stresses occurs at a point furthest away from the neutral axis. On the tension side, the highest bending stresses appears on the tensile edge of the beam, while on the compression side, the highest compression stresses occur on the compression edge of the beam. [2]

Displacement

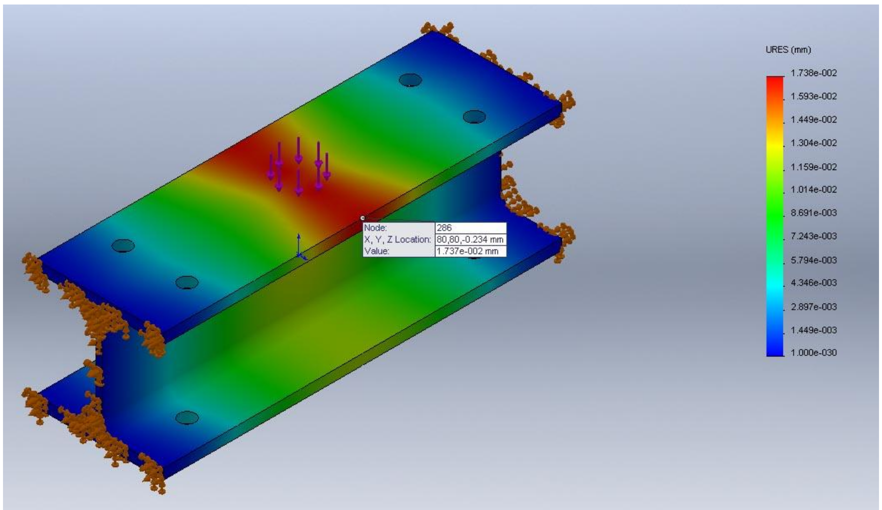


Figure 6: Displacement analysis H-beam, 11kN

The FEM analysis has some deviation compared to the manual calculation, which stated earlier, is a result of the fixed geometry in the end of the beams. The manual calculations are based on a simply supported beam. According to standard deflection criteria of $\frac{L}{200}$ gives a deflection limit of 2,5mm in the beam. [2]

To make the rig as stiff as possible, the group has chosen that the beam has to obtain a maximum deflection value of 0,1mm. The stress analysis shows a deflection of 0,017mm which satisfies requirement (ref. R28, Requirement Specification rev. 1.4)

7.3 Lower frame

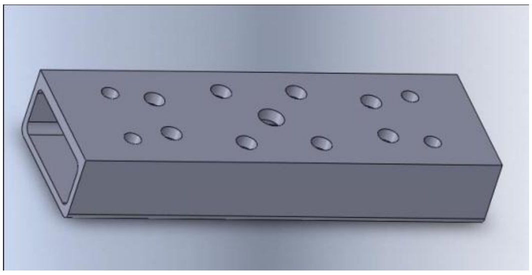


Figure 7: Lower frame

After the project decided to go with a hydraulic cylinder with a continuous rod, the group could not benefit from the design strength towards bending in the H-beam profile. The final design included the use of a rectangular tube that allows the piston rod to move through the lower frame. The rectangular tube has the dimensions 160x85x500mm.

Calculations

Bending

$M = 5500N * 0{,}25m = 1375Nm$

$\mathrm{I} = 5{,}67 * 10^{-6} m^4$

$$\sigma = \frac{M * C}{\mathrm{I}} = \frac{1375Nm * 0{,}0425m}{5{,}67 * 10^{-6} m^4} = 10{,}3MPa$$

Deflection

$$\delta = \frac{F * L}{E * \mathrm{I} * 48} = \frac{11000N * 500mm}{200000 \frac{N}{mm^2} * 5668333mm^4 * 48} = 25{,}26 * 10^{-3} mm$$

The deflection calculation shows a deflection of 0,0253mm which satisfies requirement (ref. R28, Requirement Specification rev. 1.4)

FEM analysis

Stress

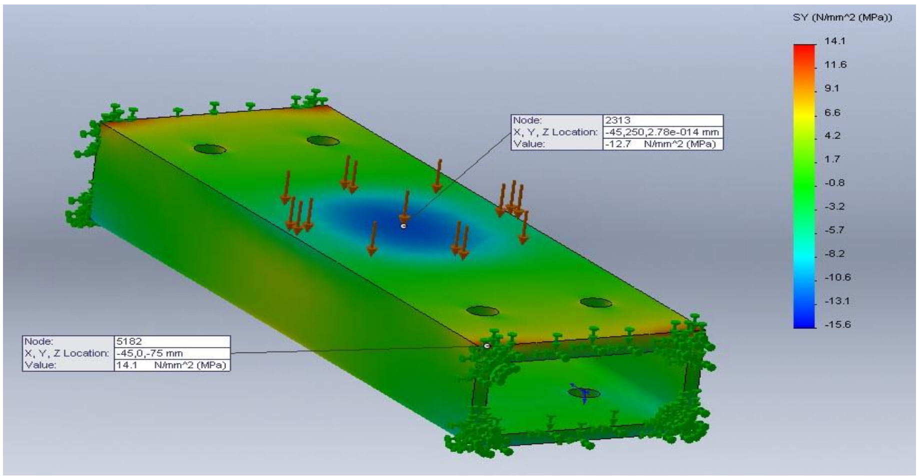


Figure 8: Stress analysis lower frame, 11kN

The figure above, show the bending stress in the lower frame. Stress analysis show a maximum stress of 14,1 MPa at the edge of the beam. There was also a stress of 12,7MPa in the middle of the beam. These stresses fulfill the requirement (ref. R15, Requirement Specification rev. 1.4).

Displacement

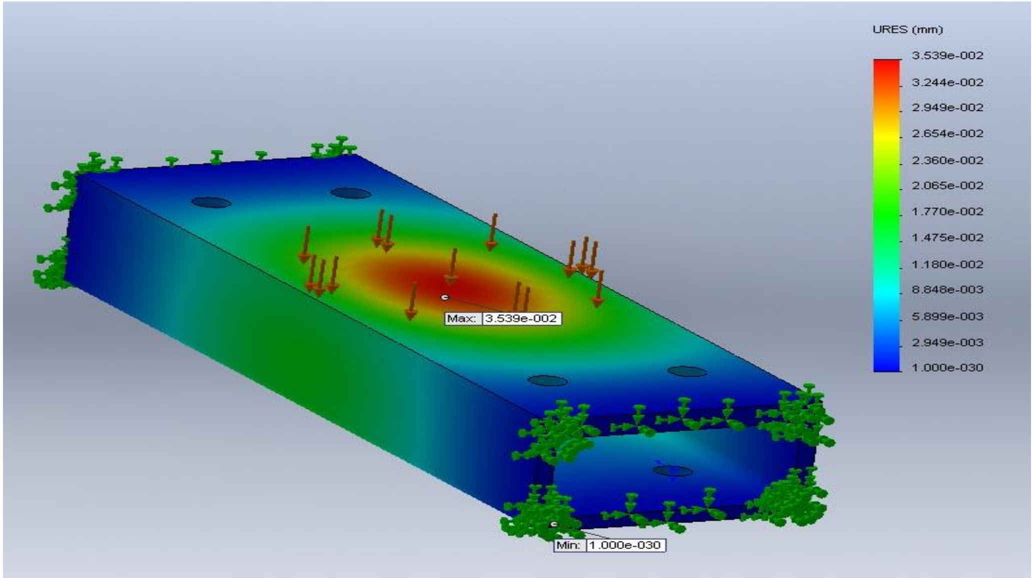


Figure 9: Displacement analysis lower frame, 11kN

Displacement analysis shows a deflection of 0,03539mm. The group aims to limit the maximum displacement as much as possible and has set a requirement of 0.1mm as a maximum deflection. The lower frame meets the requirement (ref. R28, Requirement Specification rev. 1.4).

7.4 Channel bar

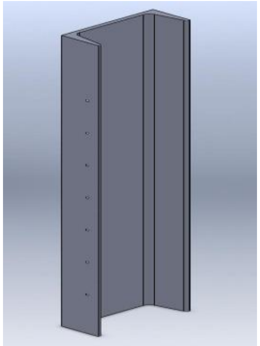


Figure 10: Channel bar

The final edition of the rig contains the mounting of two U-shaped channel bars that is welded together with the upper and lower frame. This will ensure a stiff frame for the rig. Earlier concepts made use of cylindrical rods that served both as a framework and guidance for the cylinder. By using the U- channel for the bearing structure, the rods will only ensure that the force is applied axially on to the specimen and will not be subjected to any loading.

FEM analysis

Stress

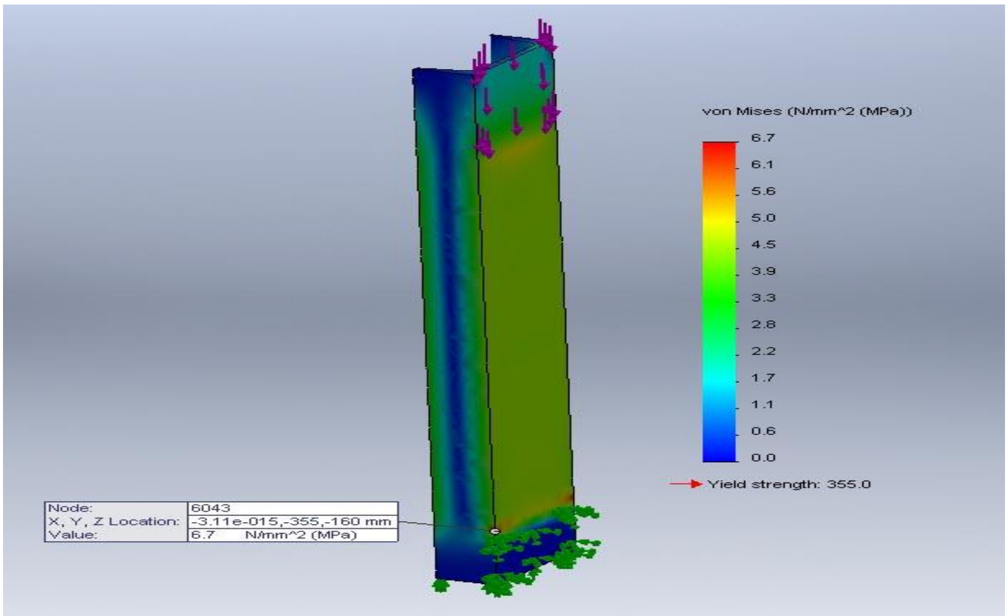


Figure 11: Stress analysis channel bar, 5,5 kN

The axial force indicated by the pink arrows is set to 5,5kN to illustrate the forces that are applied from the upper frame. The FEM analysis show that the maximum stresses in the channel bar is 6,7MPa and is located in the transition to the lower frame. This stress is well within the acceptable limit the client has set for the frame. (ref. R15 in the Requirement specification rev. 1.4)

Displacement

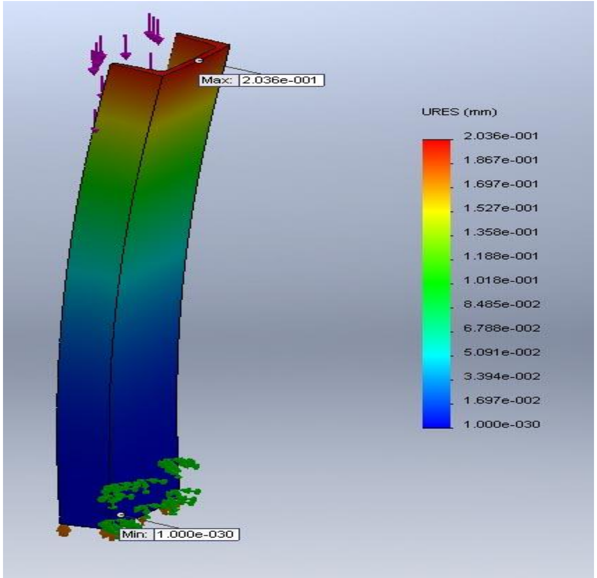


Figure 12:

The figure above shows the displacement of the channel bar of 0,2mm. The maximum displacement is located at the very top of the bar. According to the requirement for deflection of the frame, the displacement satisfy requirement (ref. R28, Requirement Specification rev. 1.4).

7.5 Cylindrical guide rods

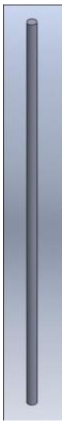


Figure 13: Cylindrical guide rod

The cylindrical guide rods are used to ensure that the force from the cylinder is evenly applied onto the test specimen. The guide rods are not subjected to any significant load and are designed to operate only as guides. To make sure the rods will cope with an unexpected scenario where the cylinder apply the forces uneven, a FEM analysis is carried out.

Calculations

$M = 100N * 0{,}45m = 22{,}5Nm$

$\mathrm{I} = 7{,}85 * 10^{-9}m^4$

$\sigma = \frac{M * C}{\mathrm{I}} = \frac{22{,}5Nm * 0{,}01m}{7{,}85 * 10^{-9}m^4} = 28{,}66MPa$

FEM analysis

Stress

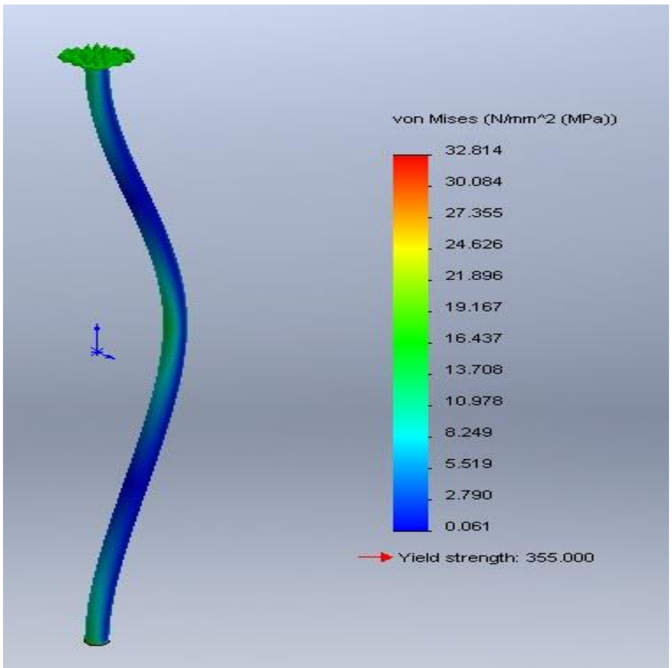


Figure 14: Stress analysis cylindrical guide rod

Analysis shows that a unexpected force of 100N to the beam will generate a stress of 32,8 MPa. The maximum stress occurs at the middle of the rod.

Displacement

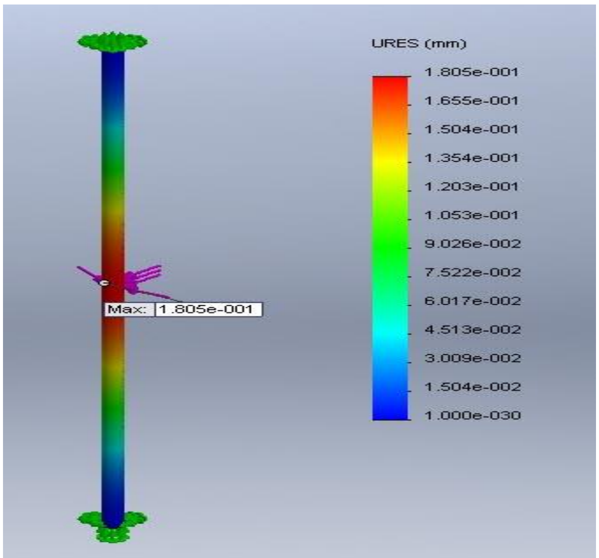


Figure 15: Displacement analysis guide rod

The figure above shows the displacement of the guide rod. The maximum displacement is 0,18mm

7.6 Stabilizer bar

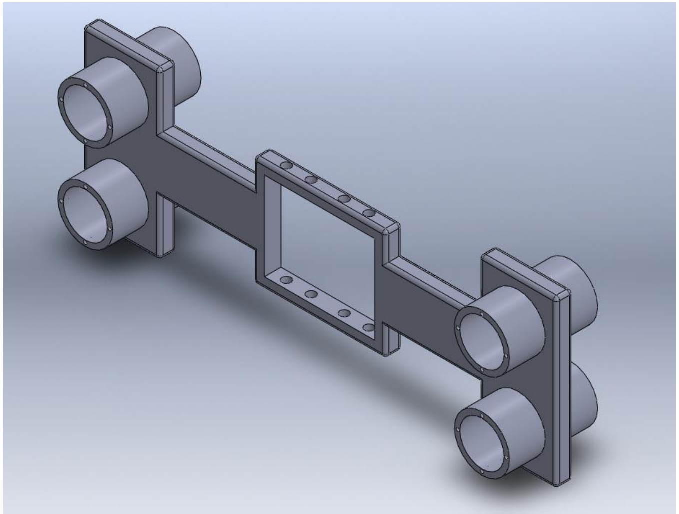


Figure 16: Stabilizer bar

The figure above shows the stabilizer bar. To ensure the application of the force onto the specimen is completely axial, the project came up with the idea of using a stabilizer bar. The bar is attached to all four of the guide rods and clamped to the lower test specimen fixture in the center of the structure. This provides a support structure to ensure that the lower test specimen fixture is not able to have a horizontal movement.

FEM analysis

Stress

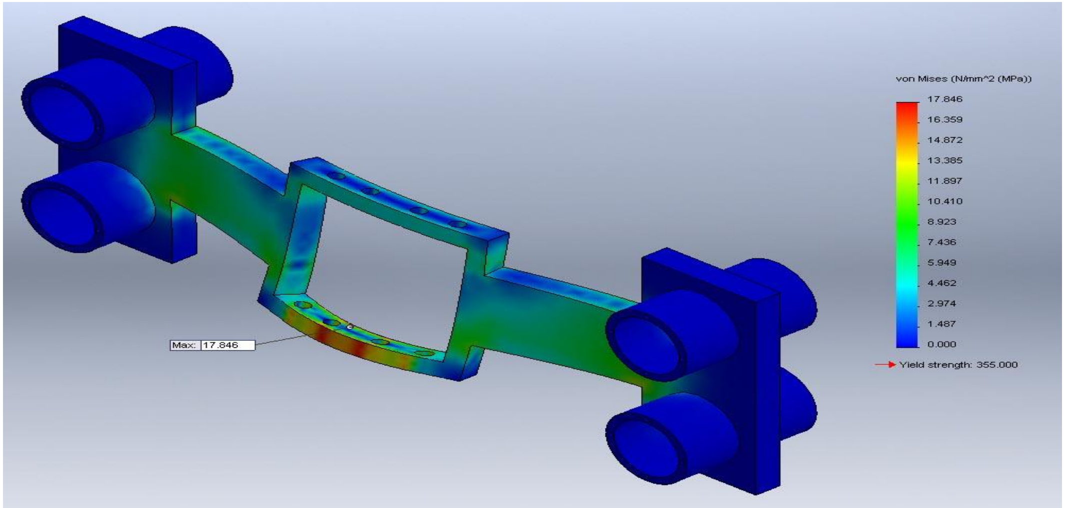


Figure 17: Stress analysis stabilizer bar 0,1kN

A FEM analysis shows that an unevenly distributed load from the lower specimen fixture of 100N would generate a maximum stress of 17,846 MPa in the center bracket of the stabilizer bar.

Displacement

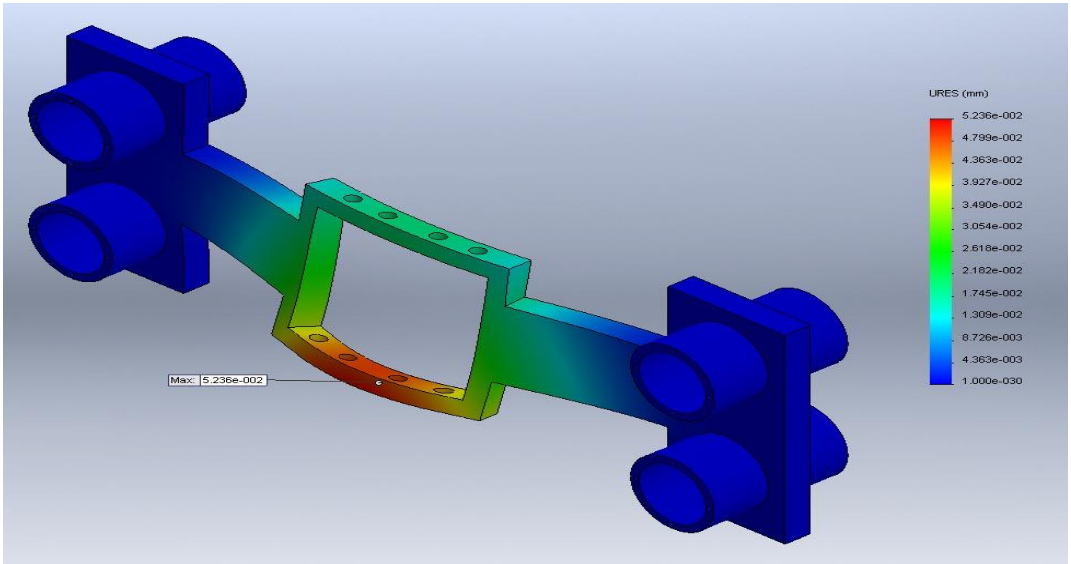


Figure 18: Displacement stabilizer bar at 0,1kN

The figure above shows how the displacement is distributed in the stabilizer bar. Maximum displacement occurs in the lower part of the bracket show on the figure. The displacement has a maximum value of 0,05236 mm.

7.7 POM-C guide bushing

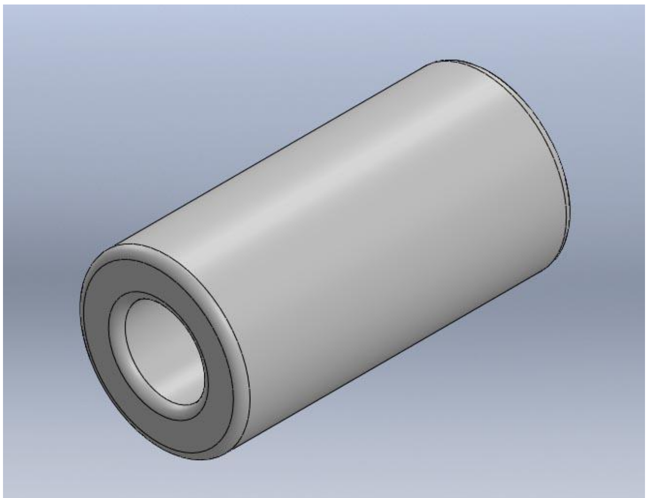


Figure 19: POM-C guide bushing

The POM-C in the figure has the task to provide a tight fit along the guide rods that insures that the test specimen is subjected to axial loading only. The low friction POM-C allows the stabilizer bar to glide smoothly on the guide rods.

The bushing forms a cylindrical tube with the dimensions (diameter x height) of 40x80 mm. The center of the POM contains an extruded cut of 20mm.

Properties POM-C	Standard	Unit	Value
Color			Black
Weight	ISO 1183	g/cm^3	1,41
Tensile strength	DIN 53455	N/mm^2	65
E-module	DIN 53457	N/mm^2	3000
Elongation	DIN 53455	%	35
Hardness, scale D	ISO 1183		81
Operation temperature permanent		C	-40/+90
Operation temperature brief		C	+160
Melting point	ISO 3146	C	+160
Tolerances expansion	ASTM D696	mm/m/C	0,09
Coefficient of friciton	On steel		0,32
Vapor admission at 23 degrees C	ISO 1110	%	0,20
Water admission at 23 degrees C	ISO 62	%	0,25

Table 2: POM-C technical data [3]

7.8 Upper specimen fixture

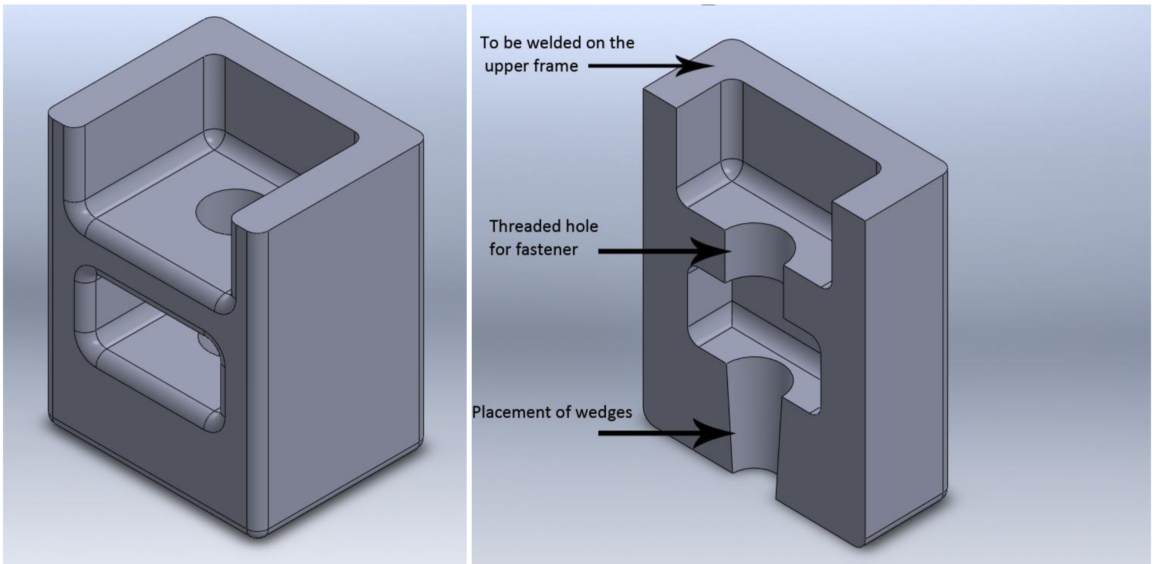


Figure 20: Upper specimen fixture

The specimen fixture is one of the main components of the rig. It is made on the basis of the ASTM e606 standard. The fixture has to provide clamping force onto the specimen during testing. In the upper part of the bracket, there is milled out a 65x70x35 mm rectangle to allow fastening of the bolt. This clearing also makes room to fasten the bolt with a wrench.

In the lower part of the milled out rectangle it is a tapped hole (M27x1) that goes through to the lower section of the specimen fixture. This hole is to be used for the tightening of the test specimen.

In the lowest part of the specimen fixture is it milled out a second rectangle with the dimensions of 60x60x30 mm. This cutout is made to house the power transfer, which is the intermediary between the bolt and the wedges.

On the surface in lowest part of the fixture, a wedge-shaped hole is milled out. The cutout is 40mm deep and goes through the frame of the fixture.

Dimensions of the upper specimen fixture are:

- Height: 125mm
- Width: 80mm
- Length: 100mm
- Thickness middle section: 20mm

FEM analysis

Stress

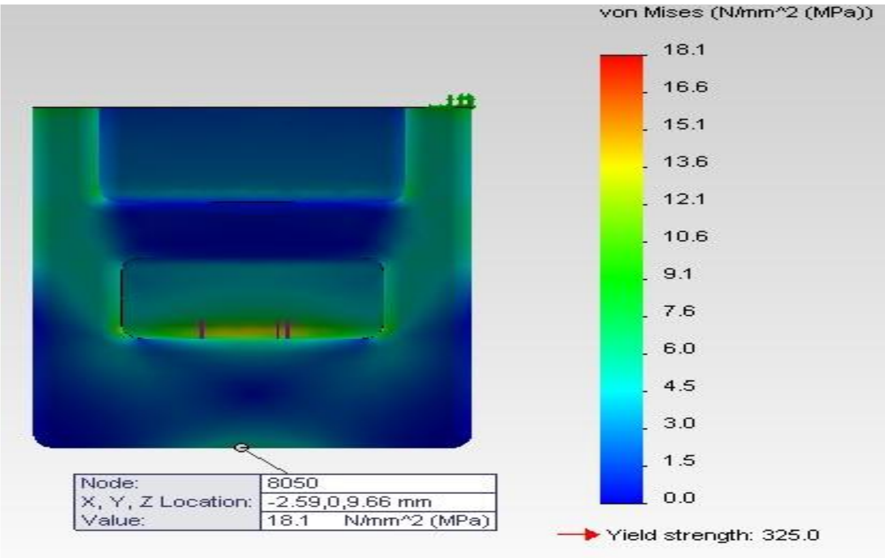


Figure 21: Stress analysis upper specimen fixture at 11kN

The FEM analysis show a stress of 18,1 MPa. The maximum stress is located in the center at the bottom of the frame, where the cutout for the wedges is located. This stress fulfills the requirement (ref. R15, Requirement Specification rev. 1.4).

Displacement

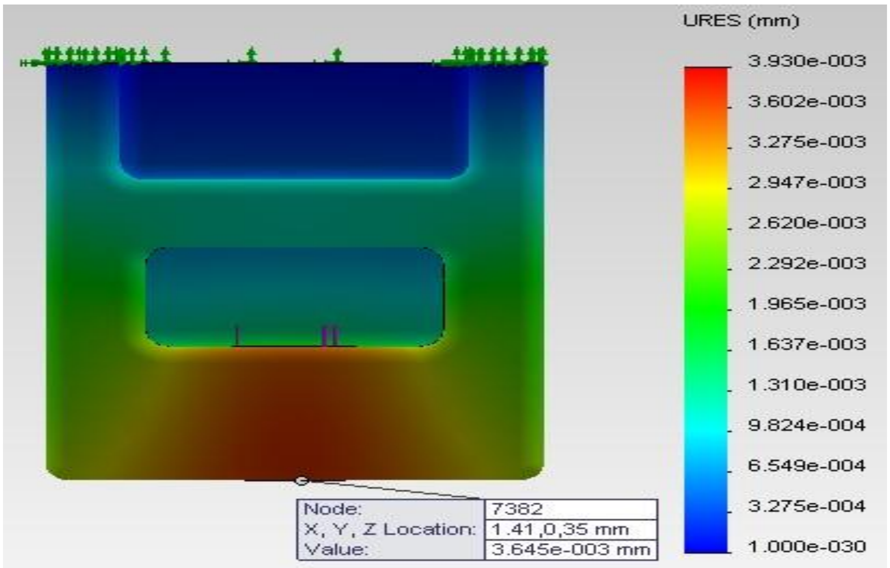


Figure 22: Displacement

Displacement analysis show a maximum displacement located at the center at the bottom of the frame. The displacement analysis shows a deflection of 0,0039mm which satisfies requirement (ref. R28, Requirement Specification rev. 1.4)

7.9 Lower specimen fixture

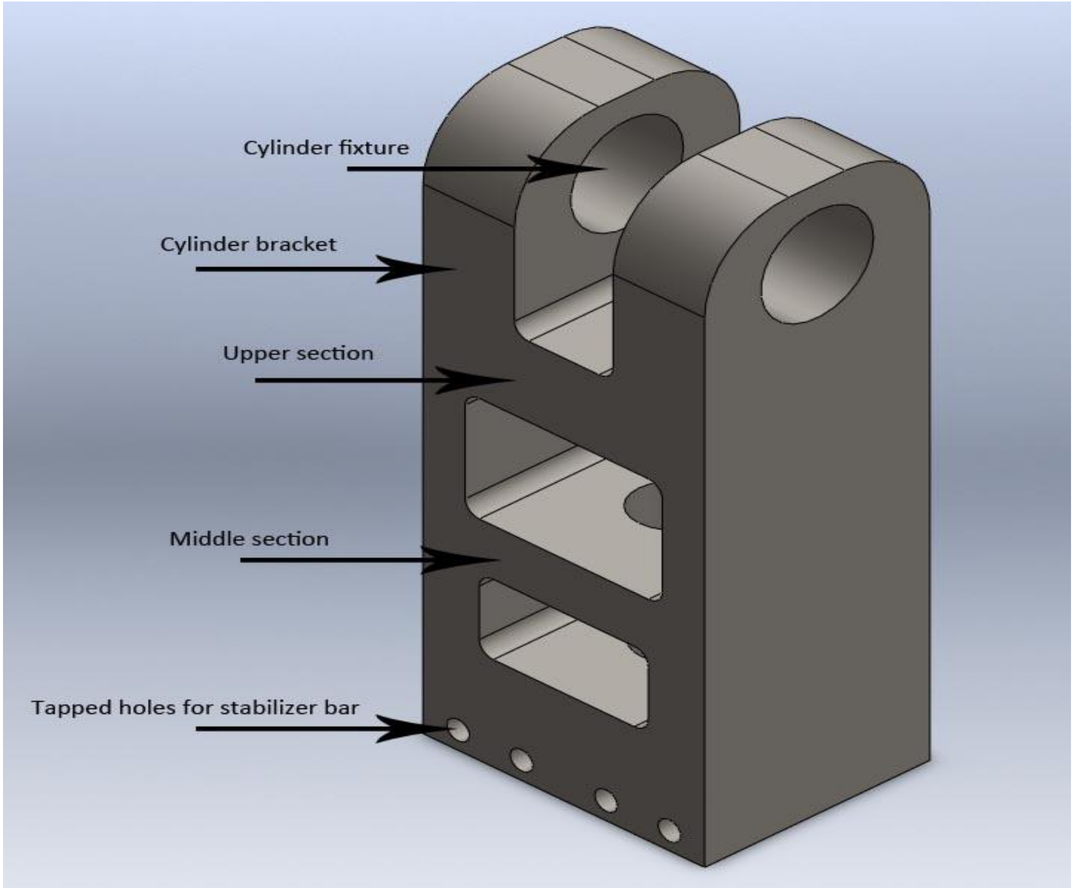


Figure 23: Lower specimen fixture

The lower specimen fixture consists mostly of the same design as the upper fixture. It differs from the upper fixture by having a bracket for attachment of the cylinder. The bracket makes a stiff construction for mounting of the cylinder. There are also four tapped holes (M8x1) on each side of the fixture. These holes are made to allow fastening of the stabilizer bar that makes sure the cylinder apply the forces axially.

Dimensions of the lower specimen fixture are:

- Height: 235mm
- Width: 80mm
- Length: 100mm
- Thickness middle section: 20mm
- Thickness upper section: 30mm
- Thickness cylinder bracket: 32,5mm
- Height cylinder bracket: 70mm
- Diameter cylinder fixture: 40mm

FEM analysis

Stress

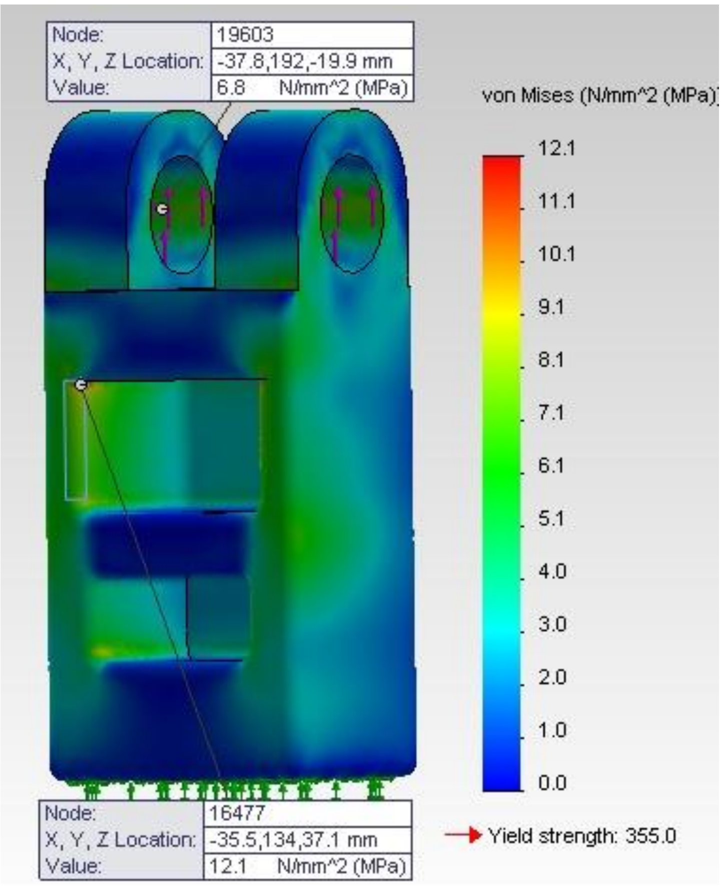


Figure 24: 11kN axial stress

Stress analysis of the lower specimen fixture show a stress of 12,1 Mpa. The maximum stress is located in the lower left corner of the upper section. The stress in the fixture meets the requirement (ref. R15, Requirement Specification rev. 1.4).

Displacement

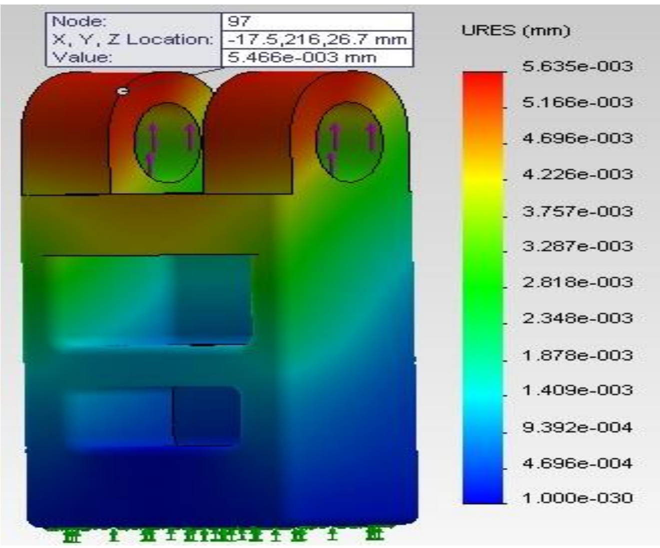


Figure 25: Displacement, 11kN axial stress

The displacement of the lower specimen fixture has a displacement of 0,005635mm. The maximum displacement is located at the upper part of the bracket. The displacement analysis satisfies requirement (ref. R28, Requirement Specification rev. 1.4)

7.10 Cylinder bracket

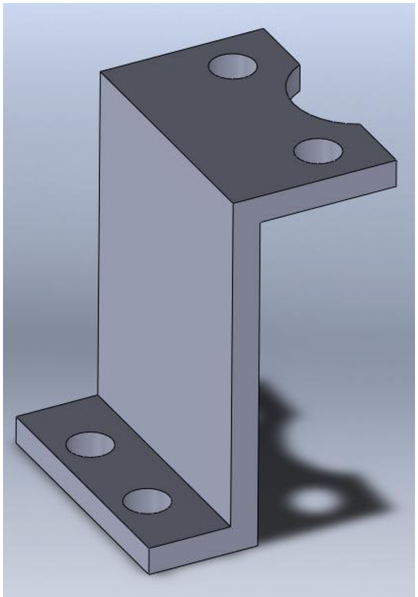


Figure 26: Cylinder bracket

The cylinder bracket provides a good support structure for the cylinder. The bottom flange has the dimensions of 140x45x15mm (length x width x height). On the flange there are cut holes (M24x3) for mounting on to the lower frame. The upper flange consists of two (M24x3) extruded cuts for mounting the flange on to the cylinder bracket. There are also a circular cut with a radius of 35mm, which allow the bracket to fit around the cylinder.

FEM analysis

Stress

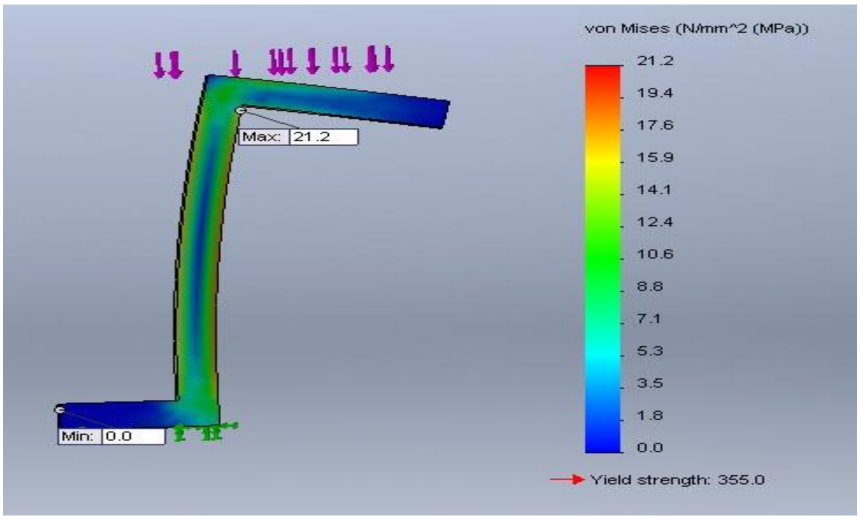


Figure 27: Cylinder bracket, 2,750kN

The stress analysis show a maximum stress of 21,2 MPa. The maximum stress is located at the corner at the upper flange. The stress in the fixture meets the requirement (ref. R15, Requirement Specification rev. 1.4).

Displacement

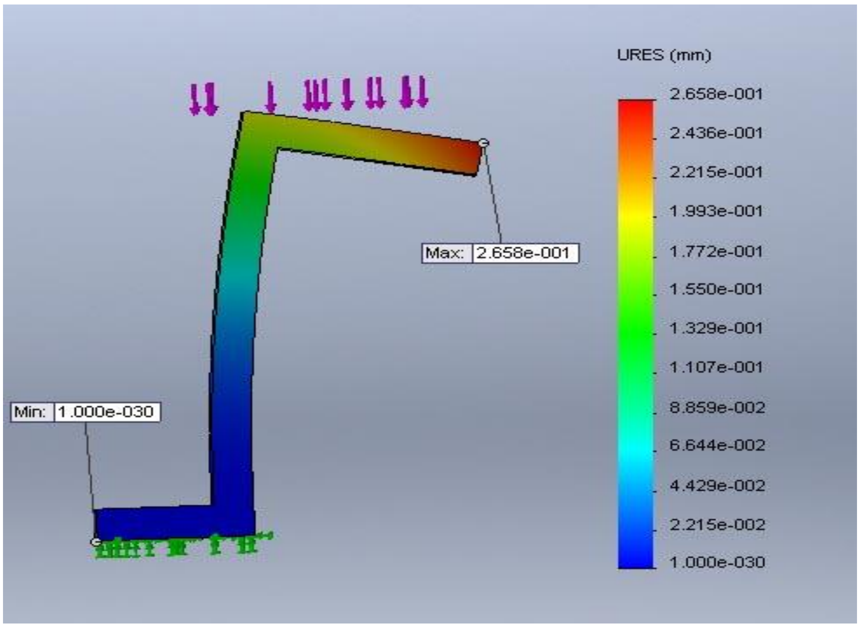


Figure 28: Cylinder bracket displacement, 2,750kN

The displacement analysis shows a maximum displacement of 0,265mm. The maximum value of the displacement is located at the very tip of the upper flange. The displacement analysis satisfies requirement (ref. R28, Requirement Specification rev. 1.4)

7.11 The power transfer

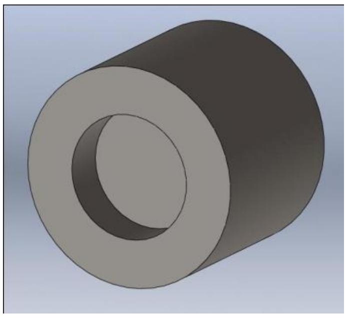


Figure 29: Power transfer

The force passing is a cylindrical cup that transfers force from the bolt onto the wedges. The component fits over the wedges to ensure a tight and stable fit during the testing.

The dimension of the force passing is:

- Height: 20mm
- Diameter: 23mm
- Center cut: 13mm

Calculations

$$\mathrm{I} = \frac{\pi}{4} * r^4$$

$$\mathrm{I} = \frac{\pi}{4} * 0{,}0115m^4$$

Stress:

The outer diameter of the cup

$$A = 415{,}47mm^2$$

$$\sigma = \frac{P}{A} = \frac{1146\mathrm{N}}{415{,}47\mathrm{mm}^4} = 2{,}75\mathrm{MPa}$$

Elongation:

$$\delta_1 = \frac{P * L}{A * E} = \frac{1146N * 0{,}002m}{415{,}47mm^2 * 200000MPa} = 2{,}75 * 10^{-5}\text{mm}$$

Stress:

The inner diameter of the cup

$$A = 282{,}73mm^2$$

$$\sigma = \frac{P}{A} = \frac{1146\text{N}}{283{,}73\text{mm}^4} = 4{,}04\text{MPa}$$

Elongation:

$$\delta_2 = \frac{P * L}{A * E} = \frac{1146N * 0{,}0005m}{273{,}73mm^2 * 200000MPa} = 1{,}009 * 10^{-5}\text{mm}$$

$$\delta_1 + \delta_2 = 3{,}76 * 10^{-5}\text{mm}$$

[4]

FEM analysis

Stress

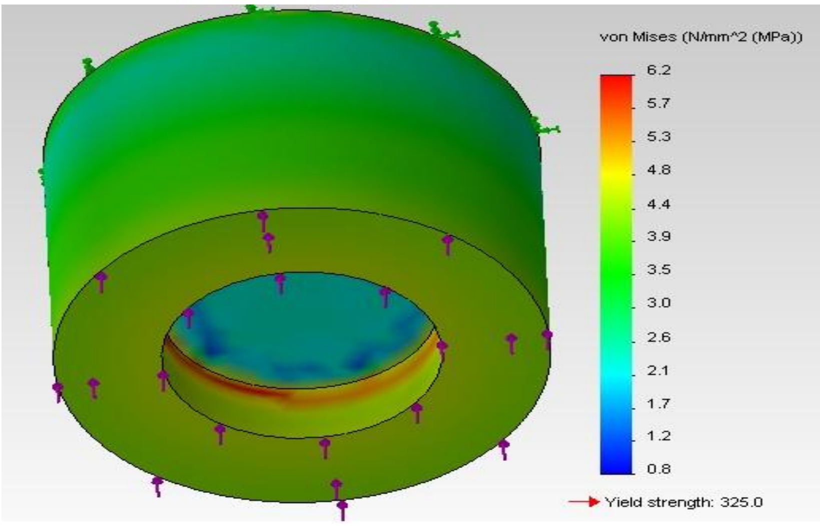


Figure 30: Stress in power transfer 1,146kN

The stress analysis of the power transfer, show a stress of 6,1 MPa. The maximum stress is located in the bottom face of the extruded cut. The stress in the fixture meets the requirement (ref. R15, Requirement Specification rev. 1.4).

Displacement

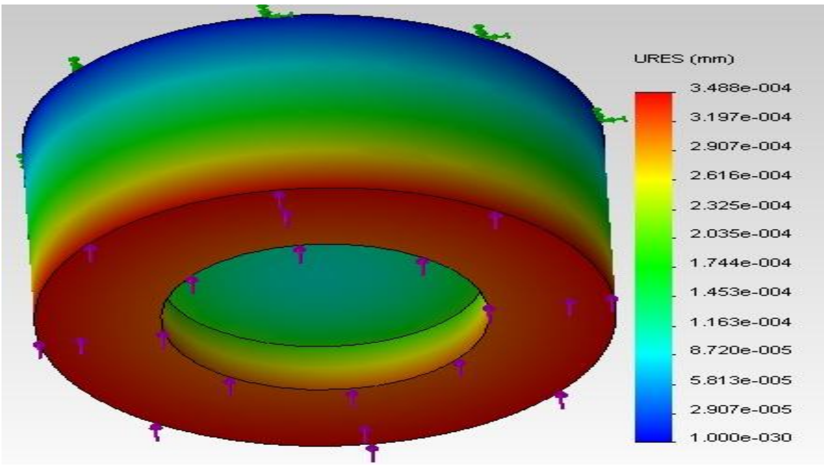


Figure 31: Displacement of power transfer

Displacement analysis of the power transfer shows a maximum displacement of 0,0003488mm. The maximum displacement is located at the surface at the bottom of the component, which is in contact with the wedges. The displacement analysis satisfies requirement (ref. R28, Requirement Specification rev. 1.4).

7.12 The fastener

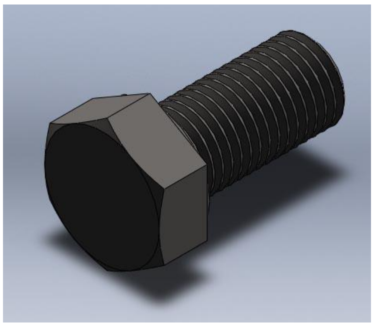


Figure 32: Fastener

The bolt has to provide enough force to allow a tight fix of the test specimen. It is crucial that the specimen is held in place during the test. The hexagonal bolt has the dimension of M27x1 and the specification of 8.8, which means it has a yield strength of 8x8x9,81=627 MPa.

Calculations

Torque the bolt need to be tightened with:

Torque needed to fasten a triangular thread:

$$\boldsymbol{M_v = F * r_m * \tan(\varepsilon_1 + \varphi)}$$

$\boldsymbol{F} = \ axial\ load\ or\ force$

$\mathbf{r_m} = \text{thread radius}(\frac{d_2}{2})$

$\boldsymbol{\varepsilon_1} = angle\ of\ friction \qquad tan(\varepsilon_1) = \left(\frac{\mu}{cos(\alpha)}\right)$

$\boldsymbol{\varphi} = pitch\ angle \qquad \varphi = \left(\frac{P}{\pi * d_2}\right)$

$\boldsymbol{\mu} = coefficient\ of\ friction$

$\boldsymbol{2\alpha} = profile\ angle\ of\ thread : 60°$

Torque needed to loosen a triangular thread:

$$\boldsymbol{M_v} = \boldsymbol{F} * \boldsymbol{r_m} * \textbf{tan}\,(\boldsymbol{\varepsilon_1} - \boldsymbol{\varphi}\,)$$

In the contact face a friction force occur which counteract the pull of the bolt. The friction force of this moment is:

$$\boldsymbol{M_s} = \mu_1 * F * r_1 m$$

Where

$$\boldsymbol{F} = axial\,force$$

$$\boldsymbol{\mu_1} = coefficient\,of\,friction\,between\,bolthead\,and\,surface$$

$$\boldsymbol{r_1 m} = the\,radius\,that\,the\,friction\,force\,acts\,upon$$

$$\boldsymbol{r_1 m} = \left(\frac{S + d_h}{4}\right)$$

$$\boldsymbol{S} = wrench\,width$$

$$\boldsymbol{d_h} = hole\,diameter$$

Total moment:

$$\boldsymbol{M} = \boldsymbol{M_v} + \boldsymbol{M_s}$$

$$M = F * r_m * \tan(\varepsilon_1 + \varphi\,) + \mu_1 * F * r_1 m$$

$$\boldsymbol{F} = 1146N$$

$$\boldsymbol{\mu} = \mu_1 = 0{,}20$$

$$\boldsymbol{r_m} = \frac{d_2}{2}$$

$$\boldsymbol{d_n} = 25{,}67mm$$

$$\boldsymbol{s} = 46mm$$

$$based\,on\,NS\,1073 - 6{:}\,1971 \quad d_2 = 26{,}3mm, P = 1\,, r_m = 13{,}5$$

$$\tan(\varepsilon_1) = \frac{\mu}{\cos\,(\alpha)} = \frac{0{,}2}{\cos\,(30)} = 0{,}231 \rightarrow \varepsilon_1 = 13{,}0°$$

$$\tan(\varphi) = \frac{P}{\pi * d_2} = \frac{1}{\pi * 26{,}3} \rightarrow \varphi = 0{,}69°$$

$$\boldsymbol{r_1 m} = \frac{s + d_n}{4} = \frac{46mm + 25{,}67mm}{4} = 17{,}91mm$$

$M = 1146N * \frac{0,0263m}{2}$ *tan(13+0,69)+0,20*1146N*0,01791m

$M = 3,67 + 4,10 = 7,77 \rightarrow 8Nm$

$\boldsymbol{The\ bolt\ has\ to\ be\ tightened\ with\ a\ torque\ of\ 8\ Nm}$

[5]

Stress

$A = \pi r^2 = \pi * 13,19^2 = 546,56mm^2$

$$\sigma = \frac{P}{A} = \frac{1146\text{N}}{283,73\text{mm}^4} = \frac{1146}{546,56} = 2,1\text{MPa}$$

Elongation

$$\delta = \frac{P * L}{A * E} = \frac{1146N * 0,001m}{546,56mm^2 * 200000MPa} = 1,04 * 10^{-5}mm$$

FEM analysis

Stress

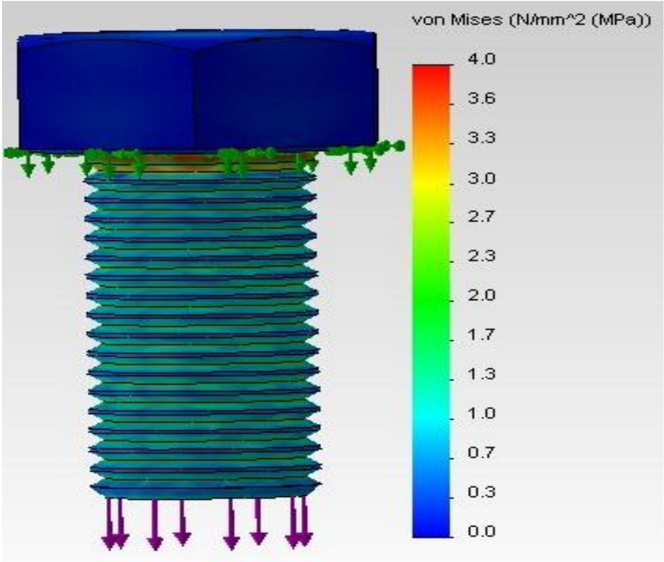


Figure 33: Stress analysis of the bolt at 1,146kN

The stress analysis of the bolt shows a maximum stress of 4,0 MPa. Maximum stress is located under the hexagonal head of the bolt.

Displacement

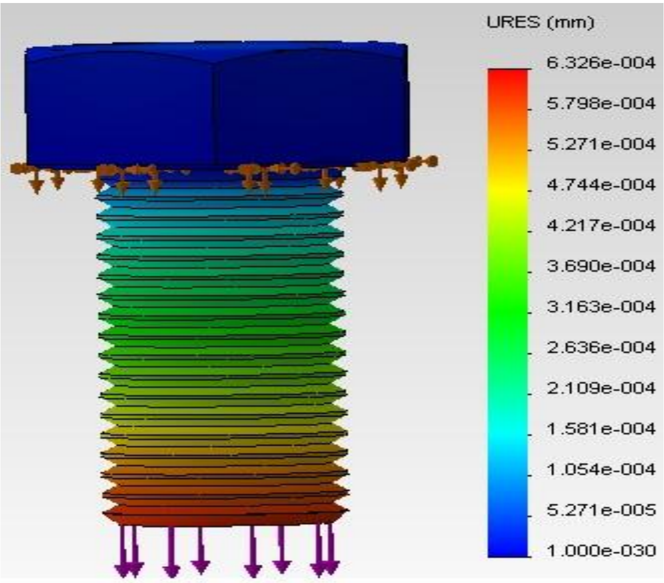


Figure 34: Displacement analysis of the bolt 1,146kN

Analysis of the bolt shows a maximum displacement of 0,0006326mm. The maximum displacement is located at the bottom of the bolt.

7.13 Wedge lock

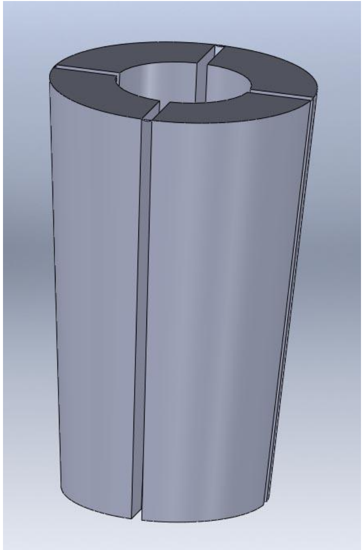


Figure 35: Wedge lock

To ensure that a tight and firm grip is applied to the test specimen the angle of the wedges is very important, as well as the vertical force applied onto the wedges. It is crucial that the test specimen is held tight during the execution of a test, not only to make sure that the rig don`t fail, but also to get reliable results. As can be seen of the calculation below, the optimal angle for the wedges will be 4,028 degrees.

Calculations

Optimal angle of the wedges:

ew: edge of the wedge

t: test specimen

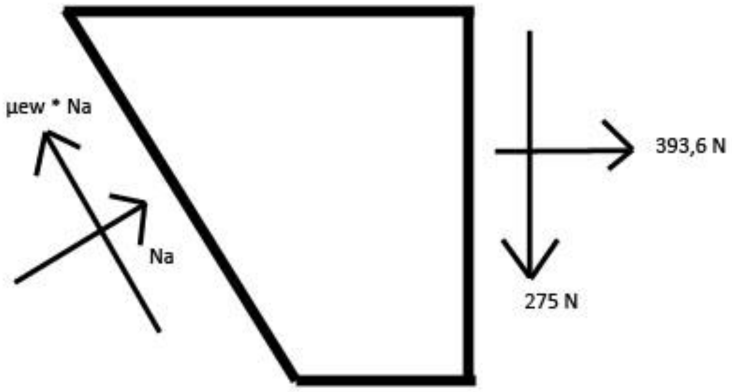
$\mu_{ew} = 0{,}6$

$\mu_t = 0{,}7$

$$\theta = tan^{-1} * \left(\frac{\mu_t - \mu_{ew}}{1 + \mu_{ew} * \mu_t}\right) = tan^{-1} * \left(\frac{0{,}7 - 0{,}6}{1 + 0{,}6 * 0{,}7}\right) = \mathbf{4{,}028°}$$

[6]

The calculation below takes a look at a $\frac{1}{40}$ section of the wedge:



$$O = 2\pi r = 2 * \pi * 6{,}35 \sim 40mm$$

Force normal to the wedge:

$$F_N = \frac{f}{\mu} = \frac{11000N}{0{,}7} = \mathbf{15714{,}3N}$$

$$F_{N\frac{1}{40}} = \frac{15714{,}3}{40} = \mathbf{392{,}85N}$$

Axial force along the wedge:

$$F_{Ax\frac{1}{40}} = \frac{11000N}{40} = \mathbf{275N}$$

$Wedge$:

$$\Sigma F_y = -275N + \mu_{ew}NA * cos4 + NA * \sin(4) = 0$$

$$\Sigma F_x = NA * \cos(4) - \mu_{ew}NA * \sin(4) - 393{,}6N = 0$$

$$NA * \cos(4) = \frac{393{,}6N + \mu_{ew}NA * \sin(4)}{\cos(4)}$$

$$NA = 393{,}6N + 0{,}0419NA$$

$$NA = \frac{393{,}6N}{0{,}9581} = 411{,}2N$$

$$NA_x = 411{,}2 * \sin(4) = 28{,}67N$$

Since this calculation is based on $\frac{1}{40}$ of the wedges, the actual force needed will be:

$$28{,}67N * 40 = \mathbf{1146N}$$

[6]

FEM analysis

Stress

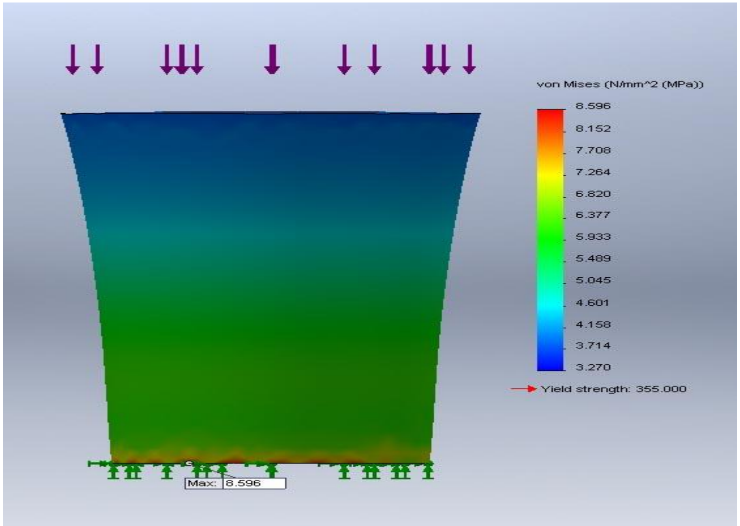


Figure 36: Wedge stress 1,146kN axial

The analysis of the wedge shows a maximum stress of 8,596 MPa. The FEM analysis will have some deviation to an actual test run due to the friction force and the normal force that acts on the wedges.

Displacement

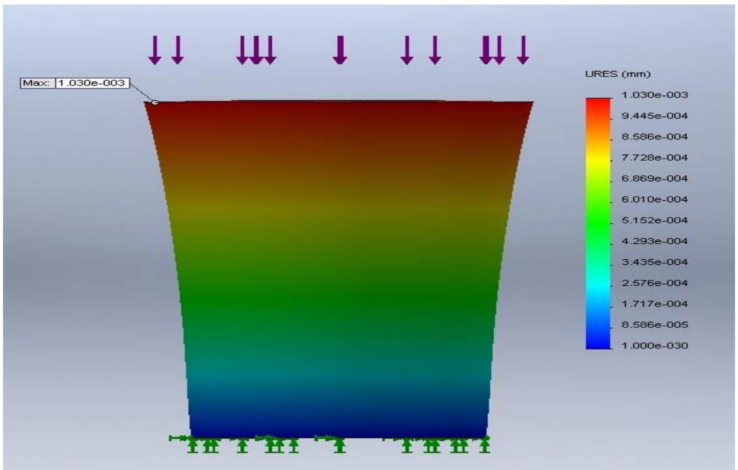


Figure 37: Displacement wedges, 1,146kN axial

Displacement analysis shows a maximum displacement of 0,001mm. The maximum displacement is located at the upper left side of the wedge.

7.14 Locking bolt

Figure 38: Locking bolt

To ensure a tight fixture of the cylinder to the lower specimen fixture, a stud bolt is shrunk fitted into the lower specimen fixture. The bolt is cooled down sufficient for it to be pushed in to the lower specimen fixture and through the hole in the cylinder rod. This will ensure a strong connection between the parts and will eliminate any play. The locking bolt has the dimensions of 42x120 mm.

FEM analysis

Stress

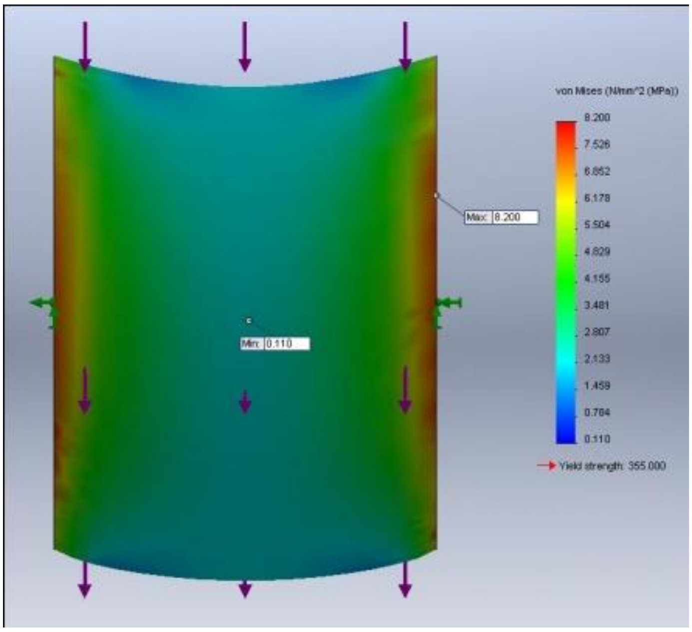


Figure 39: Stress analysis locking bolt 5,5kN

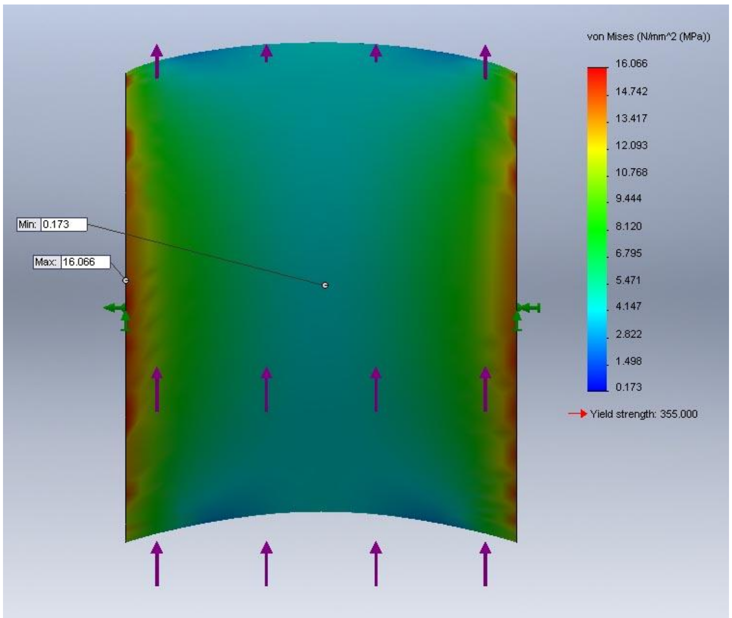


Figure 40: Stress analysis locking bolt, 11kN

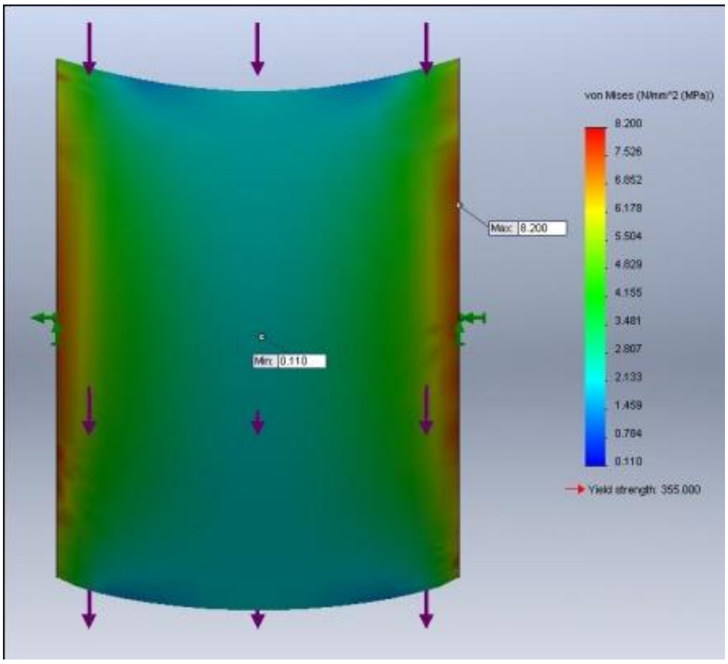


Figure 41: Stress analysis locking bolt 5,5kN

The stress analysis of the bolt shows a maximum stress of 16,0 Mpa around the middle of the bolt. To ease the analysis in the software, the bolt is divided into three parts. The analysis illustrates the cylinder pulling with a force of 11kN at the center of the bolt. The illustration on the left and the right hand side of the figure shows the section of the bolt, which is fixed to the lower specimen fixture. These parts is subjected to a maximum stress of 8,2 MPa.

Displacement

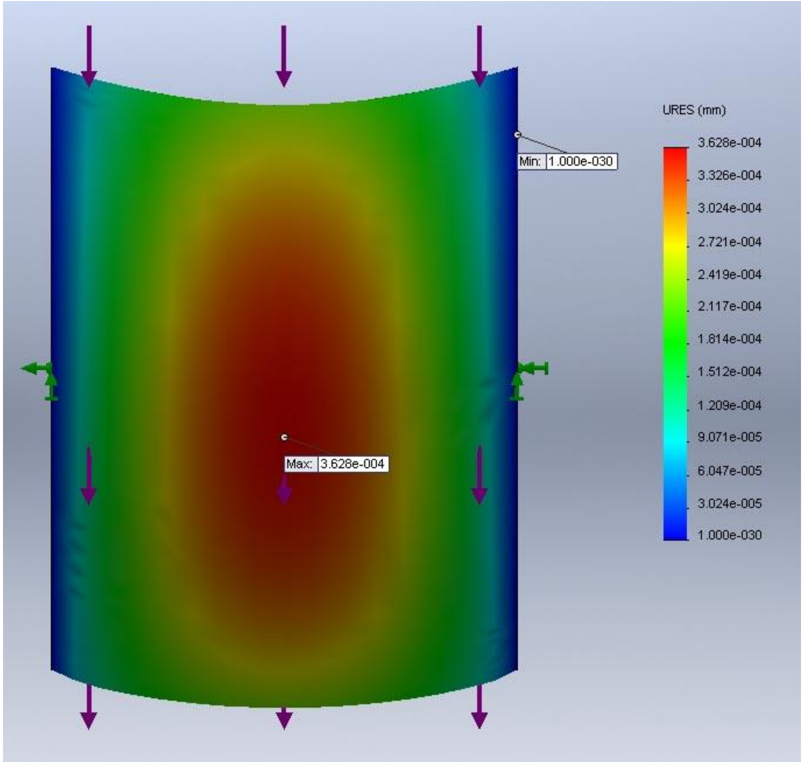


Figure 42: Displacement analysis locking bolt at 5,5kN

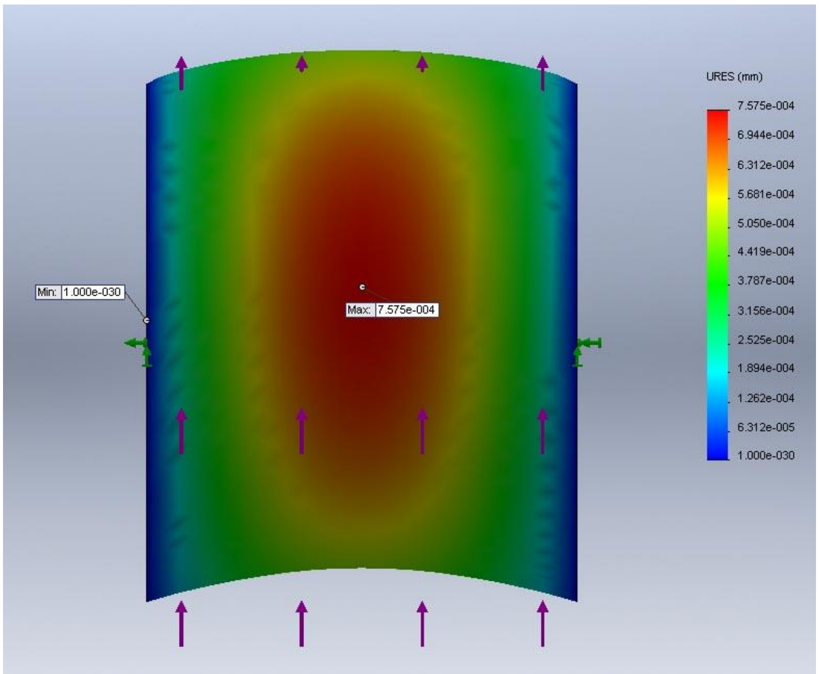


Figure 43: Displacement analysis locking bolt at 11kN

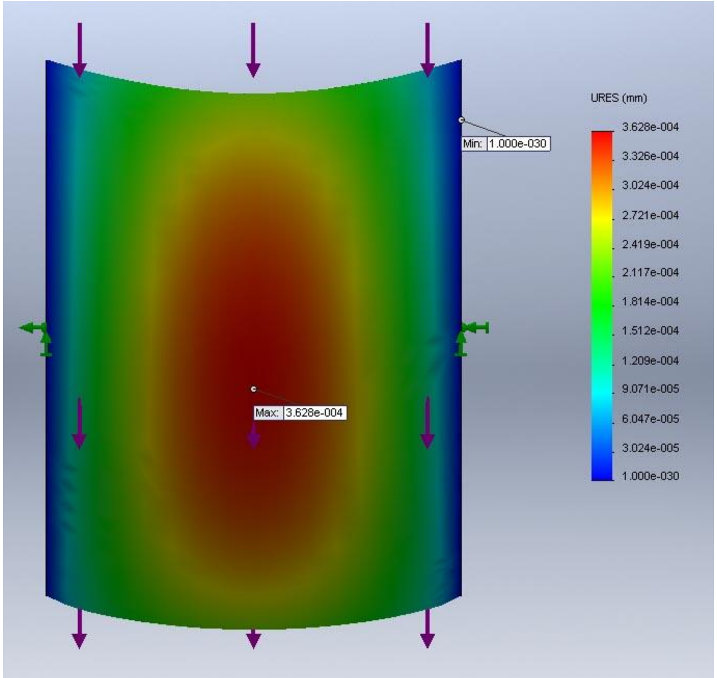


Figure 44: Displacement analysis locking bolt at 5,5kN

The displace analysis of the bolt shows a maximum displacement of 0,00075mm at the middle of the bolt. The analysis illustrates the cylinder pulling with a force of 11kN at the center of the bolt. The illustration on the left and the right hand side of the figure shows the section of the bolt, which is fixed to the lower specimen fixture. These parts is subjected to a maximum displacement of

7.15 Support legs

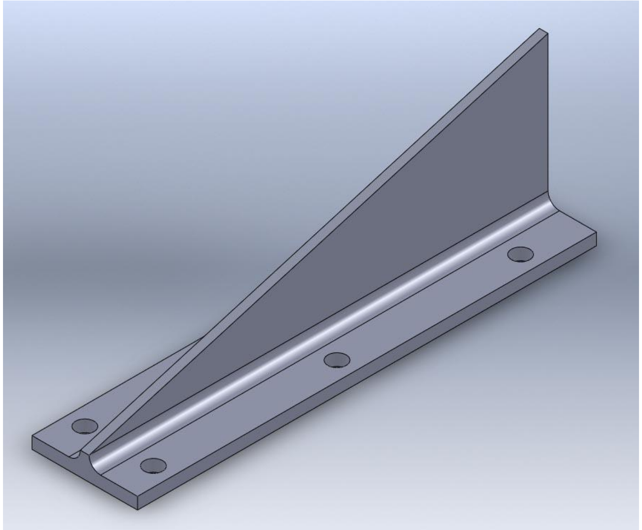


Figure 45: Support leg

The test rig has to be steady so it does not tip over during use. To ensure a rigid construction the project had to come up with a further development of the earlier support legs. The final edition of the FTR includes four bevels cut 200x46mm I- beam shaped support legs. These four support legs form a firm fastener for mounting on a flat surface.

FEM analysis

Stress

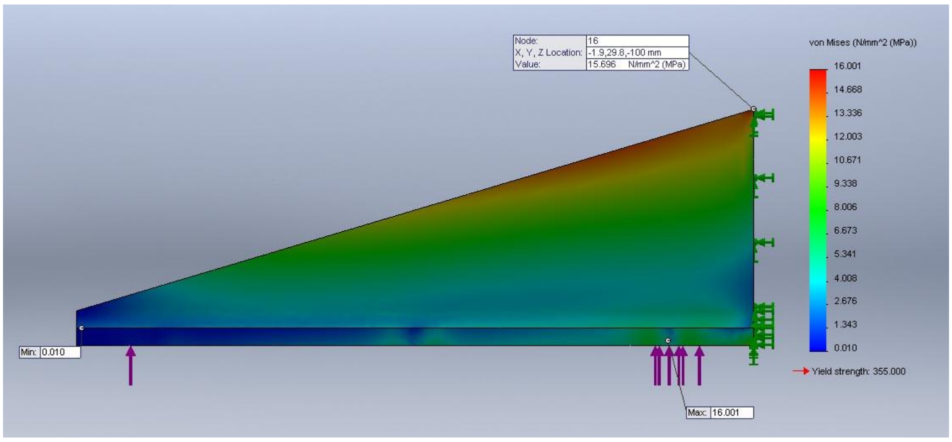


Figure 46: Stress of 0,7kN on support leg.

The stress analysis show a maximum stress of 16,0 MPa in the support leg. The analysis simulates the weight of the machine distributed on the two support legs. In the software the maximum stress occurs at one of the mounting holes. The stress concentration that occurs in the holes may be a source of error. The more realistic stress might be on the top of the leg. The stress located on the top is 15,69 MPa.

Displacement

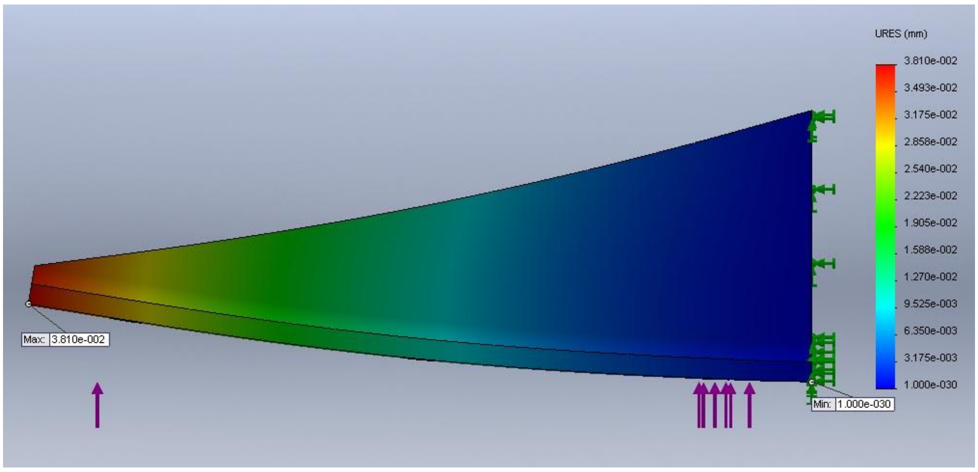


Figure 47: Support leg displacement at 0,7kN

The support leg displacement analysis show a maximum displacement of 0,0381 mm. Maximum displacement is located at the very tip of the leg.

7.16 Vibration absorption

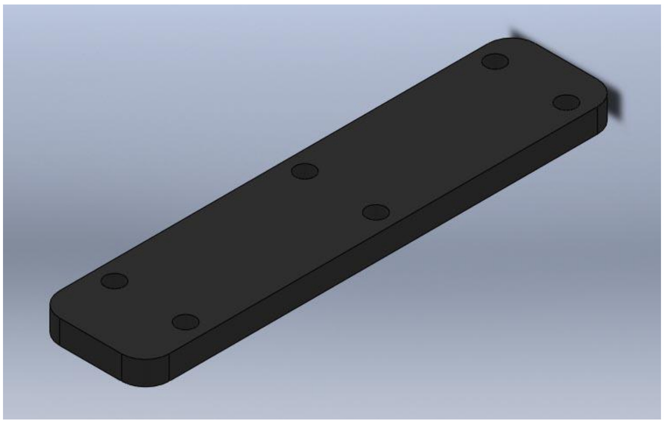


Figure 48: Rubber pad vibration damper

The vibrations that are generated from the test rig have to be reduced to a minimum. During the earlier stages of the project process the group thought of bolting the machine directly on the floor in the room where the machine is to be used. This would transfer all the machines vibrations into the surrounding structures. The might also cause problems related to resonance. After doing some research, the group came up with an idea of using a silicon rubber pad on all contact surfaces of the rig. The dimensions of the rubber pads are 205x50x10 mm.

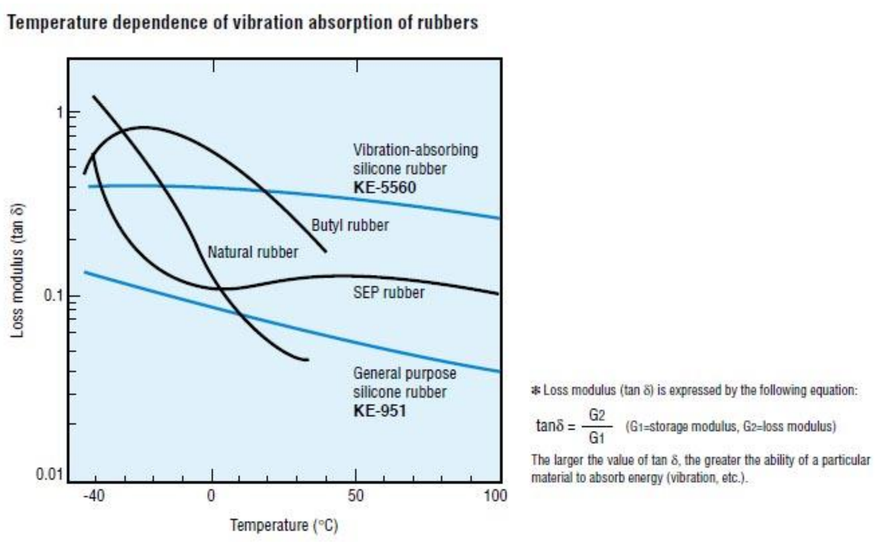


Figure 49: Vibration absorption of different rubber compounds. [7]

The ability to absorb vibrations is generally low for silicone rubber. A rubber compound with enhanced vibration absorption performance has the capability to absorb vibration consistently over a wide temperature range from -50C to +100C. [8] The group chose the use of silicone rubber rather than natural rubber due to the consistent performance of the silicone rubber.

7.17 Door

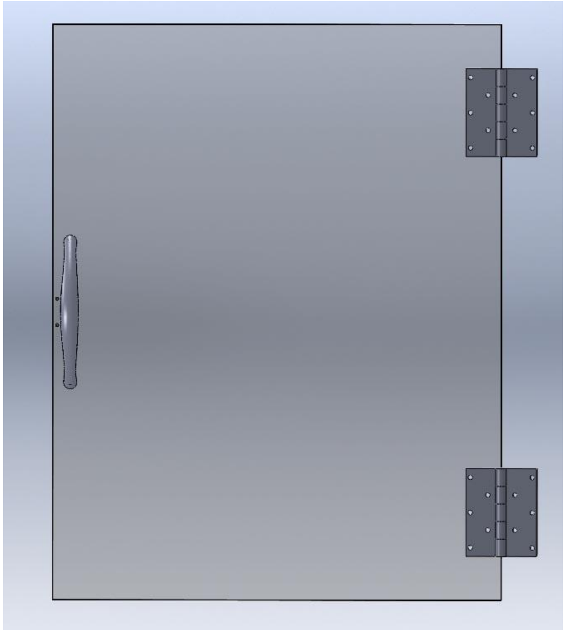


Figure 50: Door

For the rig to be as safe as possible during operation, the client set a requirement of placing all moving parts inside housing. The group decided to use PMMA as the protective screen between the user and the moving parts of the machine. The PMMA is a clear and transparent material and allows the user to inspect the process in a safe matter. The door has the dimensions of 510x655x5 (width x thickness x height). There is extruded holes (M8x1,5) to allow mounting of the door handle and (M3x0,5) for the fastening of the magnets.

Characteristics	Standard	Unit	Cast
Weight	DIN 53479	g/cm^3	1,2
Tensile strength	DIN 543455	N/mm^2	74
Impact resistance	DIN 53453	KJ/m^2	12
E-modul	DIN 53457	N/mm^2	3000
Operation temperature		C	-10/+80
Light transmission	DIN 5036	%	92

Table 3: Characteristics of PMMA [9]

7.18 Rear cover

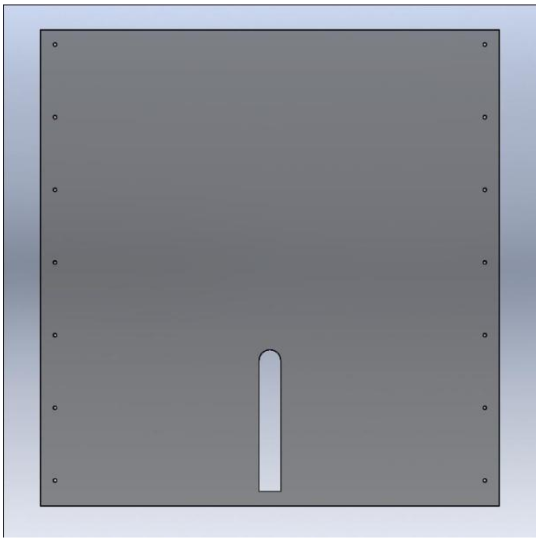


Figure 51: Rear cover

To allow the user a good overview of the process, the rear cover of the rig is made out of the same PMMA material as the door. There is extruded holes (M5x0,8) to allow attachment to the frame. In the center of the rear cover there is a cutout for the hydraulic hoses with the dimension of 30x195x5mm (width x thickness x height). The rear cover has the dimensions of 630x655x5mm (width x height x thickness).

7.19 Door magnet

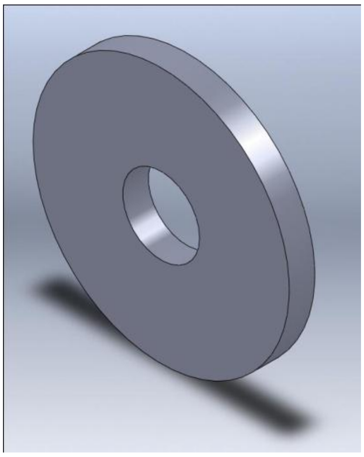


Figure 52: Door magnet

To make sure the door is held closed during the testing, the group chose the strong and powerful Neodymium magnets. The dimensions are 10x1mm (diameter x thickness).

Density	7.4-7.5 g/cm^3
Compression Strength	110 kg/mm^2
Bending Strength	25 kg/mm^2
Vickers Hardness (Hv)	560-600
Tensile Strength	7.5kg/mm^2
Young's Modulus	1.7 x 104 kg/mm^2
Recoil Permeability	1.05 μrec
Electrical Resistance (R)	160 μ-ohm-cm
Heat Capacity	350-500 J/(kg.°C)
Thermal Expansion Coefficient (0 to 100°C) parallel to magnetization direction	5.2 x 10^{-6} /°C
Thermal Expansion Coefficient (0 to 100°C) perpendicular to magnetization direction	-0.8 x 10^{-6} /°C

Table 4: Neodymium characteristics [10]

7.20 Hinges

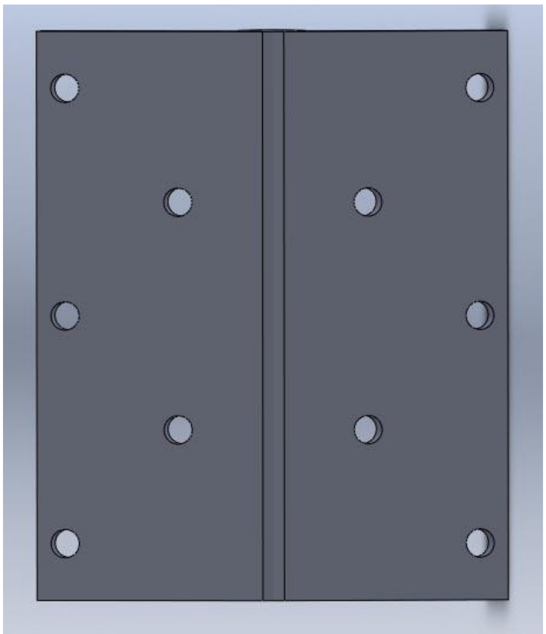


Figure 53: Hinge

The project decided to for a standard type hinge provided by Elektro importøren AS. These are cost efficient and well suited for connection to the door. The dimensions of the hinge are 100x80x5mm (length x width x thickness).

7.21 POM cover

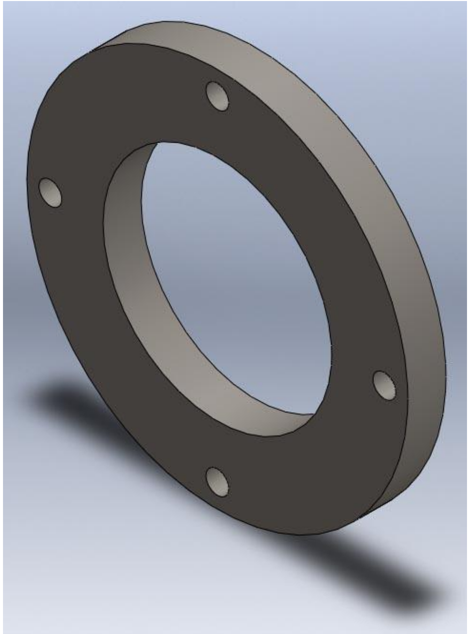


Figure 54: POM cover

The task of the cover is to make sure the POM is held in place during operation. The dimensions of the POM cover is 50x30x5mm (outer diameter x inner diameter x thickness). There are drilled four holes (M3) in the cover for mounting on the stabilizer bar.

7.22 H-beam covers

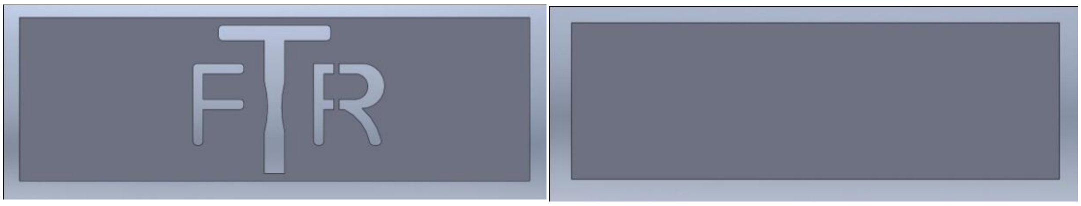


Figure 55: H-beam covers

The H-beam covers have no other task than to create a more appealing appearance to the FTR. A steel plate with an engraved logo is welded to the one side of the H-beam, while the other side has a smooth surface. The dimensions of the plates is 500x5x160mm (length x width x height).

7.23 Door handle

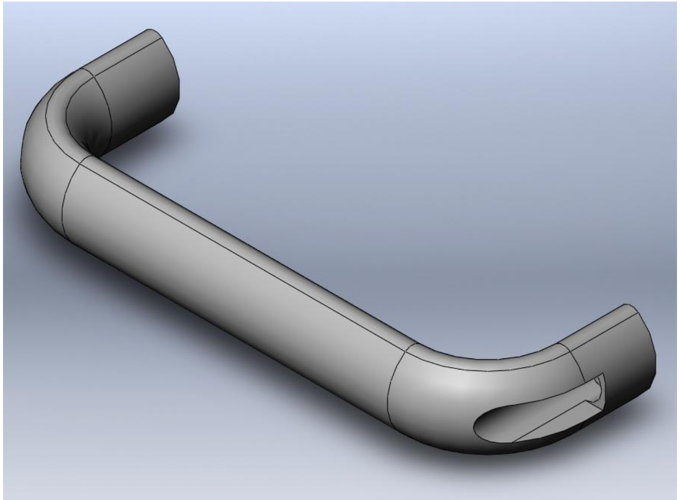


Figure 56: Door handle

The group decided to use a simple door handle provided by Erwin Halder KG. The handle has two holes (M6x1) for mounting on the door.

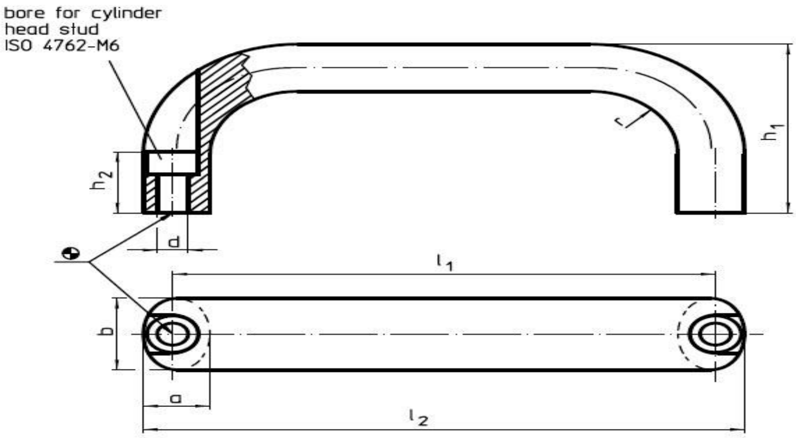


Figure 57: Dimensions of door handle [11]

Dimensions

b	l1	l2	a	d	h1	h2	r	g
26mm	164mm	178mm	17mm	6,4mm	57mm	17mm	17mm	196g

Table 5: Dimensions of handle [11]

8.0 Choice of materials

8.1 Frame

Upper frame:

The material used for the upper frame is S355J2G3 carbon steel with yield strength of 355MPa and E- module of 210GPa. [12]

Lower frame:

The material used for the frame is S355J2H carbon steel with yield strength of 355MPa and E- module of 210GPa. [12]

Channel bars:

The material used for the channel bar is hot rolled S355J2G3 steel with yield strength of 355MPa and E- module of 210GPa. [12]

Support legs

The material used for the support leg is hot rolled S355J2G3 steel with yield strength of 355MPa and E- module of 210GPa. [12]

8.2 Internal components

Test specimen:

The test specimen is made out of S355J0 steel with yield strength of 355MPa and E- module of 210GPa. [12]

Guide rods:

The guide rods are made out of S355J0 steel with yield strength of 355MPa and E- module of 210GPa. [12]

POM bushing:

The POM bushing is made out of Polyoxymethylene with a tensile strength of 65MPa and E-module of 3GPa. [13]

Upper and lower specimen fixture:

The upper and lower specimen fixture is made out of S355J0 steel with yield strength of 355MPa and E- module of 210GPa. [12]

Cylinder bracket:

The cylinder bracket is made out of S355J0 steel with yield strength of 355MPa and E-module of 210GPa. [12]

Power transfer:

The power transfer is made out of S355J0 steel with yield strength of 355MPa and E- module of 210GPa. [12]

Fastener:

The power transfer is made out of ISO 8.8 steel with yield strength of 640MPa and E- module of 210GPa.

Wedge lock:

The wedge lock is made out of S355J0 steel with yield strength of 355MPa and E- module of 210GPa. [12]

Locking bolt:

The locking bolt is made out of S355J0 steel with yield strength of 355MPa and E- module of 210GPa. [12]

Vibration absorption

The vibration absorption is made out of silicon rubber with a tensile strength of 10,5MPa [8]

Door:

The door is made out of PMMA with a tensile strength of 74MPa and E- module of 3GPa. [9]

Rear cover:

The rear cover is made out of PMMA with a tensile strength of 74MPa and E- module of 3GPa. [9]

Magnet:

The magnet is made out of Neodymium with a tensile strength of 75MPa and E- module of 1768MPa. [10]

Hinges:

The hinges are made out of R304 steel with yield strength of 290MPa and E- module of 190GPa. [14]

POM cover:

The POM covers are made out of S355J0 steel with yield strength of 355MPa and E- module of 210GPa. [12]

Front and rear H-beam cover:

The front and the rear H-beam cover are made out of S355J0 steel with yield strength of 355MPa and E- module of 210GPa. [12]

Door handle:

The door handle is made out of 1060 Aluminum with yield strength of 28MPa and E- module of 69GPa. [14]

9.0 Hydraulics

9.1 Hydraulic cylinder

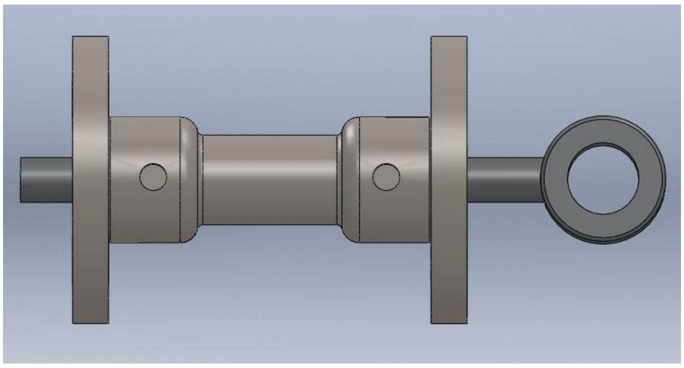


Figure 58: HM85 cylinder illustration

Name	Description
Operating pressure	max. 250 bar
Testing pressure	max. 375 bar
Hydraulic Piston Velocity	max. 0,5 m/s
Cylinder housing	St. 52-3, DIN 2393/c, Ra value max. 0,6 my
Piston rod	Hard chrome 18NV5, Ra value max. 0,3 my
Operating temperature	-30 gr. C - +100 gr. C (mineral oil)

Table 6: Technical specification HM85-FFL-GVK [15]

Hydraulics was chosen to be force supply in the rig. Hydraulic oil is hardly compressible and would lead to little deviation in the test results. The client also has good access for the use of hydraulics and this was one of the aspects in the decision.

During the project, the group considered two different options regarding the cylinder for application of the forces. Earlier in the project the use of two cylinders with single rods were applied. After discussing with an earlier tutor in hydraulics at the BUC the project came to the decision of using only one cylinder mounted in the center of the rig. The idea of using a double acting cylinder with a double rod was introduced. This would lead to a more cost efficient rig due to the need of less regulation to the system.

The double rod HM85-FFL-GVK cylinder available from Kolberg Caspary Lautom was the most suitable cylinder for the project both in cost and size. With a piston diameter of 50mm and a piston rod diameter of 25mm the cylinder is capable to deliver a force of 11 kN in either directions at 75 bar.

The highest force needed for the test will be 11 kN, which gives a maximum working pressure of:

$$\rho = \left(\frac{F}{A * 10}\right) bar = \left(\frac{11000}{14{,}7 * 10}\right) = 74{,}8 \sim 75 bar$$

Figure 59: Function of cylinder with double rod. [16]

Force calculation:

$$A = \frac{\pi * (D^2 - d^2)}{4} = \frac{\pi * (5^2 - 2{,}5^2) cm}{4} = 14{,}72 cm^2$$

$$Piston\ force: F = A * \rho * 10$$

$$F^+ = A * \rho * 10 = 14{,}72 * 75 * 10 = 11004N$$

$$F^- = A * \rho * 10 = 14{,}72 * 75 * 10 = 11004N$$

As can be seen from the calculations above, the cylinder is capable to provide the same force in both directions due to the equal area on both sides of the piston.

[16]

Hydraulic circuit for the double rod cylinder

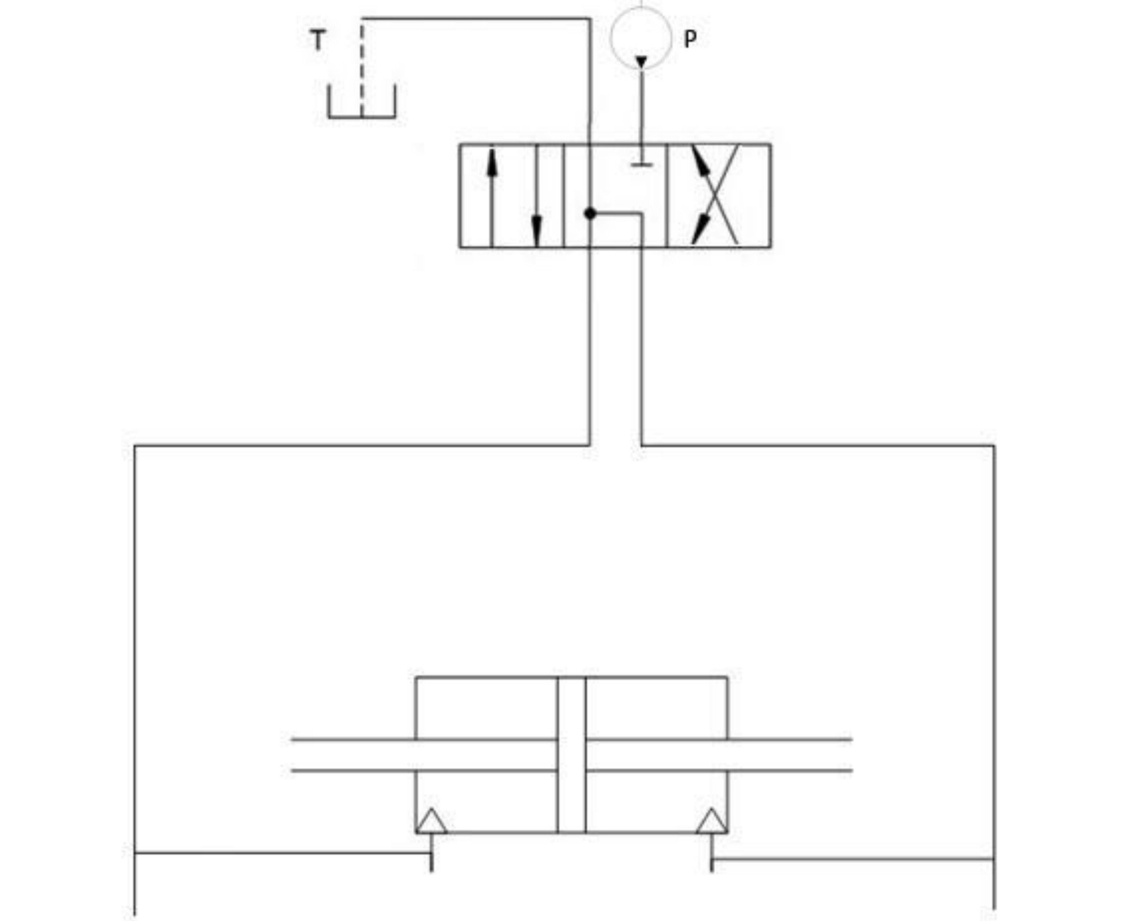


Figure 60: Hydraulic circuit drawing

The circuit above show the double rod cylinder connected with the various components of the system. The "T" symbol in the circuit illustrates the oil reservoir and the "P" shows the connection to the power source. Between the tank and the pressure source there is a 4/3 directional solenoid valve with 4 inlets and 3 positions (ref. chapter 9.2) that directs the hydraulic fluid to either side of the cylinder. When the valve is in the leftmost position, the fluid flows into the right chamber of the cylinder, pushing the piston to the left. The system is monitored by pressure transmitters that make the oil flow switch direction at a given pressure.

As can be seen on the circuit drawing, the power transfer will be equal on both sides of the piston due to the same area on both sides of the cylinder. (ref. $(Force = \frac{\rho}{A})$ [16].

9.2 Hydraulic valve

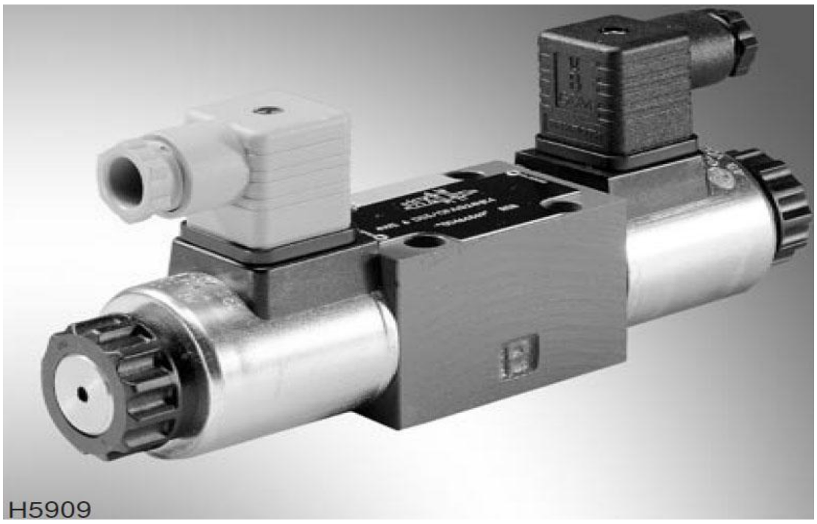


Figure 61: Bosch Rexroth 4WE 6 J6X/EG24K4 directional valve [17]

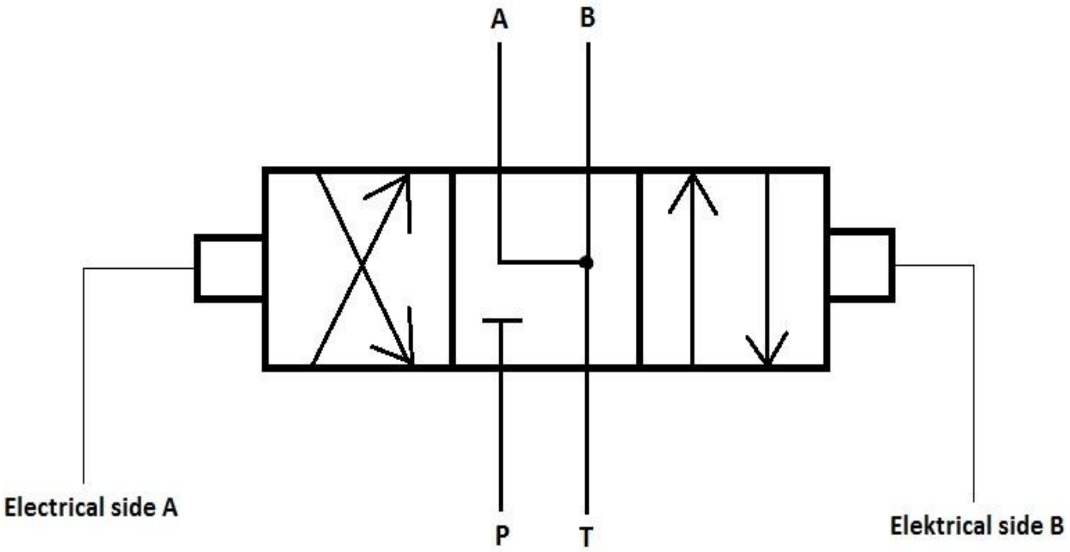


Figure 61: 4/3 valve spool

The valve is a hydraulic 4/3 valve. The valve is a directly operated directional spool valve with solenoid actuation. The valve function is to distribute and stop flow in hydraulic systems. It has two inputs and two outputs for hydraulic lines. The valve is assembled together with an ng6 Cetop sub plate. Lines A and B is to each side of the hydraulic cylinder. P is for the pressure in from the hydraulic pump and T is to the fluid reservoir. The electrical side A and B is connected to the PLC.

The magnets on each side react when they gets a signal of 230V and switch to the desired position. If the magnet spool (a) on the left of the picture gets 230V voltage it switch the slide inside to open fluid output A, and opens fluid output B when magnet spool (b) on the right side of the picture gets 230V voltage. [19] The center position is open between the lines to the cylinder and to the reservoir, which is desirable.

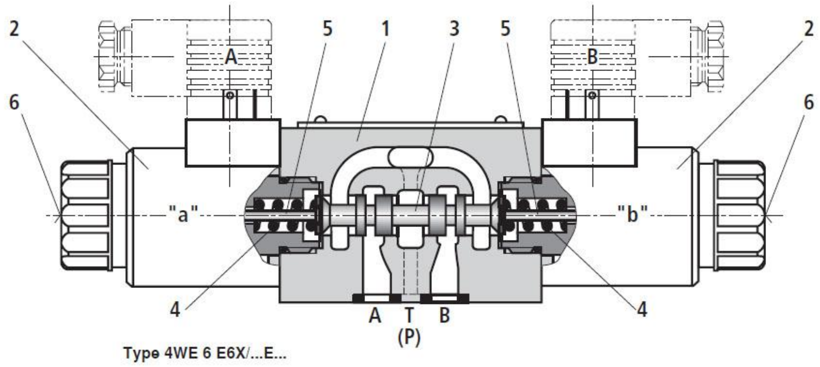


Figure 62: Internal view, Bosch Rexroth 4WE 6 J6X/EG24K4 directional valve. [17]

9.3 Sub plate

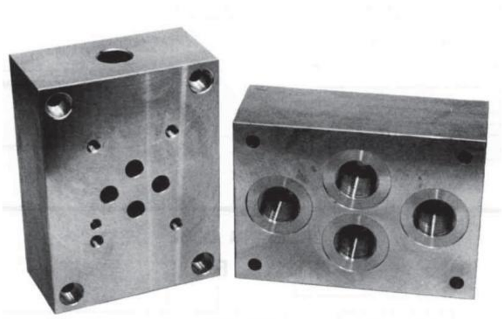


Figure 63: Sub plate for mounting of the directional valve. [18]

The sub plate is mounted on to the direct directional valve. This sub plate acts as a transition from the valve to the hydraulic pipe fittings. The side with the small holes is mounted on the valve and fittings on the hydraulic piping are mounted in the holes underneath.

10. The machine control system

10.1 Logic components

NOR-gate latch

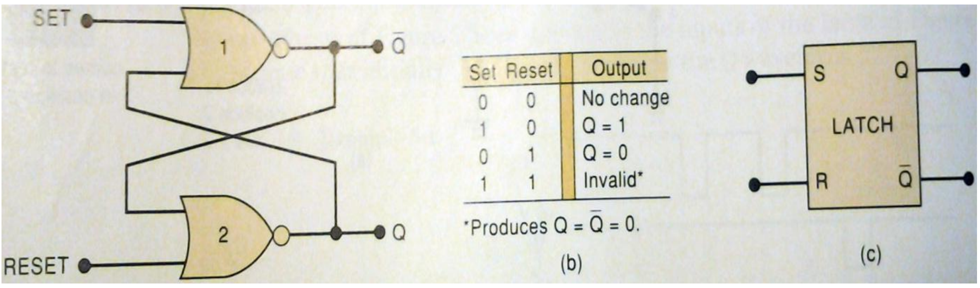
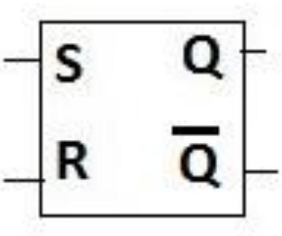


Figure 64: NOR- gate latch function [20]

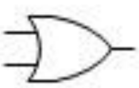


Input Output

Figure 65: NOR- gate latch

The NOR-gate latch is a SR flip flop without the clock signal, therefore the name. It is put together by two OR ports with inverted output and connections to make a function. The NOR-gate latch has as function to give a signal, after receiving a signal either in set or reset input. When the NOR-gate latch gets a signal to set, it sends out a 1 on Q output and 0 at (not) Q. When reset gets a signal the NOR-gate latch sends a signal 1 to output (not) Q and a 0 to output Q. 1 is signal, 0 is not. The concept of a "latch" circuit is important to creating memory devices. The function of such a circuit is to "latch" the value created by the input signal to the device and hold that value until some other signal changes it. [20]

OR-gate



Input Output

Figure 66: OR- gate [20]

The OR-gate is a gate which gives a signal out when either or both of the two inputs gets a signal 1. It sends forward a 1 from the output. There can be used inverts as the function becomes what is needed.

AND-gate

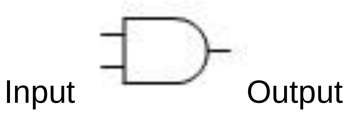


Figure 67: AND-gate [20]

The AND-gate is a gate that gives a signal out when both of the inputs has a signal 1. It sends forward a 1 from the output.

Counter

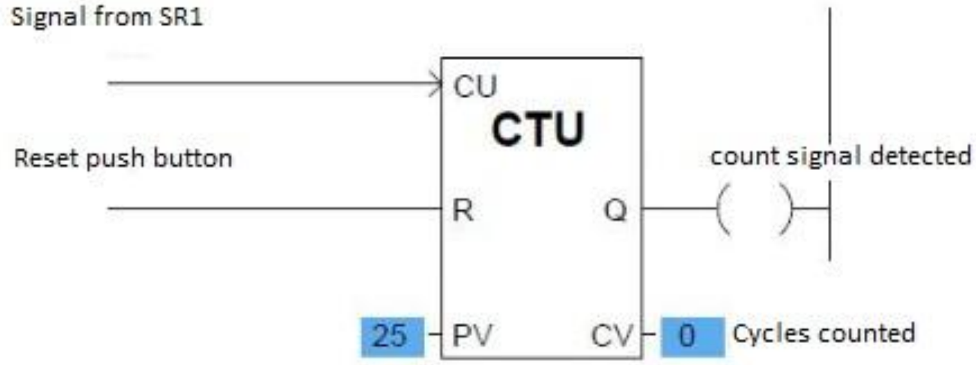


Figure 68: Counter [20] [28]

A counter in PLC is an instruction which either increment (counts up) or decrement (counts down) an integer number value when a signal in to the counter changes from 0 to 1. [28]

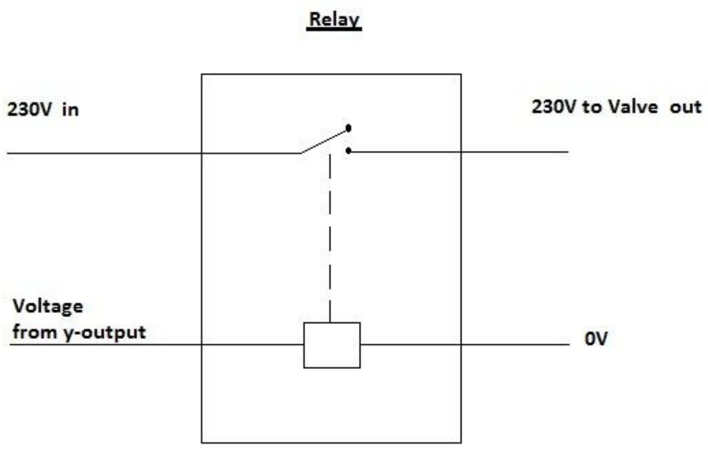
The counter used in this project is an up-counter.

The counter counts for every signal 1 into CU. The component has a memory and shows counted cycles out from CV. The counter will be reset when it gets a signal 1 from the reset button circuit. Q gives a signal that a cycle is counted. The pre set value of 25 is programmed in the counter, and works as a threshold to activate the counters output Q. When the pre set value is reached a light or similar can indicate this.

The counted cycles from CV can be programmed to be shown on the PLCs display.

10.2 Electrical components

Relay



Input Output

Figure 69: Relay [21]

A relay is a control to pass something along. In this case it passes through 230V voltage when given a signal. A relay is often used in automobile industry [20] [21] and a 4pin relay consists of two inputs, two outputs, a magnet and a switch reacting on the magnet. One circuit has a magnet and the other circuit has a switch.

An example could be the power to the horn in an automobile: When you press the horn, a signal goes to a relay, which then activates the magnet that opens for the voltage to the horn and a sound appear.

Contactor

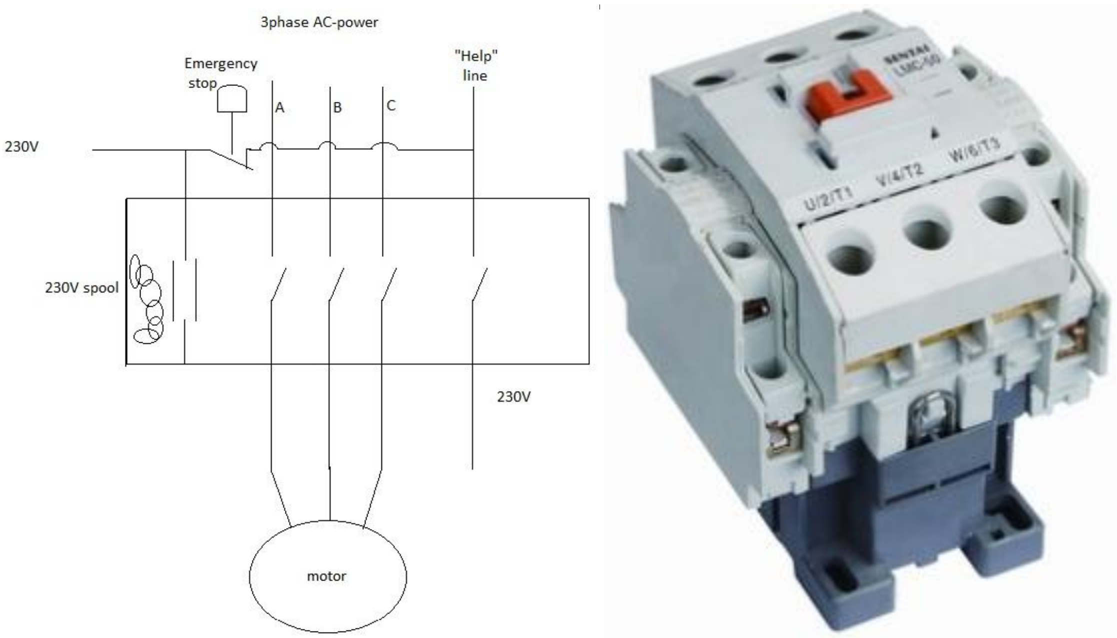


Figure 70: Contactor [22]

A contactor can be used to switch a large amount of electrical power through its contacts. The most common use of contactor is in electrical motors. [23] BUCs hydraulic pump is assumed to use this kind of contactor.

The contactor is used to supply large amount of electrical power when given a signal and this is its function. When giving a signal to the contactor, it connects the circuits and a “help” circuit connects and continues to supply signal to the magnet. When this “help” circuit is broken the circuits A, B, C gets cut off and the electrical power to the pump is breached.

Emergency stop devices

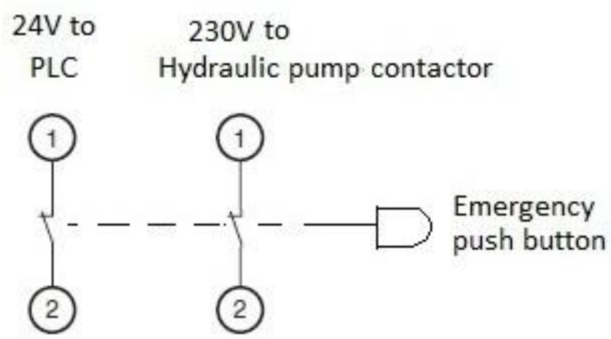


Figure 71: Emergency stop devices [25] [27]

An emergency stop switch has two circuits. The function of an emergency stop switch is to cut off any electrical power. The electrical lines will have to be connected to the desired device to stop. The switch acts when pushed.

Start button

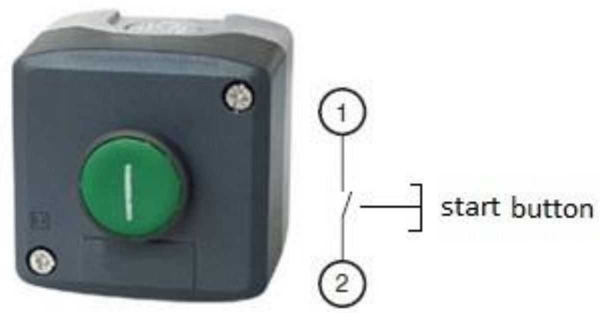


Figure 72: Start button []

The start button has one simple function. When pushed the start button connects the circuit.

Transformer

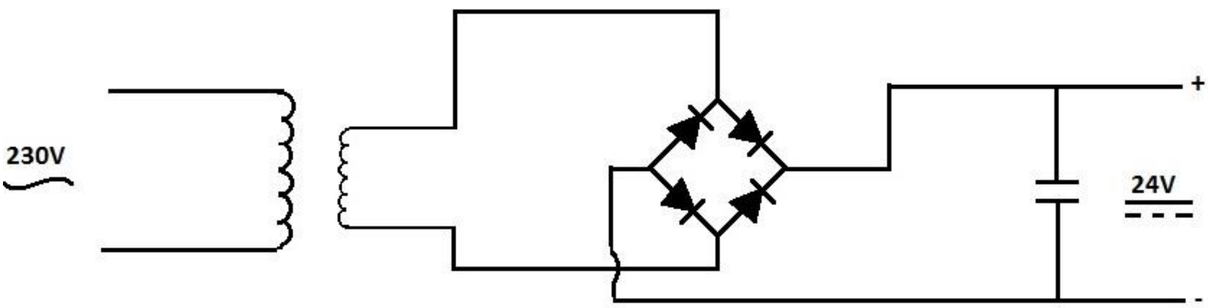


Figure 73: Transformer

The transformer for the 230V AC to 24V DC is put together by a transformer, a rectifier and a capacitor. The transformer consists of two spools that have a relation of ca 10: 1.

The transformation in a transformer is from 230V DC to 23V DC.

The spool that has 230V has 1000 windings and the spool to the right in the picture has 100 windings. To rectify the voltage, there is used a rectifier, but from the rectifier there is a pulsating DC. To even the pulses out there is used a capacitor.

Pressure switch

Figure 74: HAWE DG1 pressure switch [25]

The pressure sensor switch is a device that closes or opens electrical contacts when pressurized to a pre set value. It is usually used where electrical signal should be triggered when the set pressure is achieved or exceeded. [25] There are a lot of different types, but the easiest to use is a manometer like device, which is set by rotating the center knob.

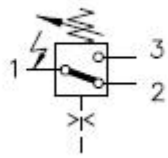
Coding Electrical connection		Operation pressure range p_{min} 2) ... p_{max} (bar)	Pressure resistant up to (bar) 3)	Symbol
Inside the device	Device socket EN 175 301-803 (ISO 4400)			
DG 1 R 4) DG 1 RF 4)	DG 1 RS 4) DG 1 R FS 4)	20 ... 600	600	

Figure 75: Pressure range of the HAWE DG1

The pressure switch can operate between 20 to 600bar, and is adequate for our use.

The pressure switch measures the pressure, and when the pre set value is achieved it gives an electrical signal into the PLC that the pressure is achieved.

10.3 Control of the rig

To control the FTR, the group started out with using only mechanical and manual equipment. The group quickly realized that to make the cylinder cycle tension and compression without an operator would be difficult. There was discussed with the client and internal supervisor, and there was made a decision to start looking for various control systems for the rig. The group decided on a mixture of both mechanical and digital control of the system. It is used switches, pressure sensors, relays counter and PLC to control the FTR. These switches, pressure sensors and relays are connected to the PLC, and the PLC is logically programmed to work in relation to these.

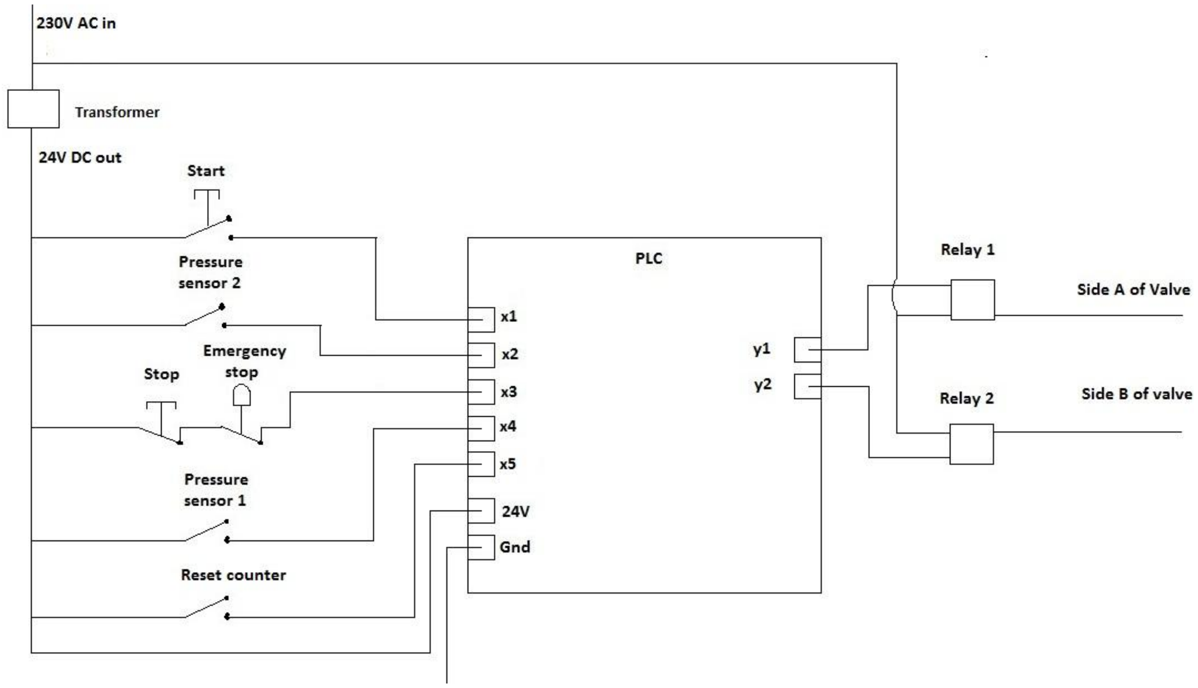


Figure 76:

How the system works outside of the PLC

When the start button is pressed, it initiates the cycling in the valve, which leads to the hydraulic cylinder. The start button gives a signal to the PLC that sends a signal to relay 1 to deliver electrical power to side A of the valve. Cycling starts when side A is initiated in the valve.

The valve, cycles between side A and B, as the pressure sensors sends signal to the PLC on a given pressure value.

When the test specimen breaks, the rope pull emergency switch will step in and cut power to the relays and hydraulic pump. The rig is now safely stopped and has no applied pressure to the system. If needed, the stop button and emergency stop button has the same function as the emergency rope pull switch.

PLC

Figure 77: Siemens 6ED1052-1FB00-0BA6 Logo! PLC

After having been in contact with both Eaton and Siemens, the project group chose to use PLC from Siemens. This controller satisfies the need of controlling the system as well as being more cost efficient than the PLC provided by Eaton. The 0BA6 PLC operates with eight inputs and four outputs.

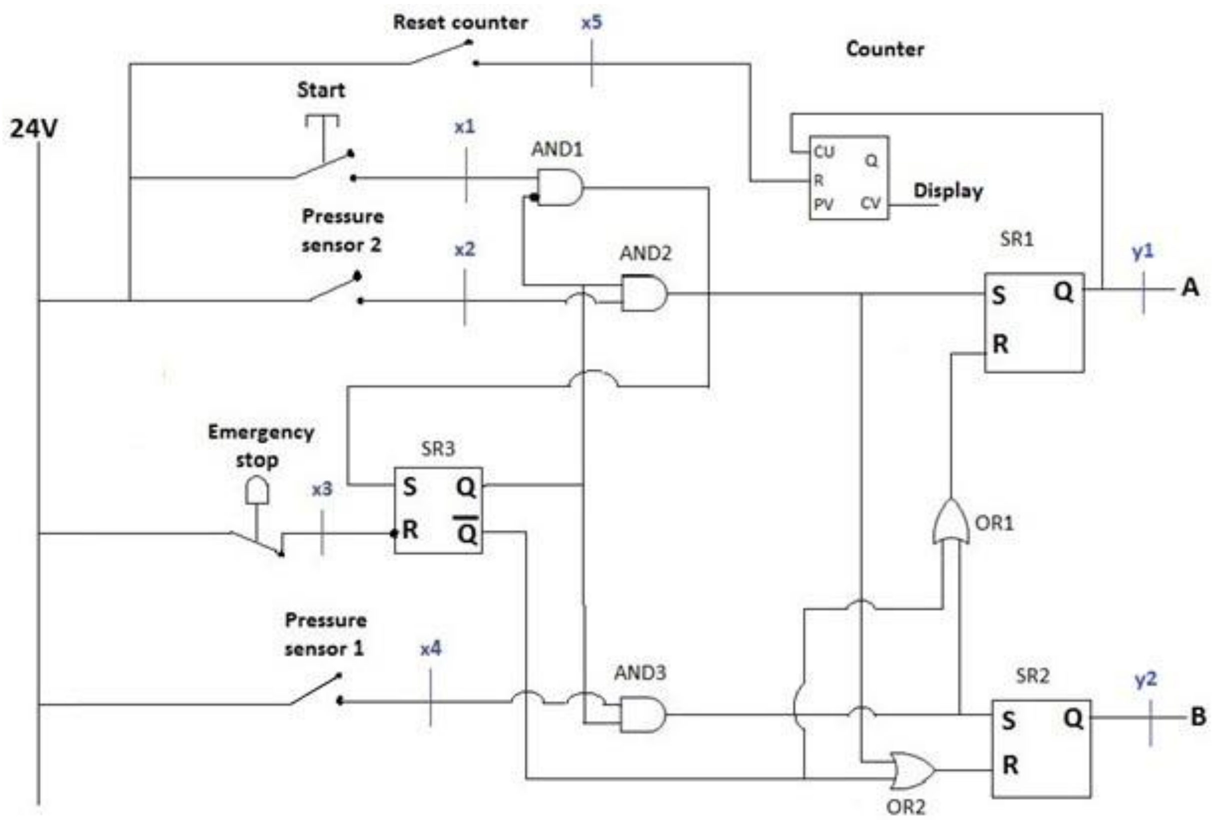


Figure 78: PLC function diagram

The PLC is mainly used as a logic circuit to control the cycles. The x1, x2 etc is inputs on the PLC from the different mechanical and manual components, and y1, y2 is outputs from the PLC to the relays that delivers electrical power to the valve. The function of the PLC is to cycle automatic between side A and B on the valve. Side A and B on the valve is different from each other, there one initiate compression from the cylinder and the other initiate tension from the cylinder.

It consists of AND-gates, OR-gates, NOR-gate latches and a counter.

How the PLC is set

When the start button outside of the PLC is pushed, the AND1 gets signal 1. The Q from SR3 is 0 and since it is inverted in to the AND1 gate, AND1 gives a signal 1 ahead to set on SR1, reset on SR2 and set on SR3. SR3 now gives signal 1 to AND2 and 3 so these are ready to run as fast they get another needed signal. When this is done the cycle for compression has begun.

Gate Q on SR1 gives signal 1 to the relay to side A on valve. When the pressure sensor1 has reached its configured value it gives signal 1 to the AND3 gate and the AND3 gate sets SR2 while it resets SR1. The OR1 and 2 is there to secure that none of the SR(NOR-gate latches) resets the other. Now the side B of the valve is initiated and the tension part of the cycle has begun.

When the pressure sensor 2 reaches its configured value it sends signal 1 to AND2 gate. AND2 then have both the needed signals to send signal 1 to set on SR1 and goes through the OR2 gate to reset SR2. The compression part of the cycle starts again.

This is what happens inside the PLC until either the test specimen breaks or the operator press emergency stop.

When one of the stop devices is pushed it breaks the circuit to the SR3 gate. Since R is inverted the reset is initiated on SR3 and signal 1 is sent out from Q-not to OR-gate 1 and 2. The OR-gates now resets both SR1 and SR2 and the cycling stops. It stops because without a signal to one of the sides on the valve, the valve is center positioned and no pressure goes to the hydraulic cylinder.

All of the stop devices are also connected to the contactor which controls the electrical power of the hydraulic pump. The stop devices break the circuit in the contactor and break the electrical power to the hydraulic pump.

The counter gets signal 1 from Q on SR1 in to CU on the counter. CV (the counted cycles) on the counter is shown on the display. To reset the counter to start counting from 0 press the reset button.

11.0 Price estimate

Priceestimate

Priceestimate w/ parts from BUC

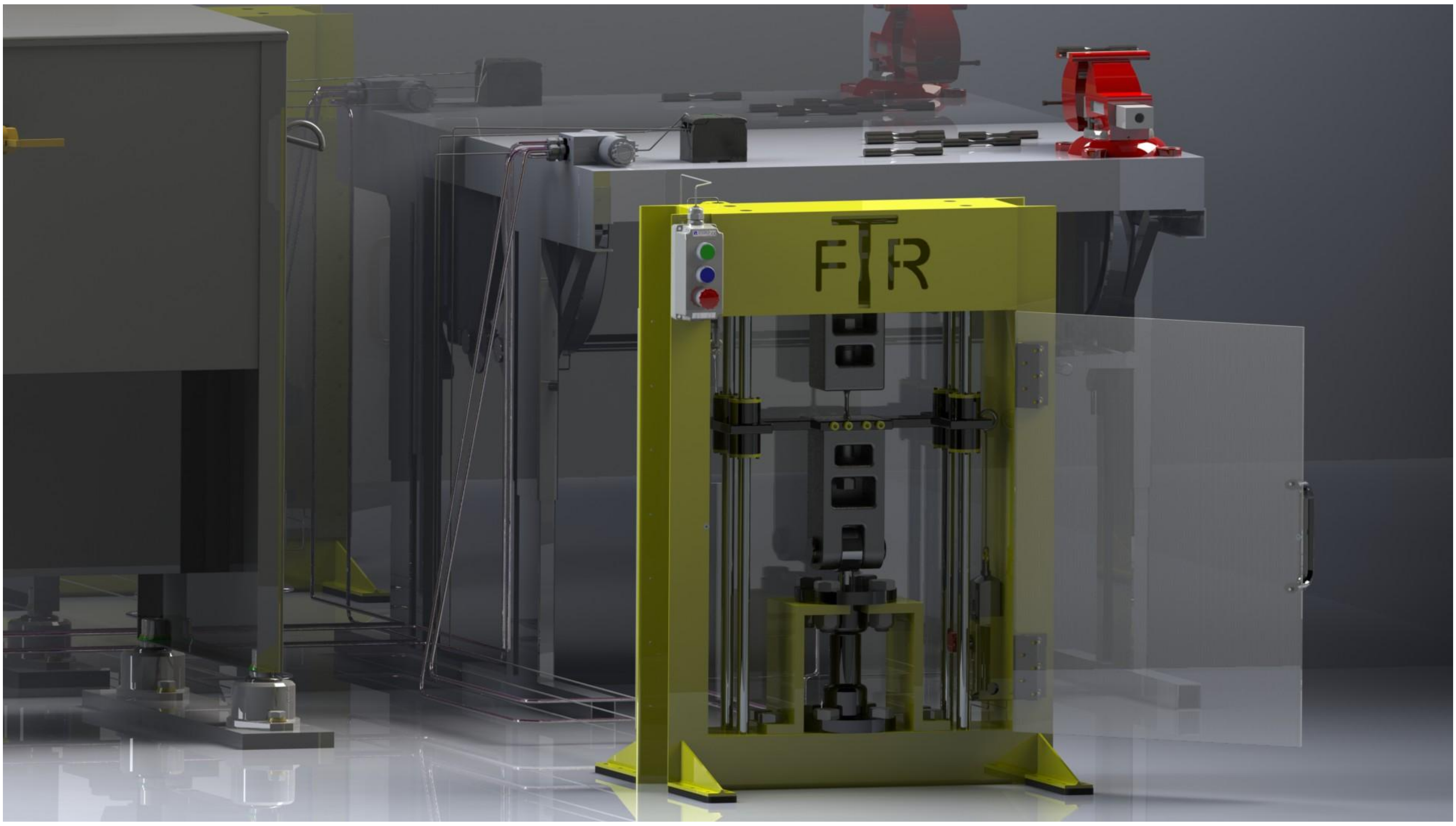
Post	Description	Qty.	Cost per item	Unit	Total
1.0	HE160B (S355J0) upper frame	1	300	Cutting:	300
2.0	Channel Bar, side frame	2	300		600
3.0	Cylindrical guiderods, availible from BUC	4,8	0	m	0
4.0	Cylinder bracket	4	100		400
5.0	Squarebeam lower frame (S355J0) 160X80X10 MM	1	300	Cutting:	300
6.0	Power transfer		1	kg	23
7.0	Doubleacting Cylinder (HM85-FFL-GV-K)	1	2500	pc	2500
8.0	Fixture bolt		10	pcs	20
9.0	Upper specimenfixture (S355J0) 0,1m3	7,8	30	kg	234
10.0	Wedges	1	5	kg	10
11.0	Lower specimenfixture (S355J0)	9	30	kg	270
12.0	Stud bolt	1	30	kg	30
13.0	Hydraulic hoses	4		m	0
14.0	Vibration absorption	4	75	pcs	300
15.0	OlsenDirectional valve	1		pc	0
16.0	Plexiglass front	1	200	pc	200
18.0	Plexiglass rear	1	200	pc	200
19.0	Gliding bushings POM	4	70	m	280
20.0	POM cover	8	8	kg	64
21.0	Support legs	4	100	Cutting:	400
22.0	Magnet	1	40	pc	40
23.0	Testspecimen	10	8,33	pcs	83,3
24.0	Hinges	2	50	pcs	100
25.0	Counter Dayton 6X596	1	750	pc	750
26.0	Steel plate	1	69	kg	69
27.0	Emergency stop Rope Pull Switch	2	2000	pc	4000
28.0	Steel plate with logo	1	64	kg	64
29.0	Door handle	1	50	pc	50
30.0	PLC	1	3207	pc	3207
31.0	Relay	1	100	pc	200
32.0	Emergency button	1	50	pc	964
33.0	Reset button	1	50	pc	50
34.0	Startbutton	1	50	pc	25
35.0	Transformer	1	400	pc	400
36.0	Pressure switch	2	1700	pc	3400
37.0	Bolts M24 hex bolt	12	12	pc	144
38.0	Bolts M5 unbrako	24		pcs	100
39.0	Bolts M3 unbrako	32		pcs	50
40.0	Bolts M8 unbrako	8		pcs	3
41.0	Sub plate to hydraulic valve	1	832		832
	Total ex. vat				20662,3
	Vat				25 %
	Total inc. vat				25827,88 ,-

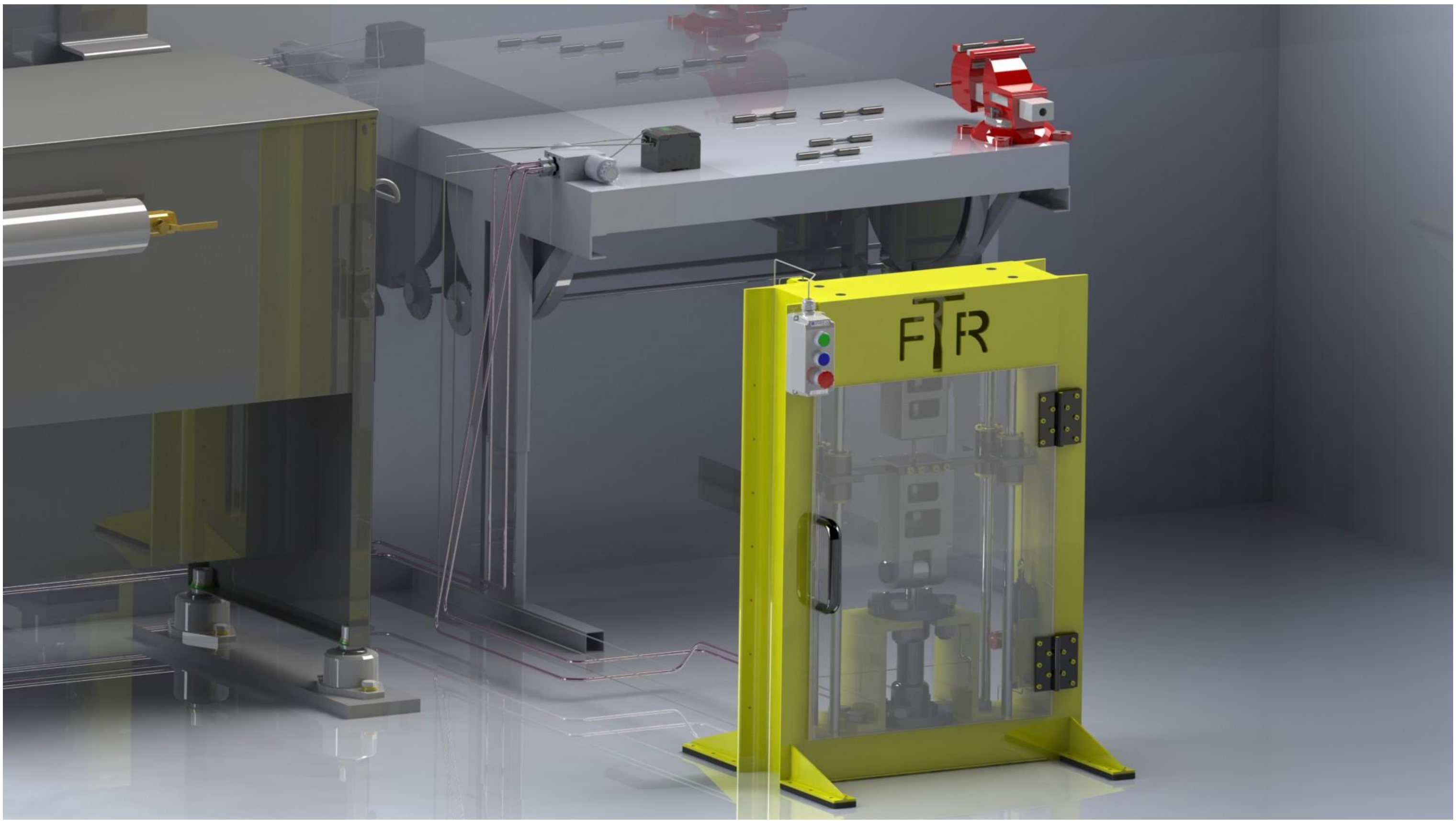
Figure 79: Price estimate with components available from BUC.

	Priceestimate				
	Priceestimate without parts from BUC				
Post	Description	Qty.	Cost per item	Unit	Total
1.0	HE160B (S355J0) upper frame	1	300	Cuttings	300
2.0	Channel Bar, side frame	2	300		600
3.0	Cylindrical guiderods, availible from BUC	4,8	37	m	200
4.0	Cylinder bracket	4	100		400
5.0	Squarebeam lower frame (S355J0) 160X80X10 MM	1	300	Cuttings	300
6.0	Power transfer		1	kg	23
7.0	Doubleacting Cylinder (HM85-FFL-GV-K)	1	2500	pc	2500
8.0	Fixture bolt		10	pcs	20
9.0	Upper specimenfixture (S355J0) 0,1m3	7,8	30	kg	234
10.0	Wedges	1	5	kg	10
11.0	Lower specimenfixture (S355J0)	9	30	kg	270
12.0	Stud bolt	1	30	kg	30
13.0	Hydraulic hoses	4	161	m	644
14.0	Vibration absorption	4	75	pcs	300
15.0	Bosch Rexroth 4WE 6 J6X/EG24K4 directional valve	1	3000	pc	3000
16.0	Plexiglass front	1	200	pc	200
18.0	Plexiglass rear	1	200	pc	200
19.0	Gliding bushings POM	4	70	m	280
20.0	POM cover	8	8	kg	64
21.0	Support legs	4	100	Cuttings	400
22.0	Magnet	1	40	pc	40
23.0	Testspecimen	10	8,33	pcs	83,3
24.0	Hinges	2	50	pcs	100
25.0	Counter Dayton 6X596	1	750	pc	750
26.0	Steel plate	1	69	kg	69
27.0	Emergency stop Rope Pull Switch	2	2000	pc	4000
28.0	Steel plate with logo	1	64	kg	64
29.0	Door handle	1	50	pc	50
30.0	PLC	1	3207	pc	3207
31.0	Relay	1	100	pc	200
32.0	Emergency button	1	50	pc	964
33.0	Reset button	1	50	pc	50
34.0	Startbutton	1	50	pc	25
35.0	Transformer	1	400	pc	400
36.0	Pressure switch	2	1700	pc	3400
37.0	Bolts M24 hex bolt	12	12	pc	144
38.0	Bolts M5 unbrako	24		pcs	100
39.0	Bolts M3 unbrako	32		pcs	50
40.0	Bolts M8 unbrako	8		pcs	3
41.0	Sub plate to hydraulic valve	1	832		832
	Total ex. vat				24506,3
	Vat				25 %
	Total inc. vat				30632,88

Figure 80: Price estimate without components available from BUC.

12.0 The FTR ready for operation





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HØGSKOLEN i Buskerud

Department of Technology

Kongsberg

Title of document: **Test report version 1.0**
Course (code/name) SFHO3200 - H11 - Hovedoppgave med prosjektstyring
Group members: Espen Sætre Kolberg Kjetil Haugmoen Kjøndal
Internal Supervisor: Jamal Safi
Date: 29.05.12
We confirm that the submitted assignment is entirely our work **Espen Kolberg** **Kjetil Kjøndal**

Table of Contents

1.0 Document history

Date	Version	Changes
07.05.2012	0.1	Document startup
29.05.2012	1.0	Tests T4, T10 and T28 are added. Finalized document

Table 1: Document history

Test report for T4

2.0 Introduction

The purpose of the test is to check if the force is axially applied on the test specimen. This is checked because if the force is not axially applied, the test result will deviate from what results that actually is wanted.

3.0 Abbreviations

SW – Solidworks

4.0 Limitations

The possibility of testing this will reduce since there is not produced and assembled a physical test rig, and the testing will only be done with the use of SW

5.0 Execution of test

5.1 What is tested?

The test is executed 07.05.2012 at the advanced hydraulic lab at BUC.

This test requirement is going to be tested with the use of SW, to check for deviations according to each other in the design and to ensure that all components are lined up axially accordingly to each other. According to the requirement, the deviation axially between the test fixtures and the cylinder piston should be 0mm and 0 degrees apart.

6.0 Test results

The picture shows that the lines drawn to check for deviations are horizontal. This means that there are no deviation in the dimension and no deviation in the angle between upper and lower test fixture.

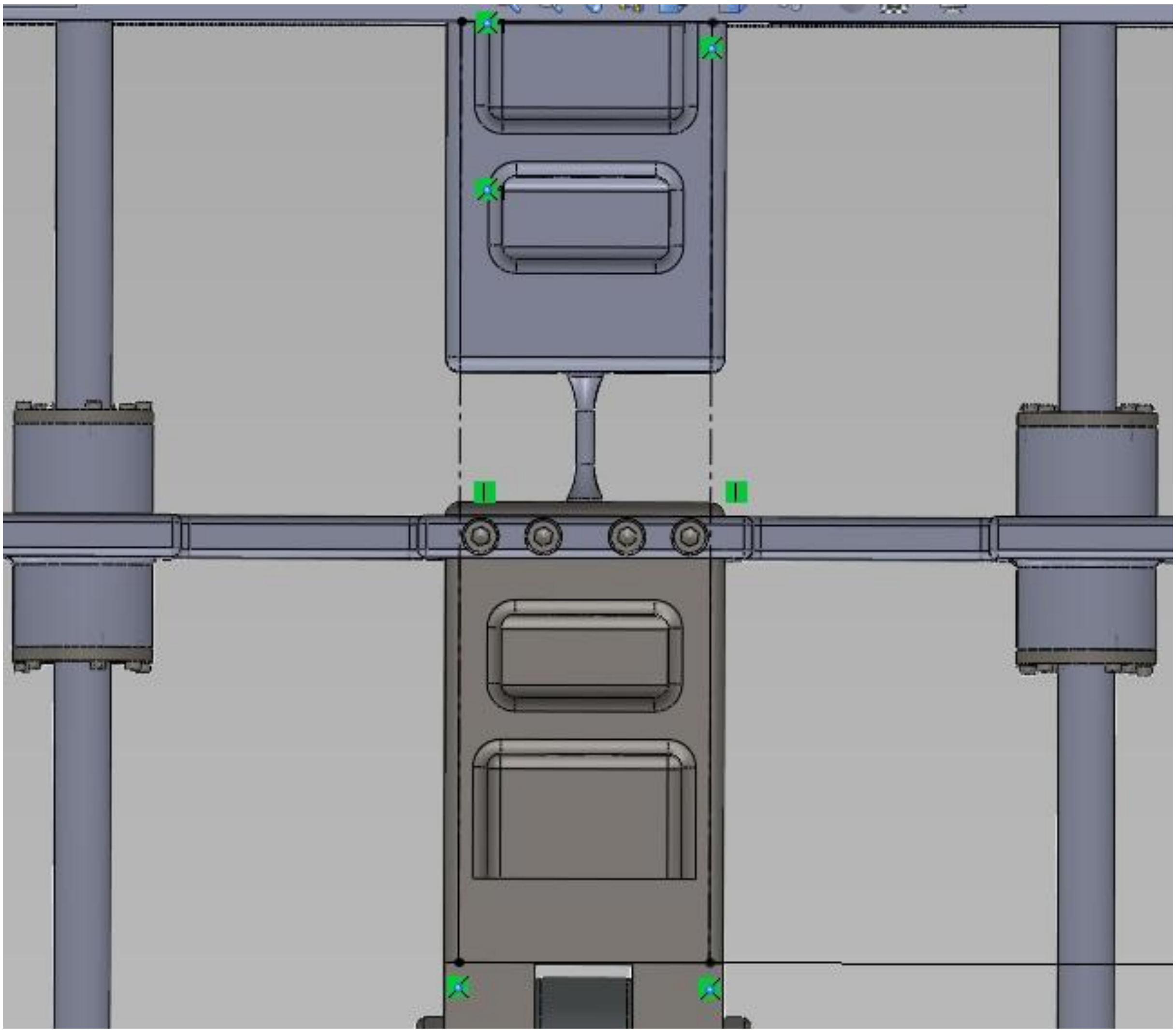


Figure 1: lineup of the specimen fixtures

To show the exact dimension to support the results, there is a horizontal line (over dimensioned to show the symmetry of both sides) which shows that the two test fixtures, both front and side is lined up axially and with 0mm and 0degrees.

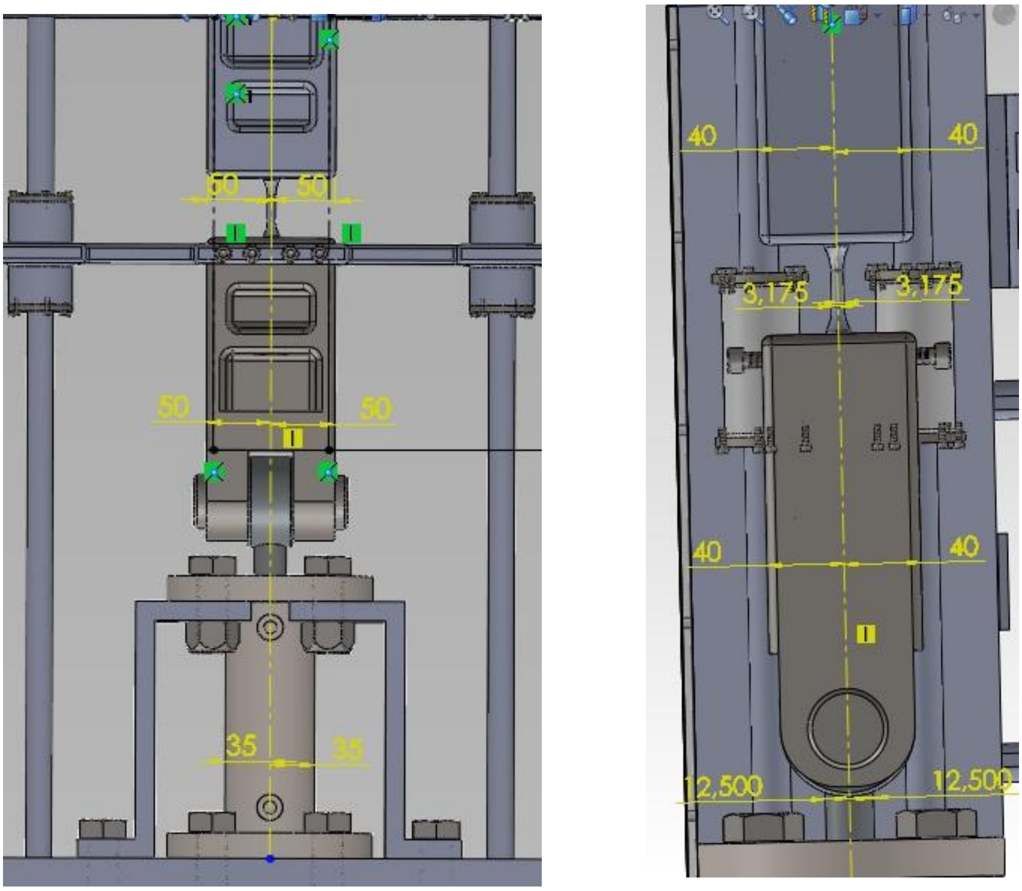


Figure 2: Lineup of the test rig from the front and side.

6.1 Critical failures

No critical failures, which can hurt the end product, are recognized under the testing.

6.2 Roles

Kjetil Haugmoen Kjøndal - Responsible for the test

Espen Sætre Kolberg - Responsible for execution of test

6.3 Equipment

The test is done on the computer and with the use of Solidworks

6.4 Evaluation

The test is executed easily, but not on a physical machine. It shows that every component is in line and should apply the load axially on the components. Since the physical machine not is produced, we have to rely on measuring in solidworks.

Based on this, the test is approved. But when the physical machine is up and running, there should be made another physical measure test to ensure that every component is according to drawings and matches.

Test report for T10

7.0Introduction

This test will be taken to ensure that the floor where the machine is located will be resistant to the load of the machine. If the load from the machine is too large relative to the floor's capacity, this would be a risk factor.

8.0 Abbreviations

SW	-SolidWorks
qk	-Uniform distributed load

9.0 Limitations

The exact floor construction in the lab where the machine is located is not known.

10.0 Execution of the test

10.1 What is tested?

This test looks at T10 from the test specification. It is a requirement that the machine's weight does not exceed the floor load capacity / 2. The implementation of this test relies on checking if the machine's weight exceeds the allowable floor load capacity.

11.1 Test results

The machine weight is calculated using the SW to find the machine's volume. Then this is multiplied by the material's density. This is compared with the floor's carrying capacity that is obtained from NS-EN 1991-1-1:2002/NA:2008. The hydraulic lab at BUC runs under the category C1 after the standard which has a load capacity of 3,0 kN per m^2 and a concentrated load capacity of 4.0 kN. The floor in the lab has an area of 30 m^2 and will handle a total load of 9 tons. The FTR has a weight of 130kg and is well within the loading capacity of the floor.

11.1 Critical failures

No critical failures were discovered in the test.

11.2 Roles

Kjetil Haugmoen Kjøndal	-	Responsible for the test
Espen Sætre Kolberg	-	Responsible for execution of test

11.3 Equipment

- Solidworks
- Standard NS-EN 1991-1-1:2002/NA:2008

11.4 Evaluation

The objective of this test was to check if the Fatigue Test Rigs weight was higher than the allowable load capacity. Since the concentrated load capacity is 4kN and the test rigs weight is 130kg the test is satisfactory.

The test was successful and the test rig can safely be used in the workshop intended at the University.

Test report for T28

12.0 Introduction

The purpose of this test is to check if the deflection in the frame is less than 0.5mm. If the Deflection exceeds 0.5mm the test has failed. The frame needs to be stiff and, it deflection is not wanted.

13.0 Abbreviations

SW - SolidWorks

kN - kilo Newton

14.0 Limitations

The possibility of testing this will reduce since there is not produced and assembled a physical test rig, and the testing will only be done with the use of FEM analysis.

15.0 Execution of the test

15.1 What is tested?

Test T28 from the test specification is tested. It is checked if the deflection in the frame of the Fatigue Test Rig is less than 0.5mm

16.0 Test results

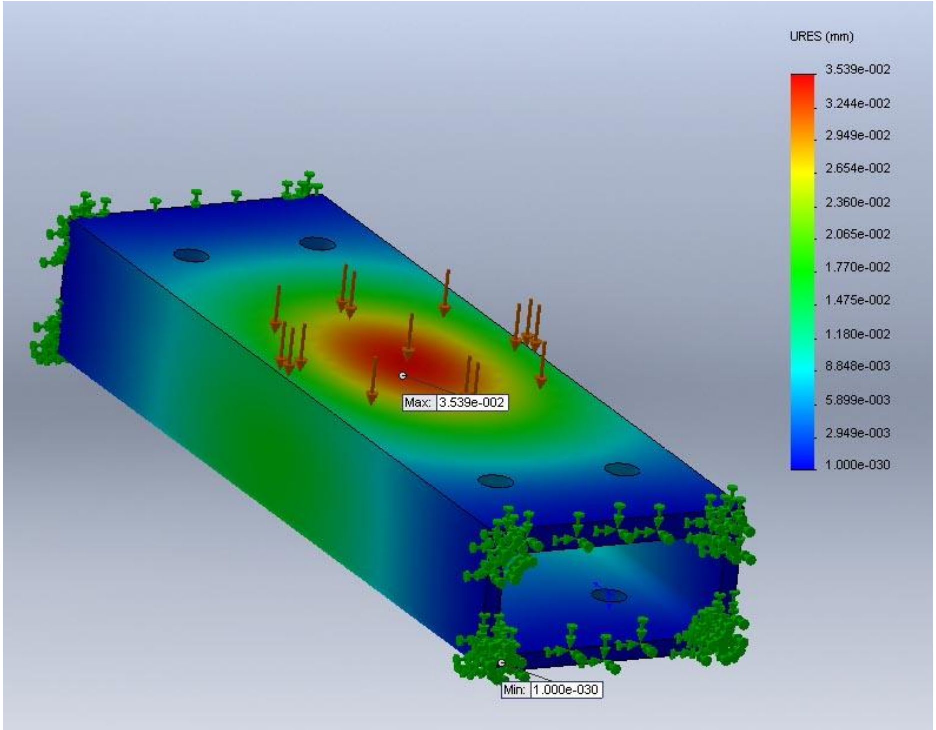


Figure 1: FEM analysis of the deflection in the rectangular beam

The testing of the rectangular beam in figure 1 shows a deflection of 0.035mm when being exposed to 11kN at the centre of the beam, simulating the cylinder in use.

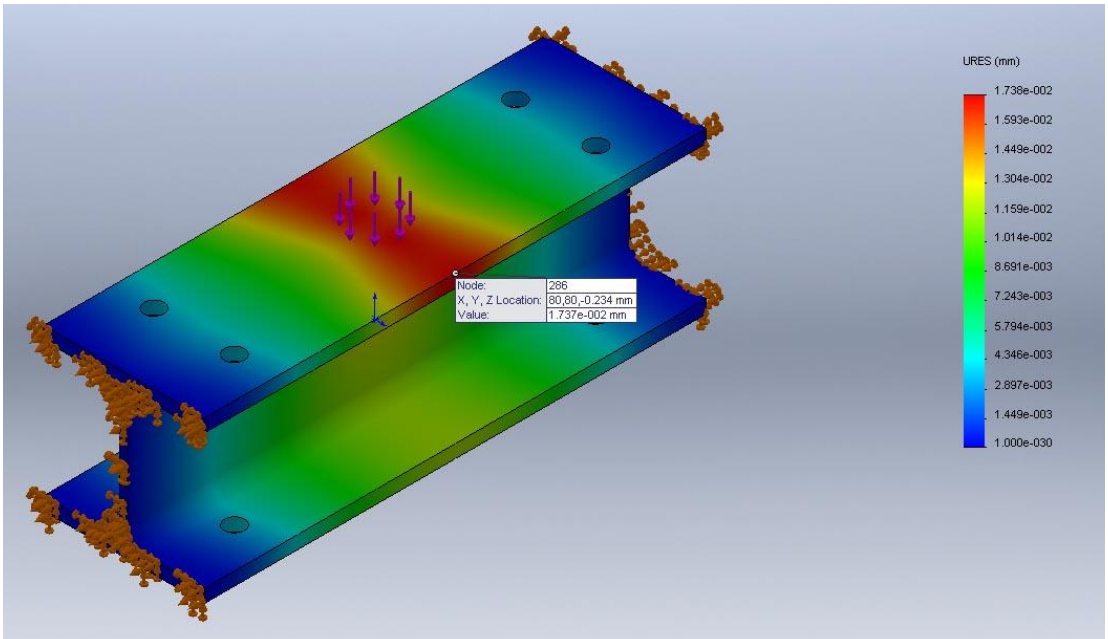


Figure 2: FEM analysis of the deflection in the H-beam

The testing of the H-beam in figure 2 shows a deflection of 0.017mm when being exposed to 11kN at the centre of the beam, simulating the cylinder in use.

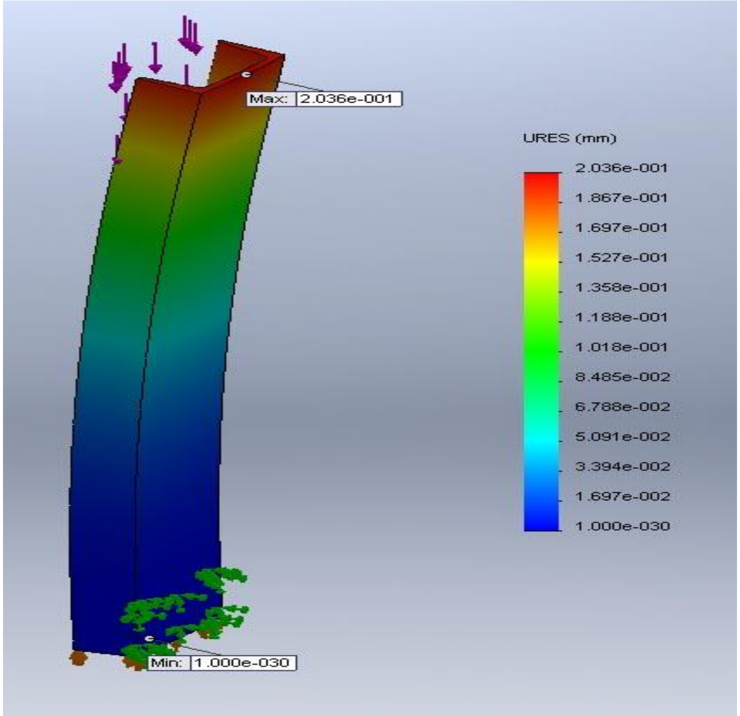


Figure 3: FEM analysis of the deflection in the channel bar

The testing of the channel bar in figure 3 shows a deflection of 0.2mm when being exposed to 5,5kN at the top of the beam, simulating the cylinder in use.

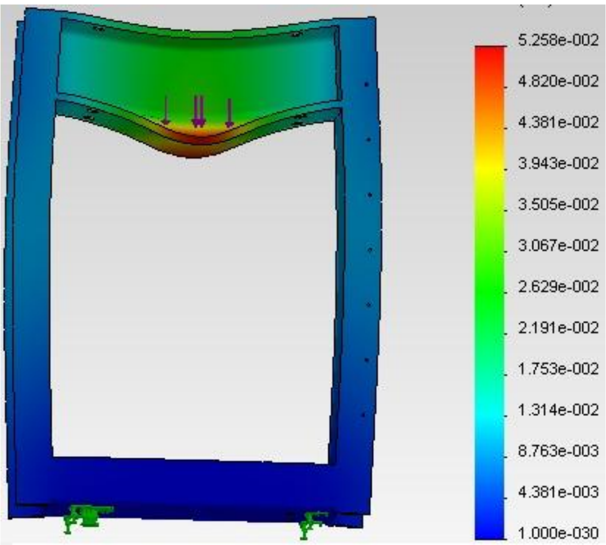


Figure 4: FEM analysis of the deflection in the frame assembled together

The testing of the frame assembled together shows a deflection of 0.05258mm when being exposed to 11kN at the centre of the h-beam, simulating the cylinder in use.

17.0 Critical failures

No critical failures were discovered in the test.

17.1 Roles

Kjetil Haugmoen Kjøndal - Responsible for the test

Espen Sætre Kolberg - Responsible for execution of test

17.2 Equipment

- Solidworks
- Finite Element Method

17.3 Evaluation

The objective of this test was to check if the deflection in the frame would be less than 05mm. The tests show that every frame component has a deflection of less than 0.5mm. The test shows that when the frame is assembled the deflection is less than 0.5mm.

Since all frame tests show a deflection of less than 0.5mm the test is satisfactory. The test was successful.

HØGSKOLEN
i Buskerud

Department of Technology
Kongsberg

Title of document: **User manual, Version 1.0**
Course (code/name) SFHO3200 - H11 - Hovedoppgave med prosjektstyring
Group Members: Espen Sætre Kolberg Kjetil Haugmoen Kjøndal
Internal Supervisor: Jamal Safi
Date: 29.05.2012
We confirm that the submitted assignment is entirely our work   **Espen Kolberg** **Kjetil Kjøndal**

1.0 Document history

Version	Date	Changes
1.0	29.05.2012	The user manual is written and done spell check. Finalized document

Table 1: Document history

2.0 Important information

This documents intention is to describe the procedure to successfully run a test. It easily explains in steps what to do. The test personnel do not have to be a qualified tester, and a regular engineer student should be able to use the rig with no problems.

Please read this manual carefully and completely before using the Fatigue Test Rig for the first time. The manual contains a great deal of information and advises which can help with the use of the rig.

Only by doing so will teach you how to use the Fatigue Test Rig in a safely manner.

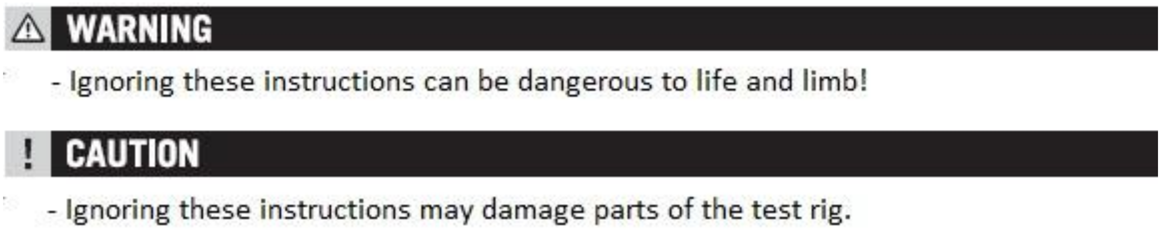


Figure 1: Warning and caution

This manual is an important part of the Fatigue Test Rig and should be passed on to any subsequent owner if the test rig is sold or given away.

2.1 Intended Purpose

The intended use of the Fatigue Test Rig is to safely and reliable do a fatigue test on a test specimens of steel and aluminum with yield strength from 0 – 355MPa. The Fatigue Test Rig is an instrument to find the fatigue strength of different aluminum and steel types.

2.3 Spare parts

To safely replace parts, make sure to order from the part list in this document. Any other products may affect the reliability and results of the test rig.

When replacing parts, the guide rods are needed to be taken out; when this is done most of the parts should be able to be replaced with some disassembling.

2.4 Transport

When transporting the test rig, make sure the door on the rig is closed and that the test rig is disassembled from the hydraulic pipes. To run the test rig away from the intended work space, make sure to bring the control system and ensure that the new work space has a hydraulic pump to provide hydraulic fluid to apply pressure. Make sure to transport the rig on the support legs to avoid unnecessary damage.

2.5 Maintenance

To make sure the test rigs lifetime is as long as possible, make sure to be carefully on the maintenance. The POM between the stabilizer bar and the cylindrical guide rods need to be lubricated every fifth time the test rig is in use.

When assembling the test rig, make sure to lubricate the bolts to avoid thread galling.

The cylinder is self lubricated by the hydraulic fluid going through it and does not require lubrication.

2.5 Environment

The test rig needs to be placed on a standard workshop floor with floor load capacity of minimum 3kN/m^2. There is needed a hydraulic pump at the workshop the rig is used. The temperature in the workshop should be between 5-30degrees to run the test rig without any problems.

Enjoy the use of your Fatigue Test Rig!

Table of Contents

3.0 Installation

When installing the test rig, make sure you have these components ready:

- The complete Fatigue Test Rig with control system
- A hydraulic pump
- The hydraulic tubing

The first thing to do is to make sure the test rig has all its components in the part list.

The Fatigue Test Rig should be connected and assembled together.

The only installation needed is to connect the pressure and reservoir lines from the hydraulic pump to the hydraulic valve, and to connect the emergency stop circuit on the "help" circuit in the contactor which controls the electrical power in the hydraulic pump.

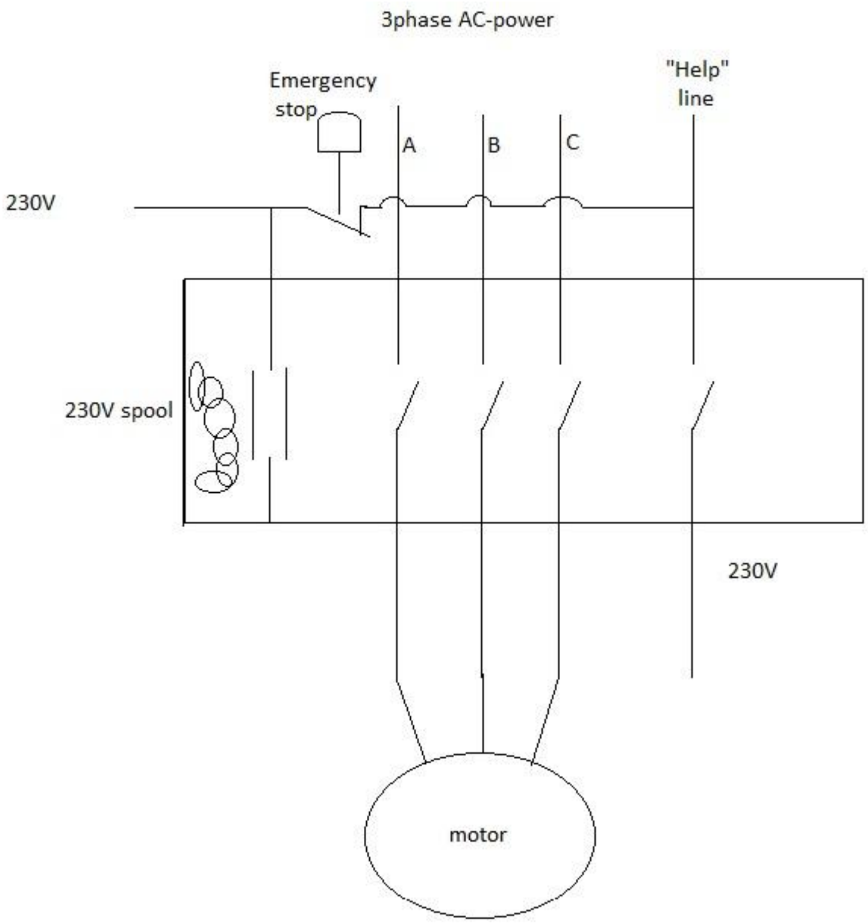


Figure 2: The contactor which control the electrical power of the hydraulic pump, Where to connect the emergency stop button in the contactor

After this is done the Fatigue test Rig is operational.

4.0 Operation instruments

4.1 Start button

Figure 3: Start button is green

The start button is the green button. This button starts the cycling in the valve and the cylinder moves.

4.2 Pressure sensor switch

Figure 4: Where to set the wanted test pressure

The pressure sensor switch is a switch to set a given work pressure for the cylinders.

The switch is set by rotating the center knob. The needle in the manometer shows what the pressure the cylinder will work on.

4.3 Manual emergency stop button

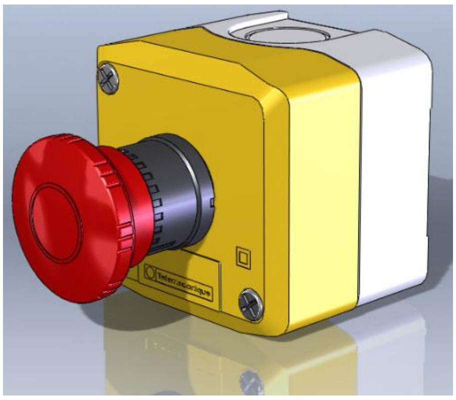


Figure 5: Manual emergency stop button, which is big and red.

The manually emergency stop button is used when something out of the ordinary happens and it is wanted to stop the test rig and hydraulic pump completely.

Push the button and the rig stops.

4.4 Automatic emergency rope pull

Figure 6: The emergency rope pull switch

This is an automatic emergency device, which is pre set to stop the test rig if the cylinder goes outside the move area.

This is also the device that stops the rig and hydraulic pump when the test is done.

This device does not need any manual attention.

4.5 Hydraulic pump start and configure.

The start button on the hydraulic pump is green. When this is pushed the pump should start.

There is also a handle bar to configure the work pressure of the pump.

5.0 User instructions

5.1 Step 1

The first thing to do is to set the pressure sensors to the wanted work pressure. The work pressure is the pressure the cylinders will work with, and the pressure in the cylinder has a direct connection to the force exposed to the test specimen. A calculation is needed to work on the right pressure for wanted force.

Calculation 1: Max appliance is 75 bar

$$F^{+} = A * \rho * 10 = 14{,}72 * 75 * 10 = 11004N$$

$$\rho = \left(\frac{F}{A * 10}\right) bar = \left(\frac{11000}{14{,}7 * 10}\right) = 74{,}8\sim 75bar$$

When calculating the pressure needed, the number to change is 11000 in the calculation. This number is the force wanted. Example: If wanted force on test specimen is 8000N the calculation is this:

$$\rho = \left(\frac{F}{A * 10}\right) bar = \left(\frac{8000}{14{,}7 * 10}\right) = 54{,}42\sim 55bar$$

The pressure sensors are set in this matter:

Figure 7: How to set the pressure switch

5.2 Step 2

The door of the test rig needs to be opened. Use the handle to open.

Figure 8: How to open the door

5.3 Step 3

The test specimen needs to be placed in the test specimen fixture. The test specimen should be between the wedges and to fasten it, it is needed a torque of 8Nm on the bolt to fasten the test specimen.

Upper test specimen fixture:

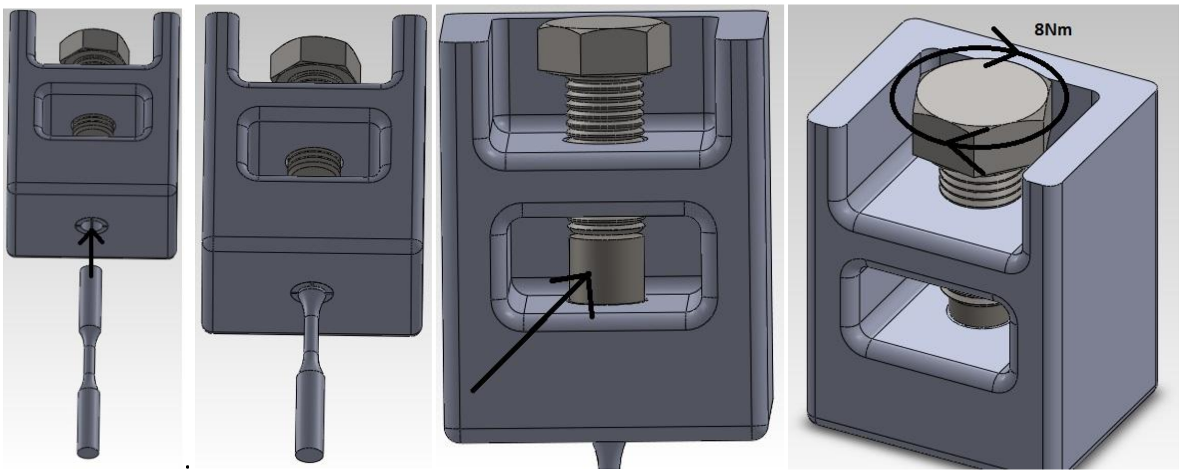


Figure 9: How to fasten the test specimen in the upper fixture frame

Illustration 1 and 2, shows that the test specimen must be placed between the wedges. Illustration 3 shows that the power passing needs to be placed between the wedges and the bolt. Illustration 4 shows how much the bolt needs to be screwed, to supply enough gripping force on the test specimen.

Lower test specimen fixture:

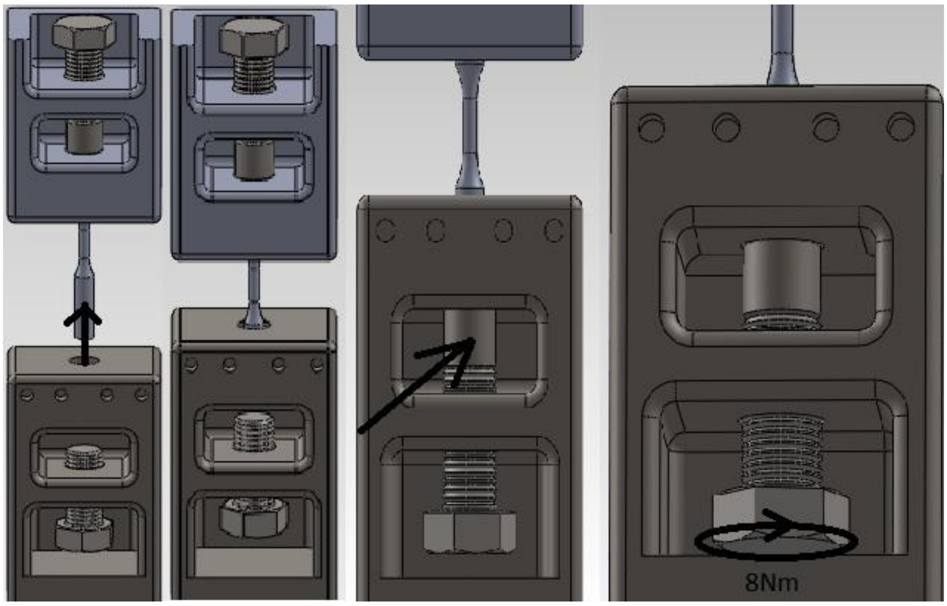


Figure 10: How to fasten the test specimen in the lower fixture frame

Illustration 1 and 2, shows that the lower frame needs to be placed around the tests specimen. Illustration 3 shows that the power passing needs to be placed between the bolt and the wedges. Illustration 4 shows that the needed torque is 8Nm to ensure enough gripping power of the test specimen.

5.4 Step 4

For a safe use of the test rig, the plexi glass door needs to be closed. The magnet on the door will keep it closed. Use the handle to close.

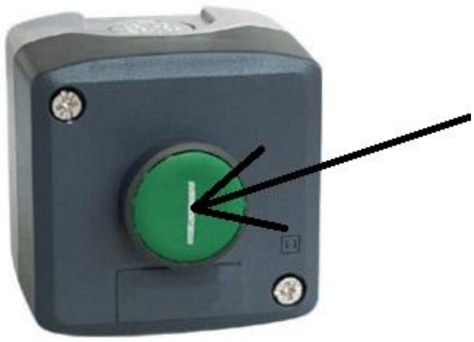
5.5 Step 5

The hydraulic pump needs to be started and configured. When pushing the start button on the hydraulic pump, the pump starts and there is a need to configure how much pressure the pump shall give. The pressure from the hydraulic pump should be the same as the pressure configured on the pressure sensors.

The pump is started and the pressure is configured by a handle to the wanted pressure.

5.6 Step 6

When this is done you press the start button on the test rig and the hydraulic cylinder starts to work. The PLC controls the compression and tension cycles.



Push the start button.

5.7 Step 7

The machine is set to stop when the test specimen breaks. But if needed there is an emergency stop button which stops the cycle of compression and tension, and stops the hydraulic pump.

If needed press the emergency stop button.

5.8 Step 8

When the test specimen is fractured and has broken into two parts. The way to disassemble the test specimen from the fixture is first to loosen the bolt, then to push the lower frame down. The lower part of the test specimen is now loose and it can be taken out. On the upper fixture frame the bolt is loosened and the upper part of the test specimen is taken out.

The rig is now ready to be used again.

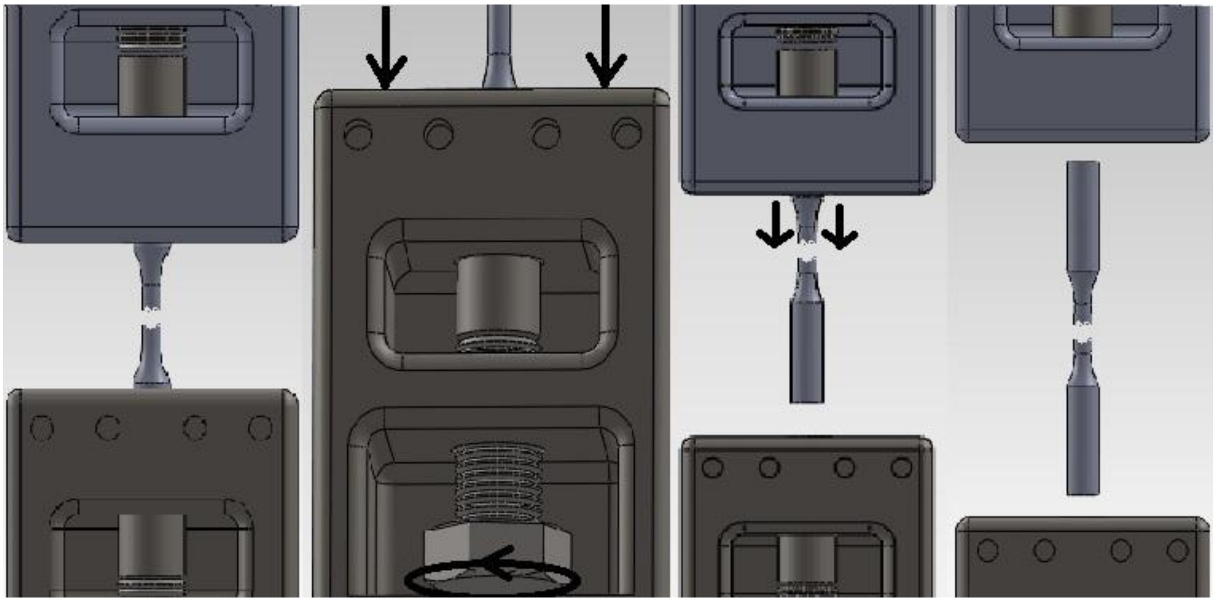
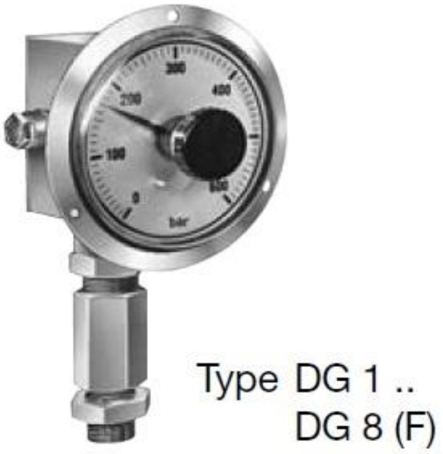


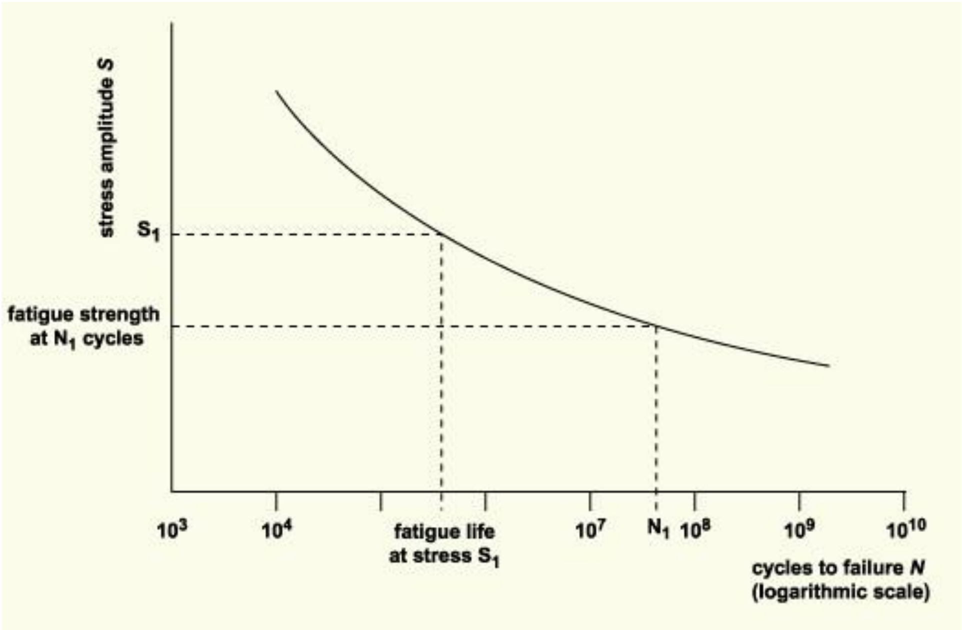
Illustration 1 shows that the test specimen is broken. Illustration 2 shows that the bolt is loosened and the lower fixture frame is pushed down. The same is done on the upper frame except that in the upper frame the test specimen is taken out. There is not a need to push the upper frame. Illustration 3 and 4 shows the upper part of the test specimen being taken out from the test specimen fixture.

5.9 Step 9

When the test specimen has been fractured and broken, the cycle count is readable on the PLC display. This cycle count and the given force from the pressure, form after several tests a SN-curve which is plotted manually. The SN- curve will after several tests show the fatigue limit of the material.

Press the reset button to reset the counter.





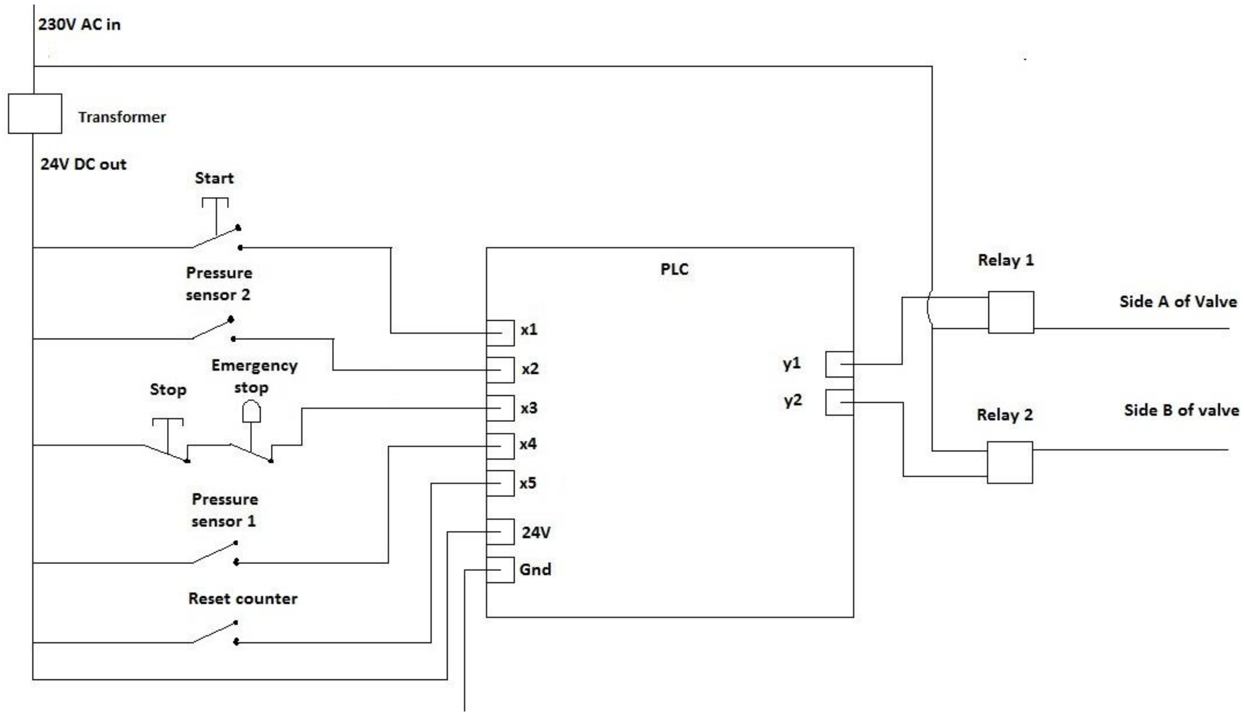
The cycle counted to failure are put in the x-direction and stress in the y-direction.

6.0 Technical data – the Fatigue Test Rig

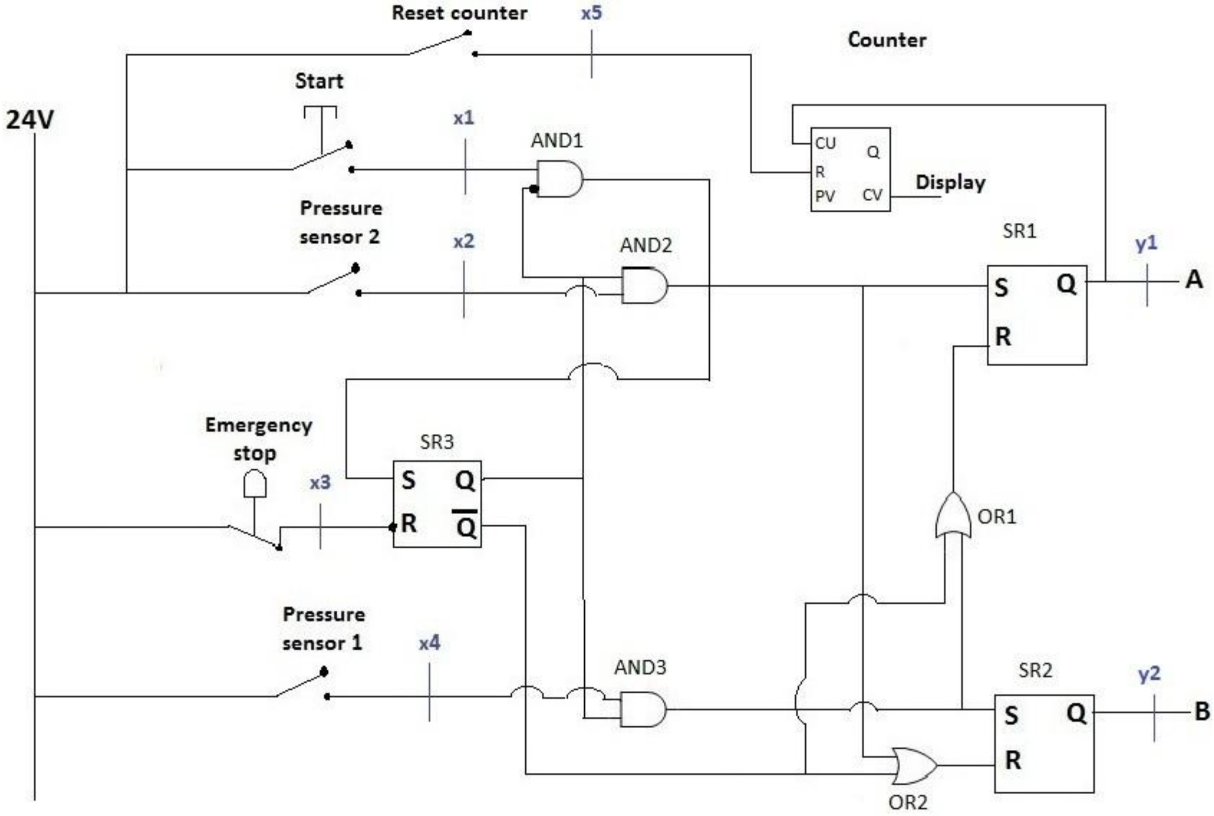
Fatigue Test rig	Specification
Weight	137 Kg
Work pressure	0-75bar
Work frequency	3Hz
Tests test specimen of	Ø6.35mm in diameter with gripping diameter of ø12,7mm
Voltage	230V
Dimensions	l=570mm w=619mm h=900mm
Starting device	Start button

7.0 Wiring diagram

7.1 Into the PLC



7.2 PLC logically controller



8.0 Part list

ITEM NO.	PART	DESCRIPTION	MATERIAL		WEIGHT	QTY.	TOTAL WEIGHT
1	H-beam	Upper frame			20.9Kg	1	20.9Kg
2	Rectangular beam	Lower frame			19.7Kg	1	19.7Kg
3	Channel Bar	Side frame			17Kg	2	34Kg
4	Cylindrical rod	Guide rod			2.2Kg	4	8.8Kg
5	Stabilizer bar				4.7Kg	1	4.7Kg
6	POM- C guide bushing	Bearing of guide rod			52.8g	4	211g
7	POM cover				47.9g	8	383.2g
8	Fixture frame with cylinder connection	Lower specimen fixture			9.5Kg	1	9.5Kg
9	Fixture frame	Upper specimen fixture			5.49Kg	1	5.49Kg
10	Cylinder bracket				4.9Kg	2	9.8Kg
11	Power transfer	Power transfer between fixture bolt and wedges				2	
12	Fixture bolt	The fastener				2	
13	Wedges	Wedge lock				8	
14	Stud bolt	Locking bolt, between lower frame and cylinder piston			1.29Kg	1	1.29Kg
15	Support leg				584g	4	2336g
16	Vibration absorption				123g	4	492g
17	Plexi glass with holes to handle	Front door of the rig			2Kg	1	2Kg
18	Plexi glass	Rear cover of the rig			2Kg	1	2Kg
19	Magnet	Door magnet				2	
20	Hinges	Hinges to the door			400g	2	800g
21	Steel plate	H-beam rear cover			3Kg	1	3Kg
22	Steel plate with logo	H-beam from cover			2.8Kg	1	2.8Kg
23	Door handle				190g	1	190g

24	Hydraulic cylinder	Double rod cylinder			10.8Kg	1	10.8Kg
25	Hydraulic valve	Direct directional valve			1.95Kg	1	1.95Kg
26	Hydraulic sub plate	Sub plate for the hydraulic valve			990g	1	990g
27	PLC				1.5Kg	1	1.5Kg
28	Relay				25g	2	50g
29	Buttons	Start button, reset button, emergency stop button			170g	1	170g
30	Transformer	Transforms from 230V to 24V			100g	1	100g
31	Pressure switch	Manometer with set knob			1.5Kg	2	3Kg
32	Bolts	M24 hex bolt			336g	12	4Kg
33	Bolts	M5 unbrako bolt			3.25g	24	78g
34	Bolts	M3 unbrako bolt			0.97g	32	31.04 g
35	Bolts	M8 unbrako bolt			14,27g	8	114g
36	Rope pull switch	Emergency stop device with wire			200g	2	400g
Total weight of the whole test rig							**136.6Kg**