Faculty of Science and Technology

MASTER'S THESIS

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Abstract

The intention for this project was to increase the collapse pressure rating for the C-Flex SS 9 5/8” by modifying the design. This project started by evaluating the existing design. This was done before the modification of the C-Flex SS 9 5/8” design was implemented. Two design alternatives were made. In the first design alternative there are placed to seals at the opposite side of the threads compared to the position of the seal in existing design. This position of the seals will prevent the threaded connection from being pressurized when the tool is exposed to collapse pressure. In the second design alternative two seals are positioned at the same side of the threads as for the existing design. The difference is that in this design there are two seals. In this design the threaded connection between the end coupling and the housing will be pressurized when the tool is exposed to collapse pressure. Calculations and analyses were made for both design alternatives. These were used to check whether the designs gave satisfying results or if some additional adjustments had to be made. Calculations and analyses for the existing design and for the two design alternatives were compared. The comparison indicated that the first design alternative would have the highest sealing capacity. When the design alternatives gave satisfying results the pressure test equipment was designed. The pressure test equipment was designed based on pressure test performed with gas. Analyses and calculations were made for the pressure test equipment to check the capacity. After the delivery of all the equipment it was assembled and prepared for collapse pressure test. The collapse pressure tests were performed with gas at IRIS in Stavanger. Maximum pressure for the test was 89.5 MPa. At 89.5 MPa there would be a tensile force of 2926 kN in the test piece for both design alternatives. No leakage was detected for the first design alternative. The test of the second design alternative failed at 79 MPa due to burst of test equipment. The burst is assumed to have been caused by collapse of the end coupling. Further investigation is necessary to determine this. The sealing capacity is better for the first design alternative than for the existing design when exposed to collapse pressure and tensile force. It is determined that the first design alternative will be implemented in the C-Flex SS portfolio for new C-Flex SS designs.

Contents

1 Introduction

This master project is a collaboration between the University of Stavanger and Archer Oil Tools AS. In this project a downhole high pressure tool is studied. The tool studied is a C-Flex SS. This is an Archer Oil Tools product. This tool is a multistage cementing collar and is used for cementing jobs of wells. There is a demand for increased collapse pressure rating for this tool. In this project the seal capacity is only being studied for when the tool is exposed to collapse pressure. In this project it will be evaluated if modifications to the existing design can increase and improve the collapse pressure rating of the C-Flex SS.

Proposals for alternative designs of this tool will be made after an evaluation of the existing design. Calculations and analyses of the proposed design alternatives are going to be made to verify that the proposed design alternatives will be applicable. These calculations and analyses will be compared with calculations and analyses made for the existing design. The proposed design alternatives are going to be collapse pressure tested to check the capacity of the seal. Pressure test equipment is needed for the collapse pressure testing. The pressure test equipment is going to be designed. This design is going to be verified through calculations and analyses. The next step will be to order the equipment. A test procedure for the collapse pressure test will be made before pressure test can start. The assembling of the equipment and performance of the pressure test of the proposed design alternatives is going to be according to this pressure test procedure. The results from the analyses and the results from the collapse pressure tests for the proposed design alternatives will show if the sealing capacity of the C-Flex SS can be improved by simple modifications of the existing design.

2 Objective of Work

This master project is studying the design of a multistage cementing collar. The tool is named C-Flex SS. The objective of the work is to modify the existing design of this tool and by this try to increase the collapse pressure rating of this equipment. The objective is to make the tool studied less prone to leakage through a specific seal when subjected to collapse pressure. New design is going to be proposed. Calculations and analyses of the proposed design alternatives are going to be compared with calculations and analyses of the existing design. Another objective is to design pressure test equipment and make a pressure test procedure for the alternative designs. The next objective is to perform pressure tests on proposed design alternatives and evaluate results from these pressure tests.

The main objectives of this master project are:

1. Evaluate Existing Design
2. Propose Alternative Designs
3. Calculations and Analyses
4. Design Test Equipment
5. Prepare Test Procedure
6. Perform Pressure Test
7. Evaluate Results

3 Methods of Work

Figure 3-1 illustrates an overview of the work method for this project. The first step is to evaluate the existing design. This evaluation will provide information about strengths and weaknesses of the existing design. The main issue to be evaluated is collapse pressure rating of the existing design of the tool. Based on this evaluation, the next step will be to propose one or more alternative designs. Autodesk Inventor Professional 2012 will be used for drawing the designs. Calculations and analyses will be made to verify that the proposals give satisfying results. Calculations will be done according to standards and be conducted by the use of Mathcad version 15. The analyses will be made by the use of ANSYS version 14. The results of the analyses and calculations will provide an indication of whether the design alternatives are adequate or whether further modifications are necessary. These results will be compared with corresponding calculations and analyses for the existing design. When the design provides satisfactory results it will proceed to the next step, which is to design the pressure test equipment for the collapse pressure test. The design of the pressure test equipment needs to be verified for pressure testing through calculations and analyses. When the test equipment is approved the next step is to order all the necessary parts to perform collapse pressure test of the alternative designs. Maximum pressure to be used in the pressure test will be calculated. A test procedure has to be prepared before the pressure testing can start. The pressure test is going to take place at the International Research Institute of Stavanger (IRIS) in Stavanger. When the parts are delivered they need to be assembled and prepared for transportation to the pressure test location. Results from the pressure tests of the alternative designs will be evaluated and compared. Evaluation and comparison of the results will show if the sealing capacity of the existing design can be increased by doing modifications of the existing design.

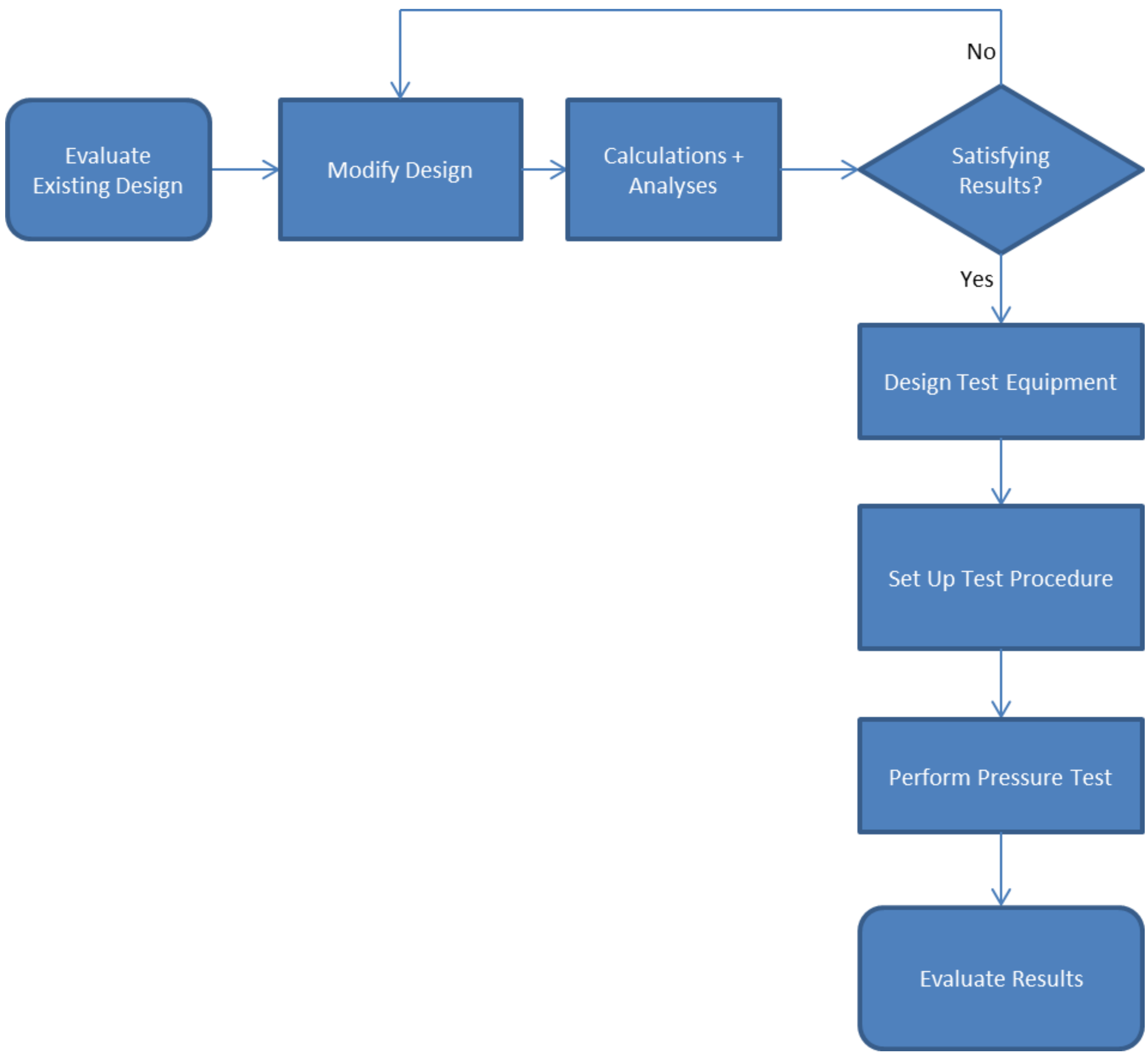


Figure 3-1: Work Method Flow Chart for Project

4 Design Evaluation

The C-Flex SS 9 5/8” tool is going to be evaluated and modified if needed. There is a request for a new design to check whether it is possible to increase the pressure rating of the equipment. Only the collapse pressure rating is considered in this project to simplify the pressure test. The intention is to make the tool less prone to leakage through one of the seals. An evaluation of the existing design and a description of the parts that are to be modified are presented in Chapter 4.1. Two alternative designs are proposed. These two alternatives are presented in chapter 4.2.

4.1 Existing Design

An exterior view of the existing design of the C-Flex SS is presented in Figure 4-1. There are different sizes of this tool. The one studied in this project is a C-Flex SS 9 5/8”. In Figure 4-1 the main parts of concern in this project can be viewed; the end coupling and the housing. On the housing there are ports. The cement flows through these ports when performing cementing jobs. These are called cementing ports in Figure 4-1. A description of the tool is given below [2].

“The C-flex SS is a stage system which can be used to perform stage cement jobs and pumping of other types of annulus liquids in the casing which it is located in. Several C-Flexes can be located in each casing string. The C-Flex can also be used to control the ECD by using it as a return flow device in the casing. The C-flex SS has full ID after operation and no part of the operation requires a drill out. The C-Flex SS are delivered with a hydro forming permanent closed/locked feature which eliminates the risk of opening the inner sleeve and the C-Flex will become a part of the casing. The entire operation of the C-Flex SS is performed by one deployment tool, called a cementing tool. The 9 5/8 C-Flex is Qualified according to testing based upon the test program described in ISO 14310 up to 150° C,” [2].

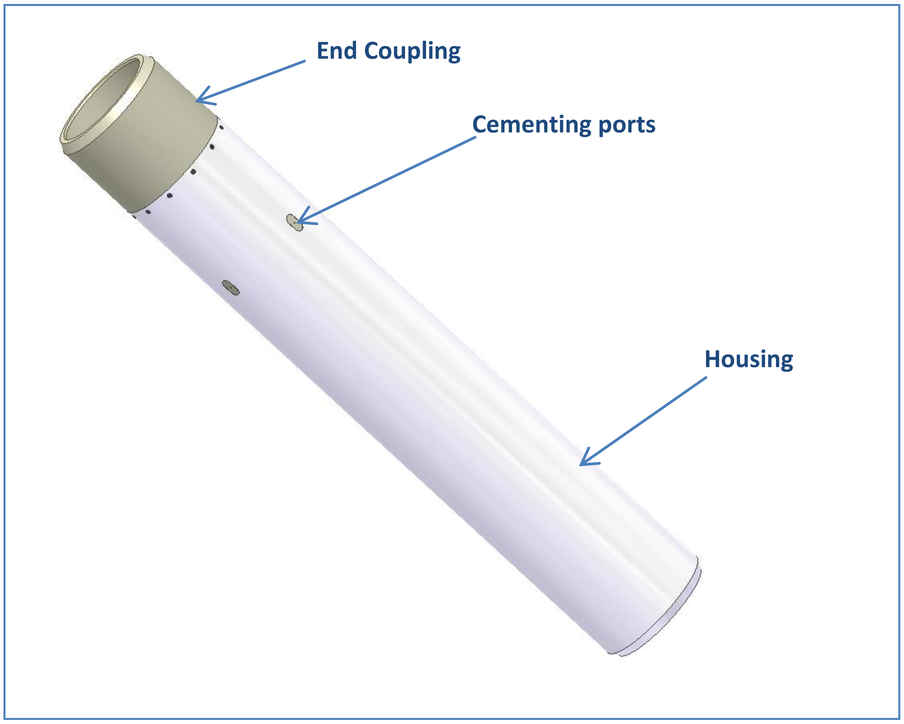


Figure 4-1: Exterior View of C-Flex SS 9 5/8" [1]

Figure 4-2 is presenting the C-Flex SS 9 5/8" together with the cementing tool when it is set in three different positions. The cementing tool is used to set and retrieve the C-Flex SS. The cementing tool provides the cement that flows through the ports on the C-Flex SS when performing cementing jobs. In open position cement can flow through the ports in the housing. In closed position and in the permanently closed there is no flow through these ports due to the position of the sleeve on the inside of the C-Flex SS. The sleeve is positioned such that the ports are blocked by the sleeve thus there is no flow through the ports. Once the C-Flex SS has been set in permanently closed position it cannot be put back in open position.

Figure 4-2: C-Flex SS 9 5/8" 53# with Cementing Tool in Open, Closed and Permanently Closed Position [1]

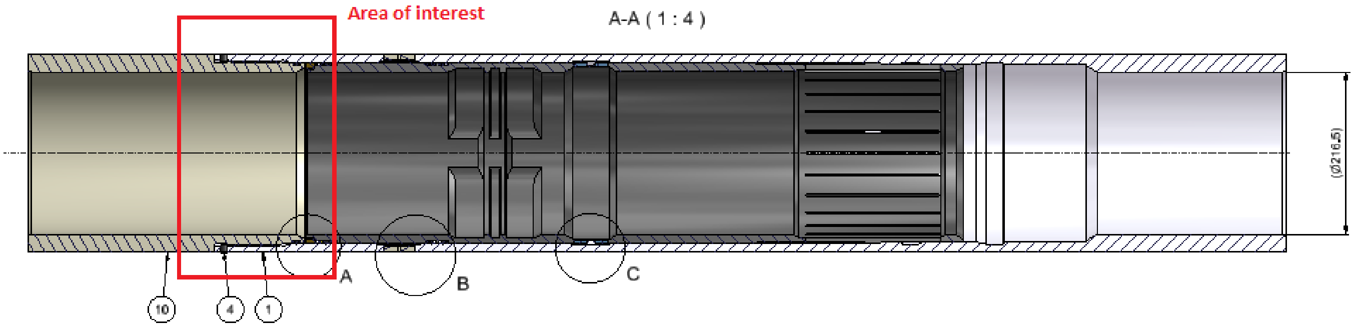


Figure 4-3: Existing Design of C-Flex SS 9 5/8" #53[1]

Figure 4-3 shows an internal view of the existing design taken from the mechanical drawing of the C-Flex SS. This drawing can be found in Appendix A. This figure illustrates how the sleeve is positioned in relation to the end coupling and the housing. The area inside the red rectangle is the section of the tool that is going to be modified. This area is the connection and seal between the end coupling and the housing. In Figure 4-4 the tool is presented 3-dimensional with a quarter cut showing the interior of the tool. This is providing a better overview of the tool. Also in this figure the relevant area is marked with a red rectangle.

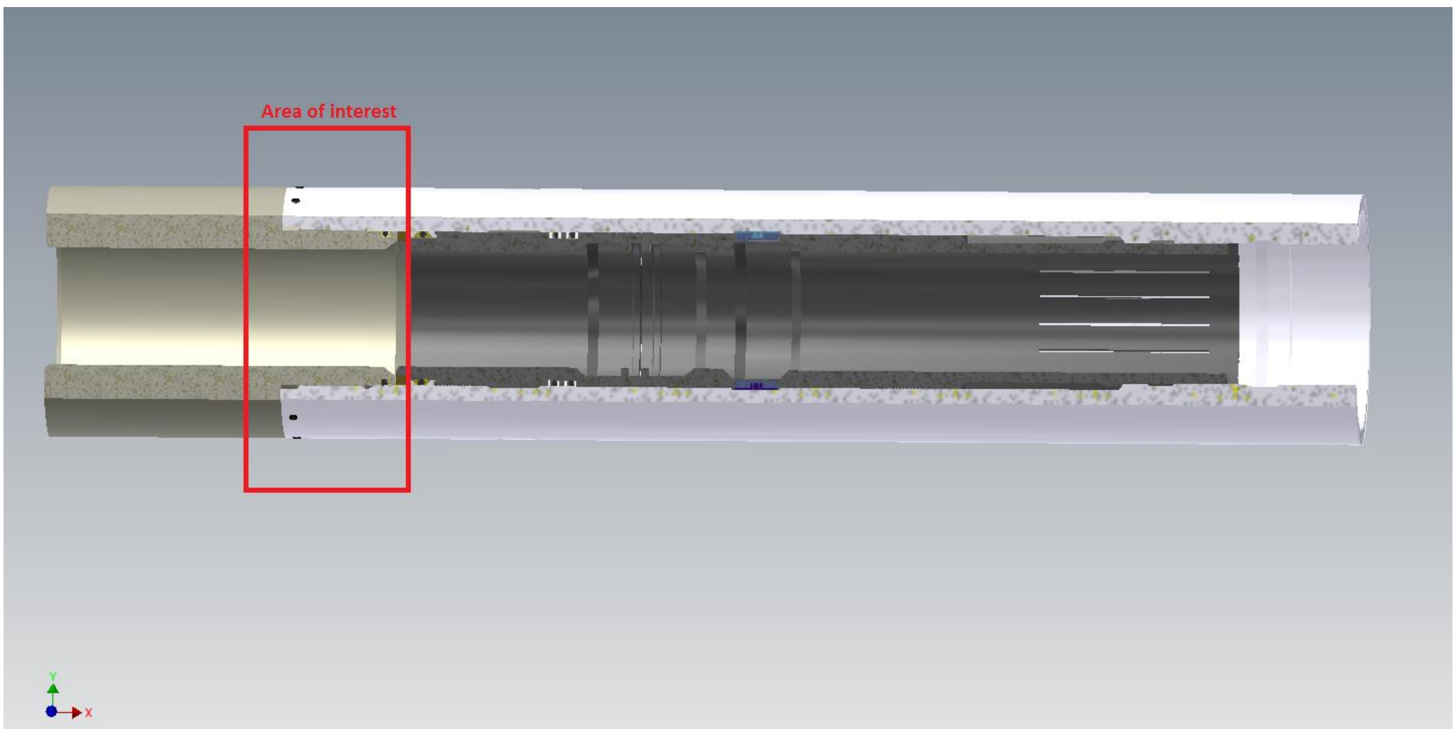


Figure 4-4: 3D Model of Existing Design of C-Flex SS 9 5/8" #53 [1]

Figure 4-5 is presenting an enlarged view of the seal area. This is taken from the mechanical drawing of the tool (Appendix A). This figure illustrates the relevant design details of the C-Flex SS which is going to be modified. This is the connection and seal between the housing and the end coupling. This is the area marked with the red rectangle in Figure 4-5. The design is to be modified with focus on collapse pressure rating. For simplification the sleeve and the parts assembled to it are excluded from this project.

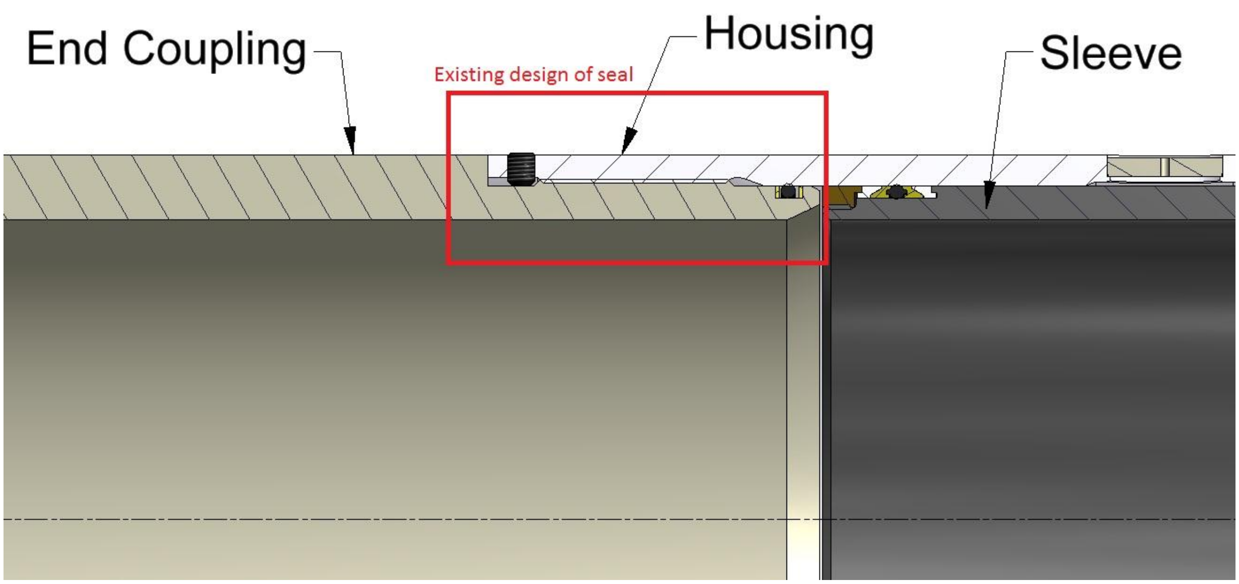


Figure 4-5: Existing Design of the Seal [1]

A detailed description of the seal design is presented in Figure 4-6. In this existing design one O-ring is placed together with two back-up rings at the right hand side of the threaded area. These back-up rings are special made for this specific tool. The thread type in this connection is Stub Acme. The set screws are placed at the left hand side of the threads right next to the intersection edge between the end coupling and the housing.

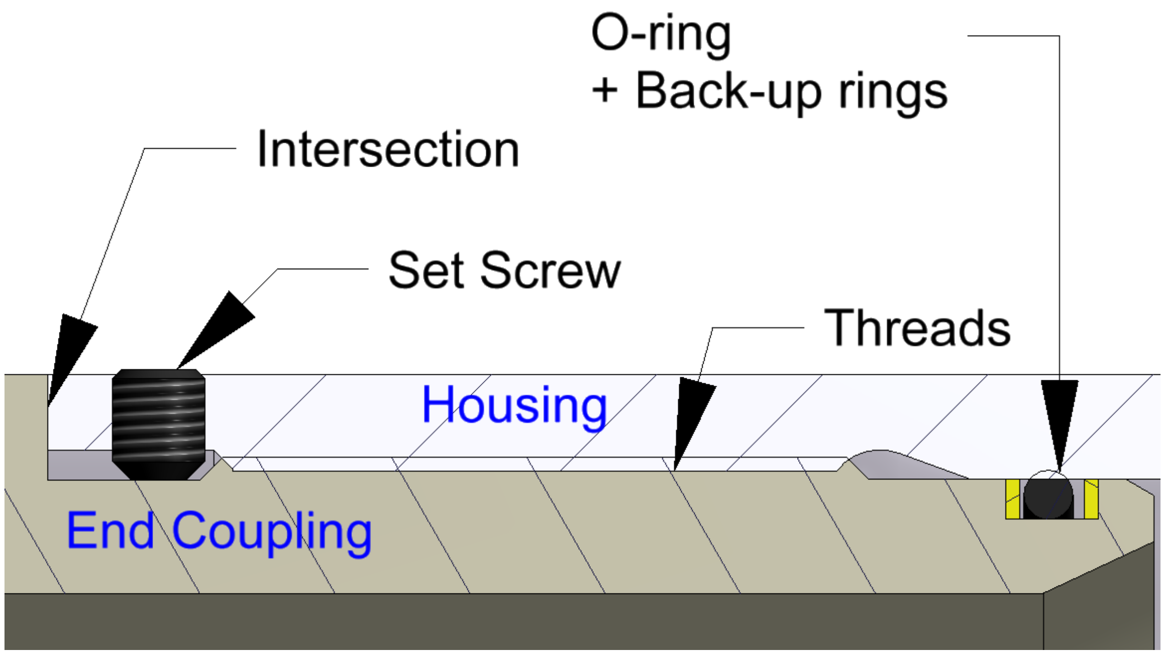


Figure 4-6: Existing Design of Seal of C-Flex SS 9 5/8" #53 [1]

The performance envelope at 150°C for the C-Flex SS 9 5/8" is shown in Figure 4-7. From this envelope we see that the maximum collapse pressure with no axial load is 513 bar = 51.3 MPa. The alternative design suggestions are going to be collapse pressure tested and exposed to tensile forces. It is the second quadrant of the performance envelope which is most relevant for this project. This is giving information about external pressure and tensile force limitations of the existing design.

The existing design is collapse pressure rated:

External pressure = 513 bar = 51.3 MPa with no axial loads.

External pressure = 200 bar = 20 MPa with tensile force of 400 tons = 3923 kN. [2]

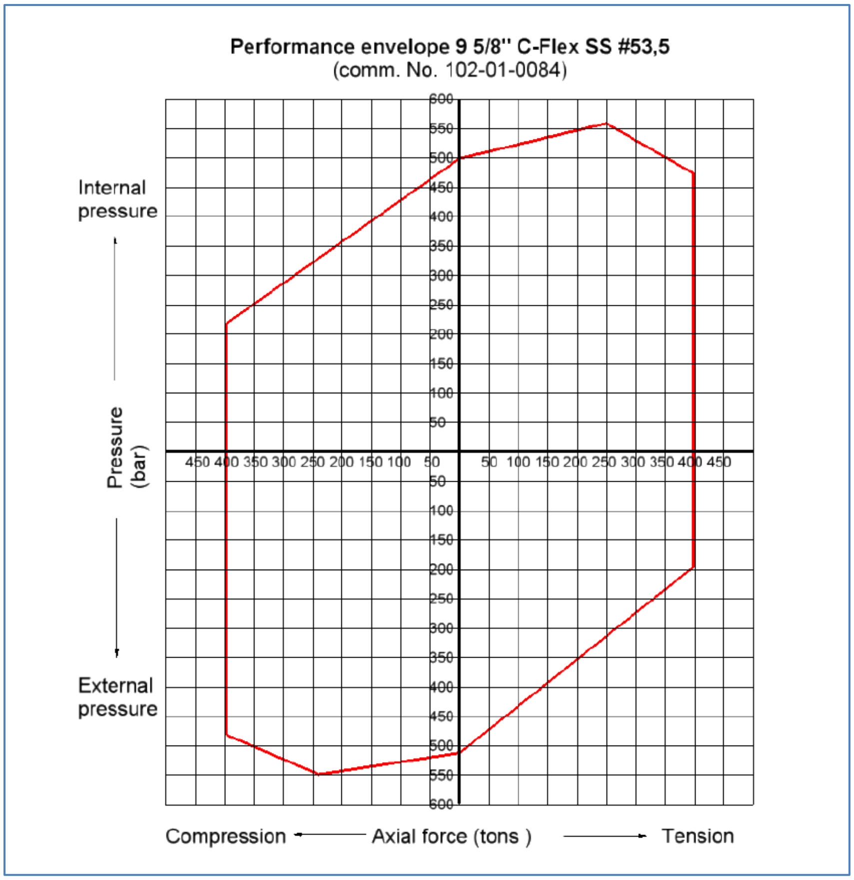


Figure 4-7: Performance Envelope C-Flex SS 9 5/8" #53 [2]

Calculations for the existing design are presented in Figure 4-8 – 4-14 [2]. In these calculations a safety factor of 1.25 is used [5]. Both the housing and the end coupling are made of AISI4140 125ksi material. The yield strength for this material is 861 MPa and the tensile strength is 965 MPa. The yield strength and the tensile strength are temperature compensated for a temperature of 150°C in these calculations. This is due to qualification according to testing based on the test program described in ISO 14310 [2], [8]. Figure 4-8 presents the calculations for temperature compensation. The yield strength is 774.9 MPa and the tensile strength is 926.4 MPa at 150°C. Figure 4-9 presents the calculations for maximum tensile force on the end coupling. The maximum tensile force on the end coupling is 5457 kN. This is equal to 556.5 tons. Calculations for the threaded connection between the end coupling and the housing are presented in Figure 4-10. An axial load of 4085 kN has been used in these calculations. This is the maximum tensile force at the bottom of the threads on the housing and is found in the calculations presented in Figure 4-11. This force is smaller than the force calculated for the end coupling and is then the maximum force the C-Flex SS 9 5/8” can be subjected to. The shear stress in the threads caused by this tensile force is 134.6 MPa. This is less than the temperature compensated yield strength of 774.9 MPa. Figure 4-12 – Figure 4-14 presents the calculations for von Mises yield criterion of the housing. The von-Mises diagram in Figure 4-14 give that maximum collapse pressure with no axial loads for the housing is between 500 - 550 bar.

Temperature compensating for materials used:

AISI 4140 125KSI (MDS274278)

$Y_{s4140.125} := 861\,\text{MPa}$ Yield strenght

$T_{s4140.125} := 965\,\text{MPa}$ Tensile strenght

$Yf := 0.9$ temp. compensation factor for yield strength from Hot Tensile Test

$Tf := 0.96$ temp. compensation factor for tensile strength from Hot Tensile Test

This gives a temperature corrected strenght of:

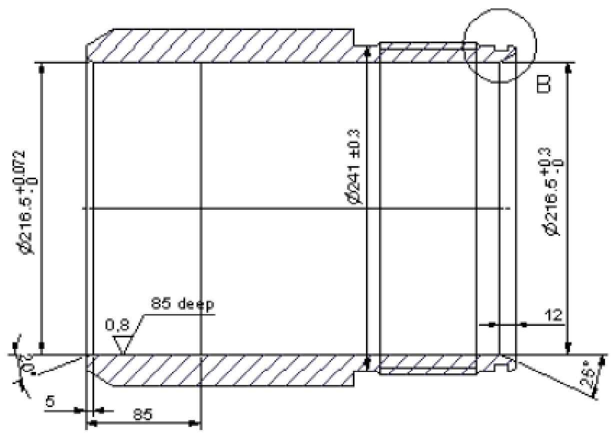
$\sigma_{y150} := Yf \cdot Y_{s4140.125} = 774.9 \cdot \text{MPa}$

$\sigma u150 := Tf \cdot T_{s4140.125} = 926.4 \cdot \text{MPa}$

Figure 4-8: Temperature Compensating for Materials Used in Existing Design [2], [4].

9 5/8" C-flex SS # 53,5

Calculation of tensile on end coupling ref dwg, 12-00213-01



Calculations with material with yield strength of 125KSI:

Input:

$d := 216.5\text{mm}$	Inner diameter
$D := 241\text{mm}$	Outer diameter
$\sigma := 861\text{MPa}$	Yield strength of 125KSI material
$\sigma_{y150} = 774.9\cdot\text{MPa}$	Temperature corrected yield strenght
$\sigma Sf := \dfrac{\sigma_{y150}}{1.25} = 619.9\cdot\text{MPa}$	Material yield limit with safety Factor Tensile 1.25

Max tensile allowed on this part:

$$F := \frac{\left(D^2 - d^2\right)\cdot\pi}{4}\cdot\sigma Sf$$

$F = 5457\cdot\text{kN}$

$F = 556.5\cdot\text{tonnef}$ Maximum force on part

$F = 1226863.6\cdot\text{lbf}$

Figure 4-9: Calculations of Tensile Force on End Coupling for Existing Design [2]

Calculations of stub acme theads

Input force

Axial forces [kN] in threaded connection:

$A1 := 416.6\,\text{tonnef}$ Axial load - housing capacity

Materials an design factors

Values, unless otherwise given

Yield stress - AISI 4140 125KSI $\sigma_{y150} = 774.9 \cdot \text{MPa}$

Safety factor $Sf := 1.25$

Thread geometry:

ACME threads:

Threads Per Inch $TPI_{acme} := 6$

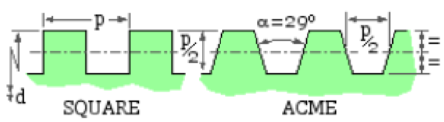
Nominal diameter of threads $D_{th} := 246\text{mm}$

Angle of teeth sides $\alpha_{acme} := 14.5\text{deg}$

Length of threaded bolt: $L_{chth} := 75\text{mm}$

Length of threaded nut: $L_{phth} := 75\text{mm}$

Effective shear area of threaded part:



Thread pitch: $p_{acme} := \dfrac{1\text{in}}{TPI_{acme}}$ $p_{acme} = 4.23 \cdot \text{mm}$

Thread height: $h_{acme} := \dfrac{p_{acme}}{2}$ $h_{acme} = 2.12 \cdot \text{mm}$

Root thickness of threads: $t_{acme} := h_{acme} + h_{acme} \cdot \tan(\alpha_{acme})$ $t_{acme} = 2.66 \cdot \text{mm}$

Inner diameter of threads: $D_{ith} := D_{th} - 2 \cdot h_{acme}$ $D_{ith} = 241.77 \cdot \text{mm}$

Number of effective threads in threaded connection:

$N_{thread} := \text{floor}\left(\dfrac{\min(L_{chth}, L_{phth})}{p_{acme}}\right) - 2$ $N_{thread} = 15$

Effective shear area of threaded connection: $A_{sthread} := N_{thread} \cdot t_{acme} \cdot \pi \cdot D_{ith}$

$A_{sthread} = 30351.8 \cdot \text{mm}^2$

Shear stress in treaded connection

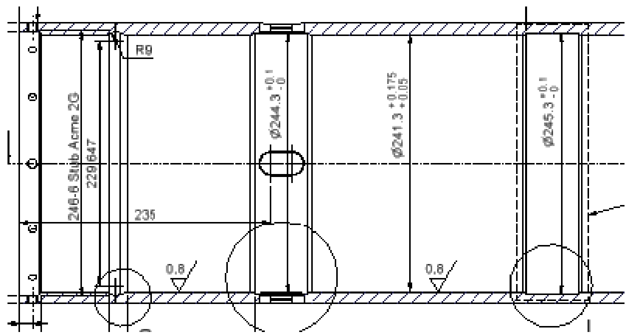
Shear stress:

$\tau_{thread} := \dfrac{A1}{A_{sthread}}$ $\tau_{thread} = 134.6 \cdot \text{MPa}$

Utilisation of threaded connection: $UF := \dfrac{\tau_{thread} \cdot Sf \cdot \sqrt{3}}{\sigma}$ $UF = 0.34$

Figure 4-10: Calculations of End Coupling for Existing Design [2]

Calculations of Housing ref dwg, 12-00210-01



Calculations of bottom end of threads:

input:

$d := 247.6\text{mm}$	Inner diameter at end of threads
$d2 := 244.3\text{mm}$	Inner diameter at section with cementing holes
$D := 264\text{mm}$	Outer diameter
$Di := 241.3\text{mm}$	Inner diameter on seal surface for sleeve
$dh := 245.3\text{mm}$	Diameter in permanent lock groove
$W := 22\text{mm}$	Width of cementing holes
$thc := \frac{D - dh}{2} = 9.3\cdot\text{mm}$	Wall thickness at permanent lock groove
$th := \frac{D - Di}{2} = 11.3\cdot\text{mm}$	Wall thickness at seal surface for seals for sleeve

Max tensile before material is deformed at Section bottom of threads:

$$F := \frac{\left(D^2 - d^2\right)\cdot\pi}{4}\cdot\sigma Sf \qquad F = 4085\cdot\text{kN}$$

$$F = 416.6\cdot\text{tonnef}$$

Calculatons of section on housing with groove for permanent lock:

$$Ft := \frac{\left(D^2 - dh^2\right)\cdot\pi}{4}\cdot\sigma Sf \qquad Ft = 4637\cdot\text{kN}$$

$$Ft = 472.8\cdot\text{tonnef}$$

Max tensile before material is deformed at section with cementing holes:

$$Fc := \left[\frac{\left(D^2 - d2^2\right)\cdot\pi}{4} - \left[W\cdot 4\cdot\frac{(D - d2)}{2}\right]\right]\cdot\sigma Sf \qquad Fc = 4338\cdot\text{kN}$$

$$Fc = 442.4\cdot\text{tonnef}$$

Figure 4-11: Calculations of Housing for Existing Design [2]

Calculation of von Mises yield criterion for a tube loaded by internal and external pressure and axial stress, ISO 13679 or API RP 5C5 representation
Equations taken from ISO 10400 page 87

$f_y := \sigma_{y150} = 774.9\,\text{MPa}$ material yield limit

$D := 264\,\text{mm}$ Outer diameter

$d := 245.3\,\text{mm}$ Diameter in permanent lock groove

I quadrant calculation:

$F1_i := 0N + i \cdot 100000N$ Axial load - positive for I and II quadrant

$$\sigma_a := \frac{F1}{\frac{(D^2 - d^2)\cdot\pi}{4}}$$ Axial load stress

$$k_{pi} := \frac{D^2 + d^2}{D^2 - d^2} = 13.6$$

$$k_A := k_{pi}^2 + k_{pi} + 1 = 200.6$$

$$k_B := (1 - k_{pi})\sigma_a$$

$$k_C := \sigma_a^2 - f_y^2$$

$$pi1 := \frac{\left[-k_B + \left(k_B^2 - 4k_A \cdot k_C\right)^{\frac{1}{2}}\right]}{2k_A}$$ pressure

II quadrant calculation:

$F2_i := 0N + i \cdot 100000N$ Axial load - positive for I and II quadrant

$$\sigma_a := \frac{F2}{\frac{(D^2 - d^2)\cdot\pi}{4}}$$ Axial load stress

$$k_{po} := \frac{2 \cdot D^2}{(D^2 - d^2)}$$

$$k_A := k_{po}^2$$

$$k_B := k_{po} \cdot \sigma_a$$

$$k_C := \sigma_a^2 - f_y^2$$

$$pi2 := \frac{\left[-k_B + \left(k_B^2 - 4k_A \cdot k_C\right)^{\frac{1}{2}}\right]}{2k_A}$$ pressure

Figure 4-12: Calculation of von Mises Yield Criterion for Housing in Existing Design 1/3 [2], [6].

III quadrant calculation:

$F3_i := 0N + i \cdot 100000N \cdot -1$ Axial load - negative for III and IV quadrant

$\sigma_a := \dfrac{F3}{\dfrac{(D^2 - d^2) \cdot \pi}{4}}$ Axial load stress

$k_{po} := \dfrac{2 \cdot D^2}{(D^2 - d^2)}$

$k_A := k_{po}{}^2$

$k_B := k_{po} \cdot \sigma_a$

$k_C := \sigma_a{}^2 - f_y{}^2$

$pi3 := \dfrac{\left[-k_B + \left(k_B{}^2 - 4k_A \cdot k_C\right)^{\frac{1}{2}}\right]}{2k_A}$ pressure

IV quadrant calculation:

$F4_i := 0N + i \cdot 100000N \cdot -1$ Axial load - negative for III and IV quadrant

$\sigma_a := \dfrac{F4}{\dfrac{(D^2 - d^2) \cdot \pi}{4}}$ Axial load stress

$k_{pi} := \dfrac{D^2 + d^2}{D^2 - d^2} = 13.6$

$k_A := k_{pi}{}^2 + k_{pi} + 1 = 200.6$

$k_B := (1 - k_{pi})\sigma_a$

$k_C := \sigma_a{}^2 - f_y{}^2$

$pi4 := \dfrac{\left[-k_B + \left(k_B{}^2 - 4k_A \cdot k_C\right)^{\frac{1}{2}}\right]}{2k_A}$ pressure

Figure 4-13: Calculation of von Mises Yield Criterion for Housing in Existing Design 2/3 [2], [6].

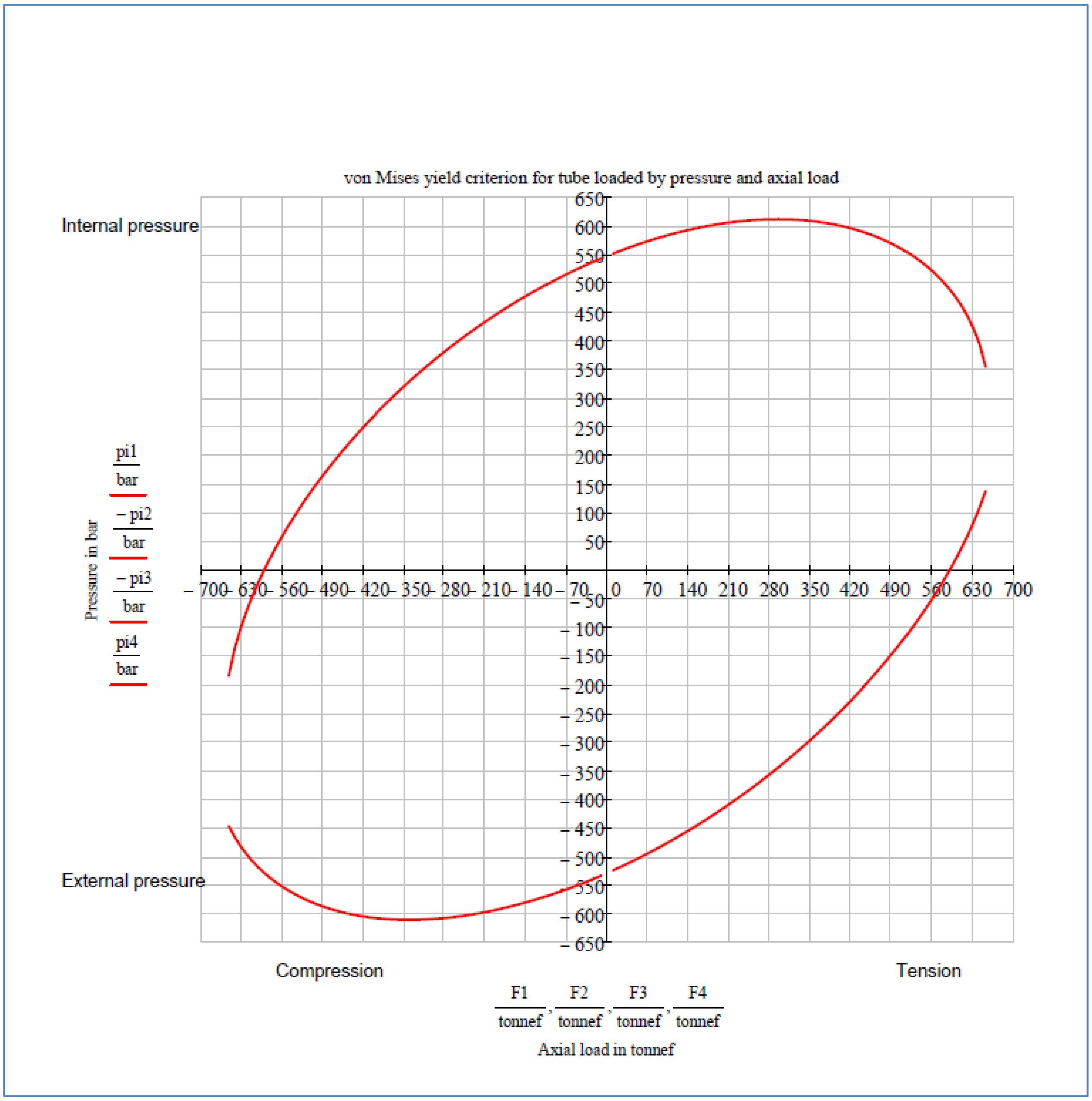


Figure 4-14: Calculation of von Mises Yield Criterion for Housing in Existing Design 3/3 [2], [6].

4.2 Alternative Designs

Two alternative designs are proposed. Both designs are presented in the following sections. Modifications are done on existing drawings of the existing design. 3-dimensional models were made of the modified designs. Based on the 3-dimensional models the mechanical drawings were made. The mechanical drawings include dimensions and tolerances. These drawings along with calculations and analyses have to verify that the design alternatives can be applicable before the parts can be approved and ordered for production. The parts have to be assembled and prepared for collapse pressure testing. These pressure tests are done at IRIS in Stavanger. The final conclusion for the designs will be made when the final results are evaluated and compared.

4.2.1 Alternative Design Nr. 1

Figure 4-15 presents the first proposal for an alternative design of the seal between the end coupling and the housing (Alt.1). This is a view taken from the assembly drawing of this design alternative. The mechanical drawings of the parts in this design can be found in Appendix B. Figure 4-16 presents a detailed description of this seal design.

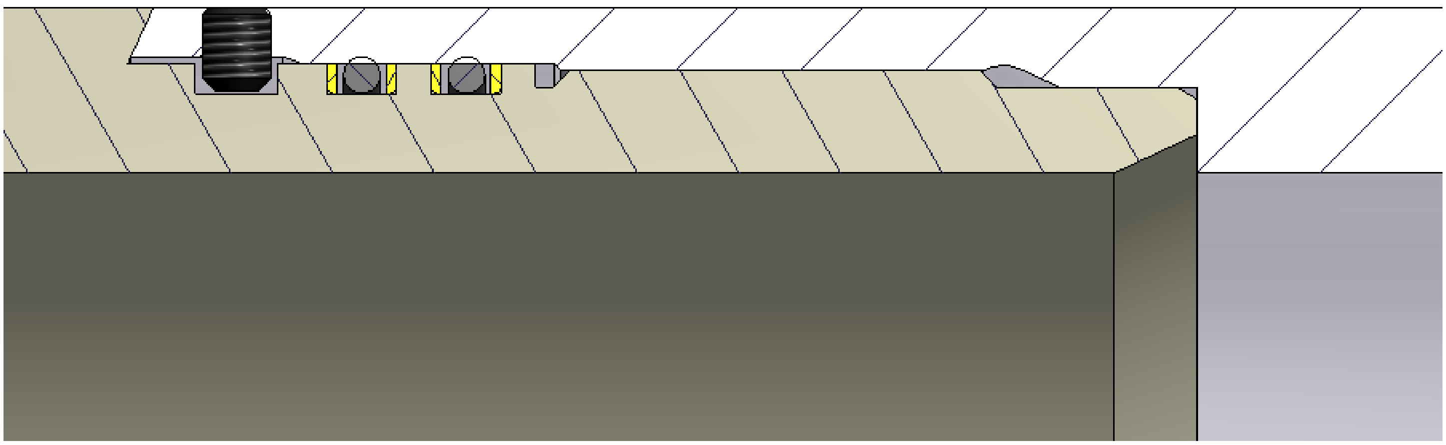


Figure 4-15: Alternative Seal Design Suggestion Number 1

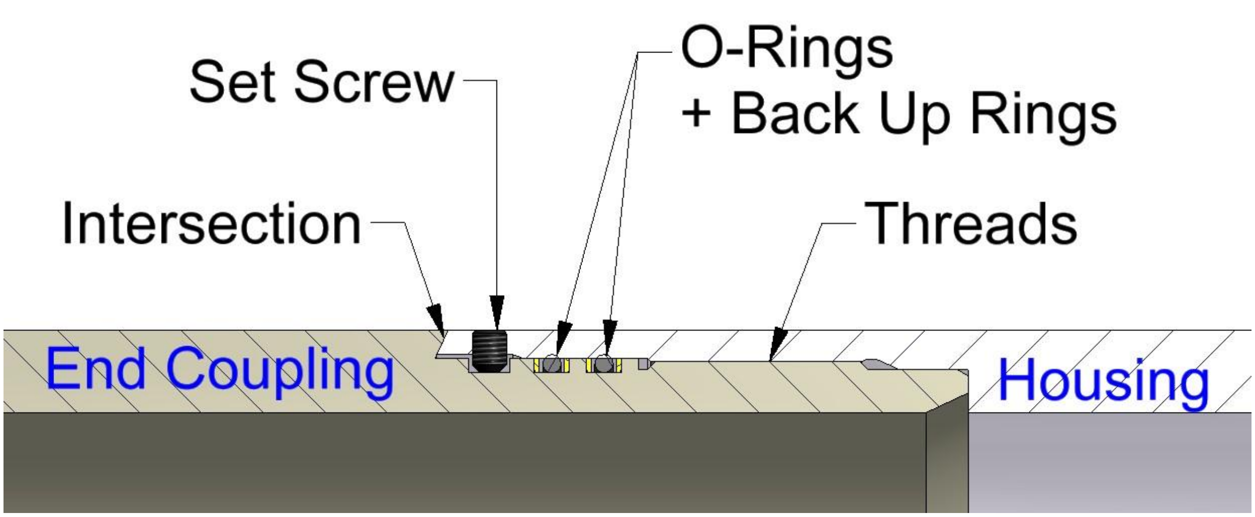


Figure 4-16: Description of Alternative Design Proposal Number 1

In this design two O-rings are placed right next to the set-screws at the left hand side of the threads. Each of the O-rings is assembled together with two back-up rings. These back-up rings are special made for this design and are made of a harder material than the O-rings. In the existing design there is one O-ring that is placed on the right hand side of the threads. There is added an extra O-ring in this design alternative. The thread type used in the connection between the end coupling and housing is Stub Acme. This is the same thread type that is used in the existing design. The length of the threads has been made shorter than for the existing design to prevent making the parts longer and to make room for the additional O-ring. By placing the O-rings on the left hand side of the threads, the threads will not be subjected to collapse pressure before the seal starts to leak. The double O-ring secures if one of the O-rings fails the other O-ring will keep sealing and by this achieve a seal with higher performance. The intention is to make the tool less prone to leakage and by this achieve higher collapse pressure rating of the tool. The edge where the housing and the end coupling intersects has been given an angle. In the existing design this contact surface is perpendicular. The intention of the added angle in this design is that it will make it more difficult for the two parts to disengage from each other when the tool is exposed to high pressure and axial loads. This design will have a stronger connection between the end coupling and the housing and will handle the collapse pressure. The housing and the end coupling are made of AISI4140 125 ksi material. This material has yield strength of 861 MPa and tensile strength of 965 MPa.

To make the pressure tests for both of the proposed design models easier to execute the design of the parts in both alternatives were simplified as much as possible. This was also done to keep the costs of the equipment to a minimum. One of the simplifications was to exclude the sleeve from the test design by making the inner diameter of the housing larger. The support that the sleeve would have provided is achieved by the increased thickness of the housing. Analyses were made in ANSYS to check and confirm that this solution was applicable for testing the strength of the seal. One of the main concerns was that this increased thickness would add more strength than for a model including the seal. These analyses are presented in Chapter 5.

3-dimensional models of the housing, the end coupling and the assembly of Alt. 1 are presented in Figure 4-17 – Figure 4-19. Figure 4-19 presents the assembly with a quarter cut which provides an internal and external view of the seal and connection between the end coupling and the housing.

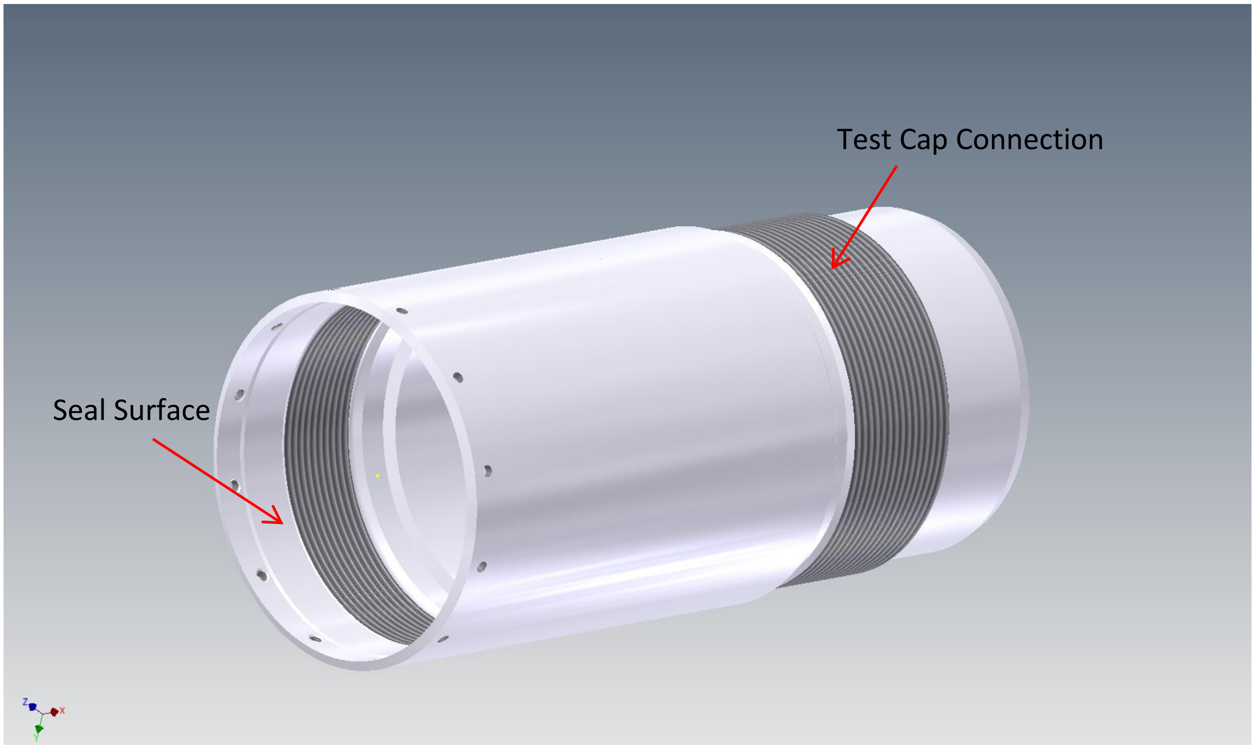


Figure 4-17: 3D-Model of Housing for Alt. 1

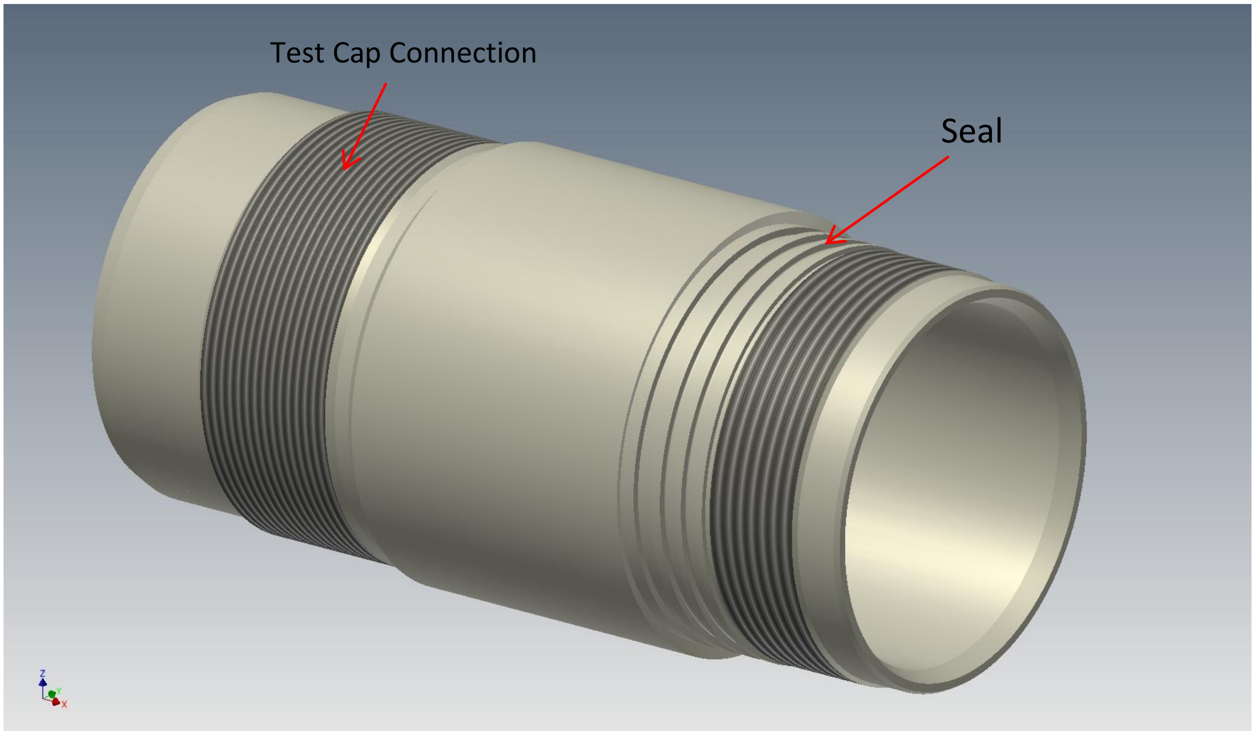


Figure 4-18: 3D-Model of End Coupling for Alt.1

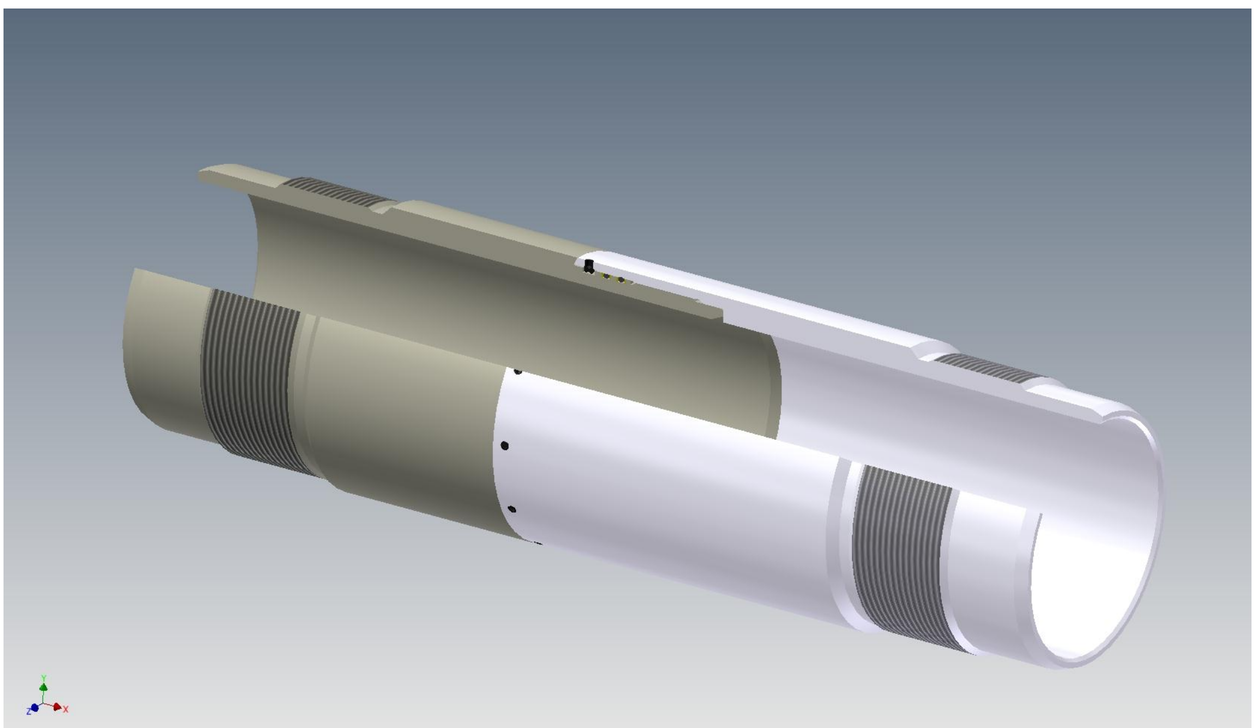


Figure 4-19: 3D-Model of Assembly of Alt.1

4.2.1.1 Calculations and Material Selection

Material selection was an important part when it came to dimensioning the different parts. When selecting the specific O-ring for the seal between the housing and the end coupling, the hardness of the rubber of the O-ring had to be selected. A diagram for extrusion limits of Parker O-rings is presented in Figure 4-20 [3]. This diagram has been used to determine which rubber hardness should be used for both of the alternative designs. There was need for O-rings with high pressure rates. This diagram shows the diametral clearance versus pressure for O-ring without back-up rings. The diagram can also be used as an indicator whether there is a need for back-up rings as well. The O-ring hardness which was chosen is 85 Shore A. This is because this rubber hardness can be used at higher pressures. Together with back up rings the pressure can be increased to more than the maximum value given in this diagram.

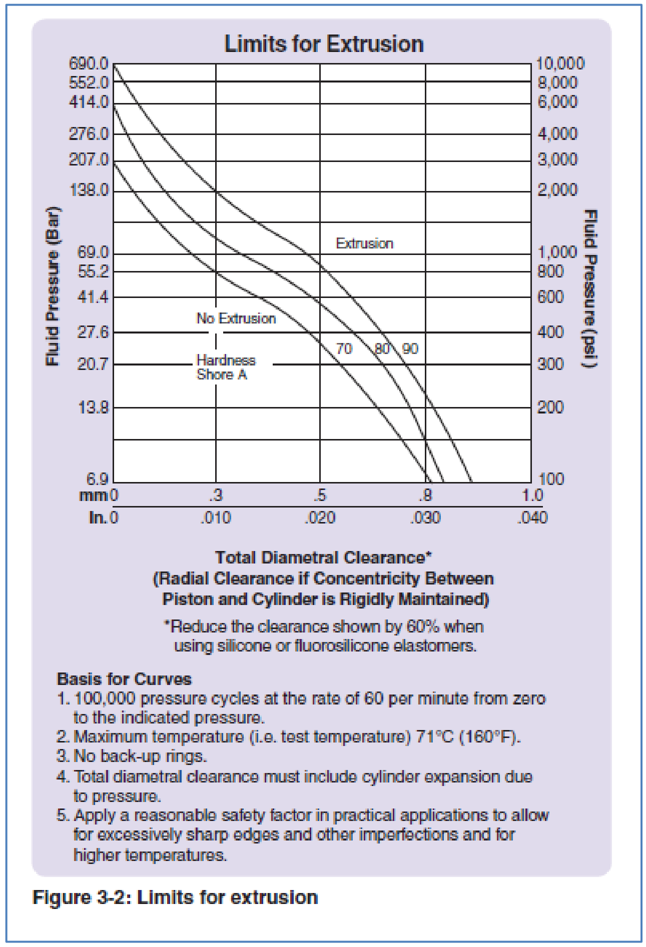
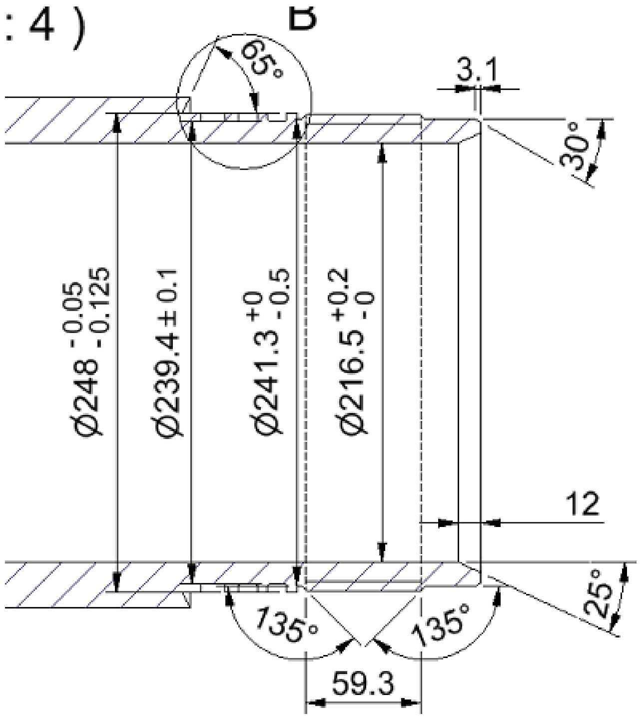


Figure 4-20: Diagram Showing Limits for Extrusion for O-rings [3]

Calculations for Alt. 1 are presented in Figure 4-21 – 4-23. A safety factor of 1.25 is used [5]. The maximum axial load is 5648 kN for the end coupling and 4565.8 kN for the housing for this design alternative. The maximum axial load for this design is therefore 4565.8 kN due to the housing capacity. This force is used for the calculation of the shear stress in the threads. The shear stress in threaded connection is 205.1 MPa. This is less than the yield strength of 861 MPa.

Calculations Modified Design Alternative Nr.1 RD-03323

Calculations of tensile force on end coupling ref. dwg RD-03325



Calculations for material with yield strength of 125KSI:

Input:

$d := 216.5\text{mm}$	Inner diameter
$D := 239.4\text{mm}$	Outer diameter (at groove for set-screw)
$\sigma_y := 861\text{MPa}$	Yield strength of 125KSI material
$Sf := 1.25$	Safety factor
$\sigma_{sf} := \dfrac{\sigma_y}{Sf} = 688.8 \cdot \text{MPa}$	Material yield limit with safety factor 1.25

Max axial load allowed on this part:

$$F_{ec} := \frac{\left(D^2 - d^2\right) \cdot \pi}{4} \cdot \sigma_{sf}$$

$F_{ec} = 5648 \cdot \text{kN}$ Maximum force on part

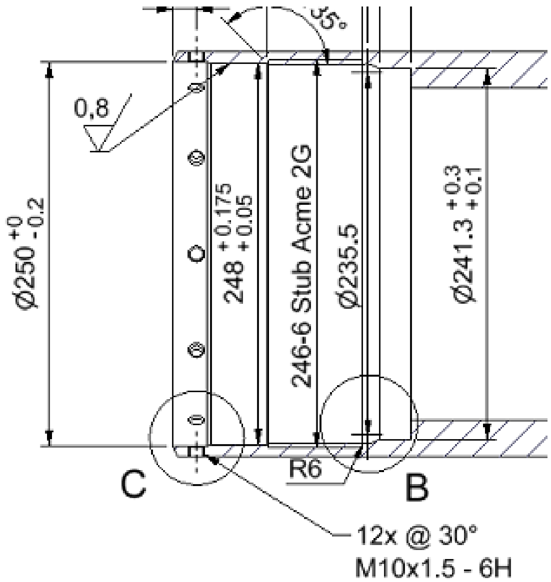
$F_{ec} = 575.9 \cdot \text{tonnef}$

$F_{ec} = 1269701.6 \cdot \text{lbf}$

Comment: Existing design is capable of 5457 kN/ 556.5 tonnef

Figure 4-21: Calculations for Modified Design Alternative Nr.1

Calculations Housing ref. dwg RD-03324



Calculations of bottom end of threads:

Input:

$d_i := 235.5mm + (2 \cdot 6mm) = 247.5 \cdot mm$ Inner diameter at end of threads

$D_o := 264mm$ Outer diameter of housing

Max axial load allowed on this part:

$$F_h := \frac{\left(D_o^{\,2} - d_i^{\,2}\right) \cdot \pi}{4} \cdot \sigma_{sf}$$

$F_h = 4565.8 \cdot kN$ Maximum force on part

$F_h = 465.6 \cdot tonnef$

$F_h = 1026423 \cdot lbf$

Comment: Existing design is capable of 4085kN/ 416.6 tonnef

Figure 4-22: Calculations for Modified Design Alternative Nr. 1

Calculations of stub acme theads

Input force

Axial forces [kN] in threaded connection:

$A1 := 465.6\,\text{tonnef} = 4566\cdot\text{kN}$ Axial load - housing capacity

Materials an design factors

Values, unless otherwise given

Yield stress - AISI 4140 125KSI $\sigma_y = 861\,\text{MPa}$

Safety factor $Sf = 1.25$

Thread geometry:

ACME threads:

Threads Per Inch $TPI_{acme} := 6$

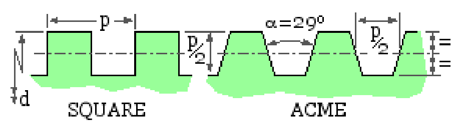
Nominal diameter of threads $D_{th} := 246\text{mm}$

Angle of teeth sides $\alpha_{acme} := 14.5\text{deg}$

Length of threaded bolt: $L_{chth} := 59\text{mm}$

Length of threaded nut: $L_{phth} := 59\text{mm}$

Effective shear area of threaded part:



Thread pitch: $p_{acme} := \dfrac{1\text{in}}{TPI_{acme}}$ $p_{acme} = 4.23\cdot\text{mm}$

Thread height: $h_{acme} := \dfrac{p_{acme}}{2}$ $h_{acme} = 2.12\cdot\text{mm}$

Root thickness of threads: $t_{acme} := h_{acme} + h_{acme}\cdot\tan(\alpha_{acme})$ $t_{acme} = 2.66\cdot\text{mm}$

Inner diameter of threads: $D_{ith} := D_{th} - 2\cdot h_{acme}$ $D_{ith} = 241.77\cdot\text{mm}$

Number of effective threads in threaded connection:

$$N_{thread} := \text{floor}\left(\frac{\min(L_{chth}, L_{phth})}{p_{acme}}\right) - 2 \qquad N_{thread} = 11$$

Effective shear area of threaded connection: $A_{sthread} := N_{thread}\cdot t_{acme}\cdot\pi\cdot D_{ith}$

$A_{sthread} = 22258\cdot\text{mm}^2$

Shear stress in treaded connection

Shear stress:

$$\tau_{thread} := \frac{A1}{A_{sthread}} \qquad \tau_{thread} = 205.1\cdot\text{MPa}$$

Utilisation of threaded connection: $UF := \dfrac{\tau_{thread}\cdot Sf\cdot\sqrt{3}}{\sigma_y}$ $UF = 0.52$

Comment:For existing design the shear stress is 134.6 MPa

Figure 4-23: Calculations for Alternative 1 [7]

4.2.2 Alternative Design Nr. 2

Figure 4-24 presents the second proposal for an alternative design of the seal between the end coupling and the housing (Alt. 2). This is a view taken from the assembly drawing of this design alternative. The mechanical drawings of the different parts in this design can be found in Appendix C. Figure 4-25 presents a detailed description of this seal design.

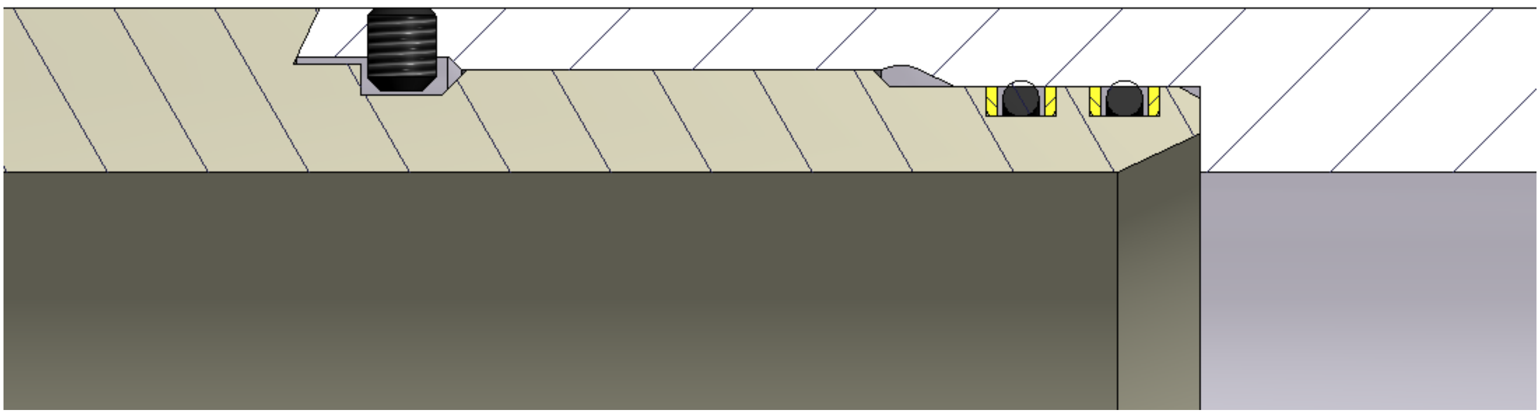


Figure 4-24: Modified Design Alternative Nr. 2

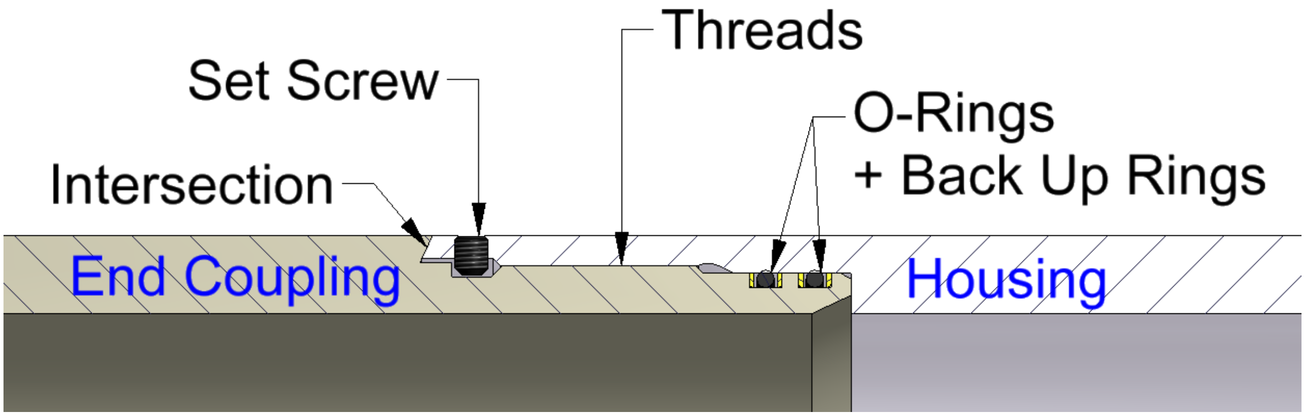


Figure 4-25: Details of Alternative Design Number 2

This design is more similar to the existing design than Alt. 1. The difference between this design and the existing design is that there are placed two O-rings on the right hand side of the threads. In the existing design there is placed one O-ring at the same location. There are placed two back-up rings together with each O-ring. The rubber hardness of the O-rings in this seal design is 85 Shore A. This is the same as for Alt. 1. The back-up rings are made of a much harder material than the O-rings. The additional O-ring is added to make the unit hold high pressure. The edge where the end coupling and the housing intersects has been given an angle. This is to make it more difficult for the housing and the end coupling to disengage from each other when exposed to high pressure. This is the same as for Alt. 1. The length of the threads has been shortened to make room for the extra O-ring and to prevent making the parts longer than necessary. The thread type is Stub Acme. This is the same thread type used for the existing design and Alt. 1. This design has the same thread length as Alt.1. The housing and the end coupling are made of AISI4140 125 ksi material. The yield strength is 861 MPa and the tensile strength is 965 MPa. To determine the inner diameter of the housing the analysis made for design alternative number 1 was used.

3-dimensional models of the housing, the end coupling and the assembly of Alt. 2 are presented in Figure 4-26 – Figure 4-28. Figure 4-28 presents the assembly with a quarter cut that provides an internal and external view of the seal and connection between the end coupling and the housing.

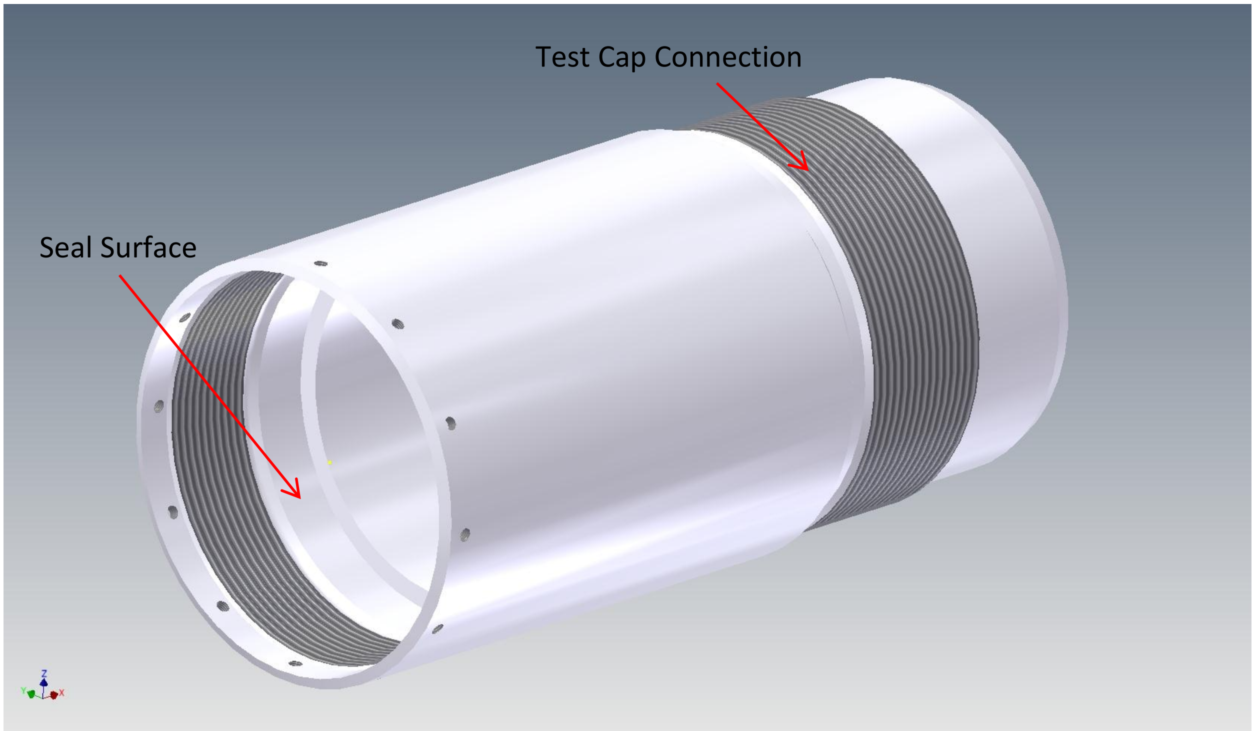


Figure 4-26: 3D-Model of Housing for Alt. 2

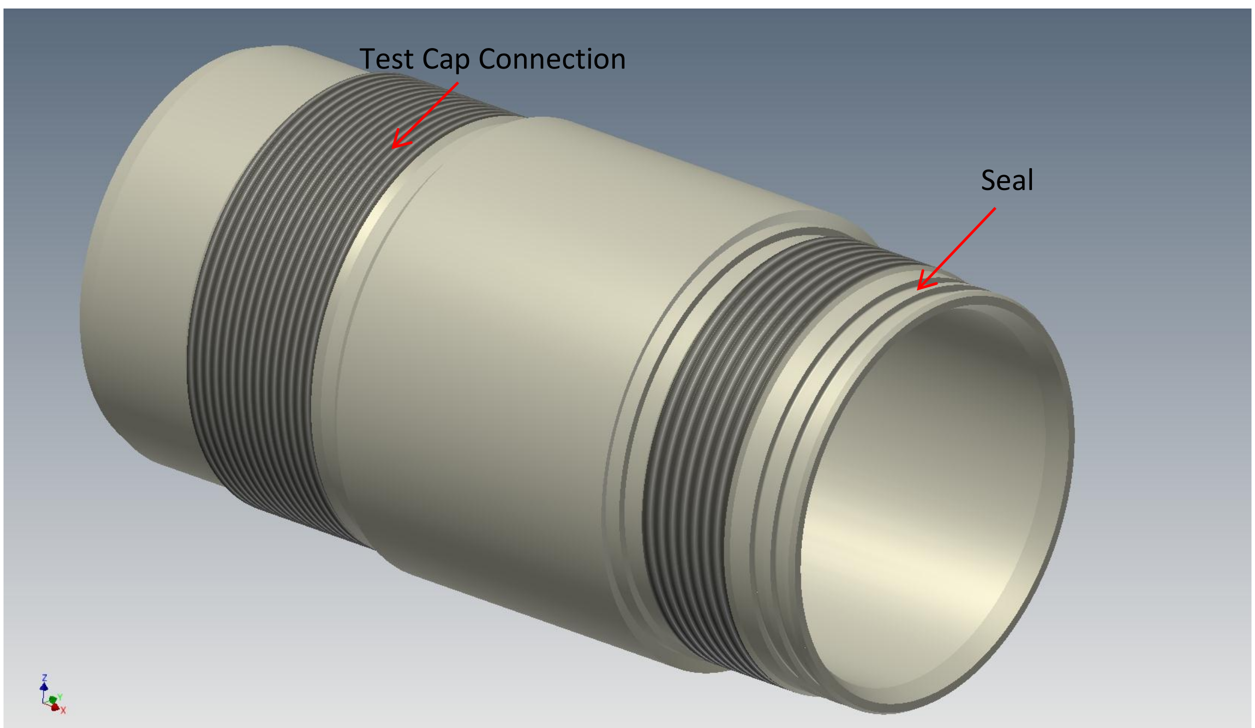


Figure 4-27: 3D-Model of End Coupling for Alt. 2

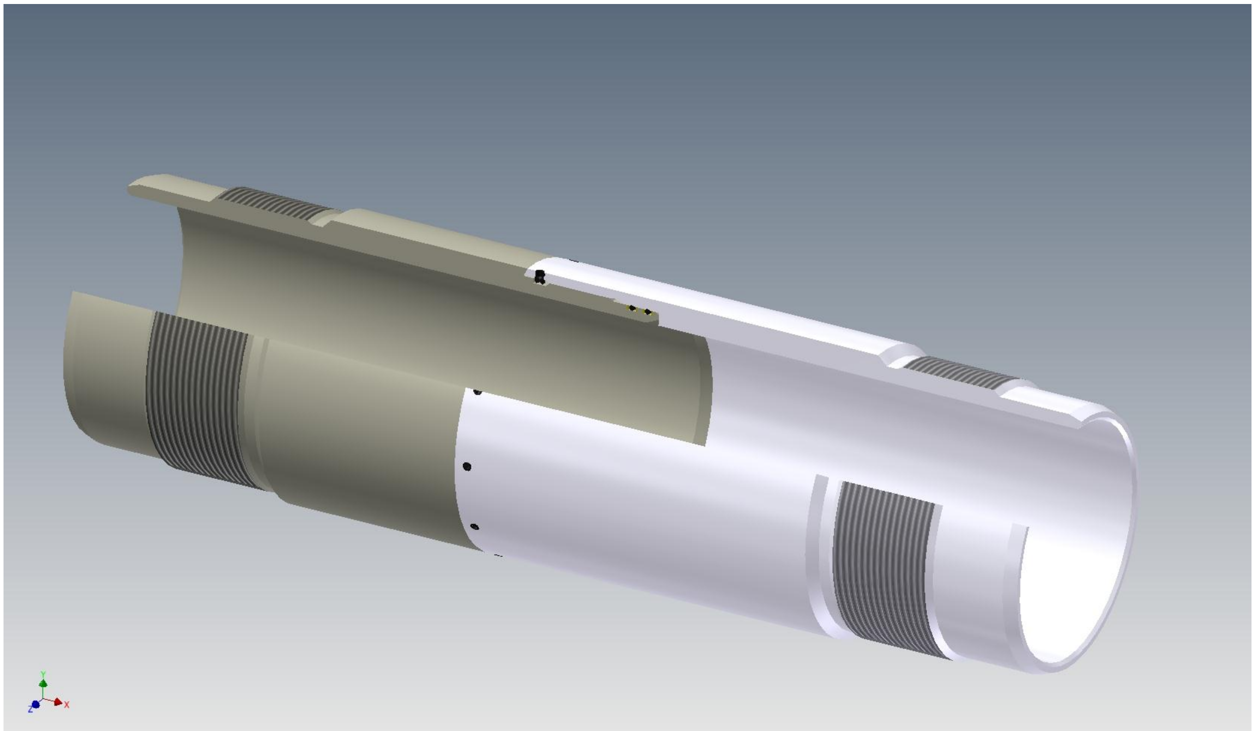
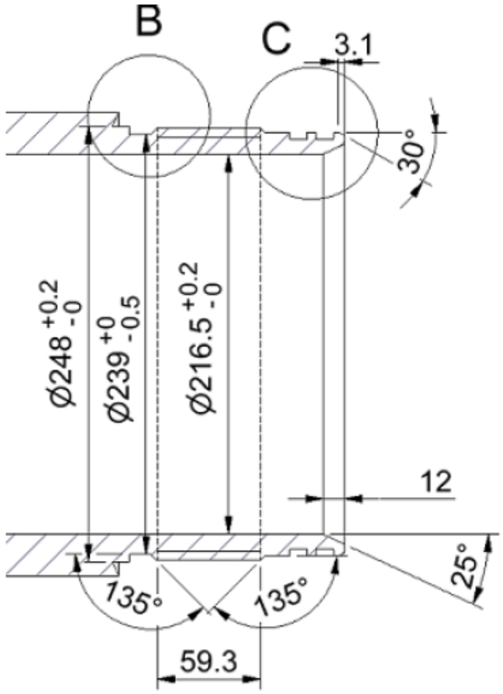


Figure 4-28: 3D-Model of Alt. 2

Calculations made for this design alternative are presented in Figure 4-29 – 4-31. A safety factor of 1.25 is used [5]. The maximum axial load is 5544 kN for the end coupling and 4566 kN for the housing for this design. Since the maximum axial load for the housing is smaller than for the end coupling, this is the limiting axial force for this design. Figure 4-31 presents calculations for the threaded connection between the end coupling and the housing. When exposed to an axial force of 4566 kN, the shear stress in the threads is 205.1 MPa. This is the same as the shear stress found for Alt. 1. This is smaller than the yield strength of 861 MPa.

Calculations Modified Design Alternative Nr.2 RD-03360

Calculations of tensile on end coupling ref. dwg RD-03362



Calculations for material with yield strength of 125KSI:

Input:

$d := 216.5\text{mm}$	Inner diameter
$D := 239\text{mm}$	Outer diameter (at groove for set-screw)
$\sigma_y := 861\text{MPa}$	Yield strength of 125KSI material
$Sf := 1.25$	Safety factor
$\sigma_{sf} := \dfrac{\sigma_y}{Sf} = 688.8 \cdot \text{MPa}$	Material yield limit with safety factor 1.25

Max axial load allowed on this part:

$$F_{ec} := \frac{\left(D^2 - d^2\right) \cdot \pi}{4} \cdot \sigma_{sf}$$

$F_{ec} = 5544 \cdot \text{kN}$ Maximum force on part

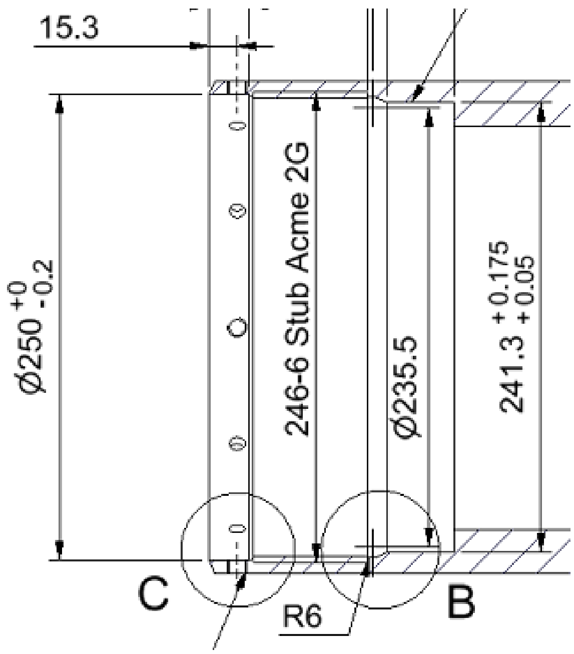
$F_{ec} = 565.371 \cdot \text{tonnef}$

$F_{ec} = 1246428.9 \cdot \text{lbf}$

Comment: Existing design is capable of 5457 kN/ 556.5 tonnef

Figure 4-29: Calculations for Modified Design Alternative Nr.2

Calculations of housing ref. dwg RD-03361



Calculations of bottom end of threads:

Input:

$d_i := 250\text{mm}$ Inner diameter at end of threads

$D_o := 264\text{mm}$ Outer diameter of housing

Max axial load allowed on this part:

$$F_h := \frac{\left(D_o^{\,2} - d_i^{\,2}\right)\cdot\pi}{4}\cdot\sigma_{sf}$$

$F_h = 3893\cdot\text{kN}$ Maximum force on part

$F_h = 397\cdot\text{tonnef}$

$F_h = 875161\cdot\text{lbf}$

Comment: Existing design is capable of 4085kN/ 416.6 tonnef

Figure 4-30: Calculations for Modified Design Alternative Nr.2

Calculations of stub acme theads

Input force

Axial forces [kN] in threaded connection:

$Al := 465.6\text{tonnef} = 4.566 \times 10^{3} \cdot \text{kN}$ Axial load - housing capacity

Materials an design factors

Values, unless otherwise given

Yield stress - AISI 4140 125KSI $\sigma_y = 861 \cdot \text{MPa}$

Safety factor $Sf = 1.25$

Thread geometry:

ACME threads:

Threads Per Inch $TPI_{acme} := 6$

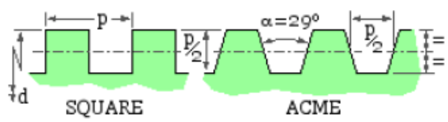
Nominal diameter of threads $D_{th} := 246\text{mm}$

Angle of teeth sides $\alpha_{acme} := 14.5\text{deg}$

Length of threaded bolt: $L_{chth} := 59\text{mm}$

Length of threaded nut: $L_{phth} := 59\text{mm}$

Effective shear area of threaded part:



Thread pitch: $p_{acme} := \dfrac{1\text{in}}{TPI_{acme}}$ $p_{acme} = 4.23 \cdot \text{mm}$

Thread height: $h_{acme} := \dfrac{p_{acme}}{2}$ $h_{acme} = 2.12 \cdot \text{mm}$

Root thickness of threads: $t_{acme} := h_{acme} + h_{acme} \cdot \tan(\alpha_{acme})$ $t_{acme} = 2.66 \cdot \text{mm}$

Inner diameter of threads: $D_{ith} := D_{th} - 2 \cdot h_{acme}$ $D_{ith} = 241.77 \cdot \text{mm}$

Number of effective threads in threaded connection:

$N_{thread} := \text{floor}\left(\dfrac{\min(L_{chth}, L_{phth})}{p_{acme}}\right) - 2$ $N_{thread} = 11$

Effective shear area of threaded connection $A_{sthread} := N_{thread} \cdot t_{acme} \cdot \pi \cdot D_{ith}$

$A_{sthread} = 22258 \cdot \text{mm}^2$

Shear stress in treaded connection

Shear stress: $\tau_{thread} := \dfrac{Al}{A_{sthread}}$ $\tau_{thread} = 205.1 \cdot \text{MPa}$

Utilisation of threaded connection: $UF := \dfrac{\tau_{thread} \cdot Sf \cdot \sqrt{3}}{\sigma_y}$ $UF = 0.52$

Comment:For existing design the shear stress is 134.6 MPa

Figure 4-31: Calculations for Modified Design Alternative Nr.2 [7]

4.3 Design of Pressure Test Equipment

To make the pressure test of the two proposed designs less complex and to reduce the cost some modifications have been made (on the housing and the end coupling). This was done to simplify the equipment for both design alternatives. One of the simplifications for both of the design alternatives is that the inner diameter of the housing is reduced. The inner diameter has been given the same inner diameter as the end coupling. This gives a larger cross-sectional area of the housing for the two alternative design suggestions than for the housing in the existing design. This enlarged cross-sectional area of the housing represents the support that the sleeve would initially apply to the tool. Analyses were carried out to decide if this could be a viable solution and to decide how much of the housing to make thicker. The analyses are presented in Chapter 5. Another simplification is that the housing has been made shorter and the cementing ports have been removed. The reason for this is that only the capacity of the seal between the end coupling and the housing is going to be tested. Elements on the housing which are not necessary for this test have therefore been removed.

The design of pressure test arrangement is made the same for both design alternatives. This is beneficial because the same pressure test equipment can be used to test both design alternatives in separate pressure tests. Initially the collapse pressure tests were going to be performed by the use of water. The initial test arrangements are presented in Figure 4-32 and Figure 4-33. Initially the tests were going to be performed by placing the test assembly in a test casing. The internal volume of this test casing is pressurized with water to create collapse pressure on the test piece. When performing the pressure test with water it would be difficult to detect leakages in the seal. A test like this would cause problems to carry out testing with consistent and stable measurements. The test setup and procedure were discarded due to lack of accuracy. It was decided that the pressure test should be performed with gas instead of water. A test performed with gas will give more accurate results because gas is more volatile than water. When pressure testing with gas it will be easier to detect leakages in the seal and to verify at which specific pressure the leakage starts.

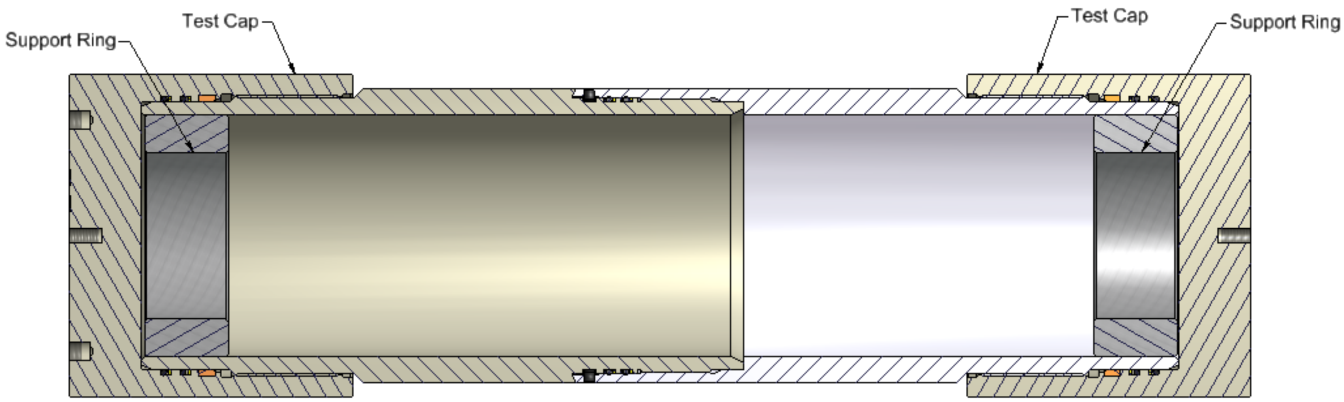


Figure 4-32: Initial Design of Test Setup for Design Alternative Nr. 1

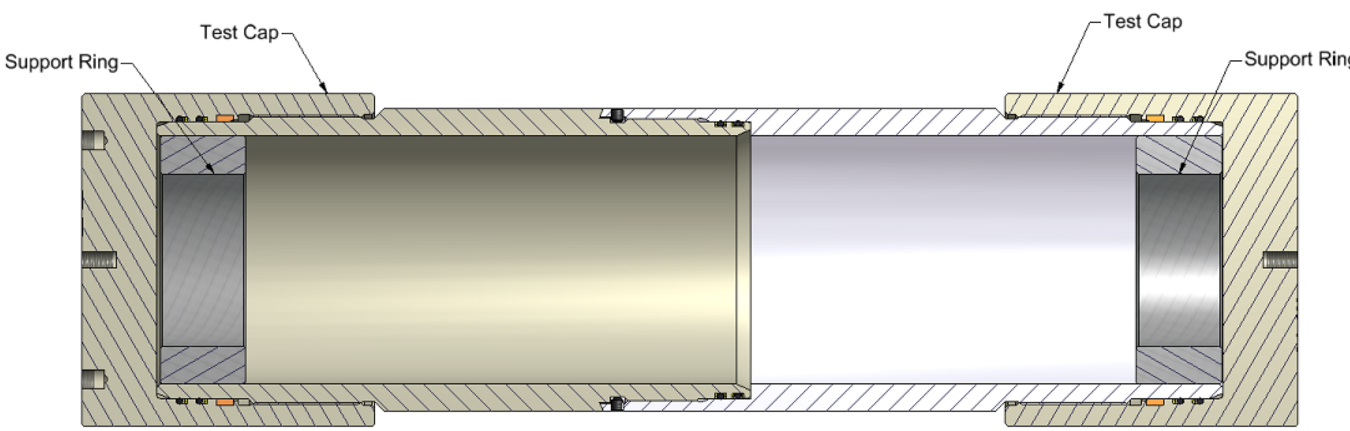


Figure 4-33: Initial Design of Test Setup for Design Alternative Nr.2

New test procedure with higher pressure specification gave technical challenges. If the test equipment were to fail, this could lead to severe consequences. After an evaluation of the initial design of the pressure test equipment it was decided to keep this design and make some modifications on this design. The test caps in the initial pressure test design were discarded. New test caps were made to fit the dimensions and threaded connection on the ends of the end coupling and the housing. The end on the housing and the end coupling has Stub Acme threads. The final design for the test setup is presented in Figure 4-34 – 4-36. Figure 4-34 and Figure 4-35 are taken from the mechanical drawings made for the assemblies. These drawings can be viewed in Appendix D. Figure 4-36 is taken from the three - dimensional drawing of one of the assemblies made in Autodesk Inventor.

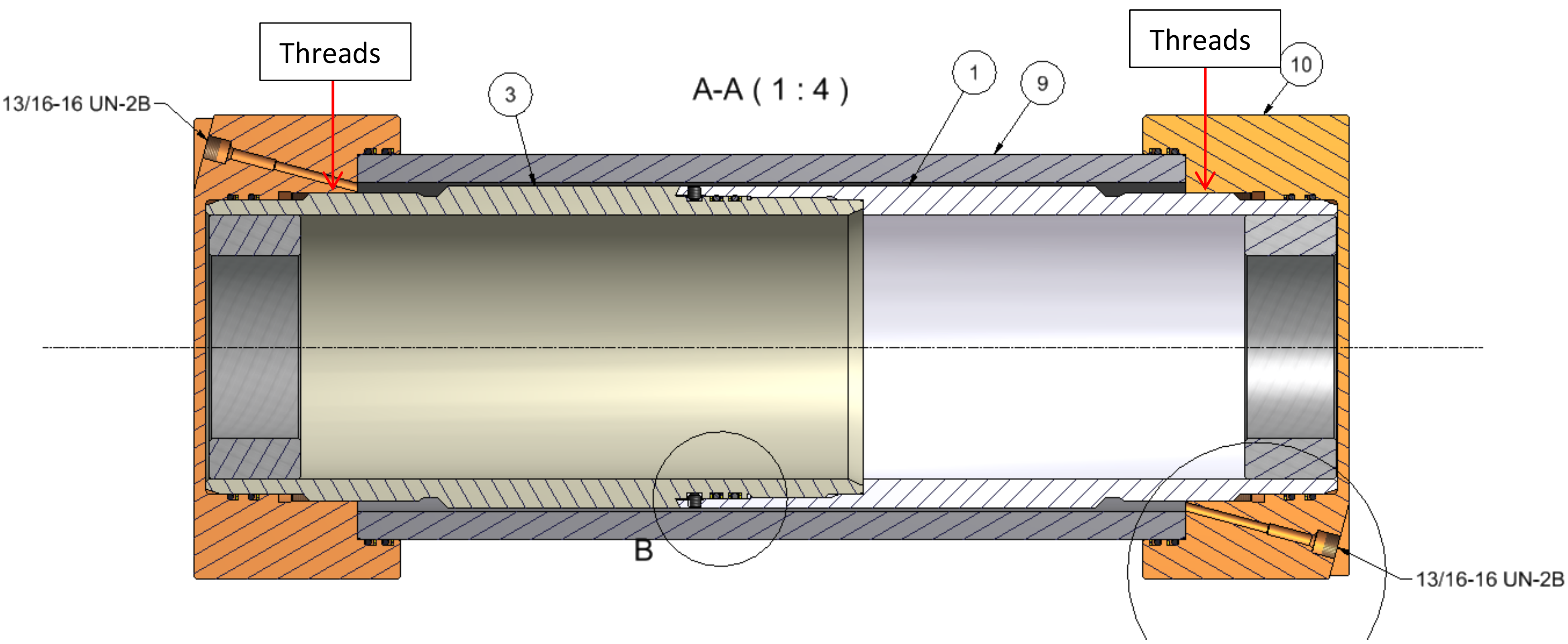


Figure 4-34: Test Setup Design for Alternative 1

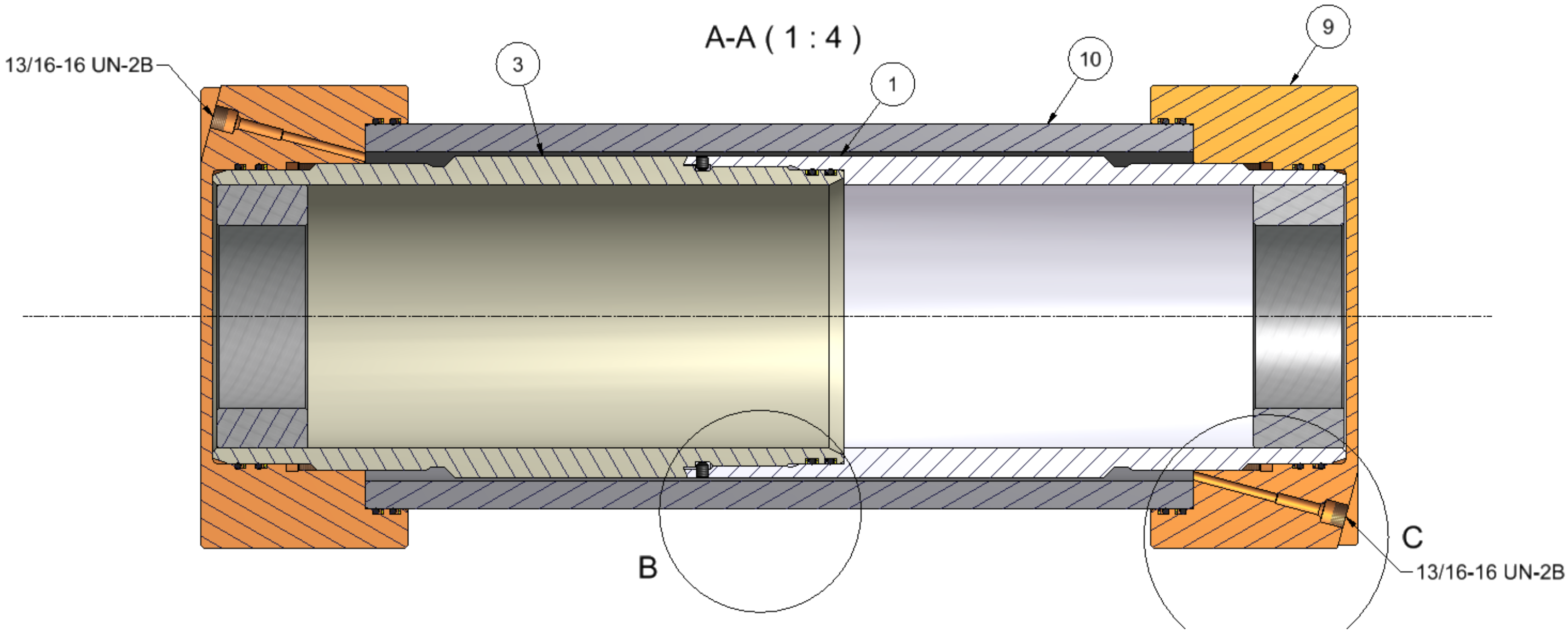


Figure 4-35: Test Setup Design for Alternative 2

In the new test setup design, the tests caps from the initial test setup were replaced by new test caps designed for this specific case. In this test setup there has been added a test casing which is mounted on the test caps. The test caps are connected to the housing and the end coupling by threads. Figure 4-34 illustrates the location of these thread connections. The test casing is going to be entered on the test caps and held in place by screwing the test caps onto the threads on the end of the end coupling and the housing. It was desirable to have an inner diameter for the test casing as small as possible yet still big enough to have the test piece inside. The reason for this was to make the volume of gas necessary to pressurize the tool as small as possible. It was decided to make the outer diameter of the test casing 316 mm. The inner diameter was set to be 270 mm. The test casing is made of AISI4140 125 ksi steel material. The yield limit of this material is 862 MPa. Mechanical drawings of the different parts in both test assemblies can be viewed in Appendix D. All of the dimensional values used in the following calculations can be found in the mechanical drawings.

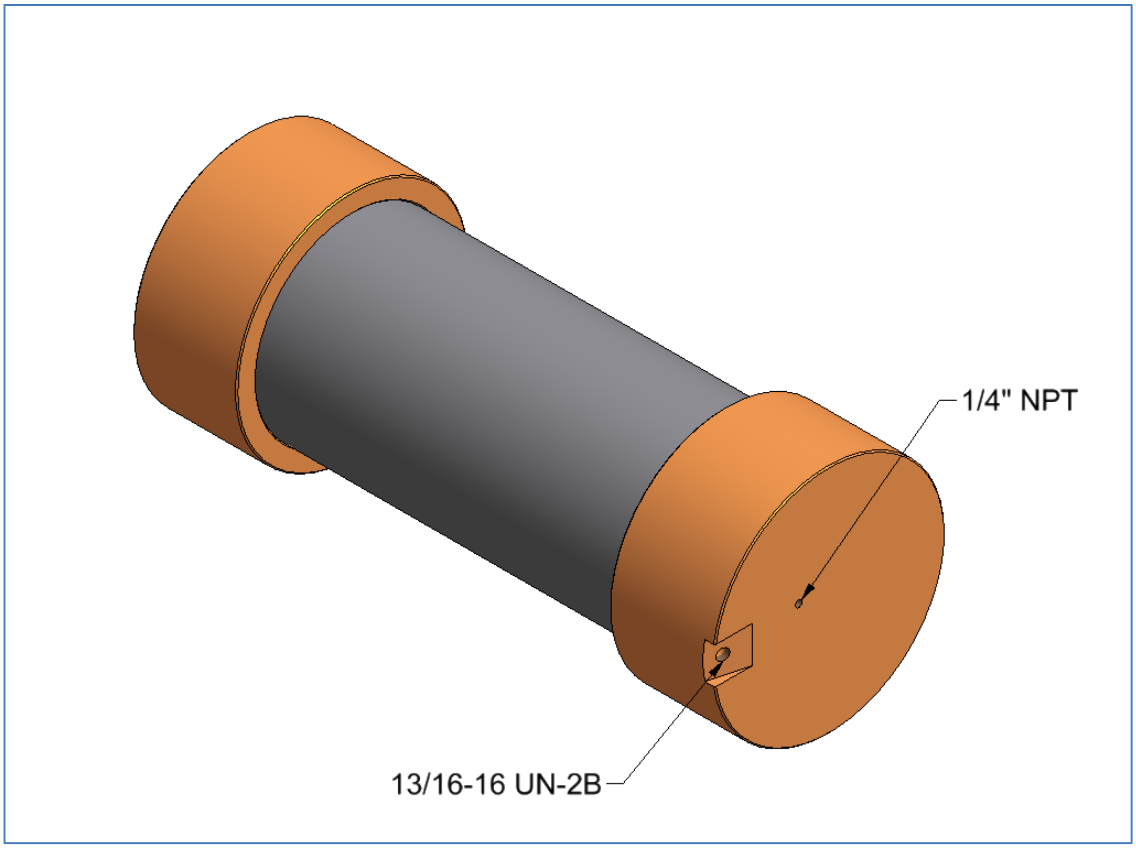


Figure 4-36: Exterior View of Test Setup

The outer diameter of the housing and the end coupling at the seal area is 264 mm. This gives a clearance between the casing and the test piece at the seal area = $\frac{(270mm-264mm)}{2} = 3\ mm.$

The test caps inner diameter at the seal area between the test caps and the test casing is 316 mm. The test cap is going to be made of S355 steel which have yield strength of 355 MPa. The seal between the test casing and the test caps were designed with two O-rings, each with one back-up ring. The inner diameter of the back-up rings is 316 mm. Since the test caps from the initial test design had a seal on the end of the housing and end coupling the new test caps were designed with the same seal. This seal on each test cap is helping to prevent the gas from leaking to the inside of the test piece during the collapse pressure test. To decide the outer diameter of the test caps there were made analyses for different diameter sizes to check the deformation at maximum test pressure. These analyses are presented in Chapter 5.

On the test caps there are 13/16”-16 UN-2B connections. In the pressure test the inlet of the gas will be connected to one of these connections and a pressure transmitter will be connected to the other. These inlets can be viewed in Figure 4-34 – 4-36. There is one 1/4” NPT (National Pipe Thread Taper) connection on each test cap; this can be seen in Figure 4-36. One of these connections is going to be connected to a pipe leading to the water tank that controls bubbles. A 3-dimensional model of the test cap is presented in Figure 4-37.

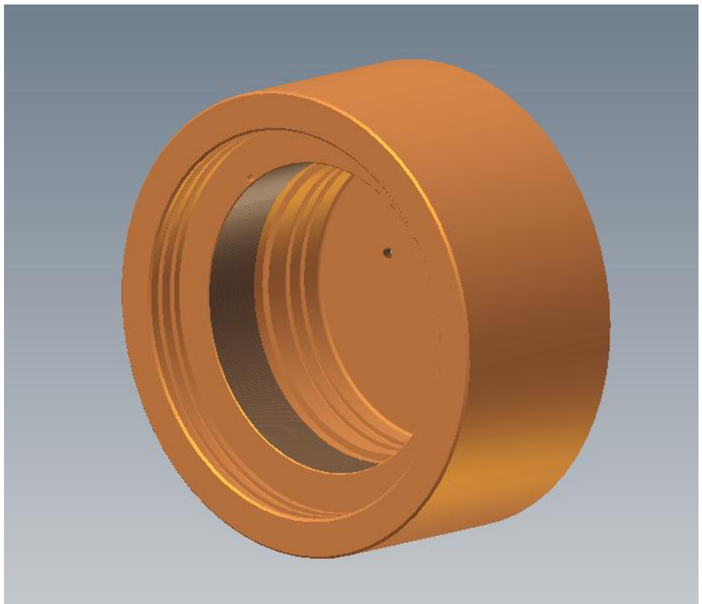
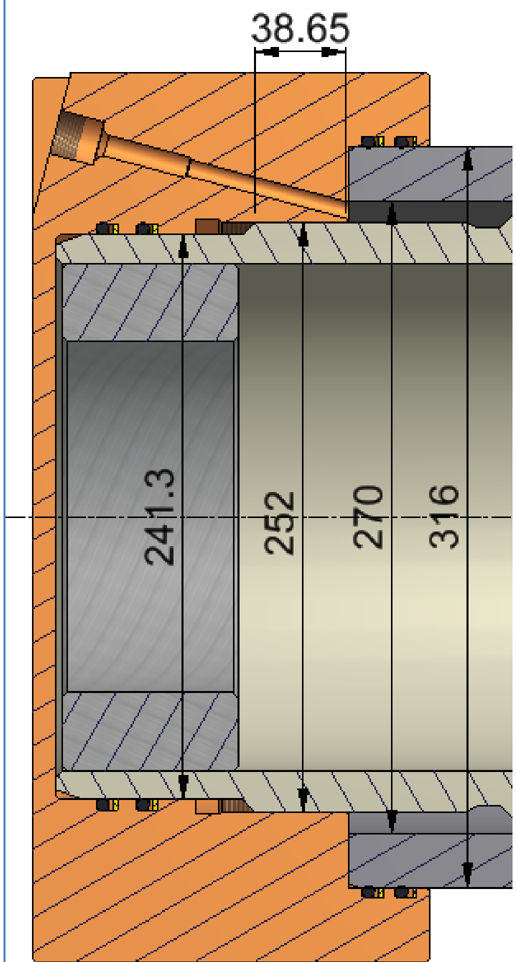


Figure 4-37: 3D View of Test Cap

Calculations for the test equipment are presented in Figure 4-38 – 4-44. To find maximum collapse pressure the parts can be exposed to in the collapse test calculations to find the von Mises yield criterion for the two designs have been made. Figure 4-39 presents the dimensions of the weakest sections of the housing and the end coupling when exposed to collapse pressure. These sections have the smallest cross-sectional area and are at the threads on both the end coupling and the housing for both alternatives. The outer diameter is 246.5 mm at this section on both ends. A safety factor of 1.1 is used in the calculations for maximum collapse pressure. Calculations of von-Mises yield criterion are presented in Figure 4-39 – 4-42. The von Mises yield criterion diagram is presented in Figure 4-42. This give that the maximum collapse pressure with no axial loads is 984 bar = 98.4 MPa. A safety factor of 1.1 give that the maximum collapse pressure is 895 bar = 89.5 MPa. Some of the dimensions used in the calculations are presented in Figure 4-38. Calculations for maximum burst pressure of the test casing are presented in Figure 4-39. A safety factor of 1.25 is used for the test equipment [5]. Maximum burst pressure for the test casing is 1004 bar = 100.4 MPa. This give that a test pressure of 89.5 MPa is applicable. During the pressure test the pressure will be acting on the area between the two seals in the test cap. The outer diameter of this area is diameter at the seal between the test casing and the test cap. This diameter is 316 mm. The inner diameter of this area is at the seal between the test cap and the end of the end cap and the housing. This diameter is 241.3 mm. These dimensions are illustrated in Figure 4-38. Calculations for the threads on the test caps are presented in Figure 4-43 – 4-44. A safety factor of 1.25 is used. The axial force acting on the threads is 2926 kN at maximum collapse pressure of 89.5 MPa. This is a tensile force. The shear stress in the threads is 31.8 MPa. This is less than the yield strength of 355 MPa of the test caps. Maximum collapse pressure of 89.5 MPa is therefore set as maximum pressure for the test. Figure 4-45 is presenting the calculations for tensile force acting on the test piece at different pressures during the pressure test. At maximum pressure the tensile force is 2926 kN.

Calculations for RD-03323 and RD-03360



Input:

$D_o := 316\text{mm}$	Outer diameter (diameter of largest O-ring)
$d_i := 270\text{mm}$	Inner diameter of casing
$D_t := 252\text{mm}$	Diameter of threaded area
$D_i := 241.3\text{mm}$	Diameter of smallest O-ring groove
$\sigma_y := 125\text{ksi} = 862 \cdot \text{MPa}$	Yield limit of test casing, housing and end coupling
$Sf := 1.25$	Safety factor

Figure 4-38: Calculations of Test Equipment 1/7

Burst Calculation for RD-03659 Test Casing

Burst according to API 7G formula A8:

$$Pb := \frac{(D_o - d_i)\cdot\sigma_y}{D_o} = 1255\cdot bar$$ Maximum burst pressure

$$Pb = 18196.2\cdot psi$$

$$P_{bSF} := \frac{Pb}{1.25} = 1004\cdot bar$$ Maximum burst pressure with safety factor = 1.25

Safety factor requirement is SF=1.25

Calculation of von Mises Yield Criterion

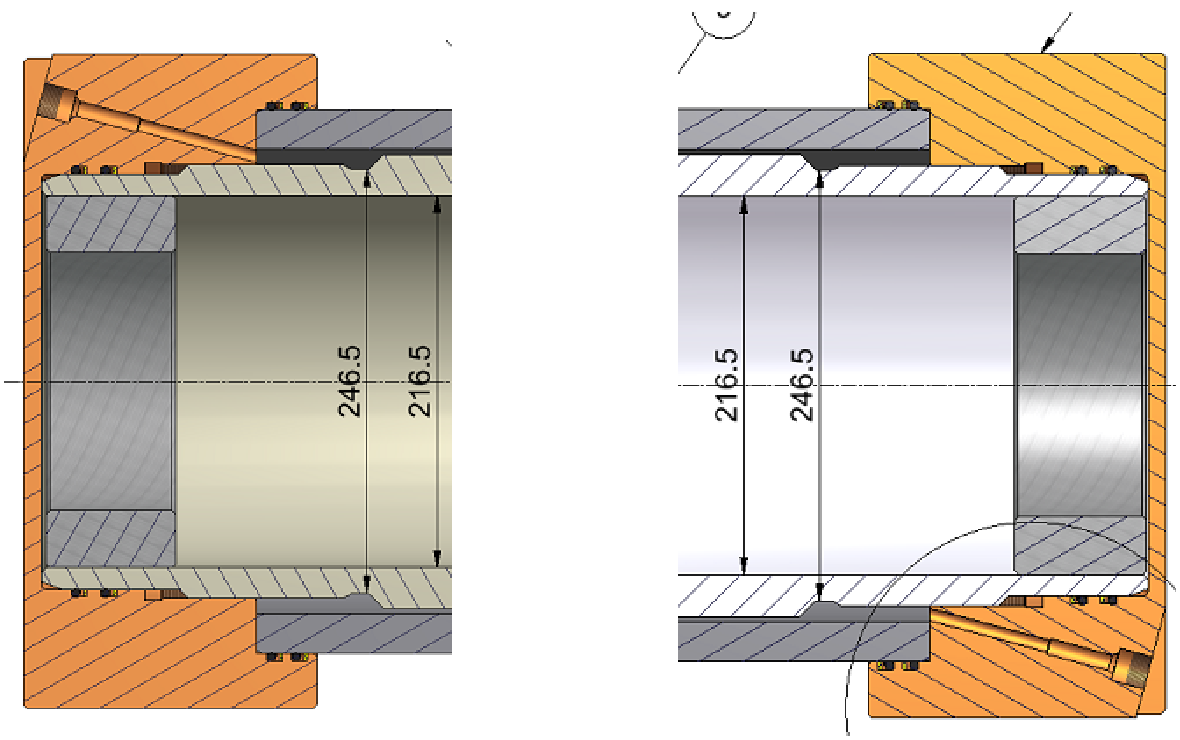


Figure 4-39: Calculations of Test Equipment 2/7

Calculation of von Mises yield criterion for a tube loaded by internal and external pressure and axial stress, ISO 13679 or API RP 5C5 representation
Equations taken from ISO 10400 page 87

$f_y := 125\text{ksi} = 862\cdot\text{MPa}$ Material Yield Limit

$D := 246.5\text{mm}$ Outer diameter at weakest section of End Coupling and Housing

$d := 216.5\text{mm}$ Inner diameter of End Coupling and Housing

I quadrant calculation:

$F1_i := 0\text{N} + i\cdot 100000\text{N}$ Axial load - positive for I and II quadrant

$$\sigma_a := \frac{F1}{\frac{(D^2-d^2)\cdot\pi}{4}}$$ Axial load stress

$$k_{pi} := \frac{D^2+d^2}{D^2-d^2} = 7.749$$

$$k_A := k_{pi}^2 + k_{pi} + 1 = 68.797$$

$$k_B := (1-k_{pi})\sigma_a$$

$$k_C := \sigma_a^2 - f_y^2$$

$$pi1 := \frac{\left[-k_B + \left(k_B^2 - 4k_A\cdot k_C\right)^{\frac{1}{2}}\right]}{2k_A}$$ pressure

II quadrant calculation:

$F2_i := 0\text{N} + i\cdot 100000\text{N}$ Axial load - positive for I and II quadrant

$$\sigma_a := \frac{F2}{\frac{(D^2-d^2)\cdot\pi}{4}}$$ Axial load stress

$$k_{po} := \frac{2\cdot D^2}{(D^2-d^2)}$$

$$k_A := k_{po}^2$$

$$k_B := k_{po}\cdot\sigma_a$$

$$k_C := \sigma_a^2 - f_y^2$$

$$pi2 := \frac{\left[-k_B + \left(k_B^2 - 4k_A\cdot k_C\right)^{\frac{1}{2}}\right]}{2k_A}$$ pressure

Figure 4-40: Calculations of Test Equipment 3/7 [6]

III quadrant calculation:

$F3_i := 0N + i \cdot 100000N \cdot -1$ Axial load - negative for III and IV quadrant

$$\sigma_a := \frac{F3}{\frac{(D^2-d^2)\cdot\pi}{4}}$$ Axial load stress

$$k_{po} := \frac{2 \cdot D^2}{(D^2 - d^2)}$$

$$k_A := k_{po}^2$$

$$k_B := k_{po} \cdot \sigma_a$$

$$k_C := \sigma_a^2 - f_y^2$$

$$pi3 := \frac{\left[-k_B + \left(k_B^2 - 4k_A \cdot k_C\right)^{\frac{1}{2}}\right]}{2k_A}$$ pressure

IV quadrant calculation:

$F4_i := 0N + i \cdot 100000N \cdot -1$ Axial load - negative for III and IV quadrant

$$\sigma_a := \frac{F4}{\frac{(D^2-d^2)\cdot\pi}{4}}$$ Axial load stress

$$k_{pi} := \frac{D^2 + d^2}{D^2 - d^2} = 7.749$$

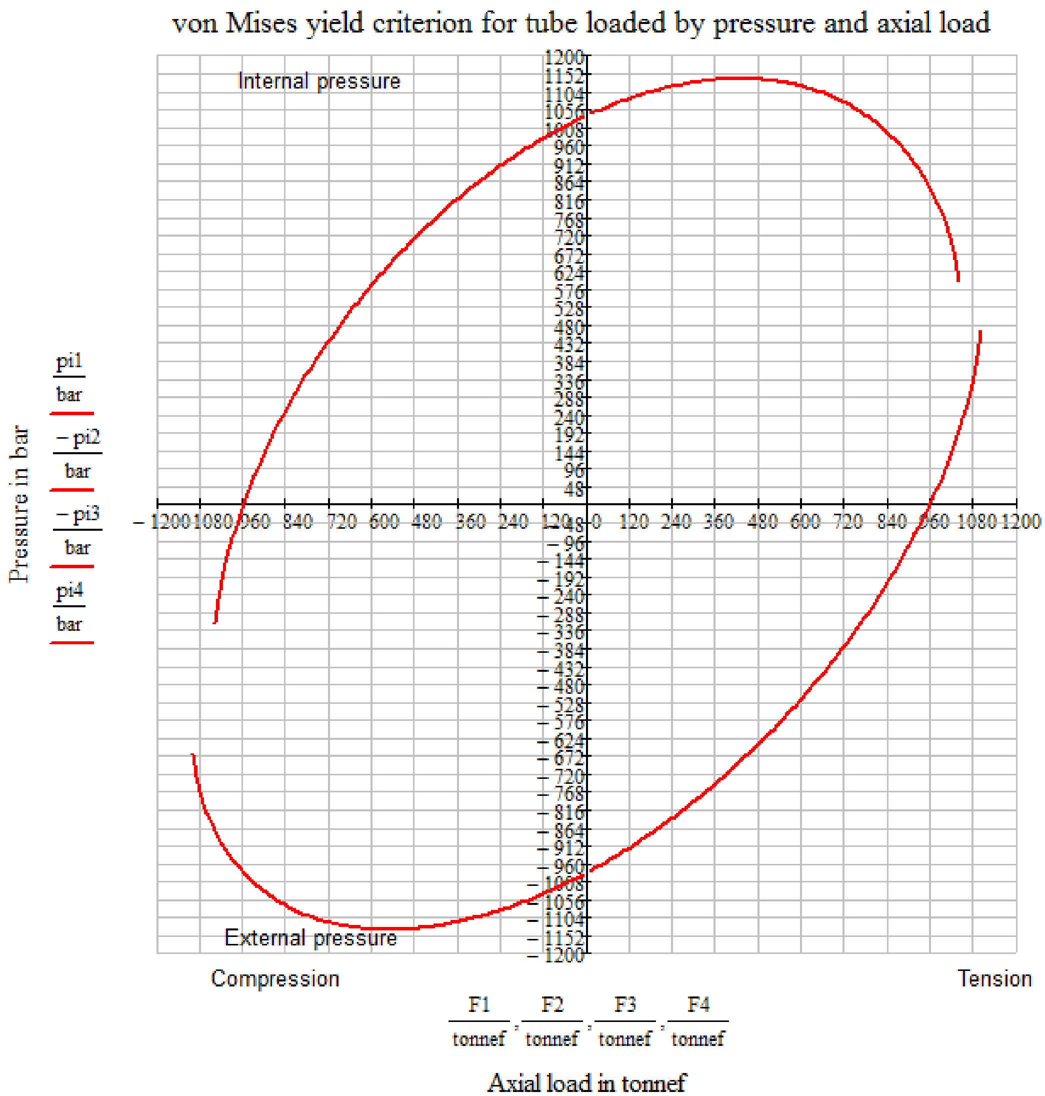
$$k_A := k_{pi}^2 + k_{pi} + 1 = 68.797$$

$$k_B := (1 - k_{pi})\sigma_a$$

$$k_C := \sigma_a^2 - f_y^2$$

$$pi4 := \frac{\left[-k_B + \left(k_B^2 - 4k_A \cdot k_C\right)^{\frac{1}{2}}\right]}{2k_A}$$ pressure

Figure 4-41: Calculations of Test Equipment 4/7 [6]



$P_{cmax} := \frac{(1008 + 960)\text{bar}}{2} = 984 \cdot \text{bar}$ Maximum Collapse Pressure with F=0 from Diagram

$SF_c := 1.1$ Safety factor

$P_{cmaxSF} := \frac{P_{cmax}}{SF_c} = 895 \cdot \text{bar}$ Maximum Collapse Pressure with F=0 and 10% Safety Factor

Figure 4-42: Calculations of Test Equipment 5/7 [6]

Calculations of Stub Acme Threads on Test Cap RD-03660:

$A_p := \left(D_o^{\,2} - D_i^{\,2}\right)\cdot\frac{\pi}{4} = 3.27\times10^{4}\cdot mm^{2}$ Pressurized area

$F_p := P_{cmaxSF}\cdot A_p = 2.925\times10^{3}\cdot kN$ Axial forces in threaded connection

$D_o = 316\cdot mm$

$D_i = 241.3\cdot mm$

Input force

Axial forces [kN] in threaded connection:

$A1 := F_p = 2.925\times10^{3}\cdot kN$ Axial load

Materials and design factors

Values, unless otherwise given

Yield stress S355 $\sigma := 355MPa$

Safety factor $Sf = 1.25$

Thread geometry:

ACME threads:

Threads Per Inch $TPI_{acme} := 4$

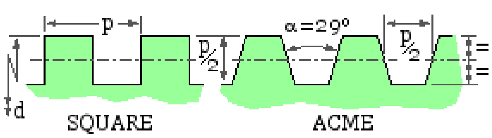
Nominal diameter of threads $D_{th} := 252mm$

Angle of teeth sides $\alpha_{acme} := 14.5deg$

Length of threaded bolt: $L_{chth} := 38.65mm$

Length of threaded nut: $L_{phth} := 38.65mm$

Effective shear area of threaded part:



Thread pitch: $p_{acme} := \frac{1in}{TPI_{acme}}$ $p_{acme} = 6.35\cdot mm$

Thread height: $h_{acme} := \frac{p_{acme}}{2}$ $h_{acme} = 3.17\cdot mm$

Root thickness of threads: $t_{acme} := h_{acme} + h_{acme}\cdot\tan(\alpha_{acme})$ $t_{acme} = 4\cdot mm$

Inner diameter of threads: $D_{ith} := D_{th} - 2\cdot h_{acme}$ $D_{ith} = 245.65\cdot mm$

Figure 4-43: Calculations of Test Equipment 6/7 [7]

Number of effective threads in threaded connection:

$$N_{thread} := \mathrm{floor}\left(\frac{\min(L_{chth}, L_{phth})}{p_{acme}}\right) - 2 \qquad N_{thread} = 4$$

Effective shear area of threaded connection: $A_{sthread} := N_{thread} \cdot t_{acme} \cdot \pi \cdot D_{ith}$

$$A_{sthread} = 12335.7 \cdot mm^2$$

Shear stress in treaded connection

Shear stress:

$$\tau_{thread} := \frac{A1}{A_{sthread}} \qquad \tau_{thread} = 237.1 \cdot MPa$$

Utilisation of threaded connection:

$$UF := \frac{\tau_{thread} \cdot Sf}{\sigma} \qquad UF = 0.83$$

Figure 4-44: Calculations of Test Equipment 7/7 [7]

Calculation of Axial Force in Test Piece During Collapse Pressure Test

$D_o := 316mm$ Outer diameter (diameter of largest O-ring)

$D_i := 241.3mm$ Diameter of smallest O-ring groove

$A_p := \left(D_o^{\ 2} - D_i^{\ 2}\right)\cdot\frac{\pi}{4} = 32696\cdot mm^2$ Pressurized area

Axial forces in threaded connection

$P_1 := 550bar$ $F_{p1} := \left(P_1\cdot A_p\right) = 1798\cdot kN$

$P_2 := 600bar$ $F_{p2} := \left(P_2\cdot A_p\right) = 1962\cdot kN$

$P_3 := 650bar$ $F_{p3} := \left(P_3\cdot A_p\right) = 2125\cdot kN$

$P_4 := 700bar$ $F_{p4} := \left(P_4\cdot A_p\right) = 2289\cdot kN$

$P_5 := 750bar$ $F_{p5} := \left(P_5\cdot A_p\right) = 2452\cdot kN$

$P_6 := 800bar$ $F_{p6} := \left(P_6\cdot A_p\right) = 2616\cdot kN$

$P_7 := 850bar$ $F_{p7} := \left(P_7\cdot A_p\right) = 2779\cdot kN$

$P_8 := 895bar$ $F_{p8} := \left(P_8\cdot A_p\right) = 2926\cdot kN$

Figure 4-45: Calculation of Axial Loads on Test Piece during Collapse Pressure Test

5 Analyses

To verify and check the design alternatives analyses were made. All of the necessary analyses are made by the use of the software ANSYS version 14.0. The analysis method in ANSYS used for the analyses in this project is Static Structural. The analyses for the final alternative design proposals are to be compared with analyses for the existing design. The most relevant analyses reports can be viewed in Appendix E.

5.1 Design basis

Results from the different analyses give indications whether the design needed to be revised or if could be transferred to pressure testing. The different parts of the designs which have been analyzed are presented in the following chapters. 2-dimensional and 3-dimensional analyses have been made. To make the 3-dimensional analyses time efficient the analyses models were reduced by 5/6 of the total size of the model. This means that only a 60° sector of the model is analyzed. This has no impact on the analyses results. For the 2-dimensional analyses the models had to be drawn in ANSYS. The geometry of the 2-dimensional models is set to axisymmetric and the results are therefore valid for full sized models.

5.1.1 Analysis Models and Analysis Setup for Existing Design

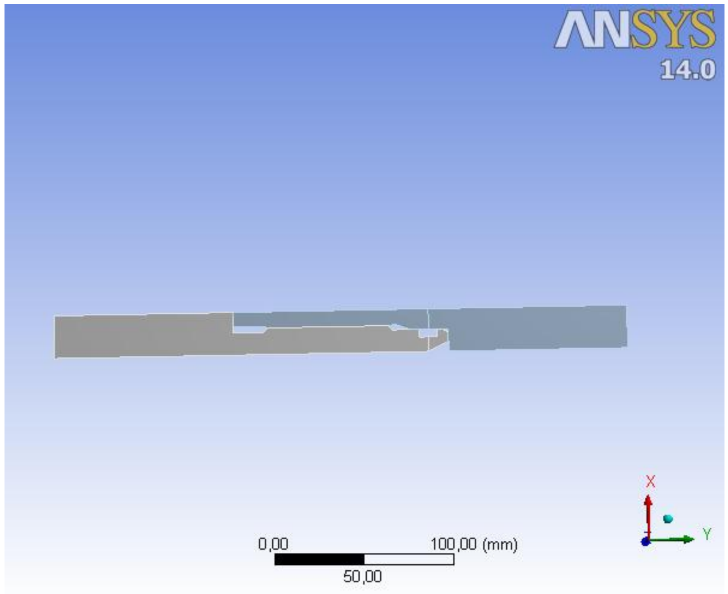


Figure 5-1: 2D Analysis Model of Existing Design [2]

To make the analysis time efficient a two dimensional analysis model of the existing design has been made. This model has been drawn in ANSYS and is presented in Figure 5-1. The sleeve has been excluded from this model and the housing has been given a smaller inner diameter as done for Alt. 1 and Alt.2. This is to make it easier to compare the three designs. In the analysis the existing design is exposed to collapse pressure together with corresponding tensile force. The pressures and the tensile forces used are the same as for the pressure test of Alt. 1 and Alt. 2. The tensile force is caused by the pressure acting on the test caps during the pressure test for the two alternatives. This analysis is therefore presenting how the existing design would behave in a similar test. Calculations in Figure 4-45 are presenting the pressures and tensile forces used in this analysis. Maximum pressure of 89.5 MPa is used in this analysis. At this pressure the tensile force is equal to 2926 kN. Figure 5-2 presents the contact surfaces between the end coupling and the housing in the existing design used in this analysis. A very fine mesh has been used and is presented in Figure 5-3. The geometry has been set to axisymmetric and the results are therefore valid for a fully sized model. The pressurized surfaces of the design model can be viewed in the Figure 5-4. The threads are exposed to collapse pressure in this design. Figure 5-5 is presenting the surfaces on the model the tensile forces and the pressure is acting on. Results from this analysis are presented in section 5.2.1.

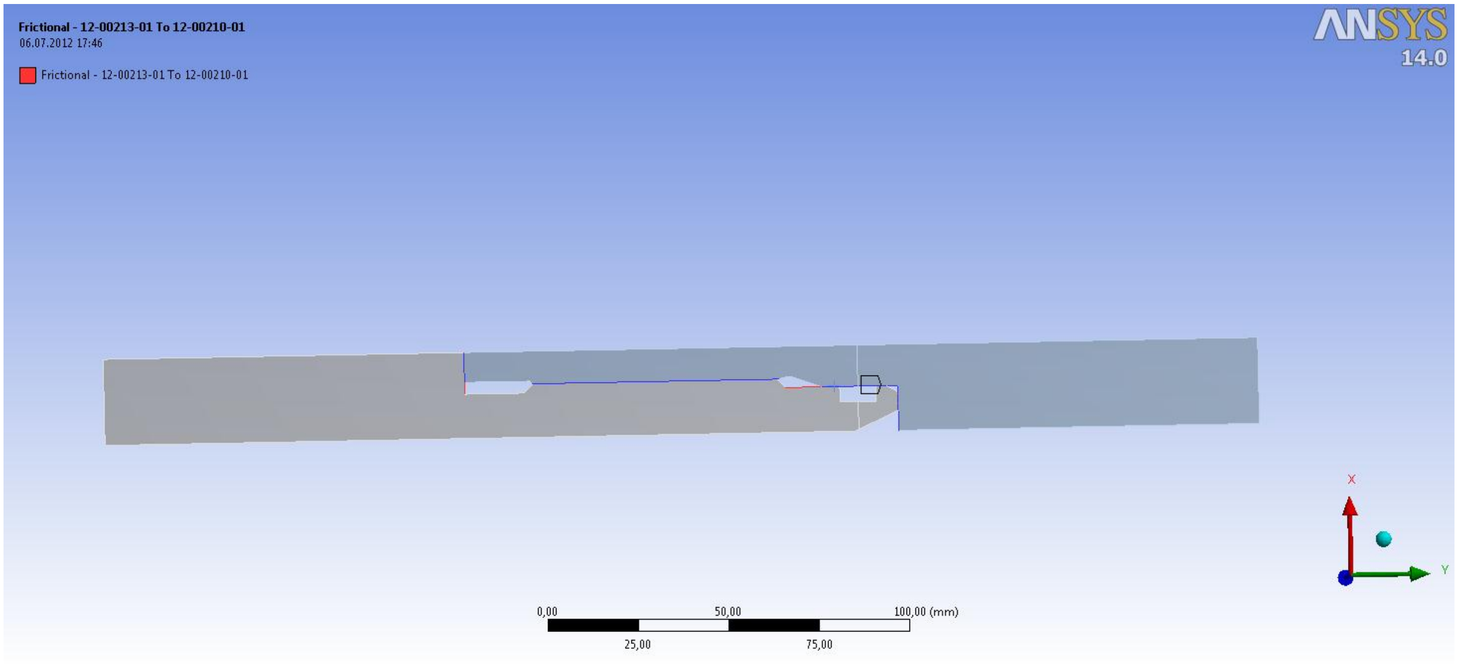


Figure 5-2: Connections in Analysis Model of Existing Design

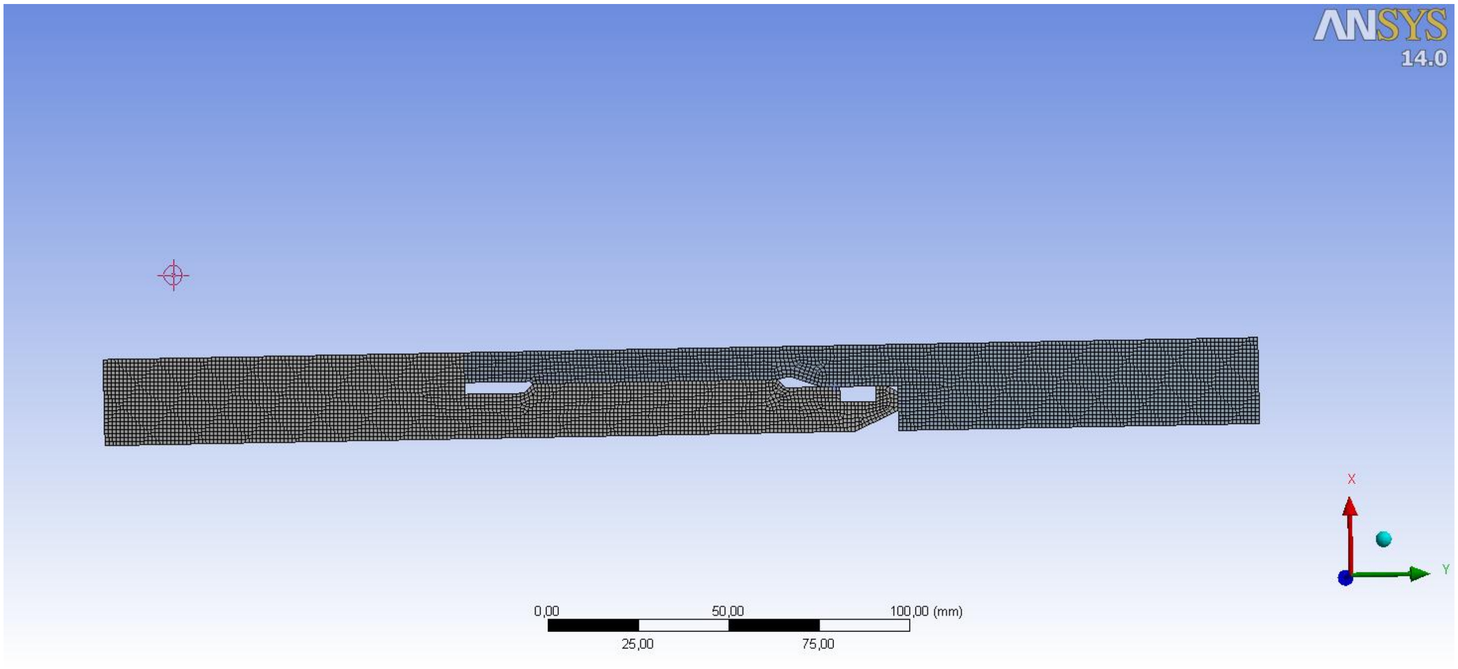


Figure 5-3: Mesh of Analysis Model of Existing Design

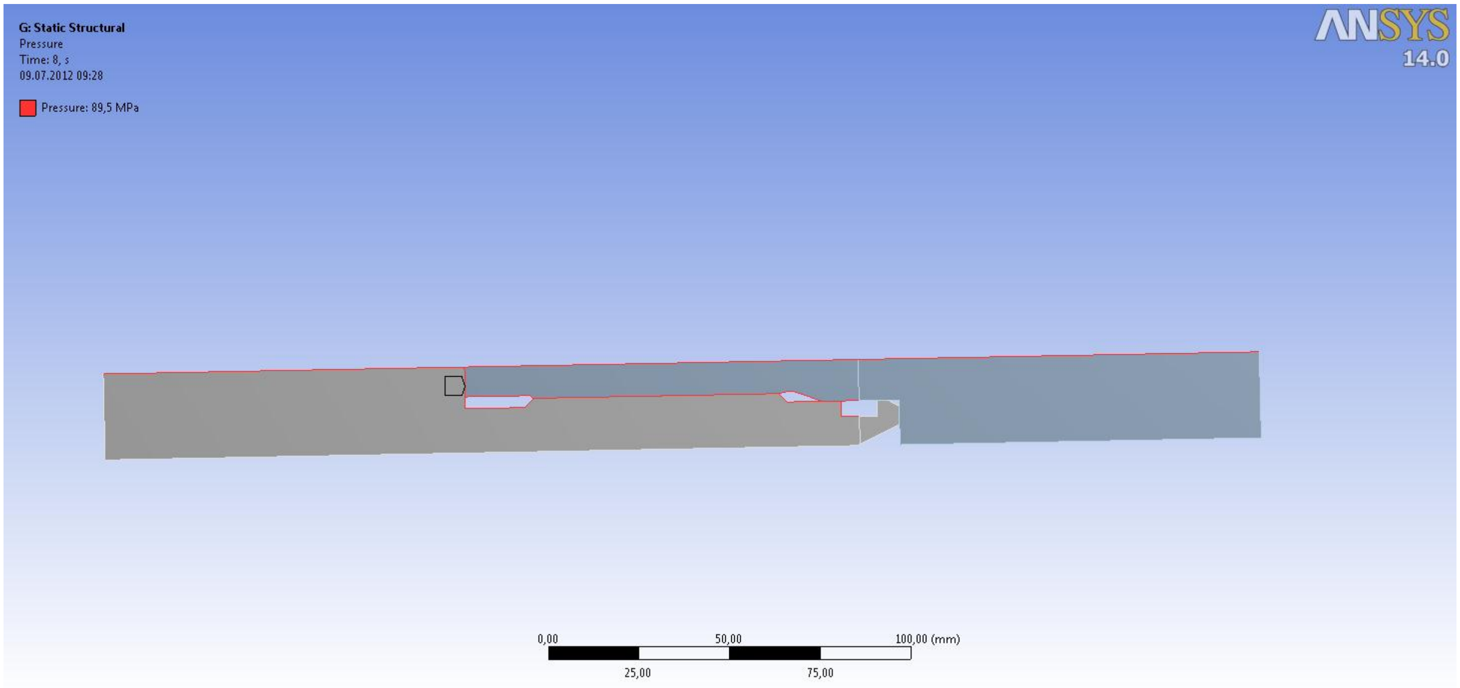


Figure 5-4: Pressurized Surfaces on Existing Design

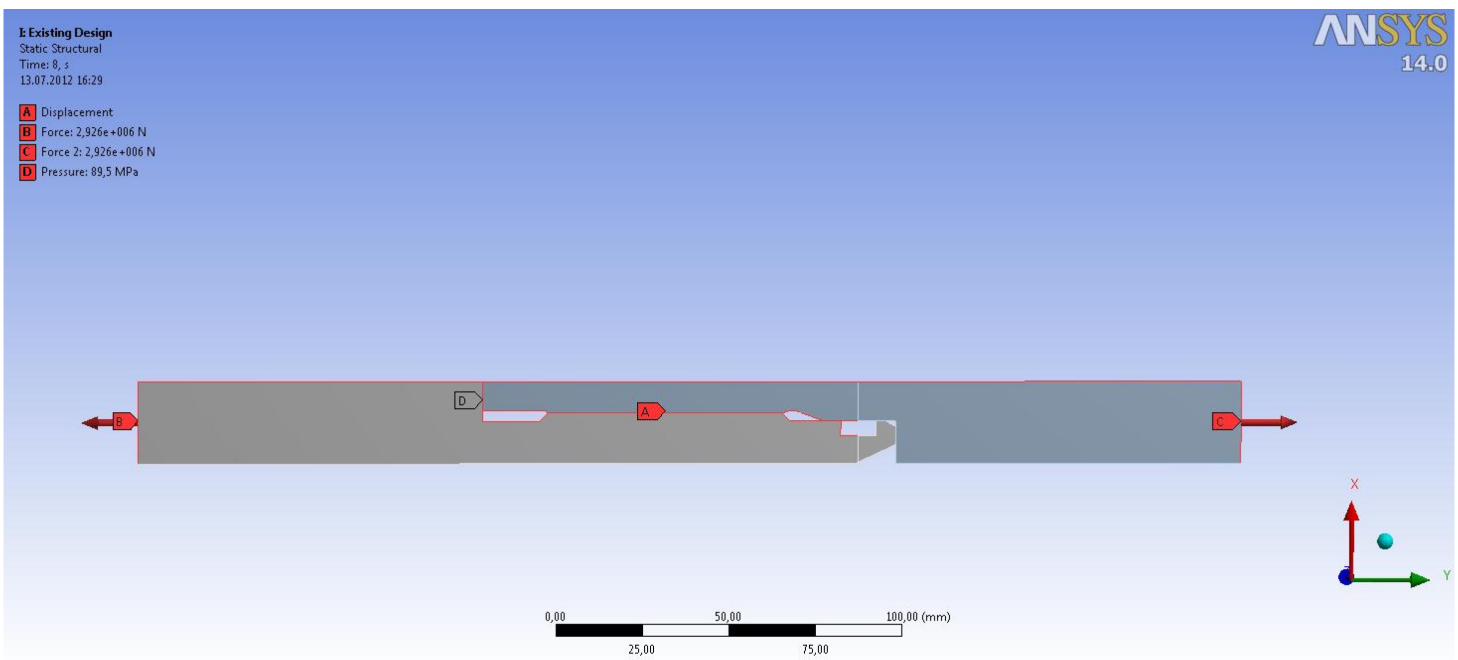


Figure 5-5: Static Structural Setup of Existing Design

5.1.2 Analysis Models and Setup for Different Housing Design Proposals

To make the equipment for the pressure tests simpler it was desirable to make a model that excludes the sleeve without excluding the support it provides to the tool. The housing in the alternative seal design suggestions had to be designed such that it provided the same support as if there was a sleeve present. Analyses were performed for different housing design suggestions to decide which design alternative to choose based on results from these analyses. For simplification the analyses are only performed for the housing in Alt.1. Results from these analyses were also used for Alt.2 when dimensioning the inner diameter of the housing for this design. Two different design alternatives for the inside of the housing are proposed. Analyses of the two proposals are made and the results from these analyses had to be compared with an analysis for a design with a sleeve. Each of the analyses models were 5/6 smaller than the full sized model. This means that only a 60° sector of the model is analyzed. Set-screws, O-rings and back-up rings have been removed to simplify the models. The models have also been shortened. This was done to make the analyses time efficient. This has no impact on the results. In all three of the analyses the models were exposed to the same collapse pressure. This pressure is set to 120 MPa in these analyses. The models have been made using Autodesk Inventor. Figure 5-6 presents the analysis model of the design with a sleeve placed on the inside. The sleeve in this model is positioned as if the C-Flex SS is set in a permanently closed position. In both these proposals the housing has been given the same inner diameter as the end coupling and the sleeve. Housing alternative 1 is presented in Figure 5-7 and housing alternative 2 is presented in in Figure 5-8. The difference is that housing alternative 2 has a 20 mm gap between thickened section and the end of the end coupling on the inside. This gap is illustrated in Figure 5-8. In housing alternative 1 there is no gap between the end of the end coupling on the inside and the section of the housing which is made thicker.

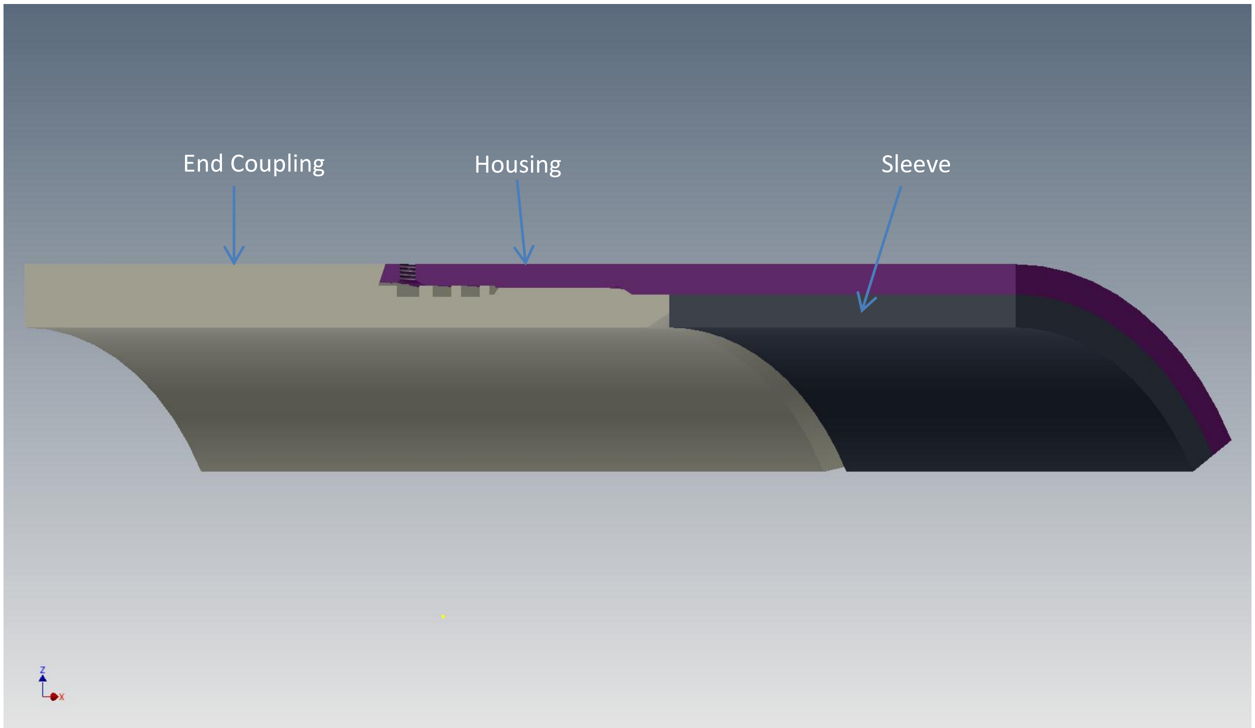


Figure 5-6: 3D Analysis Model of Design with Sleeve

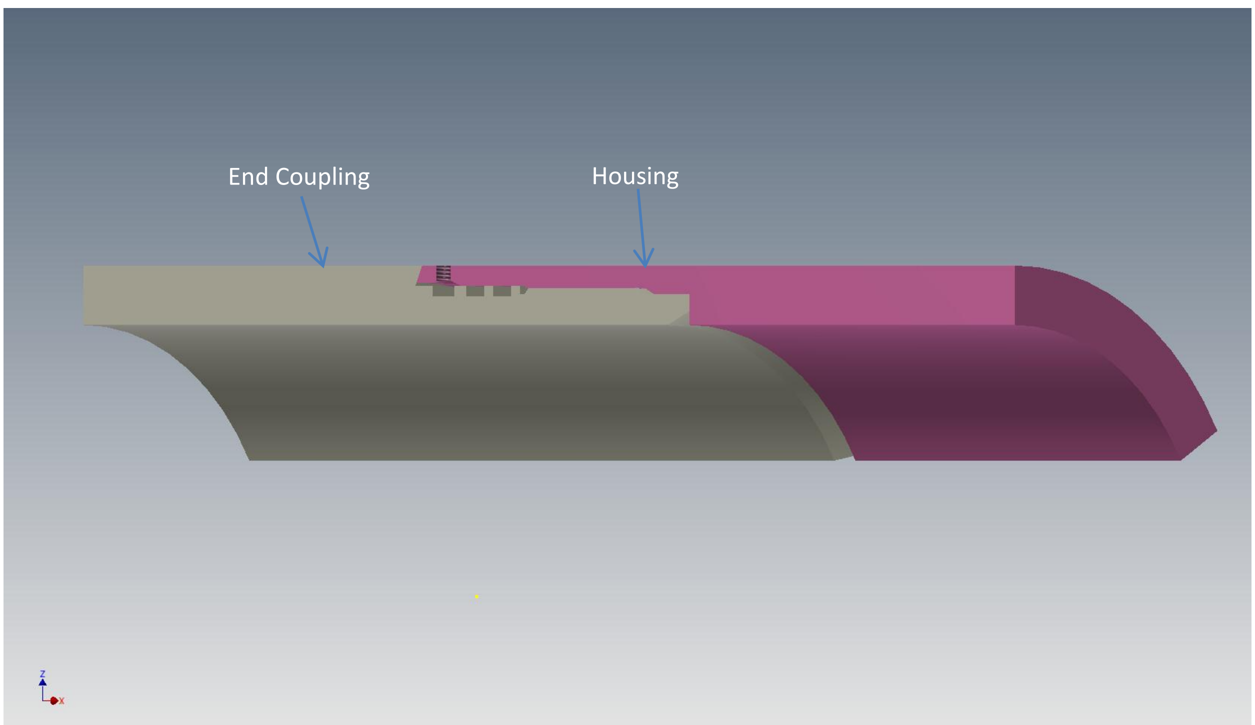


Figure 5-7: 3D Analysis Model of Housing Alternative 1

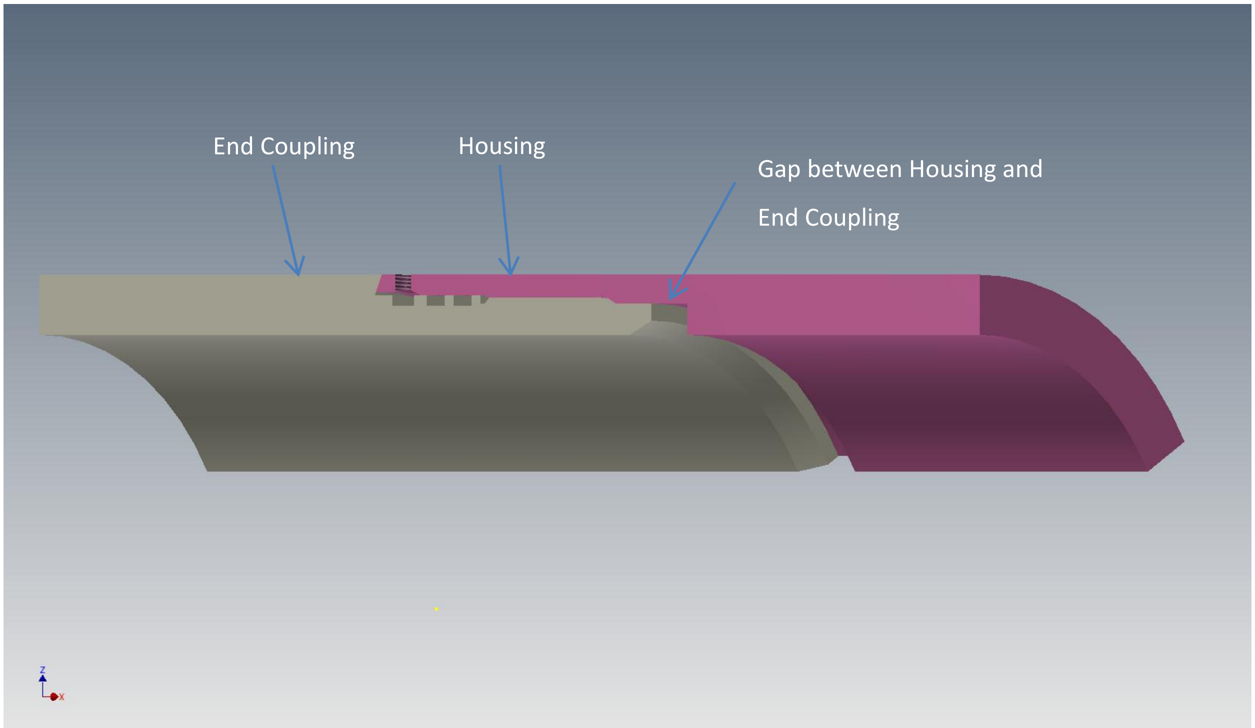


Figure 5-8: 3D Analysis Model of Housing Alternative 2

Figure 5-9 presents the mesh of the model with the sleeve. Figure 5-10 presents the pressurized surfaces of this model. A 120 MPa pressure is applied in all three of the analyses. Mesh of housing alternative 1 is presented in Figure 5-11. Figure 5-12 presents the pressurized surfaces on this model. Figure 5-13 presents the mesh of housing alternative 2 and Figure 5-14 presents the pressurized surfaces on this model. These analyses do not take axial forces into consideration. This is to simplify the analysis. A hexagonal mesh has been used for all the models. The results from these analyses are presented in section 5.2.2.

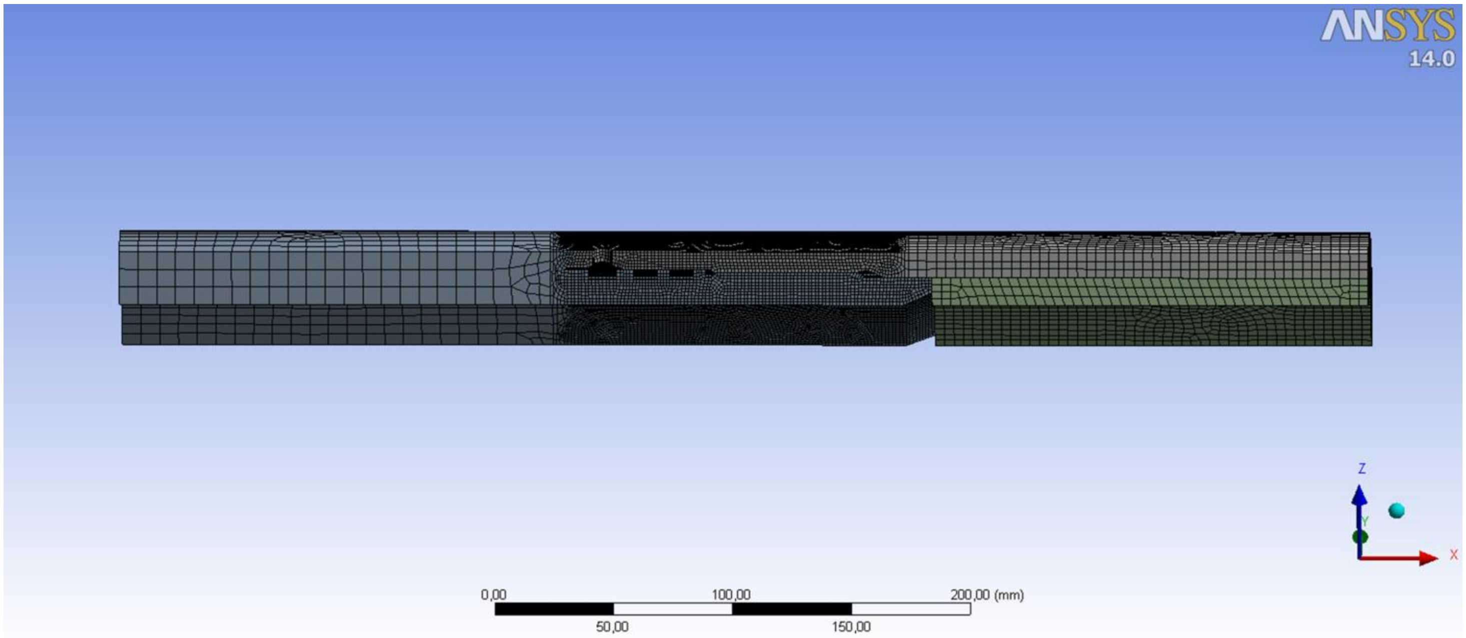


Figure 5-9: Mesh of Model with Sleeve

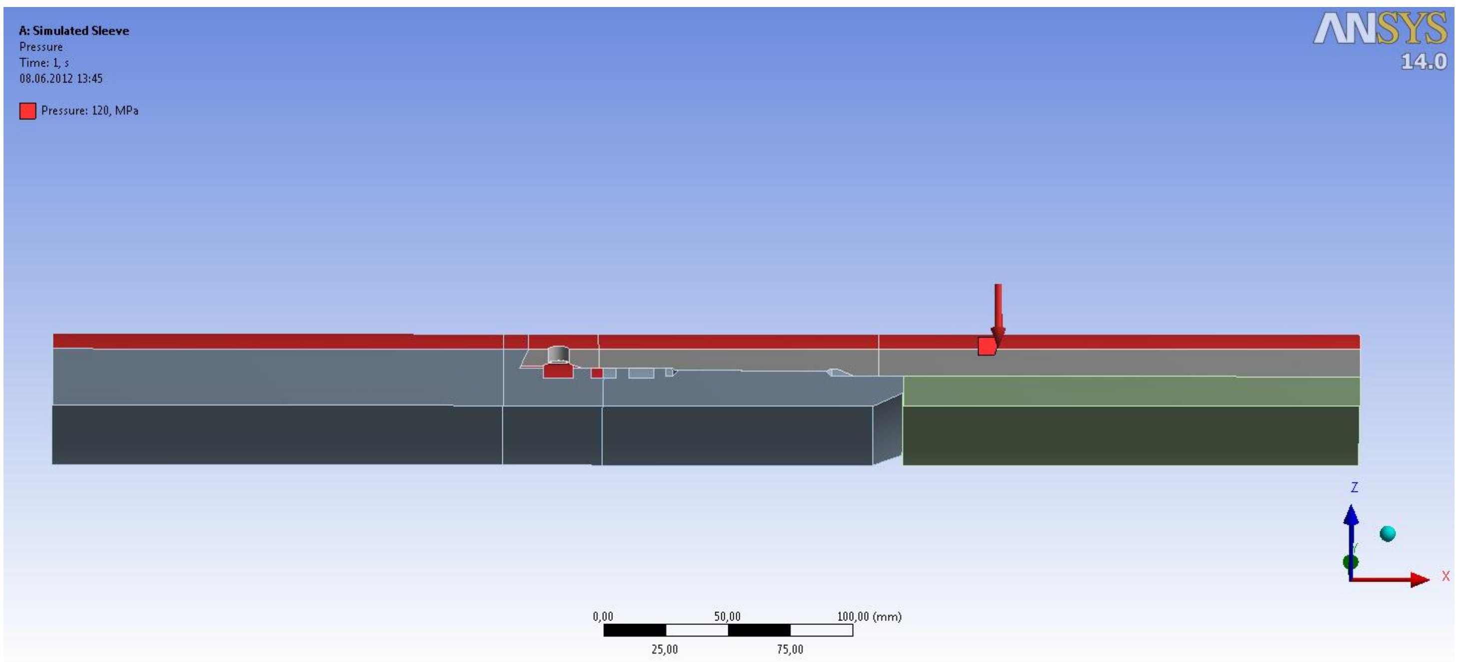


Figure 5-10: Pressure Applied on Model with Sleeve

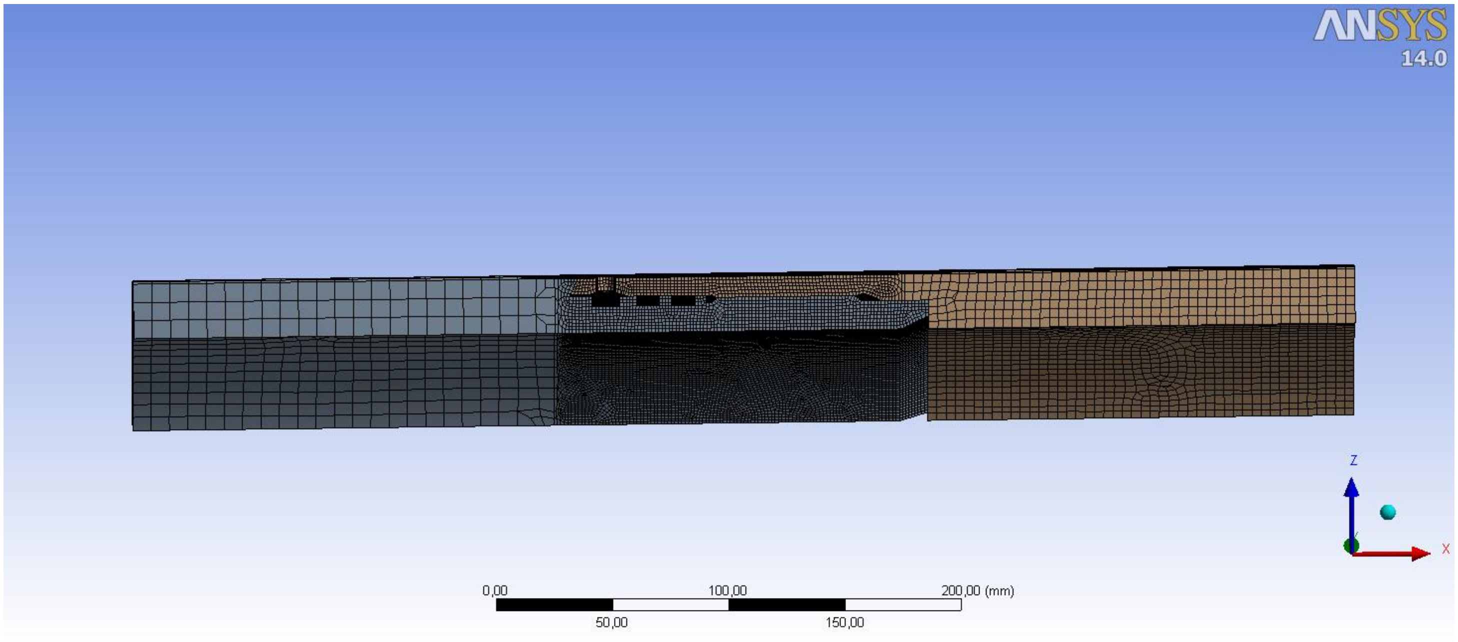


Figure 5-11: Mesh of Model with Housing Alternative 1

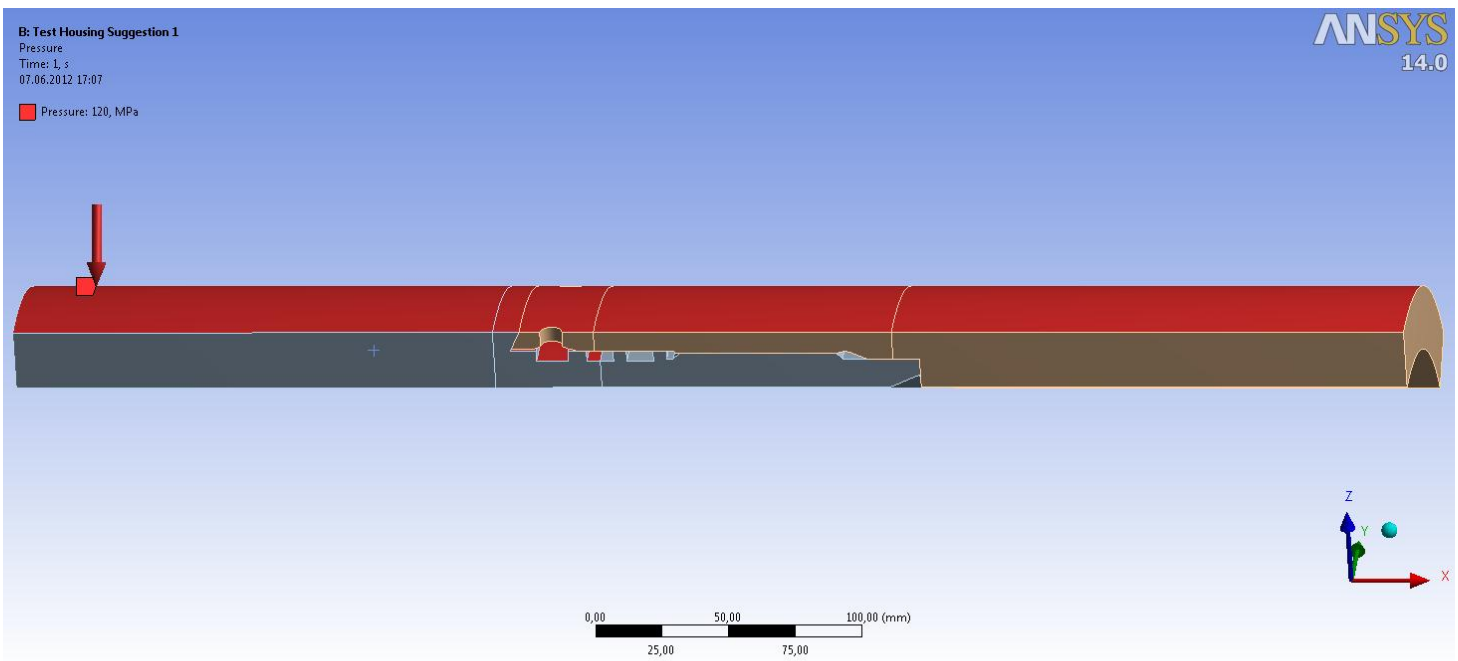


Figure 5-12: Pressure Applied on Model with Housing Alternative 1

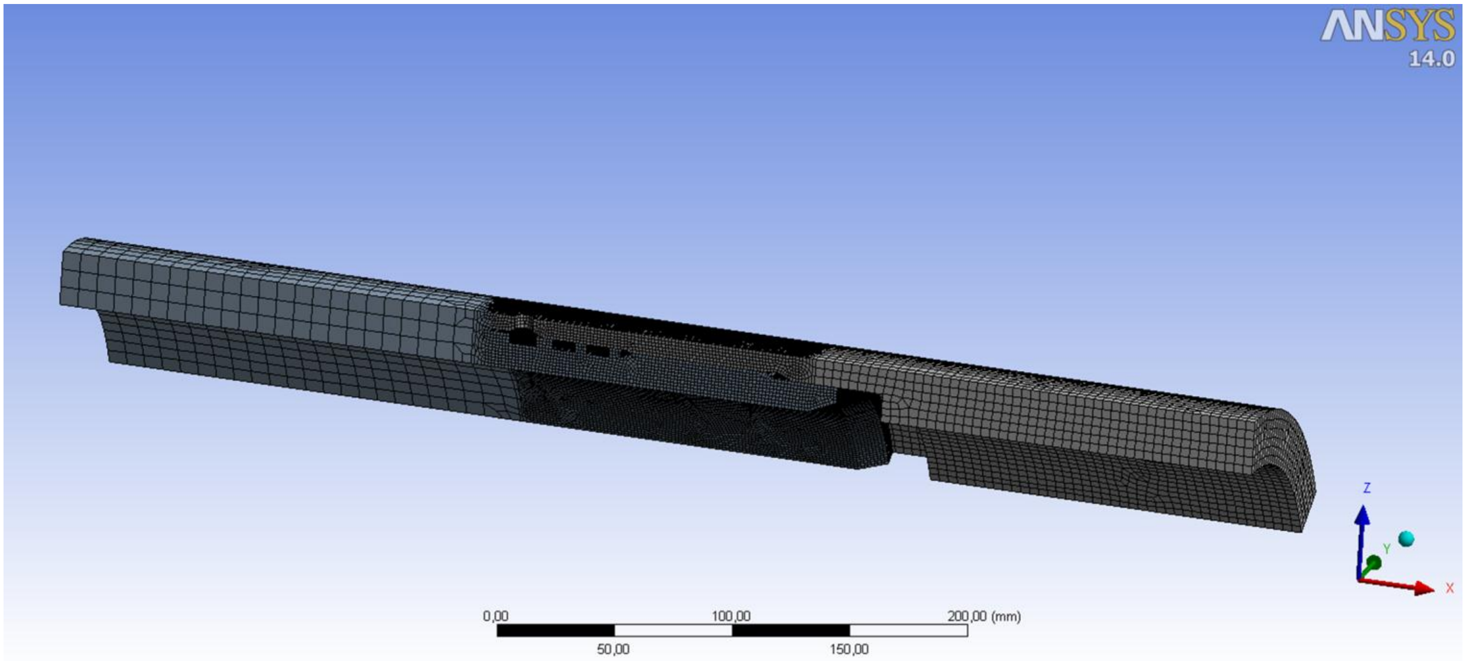


Figure 5-13: Mesh of Model with Housing Alternative 2

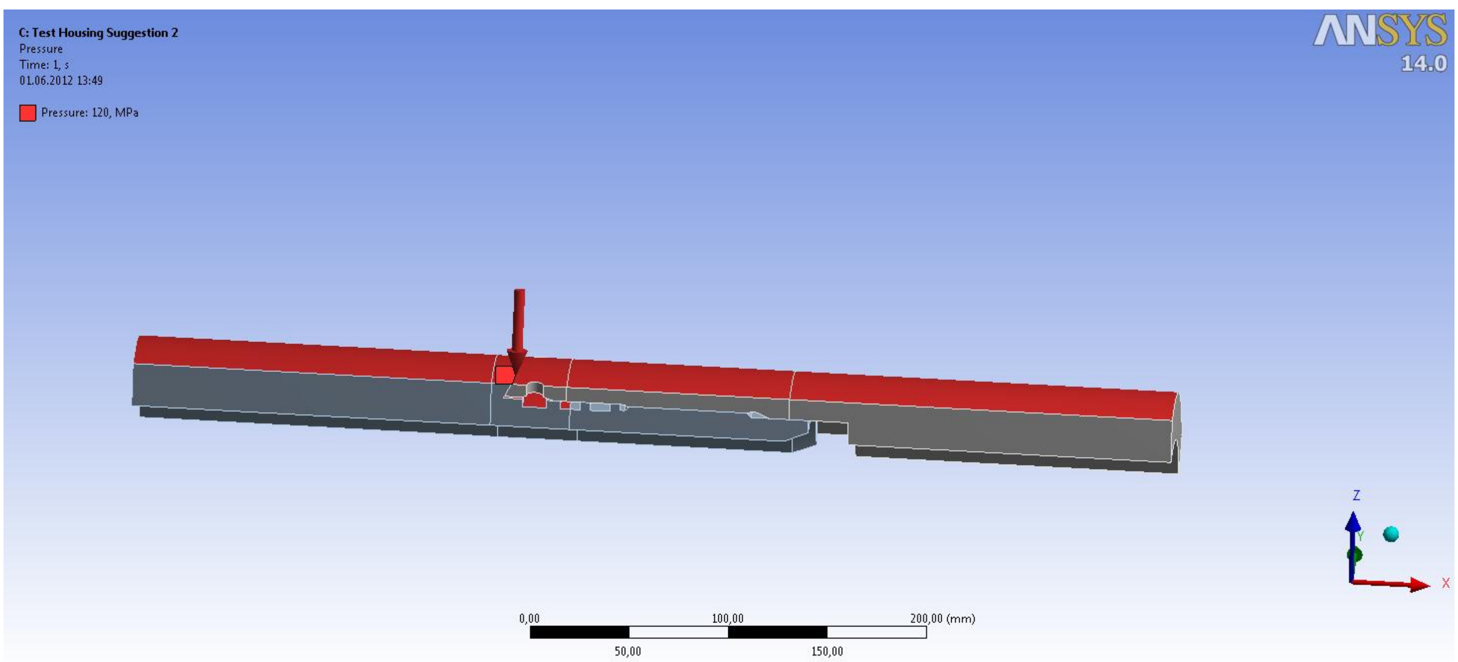


Figure 5-14: Pressure Applied on Model with Housing Alternative 2

5.1.3 Analysis Models and Setup for Alternative 1

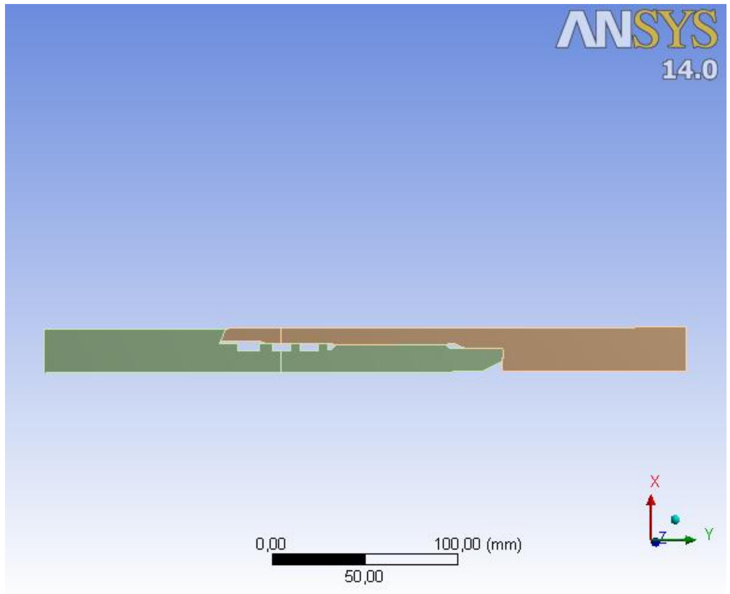


Figure 5-15: 2D Analysis Model of Alternative 1

A two dimensional analysis model of Alt. 1 has been made to make the analysis time efficient. This model has been drawn in ANSYS and is presented in Figure 5-15. In the analysis the model is exposed to collapse pressure together with corresponding tensile force. The pressures and the tensile forces used are the same as this model will be exposed to in the pressure test. The tensile forces are caused by the pressure acting on the test caps during the pressure test for the two alternatives. This analysis is demonstrating how this design alternative will behave in the pressure test. Calculations in Figure 4-45 are presenting the pressures and tensile forces used in this analysis. Figure 5-16 presents the contact surfaces between the end coupling and the housing in this design used in this analysis. A very fine mesh has been used and is presented in Figure 5-17. The geometry has been set to axisymmetric and the results are therefore valid for a fully sized model. The pressurized surfaces of the design model can be viewed in the Figure 5-18. In this design the threads are not exposed to collapse pressure. Maximum pressure in this analysis has been set to maximum collapse pressure for the pressure test. This pressure is 89.5 MPa. At this pressure the tensile force is equal to 2926 kN. Figure 5-19 is presenting the surfaces on this model the tensile forces and the pressure is acting. Results from this analysis are presented in section 5.2.3.

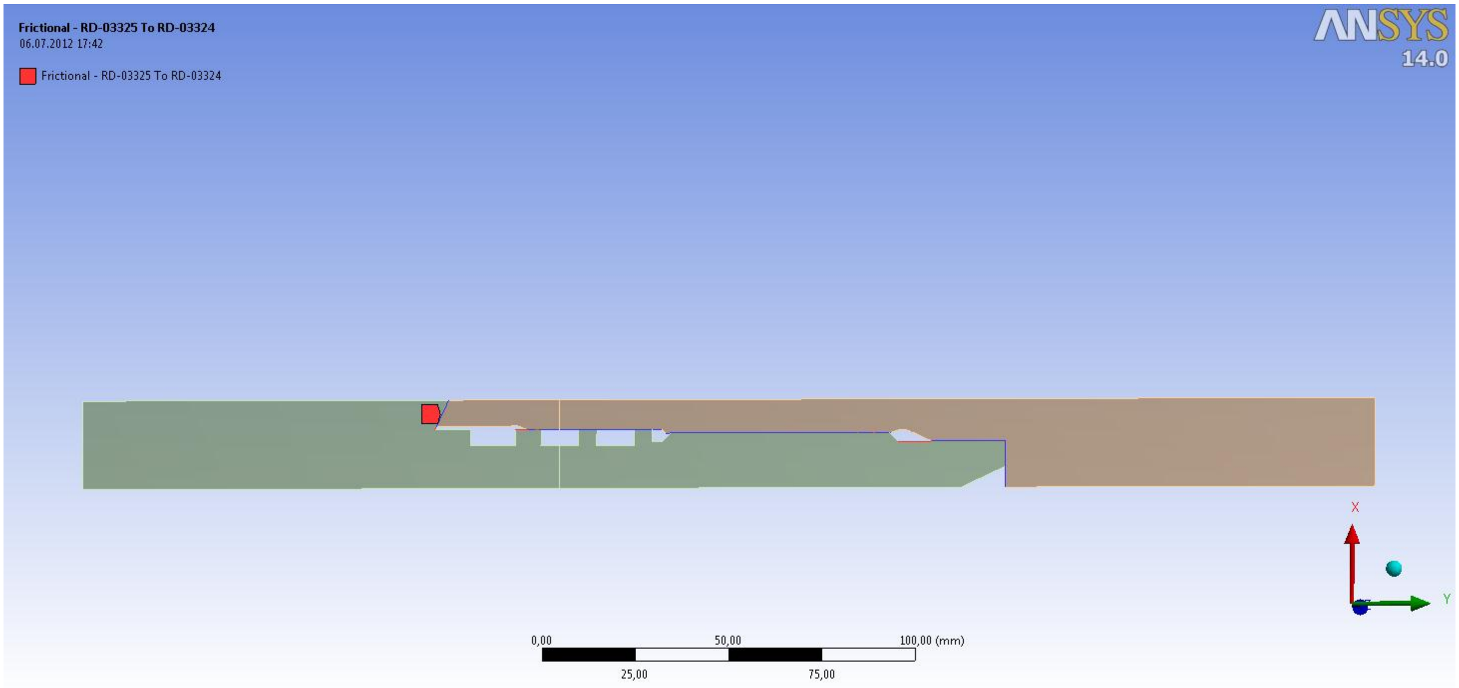


Figure 5-16: Connections in Analysis Model of Alt. 1

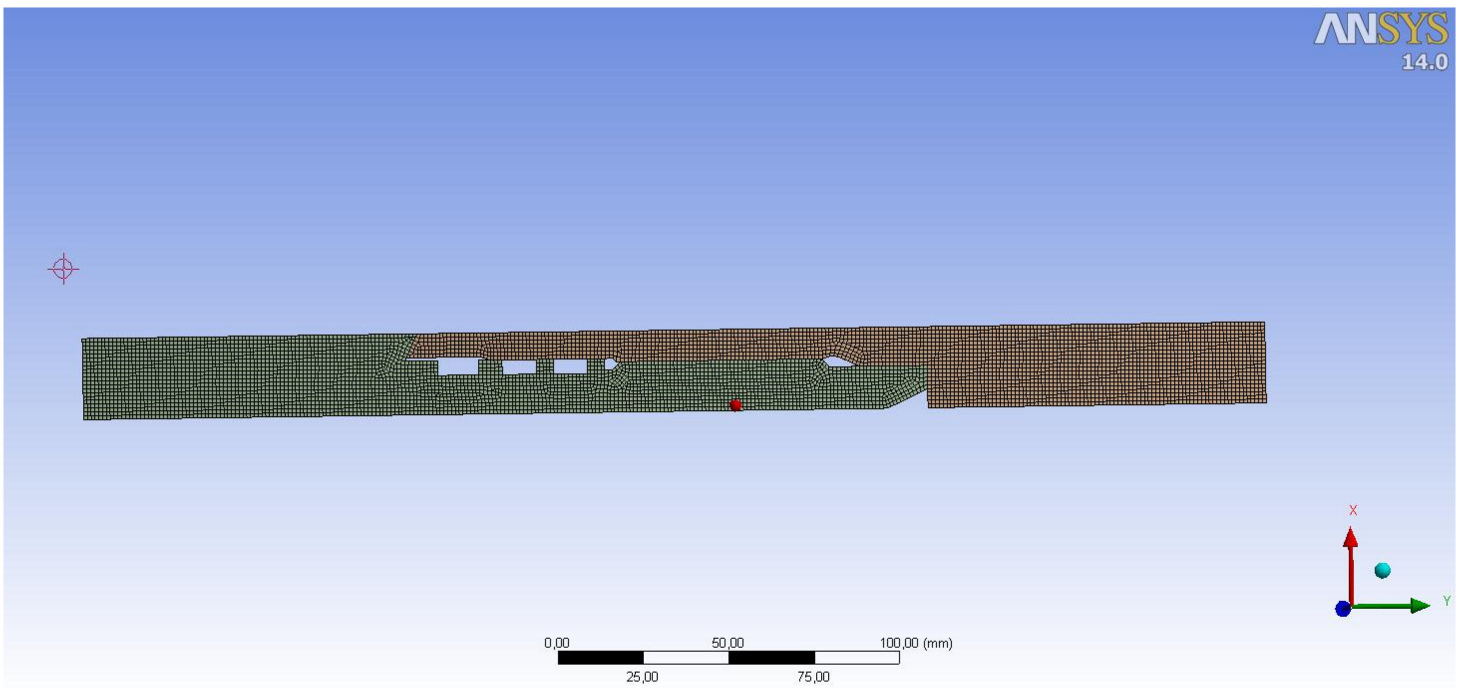


Figure 5-17: Mesh of Analysis Model of Alt. 1

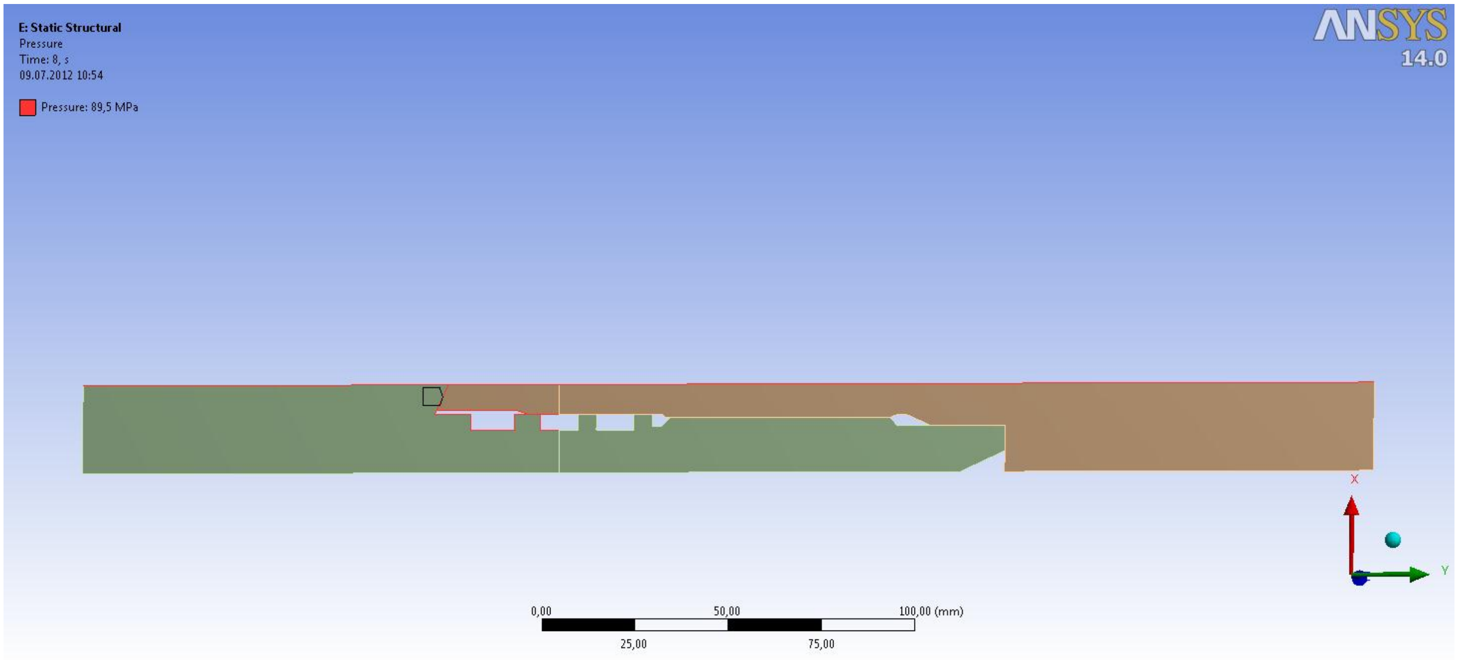


Figure 5-18: Pressurized Surfaces on Alt. 1

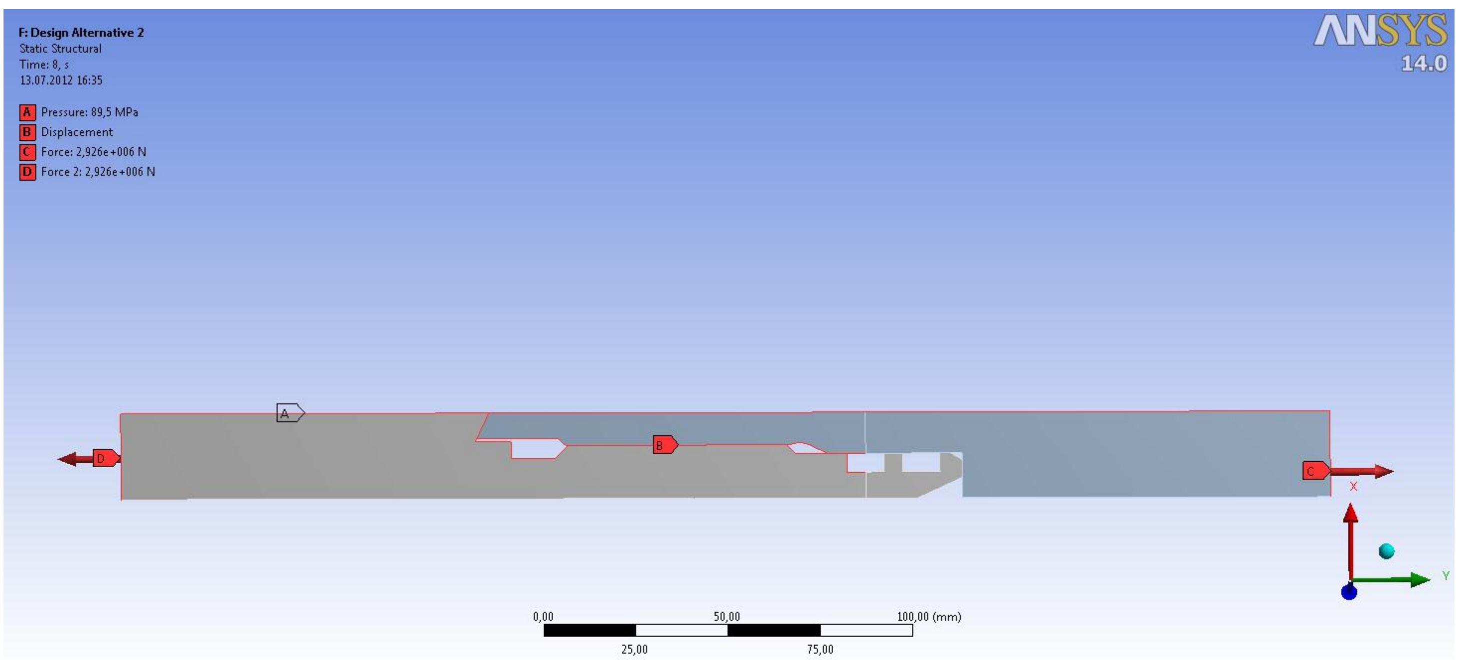


Figure 5-19: Static Structural Setup of Alt.1

5.1.4 Analysis Models and Setup for Alternative 2

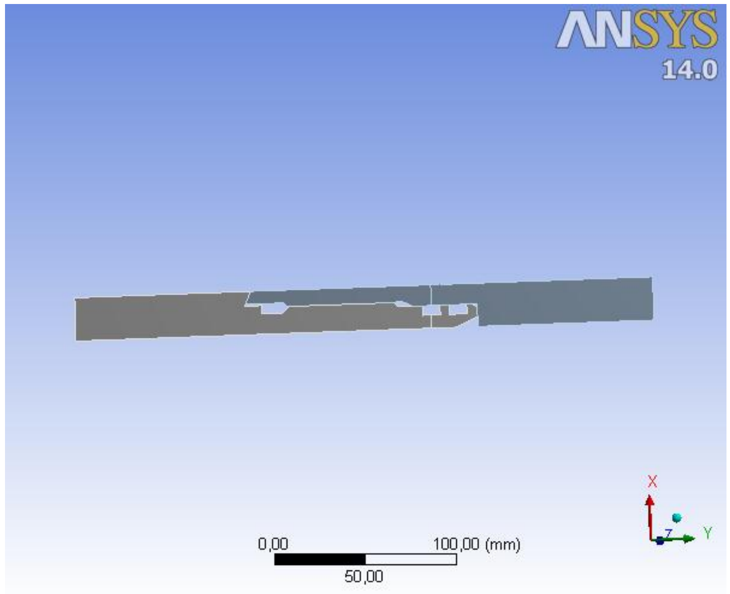


Figure 5-20: 2D Analysis Model of Alternative 2

A two dimensional analysis model of Alt. 2 has been made to make the analysis time efficient. This model has been drawn in ANSYS and is presented in Figure 5-20. In the analysis the model is exposed to the collapse pressure together with corresponding tensile force. The pressures and the tensile forces used are the same this model and Alt. 1 will be exposed to in the pressure test. Also in this analysis the tensile forces used are the ones caused by the pressure acting on the test caps during the pressure test for the two alternatives. This analysis is demonstrating how Alt.2 will behave in the pressure test. Calculations in Figure 4-45 are presenting the pressures and tensile forces used in this analysis. Figure 5-21 presents the contact surfaces between the end coupling and the housing in this design used in this analysis. A very fine mesh has been used and is presented in Figure 5-22. The geometry has been set to axisymmetric and the results are therefore valid for a fully sized model of the design. The pressurized surfaces of the design model can be viewed in the Figure 5-23. As for the existing design this design has threads that are exposed to collapse pressure. As done in the analysis of the existing design and for Alt. 1 the maximum pressure in this analysis has been set to maximum collapse pressure for the pressure test. This pressure is 89.5 MPa. At this pressure the tensile force is equal to 2926 kN. Figure 5-24 is presenting the surfaces of the model the tensile forces and the pressure is acting on. Results from this analysis are presented in section 5.2.4.

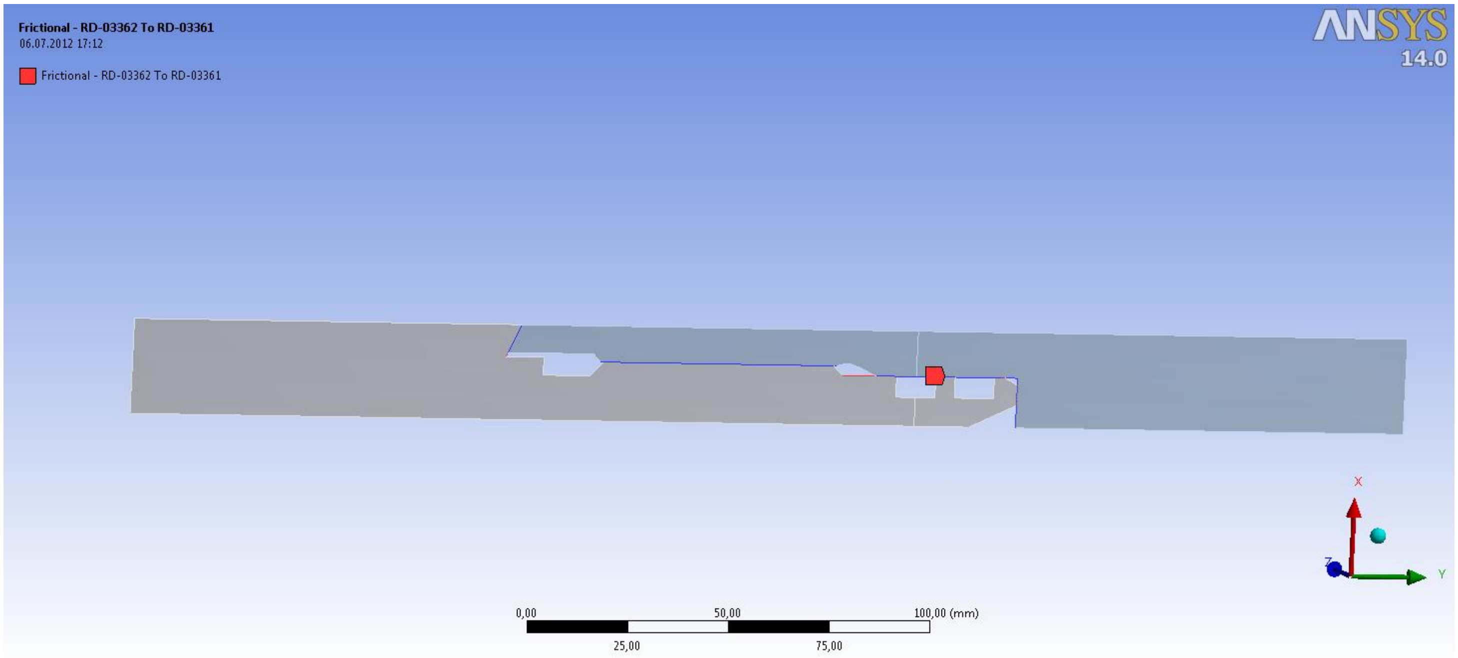


Figure 5-21: Connections in Analysis Model of Alt. 2

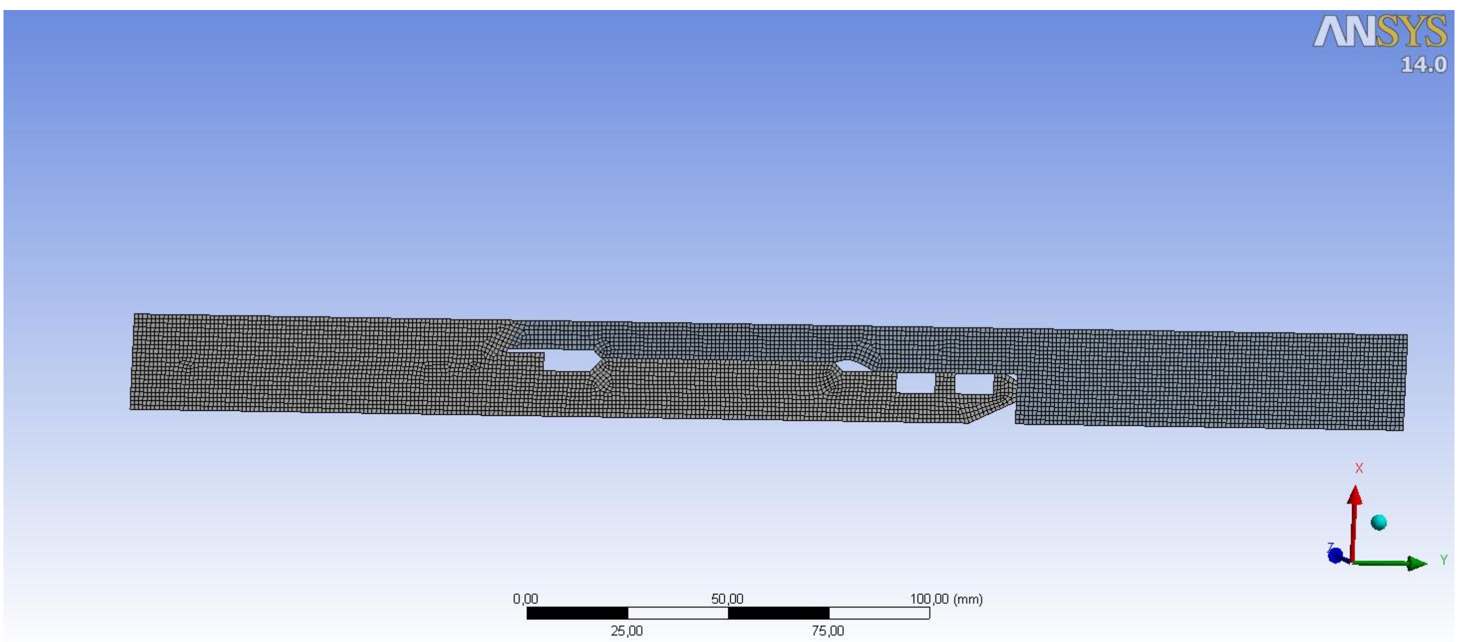


Figure 5-22: Mesh of Analysis Model of Alt. 2

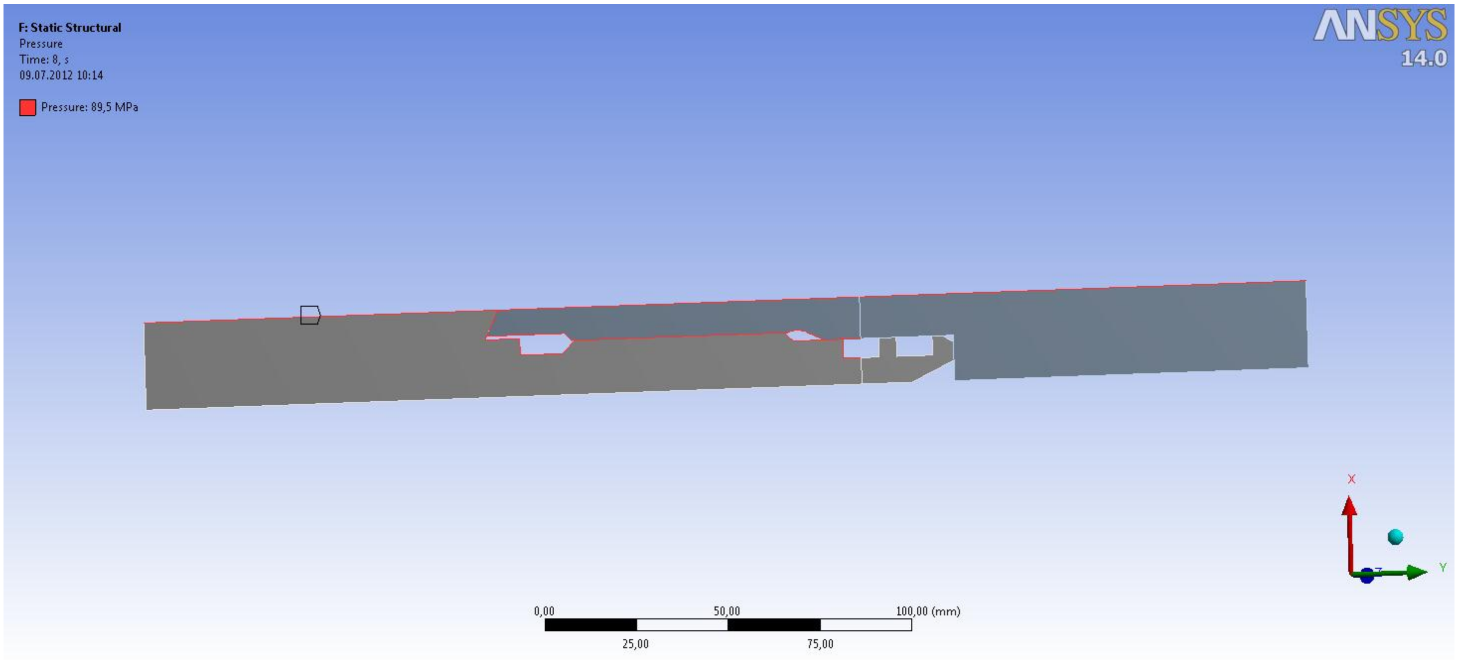


Figure 5-23: Pressurized Surfaces on Alt. 2

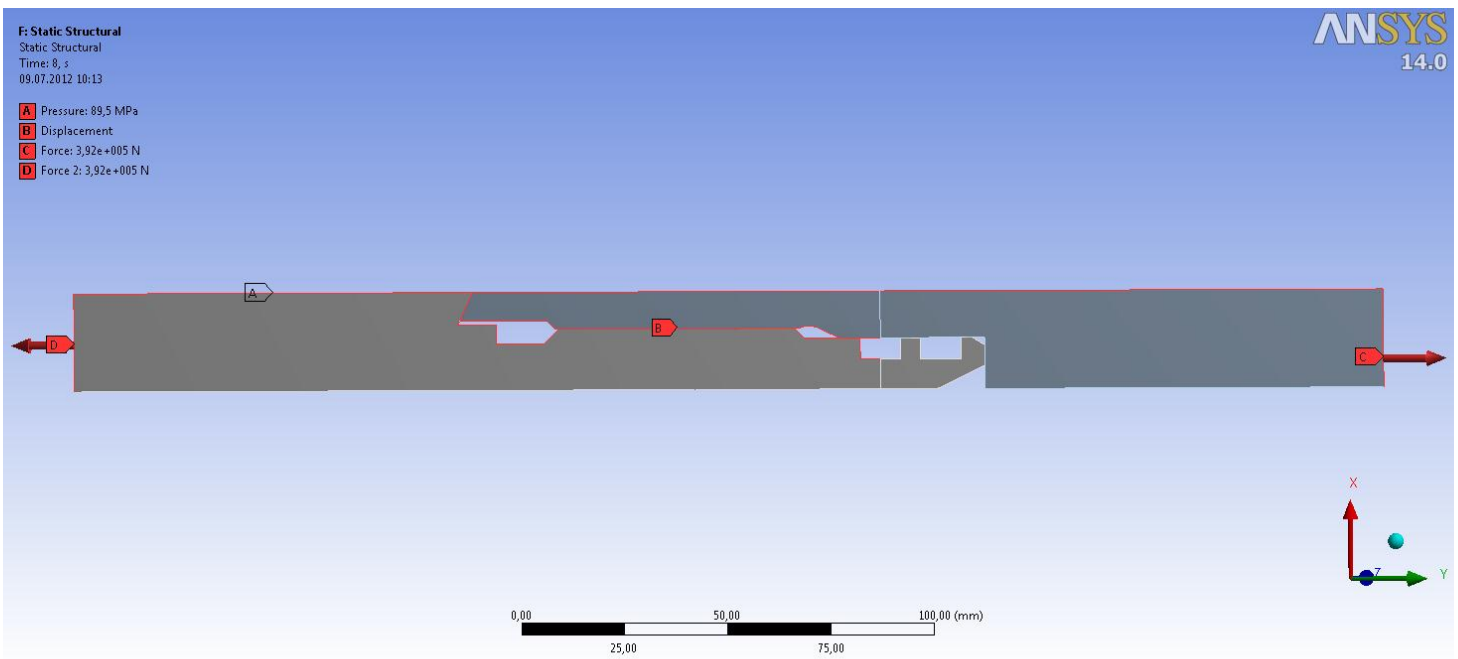


Figure 5-24: Static Structural Setup of Alt. 2

5.1.5 Models and Setup for Analyses Deciding Outer Diameter of Test Caps

When designing and dimensioning the test caps there were made analyses which were used to decide the outer diameter of the test caps. It was decided to make the test caps with S355 steel. The yield limit for the test caps is 355 MPa. The analysis model of the test cap is presented in Figure 5-25. This model is made in Autodesk Inventor.

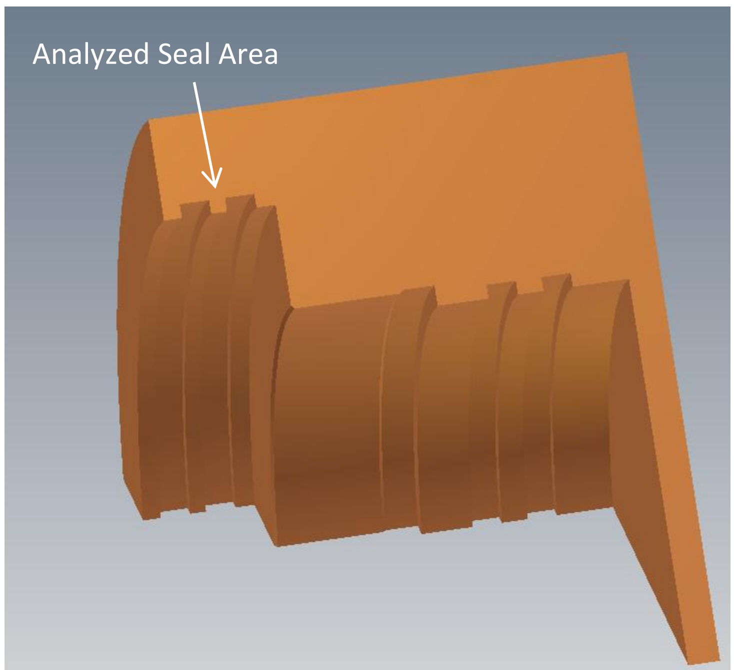


Figure 5-25: Analysis Model of Test Cap with Outer Diameter 380 mm

Only 1/6 of the test cap is being analyzed. This analysis model is a 60° sector model of the test cap. The section of interest in this analysis is the seal area between the test cap and the test casing. This section is illustrated in Figure 5-25. Analyses are made for worst case scenario of the pressure test for test caps with different outer diameters. Worst case scenario is when both of the seals between the test casing and the test cap start to leak. A fine mesh has been used for this seal area in the analyses. A model of the mesh is presented in Figure 5-26. Figure 5-27 is presenting the pressurized area of the test cap in this analysis. This pressure is 89.5 MPa. This is the maximum pressure in the pressure test. Figure 5-28 is presenting the static structural setup of these analyses. The analysis model shown in Figure 5-25 – 5-28 is the model with an outer diameter of 380 mm. The setup of the analyses of the test caps with other outer diameters is exactly the same and is therefore not illustrated. Results from these analyses are to be compared and used to determine the outer diameter of the test cap. Analysis results for test caps with outer diameter 380 mm and 360 mm are presented in this report. The results from these analyses can be viewed in section 5.2.5.

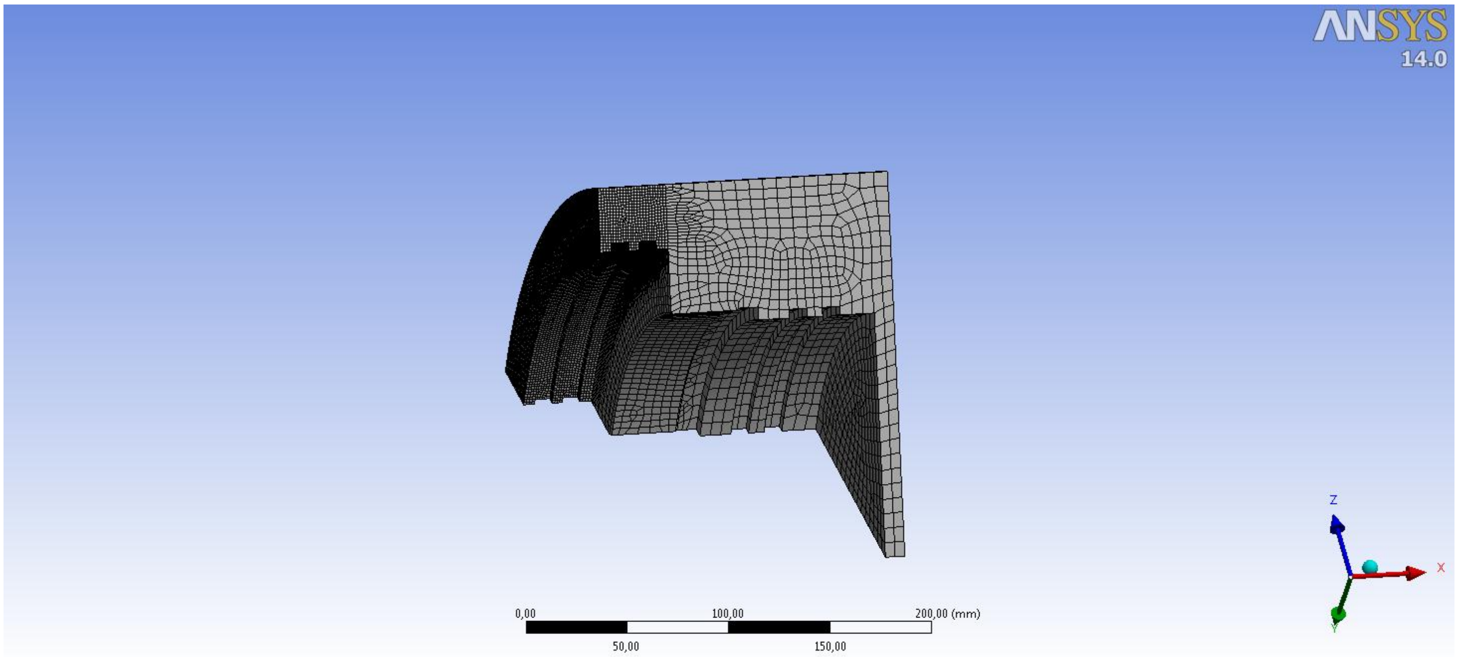


Figure 5-26: Mesh of Test Cap with OD = 380 mm

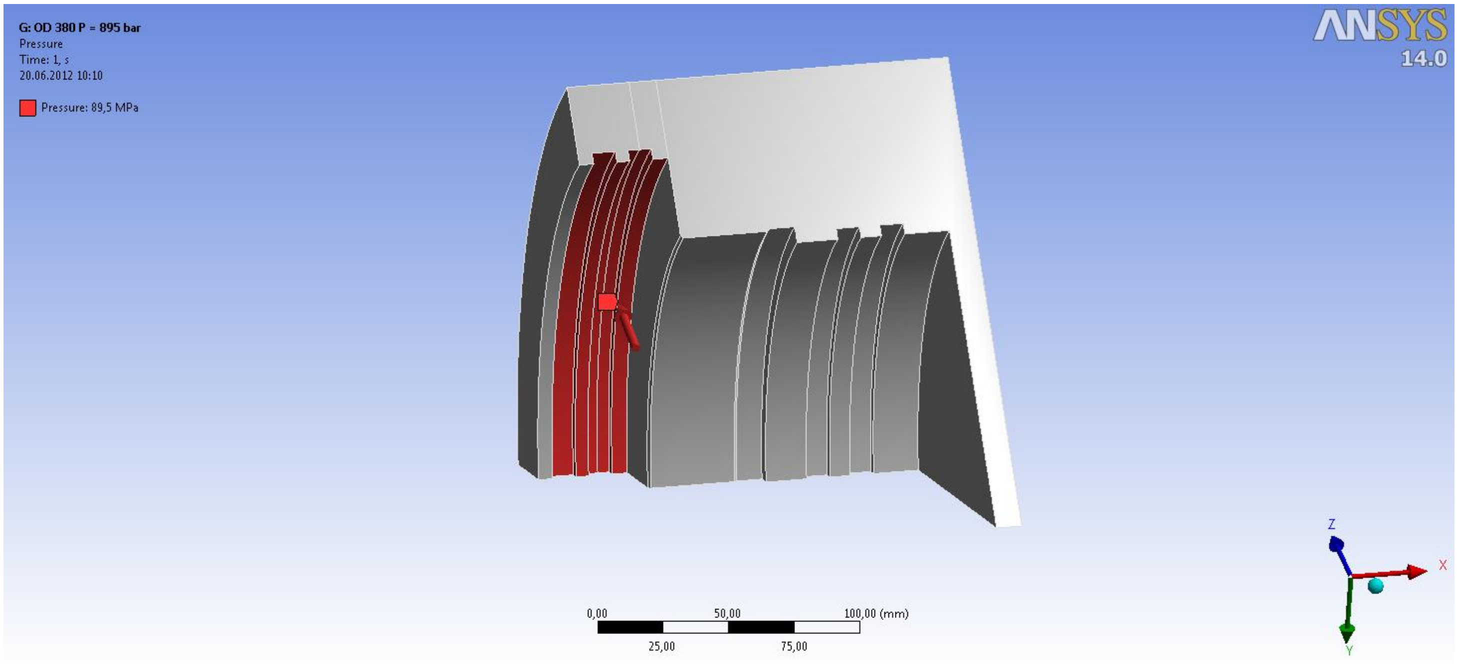


Figure 5-27: Pressure Applied on Test Cap

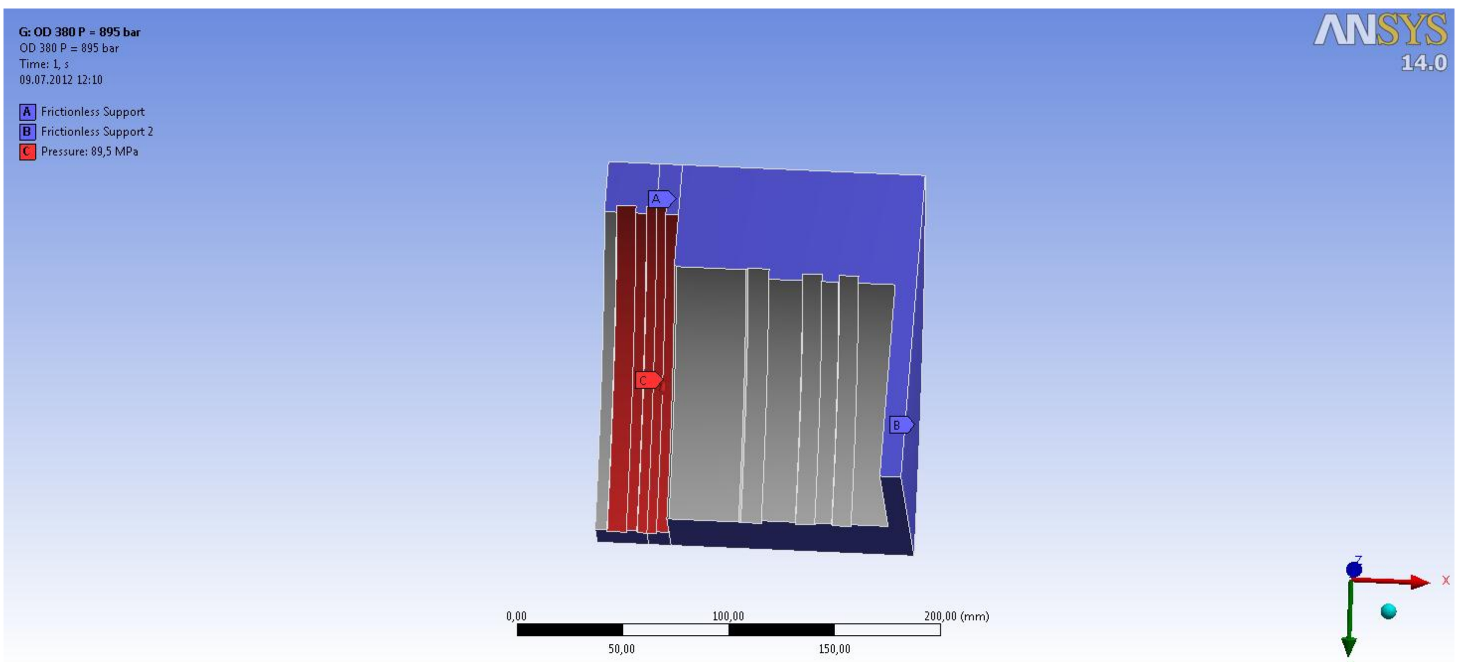


Figure 5-28: Static Structural Setup for Analysis of Test Cap

5.1.6 Models and Setup for Analysis of Internal Pressure on Test Caps

This analysis is made to check how much internal pressure the test caps can handle. This is to assure that the test caps do not burst in case of total collapse of the test piece during the collapse pressure test. Since the outer diameter of the test cap was decided to be 380 mm the model made for the test cap with outer diameter 380 mm in section 5.1.5 is also used for this analysis. Maximum internal pressure for the test cap is being found by finding the pressure where the plastic deformation is ten percent and multiplied by a factor equal to 2/3 [4]. A fine mesh has been used on the relevant area, see Figure 5-29.

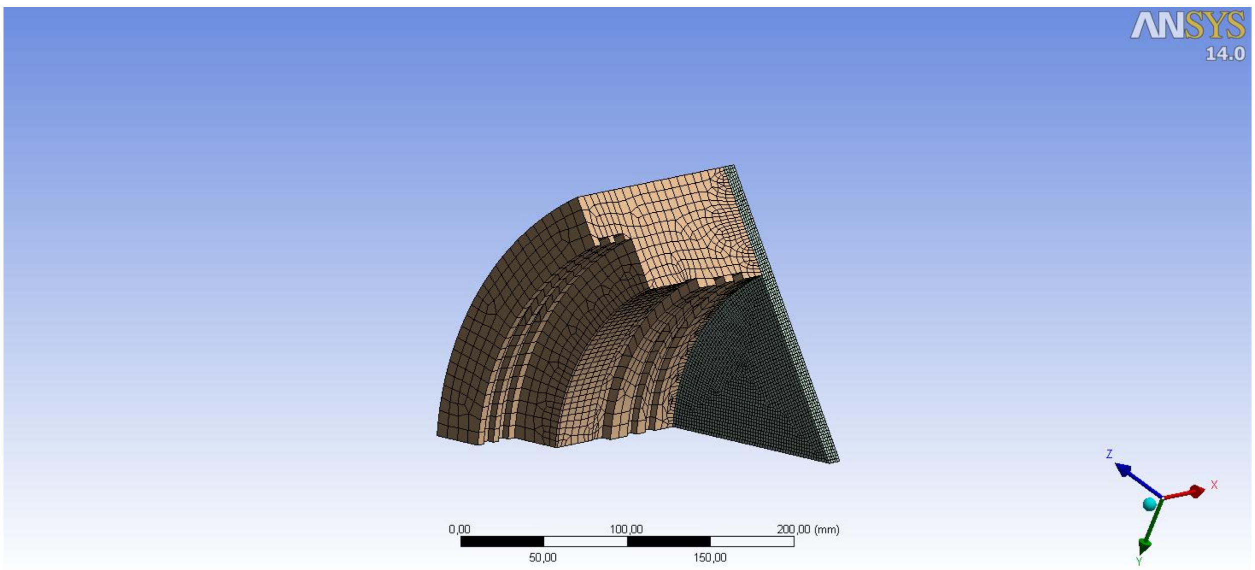


Figure 5-29: Mesh of Test Cap

Figure 5-30 is presenting the static structural setup for this analysis. 20 MPa pressure is applied on the end surface on the inside of the test cap since this is the relevant area of the test cap to check for burst capacity. The results for this analysis are presented in section 5.2.6.

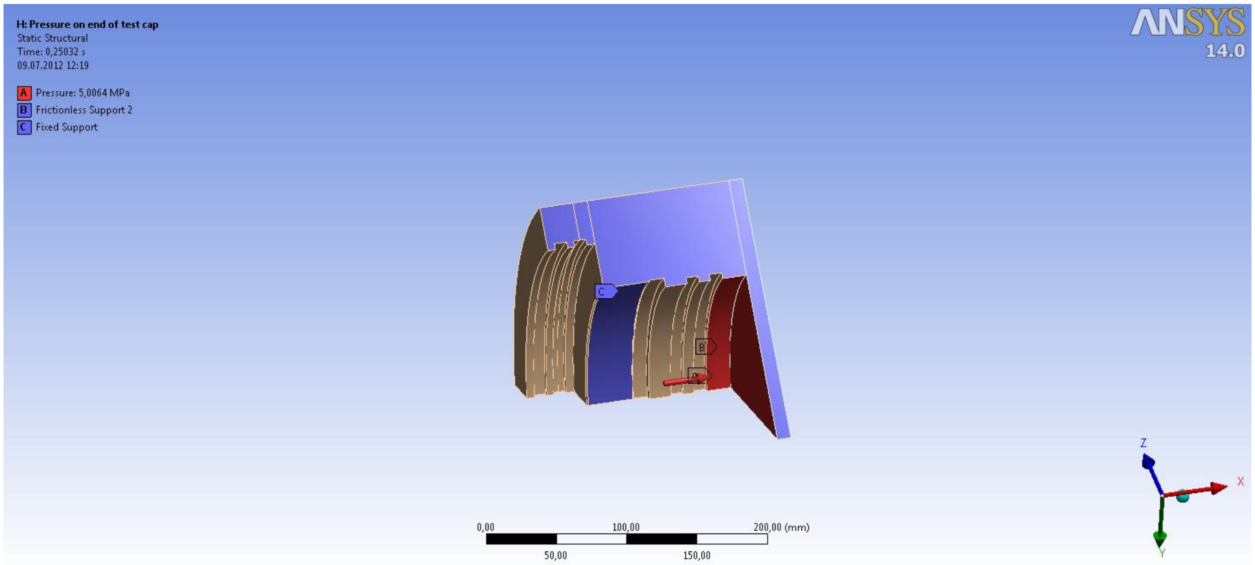


Figure 5-30: Static Structural Setup of Analysis of Test Cap

5.2 Analyses Results

All of the relevant results from the different analyses made for this project are presented in this section. The values presented in the results of the analyses are found in the diagrams illustrated at the left in the result models for each result. Complete analysis reports of the most relevant analyses can be found in Appendix E.

5.2.1 Analysis Results of Existing Design

Figure 5-31 – 5-35 presents the analysis results of the existing design when exposed to a collapse pressure of 89.5 MPa and tensile force of 2926 kN. Figure 5-31 presents results for total deformation of the existing design. The studied sections are illustrated in this figure. The total deformation of the threads on the end coupling is 0.51 mm. Total deformation of the threads on the housing is approximately 0.05 mm. Total deformation of the end coupling at the seal area is approximately 0.42 mm. Total deformation of the housing at the seal area is approximately 0.31 mm. At the section marked as intersection in Figure 5-31 the total deformation of the end coupling is approximately 0.31 mm. The total deformation of the housing at this section is 0.0002 mm.

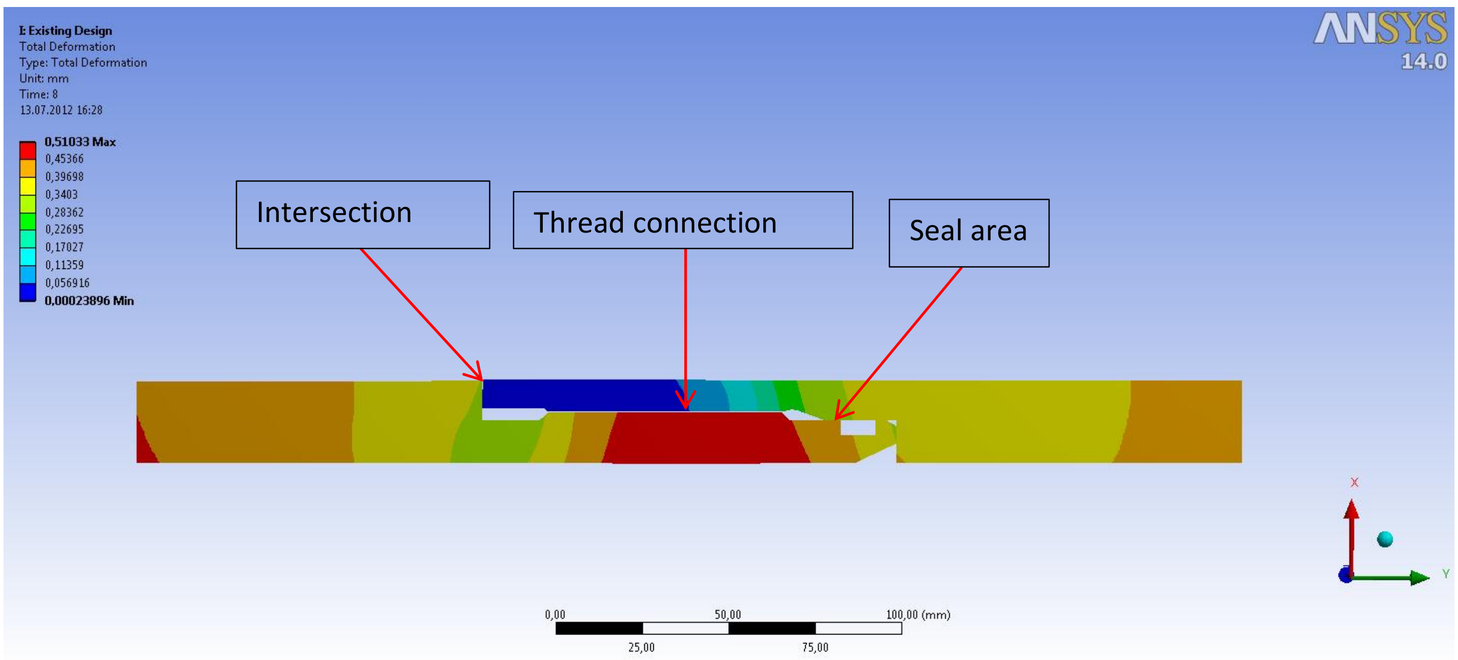


Figure 5-31: Total Deformation of Existing Design

The result for directional deformation in x-direction is presented in Figure 5-32. This is the radial deformation of the model. At the seal section the deformation of the end coupling in x-direction is approximately -0.42 mm. The deformation of the housing at the same area is approximately -0.29 mm. This gives a gap of 0.13 mm between the end coupling and the housing at the seal area. At the thread connection the end coupling has a deformation of approximately -0.51 mm in the x-direction. The deformation of the threads on the housing is approximately -0.04 mm. This value is for the orange colored section of the threads on the housing in this result. This gives gap of 0.47 mm between the end coupling and the housing at the threaded connection. At the section where the housing and the end coupling intersects (marked as intersection in Figure 5-31) the deformation of the end coupling is approximately -0.29 mm in x-direction. The deformation of the housing at this section is approximately +0.045 mm. This gives a total displacement of 0.335 mm in x-direction between the end coupling and the housing at this area.

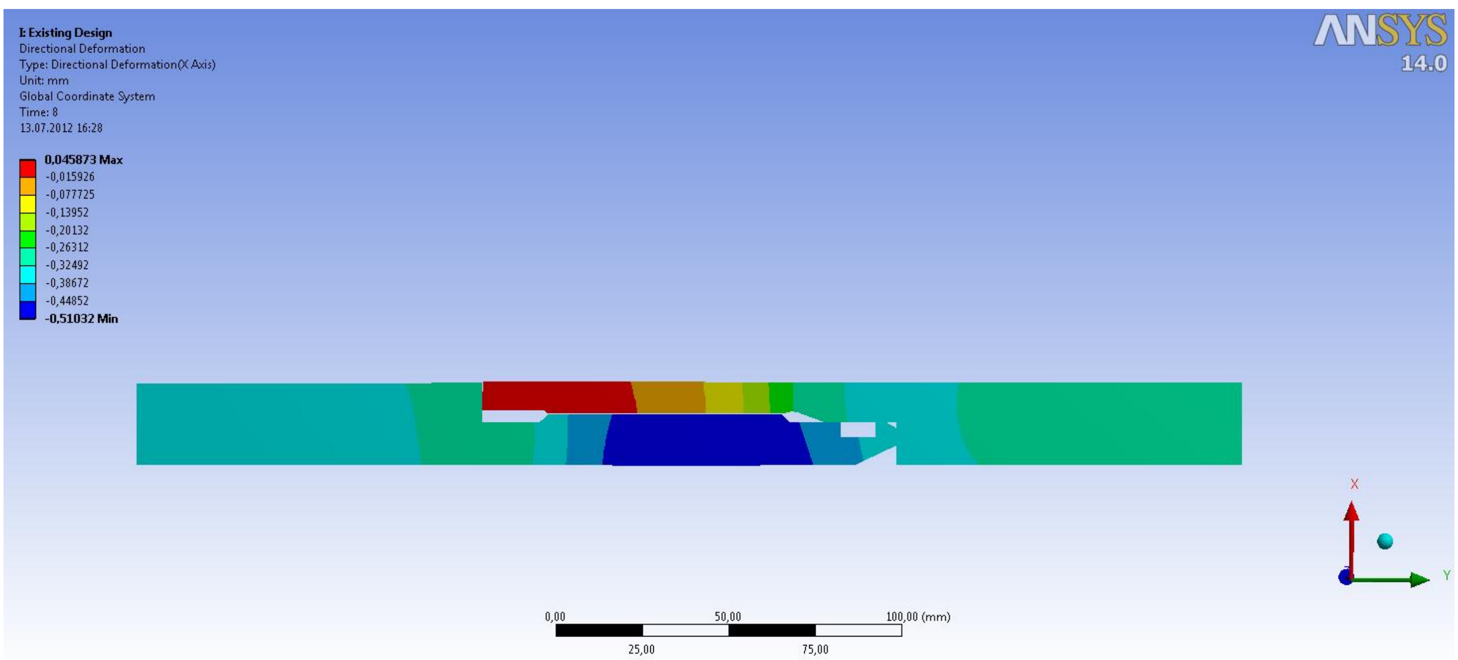


Figure 5-32: Directional Deformation (X-axis) of Existing Design

The result for directional deformation in y-direction is presented in Figure 5-33. At the seal area the deformation of the end coupling in y-direction is approximately -0.005 mm. The deformation of the housing at the same area is approximately +0.06 mm. This gives a longitudinal displacement of 0.065 mm between the end coupling and the housing at this section. The deformation of the end coupling is -0.005 mm at thread connection. The deformation of the threads on the housing is -0.005 mm. This gives that there is no displacement y-direction in the thread connection. The deformation of the housing at the intersection with the end coupling is -0.005mm. The deformation of the end coupling at this intersection is -0.18 mm. This gives as gap of 0.175 mm in y-direction between the end coupling and the housing in this section.

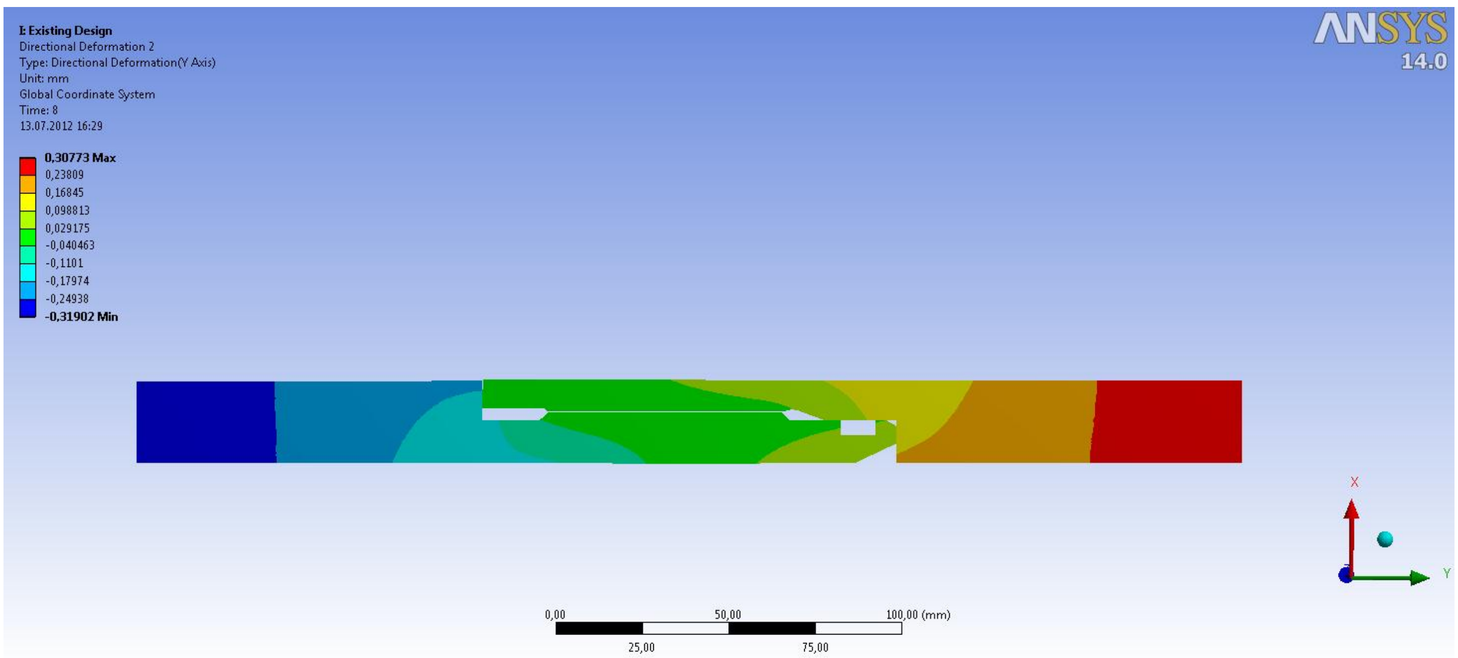


Figure 5-33: Directional Deformation (Y-axis) of Existing Design

The result for equivalent von-Mises stress is presented in Figure 5-34. The result for equivalent von-Mises strain is presented in Figure 5-35. The stress is approximately 700 MPa and the strain is approximately 0.0035 for the end coupling and for the housing in the seal area. The stress is approximately 700 MPa and the strain is approximately 0.0035 in the threads on the end coupling. The stress is approximately 60 MPa and the strain is approximately 0.0003 in the threads on the housing.

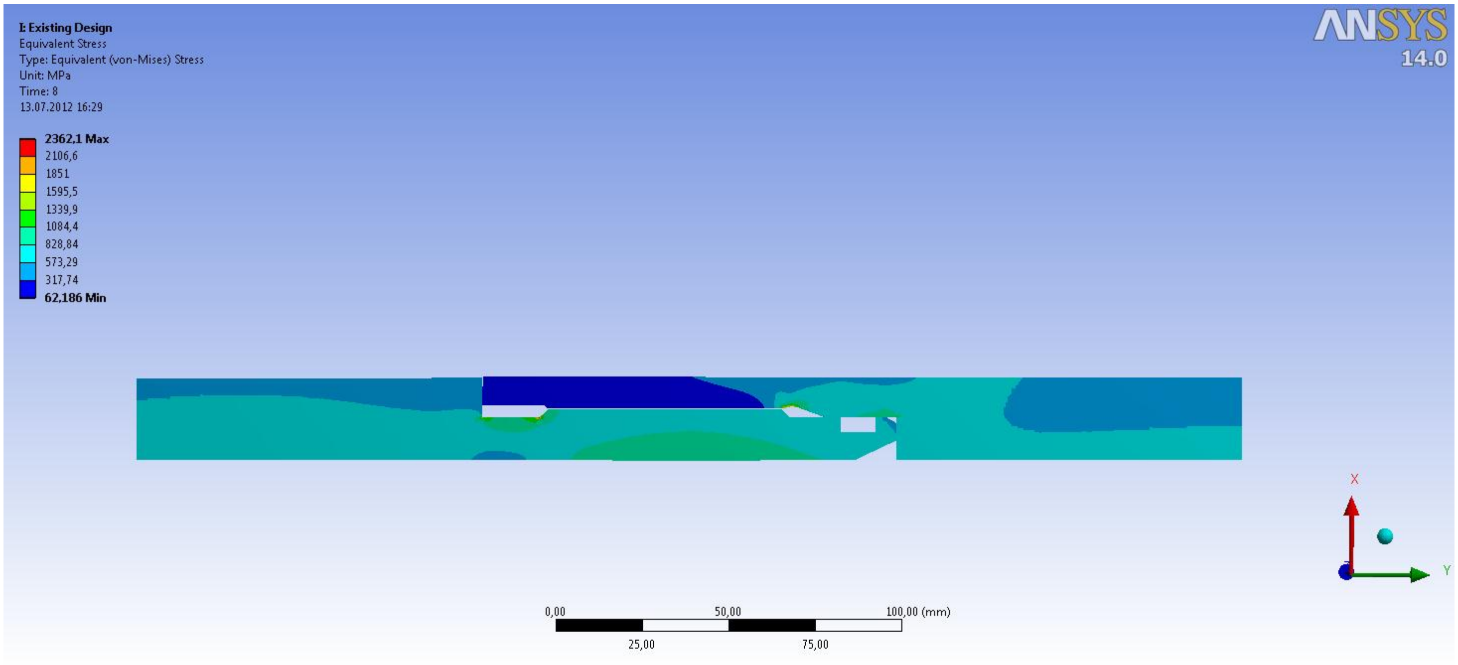


Figure 5-34: Equivalent (von-Mises) Stress of Existing Design

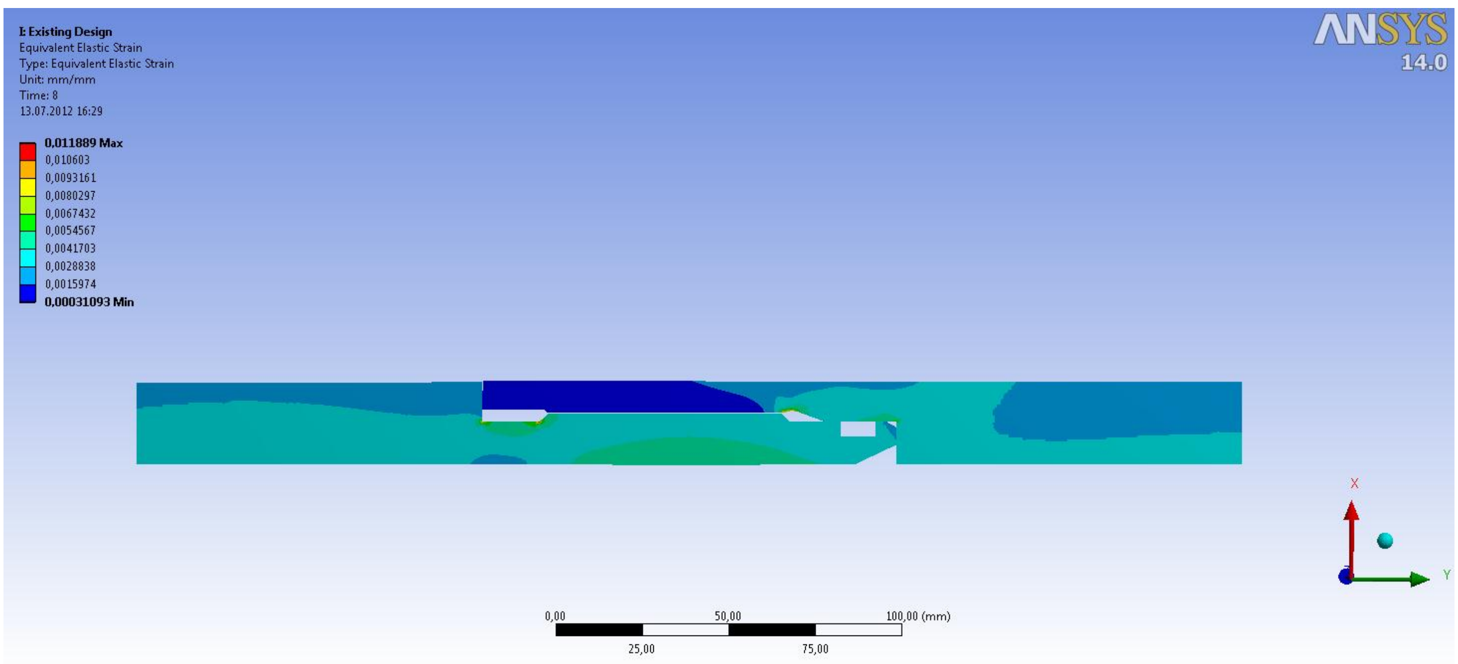


Figure 5-35: Equivalent Elastic Strain of Existing Design

5.2.2 Analysis Results for Different Housing Suggestions

Results for the model with the sleeve are presented in Figure 5-36 – 5-38. The result for directional deformation in Z-axis direction of this model is presented in Figure 5-36. The section of the model which is going to be compared is illustrated in Figure 5-36. This is where the sleeve intersects with end coupling. From this result it can be seen that the deformation in z-direction is approximately the same for the end coupling, housing and the sleeve in the section which is going to be compared. This deformation is between -0.32 mm and -0.35 mm. Result for total deformation is presented in Figure 5-37. The total deformation at the section studied is between 0.34 mm and 0.39 mm. Result for equivalent von-Mises stress is presented in Figure 5-38. This give that the stress in the section studied is approximately: (560Mpa+660MPa)/2 = 610 MPa.

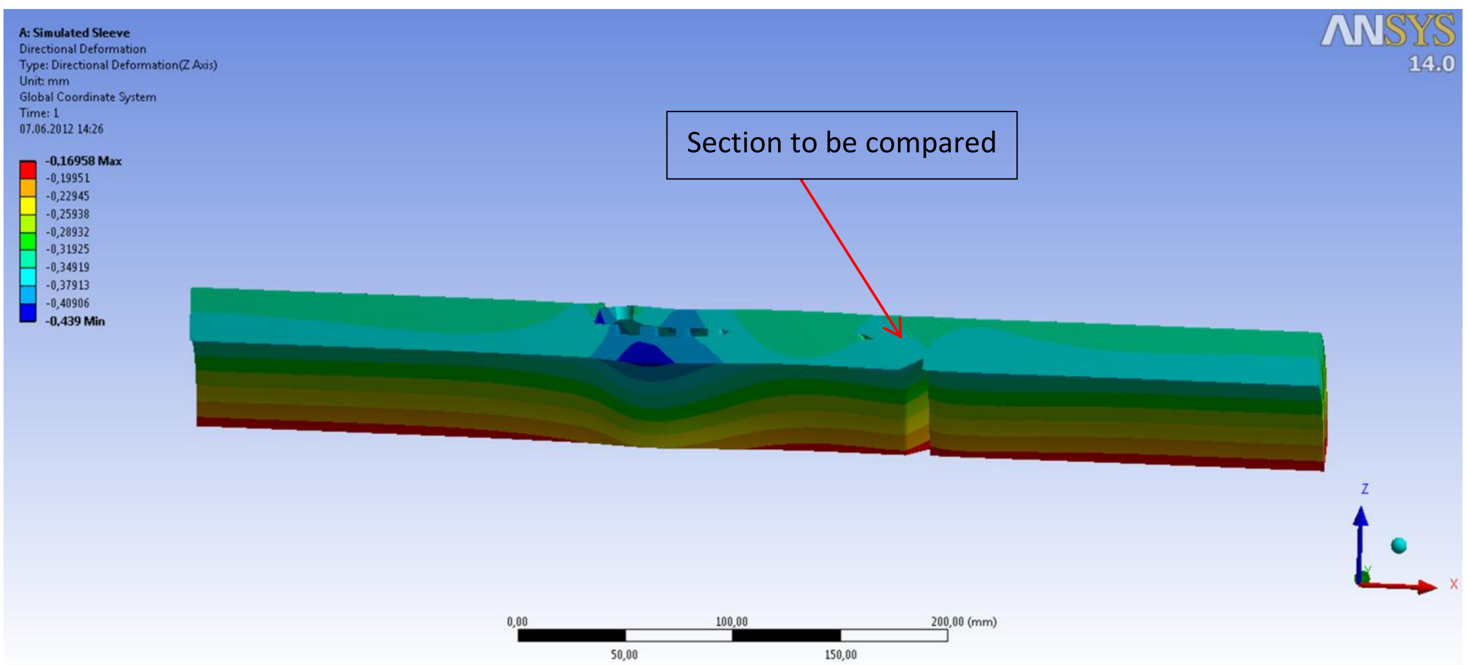


Figure 5-36: Directional Deformation of Design with Sleeve

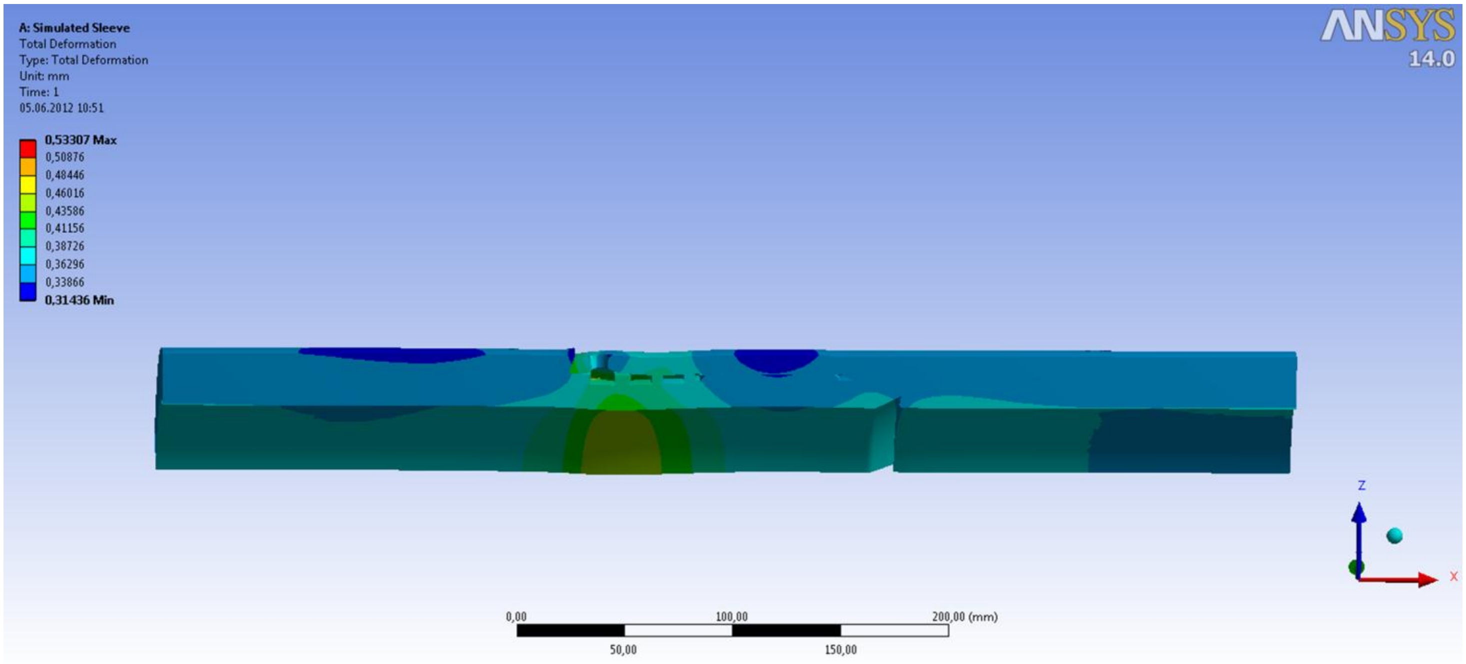


Figure 5-37: Total Deformation of Design with Sleeve

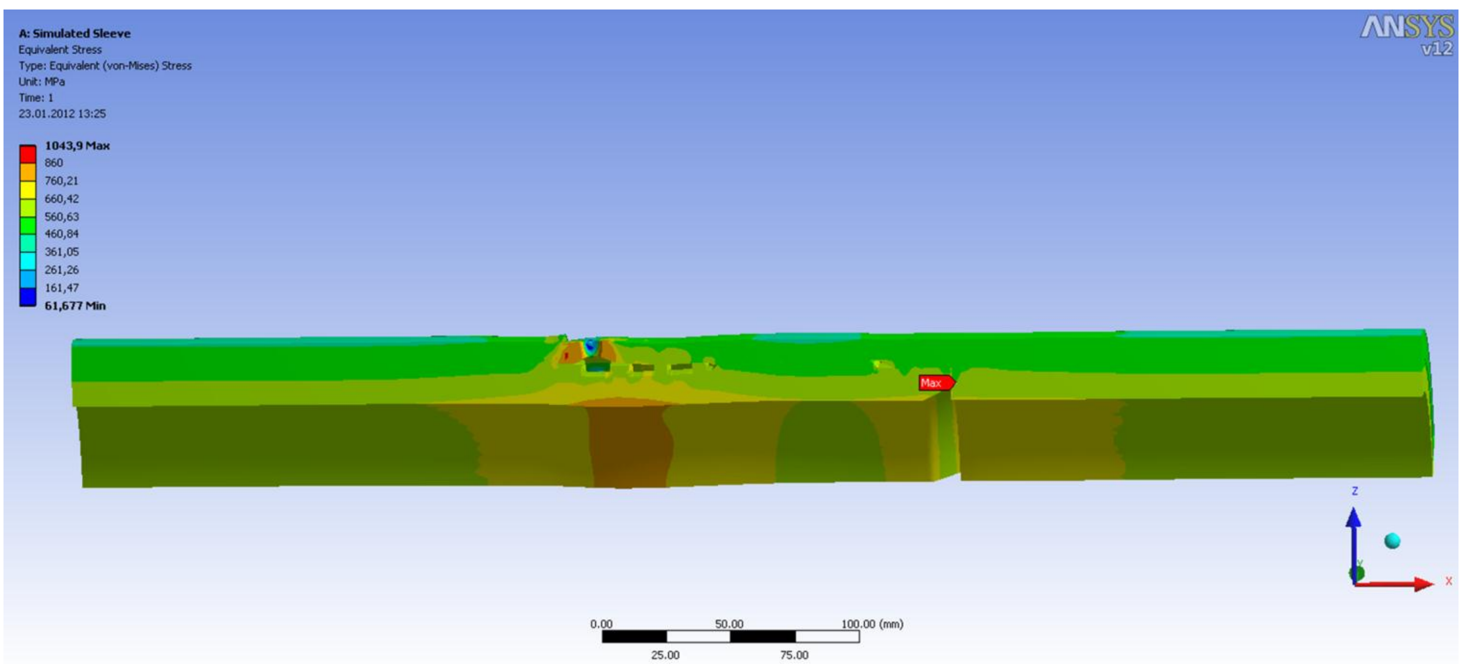


Figure 5-38: Equivalent Stress of Design with Sleeve

Results for housing design alternative 1 are presented in Figure 5-39 – 5-41. Figure 5-39 presents result for directional deformation in z-direction. The section that is going to be compared is illustrated in this figure. The deformation is between -0.31 mm and -0.34 mm. This is very similar to the deformation in z-direction found for the analysis of the model with the sleeve. Figure 5-40 presents result for total deformation of housing design alternative 1. The total deformation is between 0.34 mm and 0.38 mm at the studied section. This result is also very similar to the result for total deformation of the design with the sleeve. Result for equivalent von-Mises stress is presented in Figure 5-41. The stress at studied section is approximately (560 MPa + 660 MPa)/2 = 610 MPa. This is the same as the result found for the design with the sleeve. The results for this housing design alternative indicate that this design will give approximately the same support as for a model with sleeve.

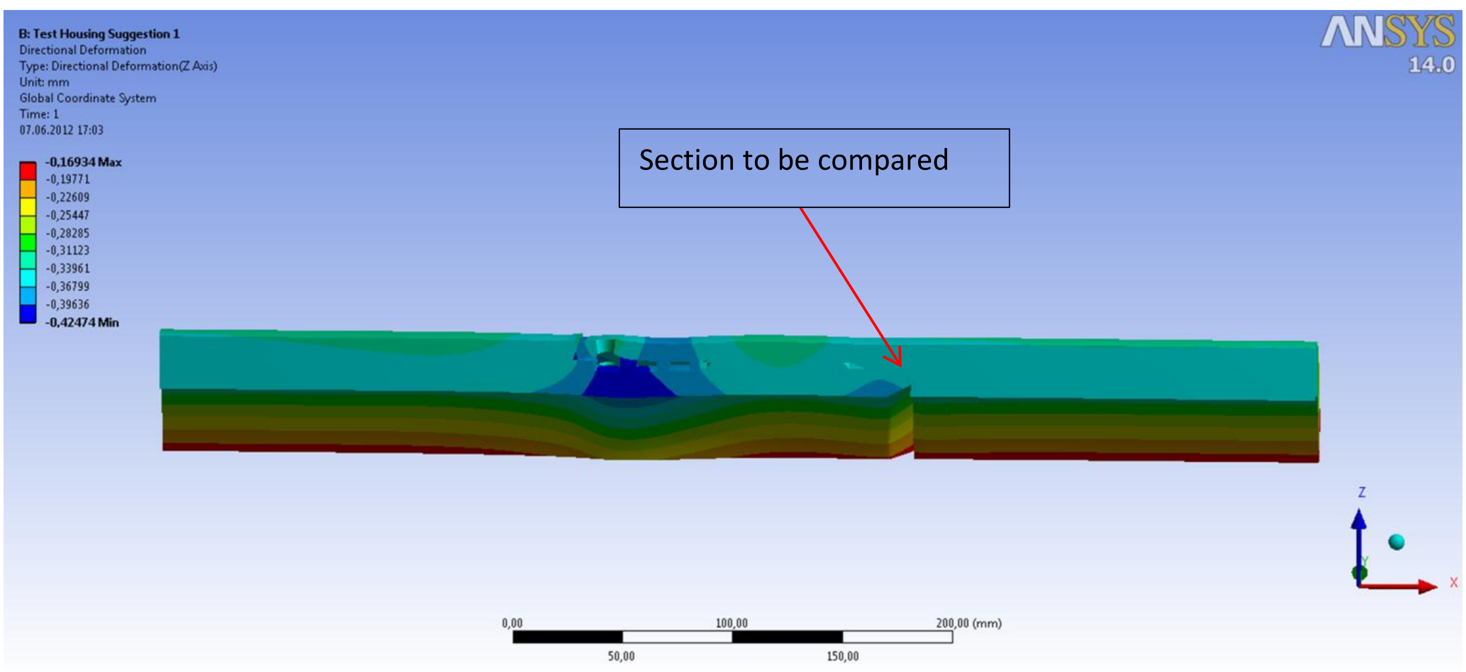


Figure 5-39: Directional Deformation for Housing Design Alternative 1

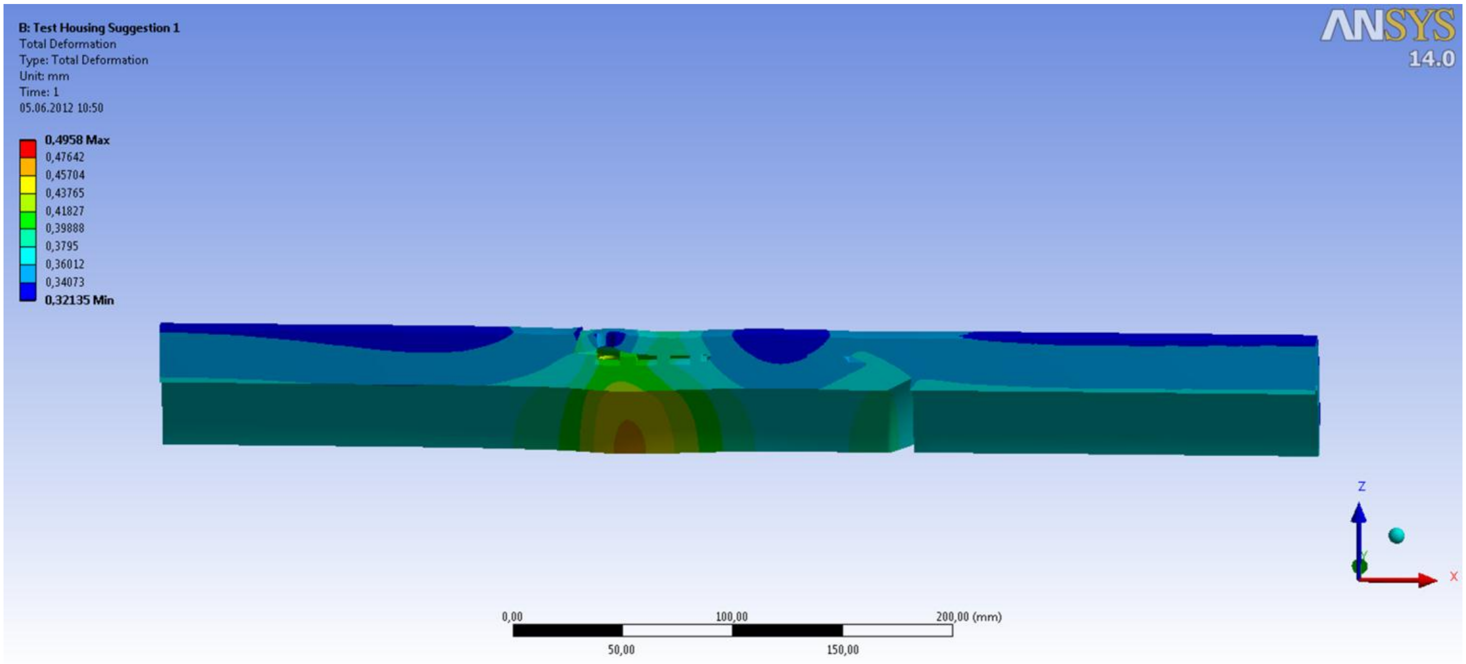


Figure 5-40: Total Deformation of Housing Design Alternative 1

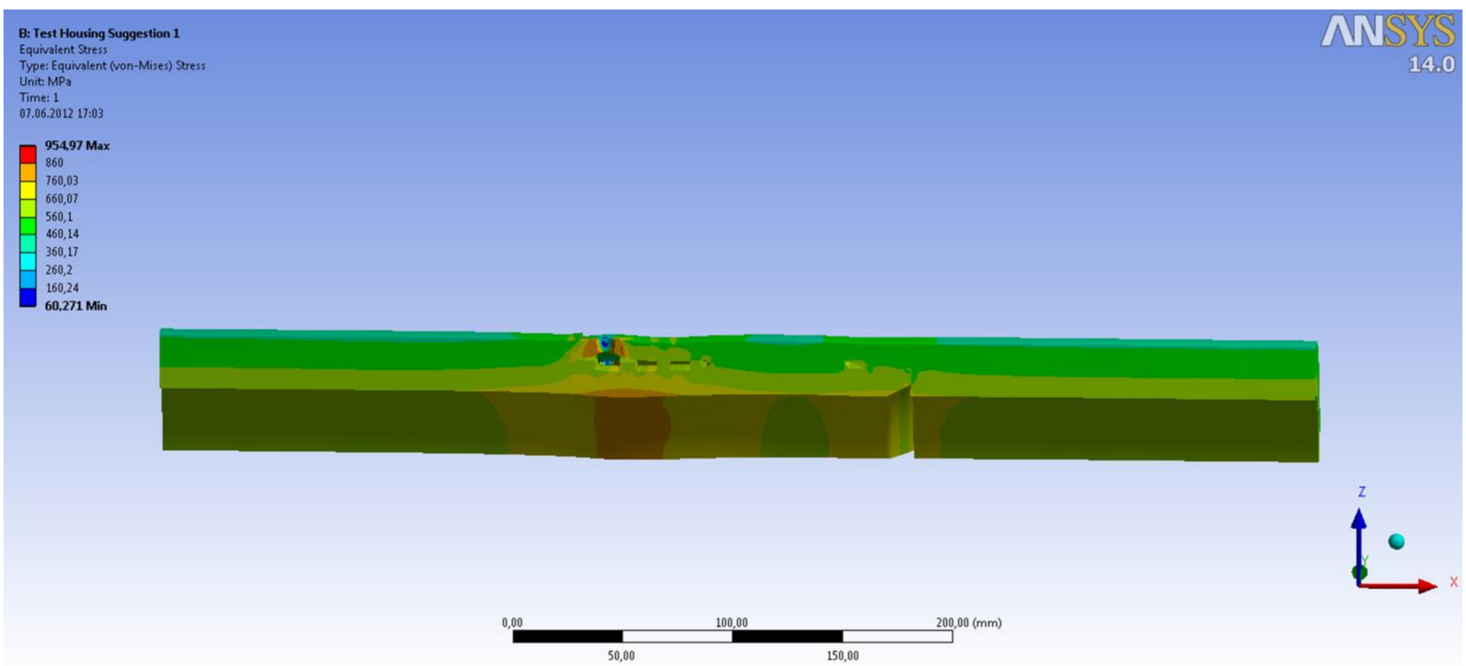


Figure 5-41: Equivalent Stress of Housing Design Alternative 1

Results for housing design alternative 2 are presented in Figure 5-42 – 5-44. The section which is going to be compared is illustrated in Figure 5-42. Result for directional deformation in z-direction is presented in Figure 5-42. The deformation is between -0.49 mm and -0.38 mm. Figure 5-40 presents result for total deformation of housing design alternative 2. The total deformation for the end coupling at the section studied is between 0.49 mm and 0.58 mm. The total deformation of the housing at this section is between 0.39 mm and 0.49 mm. Result for equivalent von-Mises stress is presented in Figure 5-44. The stress at studied section is between 669 MPa and 874 MPa. The results for this housing design alternative differ from the results for the design with the sleeve. These results indicate that this housing design alternative will give less support than for a model with sleeve.

Results for housing design alternative 1 give that this design has the same support as a design with sleeve. A design with a sleeve can be discarded and the housing design alternative 1 can be implemented for Alt.1 and Alt.2.

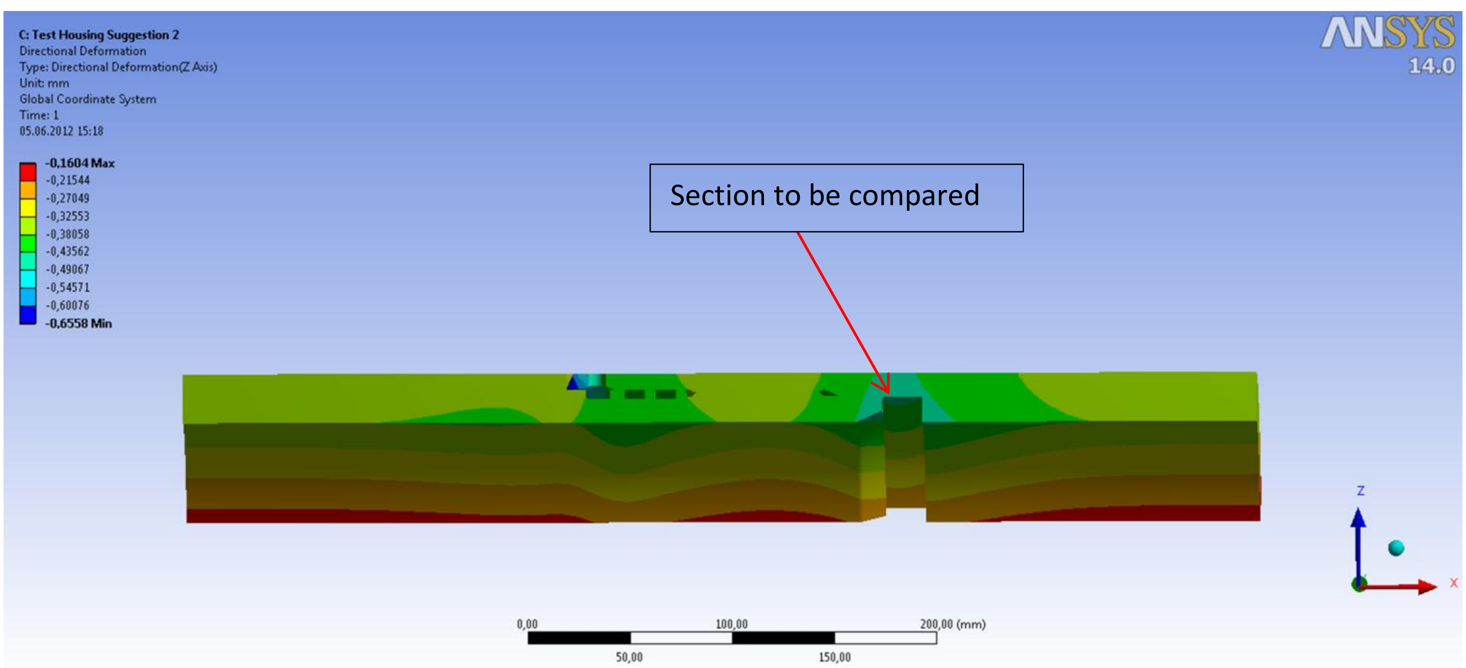


Figure 5-42: Direction Deformation (Z-axis) of Housing Design Alternative 2

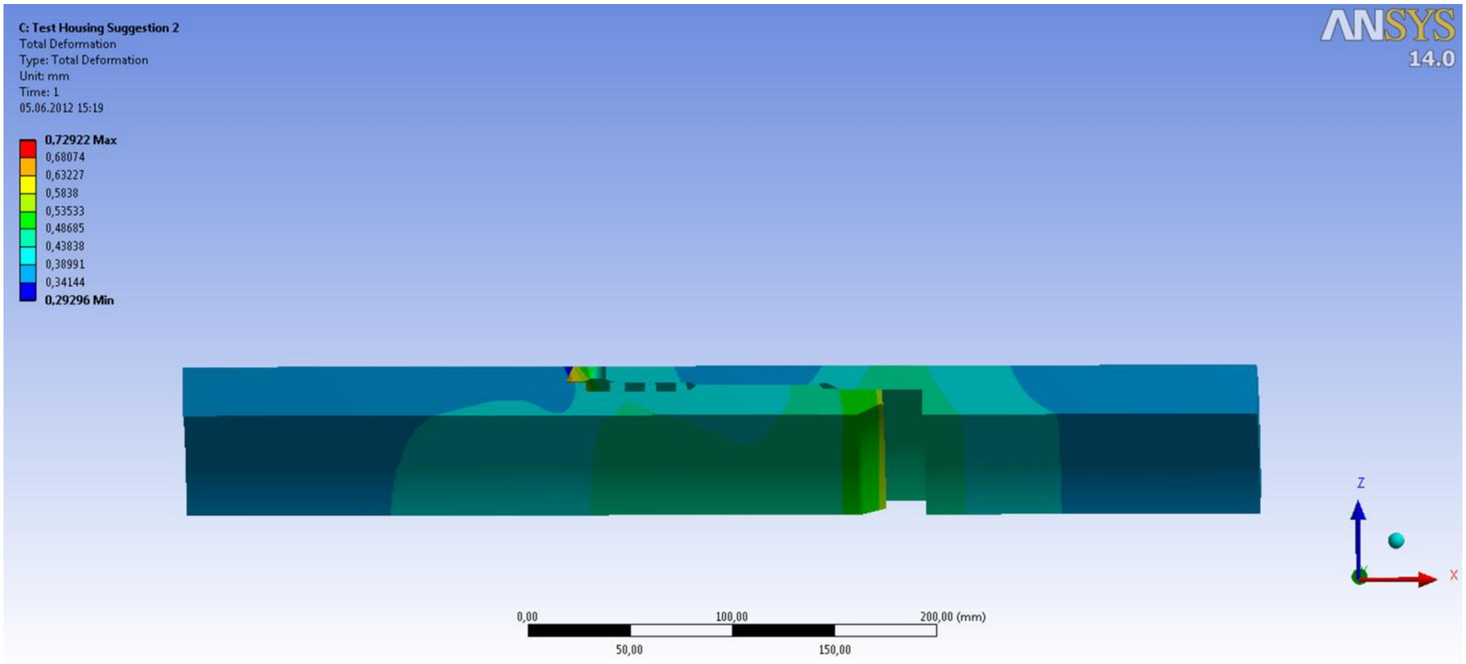


Figure 5-43: Total Deformation of Housing Design Alternative 2

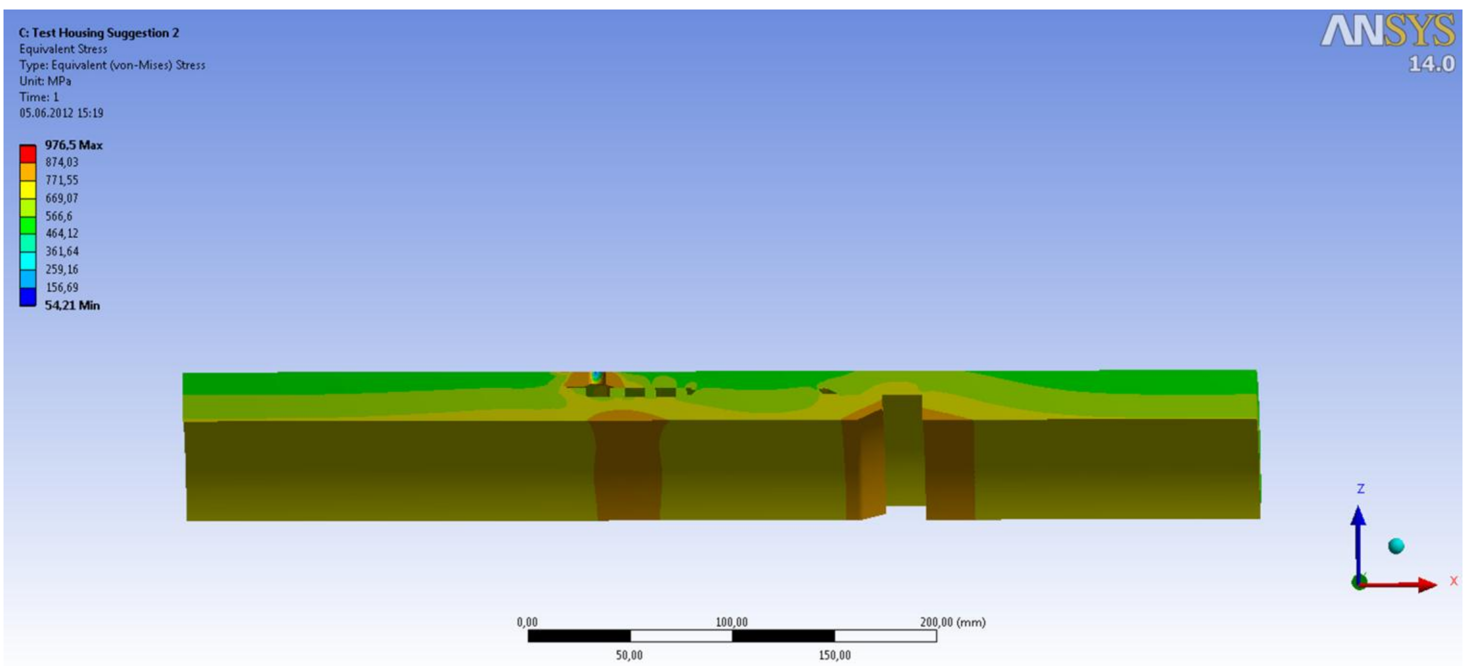


Figure 5-44: Equivalent Stress of Housing Design Alternative 2

5.2.3 Analysis Results for Design Alternative 1

Figure 5-45 – 5-49 presents the analysis results and data of Alt.1 when exposed to a collapse pressure of 89.5 MPa and tensile force of 2926 kN. Figure 5-45 presents the result for total deformation of Alt.1. The total deformation of the threads on the end coupling and on the housing is approximately 0.32 mm. Total deformation of the end coupling at the seal area is approximately 0.35 mm. Total deformation of the housing at the seal area is approximately 0.20 mm. At the section marked as intersection in Figure 5-45 the total deformation of the end coupling is approximately 0.44 mm. The total deformation of the housing at this section is between approximately 0.009 mm.

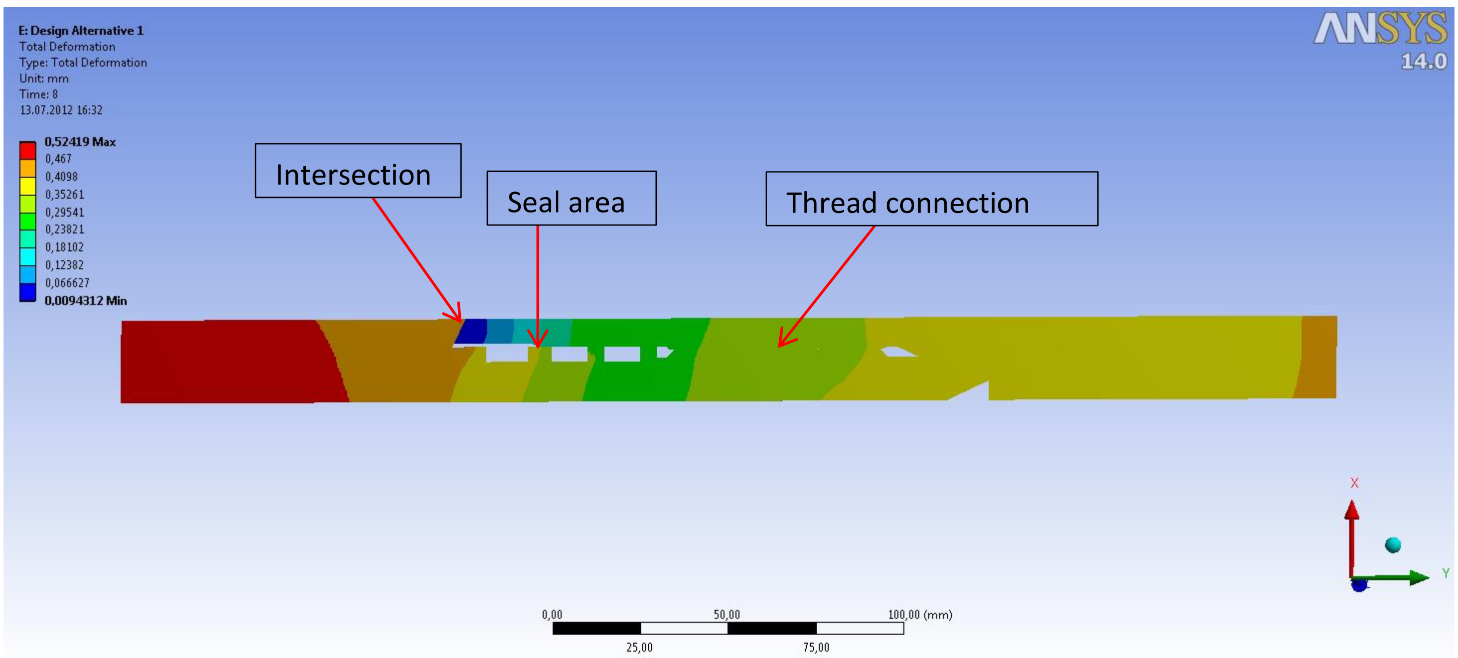


Figure 5-45: Total Deformation of Alt.1

The directional deformation in x-direction is presented in Figure 5-46. This equals the radial deformation of the model. At the seal section the deformation of the end coupling in x-direction is approximately -0.31 mm. The deformation of the housing at the same area is approximately -0.18 mm. This gives a gap of 0.13 mm in x-direction between the end coupling and the housing at the seal area. At the thread connection the end coupling has a deformation of approximately -0.31 mm. The deformation of the threads on the housing is approximately -0.31 mm. This gives that there is no gap in x-direction between the end coupling and the housing at the threaded connection. The deformation of the end coupling at the section where the housing and the end coupling intersects (marked as intersection in Figure 5-45) is approximately -0.31 mm in x-direction. The deformation of the housing is approximately +0.006 mm. This gives a total displacement of 0.316 mm in x-direction between the end coupling and the housing at this area.

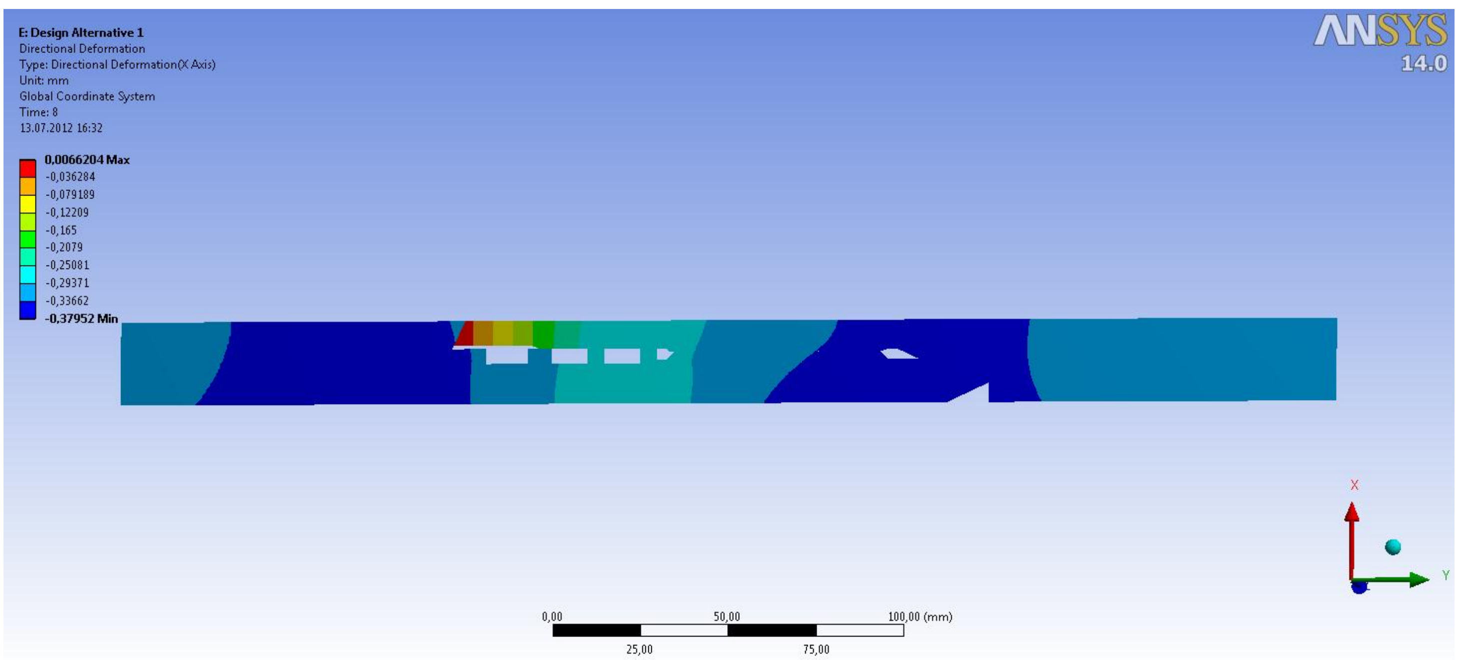


Figure 5-46: Directional Deformation (X Axis) of Alt. 1

The result and data for directional deformation in y-direction are presented in Figure 5-47. The deformation in y-direction of the end coupling at the seal area is approximately -0.14 mm. The deformation of the housing at this area is approximately -0.06 mm. This gives that there is a displacement of 0.08 mm between the end coupling and the housing at seal area. At the thread connection there is no displacement in y-direction between the end coupling and the housing. The deformation of the end coupling and of the housing is approximately –0.04 mm. The deformation of the end coupling at the intersection with housing (marked as intersection in Figure 5-45) is approximately -0.29 mm. The deformation of the housing at this intersection is approximately -0.04 mm. This gives as gap of 0.25 mm in y-direction between the end coupling and the housing at this section.

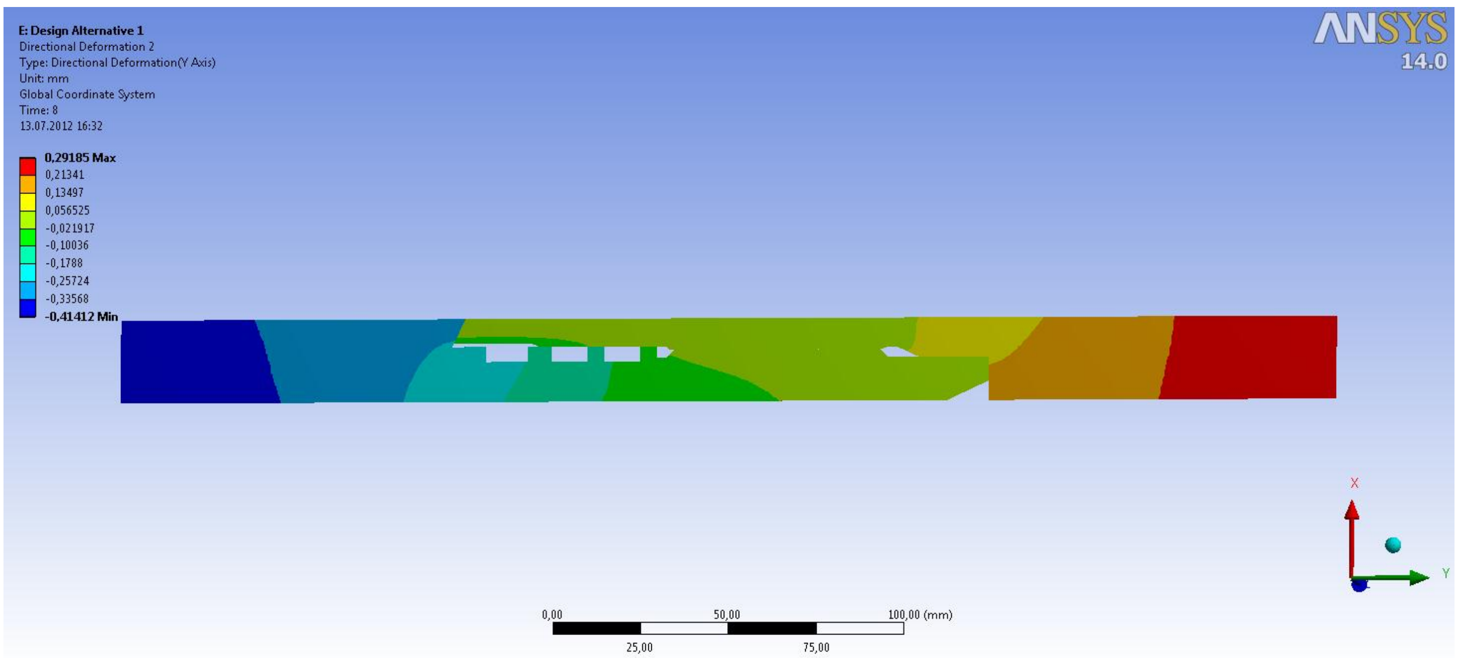


Figure 5-47: Directional Deformation (Y Axis) of Alt. 1

The result and data for equivalent von-Mises stress are presented in Figure 5-48. The result for equivalent von-Mises strain is presented in Figure 5-49. The stress is approximately 545 MPa and the strain is approximately 0.00275 for the end coupling at the seal area. The stress is approximately 330 MPa and the strain is approximately 0.00165 for the housing at the seal area. The stress is approximately 545 MPa and the strain is approximately 0.00275 in the threads on the end coupling and in the threads on the housing.

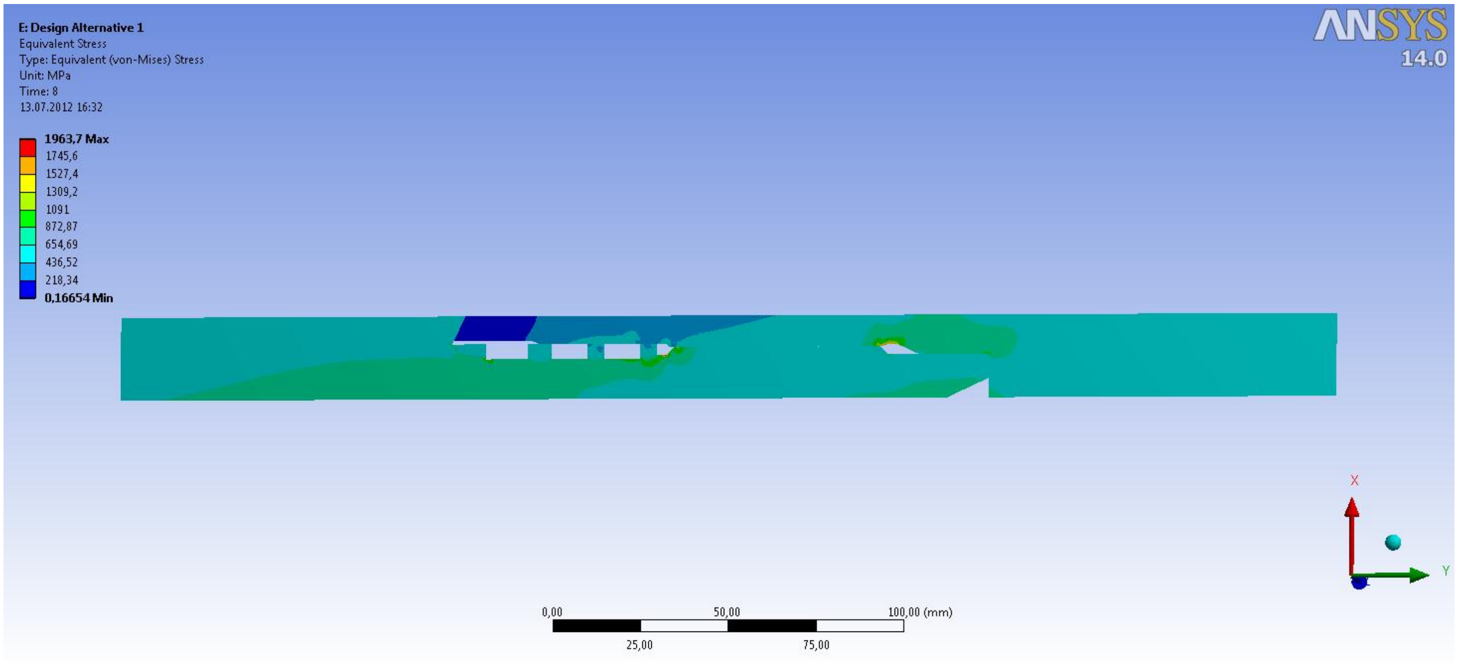


Figure 5-48: Equivalent (von-Mises) Stress of Alt.1

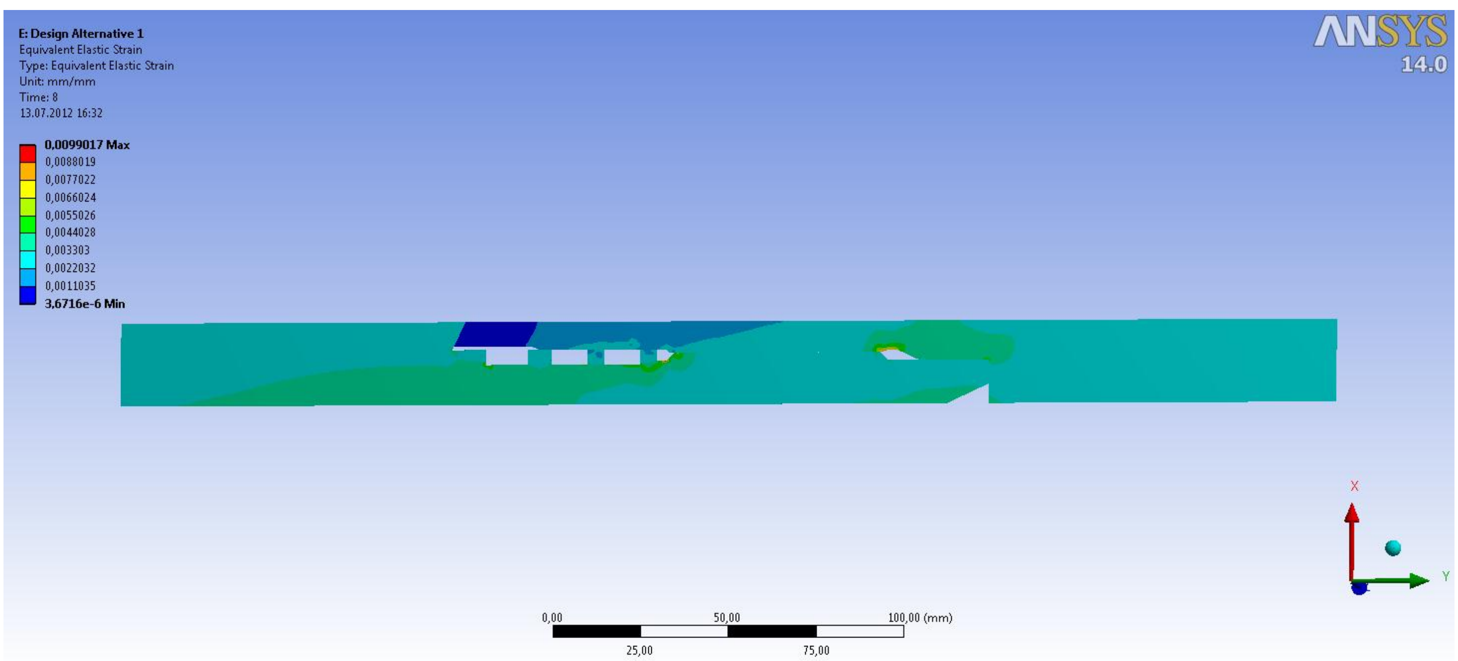


Figure 5-49: Equivalent Elastic Strain of Alt. 1

5.2.4 Analysis Results for Design Alternative 2

Figure 5-50 – 5-54 presents the analysis results and data of when Alt.2 is exposed to a collapse pressure of 89.5 MPa and tensile force of 2926 kN. Figure 5-50 presents total deformation results of Alt.2. The total deformation of the threads on the end coupling is approximately 0.51 mm. The total deformation of the threads on the housing is approximately 0.056 mm. Total deformation of the end coupling at the seal area (marked as seal area in Figure 5-50) is approximately 0.42 mm. Total deformation of the housing at the seal area is approximately 0.31 mm. At the section marked as intersection in Figure 5-50 the total deformation of the end coupling is approximately 0.37 mm. The total deformation of the housing at this section is approximately 0.14 mm.

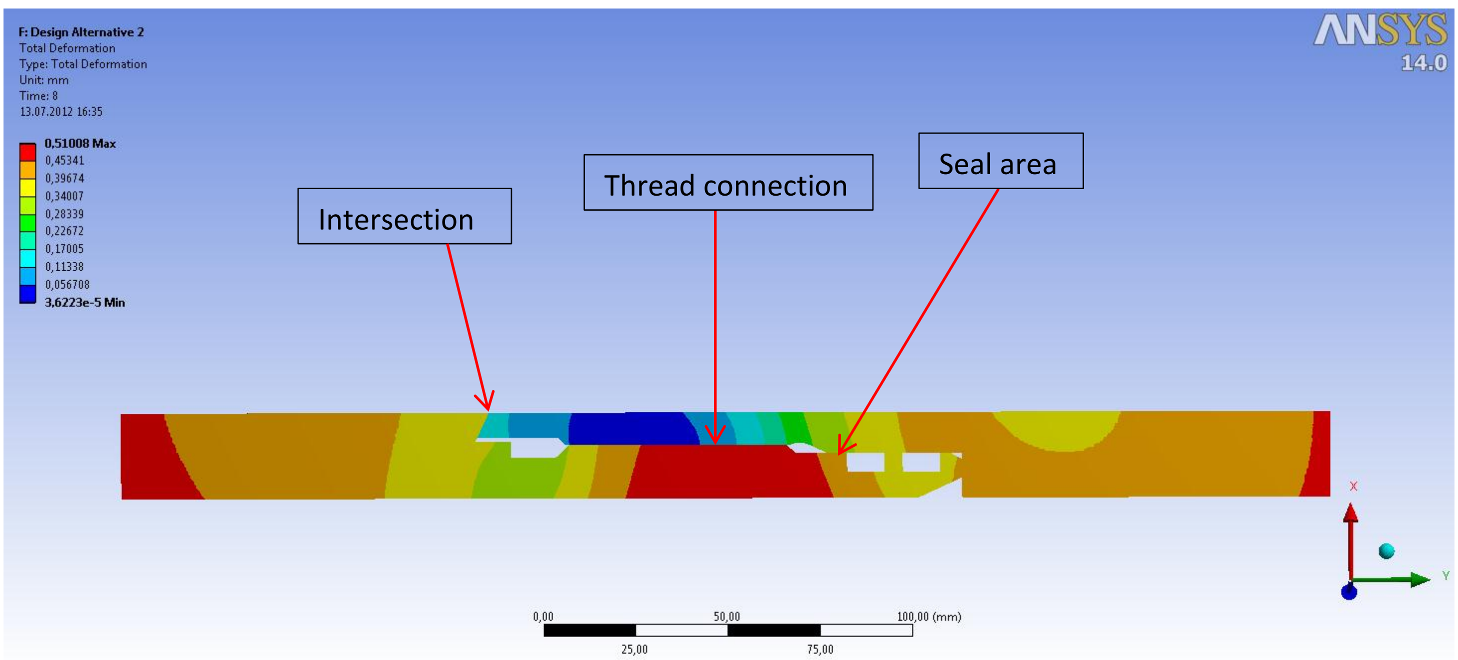


Figure 5-50: Total Deformation of Alt. 2

The directional deformation in x-direction is presented in Figure 5-51. This is the radial deformation of the model. At the seal section the deformation of the end coupling in x-direction is approximately -0.45 mm. The deformation of the housing at this area is approximately -0.29 mm. This gives a gap of 0.16 mm in x-direction between the end coupling and the housing at the seal area. At the thread connection the end coupling has a deformation of approximately -0.51 mm. The deformation of the threads on the housing is approximately -0.05 mm. This gives gap of approximately 0.46 mm in x-direction between the end coupling and the housing at the threaded connection. The deformation of the end coupling at the section where the housing and the end coupling intersects (marked as intersection in Figure 5-50) is approximately -0.29 mm in x-direction. The deformation of the housing is approximately +0.14 mm at this section. This gives a total displacement of 0.43 mm in x-direction between the end coupling and the housing at this area.

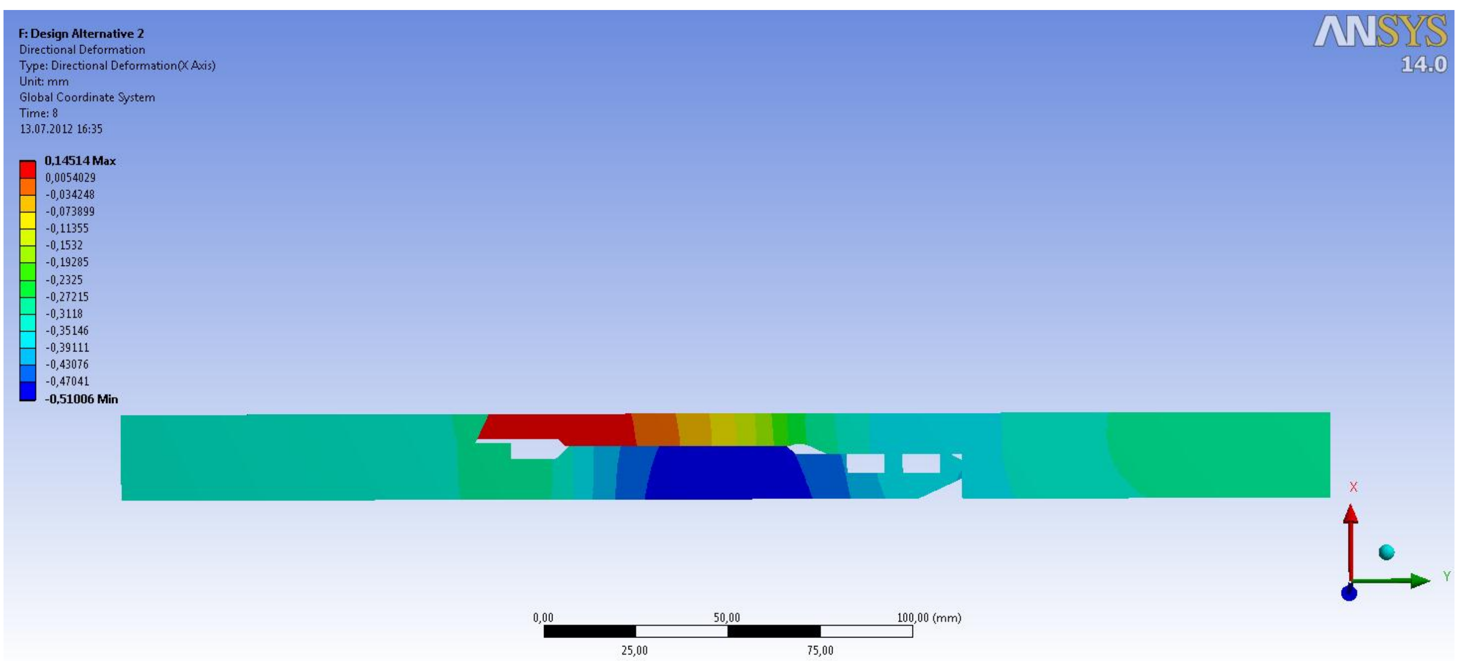


Figure 5-51: Directional Deformation (X Axis) of Alt. 2

The result for directional deformation in y-direction is presented in Figure 5-52. The deformation in y-direction of the end coupling at the seal area is approximately +0.005 mm. The deformation of the housing at the same area is approximately +0.08 mm. This gives a 0.075 mm displacement in y-direction between the end coupling and the housing at the seal area. At the thread connection there is no displacement in y-direction between the end coupling and the housing. The deformation of the end coupling and of the housing at thread connection is approximately +0.005 mm. The deformation of the end coupling at the intersection with the end coupling (marked as intersection in Figure 5-50) is approximately -0.27 mm. The deformation of the housing at this intersection is approximately +0.005 mm. This gives as gap of 0.275 mm in y-direction between the end coupling and the housing at this section.

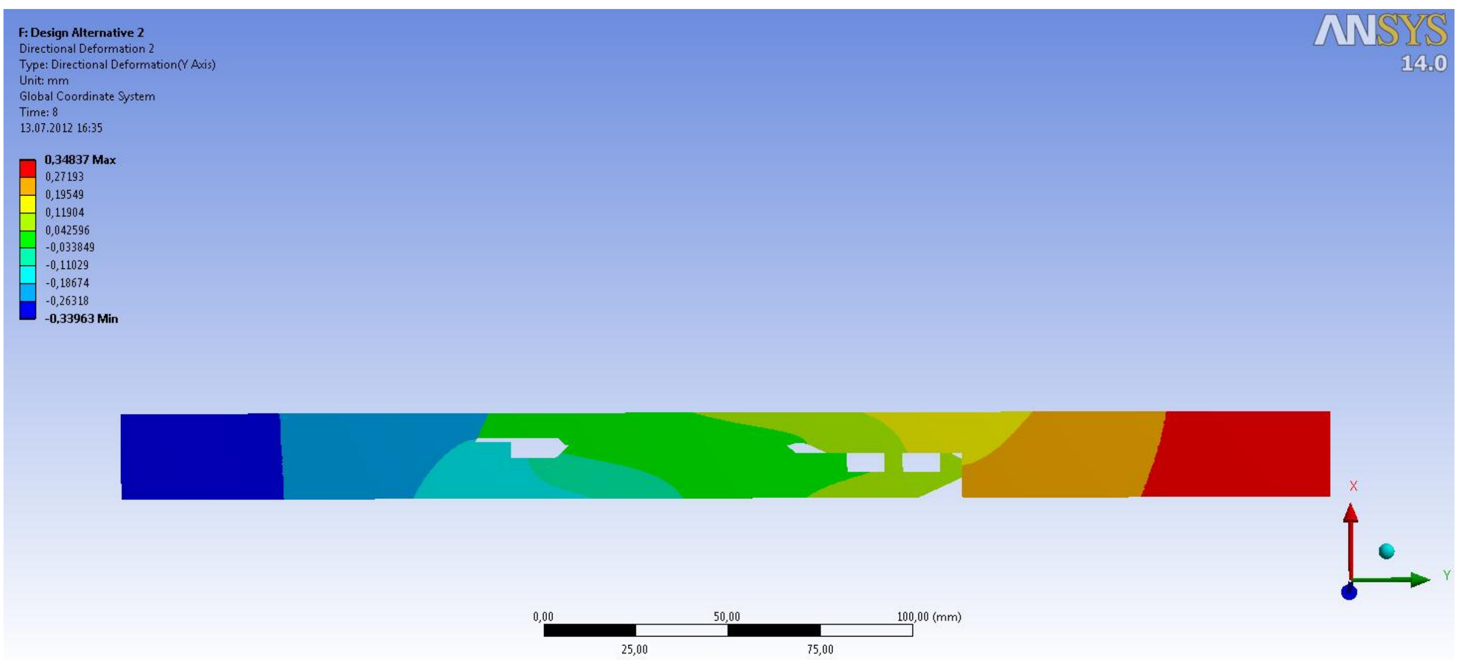


Figure 5-52: Directional Deformation (Y Axis) of Alt. 2

The result for equivalent von-Mises stress is presented in Figure 5-53. The result for equivalent von-Mises strain is presented in Figure 5-54. The stress is approximately 700 MPa and the strain is approximately 0.0035 for the end coupling and for the housing in the seal area. The stress is approximately 700 MPa and the strain is approximately 0.0035 in the threads on the end coupling. The stress is approximately 75 MPa and the strain is approximately 0.0003 in the threads on the housing.

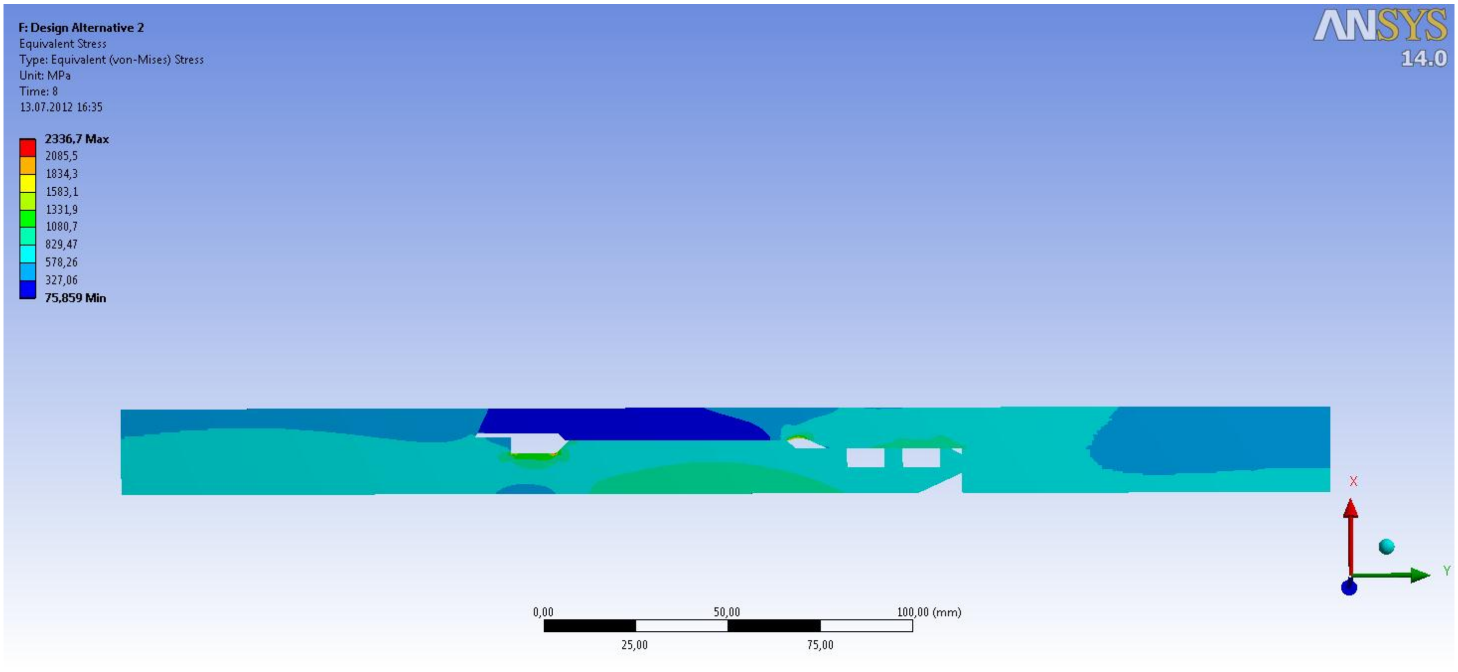


Figure 5-53: Equivalent (von-Mises) Stress of Alt. 2

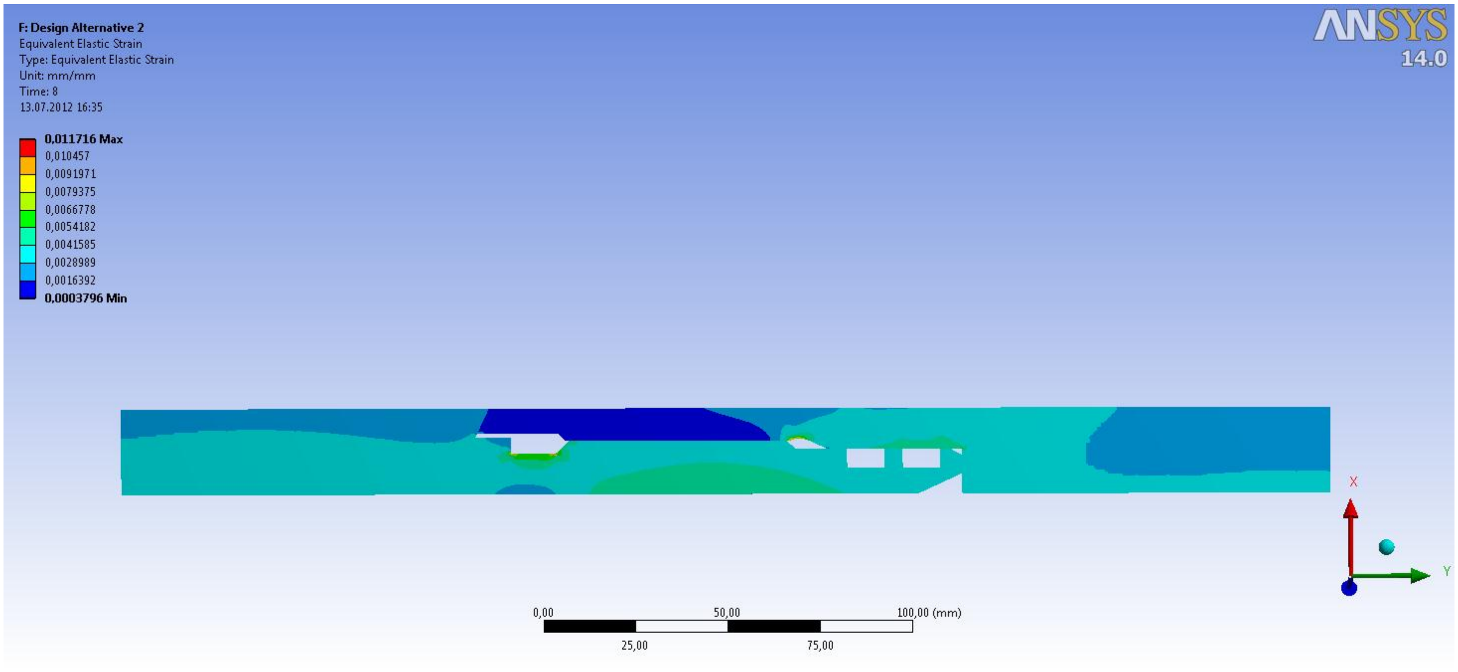


Figure 5-54: Equivalent Elastic Strain of Alt. 2

5.2.5 Analysis Results of Test Caps with Different Outer Diameters

Analysis results for test cap with 380 mm outer diameter are presented in Figure 5-55 – 5-56. Results for test cap with 360 mm outer diameter are presented in Figure 5-57 – 5-58. The results presented in this section are the results for deformation of the test caps. It was determined to choose the test cap with maximum 1/10 mm deformation at the inner O-ring groove.

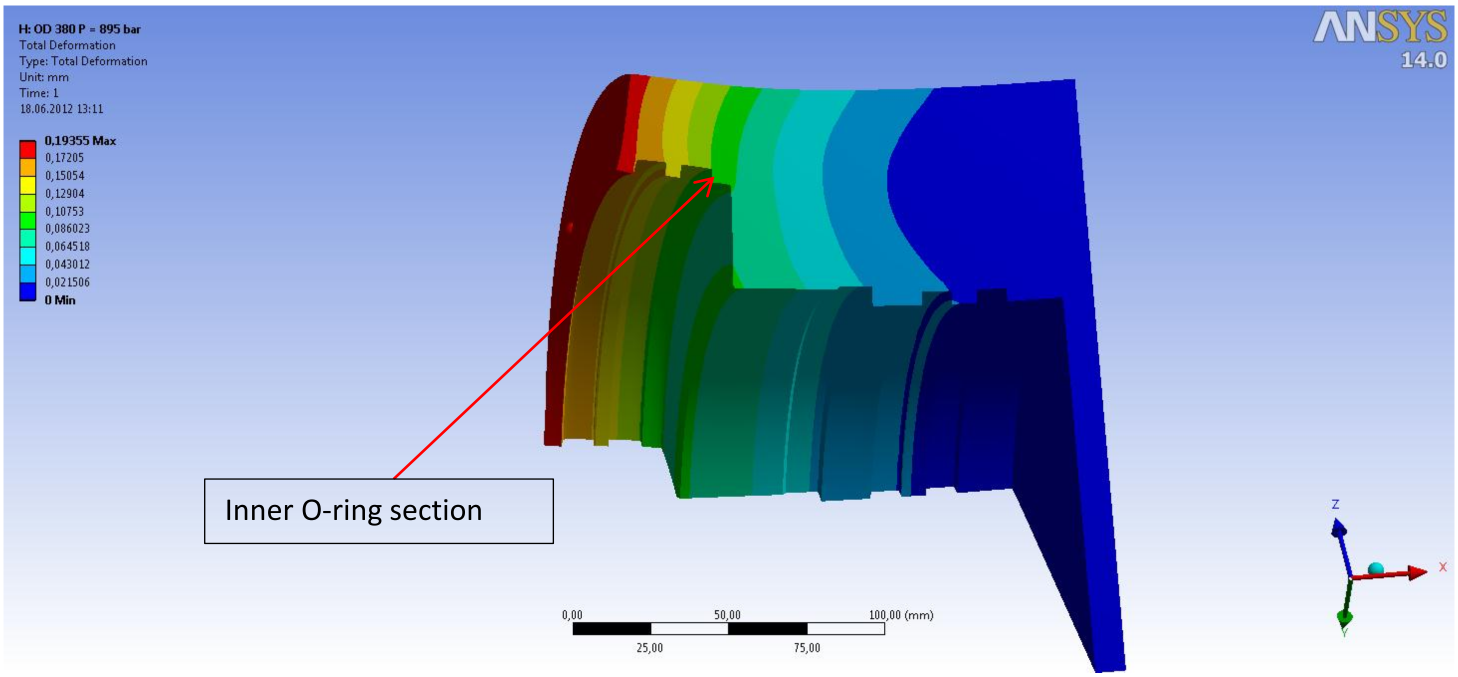


Figure 5-55: Total Deformation of Test Cap with OD = 380 mm P = 895 bar

Figure 5-55 is presenting the results for the total deformation of the test cap with an outer diameter of 380 mm. The total deformation at the inner O-ring groove (marked as inner O-ring section in Figure 5-55) when pressurized with 89.5 MPa is approximately 0.09 mm.

Directional deformation in z-axis direction for test cap with 380 mm outer diameter is presented in Figure 5-56. The deformation in z-direction at the inner O-ring groove is approximately +0.07 mm.

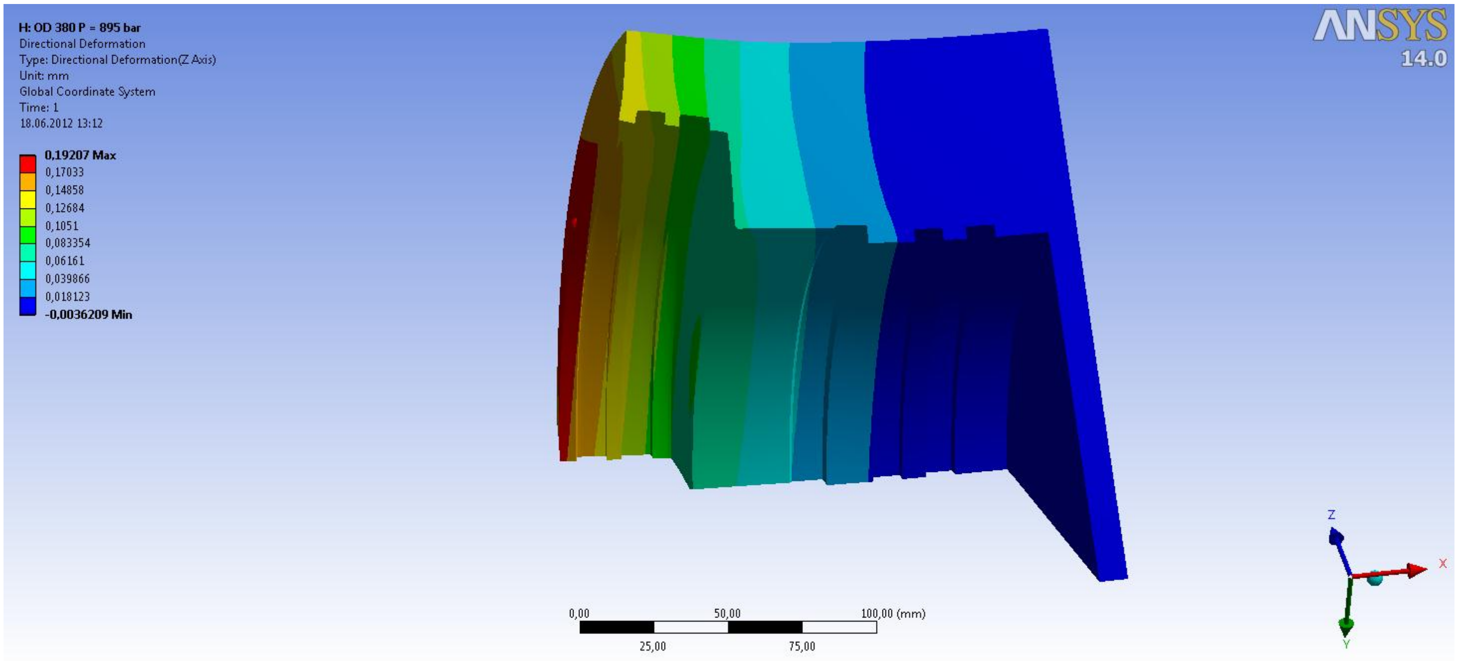


Figure 5-56: Directional Deformation of Test Cap with OD = 380 mm and P = 895 bar

Result for total deformation of test cap with 360 mm outer diameter is presented in Figure 5-57. This result gives a total deformation of approximately 0.12 mm at the inner O-ring groove on this test cap. Result for directional deformation in z-direction is presented in Figure 5-58. This result gives that the deformation in z-direction at the inner O-ring groove is approximately +0.11 mm for the test cap with 360 mm outer diameter.

The deformation results found at inner O-ring groove of the test cap with 360 mm are larger than 1/10 mm thus test cap design was discarded. The deformation results for the test cap with outer diameter of 380 mm are less than 1/10 mm. Analyses performed for test caps with larger outer diameter than 380 mm gave results that did not differ much from the results for the test cap with 380 mm outer diameter thus it was determined to use test caps with 380 mm outer diameter.

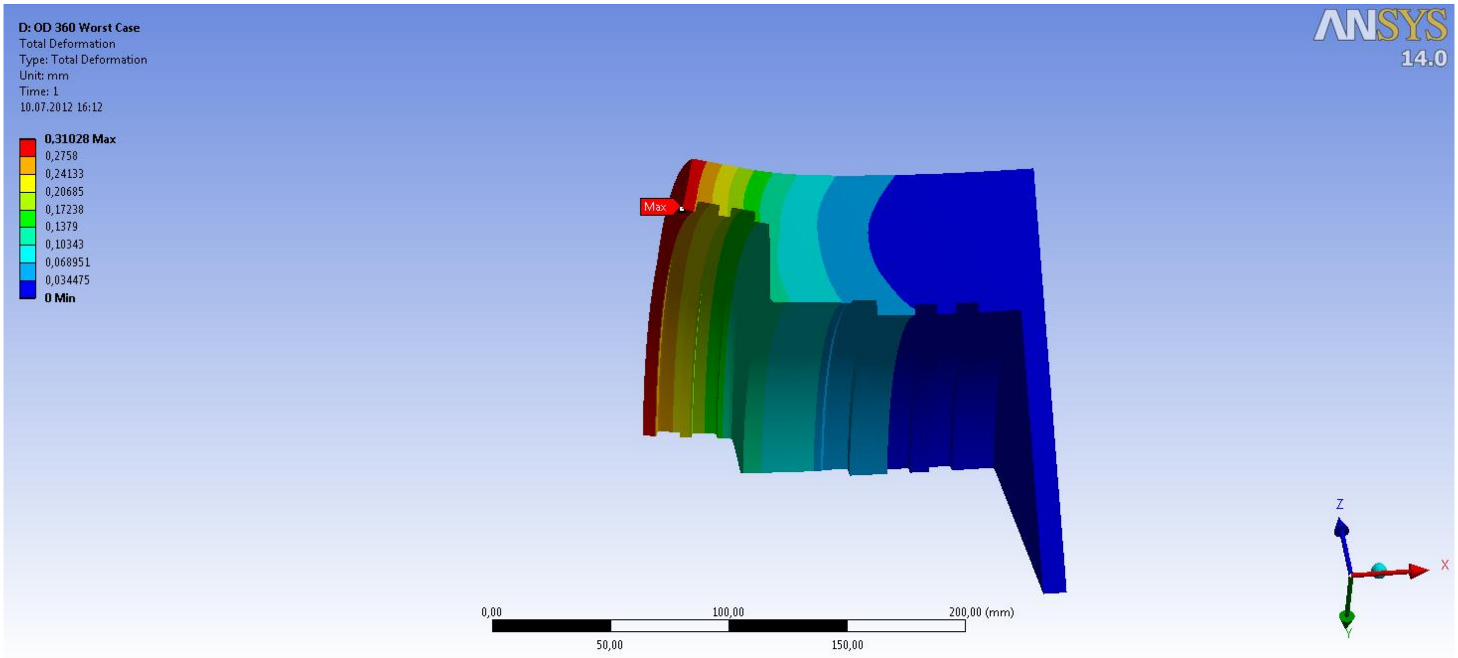


Figure 5-57: Total Deformation of Test Cap with OD = 360 mm

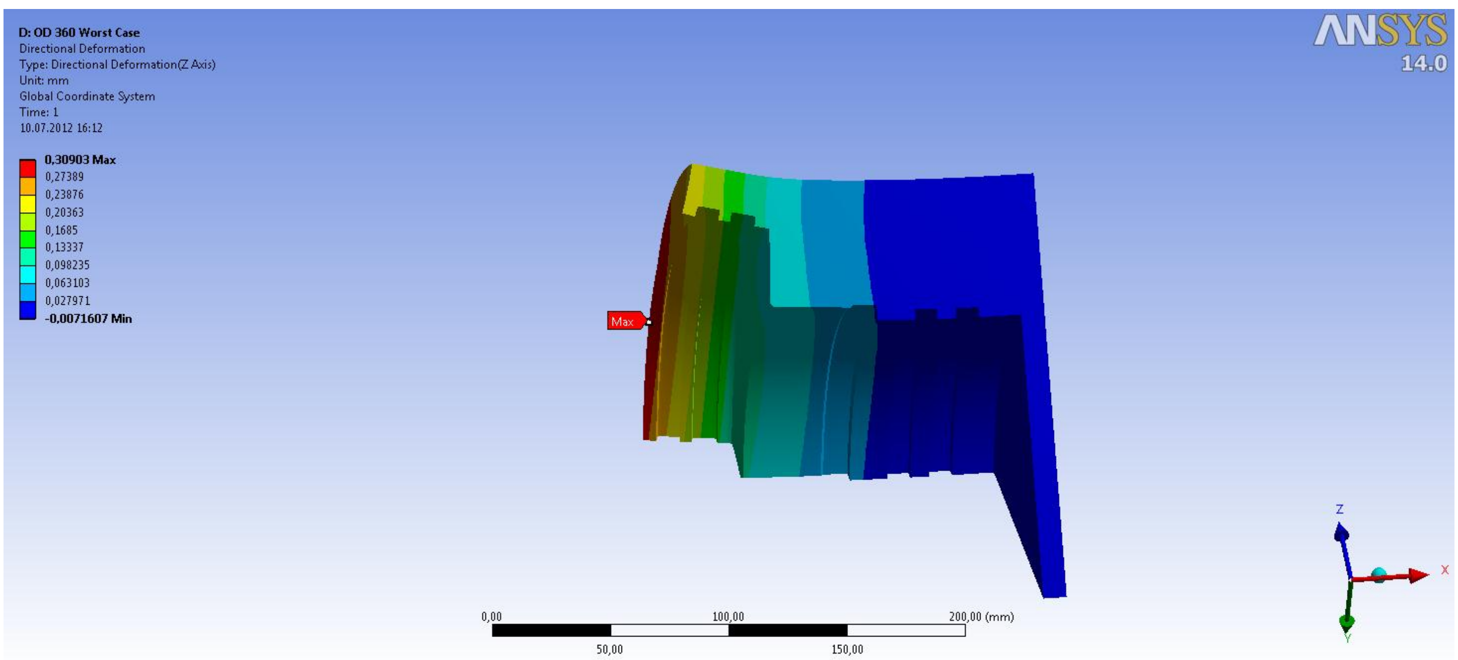


Figure 5-58: Directional Deformation (Z Axis) of Test Cap with OD = 360 mm

5.2.6 Analysis Results of Test Cap with Internal Pressure

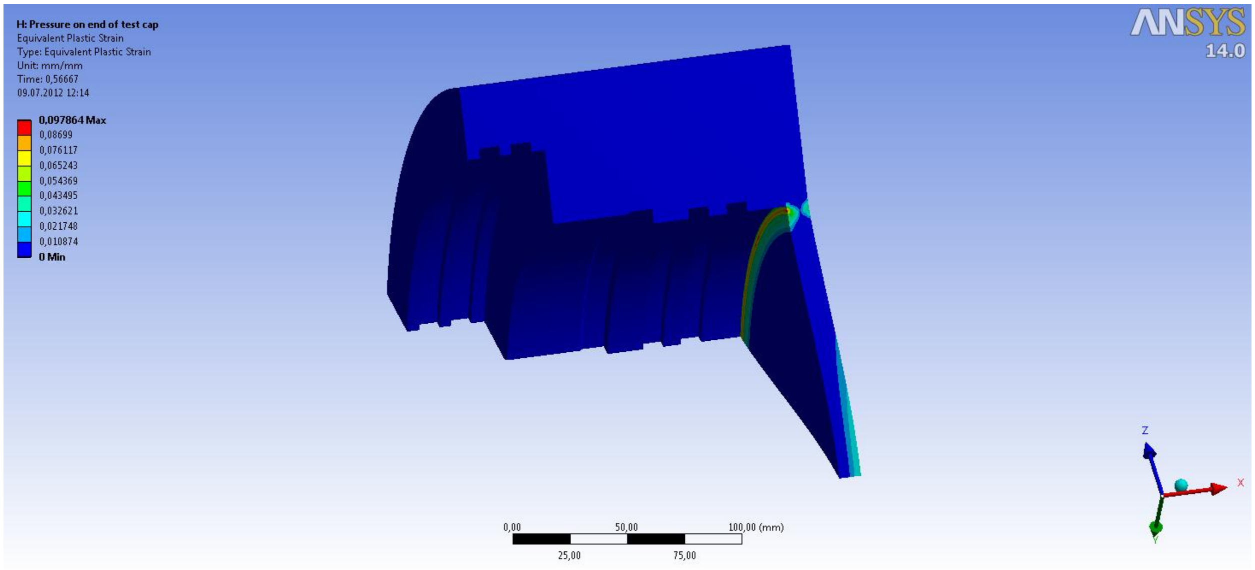


Figure 5-59: 10% Equivalent Plastic Strain of Test Cap

TABLE 18
Model (H4) > Static Structural (H5) > Solution (H6) > Equivalent Plastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
3,3333e-002	0,	0,
6,6667e-002		
0,11667		
0,16667		3,6877e-004
0,21667		1,2154e-003
0,26667		2,6287e-003
0,31667		6,2369e-003
0,36667		1,4075e-002
0,41667		3,2318e-002
0,46667		5,7211e-002
0,51667		7,8783e-002
0,56667		9,7864e-002
0,61667		0,1148
0,66667		0,13028
0,71667		0,14539
0,76667		0,1604
0,81667		0,17523
0,86667		0,18982
0,91667		0,20413
0,96667		0,21829
1,		0,22768

Figure 5-60: Table from Equivalent Plastic Strain Analysis of Test Cap

Figure 5-59 presents results for ten percent equivalent plastic strain of test cap. The equivalent plastic strain of the test cap at different time steps of the analysis are presented in the table presented in Figure 5-60. This table is from the analysis report. The pressure is applied in steps until it reaches the maximum pressure. Each time step represents a percentage of the maximum pressure applied on the test cap in the analysis. Ten percent plastic strain is between 9.7864e-002 and 0.1148. For further calculations the value obtained from 9.7864e-002 is used. This is at time step 0.56667s, which is when the pressure is 56.667% of maximum pressure applied on the test cap. Maximum pressure in this analysis is 20MPa. The pressure applied at ten percent plastic strain is:

$$P = 20MPa * 0.56667 = 11.3\ MPa$$

Maximum internal pressure on the test caps is then:

$$P_{max} = \frac{2}{3} * 11.3\ MPa = 7.5\ MPa = 75\ bar \quad [4]$$

5.3 Comparison of Designs

The three designs are compared by studying how the collapse pressure acts on the three designs. The results from the analyses made for each of the designs will be used in this comparison.

When the existing design is exposed to collapse pressure the threaded connection between the end coupling and the housing will be exposed to this pressure. This is illustrated in Figure 5-61. The pressurized surfaces are colored red. The pressure acting on the threads are illustrated with red arrows in this figure.

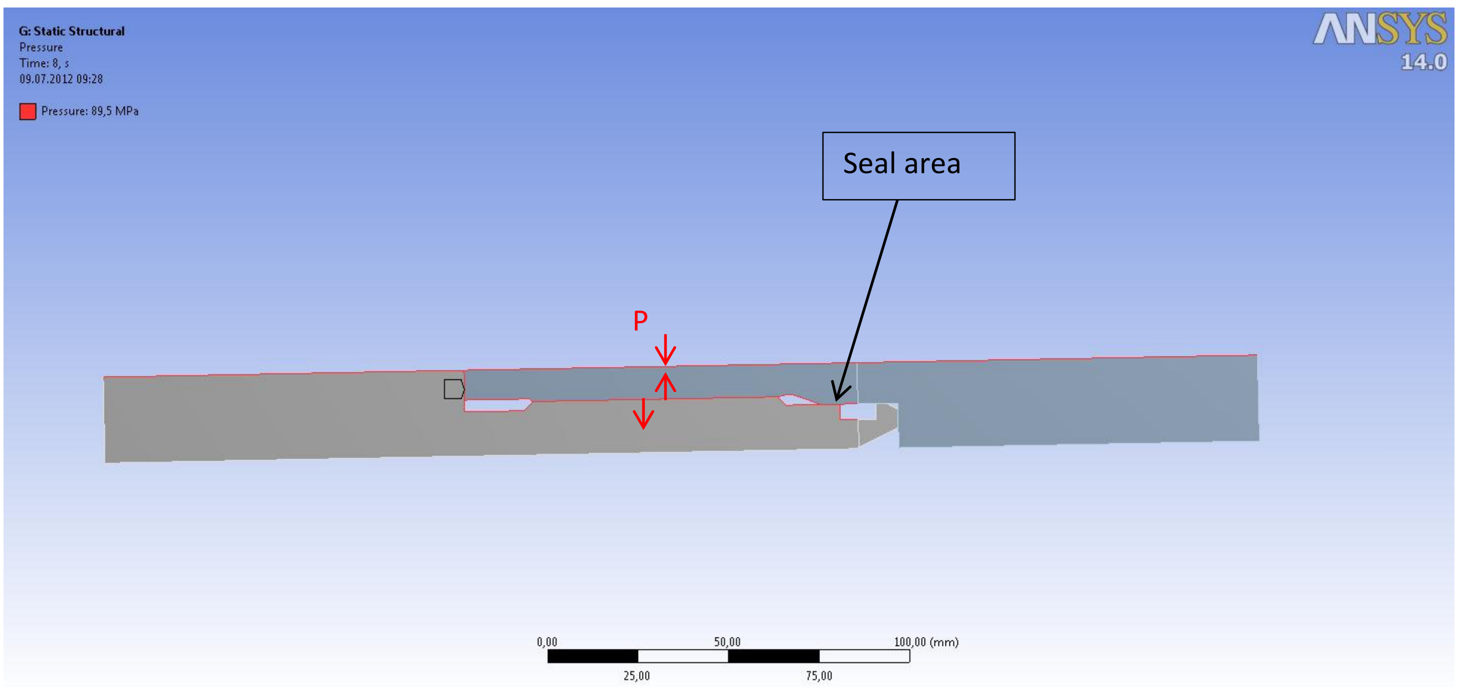


Figure 5-61: Pressurized Surfaces on Existing Design

On the housing the pressure on the threads and the pressure on the external surface of the housing will be equal. This means that the pressure acting on the threads on the housing evens out the pressure acting on the external wall of the housing. The pressure acting on the threads on the end coupling will push the threaded section of the end coupling towards the central axis of the tool. At high enough pressure this may cause displacement of the threads and in worst case cause the threads to disconnect. If the thread connection and the seal area are disengaged this may increase the possibility of leakage through the seal between the end coupling and the housing. When exposed to large tensile force and high collapse pressure the threads can in worst case be torn apart.

Figure 5-62 presents Alt. 1 when it is exposed to collapse pressure. The pressurized surfaces are colored red.

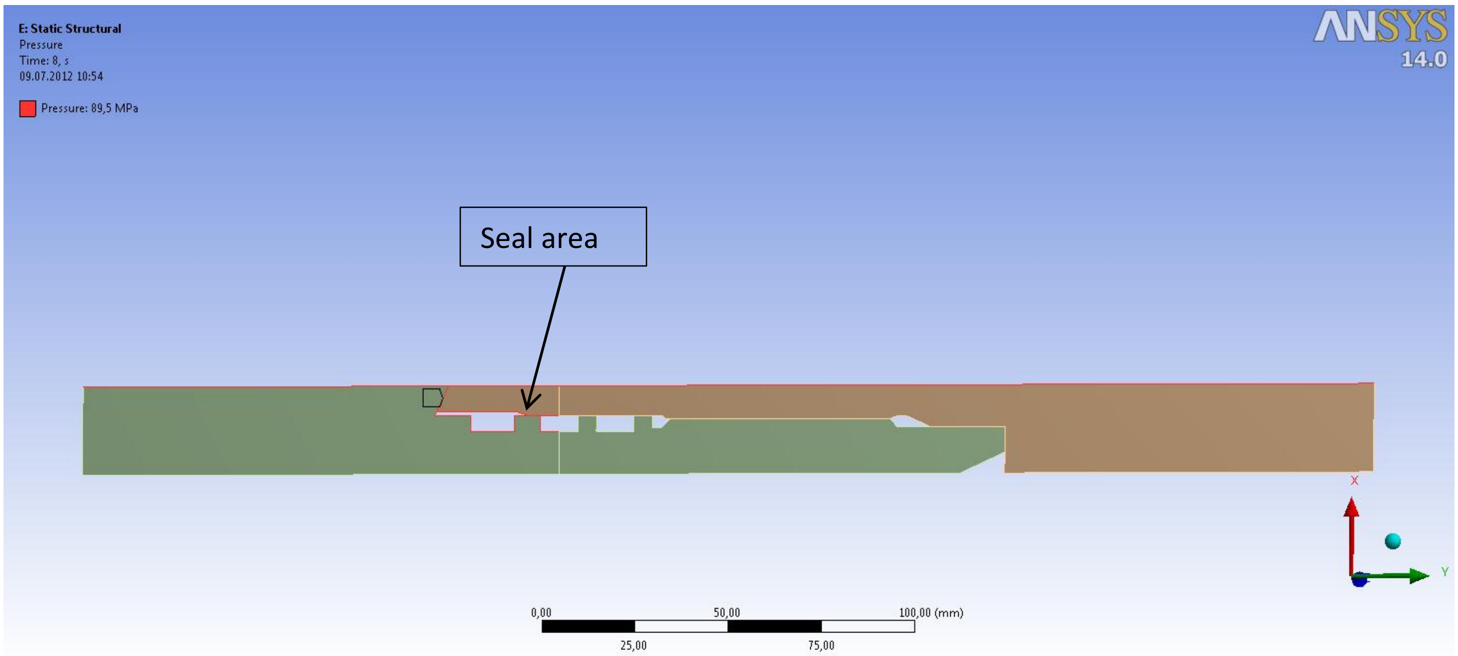


Figure 5-62: Pressurized Surfaces on Alt.1

When Alt. 1 is exposed to collapse pressure the threads will not be exposed to this pressure because of the position of the two seals in this design. By having a double seal it is expected that this design will be more resistant against leakage compared to the existing design.

Figure 5-63 presents the pressurized surfaces of Alt. 2 when exposed to collapse pressure.

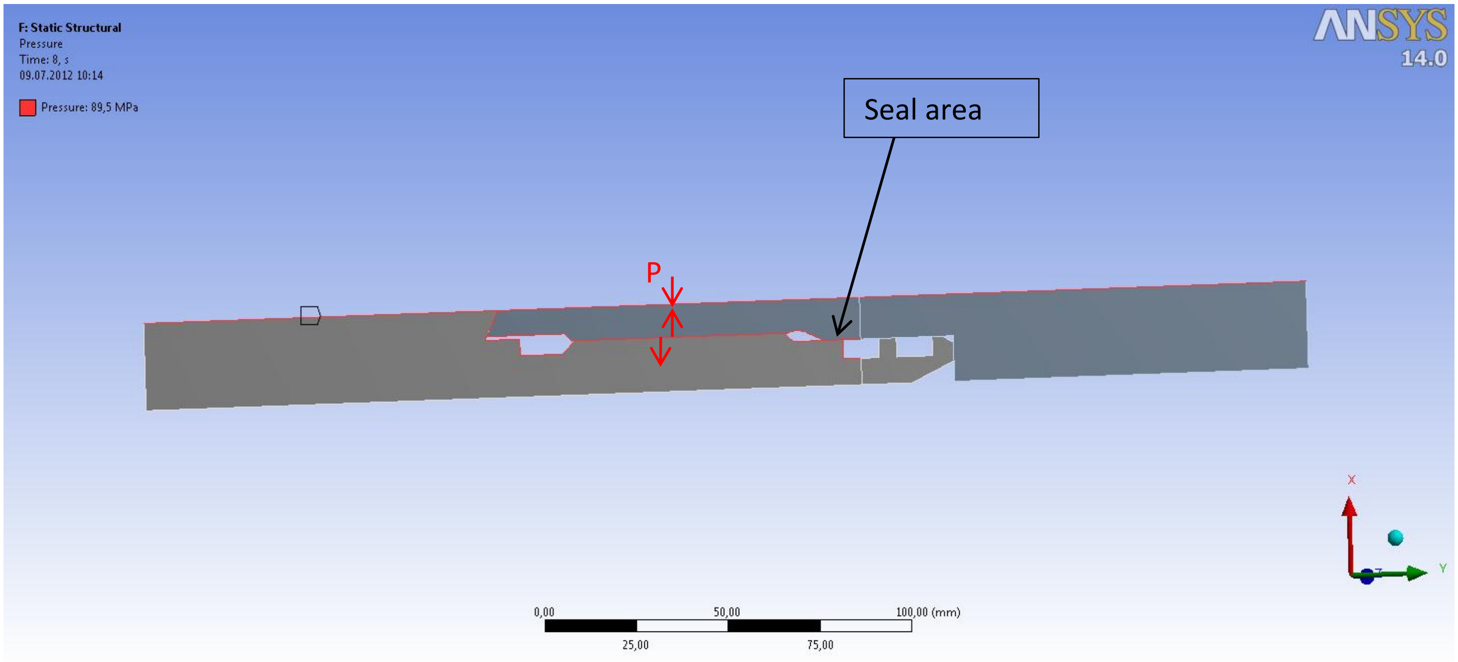


Figure 5-63: Pressurized Surfaces on Alt.2

Alt.2 has two seals that have the same position as the seal in the existing design. The threads on Alt.2 will be exposed to pressure when Alt.2 is exposed to collapse pressure. This is because of the position of the seals. The pressure acting on the threaded area is illustrated by the red arrows in Figure 5-62. On the housing the pressure on the threads and the pressure on the external surface of the housing will be equal. This meaning that the pressure acting on the threads on the housing is evened out by the pressure acting on the external wall of the housing. The pressure acting on the threads on the end coupling will push the threaded section of the end coupling towards the central axis of the tool. At high enough pressure this may cause displacement of the threads and in worst case cause the threads to disconnect. If the thread connection and the seal area are disengaged this may increase the possibility of leakage through the seal between the end coupling and the housing. When exposed to large tensile force and high collapse pressure the threads can in worst case be torn apart.

5.3.1 Comparison of analysis results

Existing Design:

Analysis results for the existing design give that there will be a gap of 0.13 mm between the end coupling and the housing at the seal when exposed to a pressure of 89.5 MPa and 2926 kN tensile force. The longitudinal displacement will be 0.065 mm between the end coupling and the housing in the seal area. The gap between the threads on the end coupling and the housing will be 0.47 mm. There will be no longitudinal displacement of the threads. The stress is approximately 700 MPa and the strain is approximately 0.0035 for the end coupling and for the housing in the seal area. The stress is approximately 700 MPa and the strain is approximately 0.0035 in the threads on the end coupling. The stress is approximately 60 MPa and the strain is approximately 0.0003 in the threads on the housing.

Design Alternative 1:

Analysis results for Alt. 1 give that the displacement of the threads on the end coupling will be equal to the deformation of the threads on the housing when Alt. 1 is exposed to a collapse pressure 89.5 MPa and a tensile force of 2926 kN. The results give that there will be a gap of 0.13 mm and a longitudinal displacement of 0.08 mm between the end coupling and the housing at the seal area. The stress is approximately 545 MPa and the strain is approximately 0.00275 for the end coupling in the seal area. The stress is approximately 330 MPa and the strain is approximately 0.00165 for the housing at the seal area. The stress is approximately 545 MPa and the strain is approximately 0.00275 in the threads on the end coupling and in the threads on the housing.

Design Alternative 2:

Analysis results for Alt.2 show that there will be a gap of 0.16 mm between the end coupling and the housing at the seal area when exposed to a pressure of 89.5 MPa and 2926 kN tensile force. The longitudinal displacement will be 0.075 mm at the seal area. The gap between the threads on the end coupling and the housing will be 0.46 mm. There will be no longitudinal displacement of the threads. The stress is approximately 700 MPa and the strain is approximately 0.0035 for the end coupling and for the housing in the seal area. The stress is approximately 700 MPa and the strain is approximately 0.0035 in the threads on the end coupling. The stress is approximately 75 MPa and the strain is approximately 0.0003 in the threads on the housing.

The analyses results give:

- The gap in the seal area is largest for Alt.2.
- The gap in the seal area is smallest and equal for the existing design and Alt.1.
- The stress and strain in the seal area on end coupling is highest and equal for the existing design and Alt.2.
- The stress and strain in the seal area on the housing is highest for Alt.2.
- The stress and strain in the seal area on the housing is lowest for Alt.1.
- The gap in the threaded connection is largest for the existing design
- The stress and strain in the threaded section on the end coupling is highest for the existing design and Alt.2
- The stress and strain in the threaded section on the housing is highest for Alt.1.
- The stress and strain in the threaded section on the housing is lowest for Alt.1.

These analyses results indicate that Alt.1 is the design that gets the highest sealing capacity. This is because this design has the smallest gap at the seal area and there is no disengaging of the threads between the end coupling and the housing in this design. Pressure tests of Alt.1 and Alt.2 will determine what design alternative that has the highest sealing capacity.

6 Pressure Test

The test is going to be done offsite at IRIS in Stavanger. The assembly of the equipment will be done onsite in workshop at Archer Oil Tools in Stavanger. The test procedure made for this project is presented in Appendix F.

6.1 Test Procedures and Test Execution

The pressure test setup for Alt.1 is presented in Figure 6-1. The pressure test setup for Alt.2 is presented in Figure 6-2. These setups are the same. A description of the pressure test setup is given below.

The inlet for the gas is on one of the test caps. This inlet is connected to a gas compressor. The gas compressor is connected to a Nitrogen gas (N_2) source. On the same test cap the outlet to the bubble control system is connected. The bubble control system will be measuring the gas leakage. This is done by measuring amount of bubbles coming into the water tank. A video camera is used to monitor the bubbles. A pressure transmitter is connected to the test cap on the other end. This is measuring the pressure on the inside of the test casing. The 1/4" NPT inlet on this test cap is not needed and is therefore going to be plugged. After connecting all the necessary connections the test assembly is going to be submerged in a water tank. This is to check if there are leakages in the test cell before pressure test starts.

Maximum pressure to be applied is 895 bar (89.5 MPa). The pressure will be applied in steps of 100 bar up to 500 bar. From 500 bar up to 895 bar the pressure will be applied in steps of 50 bar. The pressure is going to be held at each step for a couple of minutes to check the amounts of bubbles.

The pressure test equipment is going to be assembled according to the test procedure. The test procedure can be found in Appendix F.

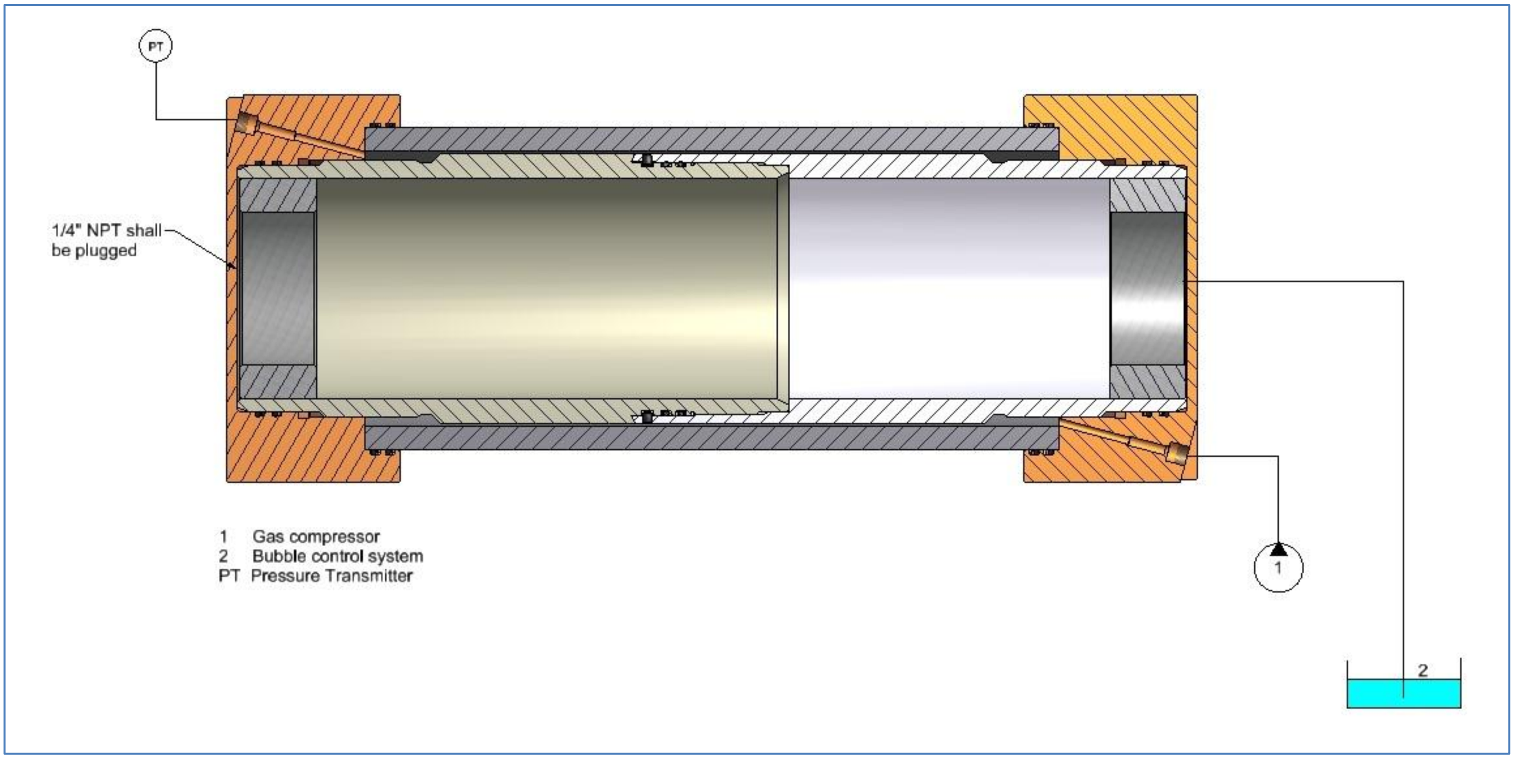


Figure 6-1: Pressure Test Setup for Alt. 1

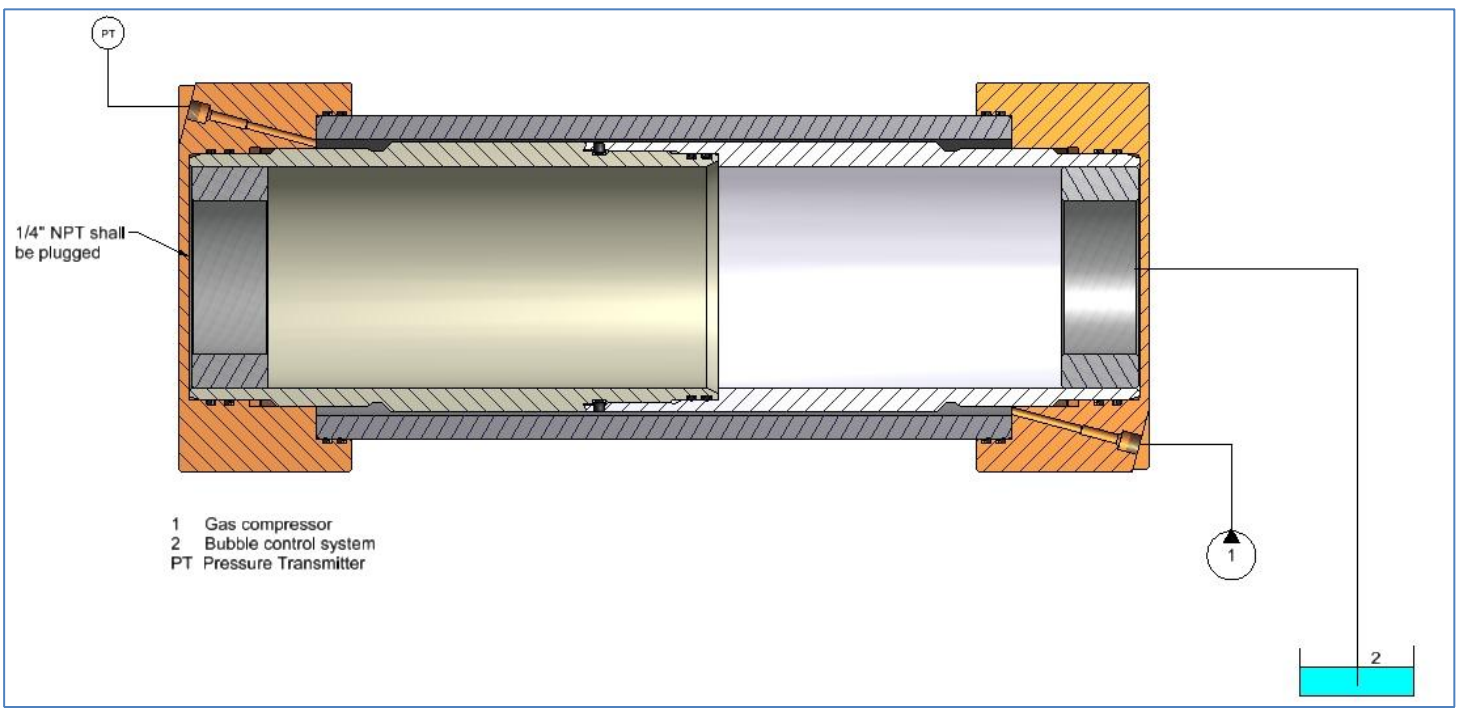


Figure 6-2: Pressure Test Setup for Alt. 2

6.1.1 Assembling of pressure test equipment and execution of pressure test

Figure 6-3 is presenting the test piece, the assembled end coupling and housing, for both design alternatives. The exterior of both these assemblies look the same. Figure 6-4 is presenting the manufactured test casing and Figure 6-5 is presenting one of the two test caps.

Figure 6-3: End Coupling and Housing Assembled

Figure 6-4: Test Casing

Figure 6-5: Test Cap

It was decided to assemble test equipment and perform pressure test on design alternative 1 first. The first step of the assembling was to mount one of the test caps on the end coupling of Alt.1. This is presented in Figure 6-6. In the next step the test casing was fitted over the test piece and on to the test cap assembled to the end coupling. This is presented in Figure 6-7.

Figure 6-6: Test Cap Mounted on End Coupling of Alt. 1

Figure 6-7: Test Casing Fitted over Test Piece of Alt. 1

Thereafter the last test cap was mounted on the end of the housing and fitted on the test casing simultaneously. A torque machine was used to tighten the connections in the test caps. This can be seen in Figure 6-8 and Figure 6-9. The total length of the test piece was checked and compared with the total length given in the mechanical drawing. The torque machine was only used when assembling the pressure test equipment for the first pressure test of Alt. 1.

Figure 6-8: Use of Torque Machine to Assemble Test Equipment on Alt. 1

Figure 6-9: Alt. 1 in Torque Machine

Figure 6-10 is presenting pressure test assembly of Alt.1 (Test Assembly 1) when ready for transportation to test location. Test Assembly 1 was transported to test location at IRIS in Stavanger.

Figure 6-10: Test Assembly 1 Ready for Transportation to Test Location

Figure 6-11 is presenting when Test Assembly 1 is installed and prepared for pressure test at IRIS in Stavanger. Figure 6-12 is presenting when Test Assembly 1 is being placed in the water tank. The connections for the pressure transmitter, bubble control system and gas inlet are illustrated in this figure.

Figure 6-11: Installing Test Equipment for Alt. 1 for Pressure Test at IRIS

Figure 6-12: Test Assembly 1 in Water Tank at IRIS

Figure 6-13 is presenting when Test Assembly 1 is submerged in the water tank and ready for pressure testing. The pressure test was executed from an isolated control room. The monitor for the bubble control system is presented in Figure 6-14.

Figure 6-13: Test Setup at IRIS

Figure 6-14: Monitor for Bubble Control System

After first pressure test of Alt.1 it was decided to drill 4 holes and plug these holes with plastic plugs in one of the test caps. This was to assure that if the test piece would collapse the volume of gas would escape from the internal volume of the test piece without bursting the test caps. The test cap with the added plugged holes is presented in Figure 6-15.

Figure 6-15: Test Cap with Plastic Plugs

The installation for second pressure test of Test Assembly 1 is presented in Figure 6-16. Since the first pressure test gave no leakage this pressure test was performed with only one O-ring in the seal between the end coupling and housing. One of the O-rings and all of the back-up rings were removed. This was done to achieve results.

Figure 6-16: Installing Test Assembly 1 for Second Pressure Test

The procedure for assembling and preparing Alt. 2 was the same as for Alt. 1. When the test equipment was assembled to Alt. 2 (Test Assembly 2) it was transported to test location at IRIS in Stavanger. Figure 6-17 is presenting Test Assembly 2 when installed for pressure test at IRIS. It was decided that the pressure test of Alt. 2 should be performed with one O-ring and no back-up rings in the seal between the end coupling and the housing. This was done to achieve leakage results.

Figure 6-17: Test Assembly 2 Installed for Pressure Test

6.2 Test Results

Diagrams of the pressure step interval from the pressure tests are presented in Figure 6-18 and Figure 6-19. Figure 6-18 presents the diagram of the second pressure test performed on Alt. 1. Figure 6-19 presents the diagram of the pressure test performed on Alt. 2. A pressure test report made by IRIS is presented in Figure 6-20 – 6-21. This report includes results from all of the pressure tests.

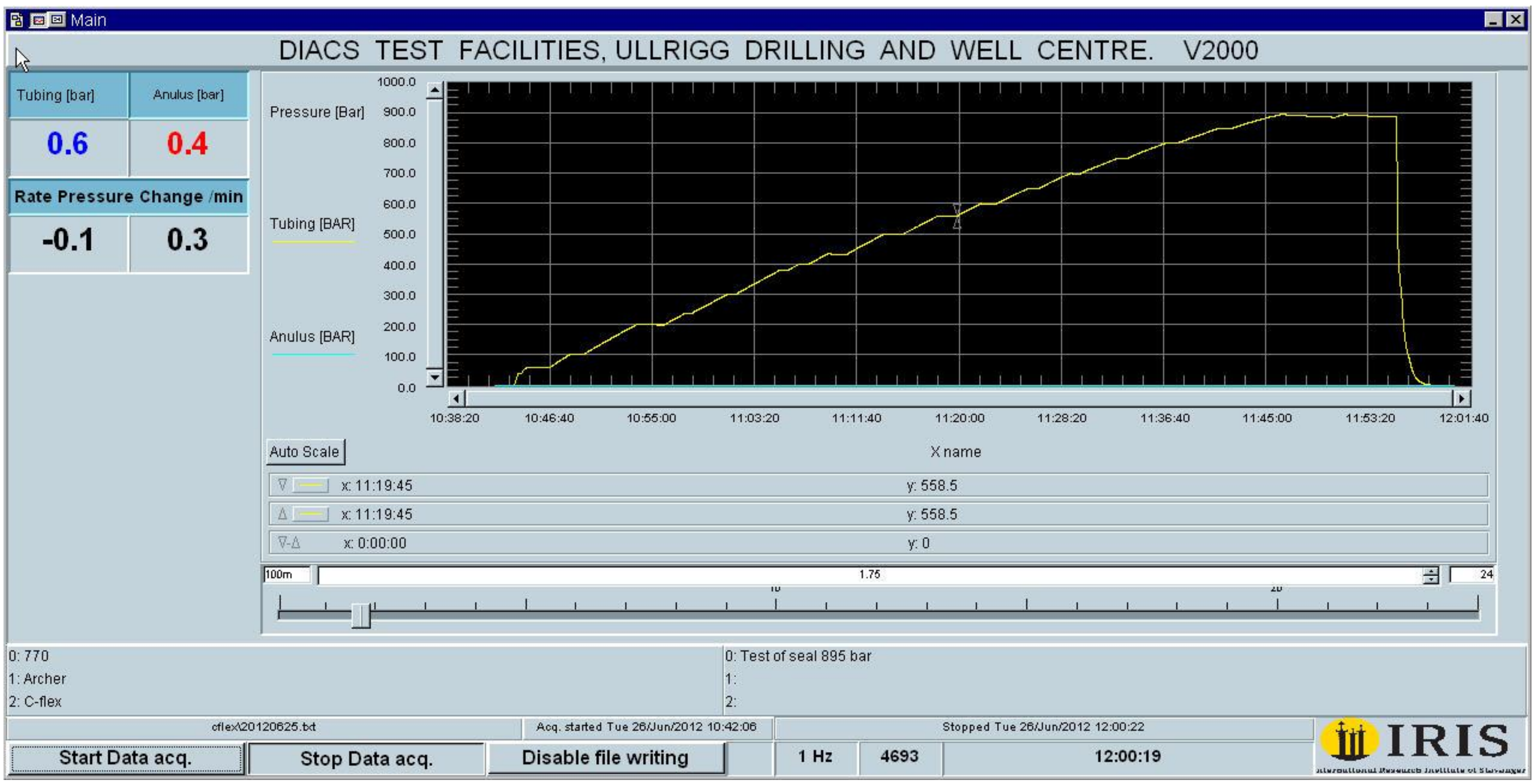


Figure 6-18: Pressure Step Interval from Second Pressure Test of Assembly 1

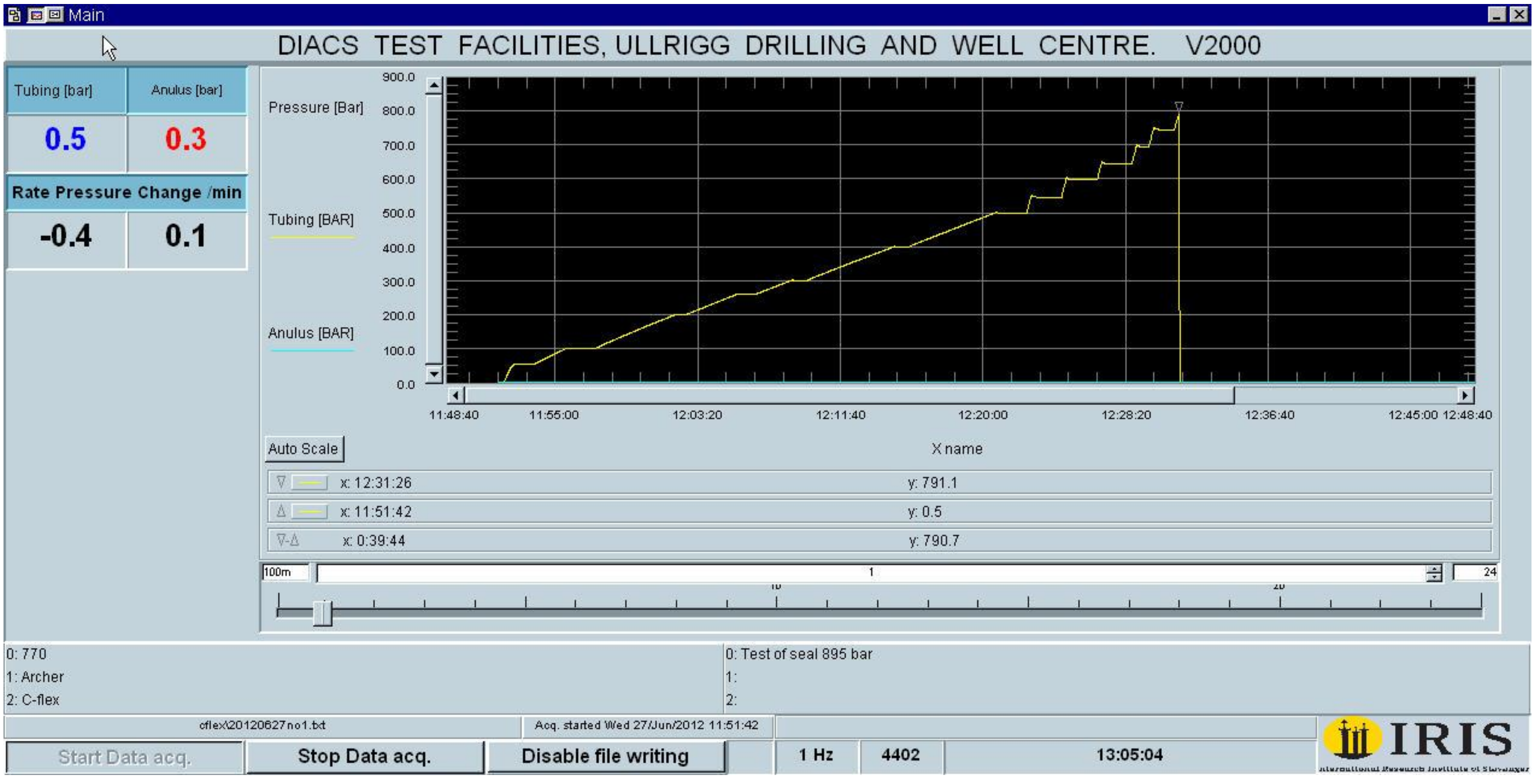


Figure 6-19: Pressure Step Interval from Pressure Test of Assembly 2

Daily Test Report - Ullrigg Drilling and Well Centre	
Client	Archer Oil Tools
Test object	

International Research Institute of Stavanger

Temperature	High	Amb	°C	Low	-	°C
Test pressure	High	895	bar	Low	-	bar
Test medium	Nitrogen					
Test program	According to Archer test procedure 12-024					
Pressure bleed program						
Client contact person						
IRIS project manager	Erling Haaland					
Date of start	25.06.2012					

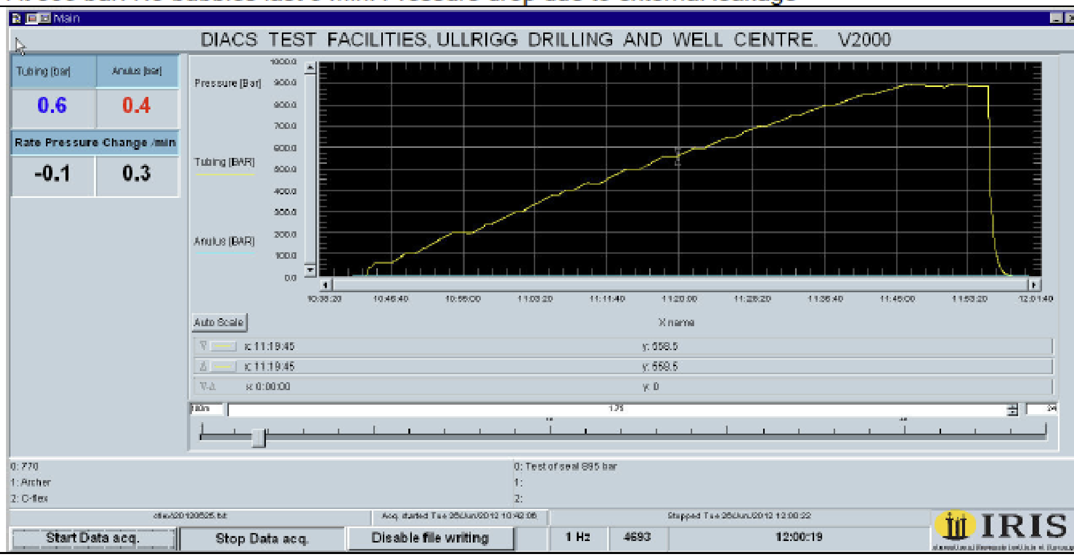
Log

Time	Text
	Monday 25.06.2012
08:30	Prepared for test of C-flex in water
	895 bar bar, at ambient – all according to test procedure Safetyvalve set to 895 bar + 10%
10:30	Preapred C-flex submerged in water Connected to Line in (lowside on rig) Pressure (lowside on rig) Bubble detection (topside on rig) For trst Lowside pressure line open Lowside bubblevalve closed Topside bubblevalve open
11:49	Test 100 bar OK
11:55	Test 200 bar OK
12:02	Test 300 bar OK
12:09	Test 400 bar OK
12:15	Test 500 bar OK
	Proceed with 50 bar step
12:19	Test 550 bar OK
12:23	Test 600 bar OK
12:26	Test 650 bar OK
12:33	Test 700 bar OK
12:45	At 750 bar
12:55	At 800 bar, Decided terminate test and bleed pressure to ambient. Archer to do new calculations on end lid before next test. This to verify inner volume pressure versus end lid capacity if a total casing collaps.
	26.06.2012
10:30	New test assembly installed. One o-ring installed
10:43	Applied pressure on annulus.
10:46	At 56 bar. N2 source pressure reading same as in log.
10:48	At 100 bar. Increased pressure after short stop
10:54	At 200 bar. Increased pressure after short stop
10:57	235 bar bar detected some bubbles 1 ml
11:01	At 300 bar. Increased pressure after short stop
11:06	Detected bubbles at 379 bar 30 ml
11:08	At 400 bar. No bubbles detected. Increased pressure after short stop
11:14	At 500 bar. Hold pressure. 1 ml bubbles between 400 to 500 bar
11:18	At 559 bar. Detected bubbles. 15 ml during 1 min then stop in bubble rate

Figure 6-20: Test Report from IRIS, page 1.

Daily Test Report - Ullrigg Drilling and Well Centre	
Client	Archer Oil Tools
Test object	

11:21	At 600 bar. Hold pressure for a short period.
11:25	At 650 bar. Some bubbles detected
11:29	At 700 bar, some bubbles detected
11:33	At 750 bar. 5 ml between 700-750 bar
11:37	At 800 bar 7 ml between 750-800 bar
11:41	At 850 bar 7 ml between 800-850 bar
11:46	At 895 bar. No bubbles last 5 min. Pressure drop due to external leakage



	27.06.2012
11:50	Applied pressure
11:56	At 100 bar, no leakage
12:02	At 200 bar, no leakage
12:05	Some bubbles detected at 243 bar, 40 ml then stopped. Increased pressure
12:08	At 300 bar, 20 ml bubbles
12:14	At 400 bar, detected 40 ml bubbles between 300-400 bar
	New N2 source installed
12:21	At 500 bar, detected 50 ml bubbles between 400-500 bar
12:22	At 550 bar, 10 ml bubbles detected between 500-550 bar
12:24	At 600 bar 20 ml bubbles detected
12:29	700 bar, 30 ml bubbles
12:30	750 bar 20 ml bubbles
12:31	Test cell failure at 791 bar. Test terminated.

Figure 6-21: Test Report from IRIS, page 2

When running the first collapse pressure test on Test Assembly 1 no leakage was detected. First it was pressurized with steps of 100 bar up to 500 bar and thereafter it was pressurized with steps of 50 bar up to 800 bar. Initially it was going to be pressurized up to 895 bar. Pressure test was stopped at 800 bar because of uncertainty of burst capacity of the test caps in case of collapse of test piece. The pressurized gas in the volume between the test casing and the test piece would flow into the internal volume of the test piece if the test piece collapses. This could create a pressure build-up on the internal volume of the test piece. Analysis of the test cap was made. Results from this analysis can be found in section 5.2.6. This analysis give 75 bar maximum burst pressure for the test caps. Figure 6-22 presents dimensions used for calculation of difference in volumes in the test piece. These calculations are presented in Figure 6-23.

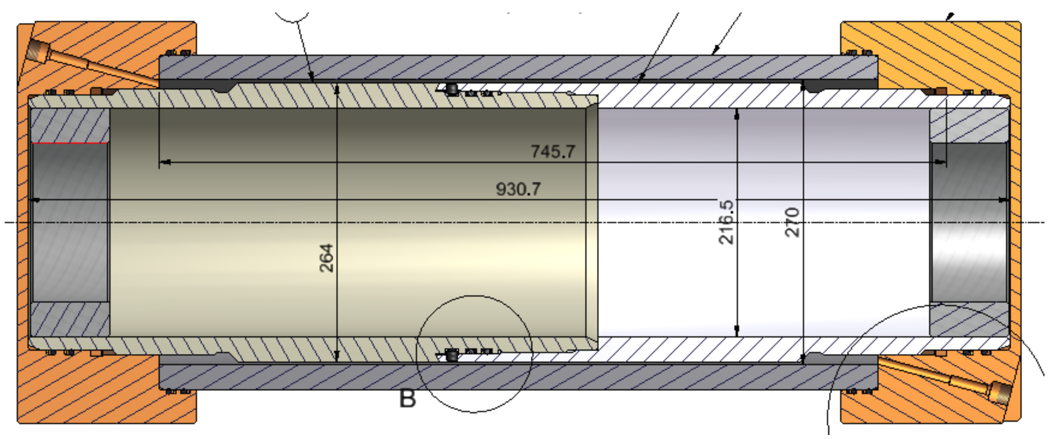


Figure 6-22: Dimensions used for Calculations of Volumes in Test Piece

Approximate Internal volume of test piece:

$$V_i := (216.5\text{mm})^2 \cdot \frac{\pi}{4} \cdot 930.7\text{mm} = 3.426 \times 10^7\ \text{mm}^3$$

Approximate volume between test piece and test casing:

$$V_o := \frac{\left[(270\text{mm})^2 - (264\text{mm})^2\right] \cdot \pi \cdot 745.7\text{mm}}{4} = 1.876 \times 10^6\ \text{mm}^3$$

$$\Delta V := \frac{V_o}{V_i} = 0.055$$

$P_o := 895\text{bar}$ Max Pressure in V_o

$P_i := P_o \cdot \Delta V = 49\,\text{bar}$ Pressure in V_i if collapse

Figure 6-23: Calculation of Pressure in Internal Volume in Case of Collapse

The volumes calculated in Figure 6-23 are approximate volumes. These volumes are the same for Alt.1 and Alt.2. The internal volume is calculated to be approximately 94.5% larger than the volume between the test casing and the test piece. If the test piece collapses at maximum pressure of 89.5 MPa, the pressure on the internal volume will be 5.5% of this pressure. The pressure in the internal volume will be approximately 4.9 MPa in case of collapse. It was determined to drill three holes that were plugged with plastic plugs. This was done to prevent pressure build up on the internal volume in case of collapse. The gas would flow through these added holes in case of pressure build up and help to prevent burst of test caps.

In further testing it was determined to perform pressure test with only one O-ring in the seal between the end coupling and the housing. One of the O-rings and all of the back-up rings were removed. This was done check the capacity of the seals with only one O-ring.

In the second test of Alt.1 it was detected some bubbles at some pressures. This is presented in the test report in Figure 6-20 – 6-21. Bubbles stabilized and disappeared when holding the pressure at these steps. This indicates that pressure stabilized and that there was no leakage. The maximum pressure applied in this test 89.5 MPa. This pressure was held for approximately 5 minutes. No leakage was detected during this test. Pictures of Alt.1 after pressure test can be viewed in Figure 6-24 – 6-26.

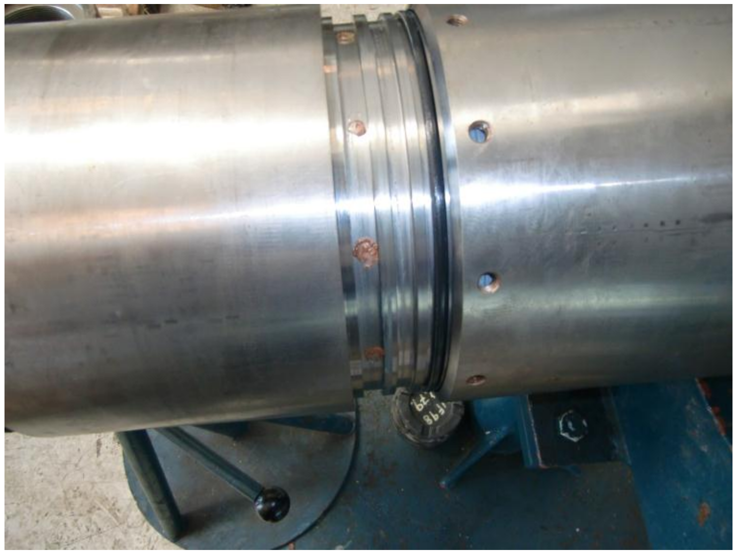


Figure 6-24: Seal Alt.1 after Pressure Test

Figure 6-25: End Coupling Alt. 1 after Pressure Test

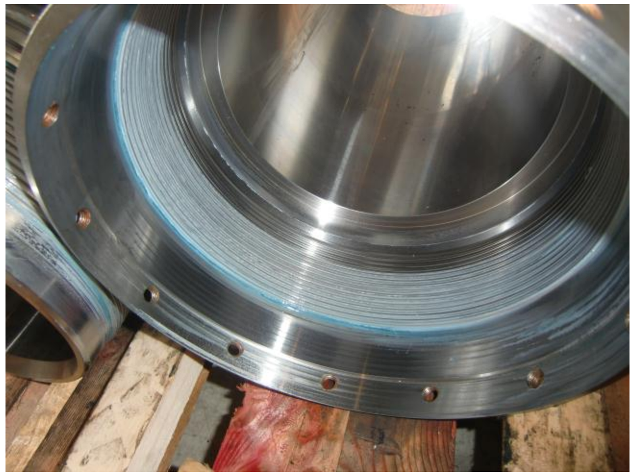


Figure 6-26: Housing Alt. 1 after Pressure Test

When pressure test of Alt.1 was completed the test equipment was disassembled and controlled for damages. The test equipment was cleared and Alt.2 was assembled with the test equipment and prepared for transport to test location at IRIS. This test was performed with one O-ring. The back-up rings and one of the O-rings were removed. The pressure test of Alt.2 was performed after the same procedure as for Alt.1. More bubbles were detected during pressure test of Alt.2 than during pressure test of Alt. 1. The bubbles stopped when holding the pressure at each step. This indicated that there was no leakage. At 750 bar there was no leakage when holding at this pressure. When increasing pressure from 750 bar and up to approximately 790 bar the assembly burst. Pictures of the parts after the test failure are presented in Figure 6-27 – 6-30. As these pictures indicate the test failed because of separation of the connection between the end coupling and housing. The equipment had to be inspected and go through an investigation to discover the reason for why this incident happened. This is presented in section 6.2.1.

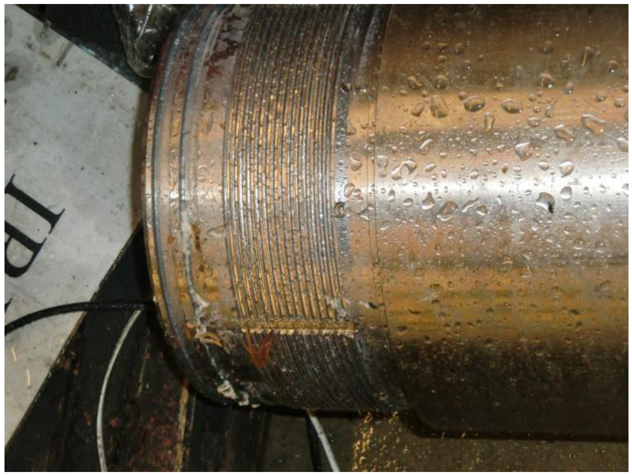


Figure 6-27: End Coupling Alt.2 after Test Failure

Figure 6-28: End Coupling Alt. 2 after Test Failure

Figure 6-29: Housing Alt. 2 after Test Failure

Figure 6-30: Test Casing after Test Failure of Alt. 2

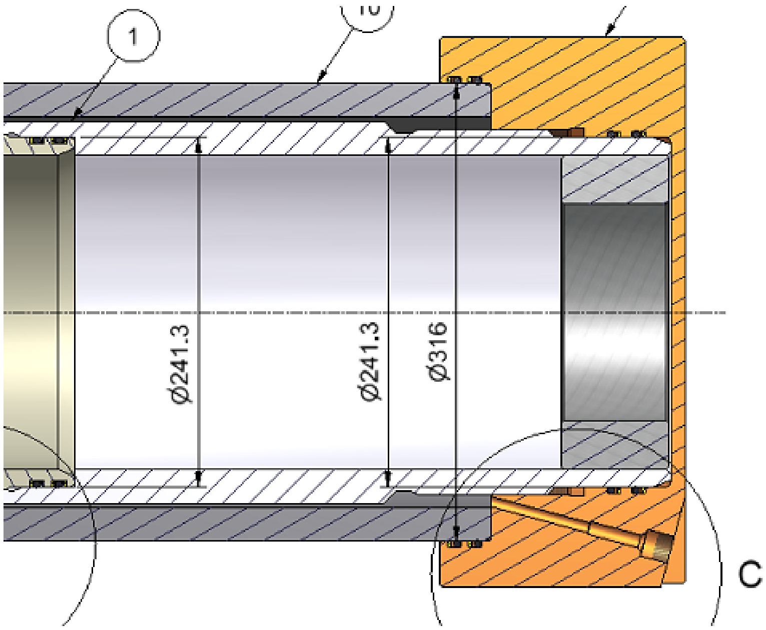
6.2.1 Evaluation of Test Failure of Alt.2

Inspection of the equipment indicates that the test failure is caused by separation of the thread connection between the end coupling and the housing. The reason for why this happened has been investigated by doing calculations, analyses, check of mechanical drawings, check of material certificates, and measurements of threads.

Calculations for the shear stress in the thread connection at 790 bar (=79 MPa) are presented in Figure 6-31 – 6-32. A safety factor of 1.25 has been used in these calculations [5]. The tensile force on the threads is 2583 kN at 79 MPa. The shear stress is 116 MPa when exposed to tensile force of 2583 kN. This load should therefore not cause the threaded connection to separate.

The material certificates were according to specifications for the housing and for the end coupling. The threads on the end coupling and on the housing were measured at GMV in Sandnes. Only a small section of the threads on the end coupling could be measured. The measurement report can be found in Appendix G. The dimensions of the threads on the end coupling and on the housing were measured to be according to drawings.

Calculation of forces acting on threads in RD-03360 at collapse pressure = 790 bar

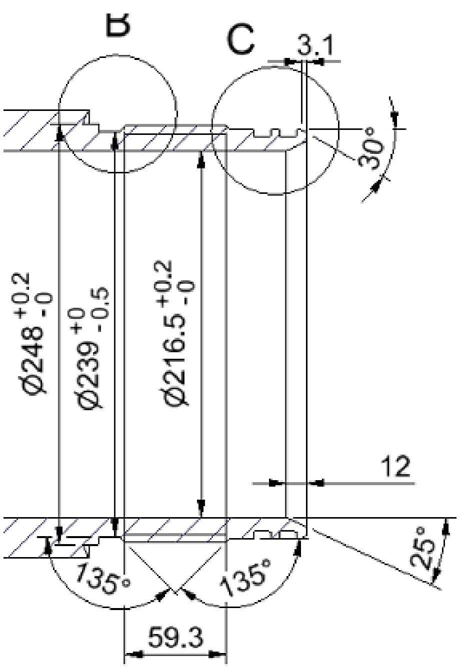


$P := 790bar = 79 \cdot MPa$ Test pressure

$A_p := \frac{\left[(316mm)^2 - (241.3mm)^2\right] \cdot \pi}{4} = 32696 \cdot mm^2$ Pressurized area

$F_p := P \cdot A_p = 2583 \cdot kN$ Load on threads

$F_p = 263.394 \cdot tonnef$



RD-03362

Figure 6-31: Calculation of Load in Threads of Alt. 2 at 790 bar 1/2

Axial forces [kN] in threaded connection:

$A1 := F_p = 263.394 \cdot tonnef$ Axial load

Materials an design factors

Values, unless otherwise given

Yield stress - AISI 4140 125KSI $\sigma_y := 125ksi = 861.845 \cdot MPa$

Safety factor $Sf := 1.25$

Thread geometry:

ACME threads:

Threads Per Inch $TPI_{acme} := 6$

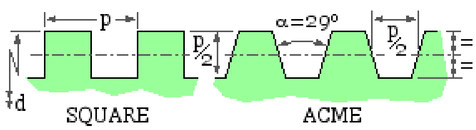
Nominal diameter of threads $D_{th} := 246mm$

Angle of teeth sides $\alpha_{acme} := 14.5deg$

Length of threaded bolt: $L_{chth} := 59mm$

Length of threaded nut: $L_{phth} := 59mm$

Effective shear area of threaded part:



Thread pitch: $p_{acme} := \frac{1in}{TPI_{acme}}$ $p_{acme} = 4.23 \cdot mm$

Thread height: $h_{acme} := \frac{p_{acme}}{2}$ $h_{acme} = 2.12 \cdot mm$

Root thickness of threads: $t_{acme} := h_{acme} + h_{acme} \cdot \tan(\alpha_{acme})$ $t_{acme} = 2.66 \cdot mm$

Inner diameter of threads: $D_{ith} := D_{th} - 2 \cdot h_{acme}$ $D_{ith} = 241.77 \cdot mm$

Number of effective threads in threaded connection:

$N_{thread} := \mathrm{floor}\left(\frac{\min(L_{chth}, L_{phth})}{p_{acme}}\right) - 2$ $N_{thread} = 11$

Effective shear area of threaded connection: $A_{sthread} := N_{thread} \cdot t_{acme} \cdot \pi \cdot D_{ith}$

$A_{sthread} = 22258 \cdot mm^2$

Shear stress in treaded connection

Shear stress:

$\tau_{thread} := \frac{A1}{A_{sthread}}$ $\tau_{thread} = 116 \cdot MPa$

Utilisation of threaded connection: $UF := \frac{\tau_{thread} \cdot Sf \cdot \sqrt{3}}{\sigma_y}$ $UF = 0.29$

Figure 6-32: Calculation of Load in Threads of Alt. 2 at 790 bar 2/2 [7]

When checking the mechanical drawings for the end coupling and the housing it was detected that there could be a gap between the end coupling and the housing at the angled intersection surface, illustrated in Figure 6-31.This is because of the tolerances for some of the dimensions. These tolerances and dimensions are illustrated in mechanical drawings in Appendix H.

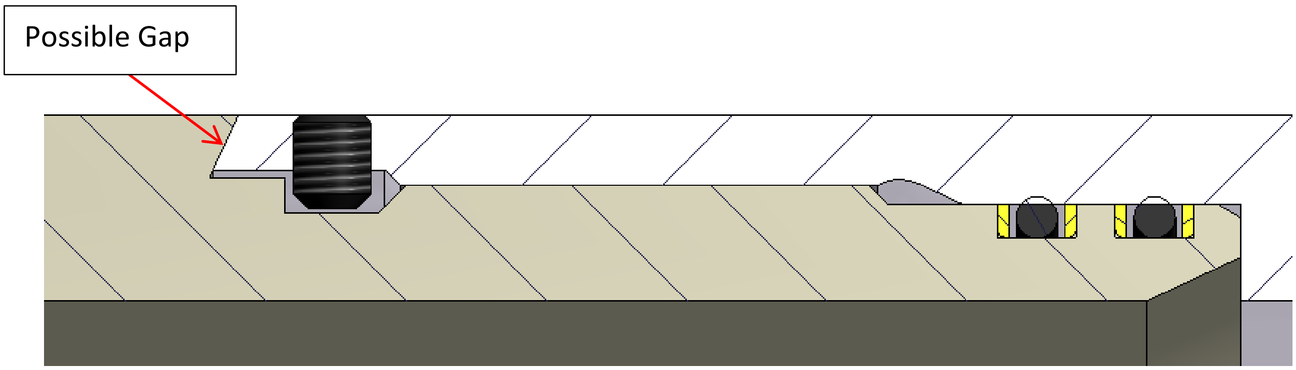


Figure 6-33: Illustration of Possible Gap in Alt. 2

Analysis was made for a model of Alt.2 with a gap at the angled intersection surface. The report can be found in Appendix E. The model is exposed to 79 MPa collapse pressure and a tensile force of 2583 kN. Result for equivalent stress is presented in Figure 6-34. Result for equivalent plastic strain is presented in Figure 6-35. The results give that there are high stresses in some sections of Alt. 2. The results for equivalent plastic strain give that there are plastic deformation of the end coupling in the end of the threaded section, next to the set-screw. This section is illustrated in Figure 6-34. If the end coupling got plastic deformation in this section in the pressure test this could have led to collapse of Alt. 2 in this section. Figure 6-36 presents result for directional deformation in x-direction of Alt.2. This is the radial deformation of Alt. 2. This result give that there is a gap of approximately 0.35 mm between the threads at the section illustrated in Figure 6-34.

The analysis results indicate that the design have failed because of collapse of the end coupling at the set-screw groove next to the threads. Recommended further investigation will be to measure the ovality of the end coupling and check for plastic deformations.

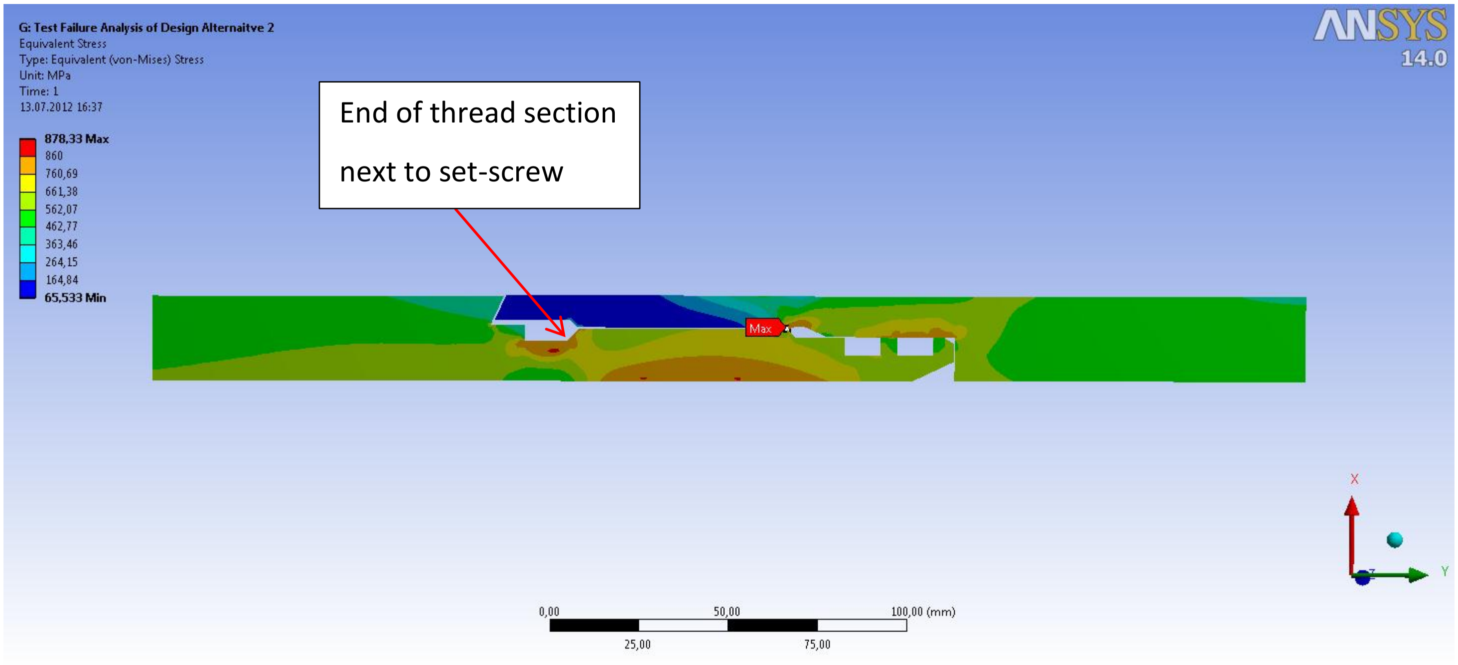


Figure 6-34: Equivalent (von-Mises) Stress of Alt.2 with Gap

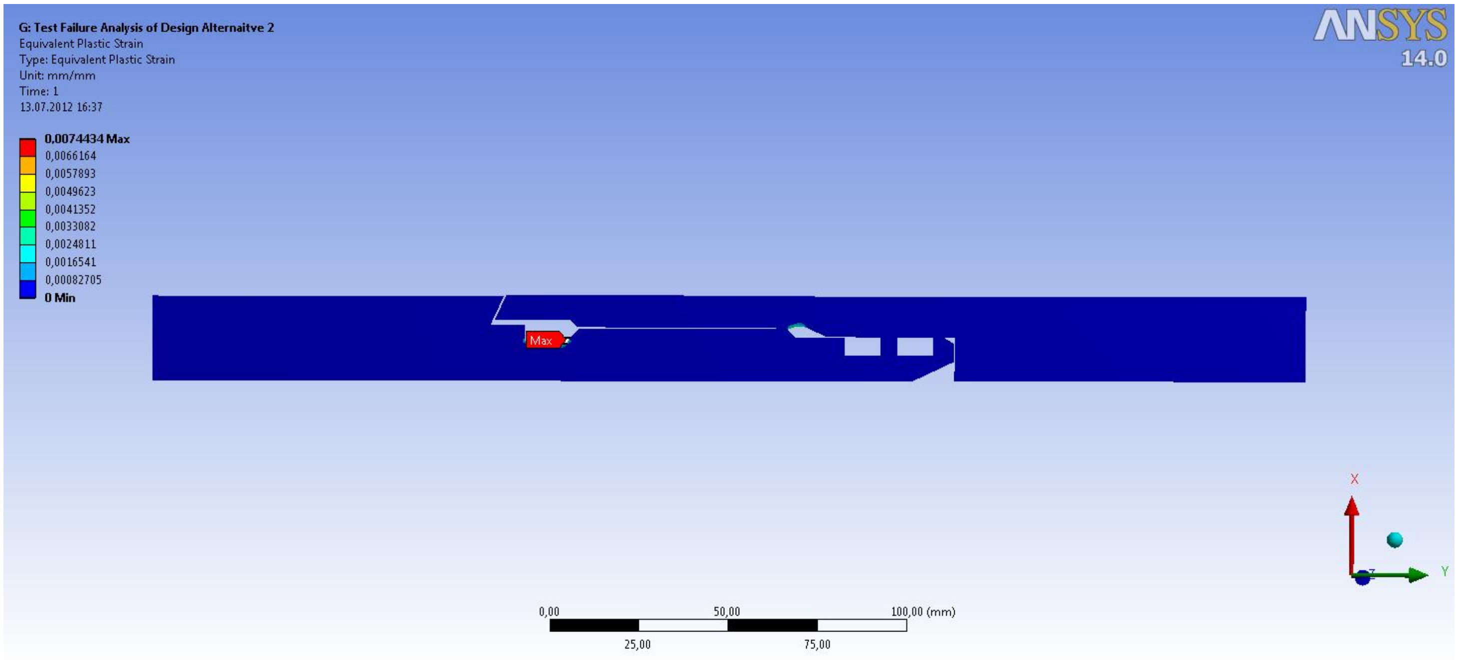


Figure 6-35: Equivalent Plastic Strain of Alt. 2 with Gap

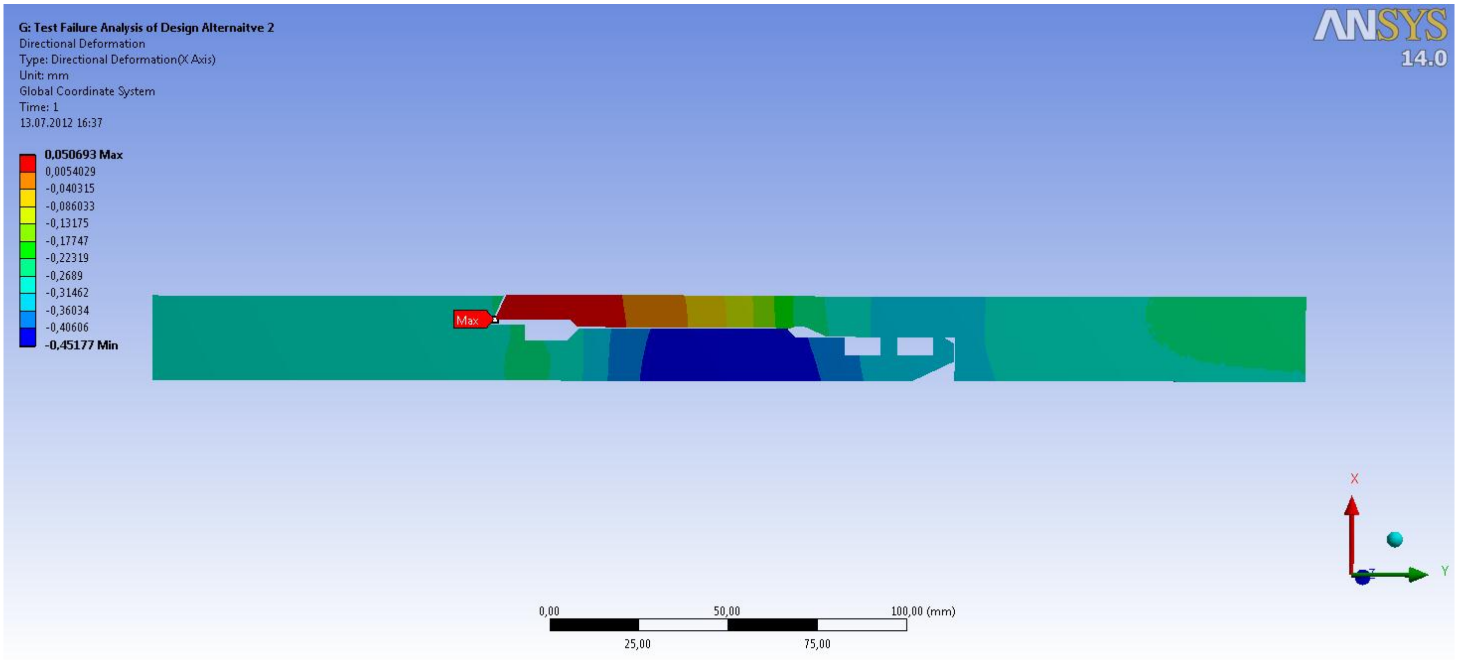


Figure 6-36: Directional Deformation of Alt. 2 with Gap

6.3 Comparison of Designs

The existing design was tested at Proserv in Tananger and according to V0 test program described in ISO 14310 [8], [9]. This test was performed at a temperature of 150 °C. In the collapse pressure test of this test procedure the C-Flex SS was exposed to compressive forces. The maximum collapse pressure applied in this test was 55 MPa. At this pressure the compressive force is 250 tons. This is from the performance envelope of the C-Flex SS 9 5/8" presented in Figure 6-37. This V0 test is verifying that the collapse pressure capacity with 250 tons compressive force is 550 bar at 150°C. From the performance envelope we have maximum collapse pressure with no axial loads is 513 bar for the existing design. Maximum collapse pressure with 400 tons tensile force is 200 bar. 400 tons is equal to3923 kN.

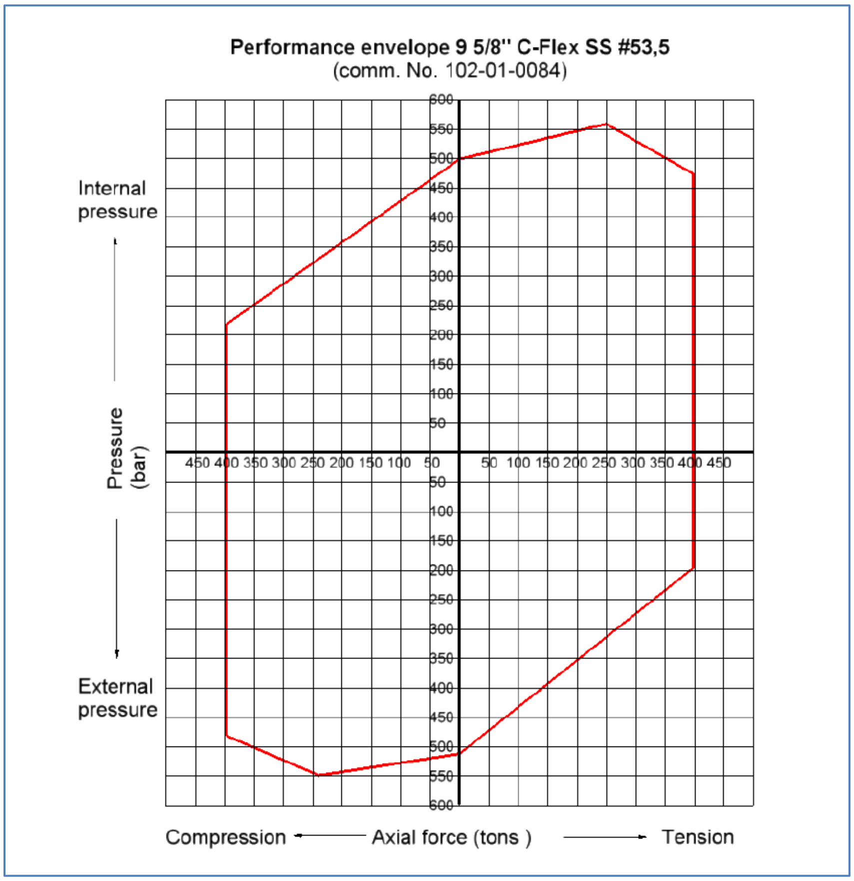


Figure 6-37: Performance Envelope at 150°C for C-Flex SS 9 5/8"

The pressure tests performed for Alt. 1 and Alt. 2 in this project were performed at ambient temperature. The test was performed with only one O-ring in the seal between the end coupling and the housing for both Alt.1 and Alt. 2.

The pressure test performed for Alt. 1 detected no leakage at 89.5 MPa at ambient temperature. In this collapse pressure test the test piece was exposed to tensile forces. The tensile force was 2926 kN at 89.5 MPa. The temperature compensated maximum pressure of Alt. 1 at 150°C is calculated to be 77 MPa. These calculations are presented in Figure 6-38.

AISI 4140 125KSI (MDS274278) 150deg.

$Y_{s4140.125} := 862\text{MPa}$ Yeld strenght

$T_{s4140.125} := 965\text{MPa}$ Tensile strenght

$Eb_{4140.125} := 12\%$ Elogation at break

Design condition factor for the operating condition is:

$C_f := 1$

The ductility reduction factor is calculated as: (from p96 ISO 13628-7)

$$\phi_{4140.125} := \frac{1.5}{2 - \left(\sqrt{\frac{Eb_{4140.125}}{56 \cdot \%}}\right)} = 0.976$$

According to table 15 p 115 if elogation at break is more than 14% the ductility reduction factor is 1

The temperature reduction factor for yield strenght at 150deg.C
Interpolation between values for temperature reduction factor for yield strength (ISO 13628-7:2005(E), Section 6.4.6, pg.96, Table 10)

$Y_{y.121} := 0.91$

$Y_{y.180} := 0.85$

$$y_{y.150} := Y_{y.121} + (150\,°C - 121\,°C) \cdot \frac{Y_{y.180} - Y_{y.121}}{180\,°C - 121\,°C} = 0.881$$

$P := 895\text{bar} \cdot 0.881 \cdot 0.976 = 769.6\,\text{bar}$ Temperature compensated pressure

$P = 76.957\,\text{MPa}$

Figure 6-38: Temperature Compensated Max. Pressure for Alt. 1[4]

The results from the pressure test of Alt. 1 indicate that this design has a better sealing capacity compared to the existing design when exposed to collapse pressure and tensile force.

There are no valid results from collapse pressure test of Alt. 2 due to failure of the pressure test. The pressure test failed at 79 MPa. It was detected more bubbles during the pressure test of Alt. 2 than for Alt. 1. Due to this it is assumed that this design has pourer sealing capacity than Alt. 1. Further investigation is needed to find the reason for pressure test failure. From evaluation of the pressure test failure in section 6.2.1 it looks like the failure was caused by collapse of the end coupling.

The pressure test results indicate that the seal capacity has been improved for Alt. 1.

7 Evaluation

The goal for this project is to improve and increase the collapse pressure rating for the C-Flex SS 9 5/8”. This was going to be implemented by making modifications on the design.

This project started with evaluation of the existing design. This was done before the modification of the C-Flex SS 9 5/8” design was implemented. Two design alternatives were proposed.

In the first design alternative there are placed to seals at the opposite side of the threaded connection between the end coupling and the housing than for the seal in existing design. This is the main difference between this design and the existing design. This position of the seals prevents the threaded connection between the end coupling and the housing to be pressurized when the tool is exposed to collapse pressure. In the existing design this thread connections is pressurized when the tool is exposed to collapse pressure.

In the second design alternative two seals are positioned at the same side of the threaded connection between the end coupling and the housing as for the existing design. The main difference between this design and the existing design is that in this design there are two seals. The intention of the added seal is that this may improve the seal capacity of the tool. In this design alternative the thread connection between the end coupling and the housing will be pressurized when exposed to collapse pressure.

Calculations and analyses were made for both design alternatives. These were used to check if the design alternatives gave satisfactory results or if some additional adjustments ought to be made. Calculations and analyses of the existing design were compared with those made for the two design alternatives. The comparison of the analyses indicated that the first design alternative would have the highest sealing capacity.

When the design alternatives gave satisfying results the pressure test equipment was designed. The pressure test equipment was designed for pressure testing performed with gas. Analyses and calculations were made for the pressure test equipment to check the capacity. After the delivery of all the equipment it was assembled and prepared for collapse pressure test. The assembling of the equipment was done in workshop at Archer Oil Tools in Stavanger. There were some difficulties when assembling the test equipment. The weight of the test caps is approximately 80 kg and there were no handles on them to use for lifting. These test caps should have been made with connections for handles to ease the assembling of the test equipment. The test caps would have been easier to assemble to the test piece if the threaded connection had been between the test casing and the test caps instead of between the test caps and the ends of the test piece. These changes should be implemented for further testing.

After assembly of the test equipment to the first design alternative it was transported to the test location at IRIS in Stavanger. The pressure test was performed in a water tank at ambient temperature. Maximum pressure for the test was 89.5 MPa. There would be a tensile force of 2926 kN when pressurized with 89.5 MPa. There were done two pressure tests on the first design alternative. In one of the tests one of the O-rings and all of the back-up rings were removed. No leakage was detected in both tests for the first design alternative. This result indicates that this design has a better seal capacity than the existing design. Maximum collapse pressure with no tensile force is 51.3 MPa at 150°C for the existing design. Maximum collapse pressure with tensile force of 3923 kN is 20 MPa at 150°C

The assembly and the running of the pressure test of the second design alternative were executed with same procedure as for the first design alternative. The test of the second design alternative failed at 79 MPa due to burst of the pressure test equipment. Material certificates were checked and these were according to specifications. The threads on the end coupling and on the housing were measured. The threads were according to specifications in the mechanical drawings. Calculation of the shears stress in threaded connection at this pressure was made. These calculations indicated that the threads should withstand the tensile force caused by 79 MPa pressure. From the mechanical drawings it was detected that there could be a gap between the end coupling and the housing next to the set screw connection. This is because of some specified dimensions and tolerances set on the design. Analysis has been made for model with this gap to check for plastic deformation. Results indicate that there has been plastic deformation in the end coupling. This indicates that collapse of the end coupling is the reason for test failure. It is suggested to measure the ovality of the end coupling and check for plastic deformation. Further investigation is necessary for determination of reason for pressure test failure.

8 Conclusion

The conclusion is that smaller modifications can be done on the existing design to increase and improve the collapse pressure rating of the C-Flex SS 9 5/8”. To increase the collapse pressure rating of the C-Flex SS 9 5/8” the following modifications were done on the existing design:

An additional O-ring was added. The O-rings were relocated on the end coupling. An angle has been made at the intersection between the end coupling and the housing next to the set screw.

These are smaller modifications done on the existing design. Results from calculations and analyses gave that these modifications of the existing design would result in higher sealing capacity. The design and use of test rig clearly shows that these modifications prove to be a good improvement. No leakage was detected when performing pressure tests on this alternative design. These modifications of the existing design can be implemented at a low cost. By implementing these modifications to the existing design the risk of leakage will be reduced.

It is assumed that the relocation of the seals is the modification that has the main impact on the improved sealing capacity and the increased collapse pressure rating.

In this project the design of C-Flex SS 9 5/8” was modified and tested. It is determined that these modifications will be implemented in the C-Flex SS portfolio for new C-Flex SS designs. Since these modifications has shown great improvement for this size, it is determined that these modifications will be implemented for all of the other C-Flex SS sizes.

9 Recommended Further Work

Recommended further work will be to continue the investigation and determine the reason for failure of pressure test of Alt. 2. The next step in this investigation will be to check for plastic deformation in the end coupling. This can be done by measuring the ovality of the end coupling. More analyses can be made to check for other possibilities.

For Alt. 1 it is recommended to test the burst pressure capacity of this design when exposed to both compressive and tensile forces. It is also recommended to perform more collapse pressure tests to determine maximum pressure before the seal will start to leak. Collapse pressure tests ought to be performed when the design is exposed to both compressive and tensile force to check the limitations of this design. When the pressure capacities are determined a performance envelope for this design ought to be made.

10 References

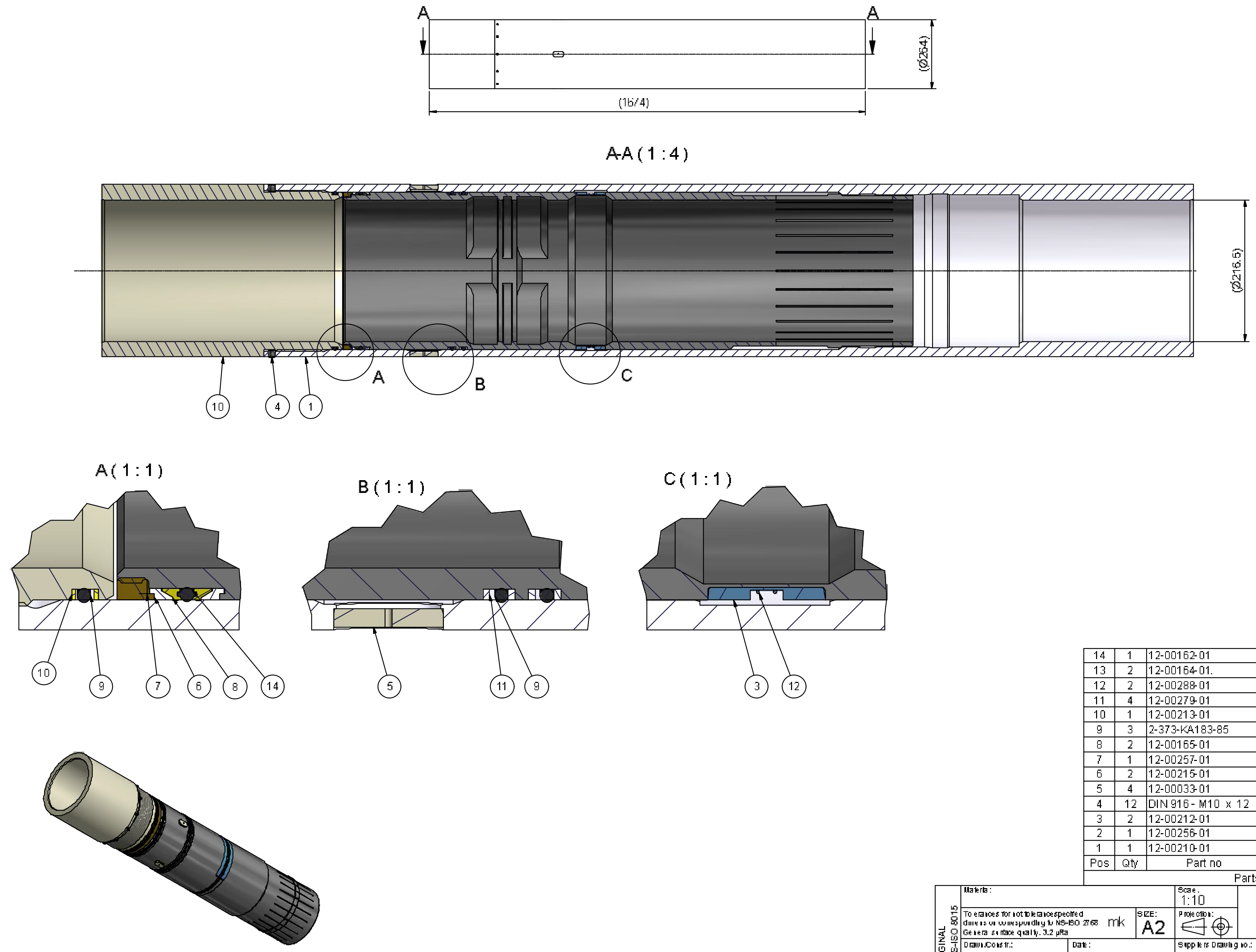
1) Archer Oil Tools File Archive
2) Technical Data Book for C-Flex SS 9 5/8” #53,5
3) Parker O-ring Handbook (online). Available from http://www.parker.com/literature/O-Ring%20Division%20Literature/ORD%205700.pdf (Downloaded on 5.1.2012)
4) ISO 13628- 7. First Edition 2005-11-15.
5) NORSOK STANDARD D-010. Rev. 3, August 2004.
6) ISO/TR 10400. First Edition 2007-12-15.
7) Oberg. E, Jones. F. D, Horton. H. L, Ryffel. H. H. (2008). *Machinery’s Handbook 28th edition.* New York: Industrial Press.[ISBN: 978-083112800-5]
8) ISO 14310. 2008-10-22.
9) ISO 41310 V0 Test Report of C-Flex SS 9 5/8” #53

Table of Figures

Appendix

Appendix A	**-**	Mechanical Drawings of Existing Design
Appendix B	**-**	Mechanical Drawings of Alternative 1
Appendix C	**-**	Mechanical Drawings of Alternative 2
Appendix D	**-**	Mechanical Drawings of Test Equipment
Appendix E	**-**	Analyses Reports
Appendix F	**-**	Test Procedure
Appendix G	**-**	Measurement Report of Threads on Alt. 2
Appendix H	**-**	Illustration of Dimensions and Tolerances in Alt. 2

Appendix A



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12	2	12-00288-01	Steel wire Ø1,25
11	4	12-00279-01	Back up ring
10	1	12-00213-01	End coupling
9	3	2-373-KA183-85	O-ring 227,97x5.33 KA183-85
8	2	12-00165-01	Backup ring 9 5/8"
7	1	12-00257-01	Nut
6	2	12-00215-01	Pressure ring
5	4	12-00033-01	Protection Disc
4	12	DIN 916 - M10 x 12	Hexagon Socket Set Screw
3	2	12-00212-01	Lock segment
2	1	12-00256-01	Sleeve
1	1	12-00210-01	Housing

Parts List

Comm. no.	Qty.	Rev.no.	Change	Drwn/date	Ctrl/date	Appr/date
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		0	Original issue	HRL 30.08.10	KER 30.08.10	ABY 30.08.10

ELECTRONIC ORGINAL
TOLERANCING NS-ISO 8015

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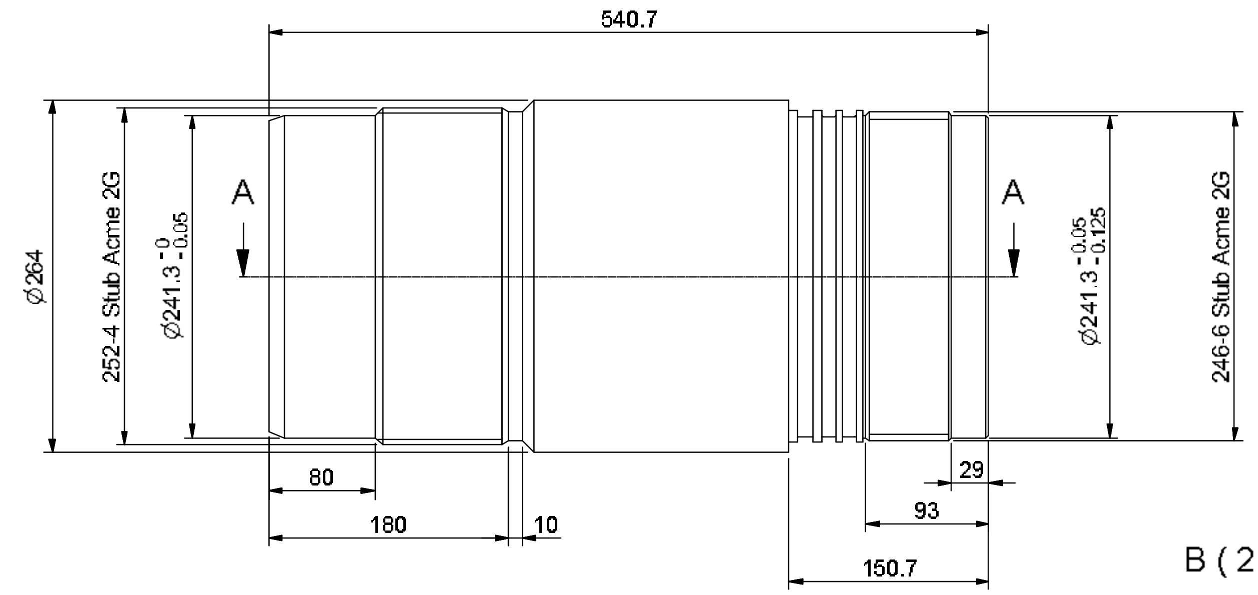
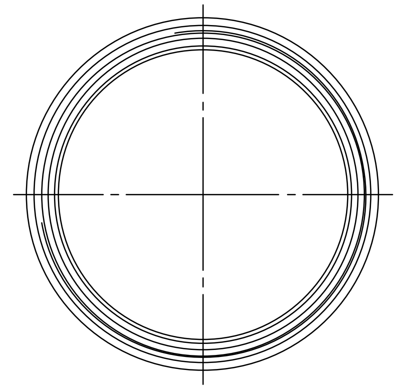
Appendix B





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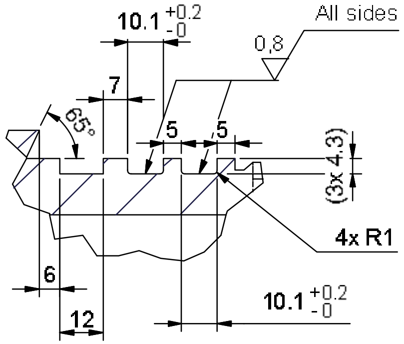

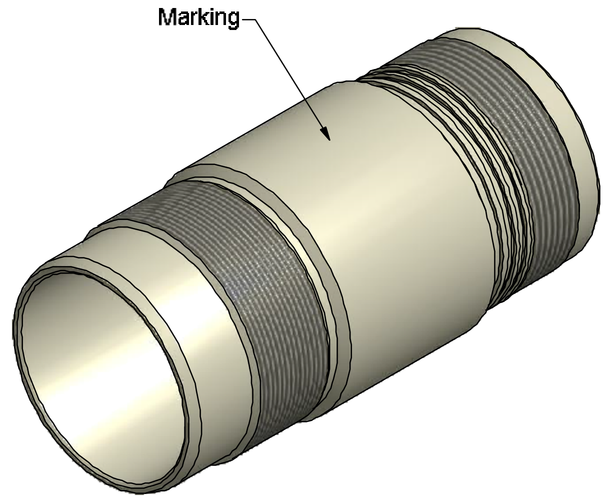

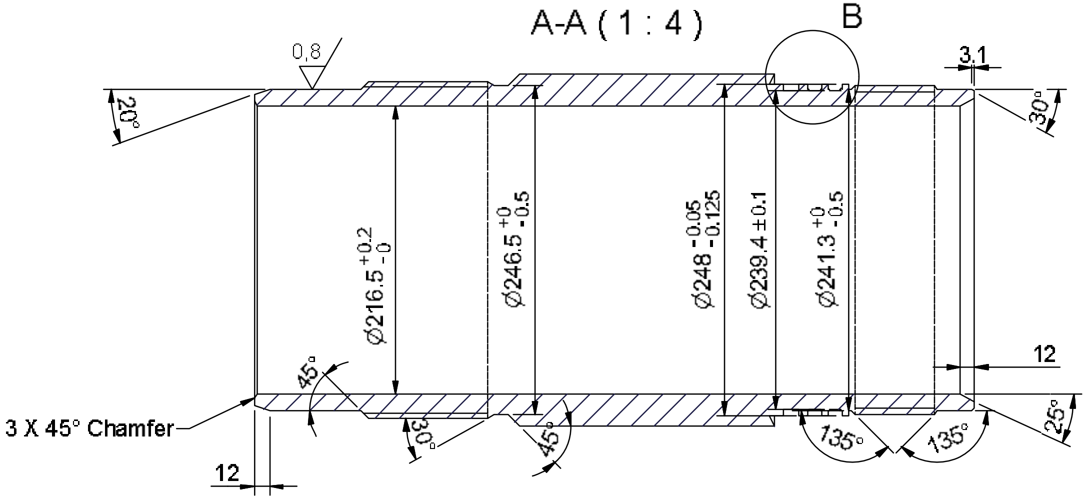

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Mach. detail End Coupling Modified 9 5/8" C-flex SS #53,5 Collapse Test1		Drawing no. RD-03325	
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TOLERANCING NS-ISO 8015

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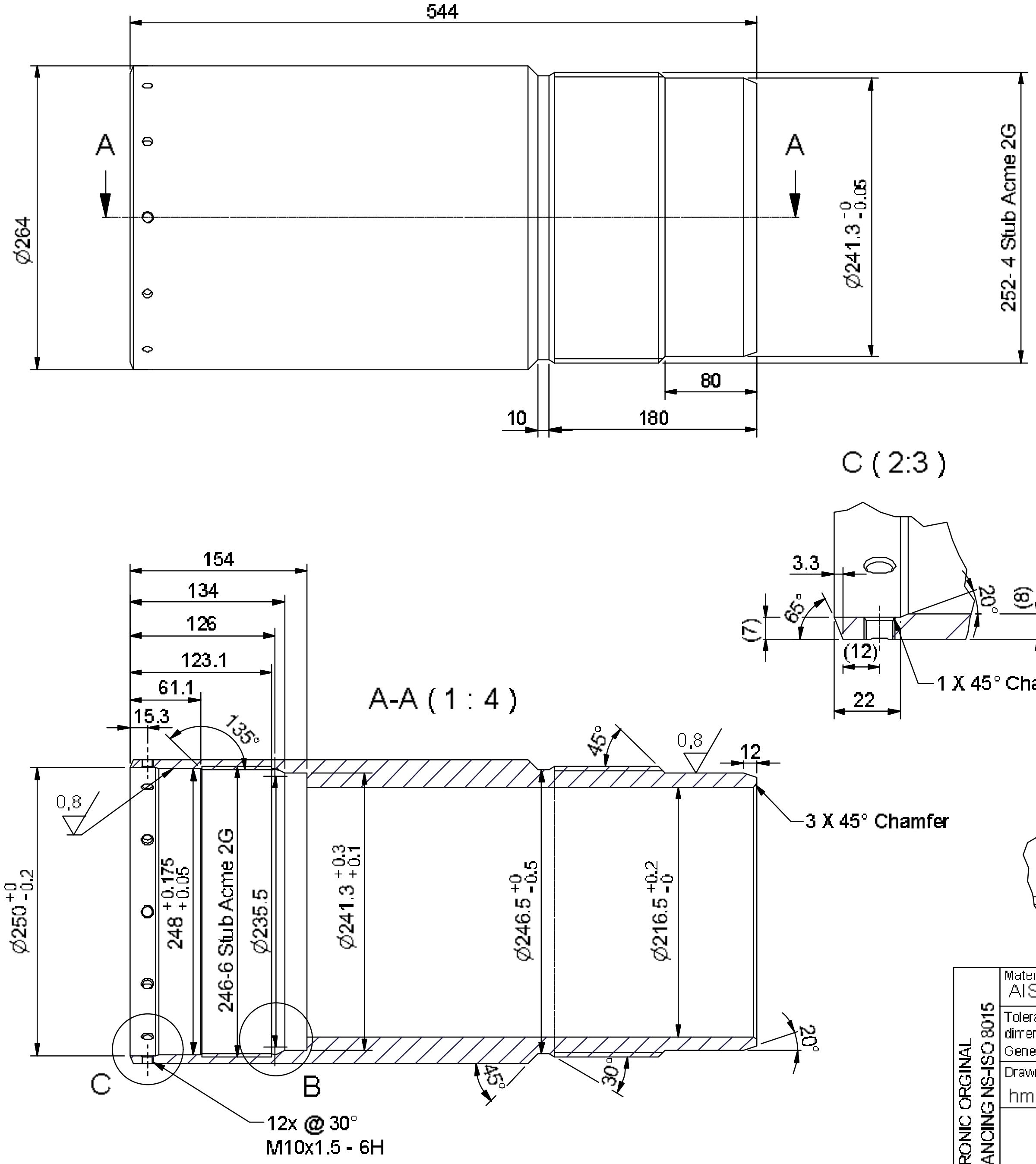

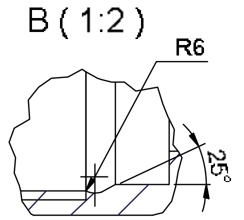

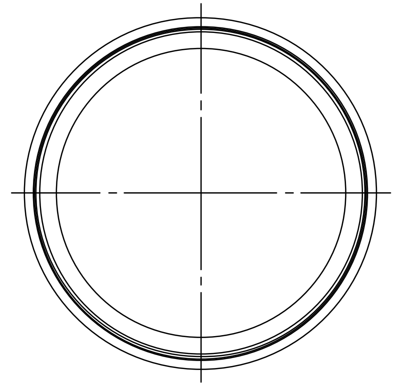

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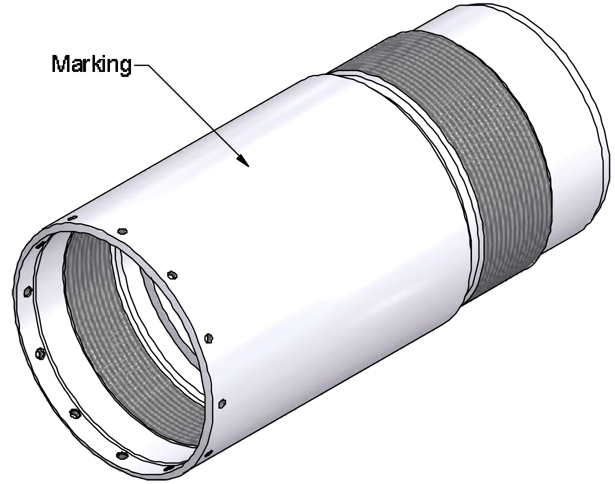

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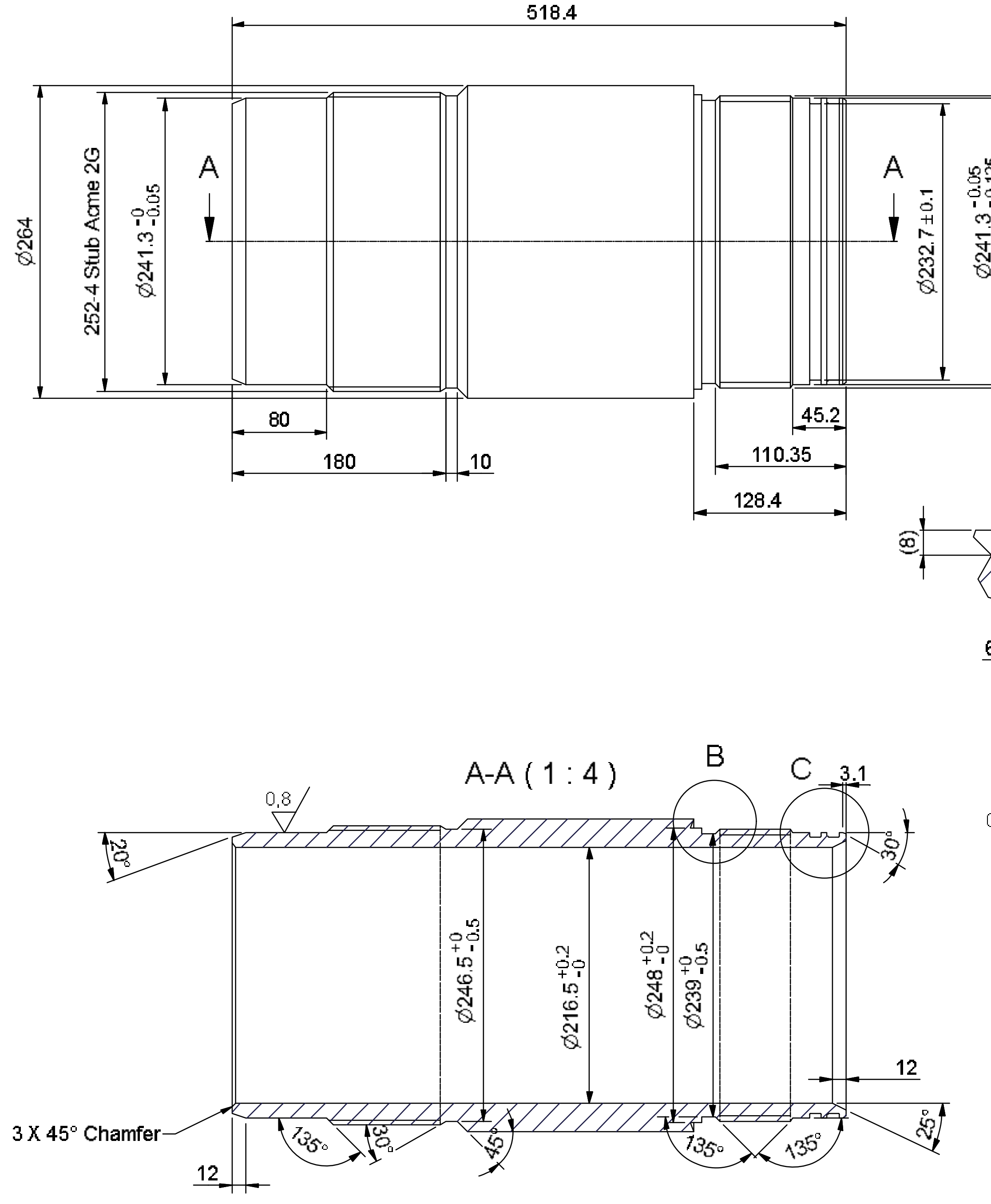
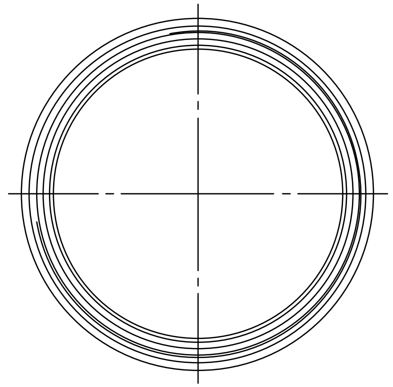
Appendix C





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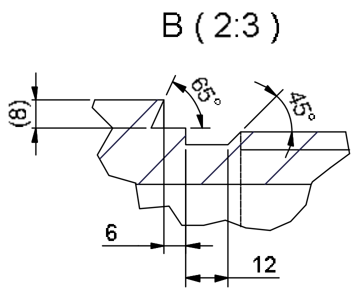

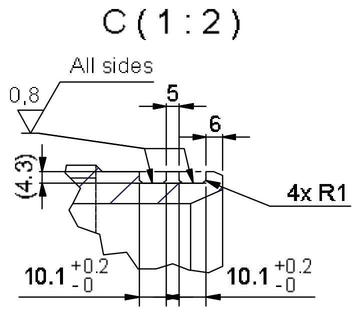

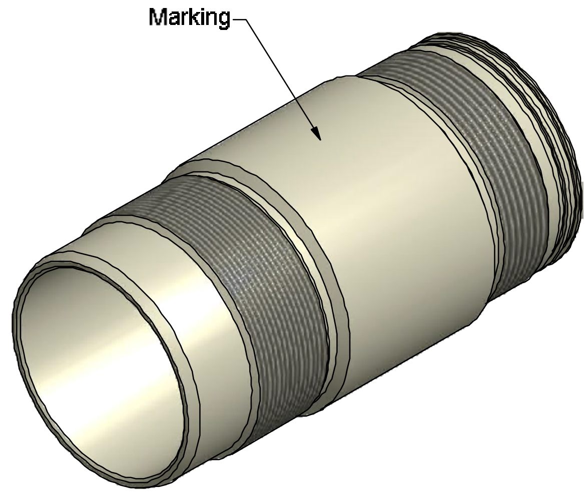

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of: 1
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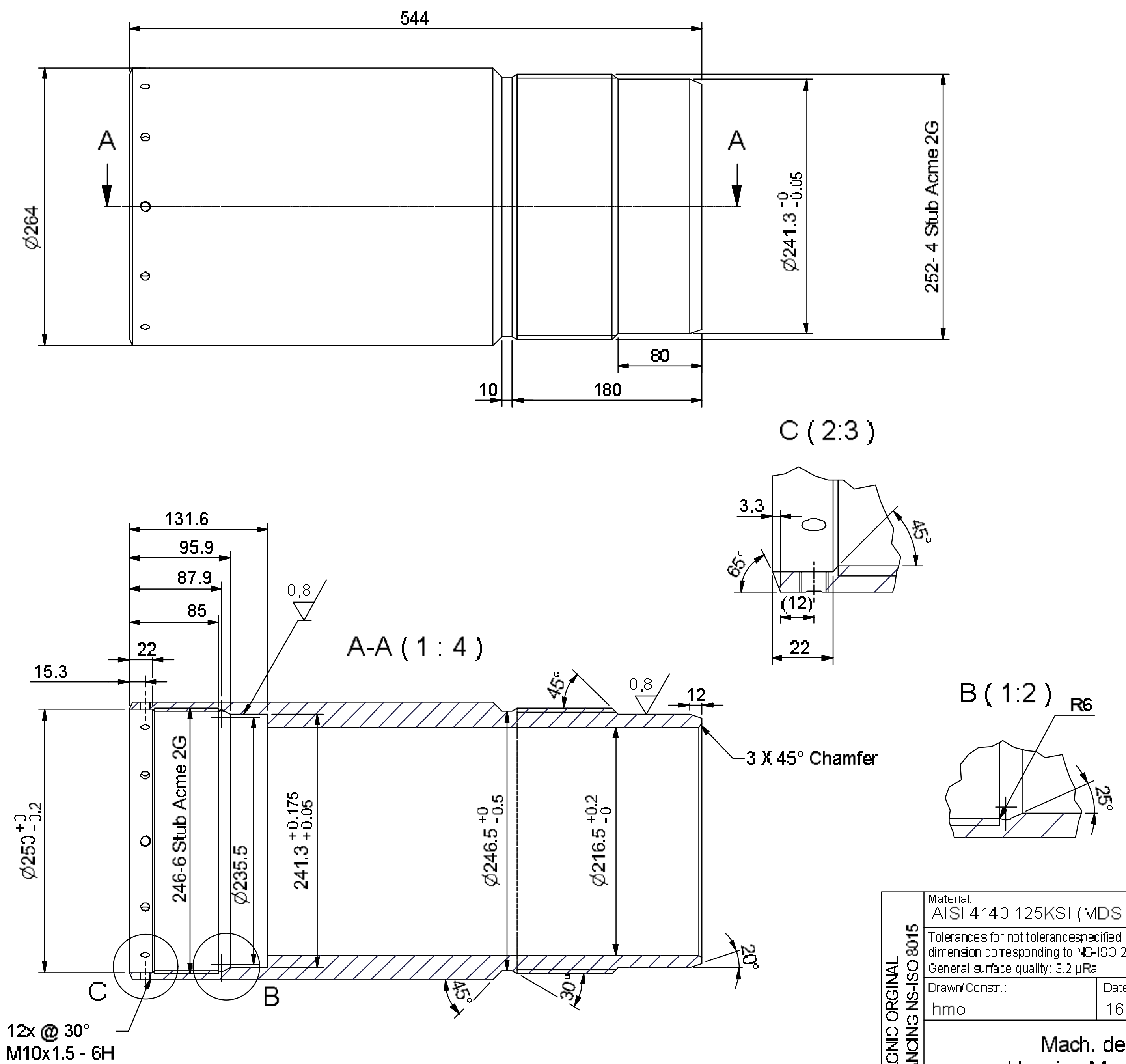

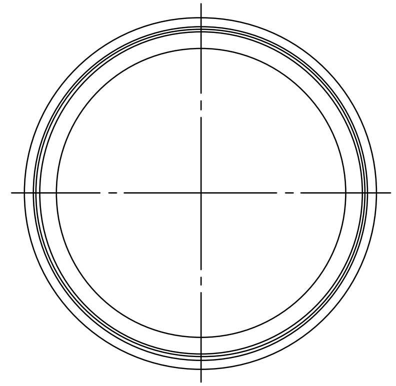

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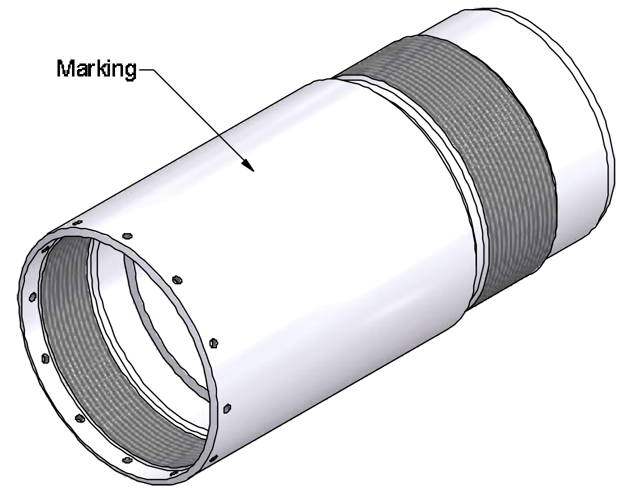

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TOLERANCING NS-ISO 8015

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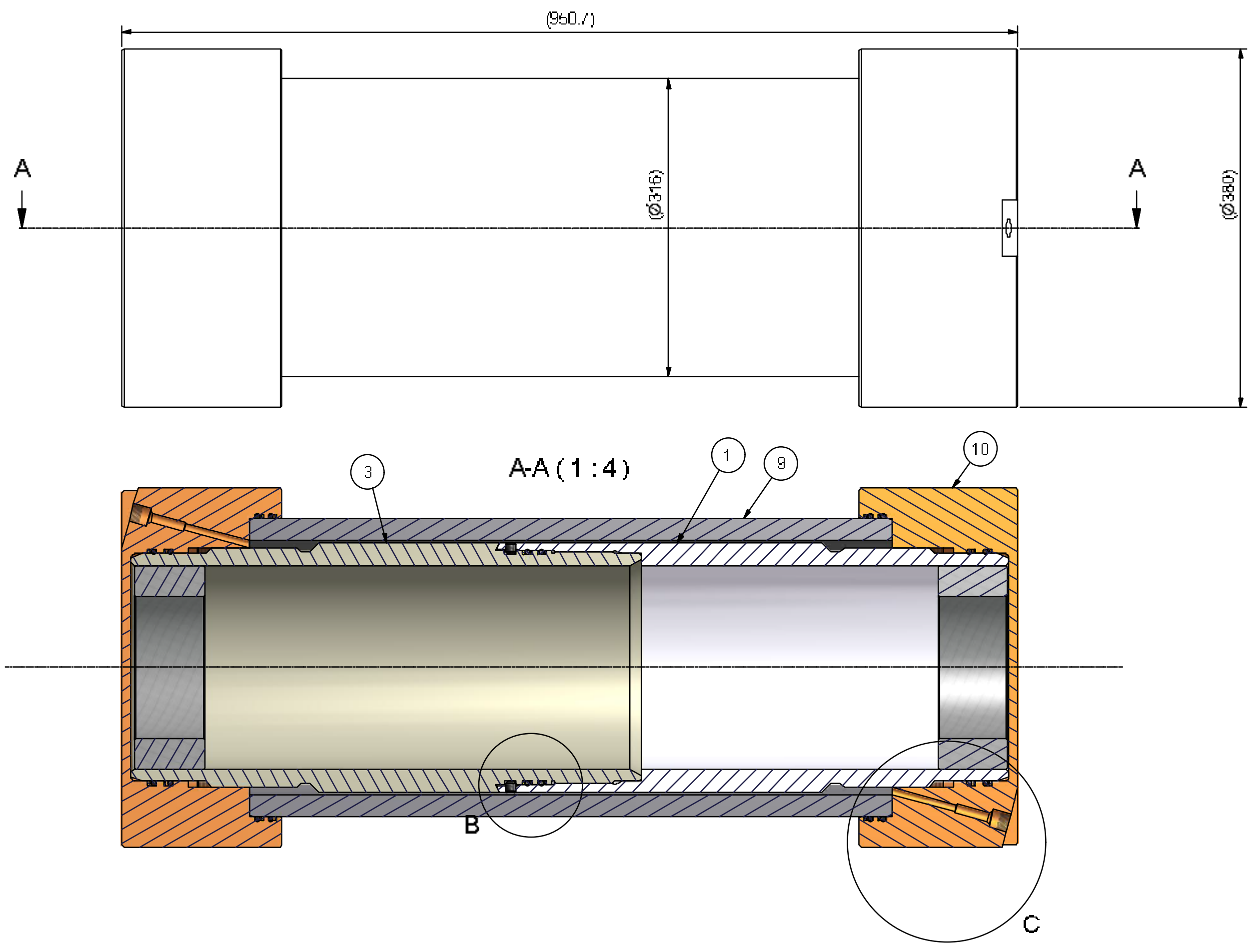
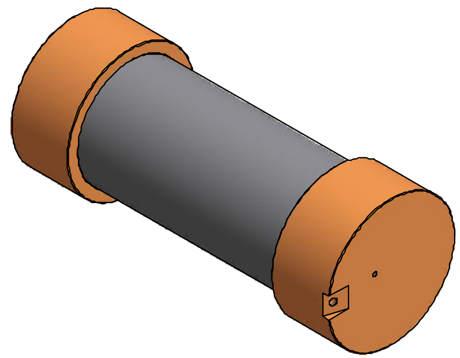
Appendix D





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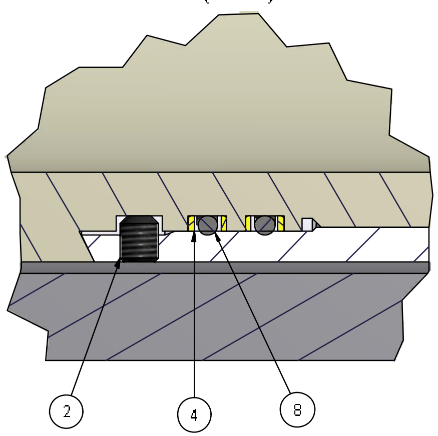

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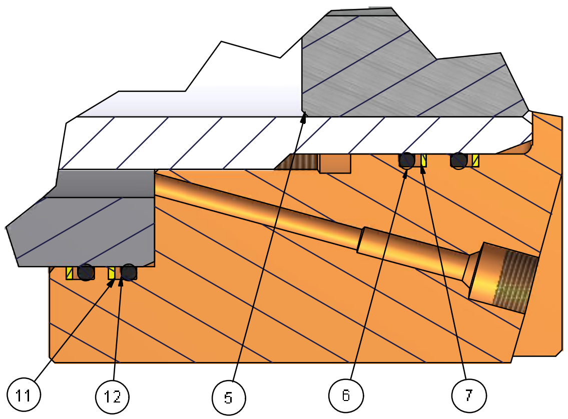

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11	4	RD-03661	Backup ring	3M Dyneon TFM4105
10	2	RD-03660	Test Cap 1/4" NPT	S355
9	1	RD-03659	Casing	AISI 4140 125KSI
8	2	2-373-KA183-85 2	O-ring 227,97x5.33 KA183-85	KA183-85
7	4	RD-02220	Back-up Ring	PEEK W4685
6	4	2-375-KB163-90	Parker O-ring	KB163-90
5	2	RD-03345	Support Ring	Aluminum
4	4	RD-03337	Back-up Ring	AP31TFM
3	1	RD-03325	End Coupling Modified	AISI 4140 125KSI (MDS 274278)
2	12	DIN 916 - M10 x 12	Hexagon Socket Set Screw	EN 20 898/5-45H
1	1	RD-03324	Housing Modified	AISI 4140 125KSI (MDS 274278)

Parts List

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		1	Removed RD-02218. Added RD-03660, RD-03659, RD-03661.	hmo 07.05.2012	ABY 07.05.2012	ABY 07.05.2012
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ELECTRONIC ORGINAL
TOLERANCING NS-ISO 8015

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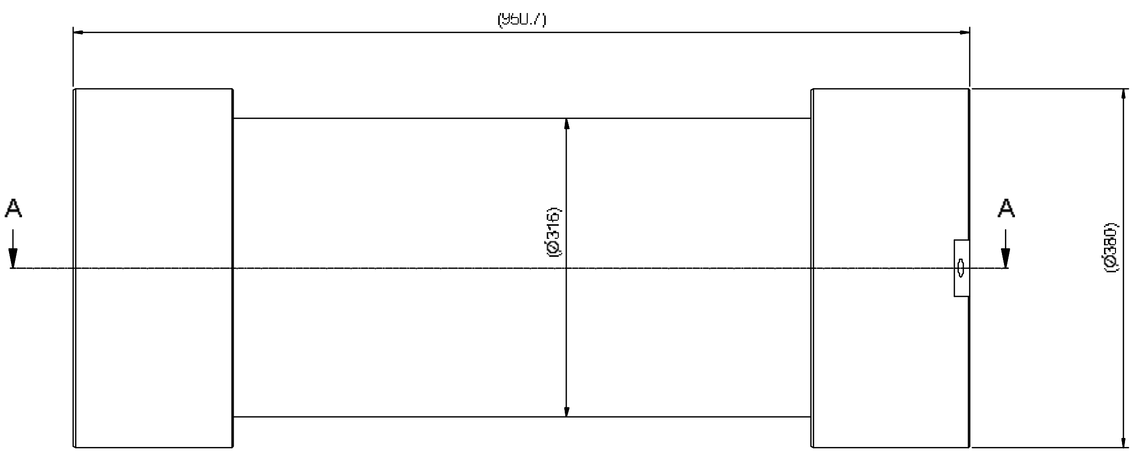

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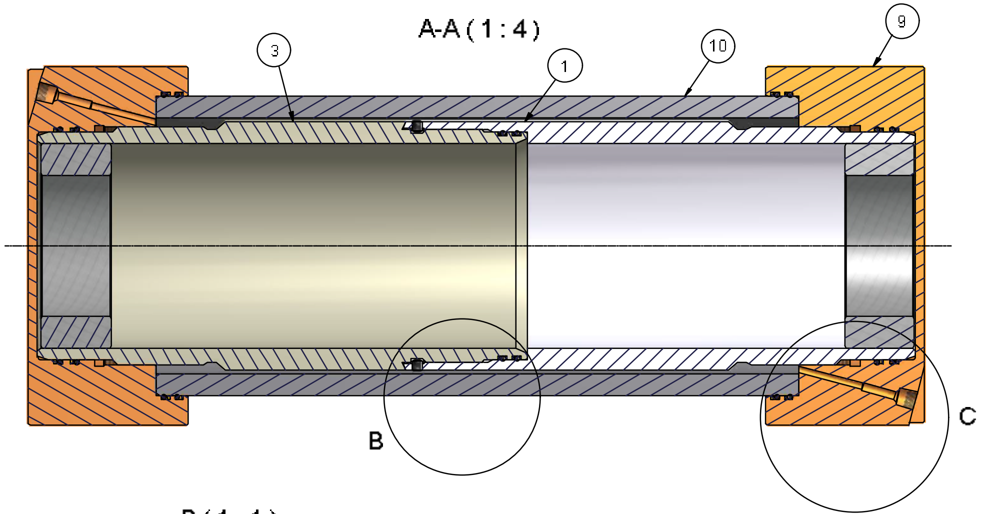

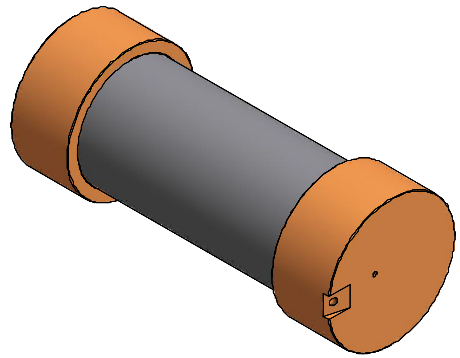

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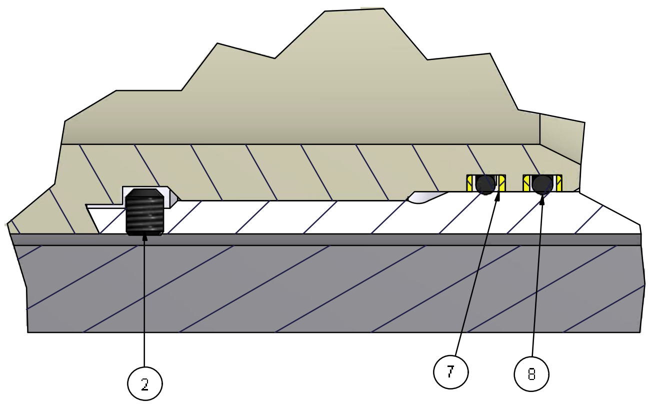
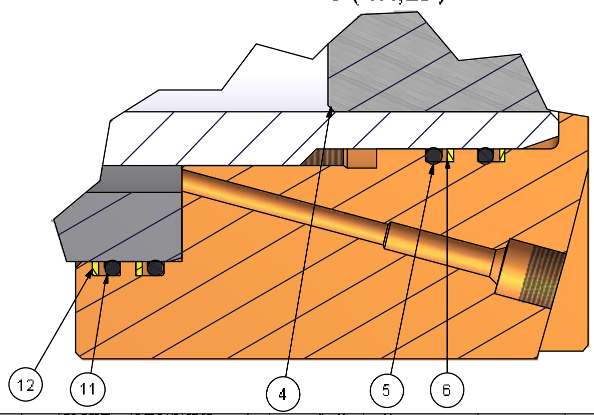


C (1:1,25)



Pos	Qty	Part no	Description	Material
12	4	RD-03661	Backup ring	3M Dyneon TFM4105
11	4	5-902-KA183-85	O-Ring 313,94x5,33 KA183-85	KA 183-85
10	1	RD-03659	Casing	AISI 4140 125KSI
9	2	RD-03660	Test Cap 1/4" NPT	S355
8	2	2-373-KA183-85	O-ring 227,97x5.33 KA183-85	KA183-85
7	4	12-00164-01.	Backup ring	PEEK W4685
6	4	RD-02220	Back-up Ring	PEEK W4685
5	4	2-375-KB163-90	Parker O-ring	KB163-90
4	2	RD-03345	Support Ring	Aluminum
3	1	RD-03362	End Coupling Modified 2	AISI 4140 125KSI (MDS 274278)
2	12	DIN 916 - M10 x 12	Hexagon Socket Set Screw	EN 20 898/5-45H
1	1	RD-03361	Housing Modified 2	AISI 4140 125KSI (MDS 274278)

Parts List

Comm. no.	Qty.	Rev.no.	Change	Drwn/date	Ctrl/date	Appr/date
		2	RD-02220 and 2-375-KB163-90 were placed on opposite side of each other.	hmo 25.06.2012	ABY 25.06.2012	ABY 25.06.2012
		1	Removed RD-02218. Added RD-03660, RD-03659, RD-03661.	hmo 07.06.2012	ABY 07.06.2012	ABY 07.06.2012
		0	Original issue	hmo 20.01.2012	aby 20.01.2012	tee 20.01.2012

ELECTRONIC ORGINAL
TOLERANCING NS-ISO 8015

Material:

Tolerances for not tolerances specified dimensions corresponding to NS-ISO 2768 mk
General surface quality: 3,2 µRa

Scale: 1:4

SIZE: A2

Projection:

Archer

Drawn/Constr.: hmo

Date: 16.01.2012

Suppliers Drawing no.:

Page: 1 of 1

Assembly
9 5/8" C-flex SS #53,5 Collapse Test2

Drawing no.: RD-03360

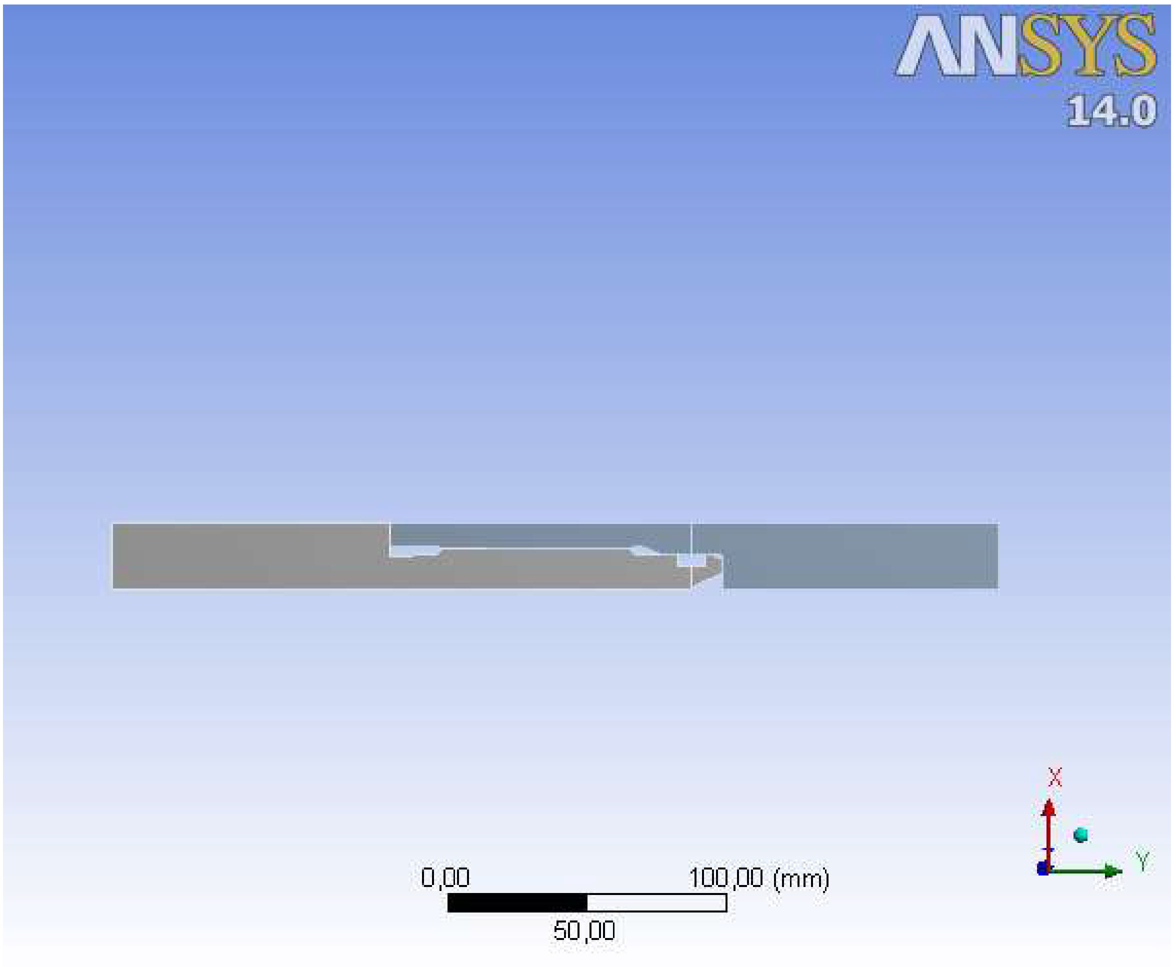
Project no.:

Weight: 407,041 kg

Appendix E

Project

First Saved	Friday, July 06, 2012
Last Saved	Friday, July 13, 2012
Product Version	14.0 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

Units

TABLE 1

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (I4)

Geometry

TABLE 2
Model (I4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Vault\Peak\R&D\R&D C-flex\Collapse analysis\New Seal nr. 1\Collapse

	Analysis of New Seal Design nr. 1_files\dp0\SYS-6\DM\SYS-6.agdb
Type	DesignModeler
Length Unit	Millimeters
Element Control	Program Controlled
2D Behavior	Axisymmetric
Display Style	Body Color
Bounding Box	
Length X	23,75 mm
Length Y	320, mm
Properties	
Volume	0, mm³
Mass	
Surface Area(approx.)	7442,1 mm²
Scale Factor Value	1,
Statistics	
Bodies	2
Active Bodies	2
Nodes	20562
Elements	6552
Mesh Metric	None
Basic Geometry Options	
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No

Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\62844\AppData\Local\Temp
Analysis Type	2-D
Decompose Disjoint Faces	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (I4) > Geometry > Parts

Object Name	*12-00213-01*	*12-00210-01*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	

Material		
Assignment	4140 125ksi	
Nonlinear Effects	Yes	
Thermal Strain Effects	Yes	
Bounding Box		
Length X	23,75 mm	
Length Y	220, mm	
Properties		
Volume	N/A	
Mass	N/A	
Centroid X	N/A	
Centroid Y	N/A	
Centroid Z	N/A	
Moment of Inertia Ip1	N/A	
Moment of Inertia Ip2	N/A	
Moment of Inertia Ip3	N/A	
Surface Area(approx.)	3945,3 mm²	3496,7 mm²
Statistics		
Nodes	10868	9694
Elements	3471	3081
Mesh Metric	None	

Coordinate Systems

TABLE 4
Model (I4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined

Definition	
Type	Cartesian
Coordinate System ID	0,
Origin	
Origin X	0, mm
Origin Y	0, mm
Directional Vectors	
X Axis Data	[1, 0,]
Y Axis Data	[0, 1,]

Connections

TABLE 5
Model (I4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (I4) > Connections > Contacts

Object Name	*Contacts*
State	Fully Defined
Definition	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection

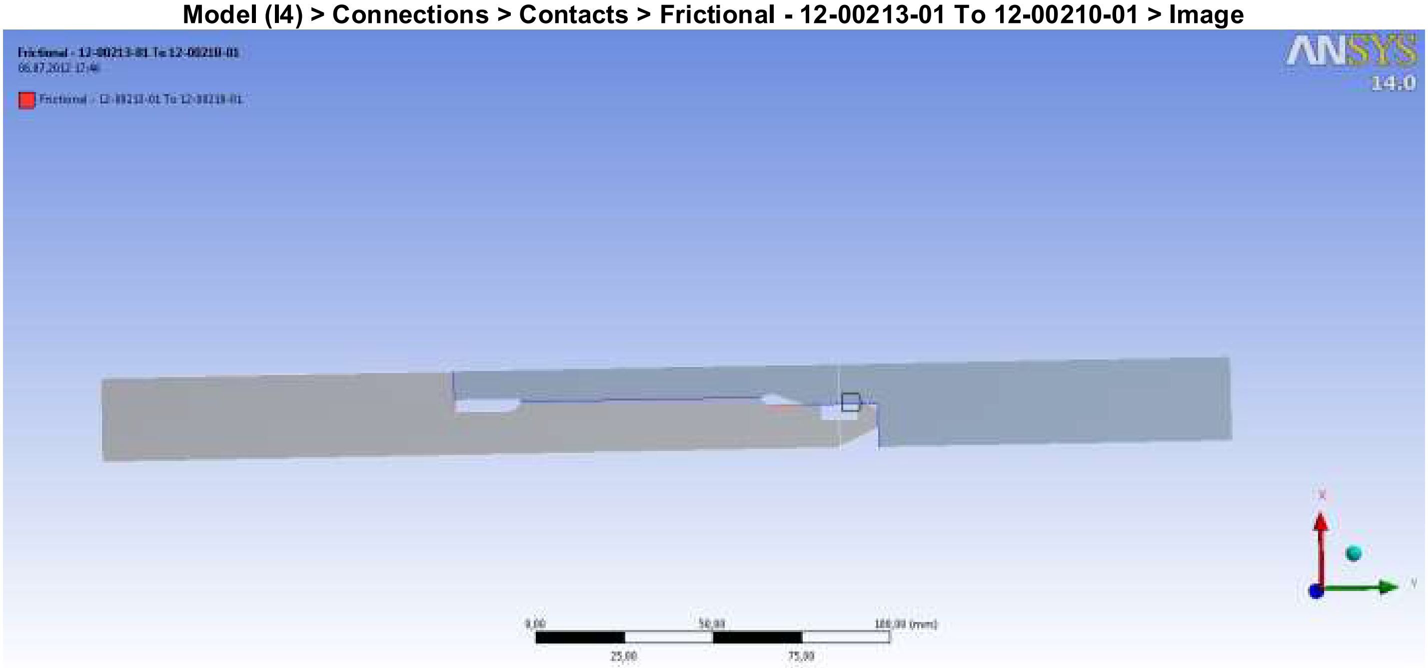
Geometry	All Bodies
Auto Detection	
Tolerance Type	Slider
Tolerance Slider	0,
Tolerance Value	0,8022 mm
Use Range	No
Face/Edge	No
Edge/Edge	Yes
Priority	Include All
Group By	Bodies
Search Across	Bodies

TABLE 7
Model (I4) > Connections > Contacts > Contact Regions

Object Name	*Frictional - 12-00213-01 To 12-00210-01*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Contact	5 Edges
Target	5 Edges
Contact Bodies	12-00213-01
Target Bodies	12-00210-01
Definition	
Type	Frictional
Friction Coefficient	0,15
Scope Mode	Manual
Behavior	Program Controlled

Suppressed	No
Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Interface Treatment	Add Offset, No Ramping
Offset	0, mm
Normal Stiffness	Program Controlled
Update Stiffness	Program Controlled
Stabilization Damping Factor	0,
Pinball Region	Program Controlled
Time Step Controls	None

FIGURE 1
Model (I4) > Connections > Contacts > Frictional - 12-00213-01 To 12-00210-01 > Image



Mesh

TABLE 8
Model (I4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Coarse
Initial Size Seed	Active Assembly
Smoothing	Medium
Span Angle Center	Coarse
Curvature Normal Angle	Default (30,0 °)
Min Size	Default (1,07830 mm)
Max Face Size	Default (5,39170 mm)
Growth Rate	Default
Minimum Edge Length	1,04820 mm
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0,272
Maximum Layers	2
Growth Rate	1,2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	

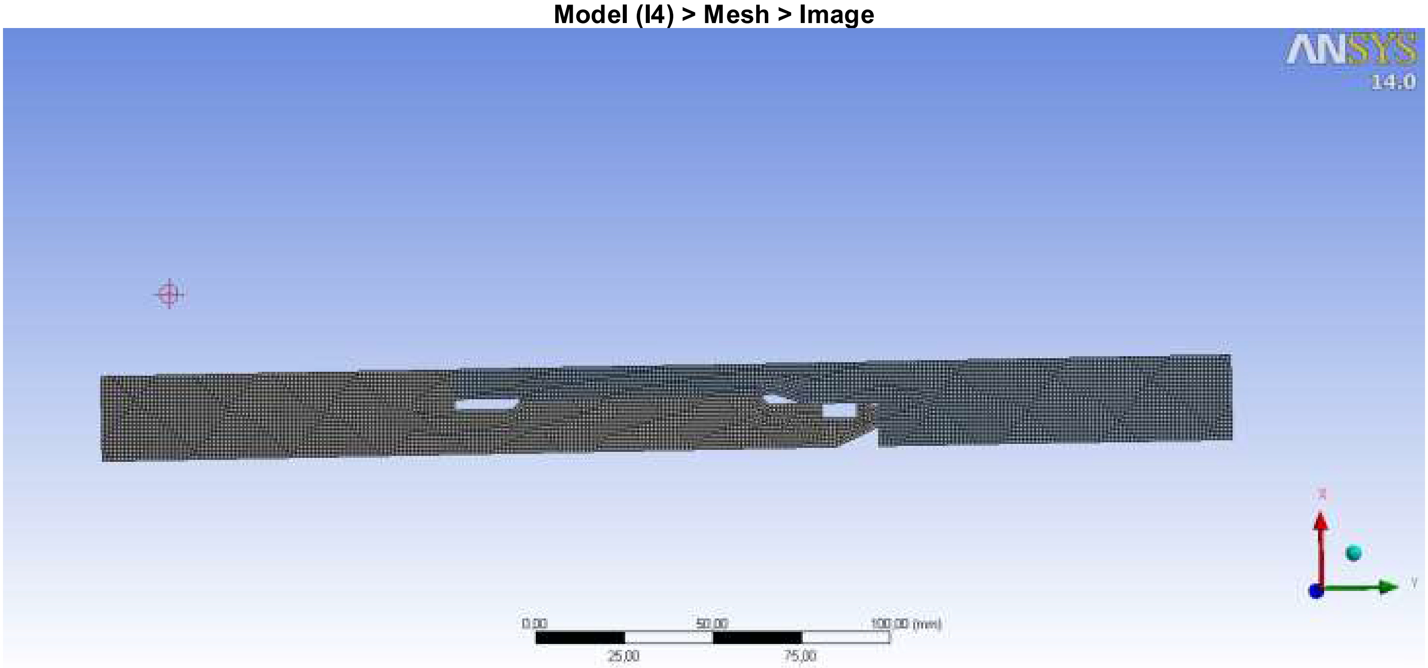
Triangle Surface Mesher	Program Controlled
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Use Sheet Thickness for Pinch	No
Pinch Tolerance	Default (0,970510 mm)
Generate Pinch on Refresh	No
Sheet Loop Removal	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default (0,808760 mm)
Statistics	
Nodes	20562
Elements	6552
Mesh Metric	None

TABLE 9
Model (I4) > Mesh > Mesh Controls

Object Name	*Body Sizing*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies

Definition	
Suppressed	No
Type	Element Size
Element Size	0,2 mm
Behavior	Soft
Curvature Normal Angle	Default
Growth Rate	Default

FIGURE 2
Model (I4) > Mesh > Image



Static Structural (I5)

TABLE 10
Model (I4) > Analysis

Object Name	*Static Structural (I5)*
State	Solved
Definition	
Physics Type	Structural

Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	22, °C
Generate Input Only	No

TABLE 11
Model (I4) > Static Structural (I5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	8,
Current Step Number	8,
Step End Time	8, s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled

Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Off
Output Controls	
Stress	Yes
Strain	Yes
Nodal Forces	No
Contact Miscellaneous	No
General Miscellaneous	No
Calculate Results At	All Time Points
Max Number of Result Sets	1000,
Analysis Data Management	
Solver Files Directory	C:\Vault\Peak\R&D\R&D C-flex\Collapse analysis\New Seal nr. 1\Collapse Analysis of New Seal Design nr. 1_files\dp0\SYS-6\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Delete Unneeded Files	Yes
Nonlinear Solution	Yes
Solver Units	Active System
Solver Unit System	nmm

TABLE 12
Model (I4) > Static Structural (I5) > Analysis Settings
Step-Specific "Step Controls"

Step	Step End Time
1	1, s
2	2, s
3	3, s
4	4, s
5	5, s
6	6, s
7	7, s
8	8, s

TABLE 13
Model (I4) > Static Structural (I5) > Analysis Settings
Step-Specific "Output Controls"

Step	Max Number of Result Sets
1	Program Controlled
2	1000,
3	
4	
5	
6	
7	
8	

TABLE 14
Model (I4) > Static Structural (I5) > Loads

Object Name	*Displacement*	*Force*	*Force 2*	*Pressure*
State	Fully Defined			
Scope				

Scoping Method	Geometry Selection		
Geometry	2 Edges	1 Edge	18 Edges
Definition			
Type	Displacement	Force	Pressure
Define By	Components	Vector	Normal To
Coordinate System	Global Coordinate System		
X Component	Free		
Y Component	0, mm (ramped)		
Suppressed	No		
Magnitude		Tabular Data	
Direction		Defined	
Tabular Data			
Independent Variable			Time

FIGURE 3
Model (I4) > Static Structural (I5) > Displacement

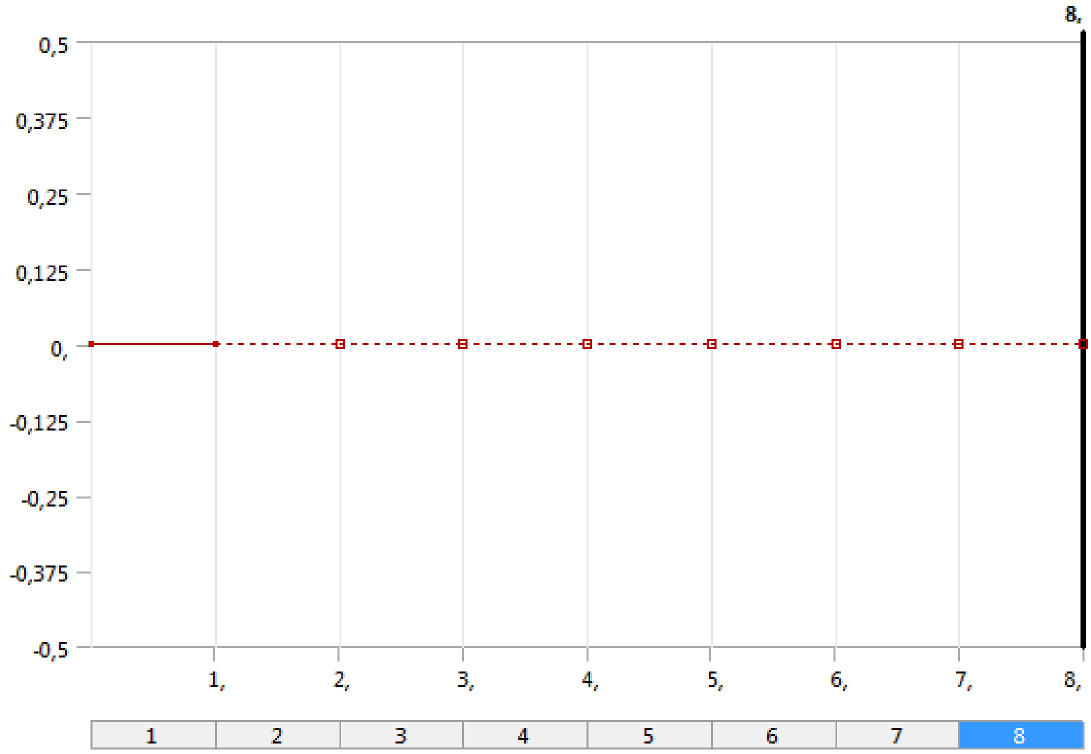


FIGURE 4
Model (I4) > Static Structural (I5) > Force

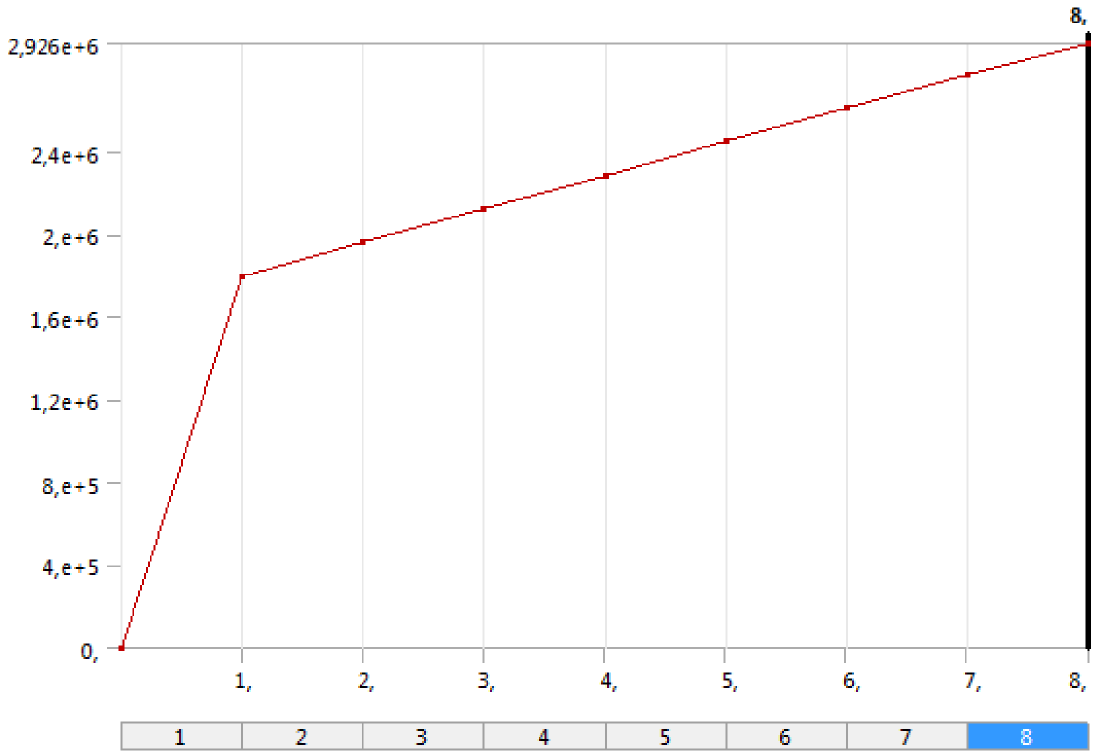


TABLE 15
Model (I4) > Static Structural (I5) > Force

Steps	Time [s]	Force [N]
1	0,	0,
	1,	1,798e+006
2	2,	1,962e+006
3	3,	2,125e+006
4	4,	2,289e+006
5	5,	2,452e+006
6	6,	2,616e+006
7	7,	2,779e+006
8	8,	2,926e+006

FIGURE 5
Model (I4) > Static Structural (I5) > Force 2

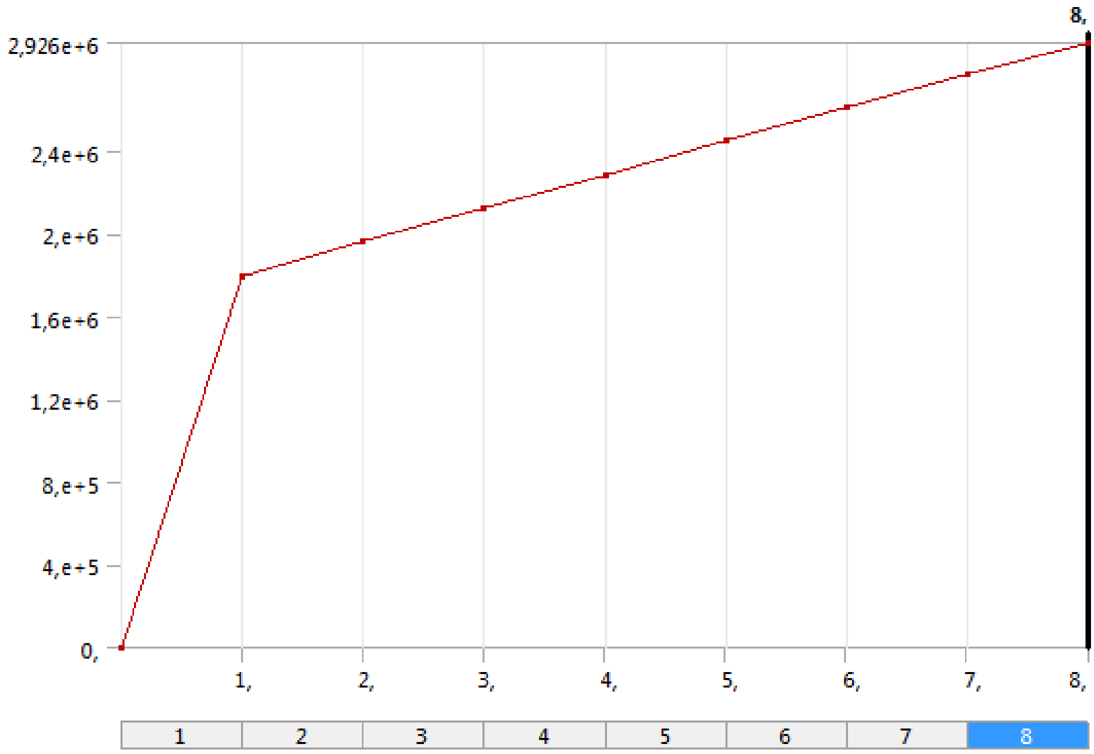


TABLE 16
Model (I4) > Static Structural (I5) > Force 2

Steps	Time [s]	Force [N]
1	0,	0,
	1,	1,798e+006
2	2,	1,962e+006
3	3,	2,125e+006
4	4,	2,289e+006
5	5,	2,452e+006
6	6,	2,616e+006
7	7,	2,779e+006
8	8,	2,926e+006

FIGURE 6
Model (I4) > Static Structural (I5) > Pressure

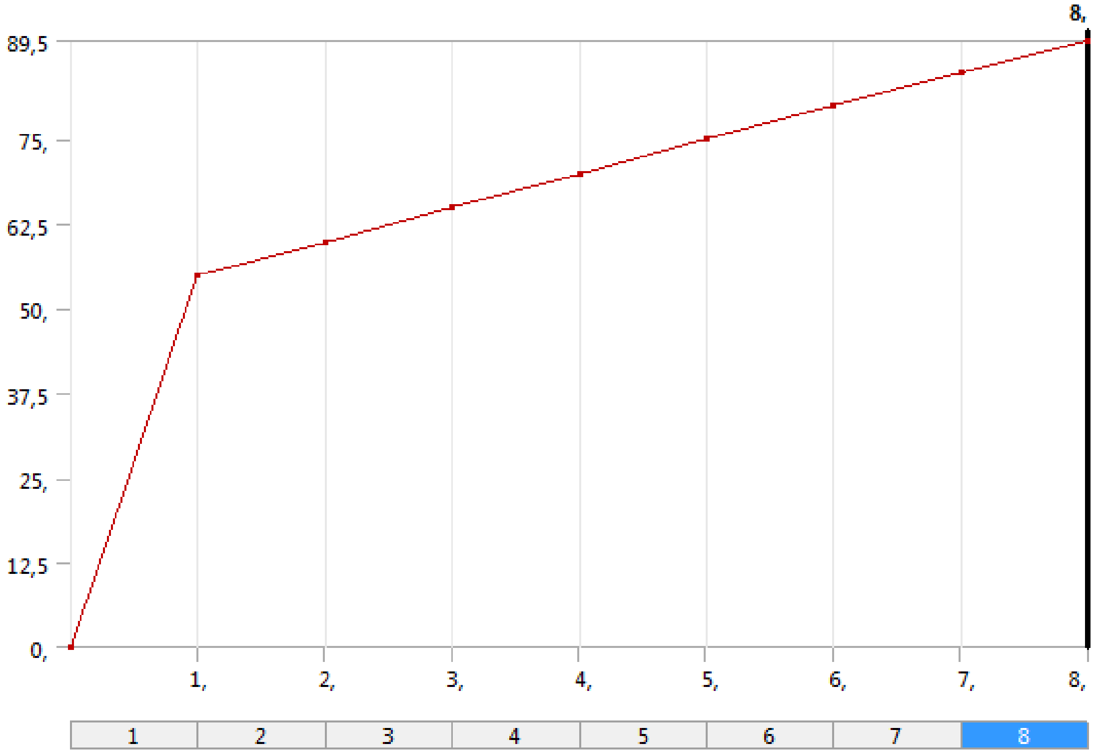


TABLE 17
Model (I4) > Static Structural (I5) > Pressure

Steps	Time [s]	Pressure [MPa]
1	0,	0,
	1,	55,
2	2,	60,
3	3,	65,
4	4,	70,
5	5,	75,
6	6,	80,
7	7,	85,
8	8,	89,5

FIGURE 7
Model (I4) > Static Structural (I5) > Pressure > Image

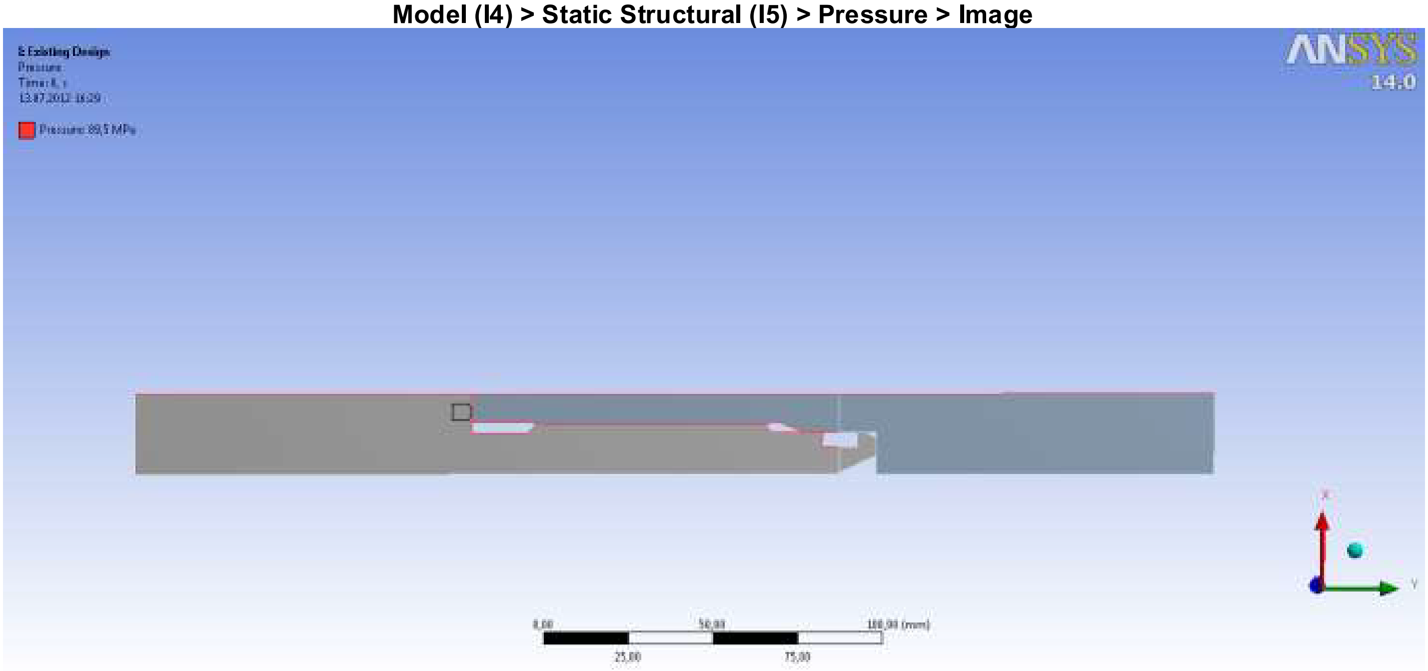
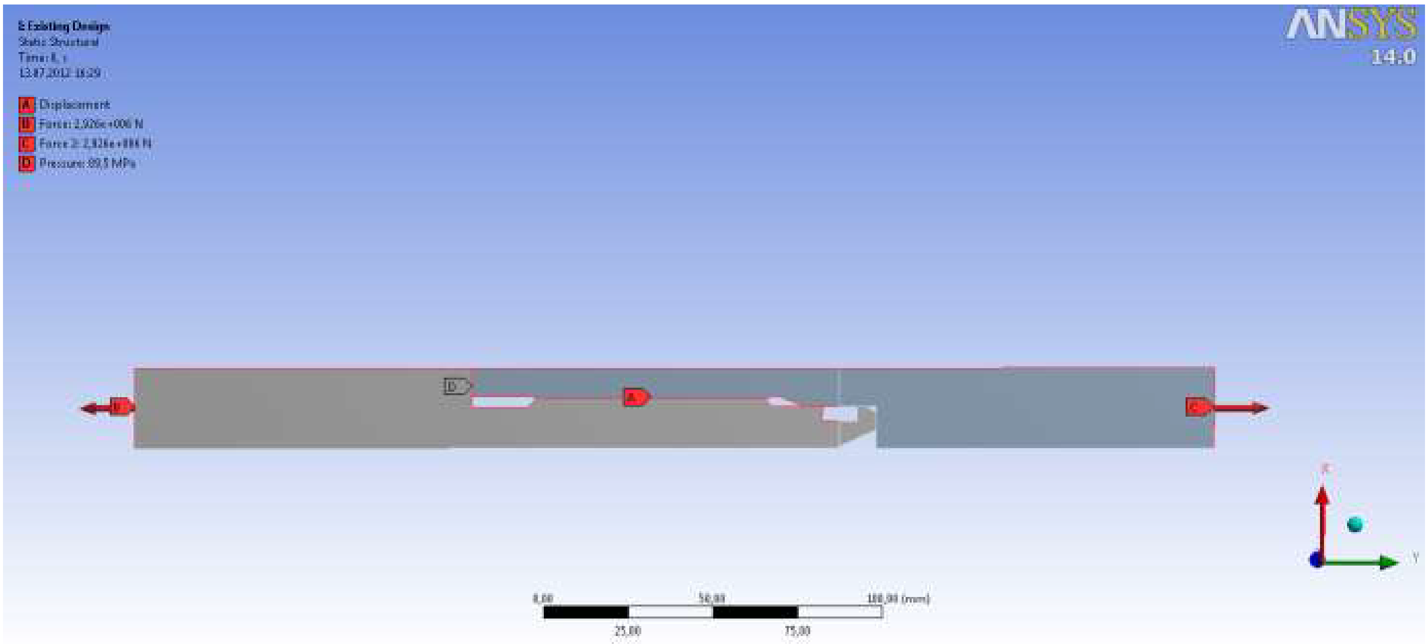


FIGURE 8
Model (I4) > Static Structural (I5) > Image



Solution (I6)

TABLE 18
Model (I4) > Static Structural (I5) > Solution

Object Name	*Solution (I6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1,
Refinement Depth	2,
Information	
Status	Done

TABLE 19
Model (I4) > Static Structural (I5) > Solution (I6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output

Newton-Raphson Residuals	0
Update Interval	2,5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 20
Model (I4) > Static Structural (I5) > Solution (I6) > Results

Object Name	*Total Deformation*	*Directional Deformation*	*Equivalent Stress*	*Equivalent Elastic Strain*	*Directional Deformation 2*
State	Solved				
Scope					
Scoping Method	Geometry Selection				
Geometry	All Bodies				
Definition					
Type	Total Deformation	Directional Deformation	Equivalent (von-Mises) Stress	Equivalent Elastic Strain	Directional Deformation
By	Time				
Display Time	Last				
Calculate Time History	Yes				
Identifier					

Suppressed	No				
Orientation		X Axis			Y Axis
Coordinate System		Global Coordinate System			Global Coordinate System
Results					
Minimum	2,3896e-004 mm	-0,51032 mm	62,186 MPa	3,1093e-004 mm/mm	-0,31902 mm
Maximum	0,51033 mm	4,5873e-002 mm	2362,1 MPa	1,1889e-002 mm/mm	0,30773 mm
Minimum Occurs On	12-00210-01	12-00213-01	12-00210-01		12-00213-01
Maximum Occurs On	12-00213-01	12-00210-01	12-00213-01		12-00210-01
Minimum Value Over Time					
Minimum	1,3566e-004 mm	-0,51032 mm	38,198 MPa	1,9099e-004 mm/mm	-0,31902 mm
Maximum	2,3896e-004 mm	-0,31359 mm	62,186 MPa	3,1093e-004 mm/mm	-0,19604 mm
Maximum Value Over Time					
Minimum	0,3136 mm	2,818e-002 mm	1451,4 MPa	7,3049e-003 mm/mm	0,18906 mm
Maximum	0,51033 mm	4,5873e-002 mm	2362,1 MPa	1,1889e-002 mm/mm	0,30773 mm
Information					
Time	8, s				
Load Step	8				
Substep	1				
Iteration Number	17				
Integration Point Results					

Display Option		Averaged	

FIGURE 9
Model (I4) > Static Structural (I5) > Solution (I6) > Total Deformation

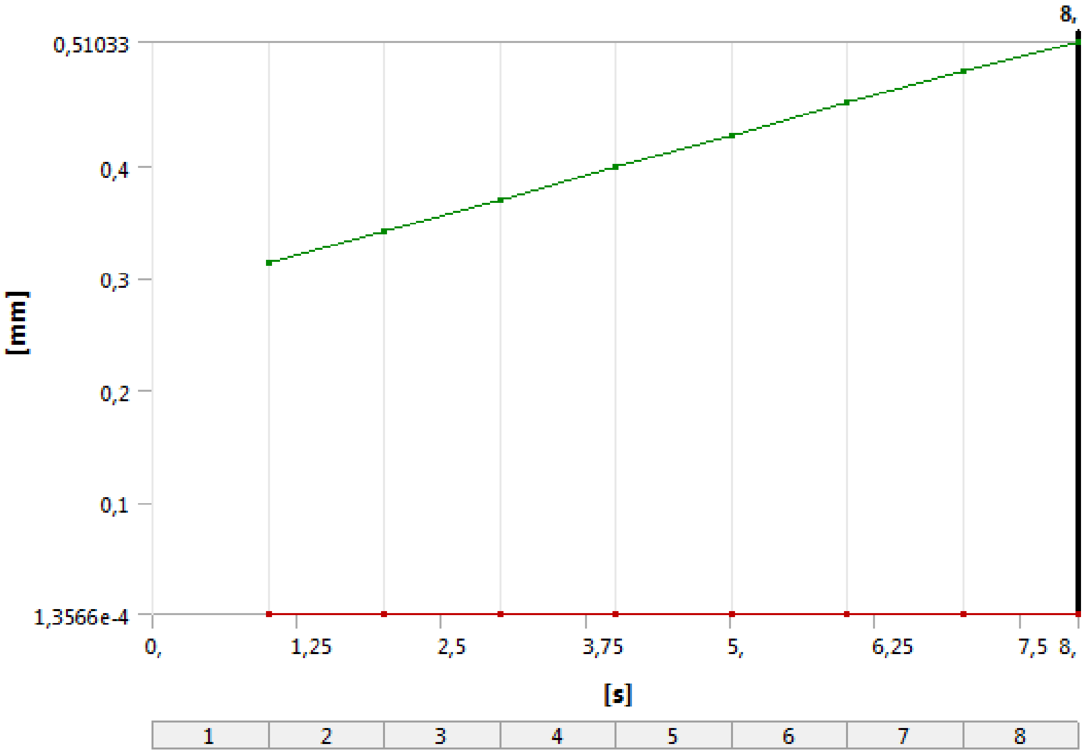


TABLE 21
Model (I4) > Static Structural (I5) > Solution (I6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,	1,3566e-004	0,3136
2,	1,655e-004	0,34213
3,	1,7447e-004	0,37063
4,	1,9148e-004	0,39915
5,	2,0144e-004	0,42765
6,	2,1841e-004	0,45617
7,	2,2844e-004	0,48468
8,	2,3896e-004	0,51033

FIGURE 10
Model (I4) > Static Structural (I5) > Solution (I6) > Total Deformation > Image

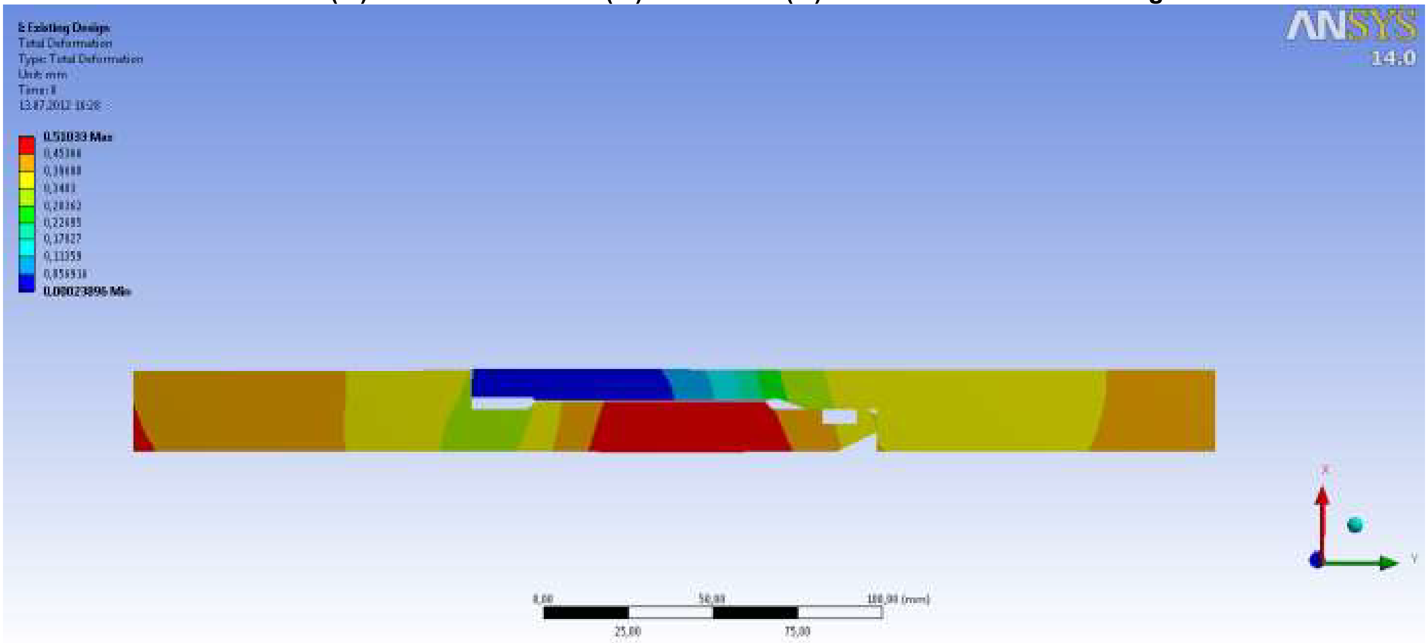


FIGURE 11
Model (I4) > Static Structural (I5) > Solution (I6) > Directional Deformation

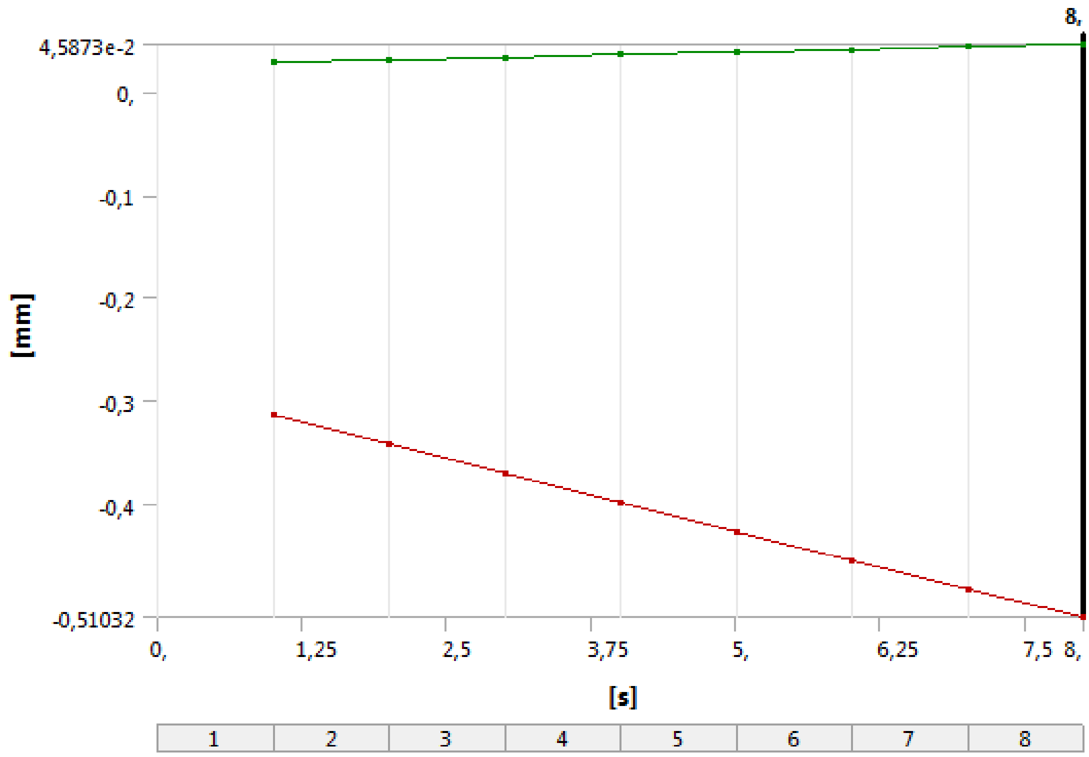


TABLE 22
Model (I4) > Static Structural (I5) > Solution (I6) > Directional Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,	-0,31359	2,818e-002
2,	-0,34212	3,0764e-002
3,	-0,37062	3,332e-002
4,	-0,39914	3,5887e-002
5,	-0,42764	3,8445e-002
6,	-0,45616	4,1012e-002
7,	-0,48466	4,3569e-002
8,	-0,51032	4,5873e-002

FIGURE 12
Model (I4) > Static Structural (I5) > Solution (I6) > Directional Deformation > Image

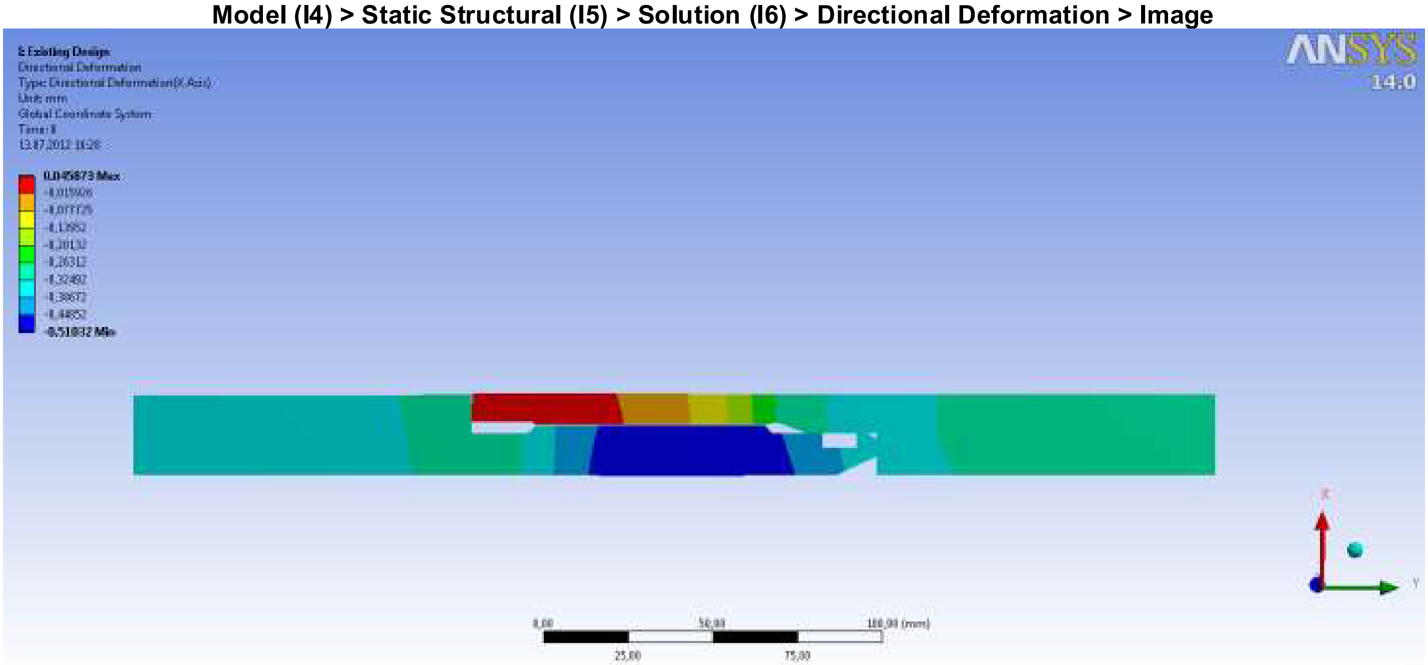


FIGURE 13
Model (I4) > Static Structural (I5) > Solution (I6) > Equivalent Stress

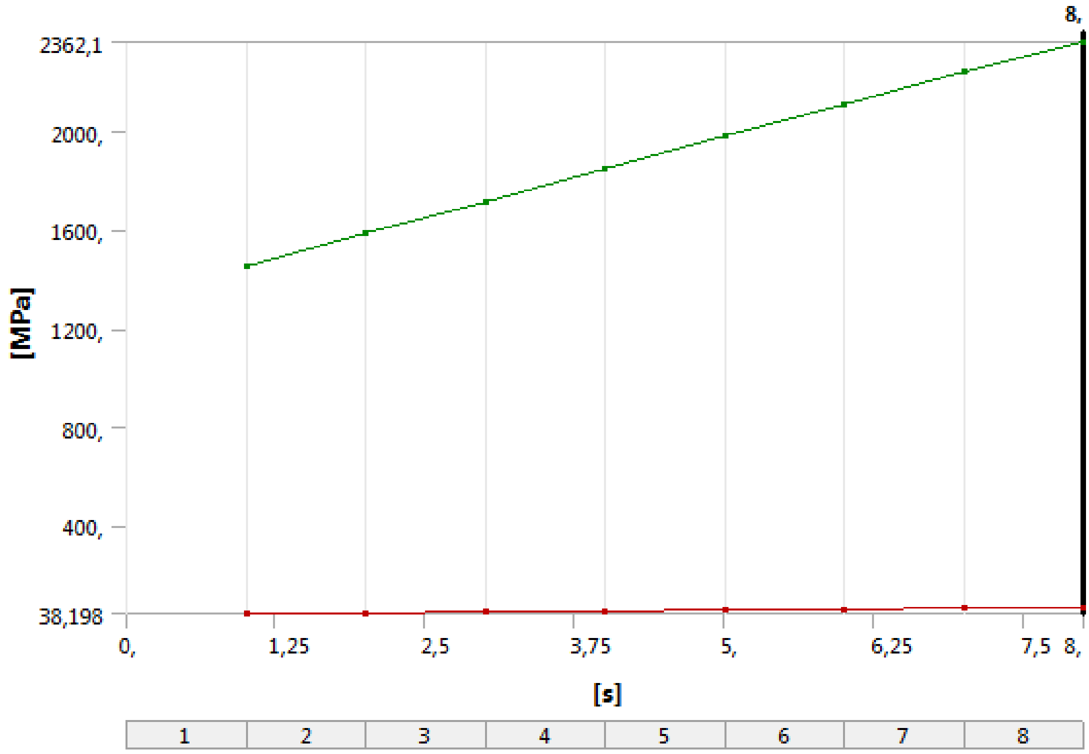


TABLE 23
Model (I4) > Static Structural (I5) > Solution (I6) > Equivalent Stress

Time [s]	Minimum [MPa]	Maximum [MPa]
1,	38,198	1451,4
2,	41,702	1583,8
3,	45,167	1715,5
4,	48,648	1847,7
5,	52,115	1979,5
6,	55,596	2111,7
7,	59,063	2243,4
8,	62,186	2362,1

FIGURE 14
Model (I4) > Static Structural (I5) > Solution (I6) > Equivalent Stress > Image

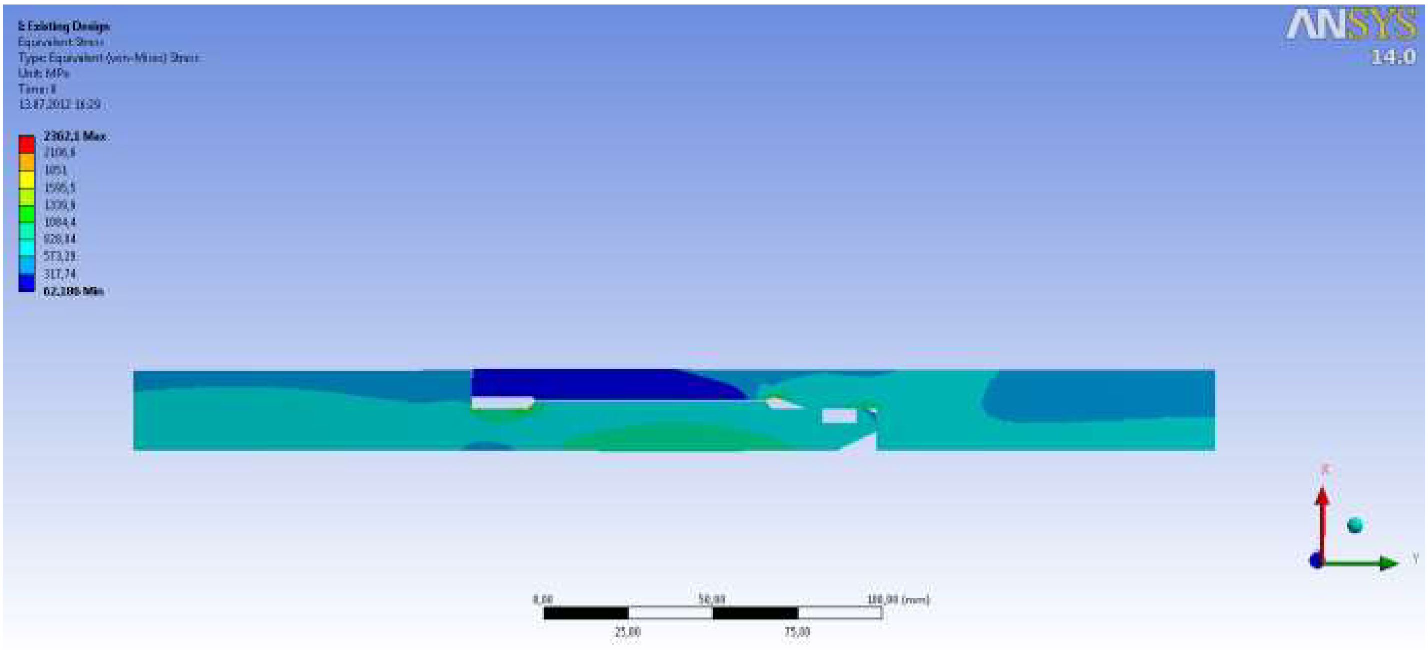


FIGURE 15
Model (I4) > Static Structural (I5) > Solution (I6) > Equivalent Elastic Strain

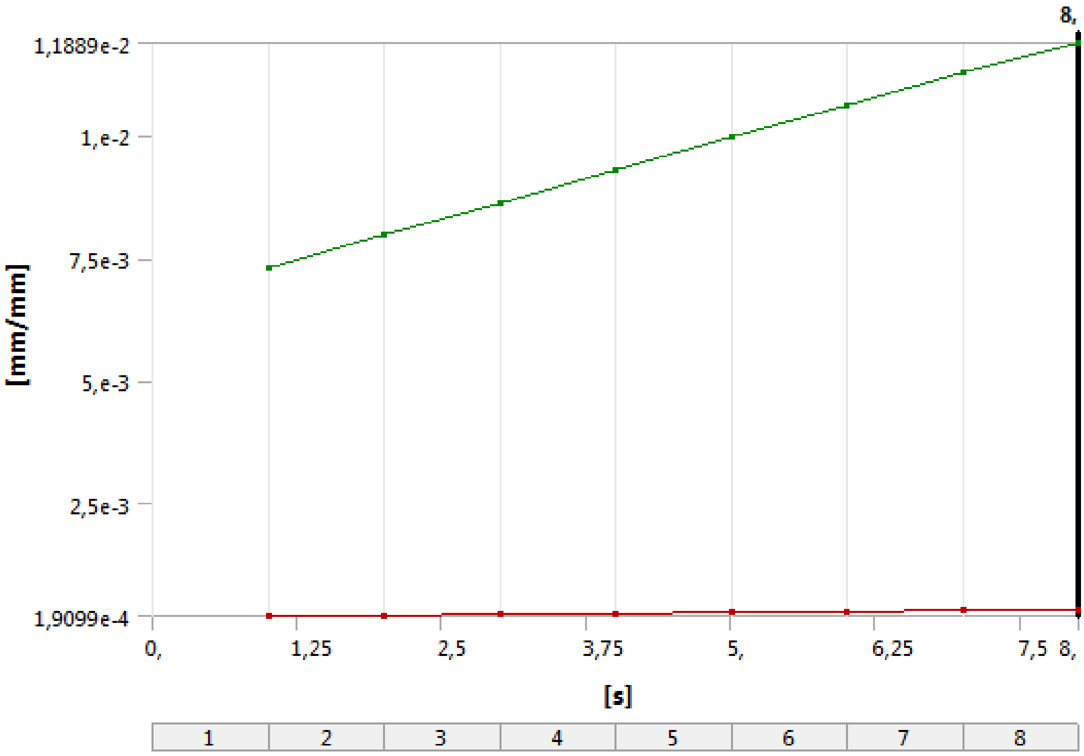


TABLE 24
Model (I4) > Static Structural (I5) > Solution (I6) > Equivalent Elastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
1,	1,9099e-004	7,3049e-003
2,	2,0851e-004	7,9715e-003
3,	2,2584e-004	8,6345e-003
4,	2,4324e-004	9,2999e-003
5,	2,6058e-004	9,963e-003
6,	2,7798e-004	1,0628e-002
7,	2,9531e-004	1,1292e-002
8,	3,1093e-004	1,1889e-002

FIGURE 16
Model (I4) > Static Structural (I5) > Solution (I6) > Equivalent Elastic Strain > Image

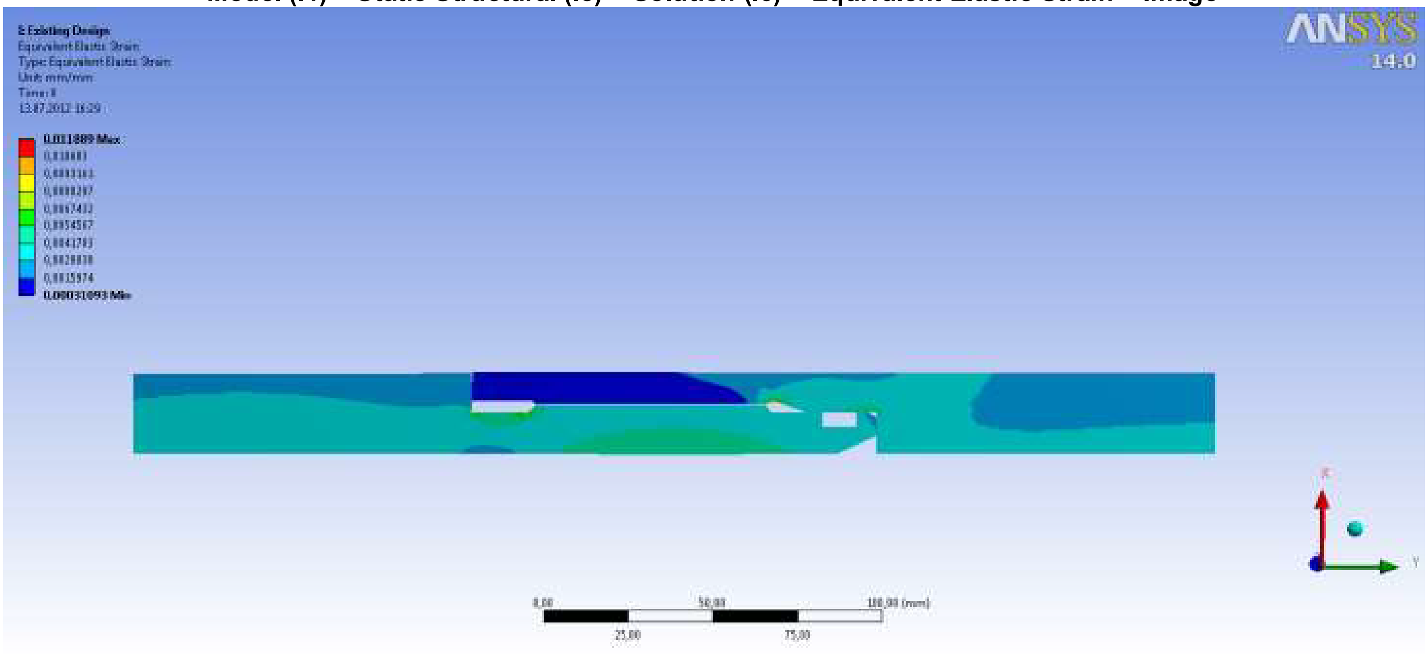


FIGURE 17
Model (I4) > Static Structural (I5) > Solution (I6) > Directional Deformation 2

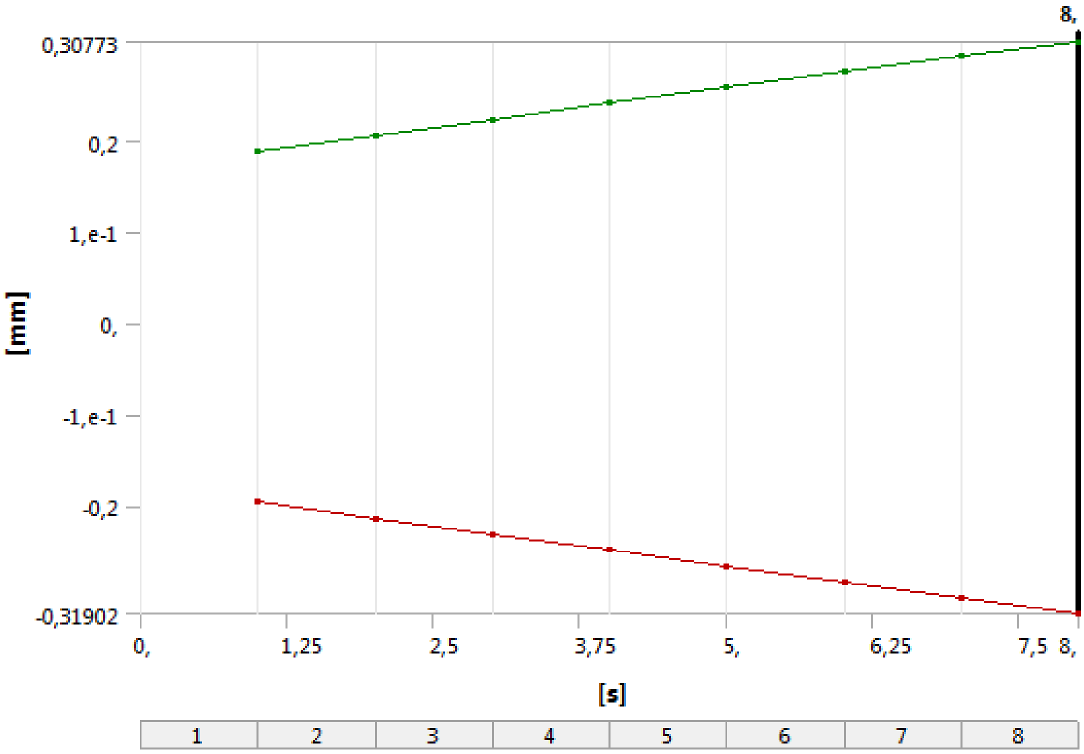
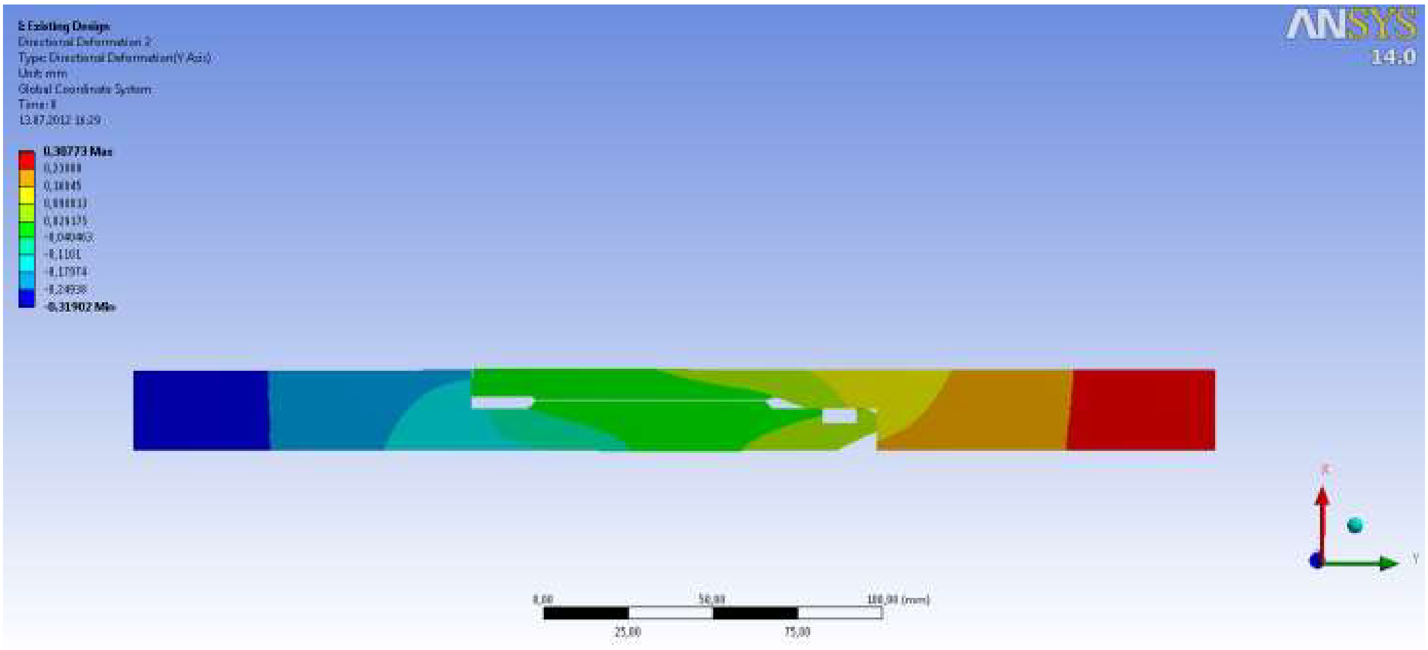


TABLE 25
Model (I4) > Static Structural (I5) > Solution (I6) > Directional Deformation 2

Time [s]	Minimum [mm]	Maximum [mm]
1,	-0,19604	0,18906
2,	-0,21389	0,20634
3,	-0,23169	0,2235
4,	-0,24954	0,24073
5,	-0,26733	0,25788
6,	-0,28519	0,27511
7,	-0,30298	0,29227
8,	-0,31902	0,30773

FIGURE 18
Model (I4) > Static Structural (I5) > Solution (I6) > Directional Deformation 2 > Image



Material Data

4140 125ksi

TABLE 26
4140 125ksi > Constants

Density	7,85e-006 kg mm^-3
Coefficient of Thermal Expansion	1,2e-005 C^-1
Specific Heat	4,34e+005 mJ kg^-1 C^-1
Thermal Conductivity	6,05e-002 W mm^-1 C^-1
Resistivity	1,7e-004 ohm mm

TABLE 27
4140 125ksi > Compressive Ultimate Strength

Compressive Ultimate Strength MPa
965,

TABLE 28
4140 125ksi > Compressive Yield Strength

Compressive Yield Strength MPa

860,

TABLE 29
4140 125ksi > Tensile Yield Strength

Tensile Yield Strength MPa
860,

TABLE 30
4140 125ksi > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
965,

TABLE 31
4140 125ksi > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22,

TABLE 32
4140 125ksi > Alternating Stress Mean Stress

Alternating Stress MPa	Cycles	Mean Stress MPa
3999,	10,	0,
2827,	20,	0,
1896,	50,	0,
1413,	100,	0,
1069,	200,	0,
441,	2000,	0,
262,	10000	0,
214,	20000	0,
138,	1,e+005	0,
114,	2,e+005	0,
86,2	1,e+006	0,

TABLE 33
4140 125ksi > Strain-Life Parameters

Strength Coefficient MPa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient MPa	Cyclic Strain Hardening Exponent
920,	-0,106	0,213	-0,47	1000,	0,2

TABLE 34
4140 125ksi > Isotropic Elasticity

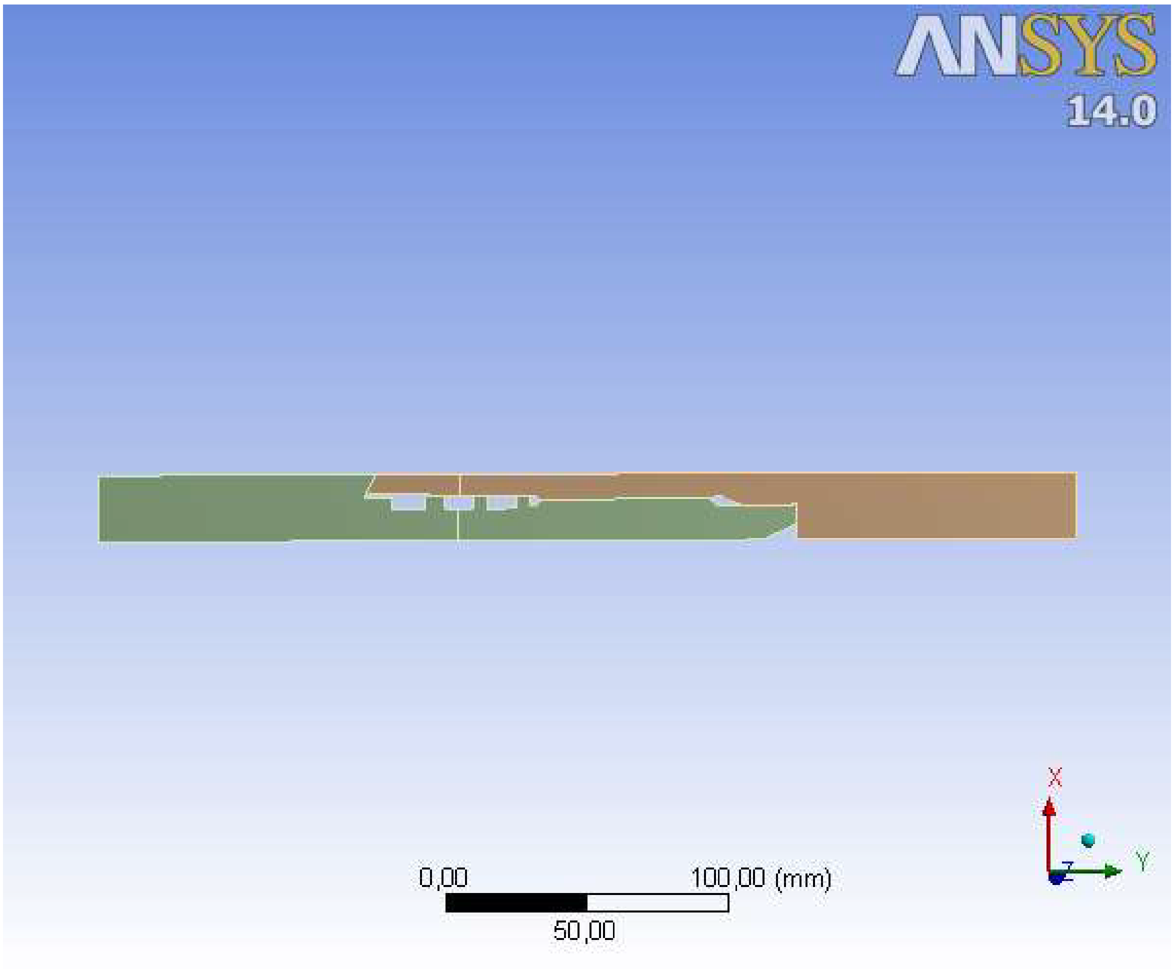
Temperature C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	2,e+005	0,3	1,6667e+005	76923

TABLE 35
4140 125ksi > Isotropic Relative Permeability

Relative Permeability
10000

Project

First Saved	Thursday, July 05, 2012
Last Saved	Friday, July 13, 2012
Product Version	14.0 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

Units

TABLE 1

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (E4)

Geometry

TABLE 2
Model (E4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Vault\Peak\R&D\R&D C-flex\Collapse analysis\New Seal nr. 1\Collapse

	Analysis of New Seal Design nr. 1_files\dp0\SYS-3\DM\SYS-3.agdb
Type	DesignModeler
Length Unit	Millimeters
Element Control	Program Controlled
2D Behavior	Axisymmetric
Display Style	Body Color
Bounding Box	
Length X	23,75 mm
Length Y	349,7 mm
Properties	
Volume	0, mm³
Mass	
Surface Area(approx.)	8077,2 mm²
Scale Factor Value	1,
Statistics	
Bodies	2
Active Bodies	2
Nodes	20501
Elements	6501
Mesh Metric	None
Basic Geometry Options	
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No

Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\62844\AppData\Local\Temp
Analysis Type	2-D
Decompose Disjoint Faces	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (E4) > Geometry > Parts

Object Name	*RD-03325*	*RD-03324*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	

Material		
Assignment	4140 125ksi	
Nonlinear Effects	Yes	
Thermal Strain Effects	Yes	
Bounding Box		
Length X	23,75 mm	
Length Y	249,7 mm	253,96 mm
Properties		
Volume	N/A	
Mass	N/A	
Centroid X	N/A	
Centroid Y	N/A	
Centroid Z	N/A	
Moment of Inertia Ip1	N/A	
Moment of Inertia Ip2	N/A	
Moment of Inertia Ip3	N/A	
Surface Area(approx.)	4362,8 mm²	3714,4 mm²
Statistics		
Nodes	11219	9282
Elements	3570	2931
Mesh Metric	None	

Coordinate Systems

TABLE 4
Model (E4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined

Definition	
Type	Cartesian
Coordinate System ID	0,
Origin	
Origin X	0, mm
Origin Y	0, mm
Directional Vectors	
X Axis Data	[1, 0,]
Y Axis Data	[0, 1,]

Connections

TABLE 5
Model (E4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (E4) > Connections > Contacts

Object Name	*Contacts*
State	Fully Defined
Definition	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection

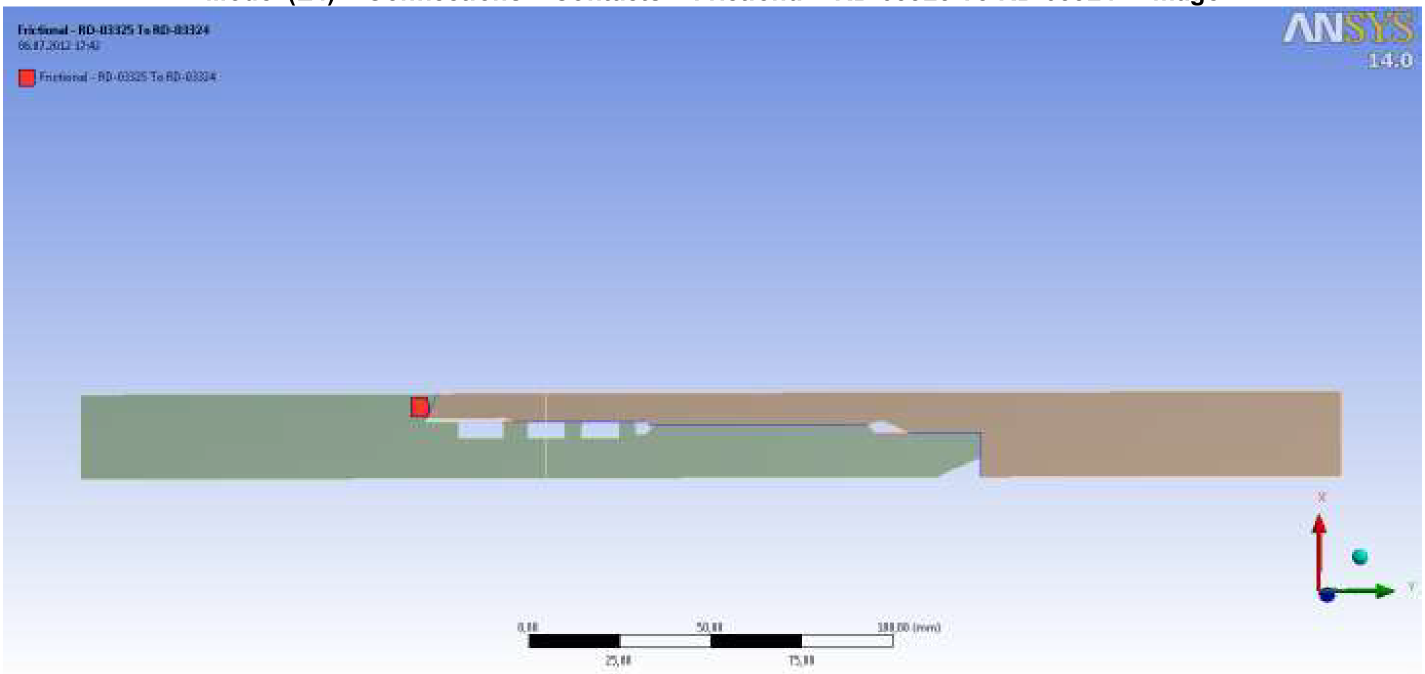
Geometry	All Bodies
Auto Detection	
Tolerance Type	Slider
Tolerance Slider	0,
Tolerance Value	0,87626 mm
Use Range	No
Face/Edge	No
Edge/Edge	Yes
Priority	Include All
Group By	Bodies
Search Across	Bodies

TABLE 7
Model (E4) > Connections > Contacts > Contact Regions

Object Name	*Frictional - RD-03325 To RD-03324*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Contact	7 Edges
Target	6 Edges
Contact Bodies	RD-03325
Target Bodies	RD-03324
Definition	
Type	Frictional
Friction Coefficient	0,15
Scope Mode	Manual
Behavior	Program Controlled

Suppressed	No
Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Interface Treatment	Add Offset, No Ramping
Offset	0, mm
Normal Stiffness	Program Controlled
Update Stiffness	Program Controlled
Stabilization Damping Factor	0,
Pinball Region	Program Controlled
Time Step Controls	None

FIGURE 1
Model (E4) > Connections > Contacts > Frictional - RD-03325 To RD-03324 > Image



Mesh

TABLE 8
Model (E4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Coarse
Initial Size Seed	Active Assembly
Smoothing	Medium
Span Angle Center	Coarse
Curvature Normal Angle	Default (30,0 °)
Min Size	Default (1,12340 mm)
Max Face Size	Default (5,61710 mm)
Growth Rate	Default
Minimum Edge Length	1,41420 mm
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0,272
Maximum Layers	2
Growth Rate	1,2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	

Triangle Surface Mesher	Program Controlled
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Use Sheet Thickness for Pinch	No
Pinch Tolerance	Default (1,01110 mm)
Generate Pinch on Refresh	No
Sheet Loop Removal	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default (0,842560 mm)
Statistics	
Nodes	20501
Elements	6501
Mesh Metric	None

TABLE 9
Model (E4) > Mesh > Mesh Controls

Object Name	*Body Sizing*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies

Definition	
Suppressed	No
Type	Element Size
Element Size	0,2 mm
Behavior	Soft
Curvature Normal Angle	Default
Growth Rate	Default

FIGURE 2
Model (E4) > Mesh > Image

Static Structural (E5)

TABLE 10
Model (E4) > Analysis

Object Name	*Static Structural (E5)*
State	Solved
Definition	
Physics Type	Structural

Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	22, °C
Generate Input Only	No

TABLE 11
Model (E4) > Static Structural (E5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	8,
Current Step Number	8,
Step End Time	8, s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled

Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Off
Output Controls	
Stress	Yes
Strain	Yes
Nodal Forces	No
Contact Miscellaneous	No
General Miscellaneous	No
Calculate Results At	All Time Points
Max Number of Result Sets	1000,
Analysis Data Management	
Solver Files Directory	C:\Vault\Peak\R&D\R&D C-flex\Collapse analysis\New Seal nr. 1\Collapse Analysis of New Seal Design nr. 1_files\dp0\SYS-4\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Delete Unneeded Files	Yes
Nonlinear Solution	Yes
Solver Units	Active System
Solver Unit System	nmm

TABLE 12
Model (E4) > Static Structural (E5) > Analysis Settings
Step-Specific "Step Controls"

Step	Step End Time
1	1, s
2	2, s
3	3, s
4	4, s
5	5, s
6	6, s
7	7, s
8	8, s

TABLE 13
Model (E4) > Static Structural (E5) > Analysis Settings
Step-Specific "Output Controls"

Step	Max Number of Result Sets
1	Program Controlled
2	1000,
3	
4	
5	
6	
7	
8	

TABLE 14
Model (E4) > Static Structural (E5) > Loads

Object Name	*Pressure*	*Force*	*Force 2*	*Displacement*
State	Fully Defined			
Scope				

Scoping Method	Geometry Selection		
Geometry	15 Edges	1 Edge	2 Edges
Definition			
Type	Pressure	Force	Displacement
Define By	Normal To	Vector	Components
Magnitude	Tabular Data		
Suppressed	No		
Direction		Defined	
Coordinate System			Global Coordinate System
X Component			Free
Y Component			0, mm (ramped)
Tabular Data			
Independent Variable	Time		

FIGURE 3
Model (E4) > Static Structural (E5) > Pressure

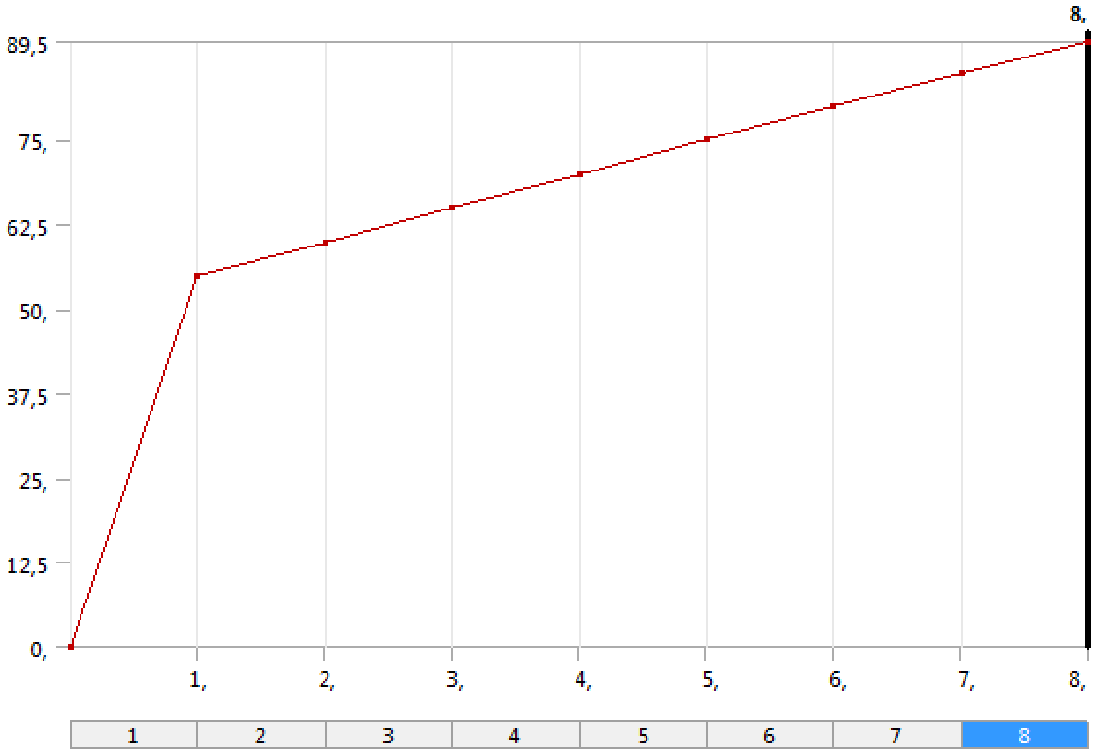


TABLE 15
Model (E4) > Static Structural (E5) > Pressure

Steps	Time [s]	Pressure [MPa]
1	0,	0,
	1,	55,
2	2,	60,
3	3,	65,
4	4,	70,
5	5,	75,
6	6,	80,
7	7,	85,
8	8,	89,5

FIGURE 4
Model (E4) > Static Structural (E5) > Pressure > Image

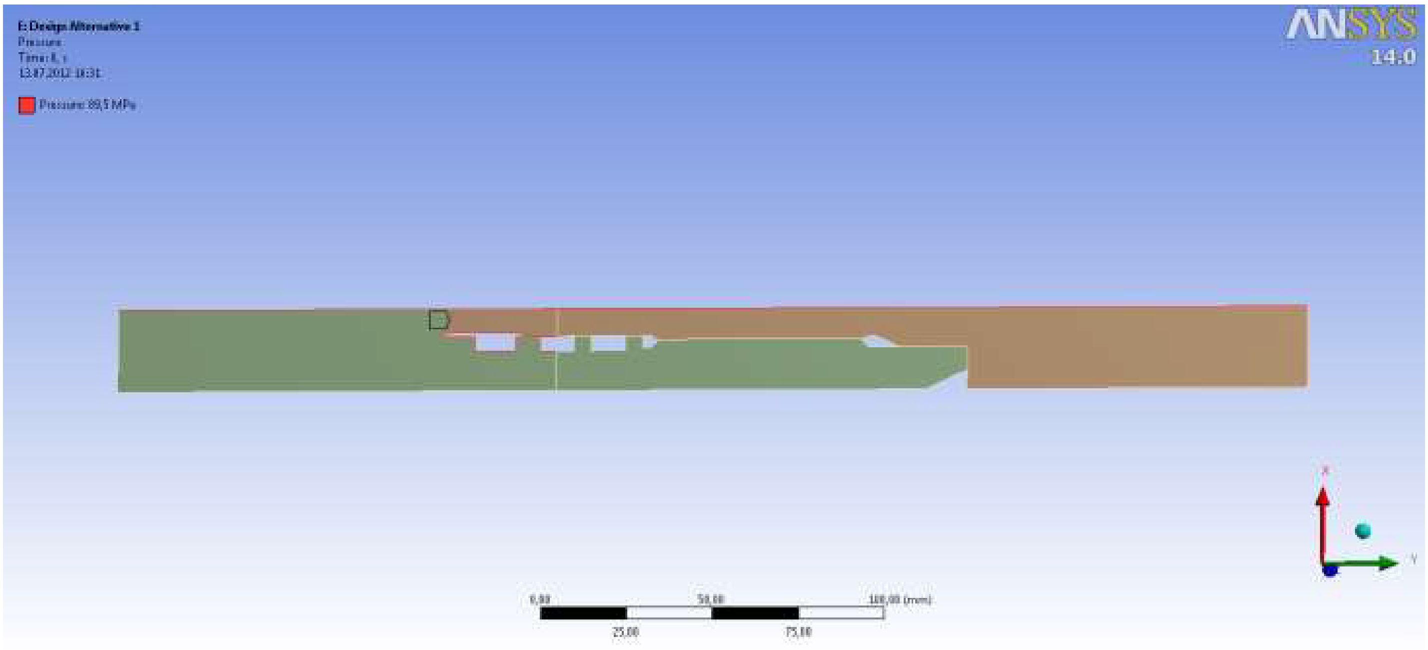


FIGURE 5
Model (E4) > Static Structural (E5) > Force

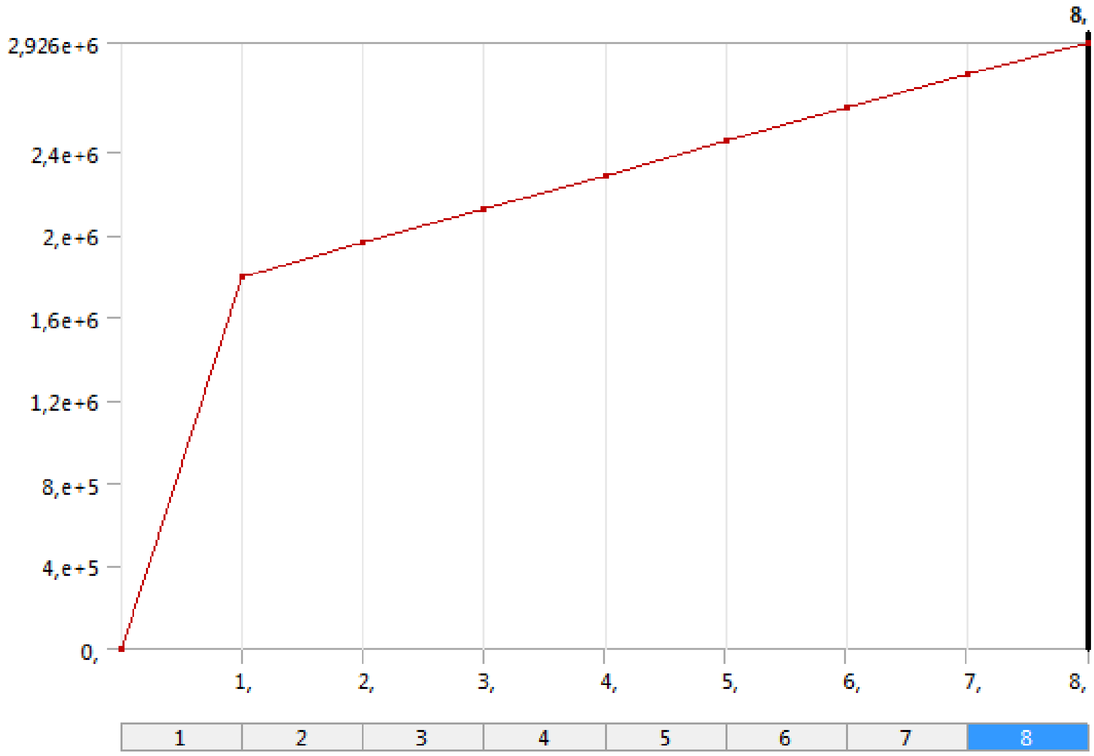


TABLE 16
Model (E4) > Static Structural (E5) > Force

Steps	Time [s]	Force [N]
1	0,	0,
	1,	1,798e+006
2	2,	1,962e+006
3	3,	2,125e+006
4	4,	2,289e+006
5	5,	2,452e+006
6	6,	2,616e+006
7	7,	2,779e+006
8	8,	2,926e+006

FIGURE 6
Model (E4) > Static Structural (E5) > Force 2

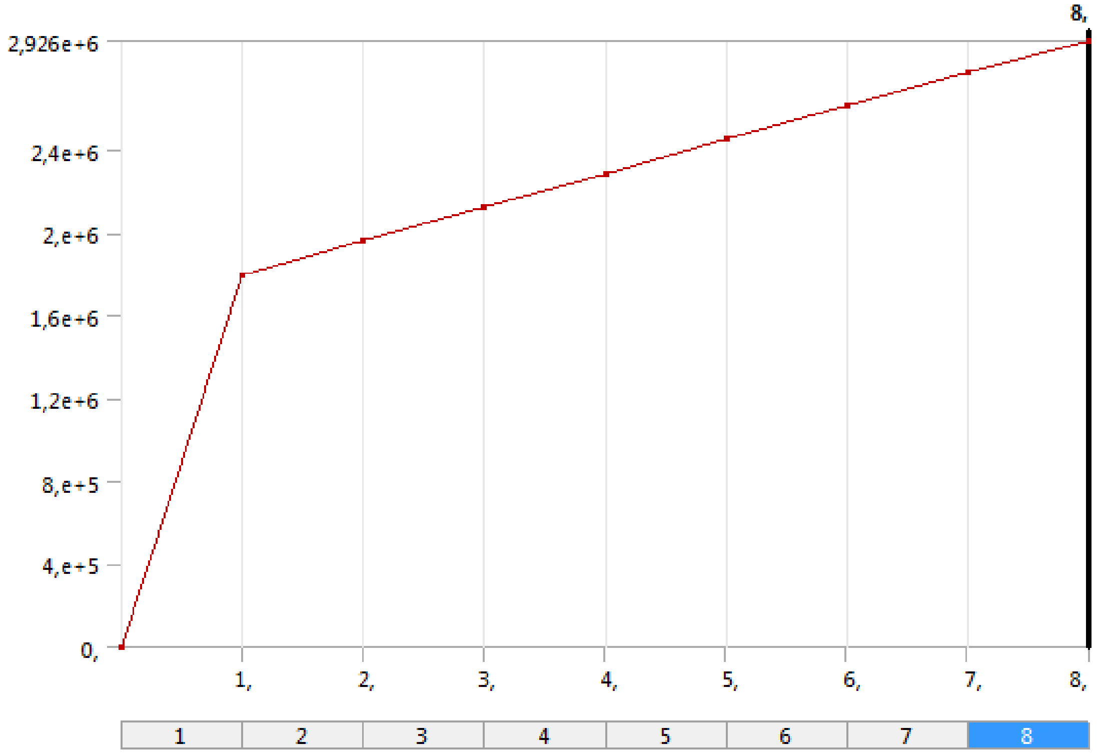


TABLE 17
Model (E4) > Static Structural (E5) > Force 2

Steps	Time [s]	Force [N]
1	0,	0,
	1,	1,798e+006
2	2,	1,962e+006
3	3,	2,125e+006
4	4,	2,289e+006
5	5,	2,452e+006
6	6,	2,616e+006
7	7,	2,779e+006
8	8,	2,926e+006

FIGURE 7
Model (E4) > Static Structural (E5) > Displacement

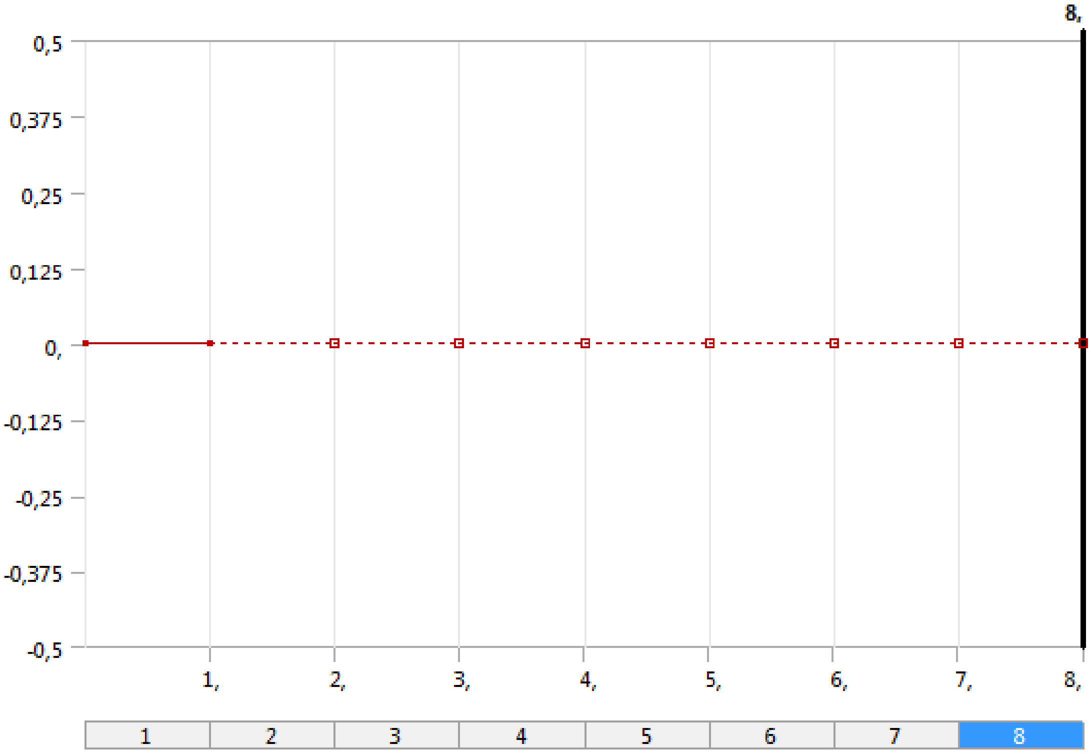
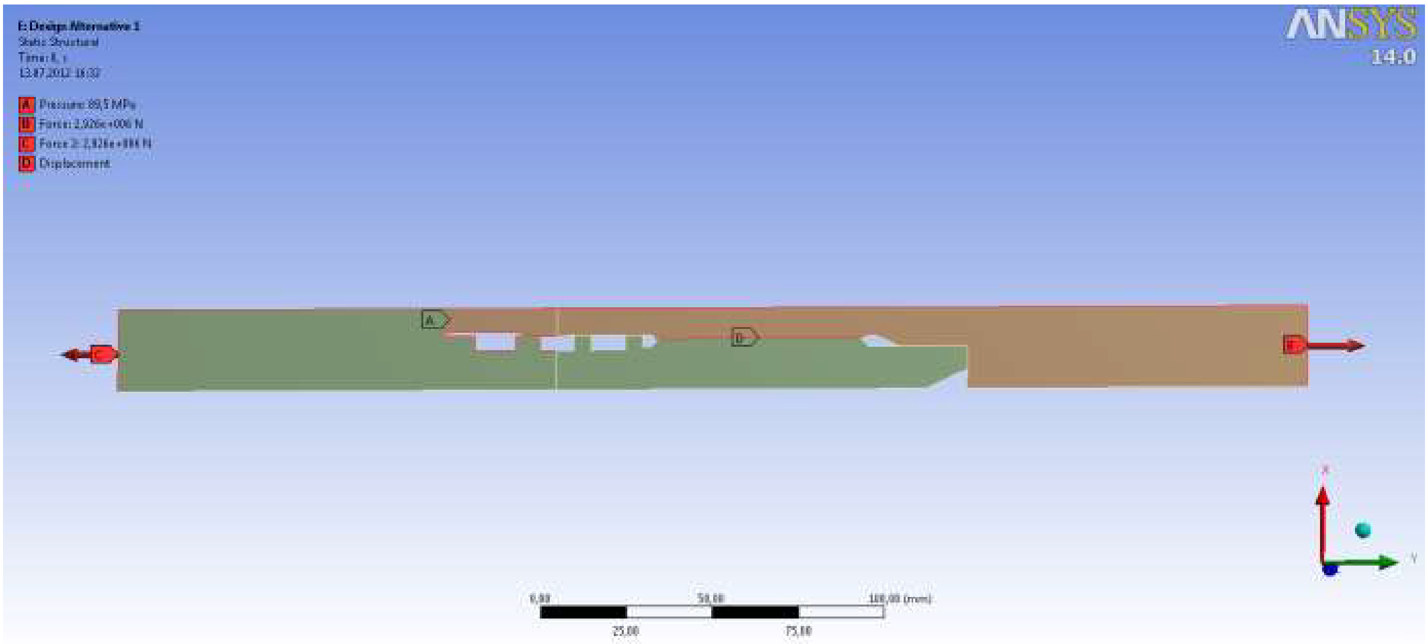


FIGURE 8
Model (E4) > Static Structural (E5) > Image



Solution (E6)

TABLE 18
Model (E4) > Static Structural (E5) > Solution

Object Name	*Solution (E6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1,
Refinement Depth	2,
Information	
Status	Done

TABLE 19
Model (E4) > Static Structural (E5) > Solution (E6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output

Newton-Raphson Residuals	0
Update Interval	2,5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	None
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 20
Model (E4) > Static Structural (E5) > Solution (E6) > Results

Object Name	*Equivalent Elastic Strain*	*Total Deformation*	*Equivalent Stress*	*Directional Deformation 2*	*Directional Deformation*
State	Solved				
Scope					
Scoping Method	Geometry Selection				
Geometry	All Bodies				
Definition					
Type	Equivalent Elastic Strain	Total Deformation	Equivalent (von-Mises) Stress	Directional Deformation	
By	Time				
Display Time	Last				
Calculate Time History	Yes				
Identifier					

Suppressed	No				
Orientation				Y Axis	X Axis
Coordinate System				Global Coordinate System	
Integration Point Results					
Display Option	Averaged		Averaged		
Results					
Minimum	3,6716e-006 mm/mm	9,4312e-003 mm	0,16654 MPa	-0,41412 mm	-0,37952 mm
Maximum	9,9017e-003 mm/mm	0,52419 mm	1963,7 MPa	0,29185 mm	6,6204e-003 mm
Minimum Occurs On	RD-03324			RD-03325	RD-03324
Maximum Occurs On	RD-03325			RD-03324	
Minimum Value Over Time					
Minimum	2,6791e-006 mm/mm	5,7566e-003 mm	0,11542 MPa	-0,41412 mm	-0,37952 mm
Maximum	3,6716e-006 mm/mm	9,4312e-003 mm	0,17621 MPa	-0,25438 mm	-0,23301 mm
Maximum Value Over Time					
Minimum	6,0554e-003 mm/mm	0,32206 mm	1200,9 MPa	0,17921 mm	4,1921e-003 mm
Maximum	9,9017e-003 mm/mm	0,52419 mm	1963,7 MPa	0,29185 mm	6,6204e-003 mm
Information					
Time	8, s				
Load Step	8				
Substep	1				
Iteration	17				

Number	

FIGURE 9
Model (E4) > Static Structural (E5) > Solution (E6) > Equivalent Elastic Strain

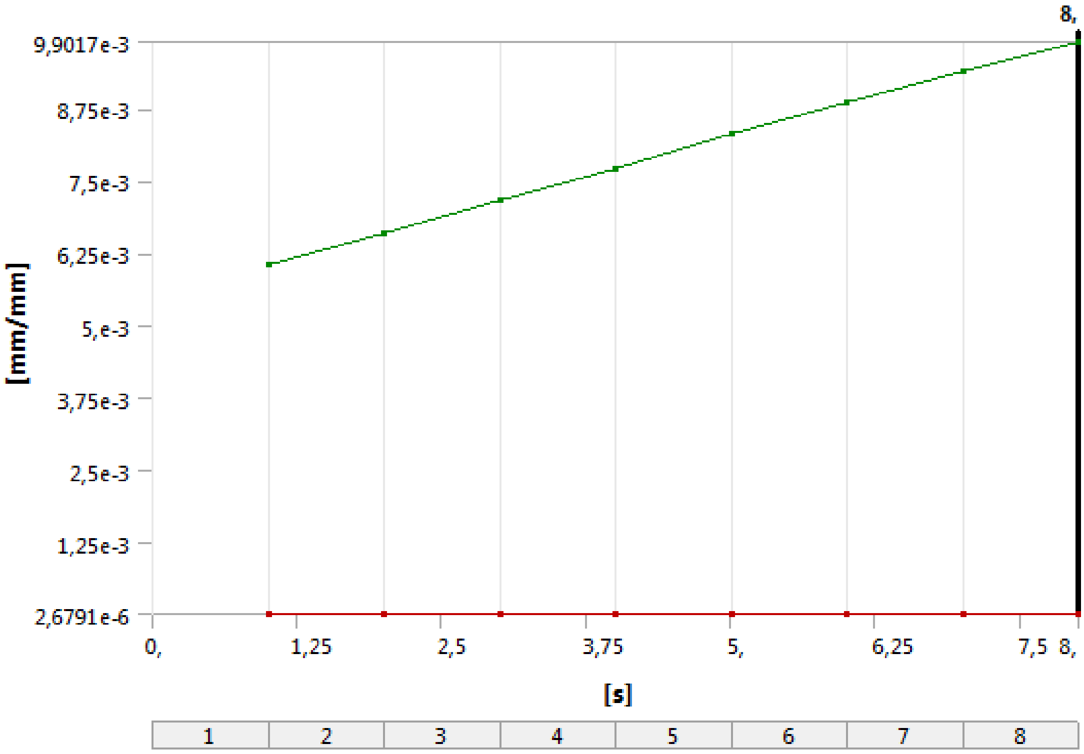


TABLE 21
Model (E4) > Static Structural (E5) > Solution (E6) > Equivalent Elastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
1,	2,6791e-006	6,0554e-003
2,	2,6875e-006	6,6136e-003
3,	2,9219e-006	7,1632e-003
4,	3,151e-006	7,7149e-003
5,	3,0285e-006	8,3063e-003
6,	3,2077e-006	8,8622e-003
7,	3,435e-006	9,4113e-003
8,	3,6716e-006	9,9017e-003

FIGURE 10
Model (E4) > Static Structural (E5) > Solution (E6) > Equivalent Elastic Strain > Image

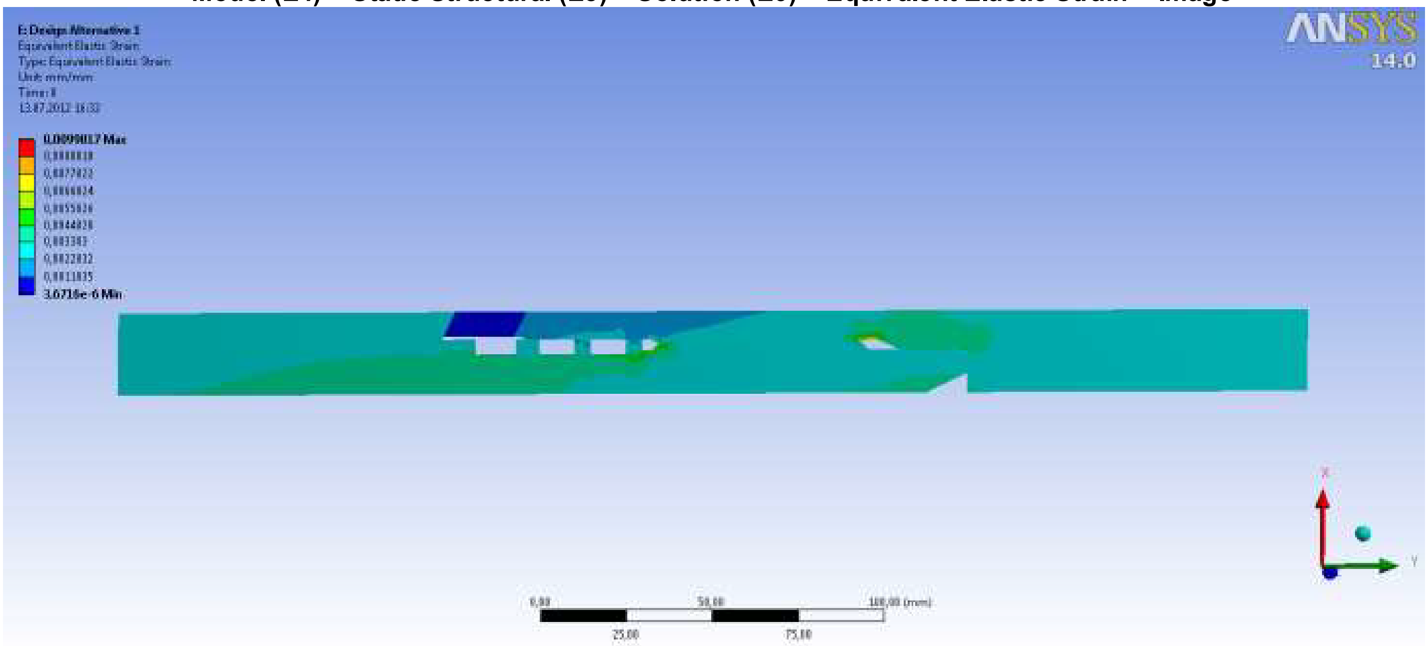


FIGURE 11
Model (E4) > Static Structural (E5) > Solution (E6) > Total Deformation

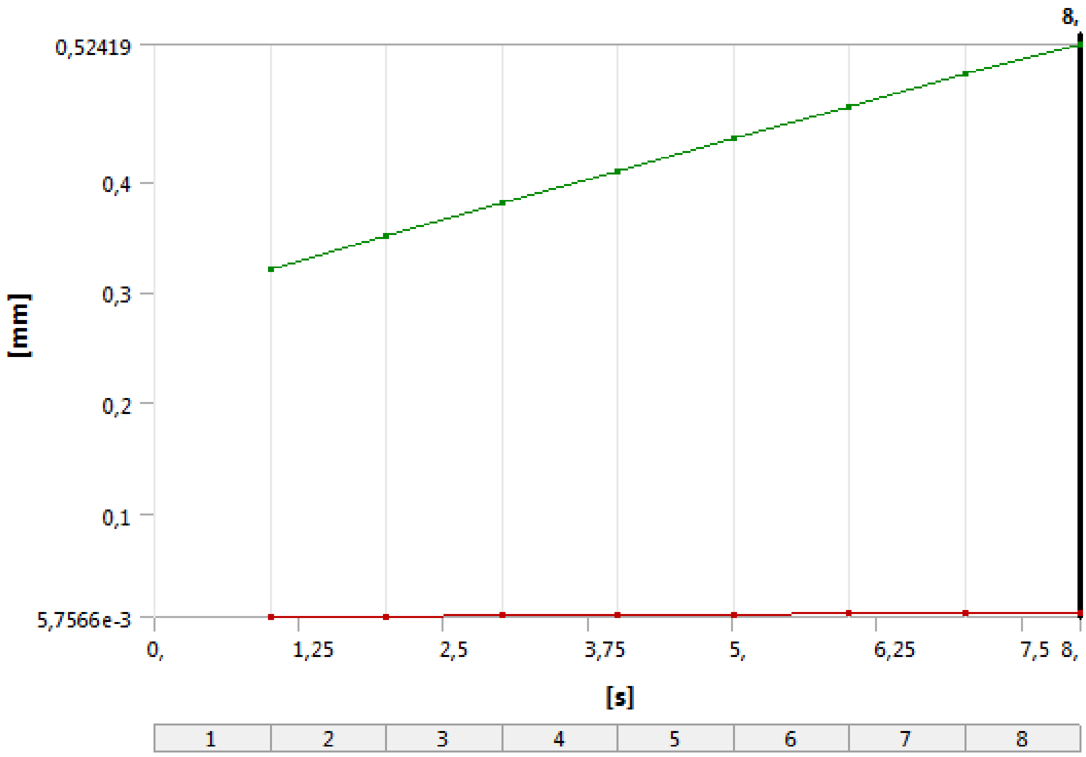


TABLE 22
Model (E4) > Static Structural (E5) > Solution (E6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,	5,7566e-003	0,32206
2,	6,3052e-003	0,3514
3,	6,8293e-003	0,38065
4,	7,3533e-003	0,40997
5,	7,9108e-003	0,43926
6,	8,4427e-003	0,4686
7,	8,9651e-003	0,49785
8,	9,4312e-003	0,52419

FIGURE 12
Model (E4) > Static Structural (E5) > Solution (E6) > Total Deformation > Image

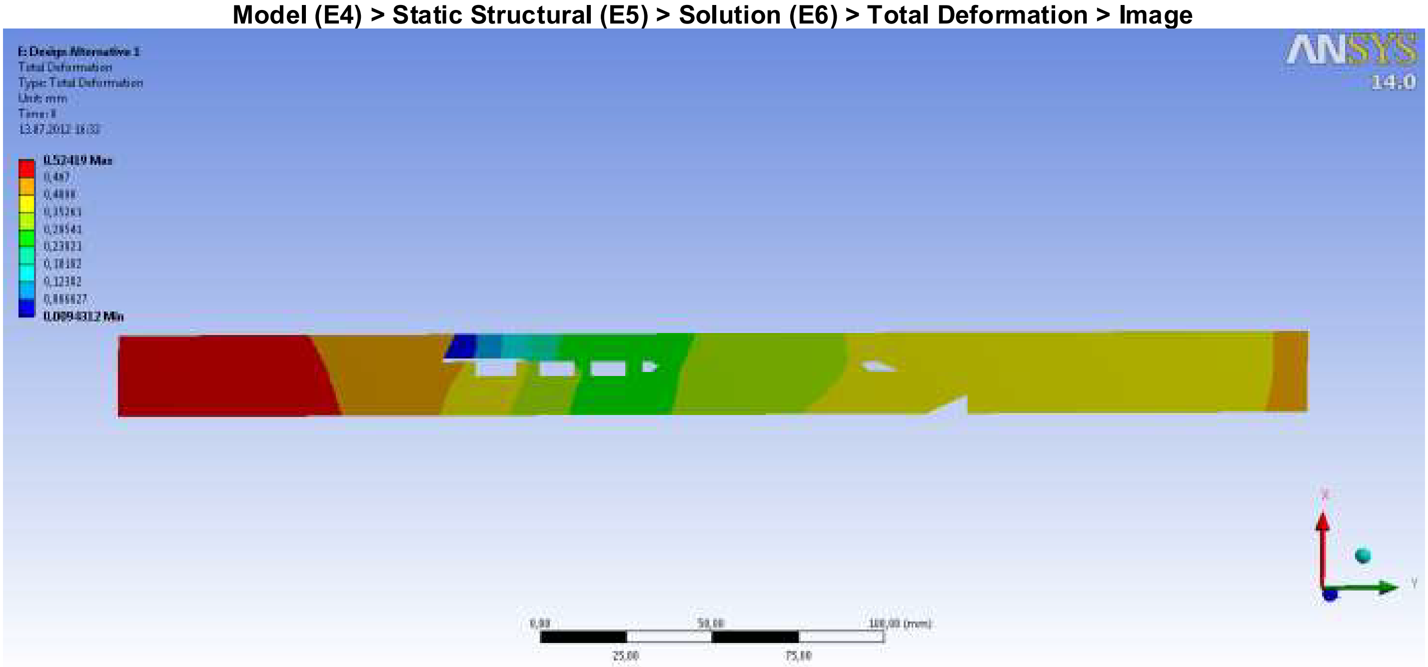


FIGURE 13
Model (E4) > Static Structural (E5) > Solution (E6) > Equivalent Stress

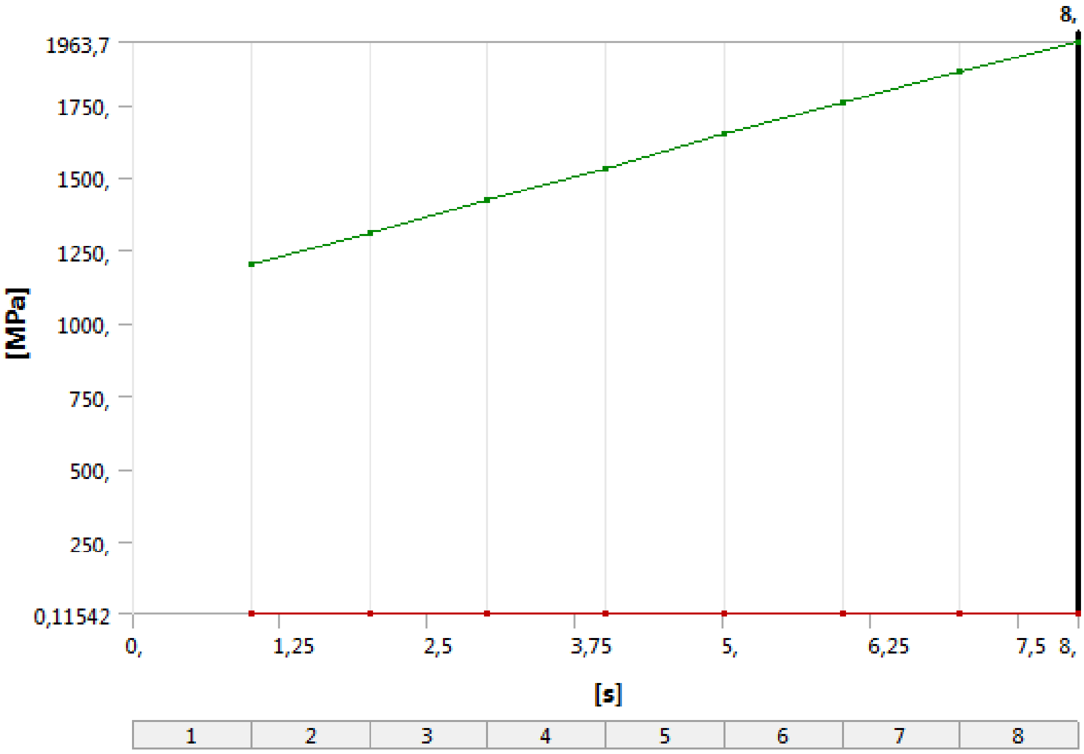


TABLE 23
Model (E4) > Static Structural (E5) > Solution (E6) > Equivalent Stress

Time [s]	Minimum [MPa]	Maximum [MPa]
1,	0,15754	1200,9
2,	0,11542	1311,6
3,	0,12709	1420,6
4,	0,13774	1530,
5,	0,15553	1647,3
6,	0,17621	1757,6
7,	0,17523	1866,5
8,	0,16654	1963,7

FIGURE 14
Model (E4) > Static Structural (E5) > Solution (E6) > Equivalent Stress > Image

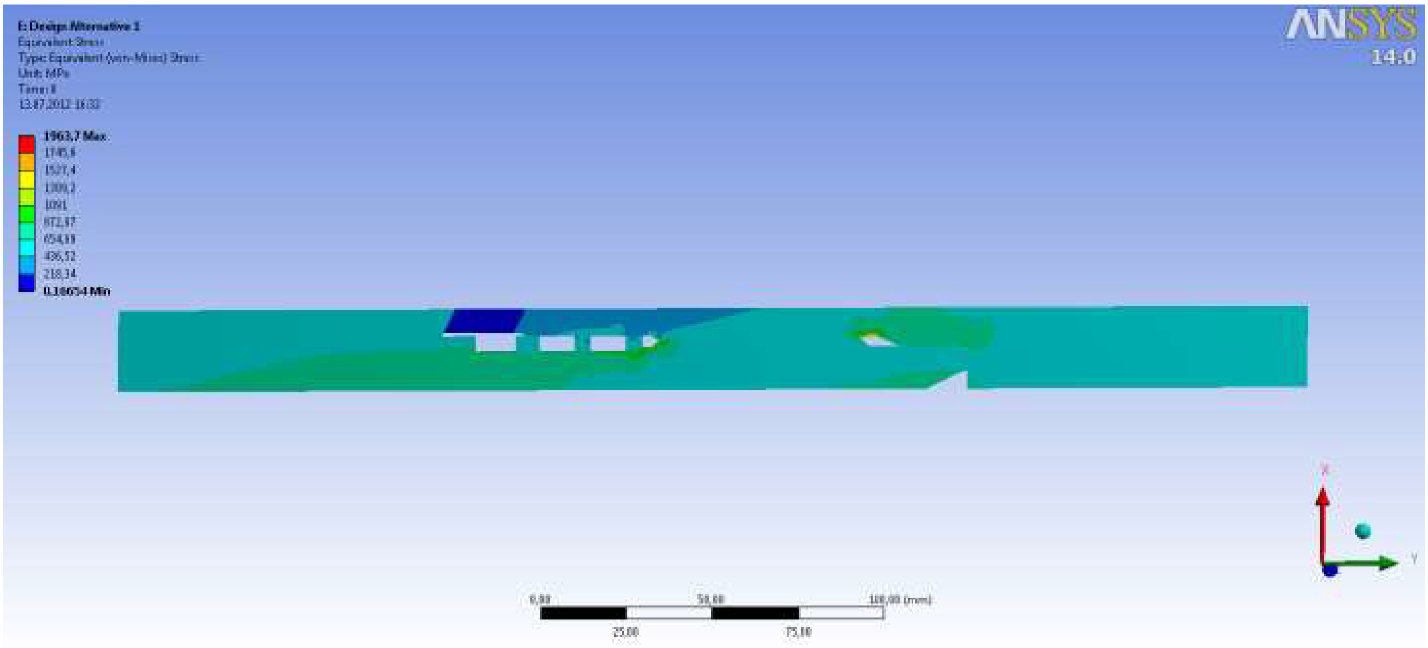


FIGURE 15
Model (E4) > Static Structural (E5) > Solution (E6) > Directional Deformation 2

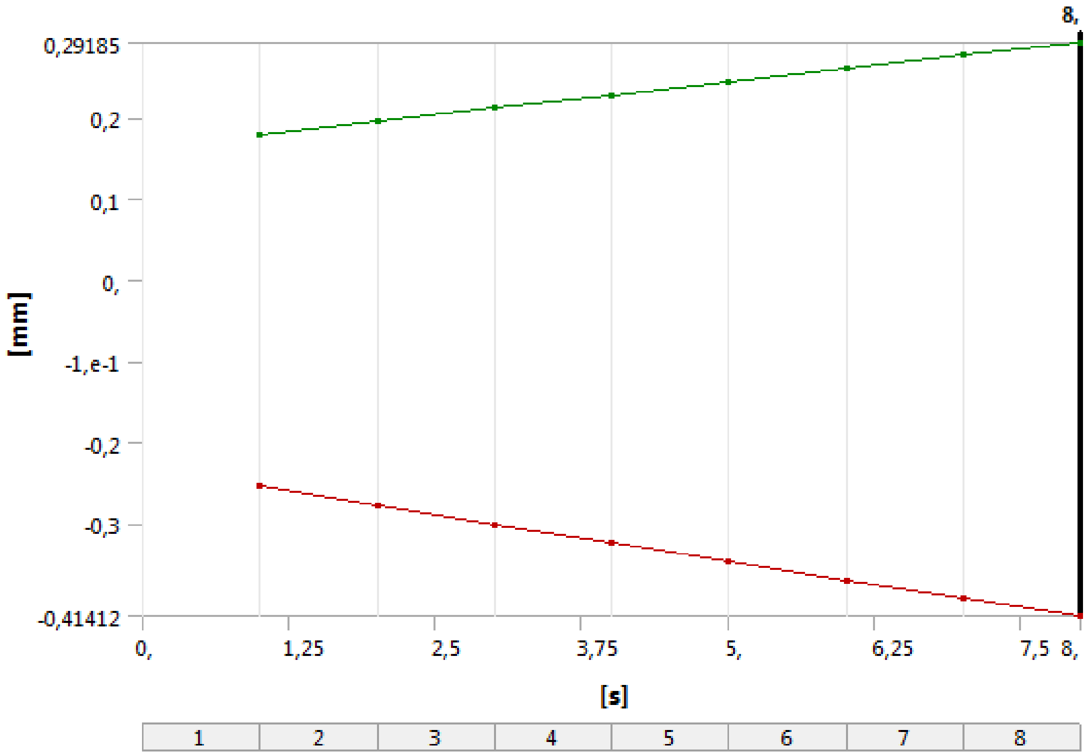


TABLE 24
Model (E4) > Static Structural (E5) > Solution (E6) > Directional Deformation 2

Time [s]	Minimum [mm]	Maximum [mm]
1,	-0,25438	0,17921
2,	-0,27759	0,19553
3,	-0,30068	0,2118
4,	-0,32385	0,22812
5,	-0,34704	0,24463
6,	-0,37023	0,26095
7,	-0,39333	0,27722
8,	-0,41412	0,29185

FIGURE 16
Model (E4) > Static Structural (E5) > Solution (E6) > Directional Deformation 2 > Image

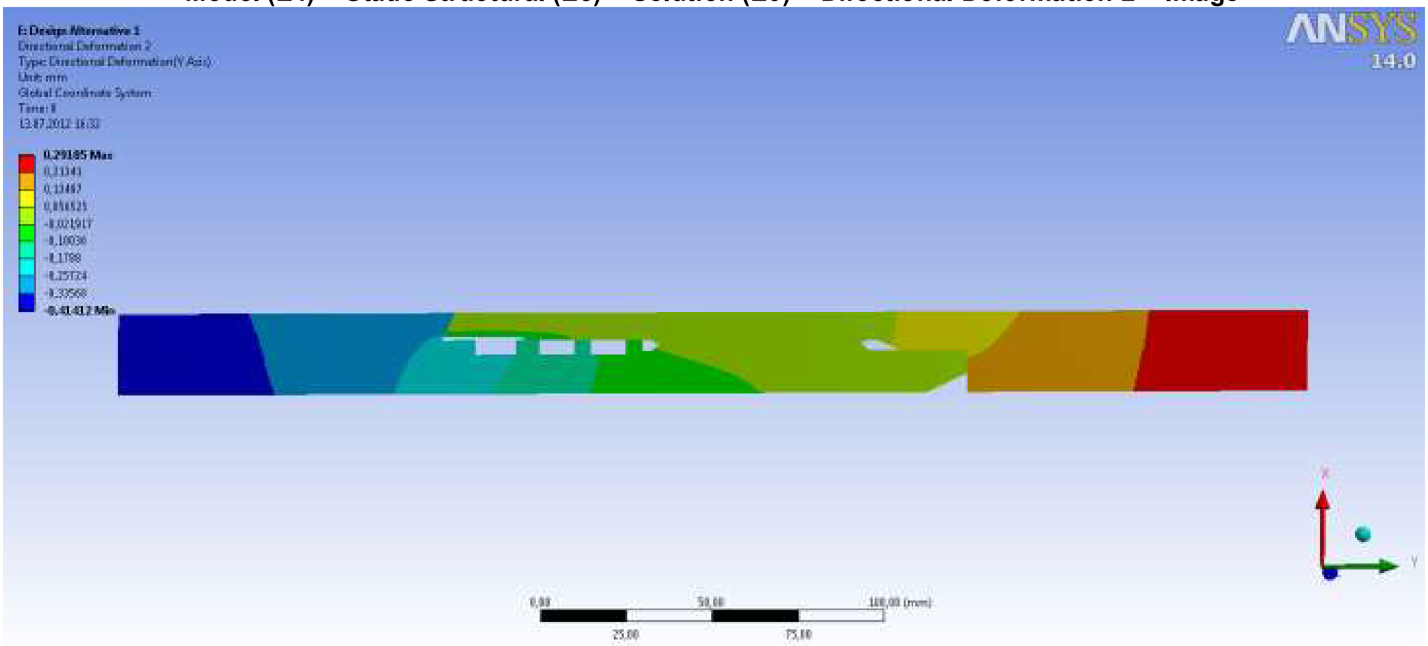


FIGURE 17
Model (E4) > Static Structural (E5) > Solution (E6) > Directional Deformation

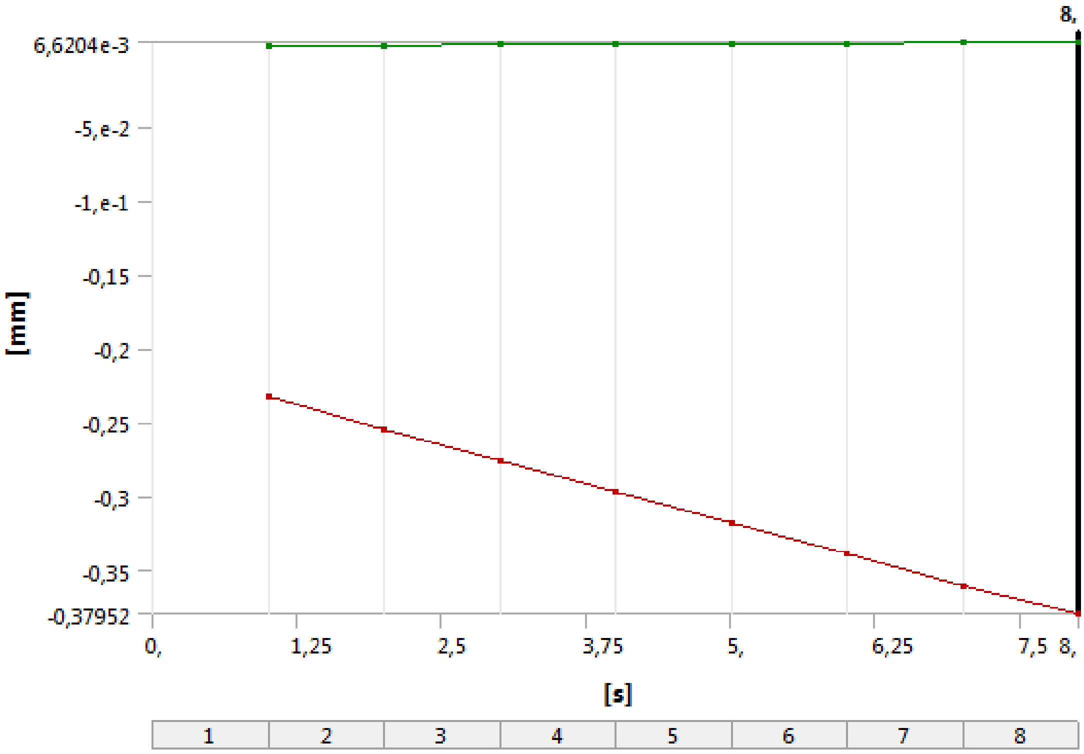
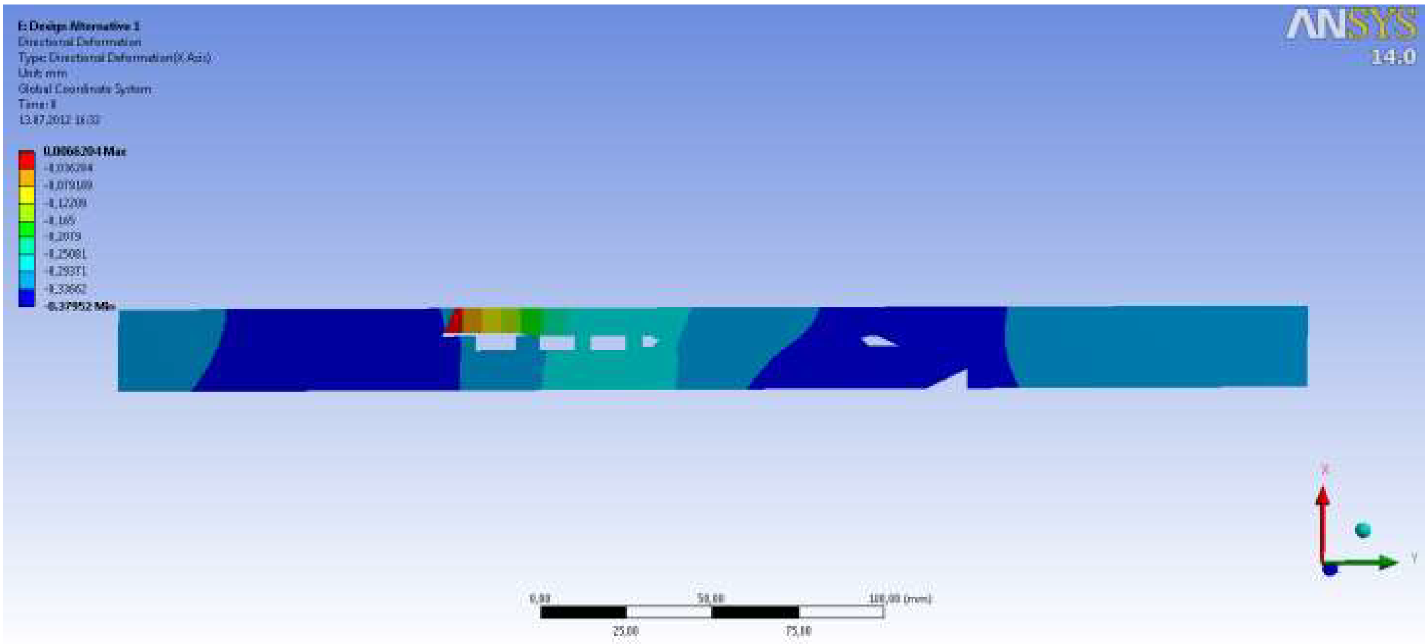


TABLE 25
Model (E4) > Static Structural (E5) > Solution (E6) > Directional Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,	-0,23301	4,1921e-003
2,	-0,25422	4,5139e-003
3,	-0,27538	4,8932e-003
4,	-0,29658	5,2702e-003
5,	-0,31814	5,5254e-003
6,	-0,33933	5,8823e-003
7,	-0,3605	6,2639e-003
8,	-0,37952	6,6204e-003

FIGURE 18
Model (E4) > Static Structural (E5) > Solution (E6) > Directional Deformation > Image



Material Data

4140 125ksi

TABLE 26
4140 125ksi > Constants

Density	7,85e-006 kg mm^-3
Coefficient of Thermal Expansion	1,2e-005 C^-1
Specific Heat	4,34e+005 mJ kg^-1 C^-1
Thermal Conductivity	6,05e-002 W mm^-1 C^-1
Resistivity	1,7e-004 ohm mm

TABLE 27
4140 125ksi > Compressive Ultimate Strength

Compressive Ultimate Strength MPa
965,

TABLE 28
4140 125ksi > Compressive Yield Strength

Compressive Yield Strength MPa

860,

TABLE 29
4140 125ksi > Tensile Yield Strength

Tensile Yield Strength MPa
860,

TABLE 30
4140 125ksi > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
965,

TABLE 31
4140 125ksi > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22,

TABLE 32
4140 125ksi > Alternating Stress Mean Stress

Alternating Stress MPa	Cycles	Mean Stress MPa
3999,	10,	0,
2827,	20,	0,
1896,	50,	0,
1413,	100,	0,
1069,	200,	0,
441,	2000,	0,
262,	10000	0,
214,	20000	0,
138,	1,e+005	0,
114,	2,e+005	0,
86,2	1,e+006	0,

TABLE 33
4140 125ksi > Strain-Life Parameters

Strength Coefficient MPa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient MPa	Cyclic Strain Hardening Exponent
920,	-0,106	0,213	-0,47	1000,	0,2

TABLE 34
4140 125ksi > Isotropic Elasticity

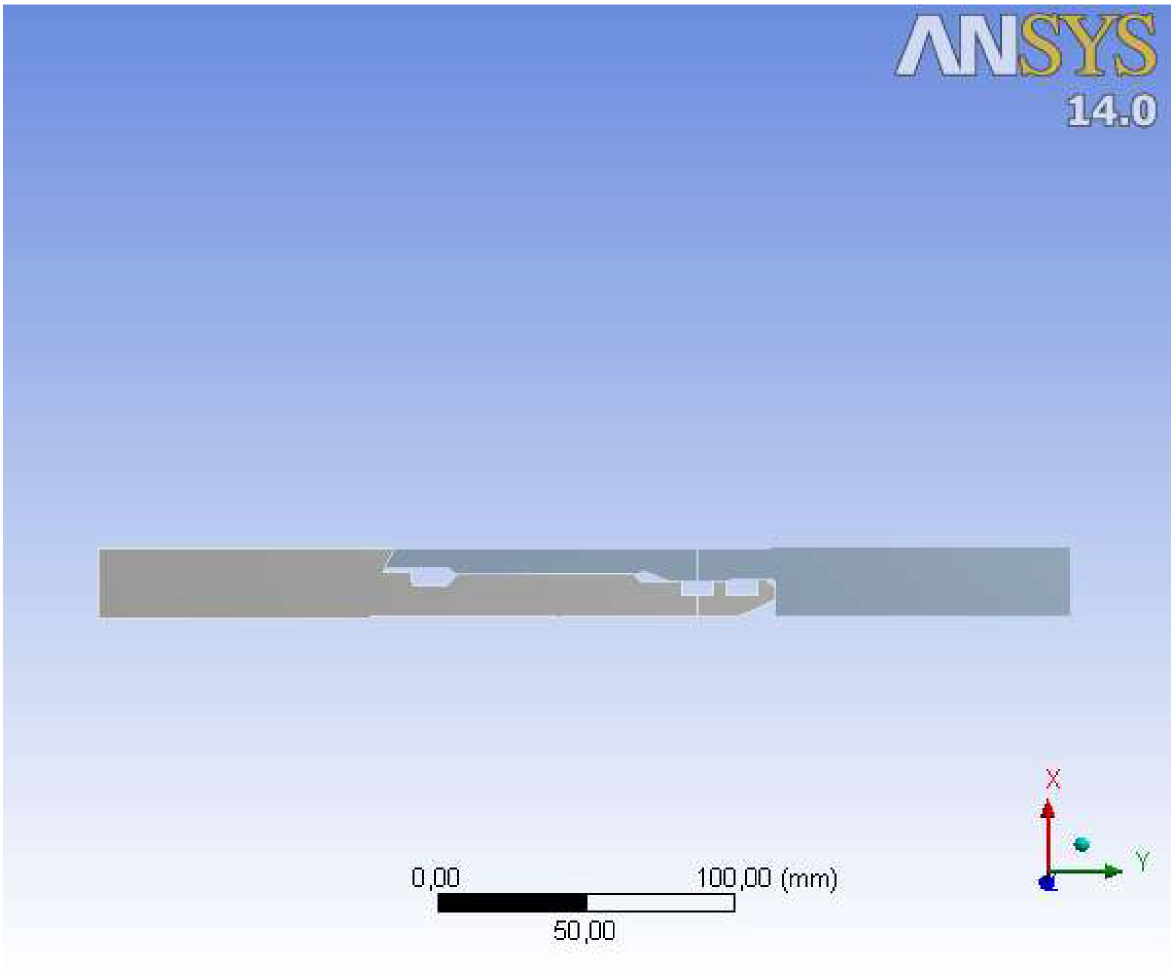
Temperature C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	2,e+005	0,3	1,6667e+005	76923

TABLE 35
4140 125ksi > Isotropic Relative Permeability

Relative Permeability
10000

Project

First Saved	Friday, July 06, 2012
Last Saved	Friday, July 13, 2012
Product Version	14.0 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

Units

TABLE 1

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (F4)

Geometry

TABLE 2
Model (F4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Vault\Peak\R&D\R&D C-flex\Collapse analysis\New Seal nr. 1\Collapse

	Analysis of New Seal Design nr. 1_files\dp0\SYS-5\DM\SYS-5.agdb
Type	DesignModeler
Length Unit	Millimeters
Element Control	Program Controlled
2D Behavior	Axisymmetric
Display Style	Body Color
Bounding Box	
Length X	23,75 mm
Length Y	328,35 mm
Properties	
Volume	0, mm³
Mass	
Surface Area(approx.)	7552,7 mm²
Scale Factor Value	1,
Statistics	
Bodies	2
Active Bodies	2
Nodes	20715
Elements	6587
Mesh Metric	None
Basic Geometry Options	
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No

Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\62844\AppData\Local\Temp
Analysis Type	2-D
Decompose Disjoint Faces	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (F4) > Geometry > Parts

Object Name	*RD-03362*	*RD-03361*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	

Material		
Assignment	4140 125ksi	
Nonlinear Effects	Yes	
Thermal Strain Effects	Yes	
Bounding Box		
Length X	23,75 mm	
Length Y	228,35 mm	231,61 mm
Properties		
Volume	N/A	
Mass	N/A	
Centroid X	N/A	
Centroid Y	N/A	
Centroid Z	N/A	
Moment of Inertia Ip1	N/A	
Moment of Inertia Ip2	N/A	
Moment of Inertia Ip3	N/A	
Surface Area(approx.)	3960,8 mm²	3591,9 mm²
Statistics		
Nodes	10944	9771
Elements	3485	3102
Mesh Metric	None	

Coordinate Systems

TABLE 4
Model (F4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined

Definition	
Type	Cartesian
Coordinate System ID	0,
Origin	
Origin X	0, mm
Origin Y	0, mm
Directional Vectors	
X Axis Data	[1, 0,]
Y Axis Data	[0, 1,]

Connections

TABLE 5
Model (F4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (F4) > Connections > Contacts

Object Name	*Contacts*
State	Fully Defined
Definition	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection

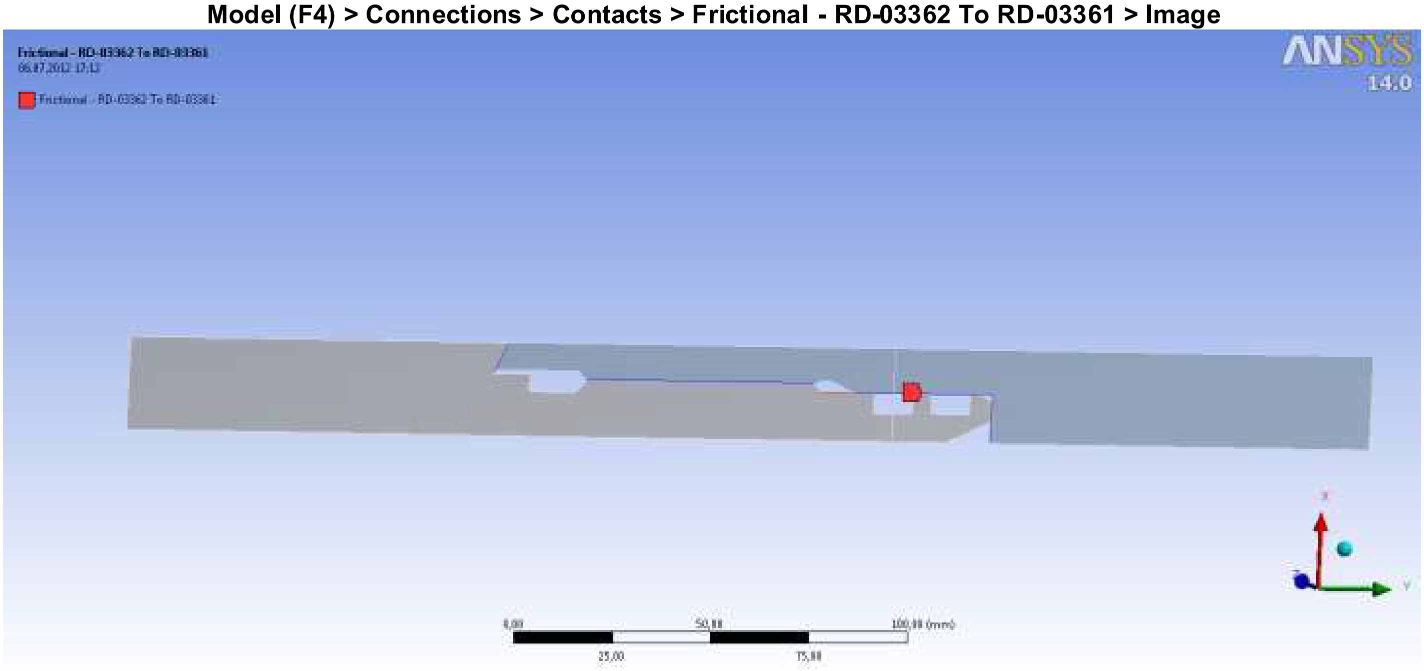
Geometry	All Bodies
Auto Detection	
Tolerance Type	Slider
Tolerance Slider	0,
Tolerance Value	0,82302 mm
Use Range	No
Face/Edge	No
Edge/Edge	Yes
Priority	Include All
Group By	Bodies
Search Across	Bodies

TABLE 7
Model (F4) > Connections > Contacts > Contact Regions

Object Name	*Frictional - RD-03362 To RD-03361*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Contact	6 Edges
Target	5 Edges
Contact Bodies	RD-03362
Target Bodies	RD-03361
Definition	
Type	Frictional
Friction Coefficient	0,15
Scope Mode	Manual
Behavior	Program Controlled

Suppressed	No
Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Interface Treatment	Add Offset, No Ramping
Offset	0, mm
Normal Stiffness	Program Controlled
Update Stiffness	Program Controlled
Stabilization Damping Factor	0,
Pinball Region	Program Controlled
Time Step Controls	None

FIGURE 1
Model (F4) > Connections > Contacts > Frictional - RD-03362 To RD-03361 > Image



Mesh

TABLE 8
Model (F4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Coarse
Initial Size Seed	Active Assembly
Smoothing	Medium
Span Angle Center	Coarse
Curvature Normal Angle	Default (30,0 °)
Min Size	Default (1,08630 mm)
Max Face Size	Default (5,43160 mm)
Growth Rate	Default
Minimum Edge Length	2,82840 mm
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0,272
Maximum Layers	2
Growth Rate	1,2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	

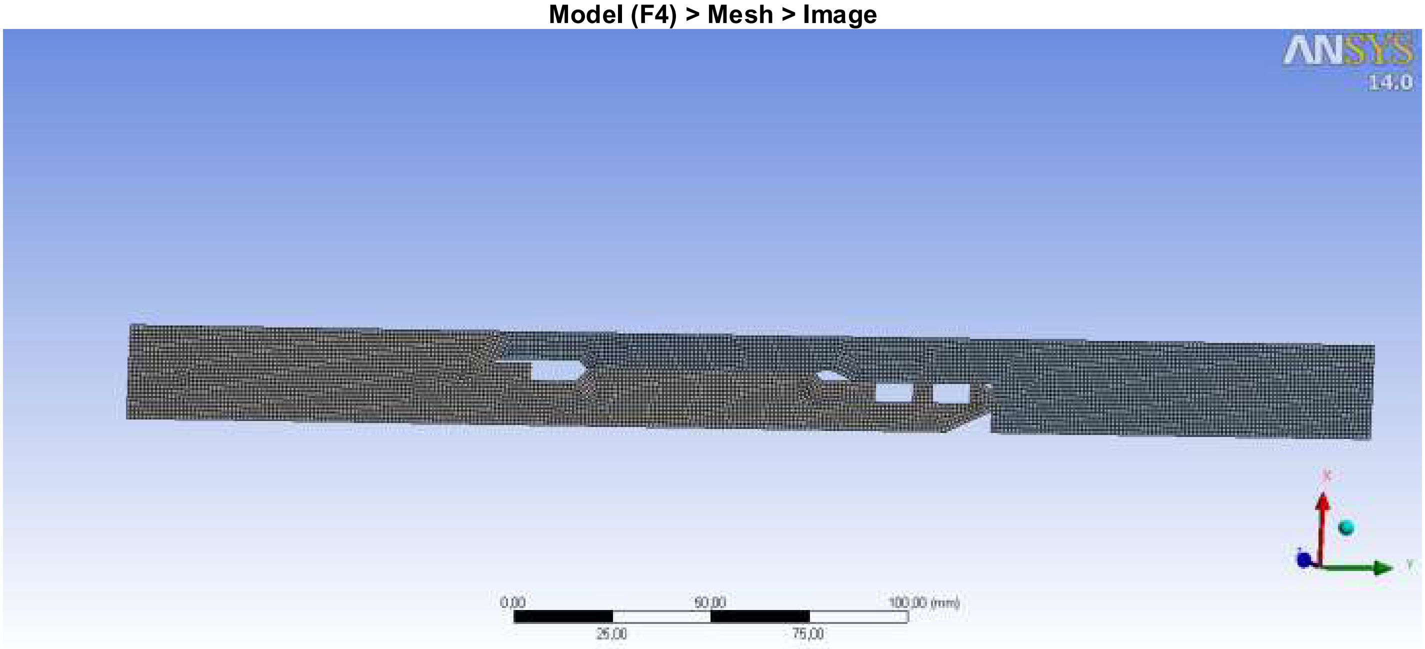
Triangle Surface Mesher	Program Controlled
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Use Sheet Thickness for Pinch	No
Pinch Tolerance	Default (0,97770 mm)
Generate Pinch on Refresh	No
Sheet Loop Removal	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default (0,814750 mm)
Statistics	
Nodes	20715
Elements	6587
Mesh Metric	None

TABLE 9
Model (F4) > Mesh > Mesh Controls

Object Name	*Body Sizing*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies

Definition	
Suppressed	No
Type	Element Size
Element Size	0,2 mm
Behavior	Soft
Curvature Normal Angle	Default
Growth Rate	Default

FIGURE 2
Model (F4) > Mesh > Image



Static Structural (F5)

TABLE 10
Model (F4) > Analysis

Object Name	*Static Structural (F5)*
State	Solved
Definition	
Physics Type	Structural

Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	22, °C
Generate Input Only	No

TABLE 11
Model (F4) > Static Structural (F5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	8,
Current Step Number	8,
Step End Time	8, s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled

Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Off
Output Controls	
Stress	Yes
Strain	Yes
Nodal Forces	No
Contact Miscellaneous	No
General Miscellaneous	No
Calculate Results At	All Time Points
Max Number of Result Sets	1000,
Analysis Data Management	
Solver Files Directory	C:\Vault\Peak\R&D\R&D C-flex\Collapse analysis\New Seal nr. 1\Collapse Analysis of New Seal Design nr. 1_files\dp0\SYS-5\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Delete Unneeded Files	Yes
Nonlinear Solution	Yes
Solver Units	Active System
Solver Unit System	nmm

TABLE 12
Model (F4) > Static Structural (F5) > Analysis Settings
Step-Specific "Step Controls"

Step	Step End Time
1	1, s
2	2, s
3	3, s
4	4, s
5	5, s
6	6, s
7	7, s
8	8, s

TABLE 13
Model (F4) > Static Structural (F5) > Analysis Settings
Step-Specific "Output Controls"

Step	Max Number of Result Sets
1	Program Controlled
2	1000,
3	
4	
5	
6	
7	
8	

TABLE 14
Model (F4) > Static Structural (F5) > Loads

Object Name	*Pressure*	*Displacement*	*Force*	*Force 2*
State	Fully Defined			
Scope				

Scoping Method	Geometry Selection		
Geometry	20 Edges	2 Edges	1 Edge
Definition			
Type	Pressure	Displacement	Force
Define By	Normal To	Components	Vector
Magnitude	Tabular Data		Tabular Data
Suppressed	No		
Coordinate System		Global Coordinate System	
X Component		Free	
Y Component		0, mm (ramped)	
Direction			Defined
Tabular Data			
Independent Variable	Time		

FIGURE 3
Model (F4) > Static Structural (F5) > Pressure

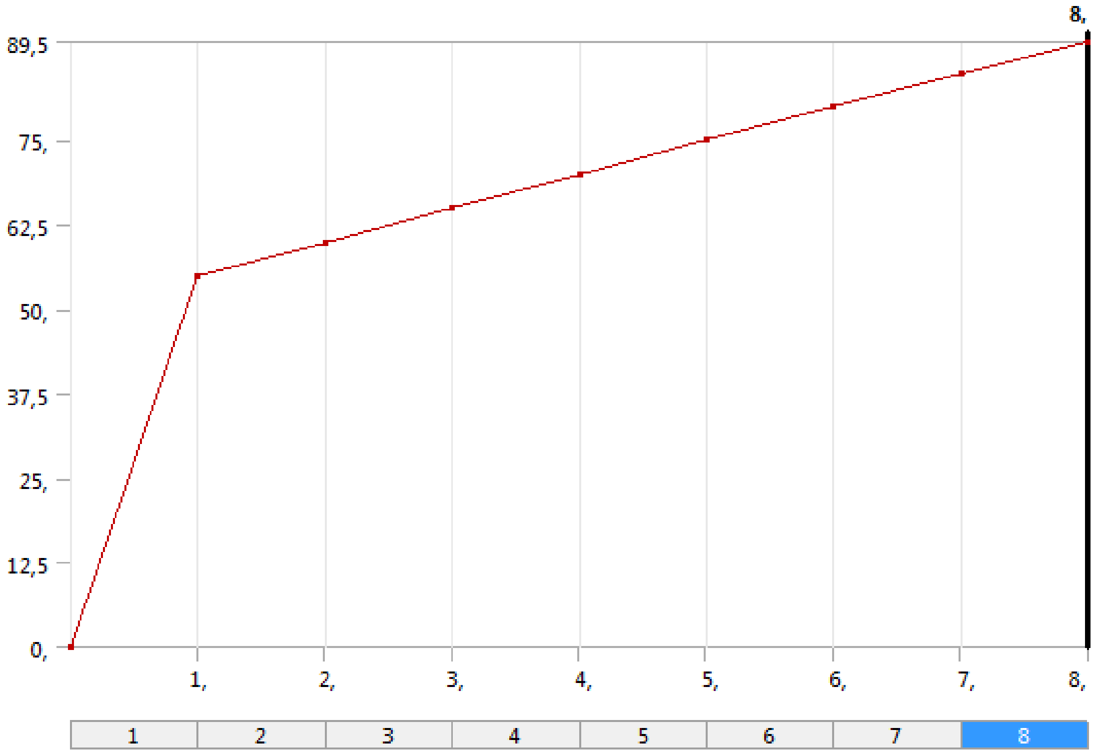


TABLE 15
Model (F4) > Static Structural (F5) > Pressure

Steps	Time [s]	Pressure [MPa]
1	0,	0,
	1,	55,
2	2,	60,
3	3,	65,
4	4,	70,
5	5,	75,
6	6,	80,
7	7,	85,
8	8,	89,5

FIGURE 4
Model (F4) > Static Structural (F5) > Pressure > Image

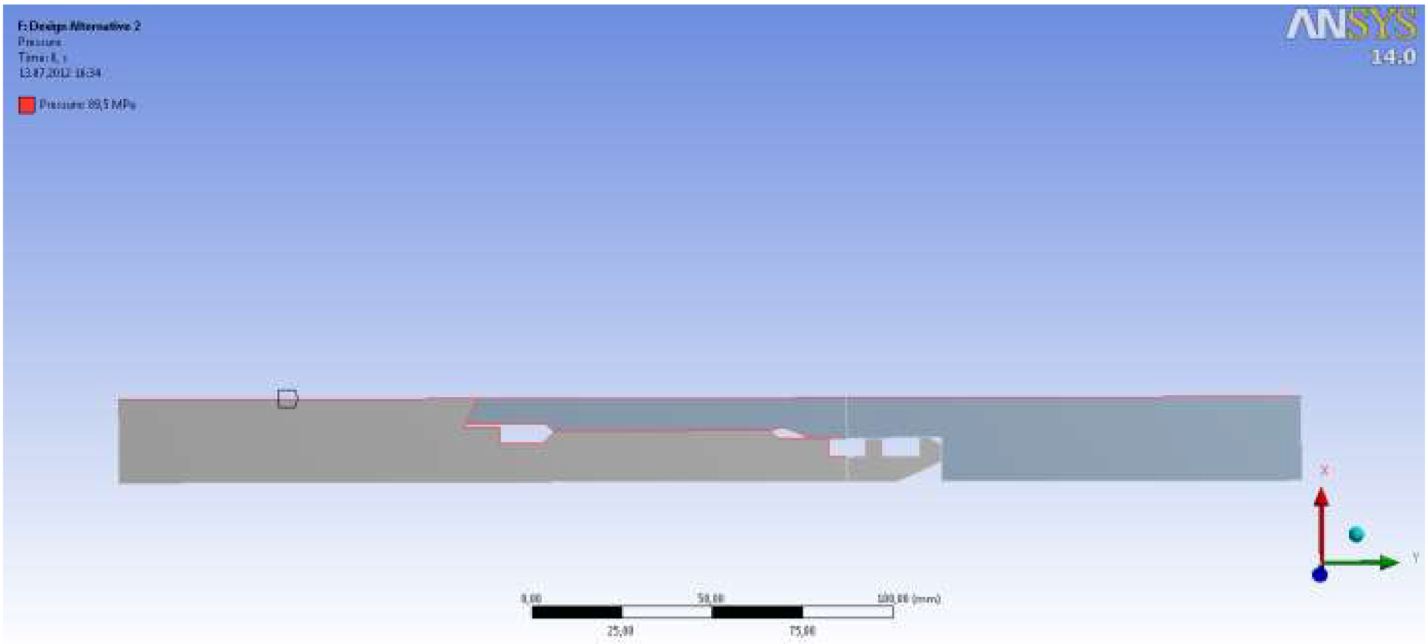


FIGURE 5
Model (F4) > Static Structural (F5) > Displacement

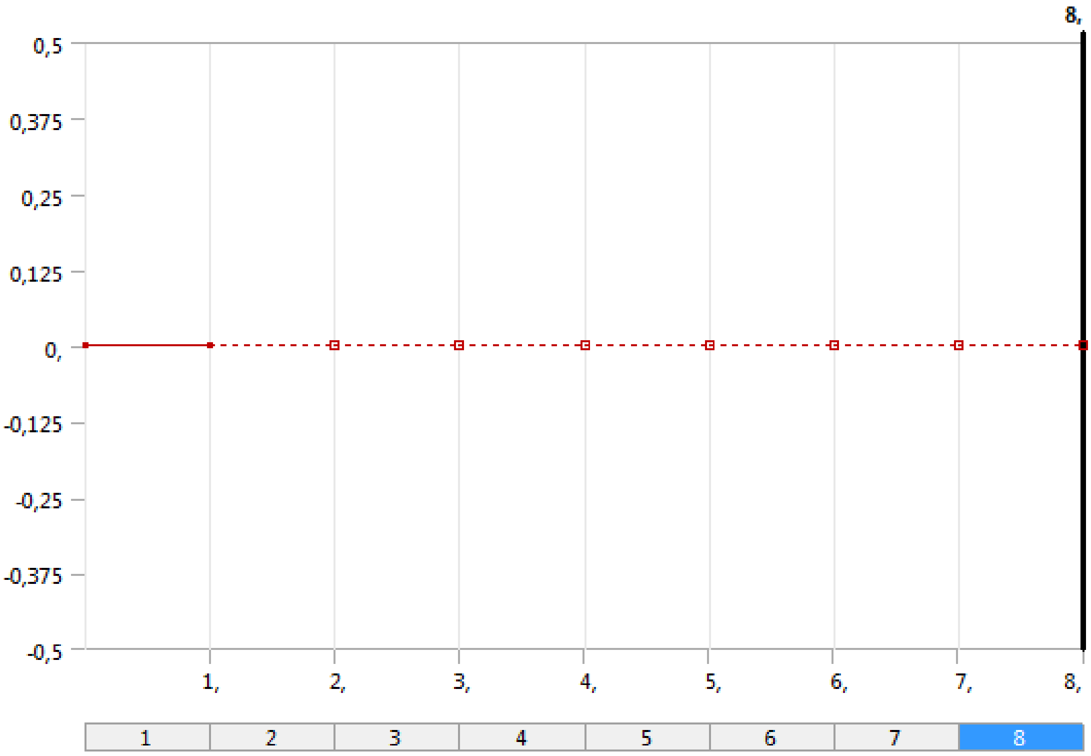


FIGURE 6
Model (F4) > Static Structural (F5) > Force

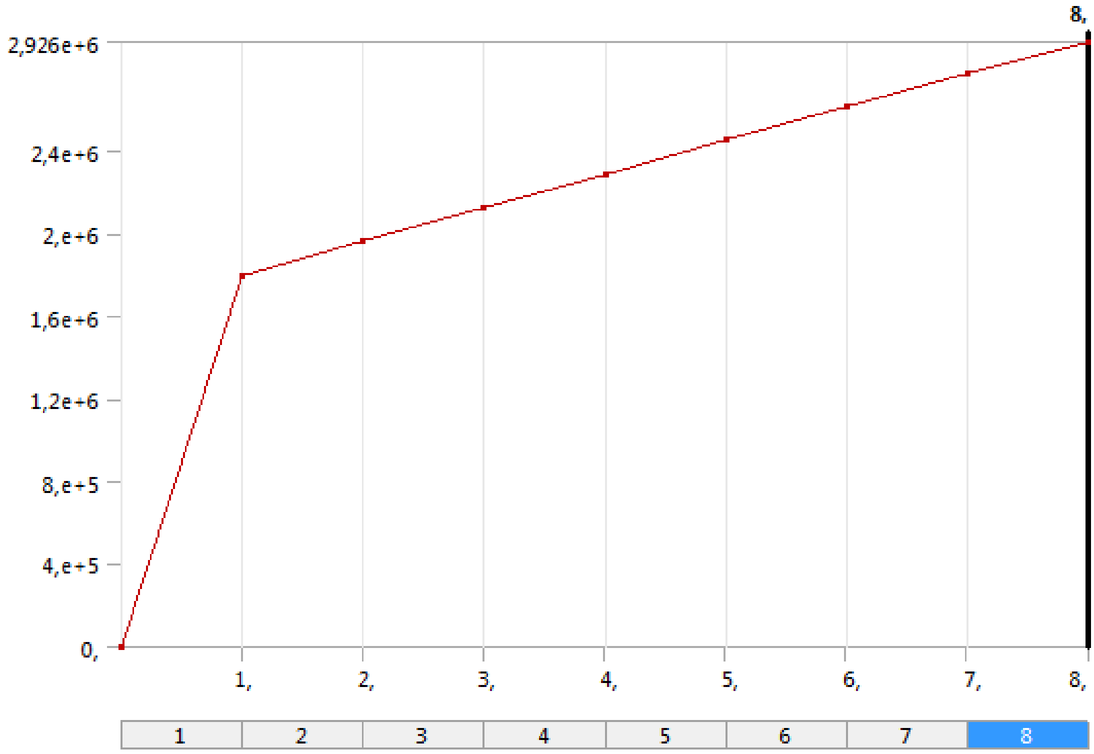


TABLE 16
Model (F4) > Static Structural (F5) > Force

Steps	Time [s]	Force [N]
1	0,	0,
	1,	1,798e+006
2	2,	1,962e+006
3	3,	2,125e+006
4	4,	2,289e+006
5	5,	2,452e+006
6	6,	2,616e+006
7	7,	2,779e+006
8	8,	2,926e+006

FIGURE 7
Model (F4) > Static Structural (F5) > Force 2

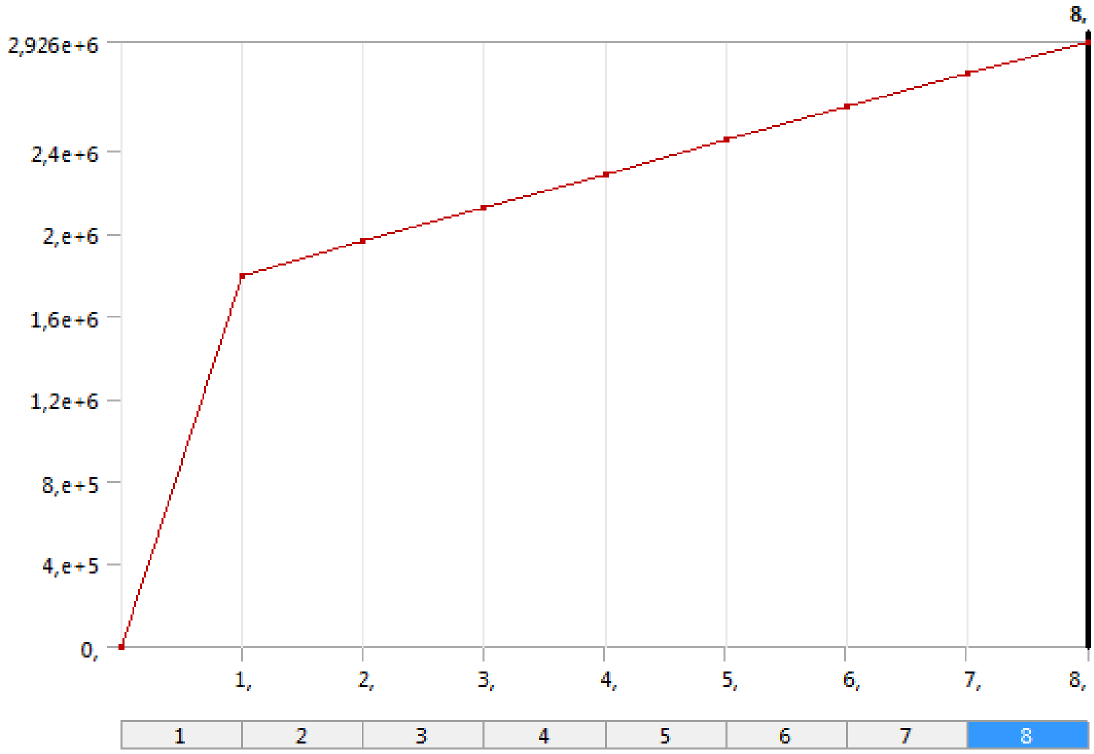
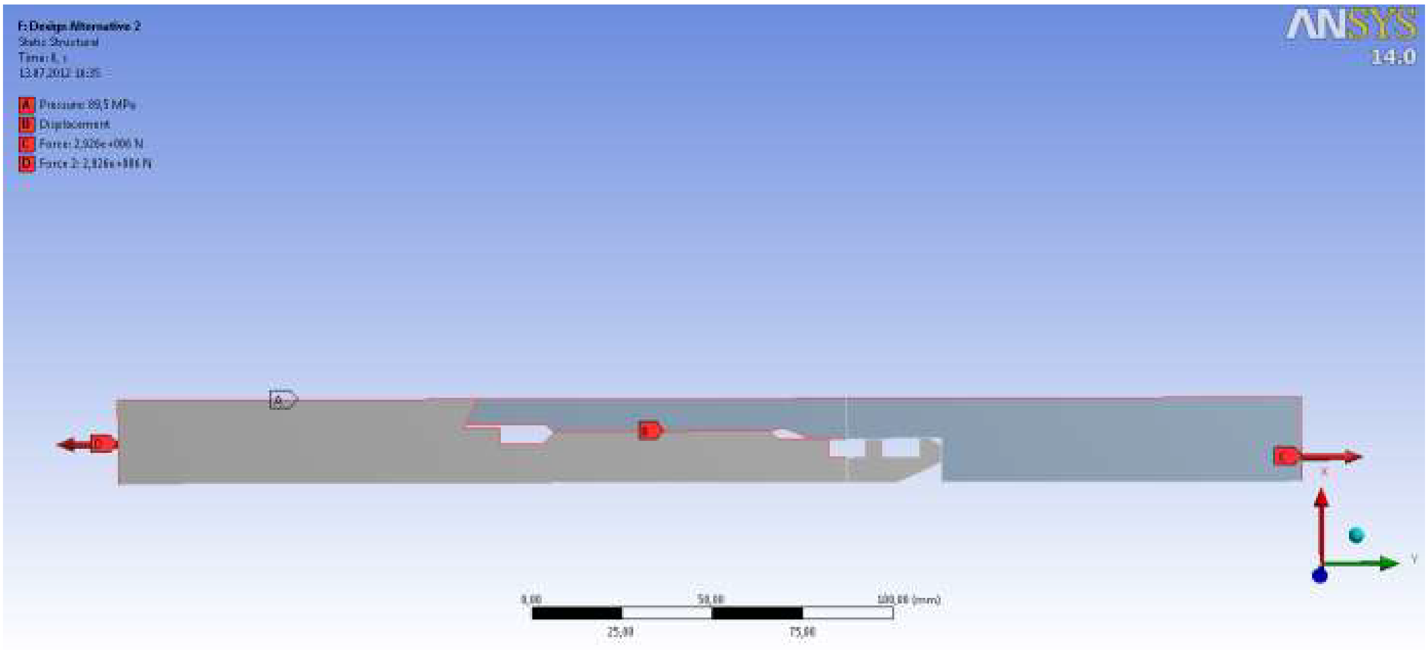


TABLE 17
Model (F4) > Static Structural (F5) > Force 2

Steps	Time [s]	Force [N]
1	0,	0,
	1,	1,798e+006
2	2,	1,962e+006
3	3,	2,125e+006
4	4,	2,289e+006
5	5,	2,452e+006
6	6,	2,616e+006
7	7,	2,779e+006
8	8,	2,926e+006

FIGURE 8
Model (F4) > Static Structural (F5) > Image



Solution (F6)

TABLE 18
Model (F4) > Static Structural (F5) > Solution

Object Name	*Solution (F6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1,
Refinement Depth	2,
Information	
Status	Done

TABLE 19
Model (F4) > Static Structural (F5) > Solution (F6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output

Newton-Raphson Residuals	0
Update Interval	2,5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 20
Model (F4) > Static Structural (F5) > Solution (F6) > Results

Object Name	*Total Deformation*	*Directional Deformation*	*Directional Deformation 2*	*Equivalent Stress*	*Equivalent Elastic Strain*
State	Solved				
Scope					
Scoping Method	Geometry Selection				
Geometry	All Bodies				
Definition					
Type	Total Deformation	Directional Deformation		Equivalent (von-Mises) Stress	Equivalent Elastic Strain
By	Time				
Display Time	8, s	Last			
Calculate Time History	Yes				
Identifier					

Suppressed	No				
Orientation		X Axis	Y Axis		
Coordinate System		Global Coordinate System			
Results					
Minimum	3,6223e-005 mm	-0,51006 mm	-0,33963 mm	75,859 MPa	3,796e-004 mm/mm
Maximum	0,51008 mm	0,14514 mm	0,34837 mm	2336,7 MPa	1,1716e-002 mm/mm
Minimum Occurs On	RD-03361	RD-03362		RD-03361	
Maximum Occurs On	RD-03362	RD-03361		RD-03362	
Minimum Value Over Time					
Minimum	3,6223e-005 mm	-0,51006 mm	-0,33963 mm	46,527 MPa	2,328e-004 mm/mm
Maximum	1,3887e-004 mm	-0,3135 mm	-0,20873 mm	75,859 MPa	3,796e-004 mm/mm
Maximum Value Over Time					
Minimum	0,31351 mm	8,9967e-002 mm	0,21382 mm	1435,6 MPa	7,1982e-003 mm/mm
Maximum	0,51008 mm	0,14514 mm	0,34837 mm	2336,7 MPa	1,1716e-002 mm/mm
Information					
Time	8, s				
Load Step	8				
Substep	1				
Iteration Number	24				
Integration Point Results					

Display Option		Averaged

FIGURE 9
Model (F4) > Static Structural (F5) > Solution (F6) > Total Deformation

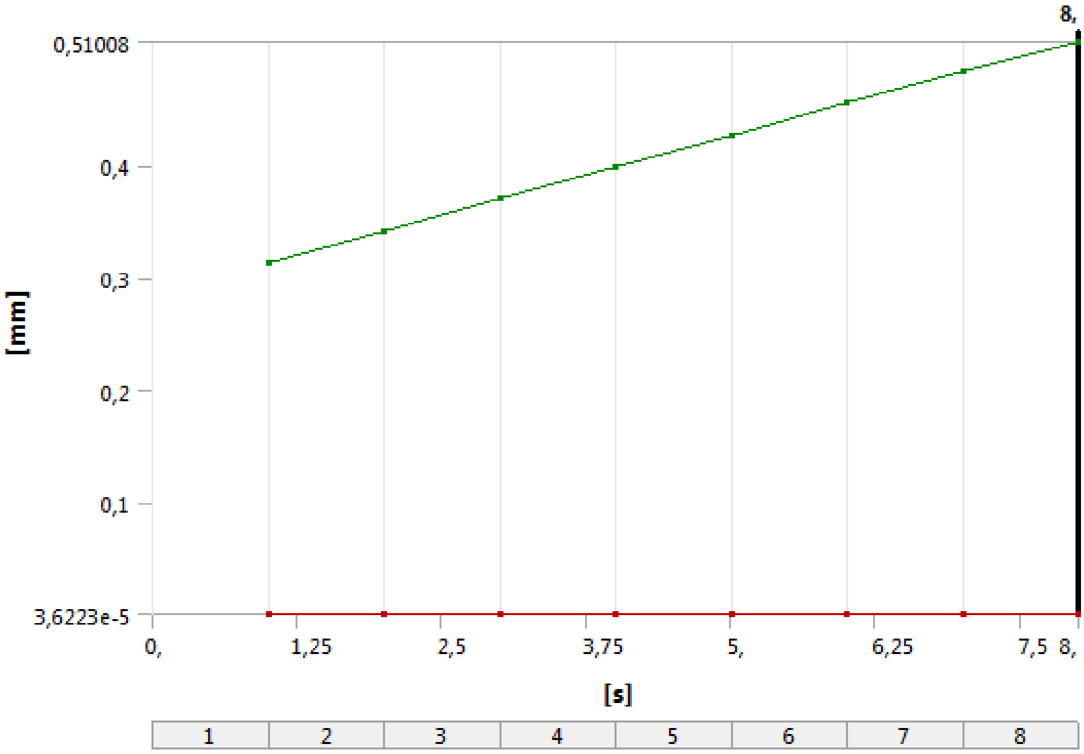


TABLE 21
Model (F4) > Static Structural (F5) > Solution (F6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,	1,0929e-004	0,31351
2,	1,3887e-004	0,34196
3,	1,3235e-004	0,37045
4,	1,1273e-004	0,39895
5,	9,5196e-005	0,42744
6,	6,2308e-005	0,45595
7,	5,5584e-005	0,48441
8,	3,6223e-005	0,51008

FIGURE 10

Model (F4) > Static Structural (F5) > Solution (F6) > Total Deformation > Image

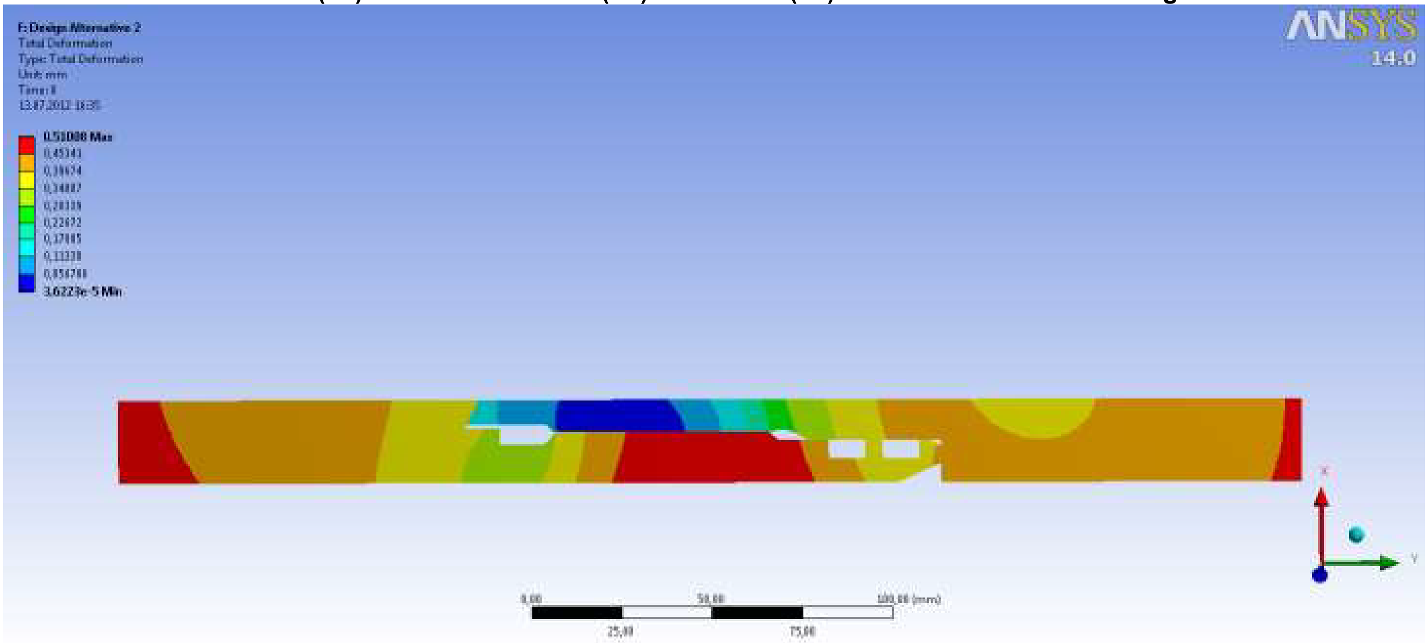


FIGURE 11

Model (F4) > Static Structural (F5) > Solution (F6) > Directional Deformation

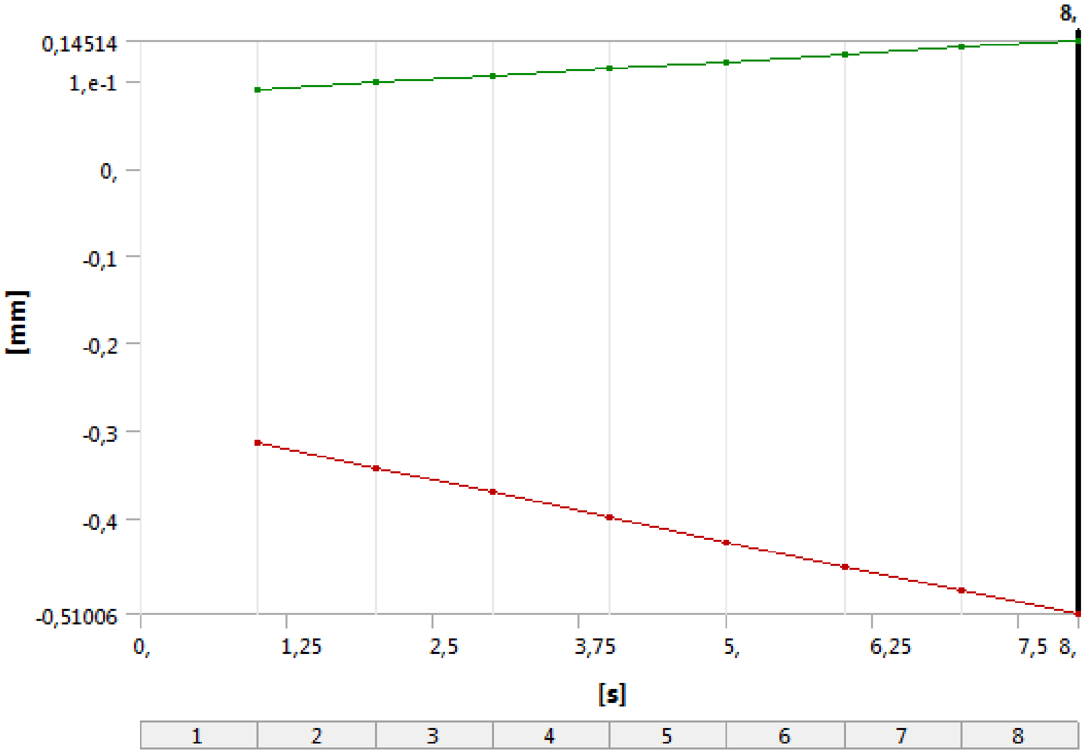


TABLE 22
Model (F4) > Static Structural (F5) > Solution (F6) > Directional Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,	-0,3135	8,9967e-002
2,	-0,34194	9,7725e-002
3,	-0,37043	0,1056
4,	-0,39894	0,11351
5,	-0,42743	0,12134
6,	-0,45593	0,12922
7,	-0,48439	0,13814
8,	-0,51006	0,14514

FIGURE 12
Model (F4) > Static Structural (F5) > Solution (F6) > Directional Deformation > Image

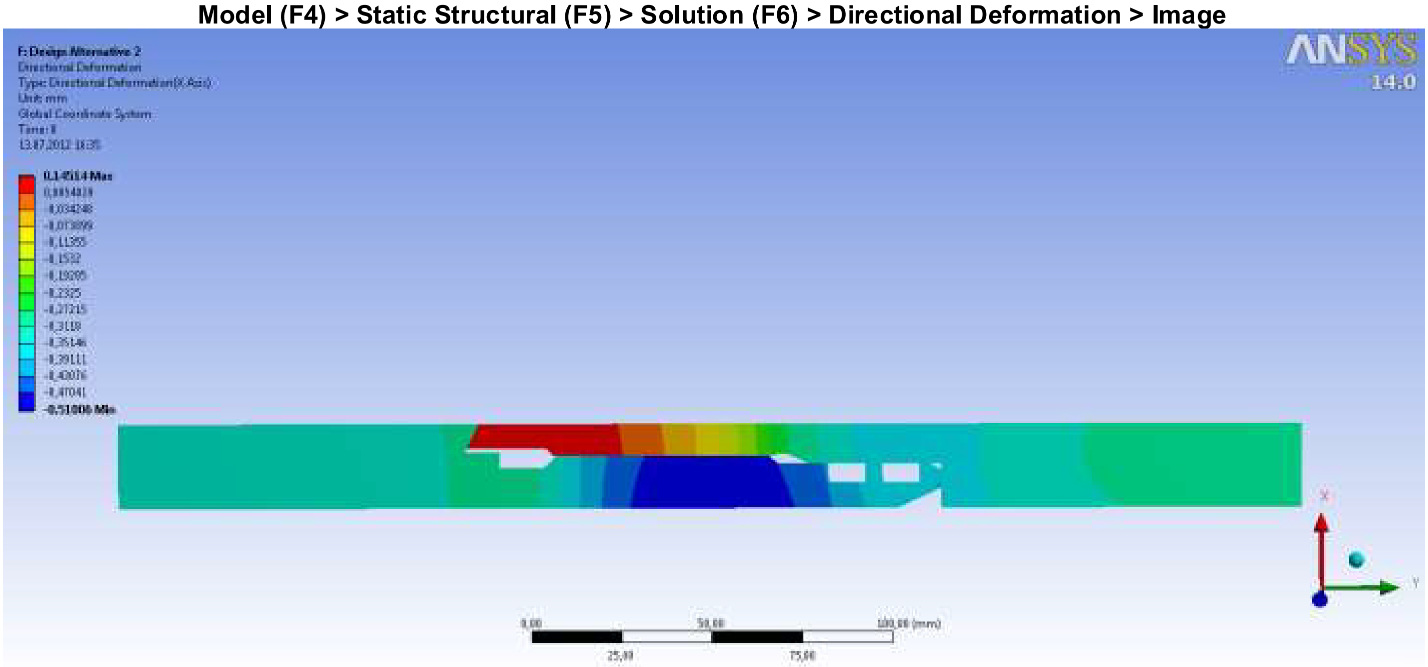


FIGURE 13
Model (F4) > Static Structural (F5) > Solution (F6) > Directional Deformation 2

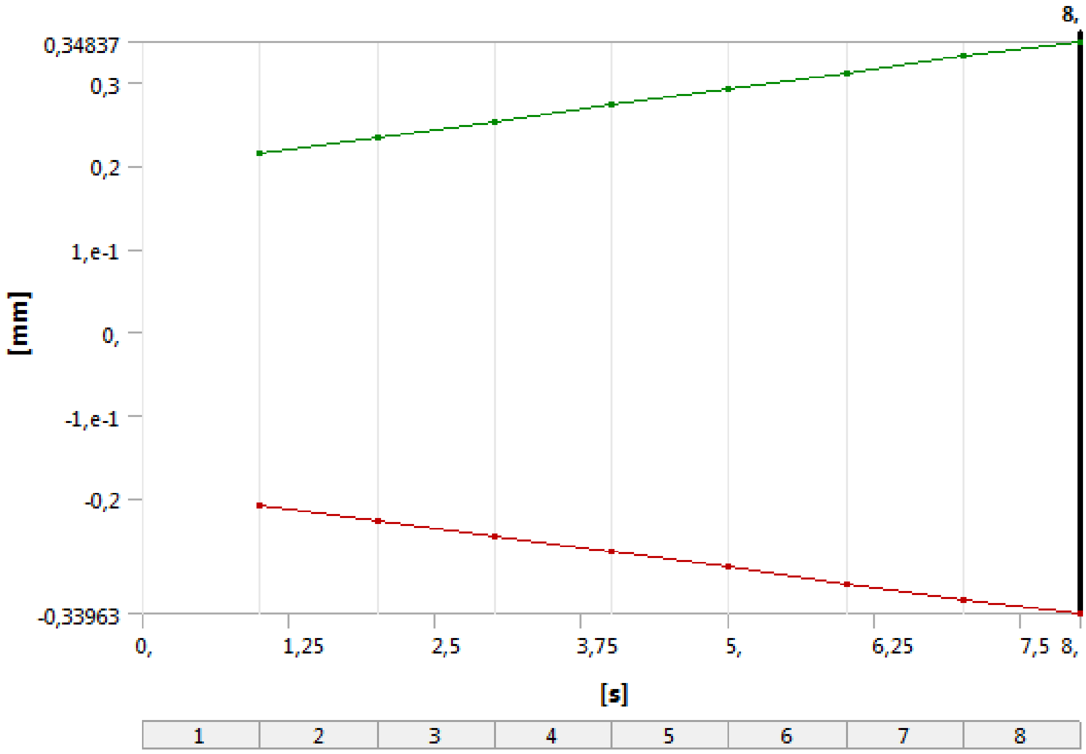


TABLE 23
Model (F4) > Static Structural (F5) > Solution (F6) > Directional Deformation 2

Time [s]	Minimum [mm]	Maximum [mm]
1,	-0,20873	0,21382
2,	-0,22768	0,23349
3,	-0,24662	0,25291
4,	-0,26562	0,2724
5,	-0,28456	0,29183
6,	-0,30356	0,31132
7,	-0,3226	0,33087
8,	-0,33963	0,34837

FIGURE 14
Model (F4) > Static Structural (F5) > Solution (F6) > Directional Deformation 2 > Image

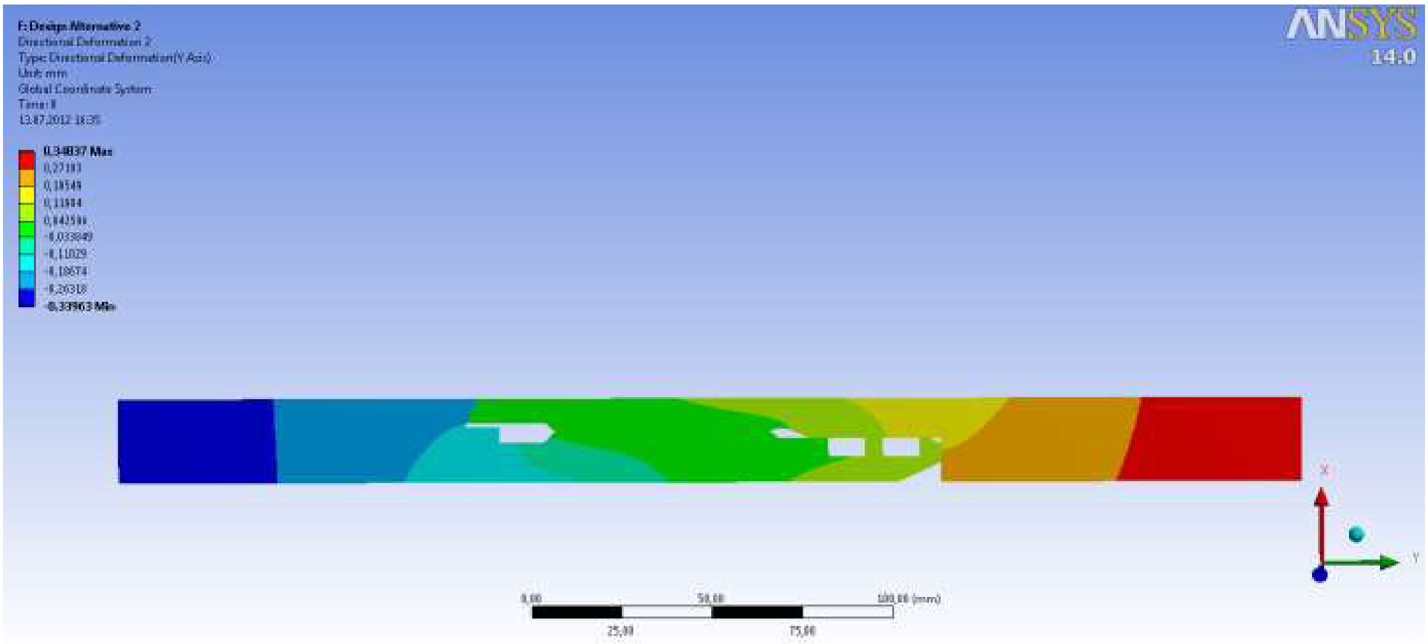


FIGURE 15
Model (F4) > Static Structural (F5) > Solution (F6) > Equivalent Stress

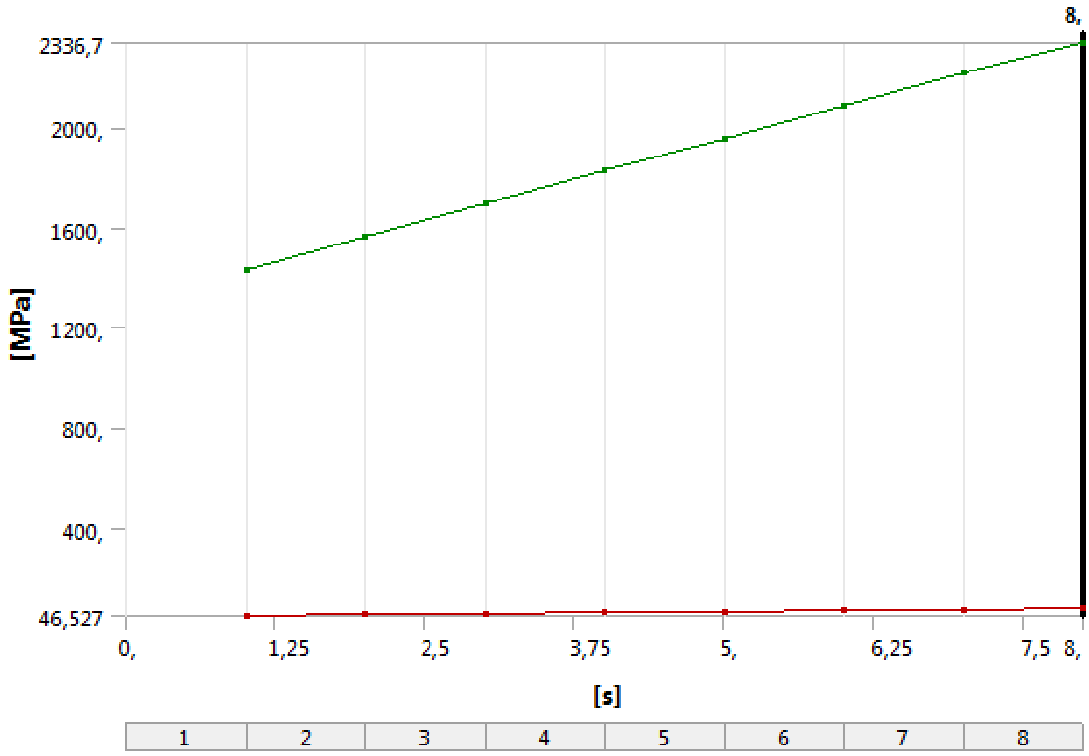


TABLE 24
Model (F4) > Static Structural (F5) > Solution (F6) > Equivalent Stress

Time [s]	Minimum [MPa]	Maximum [MPa]
1,	46,527	1435,6
2,	50,786	1566,
3,	55,011	1696,3
4,	59,251	1827,
5,	63,478	1957,3
6,	67,723	2088,
7,	72,091	2219,9
8,	75,859	2336,7

FIGURE 16
Model (F4) > Static Structural (F5) > Solution (F6) > Equivalent Stress > Image

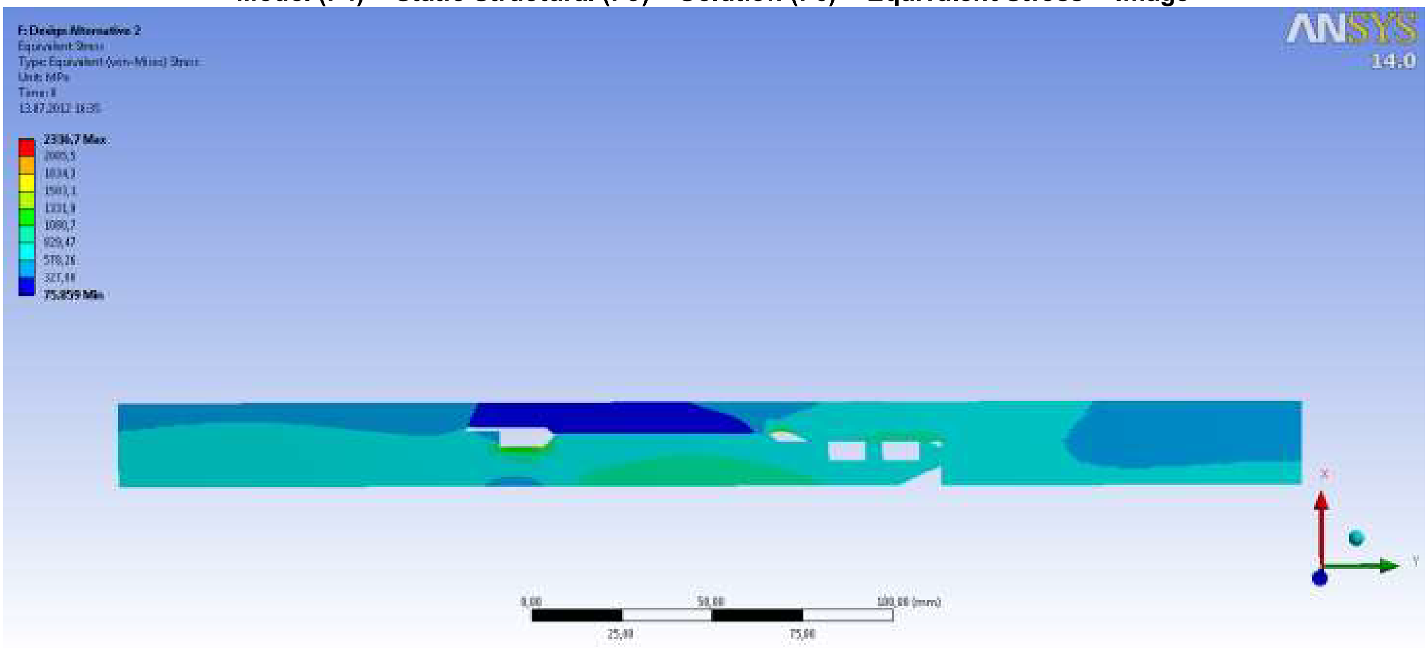


FIGURE 17
Model (F4) > Static Structural (F5) > Solution (F6) > Equivalent Elastic Strain

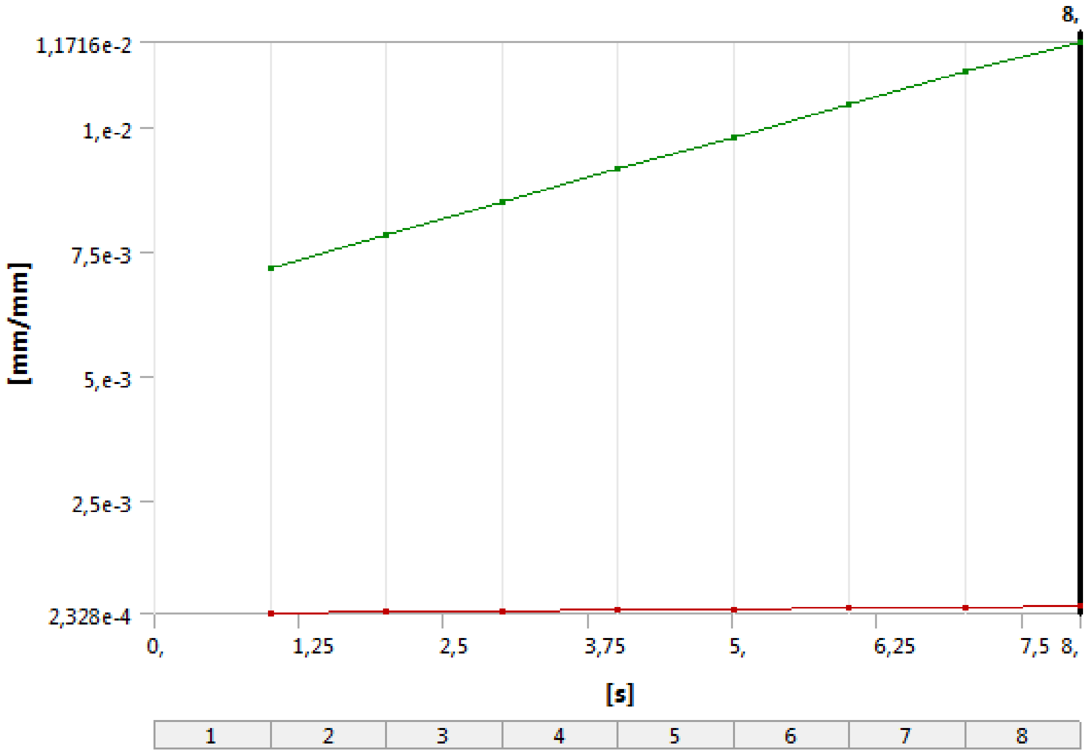
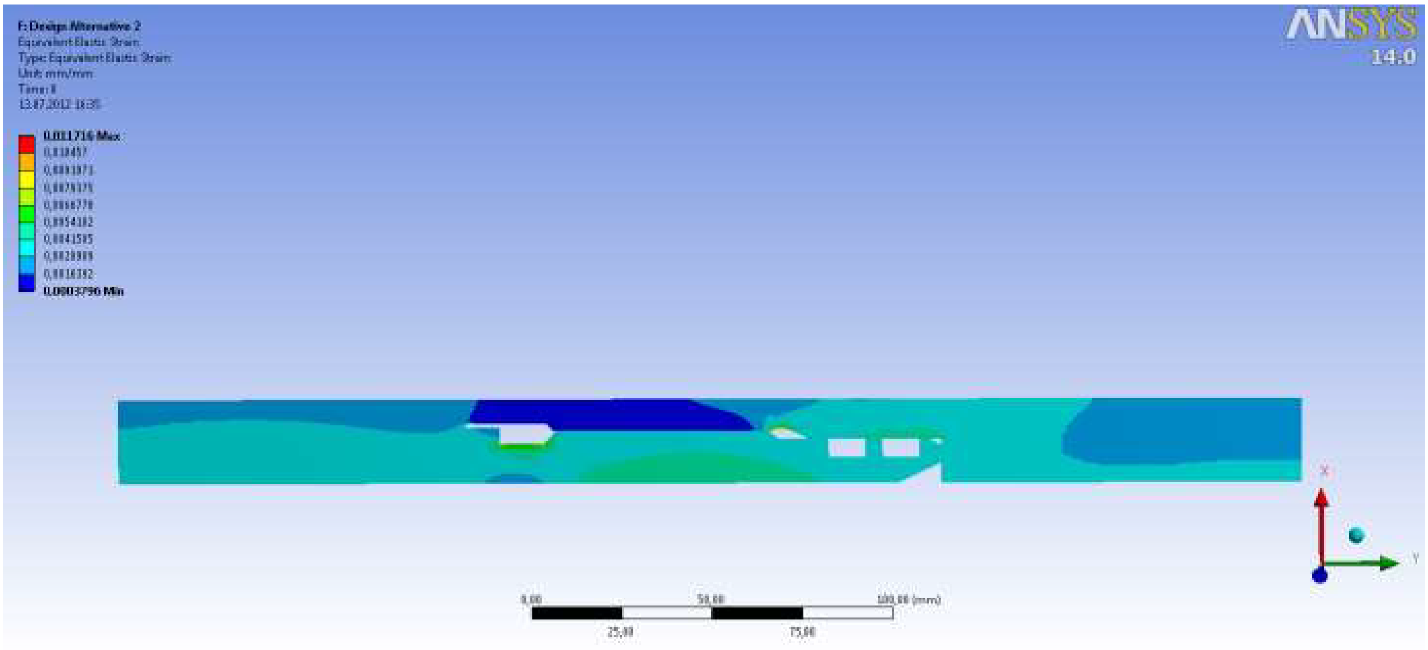


TABLE 25
Model (F4) > Static Structural (F5) > Solution (F6) > Equivalent Elastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
1,	2,328e-004	7,1982e-003
2,	2,541e-004	7,8523e-003
3,	2,7524e-004	8,5055e-003
4,	2,9647e-004	9,1608e-003
5,	3,1762e-004	9,814e-003
6,	3,3887e-004	1,0469e-002
7,	3,6074e-004	1,1131e-002
8,	3,796e-004	1,1716e-002

FIGURE 18
Model (F4) > Static Structural (F5) > Solution (F6) > Equivalent Elastic Strain > Image



Material Data

4140 125ksi

TABLE 26
4140 125ksi > Constants

Density	7,85e-006 kg mm^-3
Coefficient of Thermal Expansion	1,2e-005 C^-1
Specific Heat	4,34e+005 mJ kg^-1 C^-1
Thermal Conductivity	6,05e-002 W mm^-1 C^-1
Resistivity	1,7e-004 ohm mm

TABLE 27
4140 125ksi > Compressive Ultimate Strength

Compressive Ultimate Strength MPa
965,

TABLE 28
4140 125ksi > Compressive Yield Strength

Compressive Yield Strength MPa

860,

TABLE 29
4140 125ksi > Tensile Yield Strength

Tensile Yield Strength MPa
860,

TABLE 30
4140 125ksi > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
965,

TABLE 31
4140 125ksi > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22,

TABLE 32
4140 125ksi > Alternating Stress Mean Stress

Alternating Stress MPa	Cycles	Mean Stress MPa
3999,	10,	0,
2827,	20,	0,
1896,	50,	0,
1413,	100,	0,
1069,	200,	0,
441,	2000,	0,
262,	10000	0,
214,	20000	0,
138,	1,e+005	0,
114,	2,e+005	0,
86,2	1,e+006	0,

TABLE 33
4140 125ksi > Strain-Life Parameters

Strength Coefficient MPa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient MPa	Cyclic Strain Hardening Exponent
920,	-0,106	0,213	-0,47	1000,	0,2

TABLE 34
4140 125ksi > Isotropic Elasticity

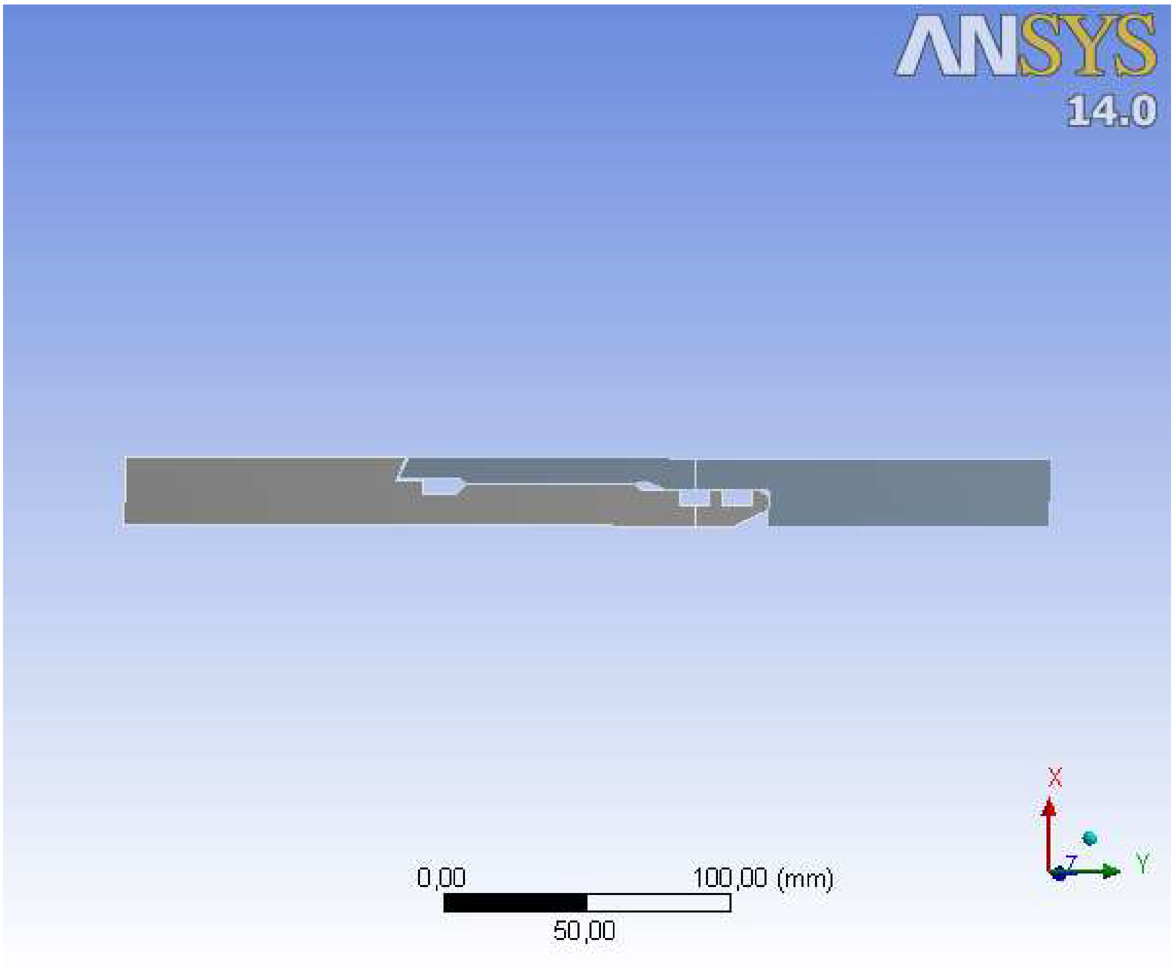
Temperature C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	2,e+005	0,3	1,6667e+005	76923

TABLE 35
4140 125ksi > Isotropic Relative Permeability

Relative Permeability
10000

Project

First Saved	Friday, July 06, 2012
Last Saved	Friday, July 13, 2012
Product Version	14.0 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

Units

TABLE 1

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (G4)

Geometry

TABLE 2
Model (G4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Vault\Peak\R&D\R&D C-flex\Collapse analysis\New Seal nr. 1\Collapse

	Analysis of New Seal Design nr. 1_files\dp0\SYS-7\DM\SYS-7.agdb
Type	DesignModeler
Length Unit	Millimeters
Element Control	Program Controlled
2D Behavior	Axisymmetric
Display Style	Body Color
Bounding Box	
Length X	23,75 mm
Length Y	328,35 mm
Properties	
Volume	0, mm³
Mass	
Surface Area(approx.)	7549, mm²
Scale Factor Value	1,
Statistics	
Bodies	2
Active Bodies	2
Nodes	20667
Elements	6571
Mesh Metric	None
Basic Geometry Options	
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No

Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\62844\AppData\Local\Temp
Analysis Type	2-D
Decompose Disjoint Faces	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (G4) > Geometry > Parts

Object Name	*RD-03362*	*RD-03361*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	

Material		
Assignment	4140 125ksi	
Nonlinear Effects	Yes	
Thermal Strain Effects	Yes	
Bounding Box		
Length X	23,75 mm	
Length Y	228,35 mm	231,08 mm
Properties		
Volume	N/A	
Mass	N/A	
Centroid X	N/A	
Centroid Y	N/A	
Centroid Z	N/A	
Moment of Inertia Ip1	N/A	
Moment of Inertia Ip2	N/A	
Moment of Inertia Ip3	N/A	
Surface Area(approx.)	3960,8 mm²	3588,2 mm²
Statistics		
Nodes	10899	9768
Elements	3470	3101
Mesh Metric	None	

Coordinate Systems

TABLE 4
Model (G4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined

Definition	
Type	Cartesian
Coordinate System ID	0,
Origin	
Origin X	0, mm
Origin Y	0, mm
Directional Vectors	
X Axis Data	[1, 0,]
Y Axis Data	[0, 1,]

Connections

TABLE 5
Model (G4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (G4) > Connections > Contacts

Object Name	*Contacts*
State	Fully Defined
Definition	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection

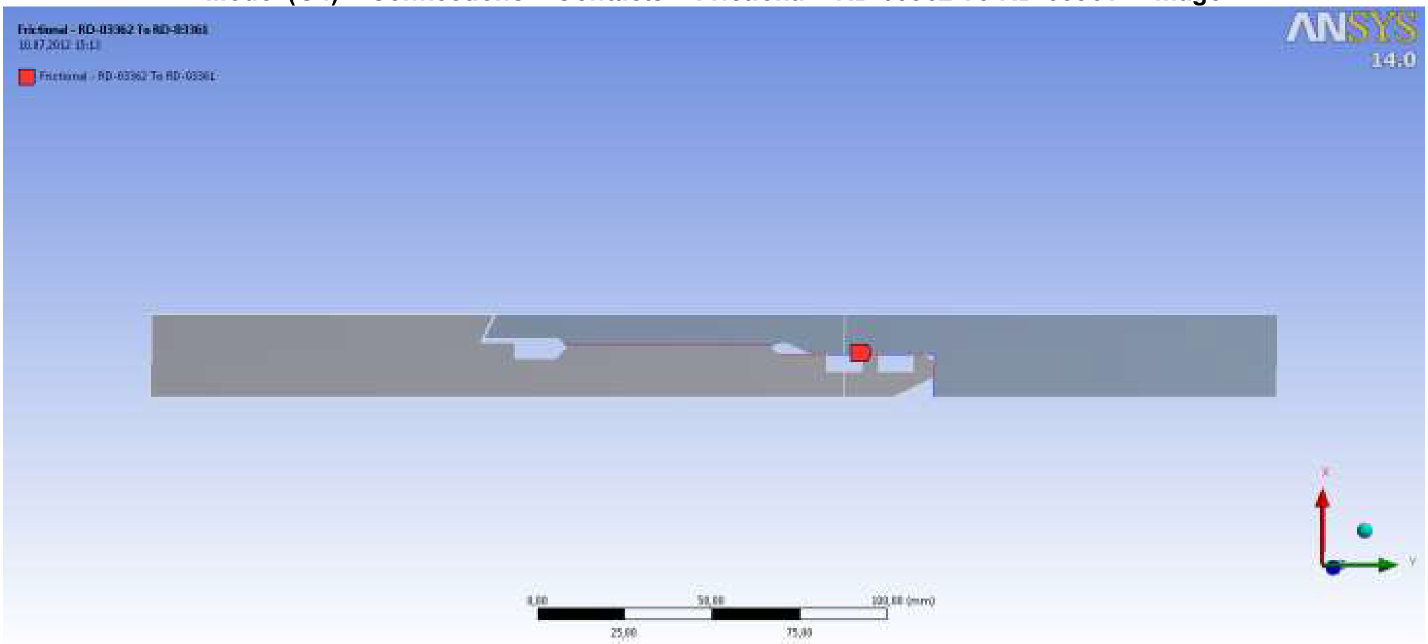
Geometry	All Bodies
Auto Detection	
Tolerance Type	Slider
Tolerance Slider	0,
Tolerance Value	0,82302 mm
Use Range	No
Face/Edge	No
Edge/Edge	Yes
Priority	Include All
Group By	Bodies
Search Across	Bodies

TABLE 7
Model (G4) > Connections > Contacts > Contact Regions

Object Name	*Frictional - RD-03362 To RD-03361*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Contact	5 Edges
Target	4 Edges
Contact Bodies	RD-03362
Target Bodies	RD-03361
Definition	
Type	Frictional
Friction Coefficient	0,15
Scope Mode	Manual
Behavior	Program Controlled

Suppressed	No
Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Interface Treatment	Add Offset, No Ramping
Offset	0, mm
Normal Stiffness	Program Controlled
Update Stiffness	Program Controlled
Stabilization Damping Factor	0,
Pinball Region	Program Controlled
Time Step Controls	None

FIGURE 1
Model (G4) > Connections > Contacts > Frictional - RD-03362 To RD-03361 > Image



Mesh

TABLE 8
Model (G4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Coarse
Initial Size Seed	Active Assembly
Smoothing	Medium
Span Angle Center	Coarse
Curvature Normal Angle	Default (30,0 °)
Min Size	Default (1,08610 mm)
Max Face Size	Default (5,43030 mm)
Growth Rate	Default
Minimum Edge Length	2,82840 mm
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0,272
Maximum Layers	2
Growth Rate	1,2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	

Triangle Surface Mesher	Program Controlled
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Use Sheet Thickness for Pinch	No
Pinch Tolerance	Default (0,977460 mm)
Generate Pinch on Refresh	No
Sheet Loop Removal	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default (0,814550 mm)
Statistics	
Nodes	20667
Elements	6571
Mesh Metric	None

TABLE 9
Model (G4) > Mesh > Mesh Controls

Object Name	*Body Sizing*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies

Definition	
Suppressed	No
Type	Element Size
Element Size	0,2 mm
Behavior	Soft
Curvature Normal Angle	Default
Growth Rate	Default

Static Structural (G5)

TABLE 10
Model (G4) > Analysis

Object Name	*Static Structural (G5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	22, °C
Generate Input Only	No

TABLE 11
Model (G4) > Static Structural (G5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1,
Current Step Number	1,

Step End Time	1, s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Off
Output Controls	
Stress	Yes
Strain	Yes
Nodal Forces	No
Contact Miscellaneous	No
General	No

Miscellaneous	
Calculate Results At	All Time Points
Max Number of Result Sets	Program Controlled
Analysis Data Management	
Solver Files Directory	C:\Vault\Peak\R&D\R&D C-flex\Collapse analysis\New Seal nr. 1\Collapse Analysis of New Seal Design nr. 1_files\dp0\SYS-7\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Delete Unneeded Files	Yes
Nonlinear Solution	Yes
Solver Units	Active System
Solver Unit System	nmm

TABLE 12
Model (G4) > Static Structural (G5) > Loads

Object Name	*Pressure*	*Displacement*	*Force*	*Force 2*
State	Fully Defined			
Scope				
Scoping Method	Geometry Selection			
Geometry	21 Edges	2 Edges	1 Edge	
Definition				
Type	Pressure	Displacement	Force	
Define By	Normal To	Components	Vector	
Magnitude	79, MPa (ramped)		2,583e+006 N (ramped)	
Suppressed	No			

Coordinate System		Global Coordinate System	
X Component		Free	
Y Component		0, mm (ramped)	
Direction			Defined

FIGURE 2
Model (G4) > Static Structural (G5) > Pressure

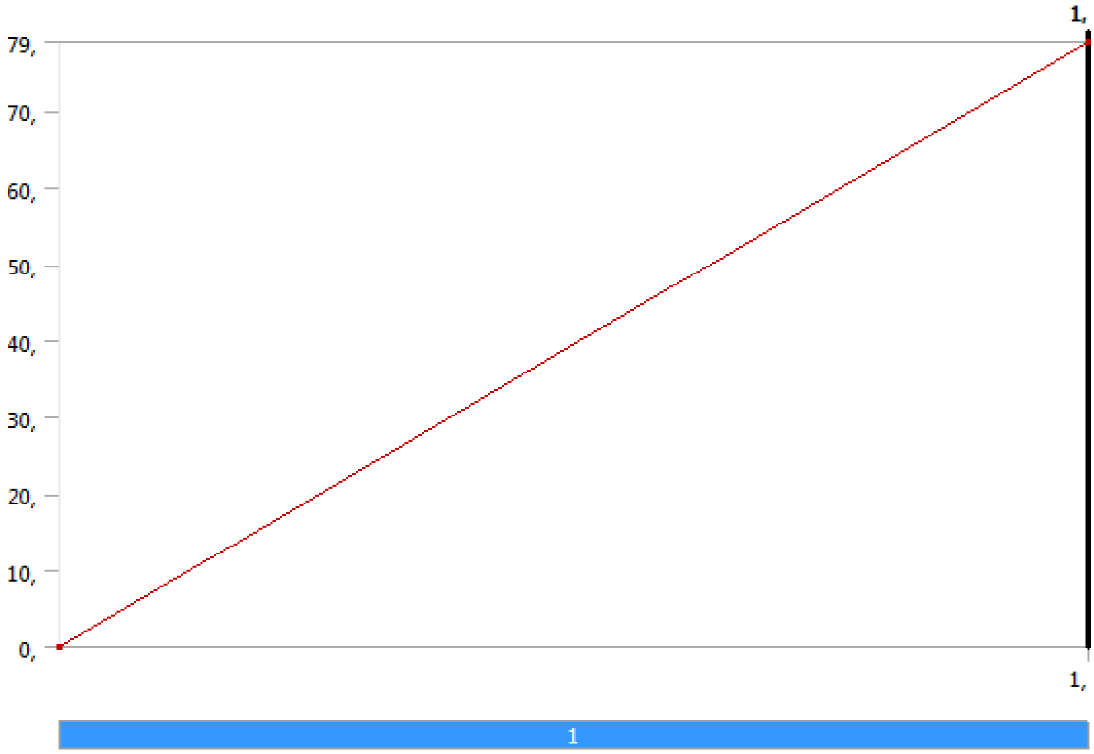


FIGURE 3
Model (G4) > Static Structural (G5) > Pressure > Image

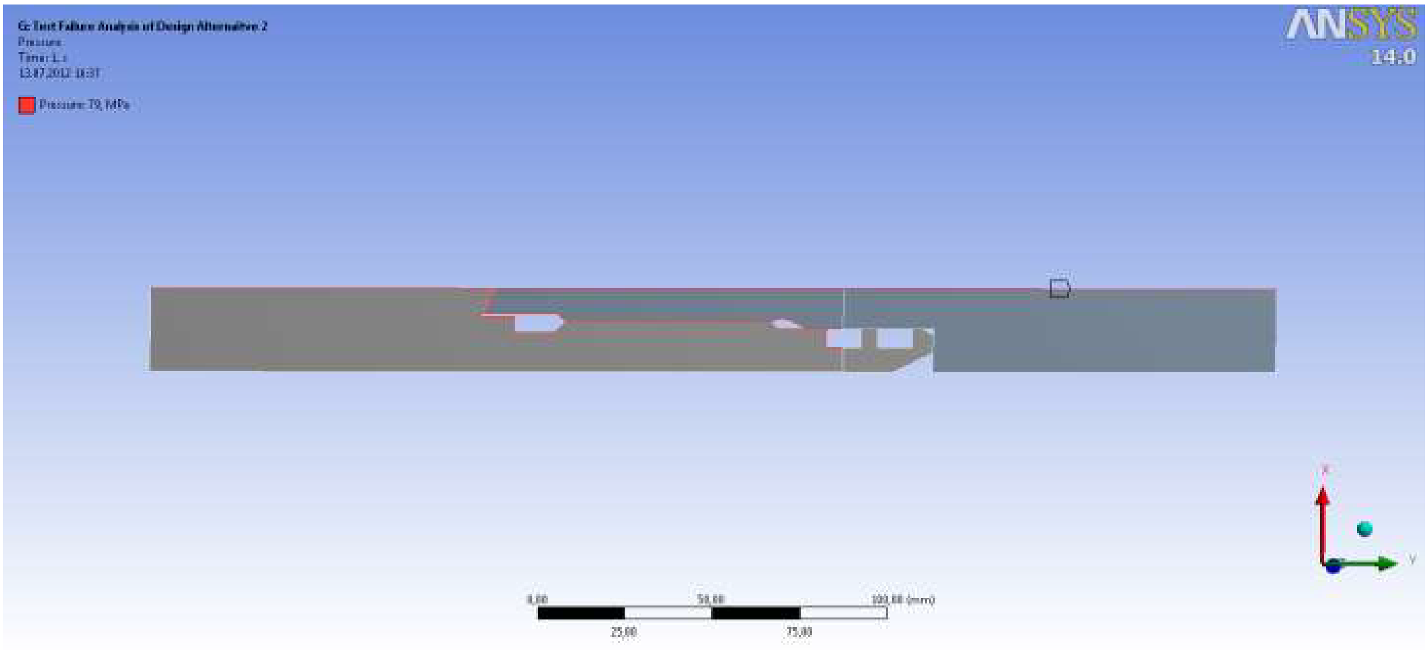


FIGURE 4
Model (G4) > Static Structural (G5) > Displacement

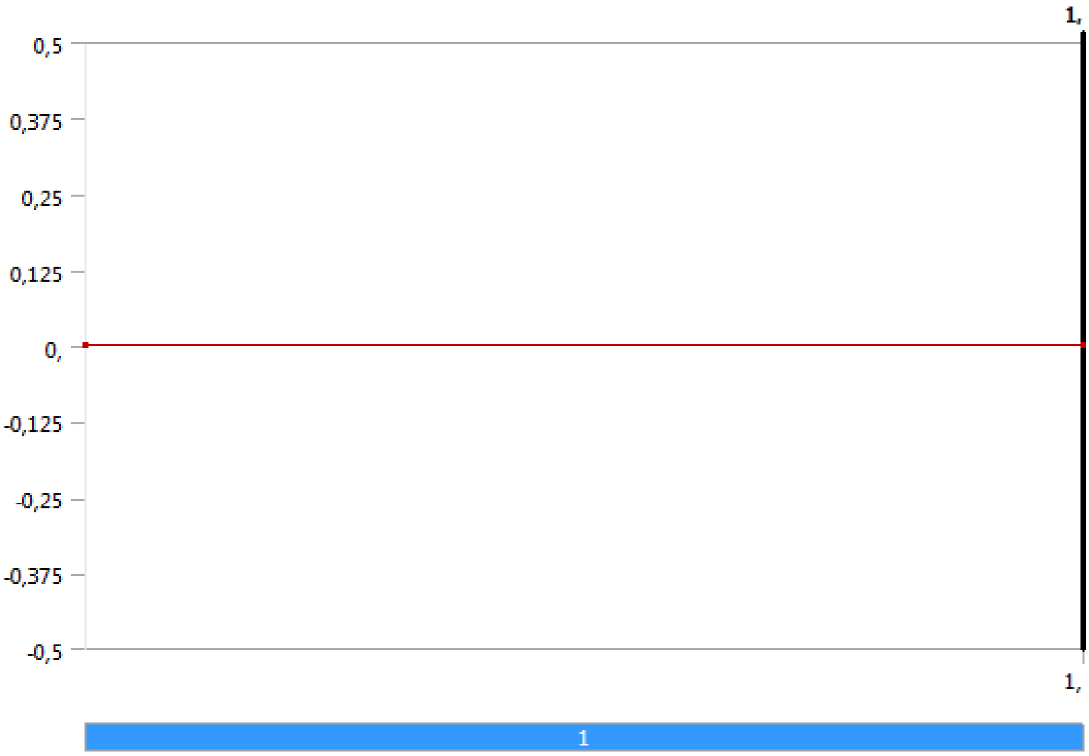


FIGURE 5
Model (G4) > Static Structural (G5) > Force

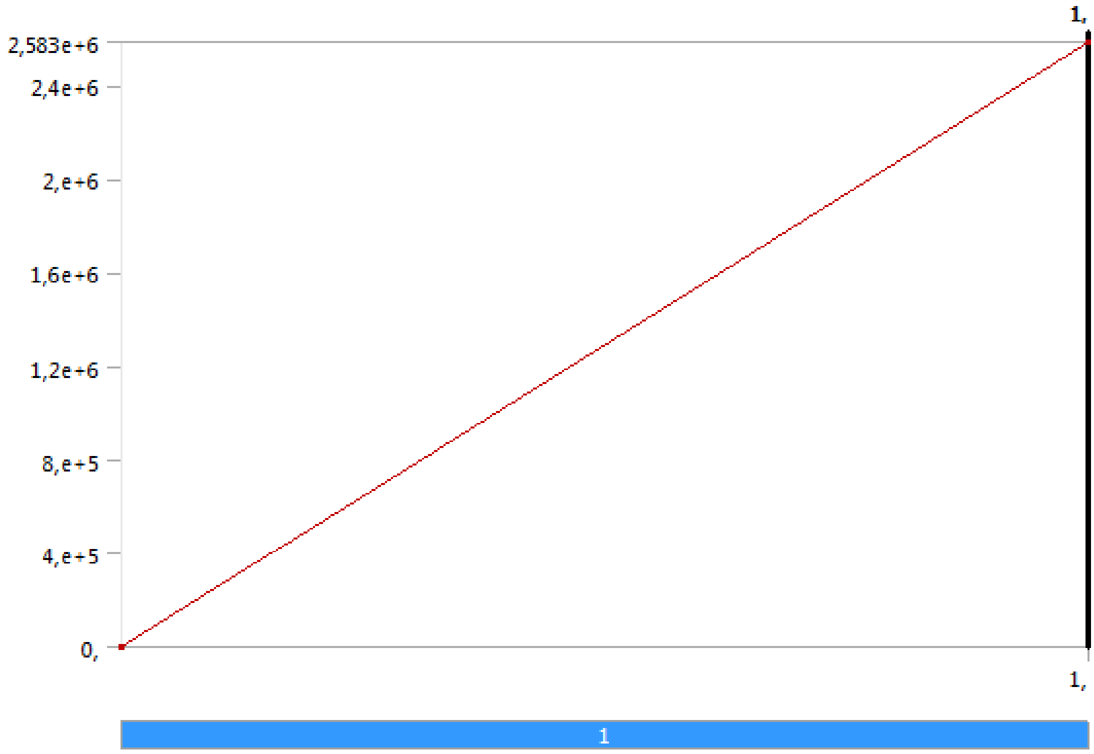


FIGURE 6
Model (G4) > Static Structural (G5) > Force 2

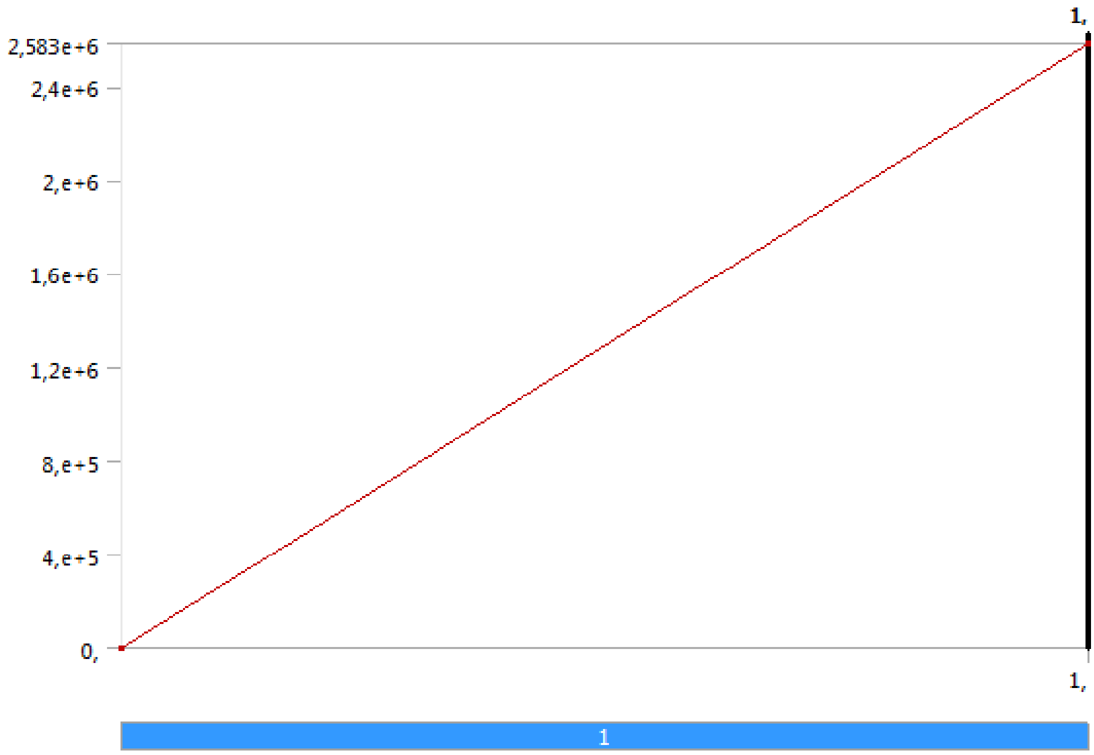
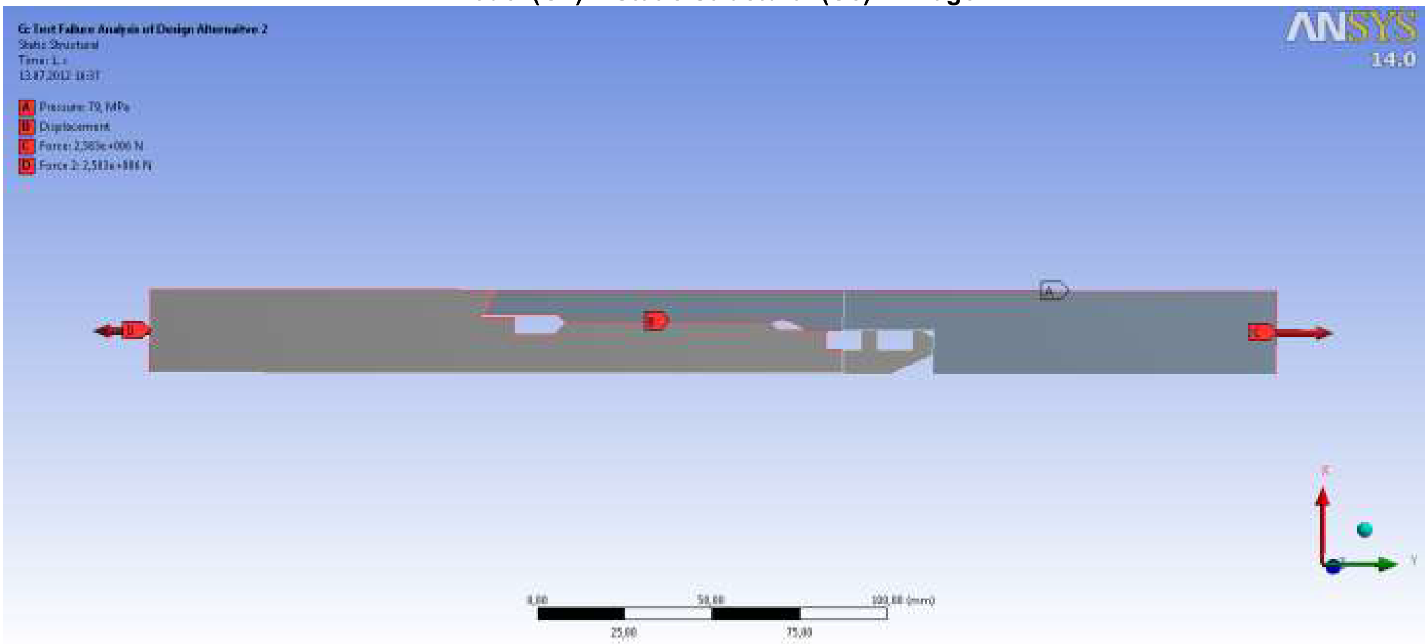


FIGURE 7
Model (G4) > Static Structural (G5) > Image



Solution (G6)

TABLE 13
Model (G4) > Static Structural (G5) > Solution

Object Name	*Solution (G6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1,
Refinement Depth	2,
Information	
Status	Done

TABLE 14
Model (G4) > Static Structural (G5) > Solution (G6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	

Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2,5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 15
Model (G4) > Static Structural (G5) > Solution (G6) > Results

Object Name	*Total Deformation*	*Directional Deformation*	*Directional Deformation 2*	*Equivalent Stress*	*Equivalent Elastic Strain*
State	Solved				
Scope					
Scoping Method	Geometry Selection				
Geometry	All Bodies				
Definition					
Type	Total Deformation	Directional Deformation		Equivalent (von-Mises) Stress	Equivalent Elastic Strain
By	Time				
Display Time	1, s	Last			
Calculate Time History	Yes				

Identifier					
Suppressed	No				
Orientation		X Axis	Y Axis		
Coordinate System		Global Coordinate System			
Results					
Minimum	5,0128e-005 mm	-0,45177 mm	-0,30114 mm	65,533 MPa	3,3037e-004 mm/mm
Maximum	0,45179 mm	5,0693e-002 mm	0,31 mm	878,33 MPa	4,4418e-003 mm/mm
Minimum Occurs On	RD-03361	RD-03362		RD-03361	
Maximum Occurs On	RD-03362	RD-03361			
Minimum Value Over Time					
Minimum	5,0128e-005 mm	-0,45177 mm	-0,30114 mm	12,722 MPa	6,4129e-005 mm/mm
Maximum	2,6874e-004 mm	-8,9851e-002 mm	-5,9139e-002 mm	65,533 MPa	3,3037e-004 mm/mm
Maximum Value Over Time					
Minimum	8,9855e-002 mm	9,6999e-003 mm	6,1282e-002 mm	404,33 MPa	2,0274e-003 mm/mm
Maximum	0,45179 mm	5,0693e-002 mm	0,31 mm	938,8 MPa	4,8334e-003 mm/mm
Information					
Time	1, s				
Load Step	1				
Substep	4				
Iteration Number	15				

Integration Point Results		
Display Option		Averaged

FIGURE 8
Model (G4) > Static Structural (G5) > Solution (G6) > Total Deformation

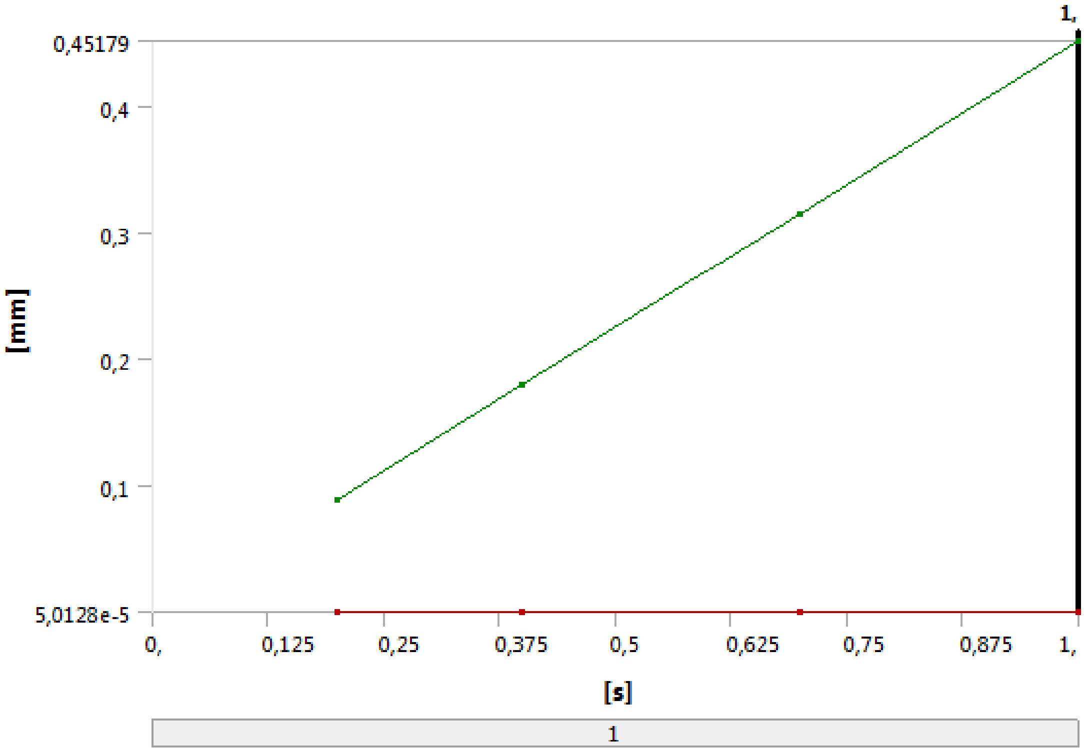


TABLE 16
Model (G4) > Static Structural (G5) > Solution (G6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]
0,2	8,5751e-005	8,9855e-002
0,4	1,6373e-004	0,17972
0,7	2,6874e-004	0,31463
1,	5,0128e-005	0,45179

FIGURE 9
Model (G4) > Static Structural (G5) > Solution (G6) > Total Deformation > Image

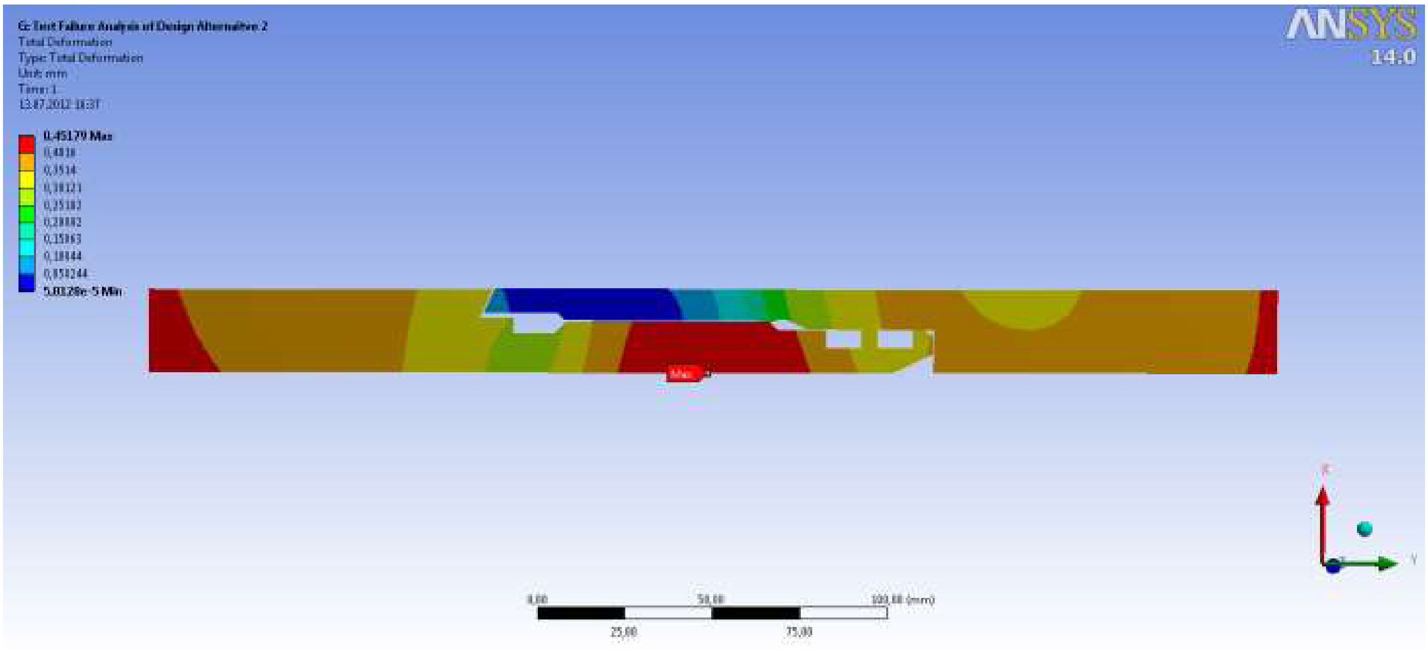


FIGURE 10

Model (G4) > Static Structural (G5) > Solution (G6) > Directional Deformation

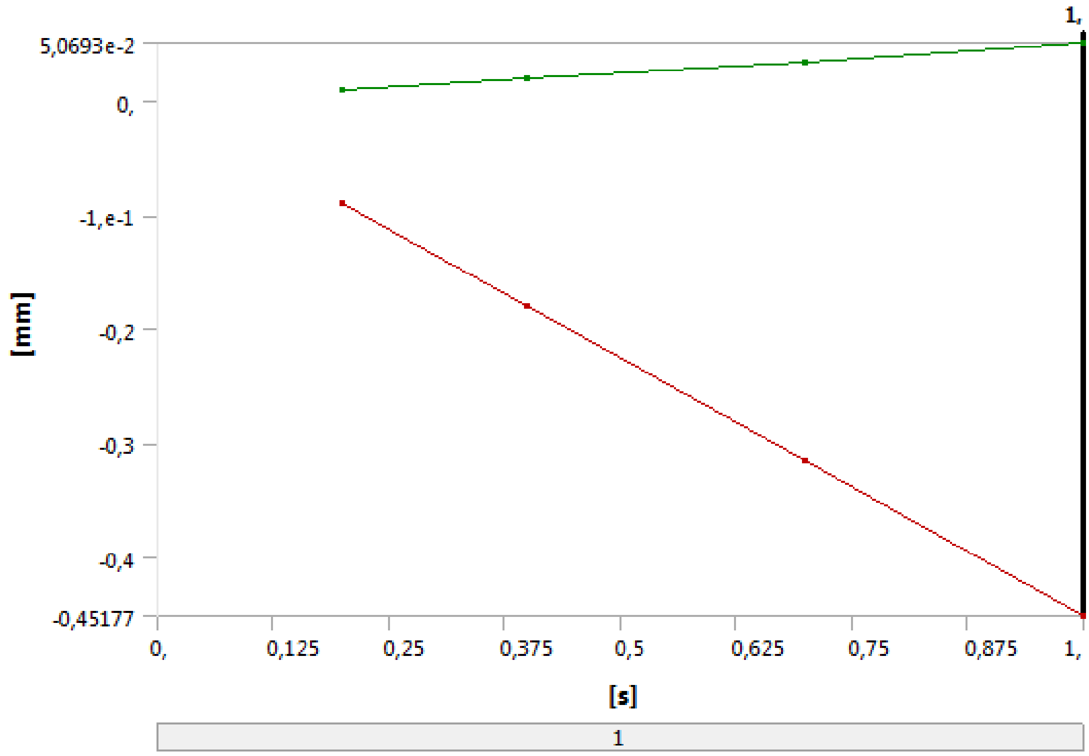


TABLE 17
Model (G4) > Static Structural (G5) > Solution (G6) > Directional Deformation

Time [s]	Minimum [mm]	Maximum [mm]
0,2	-8,9851e-002	9,6999e-003
0,4	-0,17972	1,9419e-002
0,7	-0,31462	3,4149e-002
1,	-0,45177	5,0693e-002

FIGURE 11
Model (G4) > Static Structural (G5) > Solution (G6) > Directional Deformation > Image

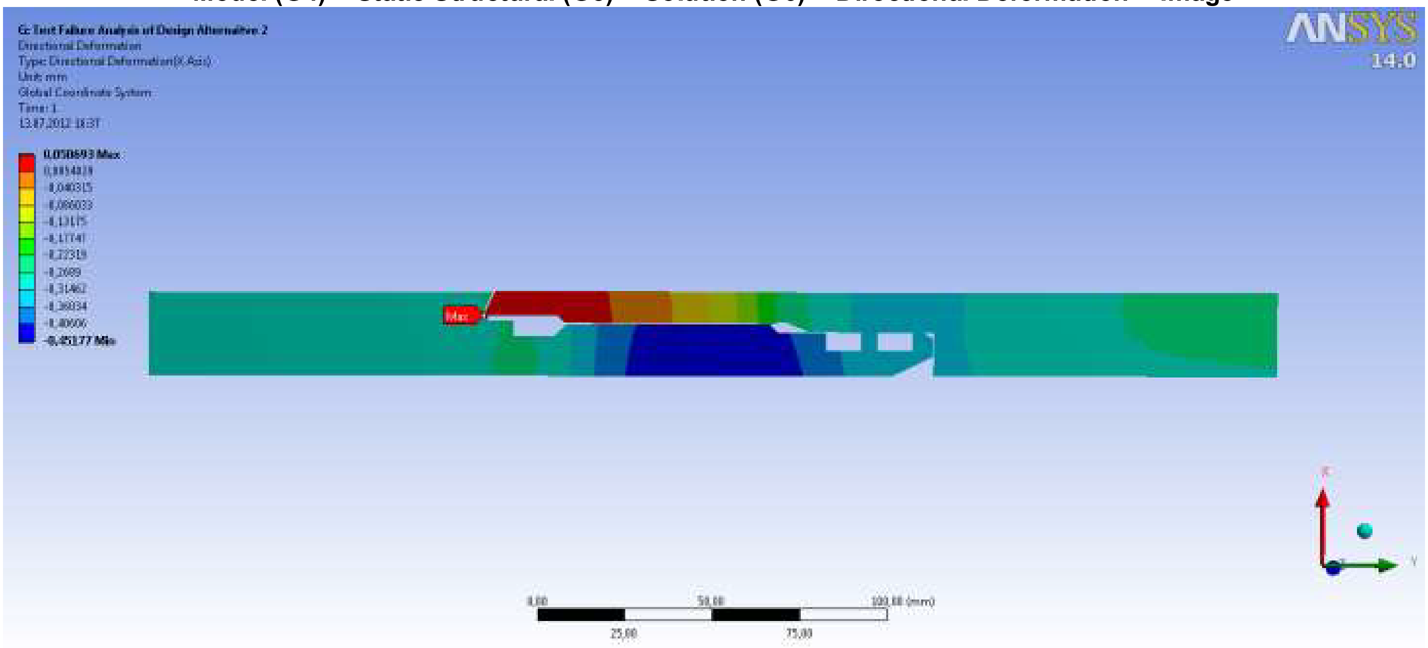


FIGURE 12
Model (G4) > Static Structural (G5) > Solution (G6) > Directional Deformation 2

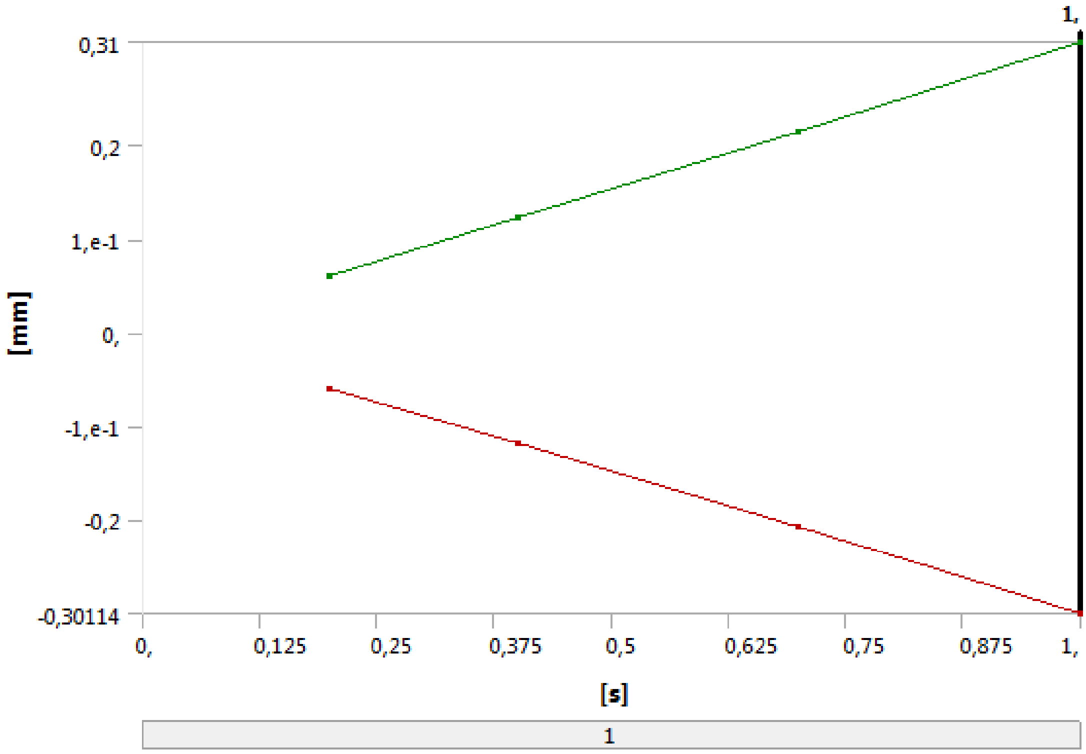


TABLE 18
Model (G4) > Static Structural (G5) > Solution (G6) > Directional Deformation 2

Time [s]	Minimum [mm]	Maximum [mm]
0,2	-5,9139e-002	6,1282e-002
0,4	-0,11828	0,1226
0,7	-0,20742	0,21479
1,	-0,30114	0,31

FIGURE 13
Model (G4) > Static Structural (G5) > Solution (G6) > Directional Deformation 2 > Image

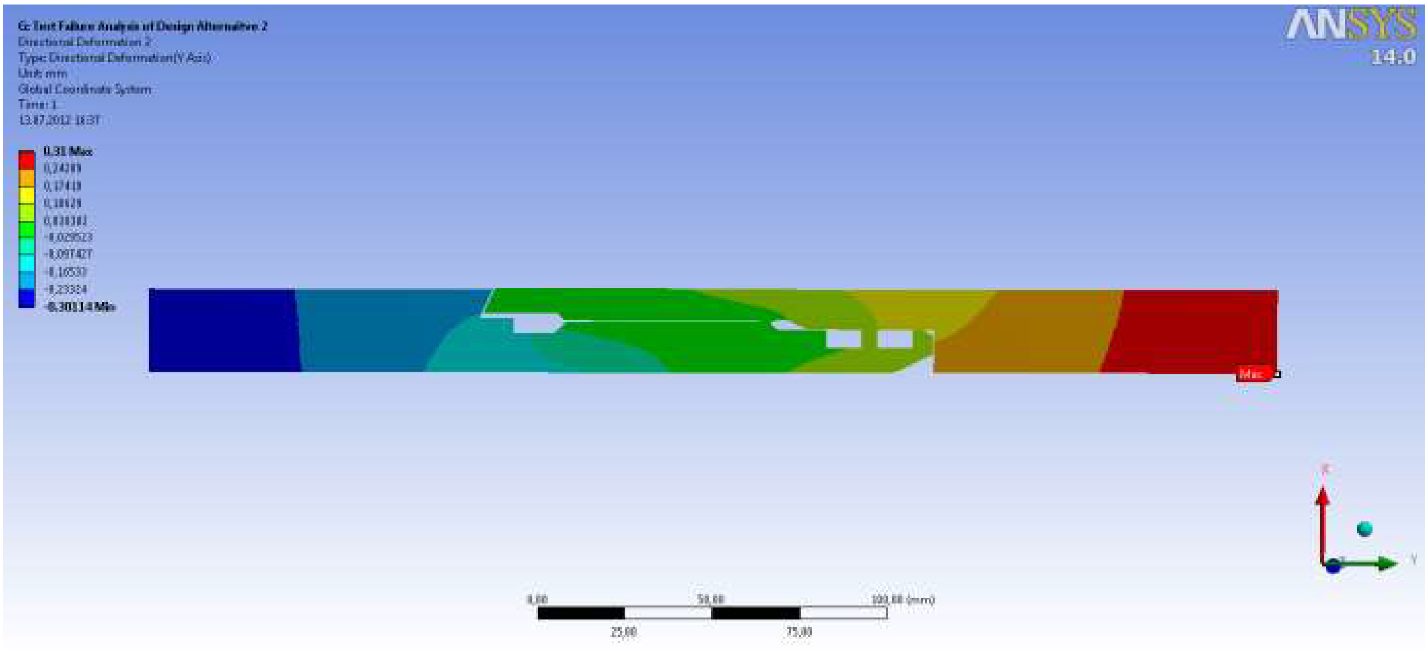


FIGURE 14

Model (G4) > Static Structural (G5) > Solution (G6) > Equivalent Stress

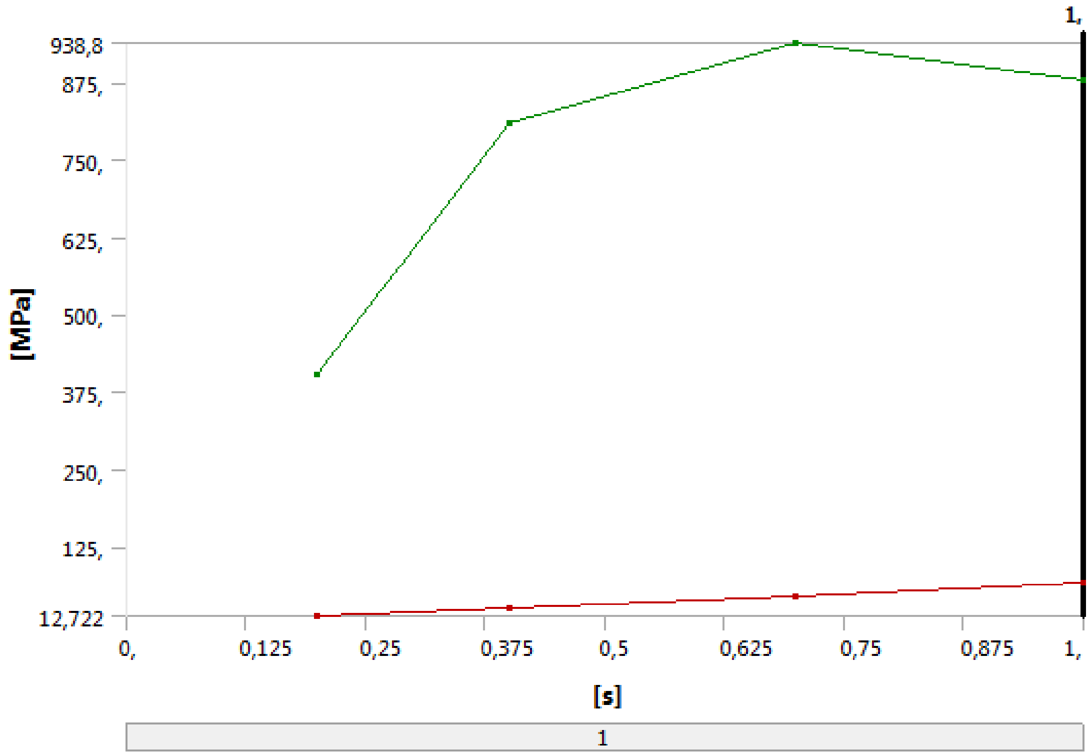


TABLE 19
Model (G4) > Static Structural (G5) > Solution (G6) > Equivalent Stress

Time [s]	Minimum [MPa]	Maximum [MPa]
0,2	12,722	404,33
0,4	25,464	808,89
0,7	44,697	938,8
1,	65,533	878,33

FIGURE 15
Model (G4) > Static Structural (G5) > Solution (G6) > Equivalent Stress > Image

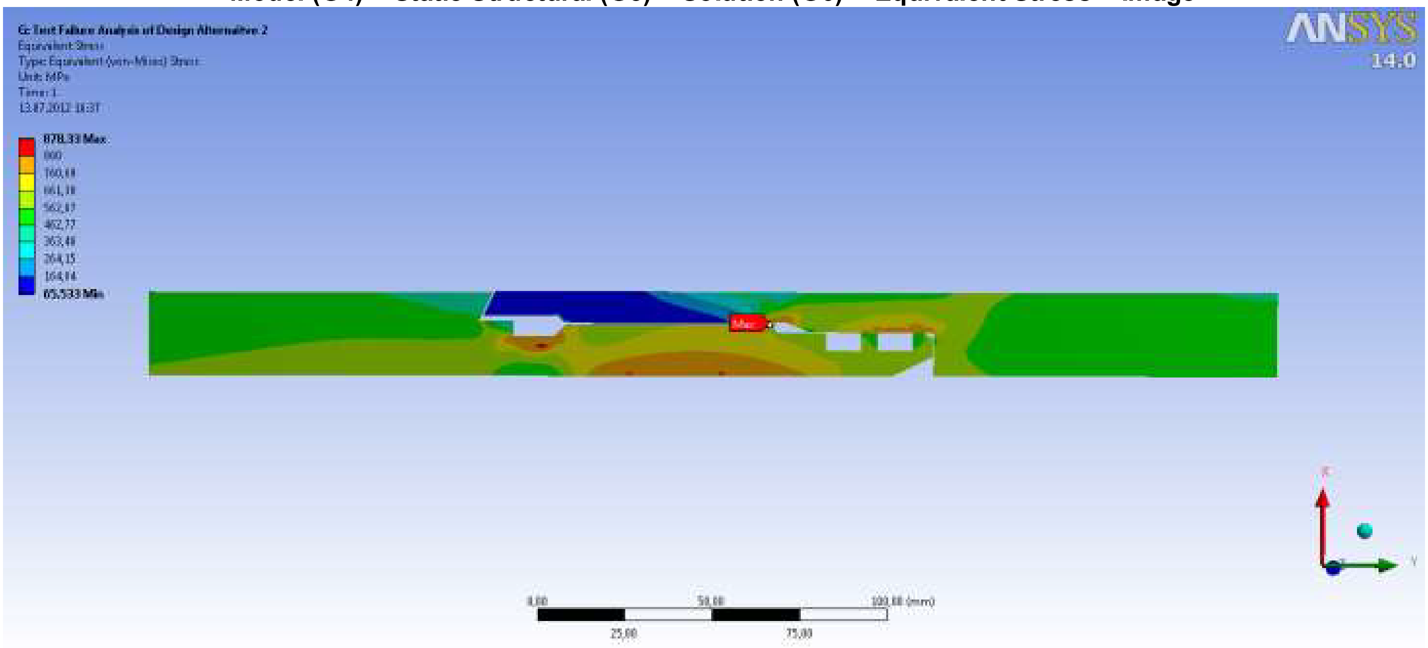


FIGURE 16
Model (G4) > Static Structural (G5) > Solution (G6) > Equivalent Elastic Strain

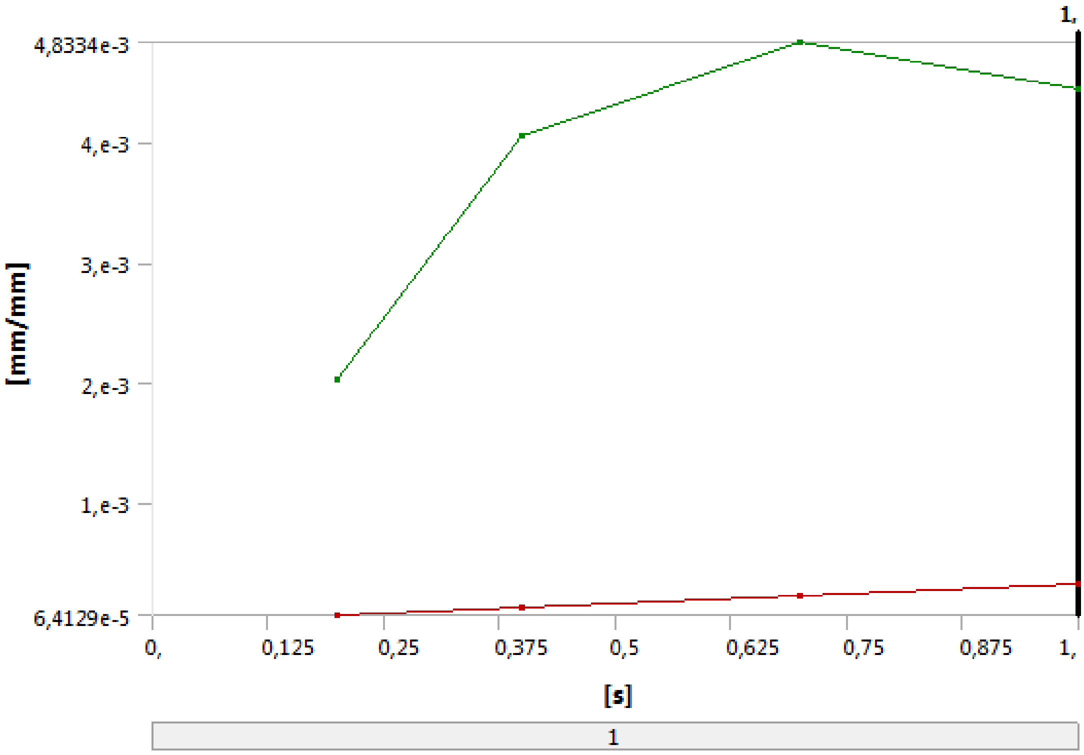


TABLE 20
Model (G4) > Static Structural (G5) > Solution (G6) > Equivalent Elastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
0,2	6,4129e-005	2,0274e-003
0,4	1,2836e-004	4,0559e-003
0,7	2,2532e-004	4,8334e-003
1,	3,3037e-004	4,4418e-003

FIGURE 17
Model (G4) > Static Structural (G5) > Solution (G6) > Equivalent Elastic Strain > Image

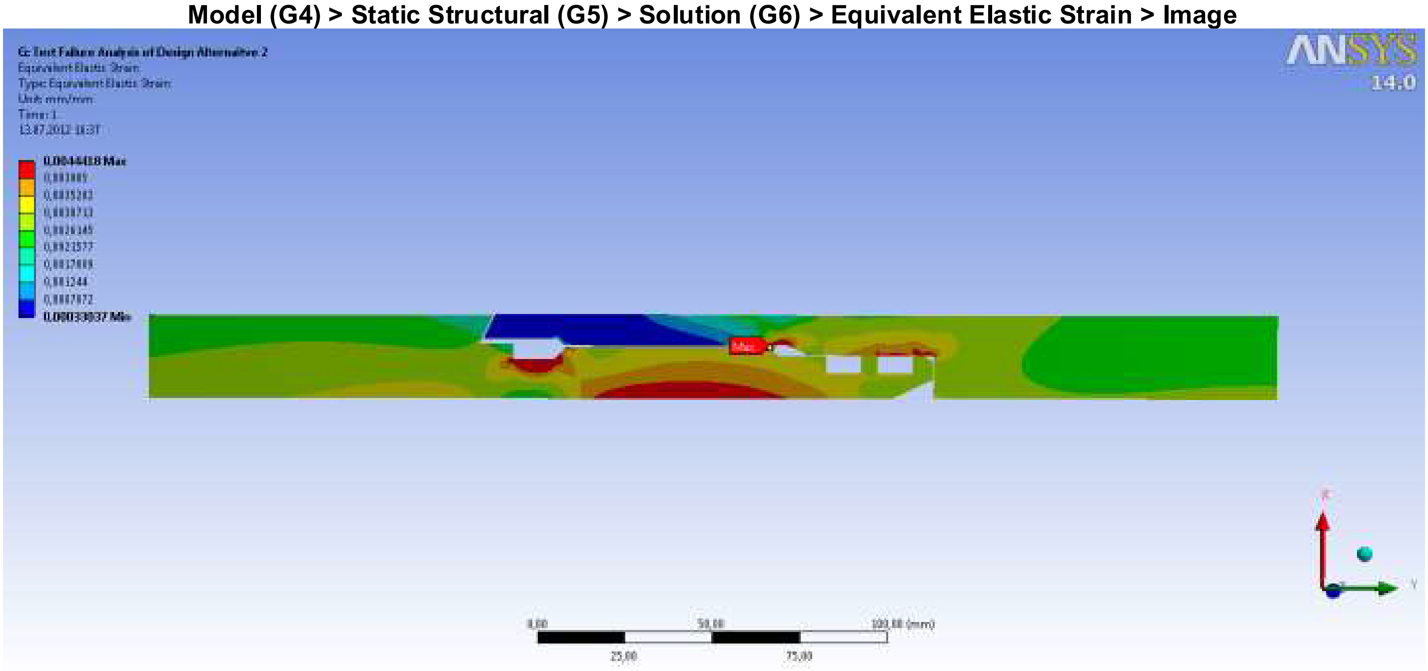


TABLE 21
Model (G4) > Static Structural (G5) > Solution (G6) > Results

Object Name	*Equivalent Plastic Strain*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Equivalent Plastic Strain
By	Time
Display Time	Last

Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged
Results	
Minimum	0, mm/mm
Maximum	7,4434e-003 mm/mm
Minimum Occurs On	RD-03362
Maximum Occurs On	RD-03362
Minimum Value Over Time	
Minimum	0, mm/mm
Maximum	0, mm/mm
Maximum Value Over Time	
Minimum	0, mm/mm
Maximum	7,4434e-003 mm/mm
Information	
Time	1, s
Load Step	1
Substep	4
Iteration Number	15

FIGURE 18
Model (G4) > Static Structural (G5) > Solution (G6) > Equivalent Plastic Strain

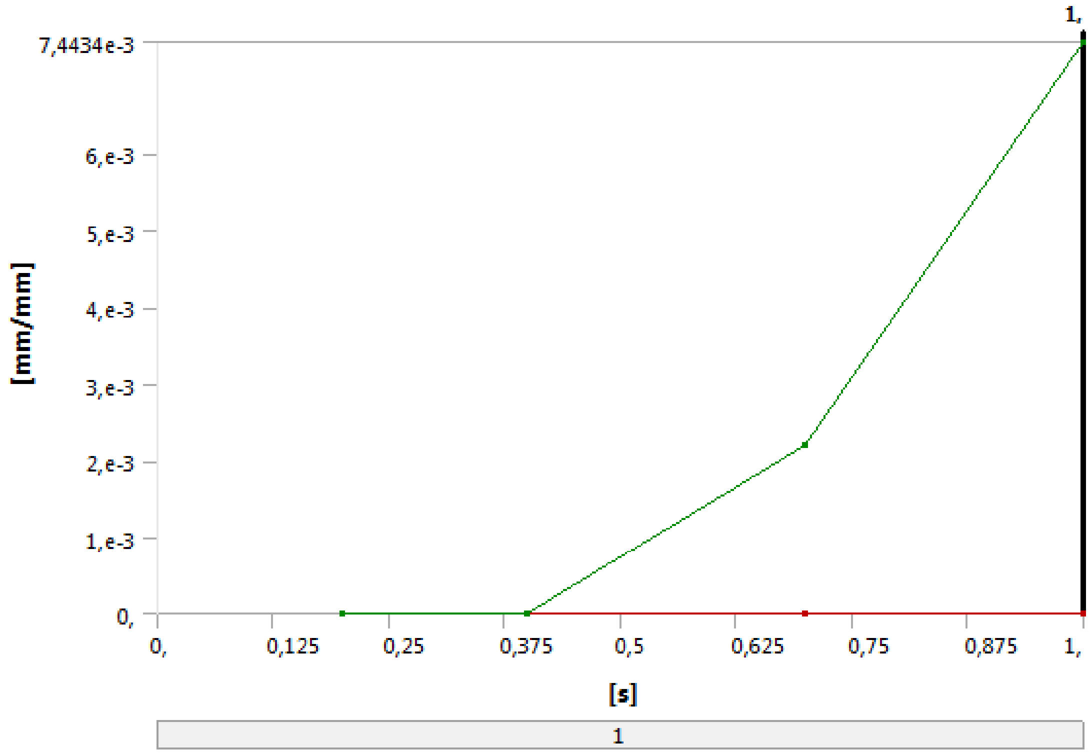
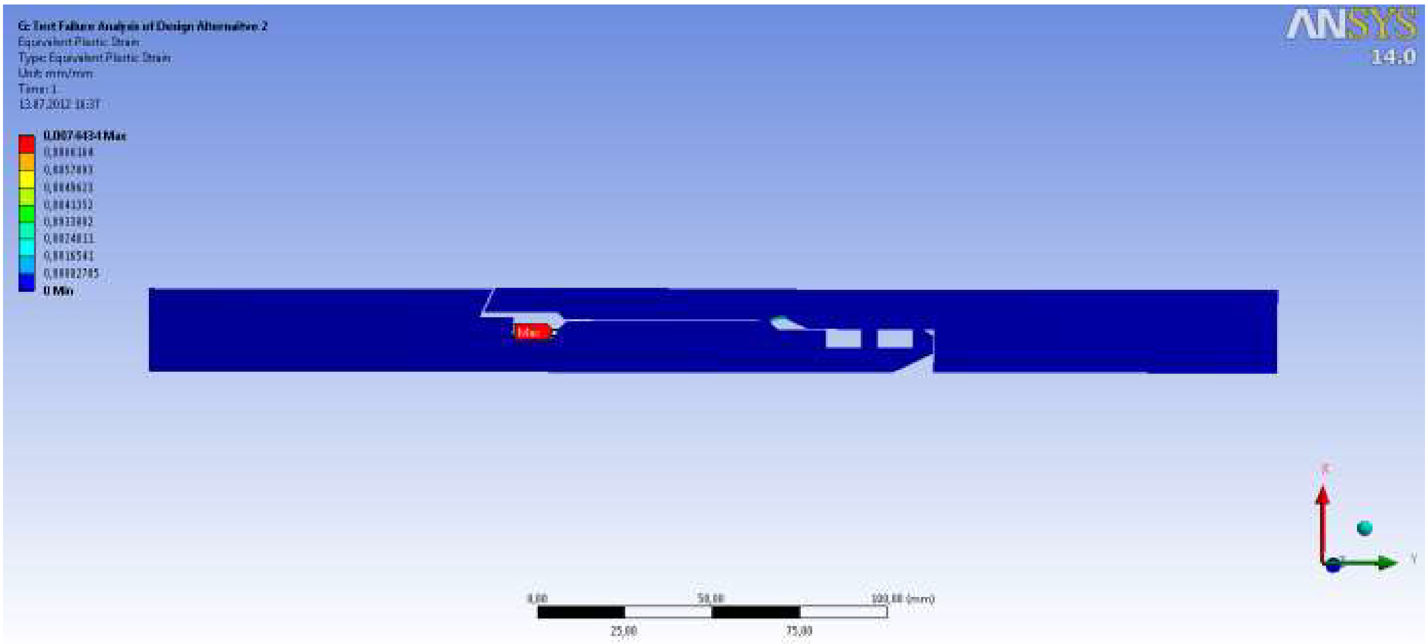


TABLE 22
Model (G4) > Static Structural (G5) > Solution (G6) > Equivalent Plastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
0,2	0,	0,
0,4		
0,7		2,1985e-003
1,		7,4434e-003

FIGURE 19
Model (G4) > Static Structural (G5) > Solution (G6) > Equivalent Plastic Strain > Image



Material Data

4140 125ksi

TABLE 23
4140 125ksi > Constants

Density	7,85e-006 kg mm^-3
Coefficient of Thermal Expansion	1,2e-005 C^-1
Specific Heat	4,34e+005 mJ kg^-1 C^-1
Thermal Conductivity	6,05e-002 W mm^-1 C^-1
Resistivity	1,7e-004 ohm mm

TABLE 24
4140 125ksi > Compressive Ultimate Strength

Compressive Ultimate Strength MPa
965,

TABLE 25
4140 125ksi > Compressive Yield Strength

Compressive Yield Strength MPa

860,

TABLE 26
4140 125ksi > Tensile Yield Strength

Tensile Yield Strength MPa
860,

TABLE 27
4140 125ksi > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
965,

TABLE 28
4140 125ksi > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22,

TABLE 29
4140 125ksi > Alternating Stress Mean Stress

Alternating Stress MPa	Cycles	Mean Stress MPa
3999,	10,	0,
2827,	20,	0,
1896,	50,	0,
1413,	100,	0,
1069,	200,	0,
441,	2000,	0,
262,	10000	0,
214,	20000	0,
138,	1,e+005	0,
114,	2,e+005	0,
86,2	1,e+006	0,

TABLE 30
4140 125ksi > Strain-Life Parameters

Strength Coefficient MPa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient MPa	Cyclic Strain Hardening Exponent
920,	-0,106	0,213	-0,47	1000,	0,2

TABLE 31
4140 125ksi > Isotropic Elasticity

Temperature C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	2,e+005	0,3	1,6667e+005	76923

TABLE 32
4140 125ksi > Isotropic Relative Permeability

Relative Permeability
10000

TABLE 33
4140 125ksi > Bilinear Isotropic Hardening

Yield Strength MPa	Tangent Modulus MPa	Temperature C
860,	0,	

Appendix F

Archer Oil Tools
R&D Engineering Test Procedure

Test Number:	12-024
Test Title:	9 5/8" C-flex SS 53,5# collapse test
Customer reference:	NA
Project Number:	NA
Project Name:	9 5/8" C-flex collapse test
Project Responsible:	Hanne Lohne Morken
Test Execution Date:	Week 26
Test Location:	IRIS, Stavanger

Archer Oil Tools AS

Main phone..........+47 51 30 88 00
Office fax..............+47 51 30 88 01
Duty phone..........+47 98 24 55 40

Visit address ....Lagerveien 24, 4033 Stavanger, NOR
Post address ....P.O Box: 8037 4068 Stavanger, NOR
Web…………………..……..www.archerwell.com

Revisions

Rev.:	Date	Description	Issue by	Checked	Approved
A	21.06.12	1st draft	HMO	THE and Erling Haaland(IRIS)	ABY

References

- RD-03323 Assembly 9 5/8" C-flex SS #53,5 Collapse Test1
- RD-03360 Assembly 9 5/8" C-flex SS #53,5 Collapse Test2
- Material certificates
- Risk-/SJ analysis

Index

Archer

1. HSE

Before test rig-up there will be held a pre-job meeting with all involved personnel with high focus on safe operations and procedure understanding according to Archer's standard for QHSSE. After this meeting all personnel shall be aware of their role and tasks.

Archer Oil Tools test personnel shall always have focus on safety and evaluate occurrences that may go wrong before starting operation. Test personnel shall always follow test facility's safety regulations in addition to Archers.

Remember key points:

Use Best Practice for all operation if available.
Follow rules and procedures.
Ensure that you have enough time, so that work is carried out in a safe manner.
Take action when undesirable condition is discovered.

Dangerous operation like crane operation, pressure testing, etc. shall always be evaluated before start and stayed cleared off.

Before test start-up there shall be held a pre-job meeting with relevant personnel which shall include do and don'ts regarding the operation.

Project responsible shall be contacted if any deviation from this test procedure occurs. No conclusions are to be made without involving the project responsible.

2. Background

To check if the capacity regarding collapse pressure rating can be increased for the seal between the Housing and the End Coupling for the C-Flex SS by modifying the design.

3. Part List

Part Number:	Part Name	Serial No.:	Heat No.:
RD-03324	Housing Modified	310695-1-001	
RD-03325	End Coupling Modified	310695-1-001	
RD-03337	Back-Up Ring		
RD-03345	Support Ring	310695-1-002	
RD-02220	Back-Up Ring	92381-2	
RD-03659	Casing	13713-1-1	
RD-03660	Test Cap 1/4" NPT	311574-1-001	
RD-03660	Test Cap 1/4" NPT	311574-1-002	
RD-03661	Backup Ring	TFM186591	
RD-03361	Housing Modified 2	310695-1-001	
RD-03362	End Coupling 2	310695-1-001	

4. Objective

4.1. Primary test objective:

Primary test objective is to check the capacity, regarding collapse pressure rating, for two new seal design suggestions for C-Flex SS.
Two collapse pressure tests shall be performed; one for RD-03323 and one for RD-03360. The procedures for both tests are the same.
The inside of the casing (RD-03659), for both RD-03323 and RD-03360, shall be pressurized until the seal between the End Coupling Modified and the Housing Modified starts to leak.
Both assemblies will be pressurized with gas at ambient temperature up to maximum 895 bar, which is the maximum collapse pressure the parts inside the test casing can be exposed to with a safety factor = 1.1.
Maximum burst pressure for the test casing is 896 bar with safety factor = 1.4.
At 895 bar and with a safety factor = 1.4 the threads in the test caps are exposed to a shear stress of 31.8 MPa. The yield strength for the test caps is 355 MPa.
It is expected that the maximum collapse pressure when the seal fails is between 500-600 bar.

4.2. Secondary test objective:

The secondary test objective is to check which one of the two new seal design suggestions for C-Flex SS has the highest capacity regarding collapse pressure rating.

5. Acceptance Criteria

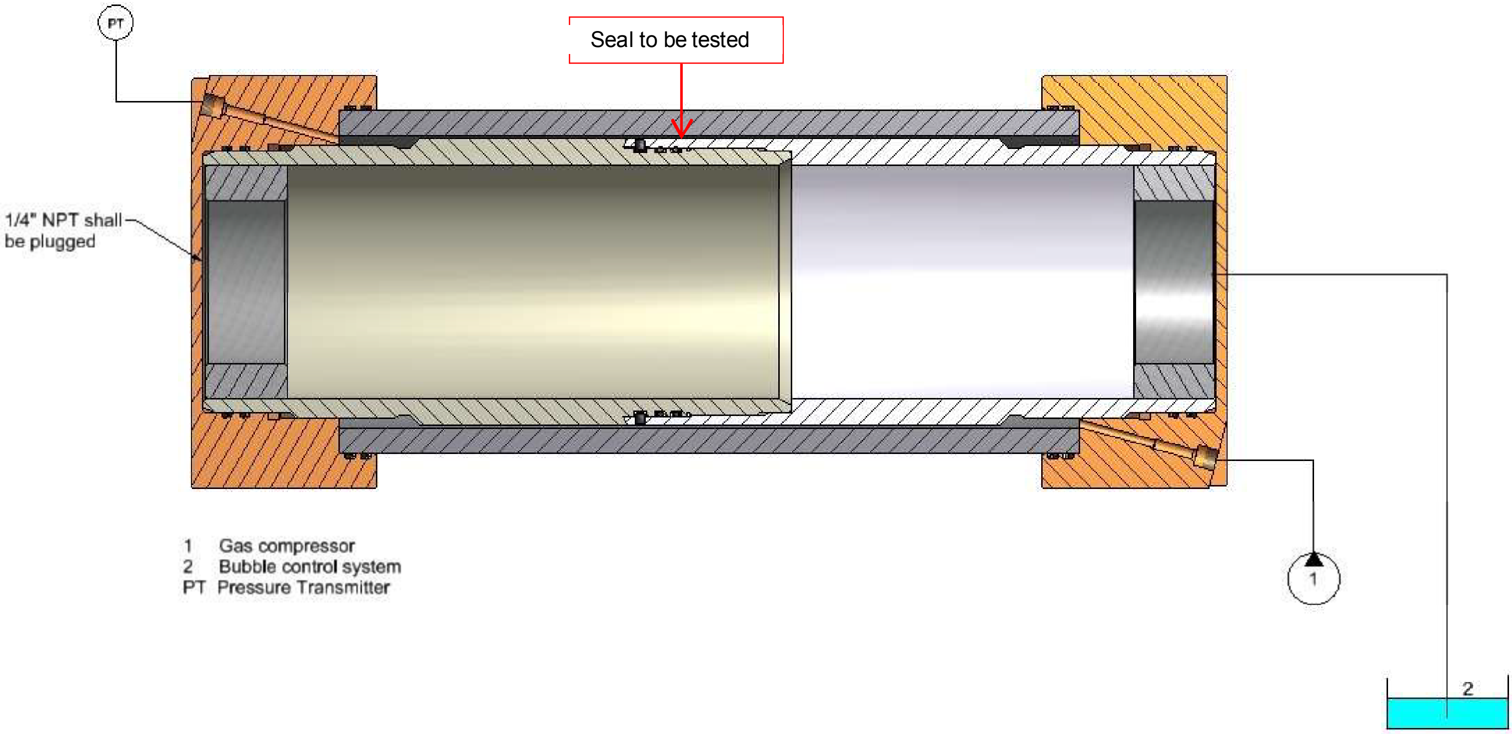
- Apply pressure on the test assembly in both tests until seal leaks. Can apply a maximum pressure of 895 bar.

- Measure at what collapse pressure seal starts to leak (if it starts to leak).

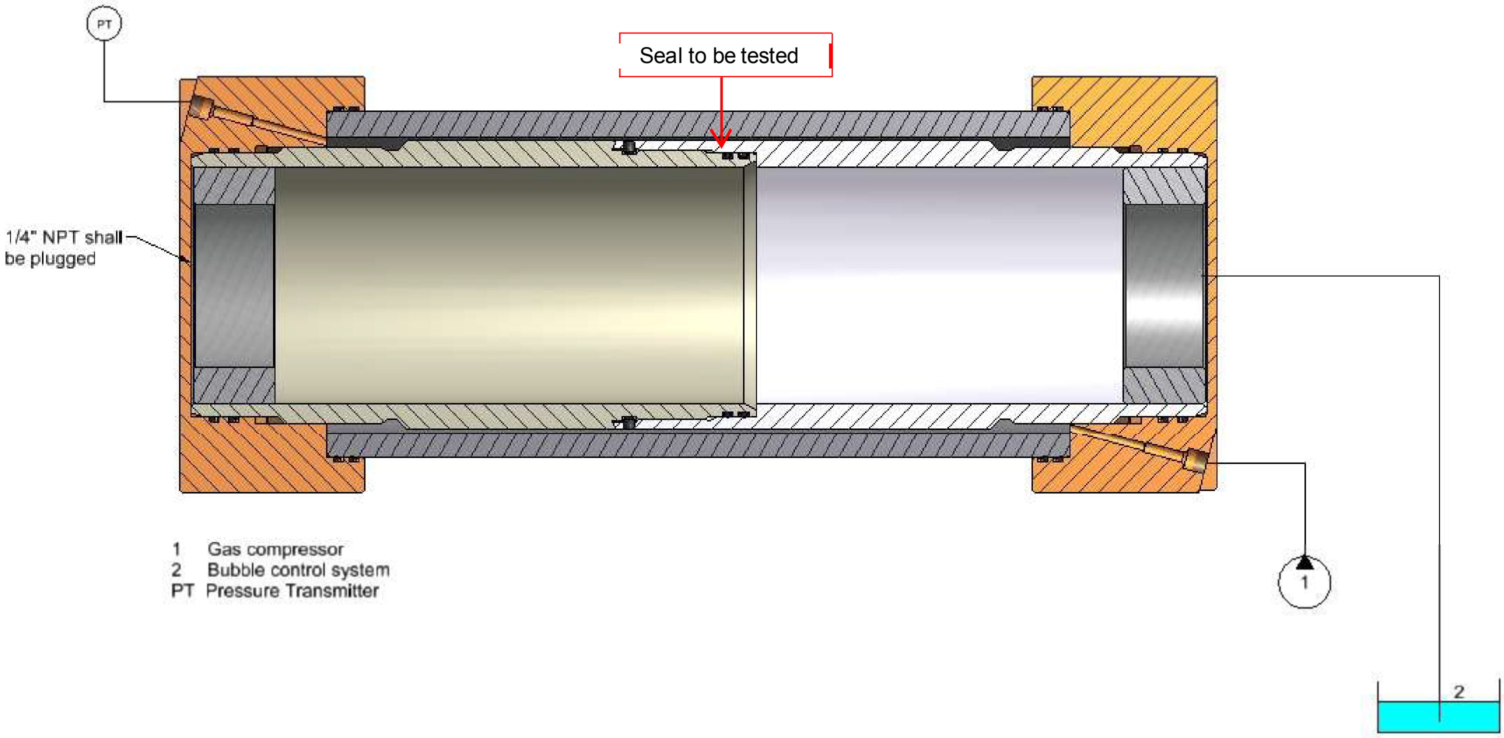
- Check if the capacity is higher than 550 bar, which is maximum collapse pressure for C-Flex SS 9 5/8" #53 (102-01-0084) (taken from performance envelope).

6. Setup/Schematic

Setup for Assembly 1; RD-03323



Setup for Assembly 2; RD-03360



7. Procedure

7.1. Prepare assemblies in Stavanger

7.1.1. Assembly 1

1. Assemble RD-03324 (Housing Modified) and RD-03325 (End Coupling Modified) with seals according to drawing RD-03323.
2. Install set/lock screws in slots, see appendix for torque guidelines.
3. Mount one of the test caps (RD-03660) on one end first and mount the test casing (RD-03659) to this. Then mount the last test cap on the other end. This shall be done according to drawing RD-03323.
4. Secure assembly for transport to IRIS, Stavanger.

7.1.2. Assembly 2

1. Assemble RD-03361 (Housing Modified 2) and RD-03362 (End Coupling Modified 2) with seals according to drawing RD-03360
2. Install set/lock screws in slots, see appendix for torque guidelines.
3. Secure assembly and remaining parts for transport to IRIS. The rest is going to be assembled at test location after pressure test of Assembly 1 is complete.

7.2. Test at IRIS, Stavanger

1. Install/prepare Assembly 1 for pressure test according to setup schematics.

2. Place Assembly 1 in water tank.

3. Apply pressure with steps of 100 bar up to 500 bar. Hold pressure at each step to control bubbles.

4. Apply pressure with steps of 50 bar and hold pressure at each step to control bubbles. Proceed till bubble control system indicates leakage and/or up to maximum pressure 895 bar. Expected pressure for leakage is 500-600 bar.

5. Bleed off pressure 6.9 bar/ 5 minutes.

6. Log values and results.

7. Disassemble Assembly 1 and check for findings. Pay special attention to seal between end coupling and housing. Document findings and take photos.

8. If there was a leakage proceed from step 11 and if there was no leakage proceed with the following steps.

9. Disassemble end coupling and housing and remove backup rings and one of the O-rings in the seal between the end coupling and the housing.

10. Assemble Assembly 1 as described in Chapter 7.1.1 and perform same test procedure as described in step 1-7.

11. Disassemble RD-03660 (Test Caps) and RD-03659 (Casing) from Assembly 1. Assemble these and the remaining parts on Assembly 2 (RD-03360) using same procedure as for Assembly 1, but according to drawing RD-03360.

12. Install/prepare Assembly 2 for pressure test according to setup schematics.

13. Place Assembly 2 in water tank.

14. Apply pressure with steps of 100 bar up to 500 bar. Hold pressure at each step to control bubbles.

15. Apply pressure with steps of 50 bar and hold pressure at each step to control bubbles. Proceed till bubble control system indicates leakage and/or up to maximum pressure 895 bar. Expected pressure for leakage is 500-600 bar.

16. Bleed off pressure 6.9 bar/ 5 minutes.

17. Log values and results.

18. Disassemble Assembly 2 and check for findings. Pay special attention to seal between end coupling and housing. Document findings and take photos.

19. If there was a leakage the test is completed. If there was no leakage proceed with the following steps.

20. Disassemble end coupling and housing and remove backup rings and one of the O-rings in the seal between the end coupling and the housing.

21. Assemble Assembly 2 as described in Chapter 7.1.2 and perform same test procedure as described in step 12-18.

22. Test complete.

8. Notes

Archer

9. Sign Off

Test procedure approved	☐
Test personnel qualified for work required to perform test	☐
Risk analysis/safe job analysis preformed	☐
Test area secured	☐
Retrieve and sign print out records	☐
Pictures taken	☐
Clean up test area, disassemble test equipment and store according to guidelines.	☐

Test Responsible: Hanne Lohne Morken

Name

Date/Sign

10. Verification

Test Witnessed By: Tor Eivind Hansen

Name

Date/Sign

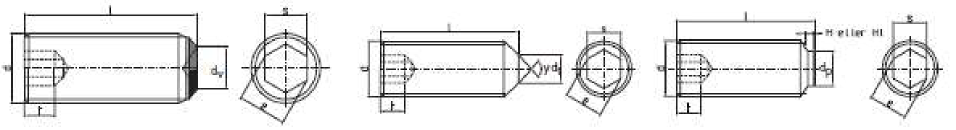
Third Party Verification:

Name/Company

Date/Sign

Appendix

Gjengestift



DIN 916 DIN 914 DIN 915

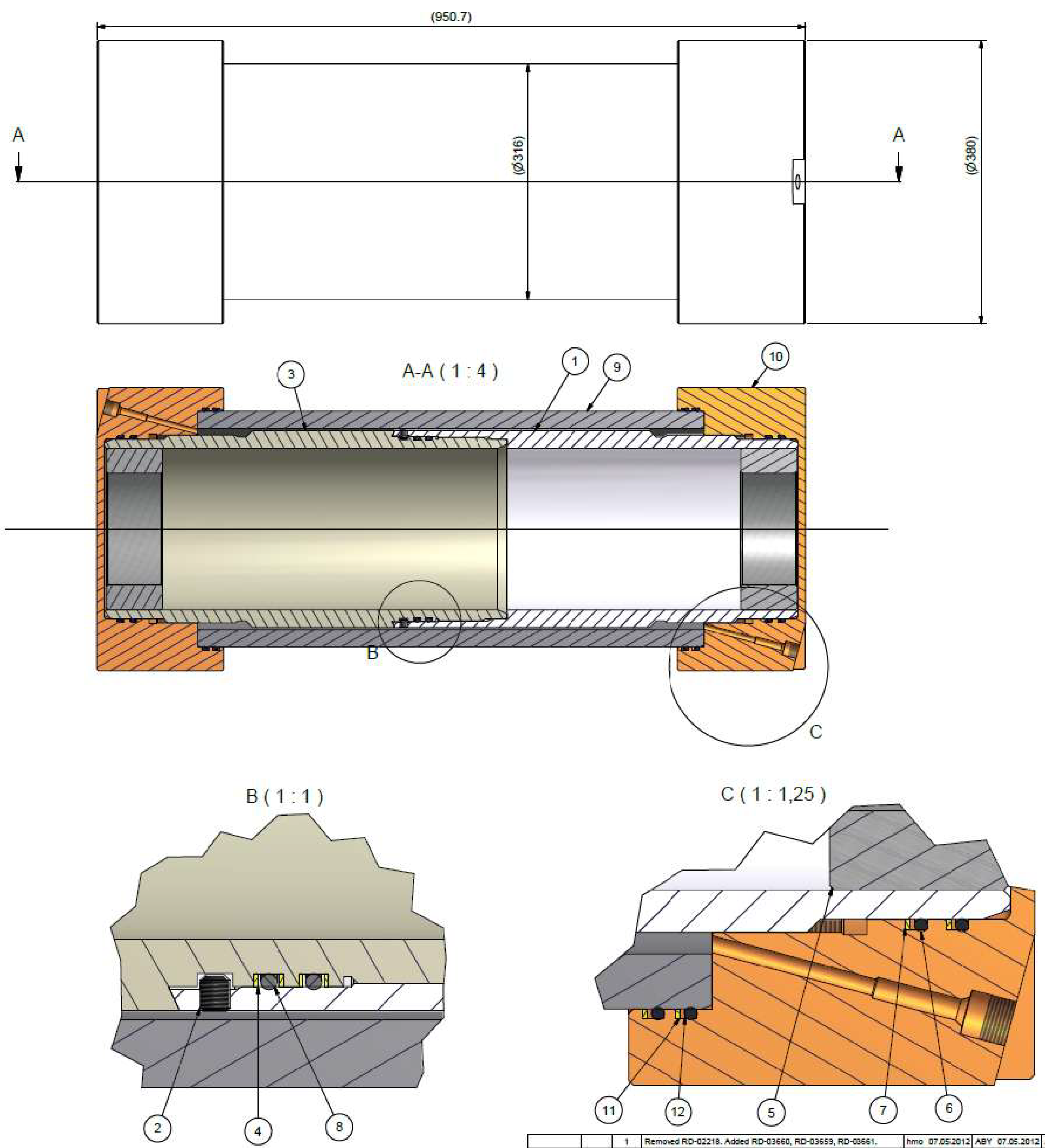
Alle dimensjoner i mm

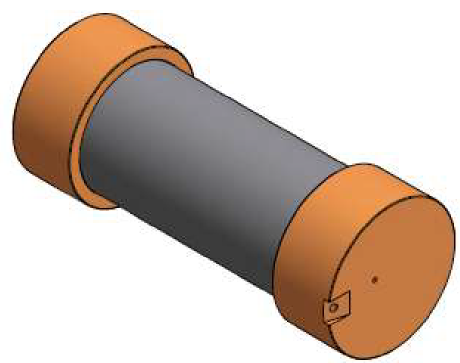
Nom. dia-meter	Hulende DIN 916 ISO 4029		Riflet hulende DIN 916 ISO 4029		Konisk ende DIN 914 ISO 4027		Tappende DIN 915 ISO 4028				Maks. tiltrekn. moment
d	dv max	s nom	dv max	s nom	dt max	s nom	H max	HL max	dp max	s nom	Nm max
M1.4	0.7	0.71									0.10
M1.6	0.8	0.71									0.10
M1.8	0.9	0.71									0.10
M2.0	1.0	0.89									0.21
M2.5	1.5	1.27									0.60
M3			1.30	1.5	spiss	1.5	1.00	1.75	2.00	1.5	0.87
M4			2.10	2.0	spiss	2.0	1.25	2.25	2.50	2.0	2.20
M5			2.40	2.5	spiss	2.5	1.50	2.75	3.50	2.5	4.60
M6			3.30	3.0	1.50	3.0	1.75	3.25	4.00	3.0	7.80
M8			4.30	4.0	2.00	4.0	2.25	4.30	5.50	4.0	18.00
M10			5.25	5.0	2.50	5.0	2.75	5.30	7.00	5.0	36.00
M12			6.60	6.0	3.00	6.0	3.25	6.30	8.50	6.0	62.00
M14			8.10	6.0	4.00	6.0	3.80	7.36	10.00	6.0	62.00
M16			9.10	8.0	4.00	8.0	4.30	8.36	12.00	8.0	150.00
M18			10.30	10.0	5.00	10.0	4.80	9.36	13.00	10.0	290.00
M20			11.50	10.0	5.00	10.0	5.30	10.36	15.00	10.0	290.00
M22			12.65	12.0	6.00	12.00	5.80	11.43	17.00	12.0	475.00
M24			14.65	12.0	6.00	12.00	6.30	12.43	18.00	12.0	475.00

Stål:
Materiale: Unbrako legert spesialstål
Mekaniske egenskaper: EN 20 898/5 - 45H
Hardhet: 45 - 53 HRC
Rustfritt stål: A2/A4 ISO3506
Spesial
Sertifikater: EN 20204 - referanse på hver boks

Benytt aldri skruer som er for lange. Settskruen skal sitte flush eller dykke like under overflaten. Stikker skruen for langt over vil lett brudd i den innvendige sekskanten oppstå. Bruk kun orginale Unbrako nøkler. Originale Unbrako-nøkler er fremstilt i spesiallegert stål med meget høye krav til toleranser og hardhet. Oppstår brudd i nøkkelen vil den ikke splintre, men skjære av like over skruen. Den brukne enden kan plukkes ut av sporet med en magnet uten at sporet er ødelagt. Er nøkkelen for myk, vil den ødelegge sporet i skruen og er den for hard, vil den kunne splintre med fare for skade på montøren.

Eksempel på etikett-original Unbrako





Pos	Qty	Part no	Description	Material
12	4	5-902-KA183-85	O-Ring 313,94x5,33 KA183-85	KA 183-85
11	4	RD-03661	Backup ring	3M Dyneon TFM4105
10	2	RD-03660	Test Cap 1/4" NPT	S355
9	1	RD-03659	Casing	AISI 4140 125KSI
8	2	2-373-KA183-85 2	O-ring 227,97x5.33 KA183-85	KA183-85
7	4	RD-02220	Back-up Ring	PEEK W4685
6	4	2-375-KB163-90	Parker O-ring	KB163-90
5	2	RD-03345	Support Ring	Aluminum
4	4	RD-03337	Back-up Ring	AP31TFM
3	1	RD-03325	End Coupling Modified	AISI 4140 125KSI (MDS 274278)
2	12	DIN 916 - M10 x 12	Hexagon Socket Set Screw	EN 20 898/5-45H
1	1	RD-03324	Housing Modified	AISI 4140 125KSI (MDS 274278)

Parts List

Comm. no.	Qty.	Rev.no.	Change	Drwn/date	Ctrl/date	Appr/date
		1	Removed RD-02218. Added RD-03660, RD-03659, RD-03661.	hmo 07.05.2012	ABY 07.05.2012	ABY 07.05.2012
		0	Original issue	hmo 20.01.2012	aby 20.01.2012	fee 20.01.2012

ELECTRONIC ORGINAL
TOLERANCING NS-ISO 8015

Material:

Tolerances for not tolerancespecified dimension corresponding to NS-ISO 2768 mk
General surface quality: 3.2 µRa

SIZE: A2

Scale: 1:4

Projection:

Archer

Drawn/Constr.: hmo

Date: 03.01.2012

Suppliers Drawing no.:

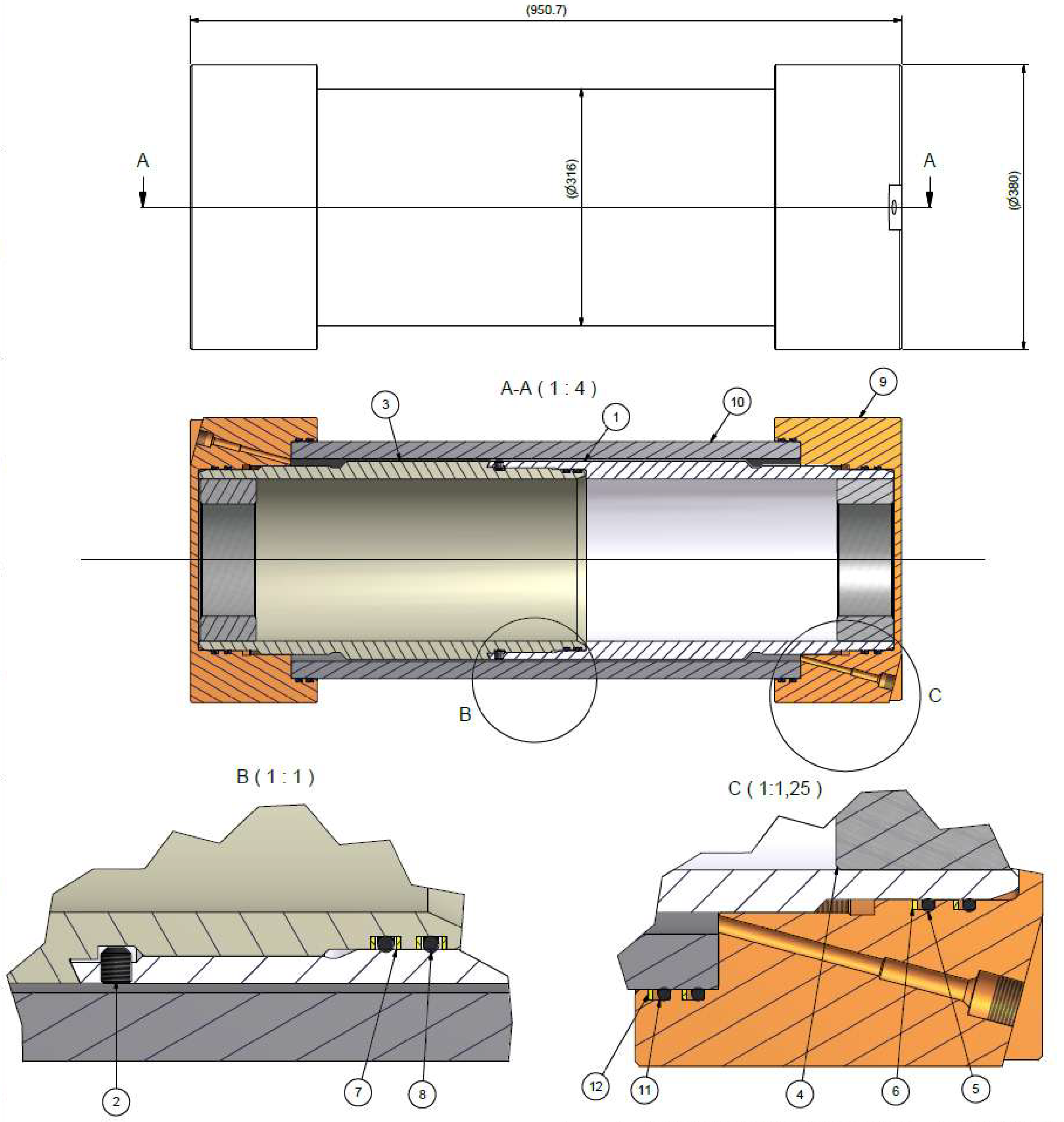
Page: 1 of: 1

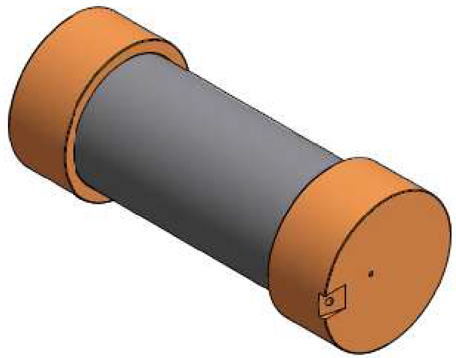
Assembly
9 5/8" C-flex SS #53,5 Collapse Test1

Drawing no: RD-03323

Project no.:

Weight: 407,022 kg





Pos	Qty	Part no	Description	Material
12	4	RD-03661	Backup ring	3M Dyneon TFM4105
11	4	5-902-KA183-85	O-Ring 313,94x5,33 KA183-85	KA 183-85
10	1	RD-03659	Casing	AISI 4140 125KSI
9	2	RD-03660	Test Cap 1/4" NPT	S355
8	2	2-373-KA183-85	O-ring 227,97x5.33 KA183-85	KA183-85
7	4	12-00164-01.	Backup ring	PEEK W4685
6	4	RD-02220	Back-up Ring	PEEK W4685
5	4	2-375-KB163-90	Parker O-ring	KB163-90
4	2	RD-03345	Support Ring	Aluminum
3	1	RD-03362	End Coupling Modified 2	AISI 4140 125KSI (MDS 274278)
2	12	DIN 916 - M10 x 12	Hexagon Socket Set Screw	EN 20 898/5-45H
1	1	RD-03361	Housing Modified 2	AISI 4140 125KSI (MDS 274278)

Parts List

ELECTRONIC ORGINAL
TOLERANCING NS-ISO 8015

Material:

Tolerances for not tolerancespecified dimension corresponding to NS-ISO 2768 mk
General surface quality: 3.2 µRa

Scale: 1:4

SIZE: A2

Projection:

Archer

Drawn/Constr.: hmo

Date: 16.01.2012

Suppliers Drawing no.:

Page: 1

of: 1

Assembly
9 5/8" C-flex SS #53,5 Collapse Test2

Drawing no: RD-03360

Project no.:

Weight: 407,041 kg

Comm. no.	Qty.	Rev.no.	Change	Drwn/date	Ctrl/date	Appr/date
		1	Removed RD-02218. Added RD-03660, RD-03659, RD-03661.	hmo 07.05.2012	ABY 07.05.2012	ABY 07.05.2012
		0	Original Issue	hmo 20.01.2012	aby 20.01.2012	fee 20.01.2012

Appendix G

Måleprotokoll

Tegningsnr.: "tegningsnummer" RD-03361

Her har vi målt innv. 246-6 Stub Acme og funnet gjengen ihht. tegning. Måleutstyr som er brukt er GAUGEMAKER

Tegningsnr.:"tegningsnummer" RD-03362

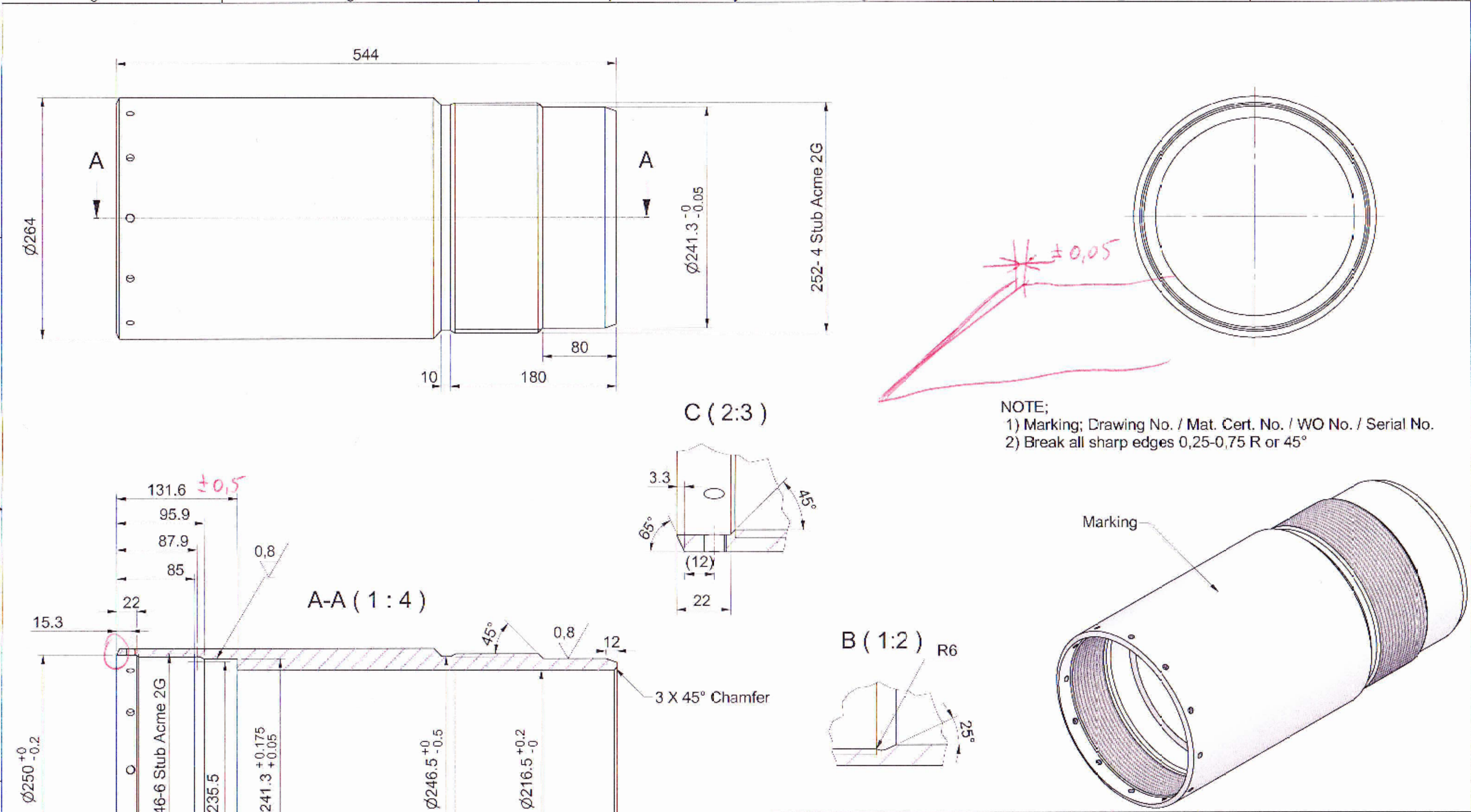
Denne delen er deformert. Vi har prøvd å måle på innerste gjenger som er minst deformert og funnet de OK ihht. tegning Måleutstyr som er brukt er Gaugemaker.

Date: 03.07.2012

Sign: Tommy Egeland

Tommy Egeland

Appendix H

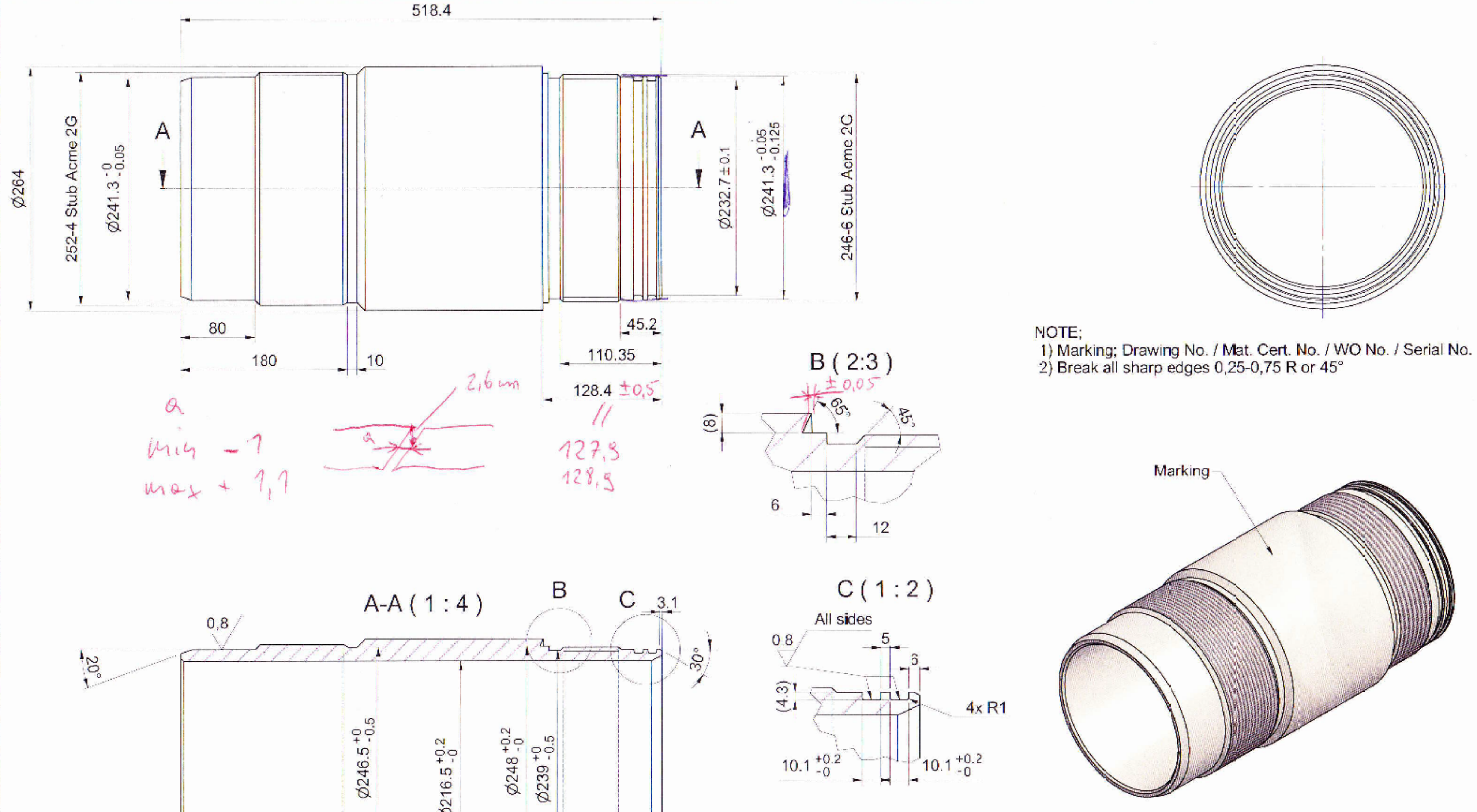


NOTE;
1) Marking; Drawing No. / Mat. Cert. No. / WO No. / Serial No.
2) Break all sharp edges 0,25-0,75 R or 45°

Comm. no.	Qty.	Rev.no.	Change	Drwn/date	Ctrl/date	Appr/date
		0	Original Issue	hmo 20.01.2012	aby 20.01.2012	fee 20.01.2012

ELECTRONIC ORGINAL
TOLERANCING NS-ISO 8015

Material: AISI 4140 125KSI (MDS 274278)		SIZE: A3	Scale: 1:4	Archer
Tolerances for not tolerancespecified dimension corresponding to NS-ISO 2768 mk; General surface quality: 3,2 µRa			Projection:	
Drawn/Constr.: hmo	Date: 16.01.2012		Suppliers Drawing no.:	Page: 1 of: 1
Mach. detail Housing Modified 2 9 5/8" C-flex SS #53,5 Collapse Test2			Drawing no: RD-03361	
			Project no.:	Weight.: 54,959 kg



NOTE;
1) Marking; Drawing No. / Mat. Cert. No. / WO No. / Serial No.
2) Break all sharp edges 0,25-0,75 R or 45°

Material: AISI 4140 125KSI (MDS 274278)		Scale: 1:4	Archer
Tolerances for not tolerancespecified dimension corresponding to NS-ISO 2768 mk General surface quality: 3.2 µRa	SIZE: A3	Projection:	
Drawr/Constr.: hmo	Date: 16.01.2012	Suppliers Drawing no.:	Page: 1 of: 1
Mach. detail End Coupling Modified 2 9 5/8" C-flex SS #53,5 Collapse Test2		Drawing no: RD-03362	
		Project no.:	Weight.: 53,331 kg

ELECTRONIC ORGINAL
TOLERANCING NS-ISO 8015

Comm. no.	Qty.	Rev.no.	Change	Drwn/date	Ctrl/date	Appr/date
		0	Original Issue	hmo 20.01.2012	aby 20.01.2012	fee 20.01.2012