Development of deployable Centralizer

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Preface

This bachelor thesis is the conclusion to our degree in Mechanical Engineering at the Western Norway University of Applied Science, campus Kronstad. This project tests our knowledge over several fields, with a focus on 3D modeling and design, and gives us a practical experience that is of big value for our future work. The bachelor thesis is written at the Department of Mechanical and Marine engineering under internal supervision from Professor Anna Dorota Kosinska.

This project was completed for Moonshine Solution AS, a company that specializes in petroleum industry solutions. They are working on a new approach for dynamic bow spring centralizers, and they asked us to come up with an engineering solution for a locking mechanism that prevents the device from engaging until it's in the right place.

We'd like to express our gratitude to Moonshine Solutions' CEO Helge Hope and Head of Engineering Jan Georg Tveiterås for allowing us to participate in the production of Smartalizer. We appreciate all of Helge and Jan Georg's assistance and advice during the process.

We'd like to express our gratitude to Assistant Professor Anna Dorota Kosinka our HVL supervisor. The positive feedback and timely answers to our daily questions have been extremely beneficial to this project. We really value all of the suggestions and assistance with the report's format.

Summary

Moonshine solutions have been granted the patent: *EP3164568 CENTRALIZER DEVICE AND METHOD FOR DEPLOYMENT OF A BORE HOLE COMPONENT IN A BOREHOLE* in this patent, they suggest an innovative way to create a deployable centralizer. The benefits of such a device are mense and will solve multiple problems related to the centralizers used in the industry. One possible way to do this is to insert a fluid pill filled with sodium hydroxide (NaOH) down the casing and up through the annulus. The fluid will then react in an exothermic reaction with aluminum until the aluminum no longer can support the stresses and thereby deploying a mechanism that activates the centralizer. Moonshine Solutions AS has come up with a design that uses this mechanism but further development is needed. In this thesis, we have been tasked to develop a locking mechanism that can support the large forces from the centralizer, but at the same time can be held back by the fragile aluminum. Multiple iterations following the Shigley's design process have been evaluated and analyzed until a final design is chosen. The final design is a viable and simplified version of the already existing design from Moonshine Solutions AS. This design lowers the cost of manufacture and ensures a high standoff in deviated wells. As the positive results from this thesis Moonshine Solution have brought this idea forwards to Schlumberger.

Sammendrag

Moonshine Solution AS har fått patent: *EP3164568 CENTRALIZER DEVICE AND METHOD FOR DEPLOYMENT OF A BORE HOLE COMPONENT IN A BOREHOLE* I dette patentet foreslår de en innovativ måte å skape en utløsbar Centralizer. Fordelene med en slik enhet er store og vil løse flere problemer knyttet til centralizere som brukes i bransjen. En mulig måte å gjøre dette på er å sette inn en væskepille fylt med natriumhydroksid (NaOH) ned i foringsrøret og opp gjennom annulus. Væsken vil da reagere i en eksotermisk reaksjon med aluminium, til aluminiumet ikke lenger kan støtte påkjenningene fra centrelizeren dermed vill mekanismen aktivere centralizeren. Moonshine Solutions AS har kommet med et design som bruker denne mekanismen, men videre utvikling er nødvendig. I detter prosjektet har vi fått i oppgave å utvikle en låsemekanisme som kan støtte de store kreftene fra centralizeren, men som samtidig kan holdes tilbake av det skjøre aluminiumet. Flere versjoner av mekanismen er lagd etter Shingly's designprosess. De er evaluert og analysert til en endelig modell er valgt. Den endelige modellen er en god mulighet til utførelsen av denne mekanismen. Det har også vært ett stort fokus på å forenklet mekanismen og der med senke produksjonskostnadene sammtidig som mekansimen er sikker. Etter de positive resultatene fra dette prosjektet har Moonshine Solutions AS vist fram ideen for schlumberger.

Abstract

Moonshine Solution is a small company consisting of four employees working part time. Due to this their resources are limited. They are focusing on innovative technologies in the petroleum industry is a large challenge due to the high standards and thorough testing that is required to bring products to the market. Because of this, their main focus is on

patenting the technologies and develop the technologies to the point where bigger actors in the industry can take their ideas further.

One of their most promising patented technology they have been granted is a patent EP3164568 CENTRALIZER DEVICE AND METHOD FOR DE-PLOYMENT OF A BORE HOLE COMPONENT IN A BOREHOLE which has led to an invention called The Smartalizer. The technologies described in the patent are a new method to infer an action on the outside of a liner or casing when downhole. This leads to the ability to make something like a centralizer which normally is a static component to a dynamic component, with this comes some crucial benefits. During a cementing job in a well, a bore is crucial to achieving a good annular space between the wellbore and the casing wall. If this is not achieved it has the potential to escalate into a serious situation. This happened in the Deepwater Horizon accident in 2010 that killed 11 people. After the investigation, it was determined that insufficient standoff in the well caused a bad cementing job and therefore the collapse of the well which resulted in an uncontrolled blowout. The Smartalizer solves multiple of the problems associated with the conventional bow spring centralizer. The Smartalizer delivers a higher restoring force which will lead to a better standoff. And it opens up the opportunity to use a bow spring-type centralizer in the whole wellbore, where commonly they are only used in vertical wells with some deviation.

Even though the patent was issued as new technology, it is still some uncertainty about the feasibility of material for the method of deployment for the technology. This project will do further development and feasibility test to further reassure the technologies application. As part of the process, a 3D model will be created using CAD software.

Contents

1 introduction

1.1 Report structure

The thesis will include an overview of the field of centralizers, as well as examples of how various types of centralizers are used and their limitations in chapters 2 and 3. Following this, the Shingley's design process is introduced which governs the structure of the design process and will be followed in sequence. This ensures a structured and well-composition design. The thesis finishes of with a conclusion to the design and recommendations for further work that must be done to bring this product to production.

1.2 Moonshine Solutions AS

The Moonshine Solutions AS is a local company from Bergen, Norway, specialised in the solutions for the oil industry. The company was funded in 2013 by Helge Hope, Jan Georg Tveiterås and Alf Breivik who together have over 60 years of experience working on oil platforms, where thay have been on positions as Driller, Rig manager, Rig Safety Officer and Driller engineer. This first-hand experience is foundation for their interest and innovative ideas in the industry. Today they have base office at VilVite and are a part of the VIS Innovasjon.

The company has acquired multiple patents since its infancy, naturally, their main patents are focusing on developing and improving new and existing technology which overcome everyday challenges in the oil industry and improve the overall efficiency.

1.3 Background theory

1.3.1 Drilling

When drilling an on- or off-shore well, drilling mud also referred to as drilling fluid serves multiple purposes. The drilling mud is a water-based substance that has been added particles and chemicals to, this alters the density and lubricating abilities that help during drilling. If the pressure gets too high in the well, the pressure will then overcome the drilling fracture pressure (1) and can cause loss of circulation. If the pressure becomes too low contaminations from the surrounding formation can leak into the well, and in the worst case can the formation collapses in on the wellbore and cause loss of the well. To be able to keep the pressure within the drilling window as seen in figure (1) geologist specializing in well pressure creates models based on geological surveys to keeps the delicate balance in the well. When keeping the pressure inside the drilling window is no longer possible as seen in figure (1) it is then necessary to run casing followed by cement, this will reinforce the wellbore to keep the well pressure separate from the formation. This gives the driller the possibility to further increase the pressure above the previous limits. In figure (1) this can be seen in the horizontal lines this makes sure that the pressure at any point during the drilling process surpasses the allowable drilling window.

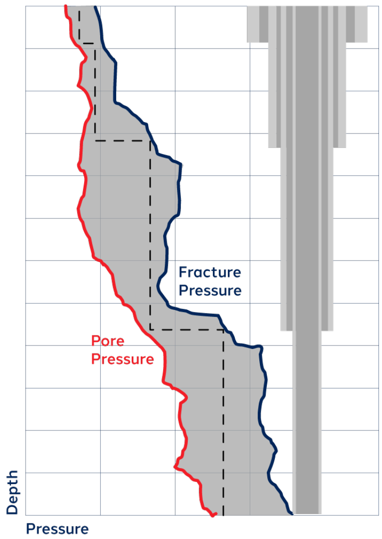


Figure 1: Drilling window

1.3.2 Cementing

To initiate the cementing process, it is first necessary to run casing total depth (TD). On the outside of the casing wall the centralizers are installed to keep the casing from touching the well bore. This ensures that the casing is centered in the well bore so the flow around the annulus of the casing can be as uniform as possible. Then the clean-out process begins, this is done by flushing out the remaining residue and mud from the annulus. Then a cementing plug is inserted into the casing. This is done to create a barrier between the mud and cement slurry on the way down to TD, which prevents contamination in the slurry. When the plug has reached TD a diaphragm in the plug will burst when a predetermined pressure is applied, this allows the cement slurry to ow into the annulus.

1.4 Different types of centralizers

Today there are centralizers which differ in characteristics, so they cover different needs when centralizing the casing.

Bow-spring centralizers are characterised by flexible springs attached to two collars. Outer diameter of such centralizer is slightly bigger than the well diameter, so the springs are supposed to compress uniformly and cause desired standoff. Size, shape and the number of bows can be alternated, but the performance requirements such as starting force and restoring force are determined in API Spec 10D. Bow-spring centralizers are particularly used in vertical sections because they are less expensive than other types and can pass through narrow passages with ease because of the bow's flexibility.

The downside of bow-spring centralizers is that they are subject to the restoring force, so in cases of highly deviated and/or casing weight they would certainly collapse. Such cases can easily lead to the restoring forces of 200-400kN, way beyond centralizer limits. [10]

In cases where the sturdy centralizer is mandatory, the rigid centralizer is used. **Rigid centralizers** are sized with respect to specific casing and/or hole size and the side force is not a big factor here. Rigid centralizer blades are usually produced using steel bars or cast iron, assuring high limits and possibility to be used in deviated well bores. However, the rigid centralizers are often smaller than the well bore, reducing centralization effectiveness, so bow-spring centralizers are more suitable to use when possible.

Semi-rigid centralizers have characteristics of both bow spring and rigid centralizers. They are manufactured by double-crested bows. Those bows can compress and get through tight places, but because of their design they can support restoring forces exceeding the standards outlined by API.

Lastly, there are **mold-on centralizers**. As name suggest those are applied directly to the casing surface. They are fabricated to exact dimensions using carbon fibre ceramic materials, so they suit specific well applications. Carbon fibre produces friction forces lower than those which occur when metal is used, so it also reduces the chance of casing buckling.

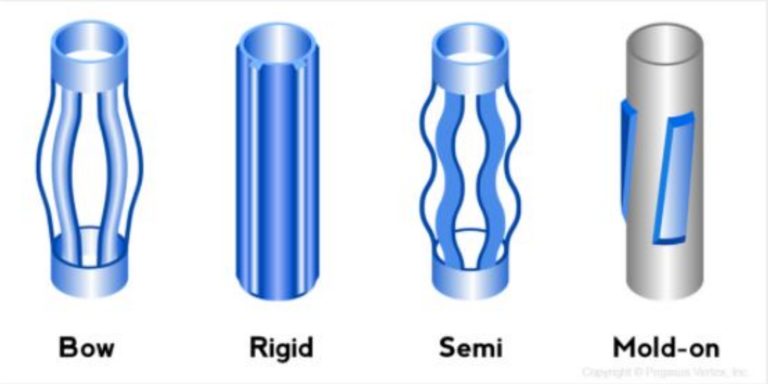


Figure 2: Different types of centralizers[10]

1.4.1 Application of bow spring centralizer

As already mentioned, a good cementing job is crucial for good petroleum and natural gas extraction. To achieve that centralizers are commonly used in the indusrty, as name suggests, they are used to centralize case inside an well bore before cementing process. The goal when using an centralizer is to achieve best possible standoff between well bore and casing, according to the API 10D [7] a bow spring centralizer should minimum create a 67% standoff, a better standoff is preferred for an cementing job of high quality. For ease of understanding, 0 percent standoff means that case and well bore are touching, 100 percent means that the case is perfectly centralized inside the bore.

The biggest challenge when cementing are mud pits inside the well bore. They occur because of poorly placed cases, mud is prohibited from escaping the bore as a result of bad standoff, it gets stuck, creating mud pockets between well bore and casing. Naturally, cement does not get through those pockets, and therefore fails to support the casing as intended. Simultaneously, empty pockets can be formed inside concrete itself because of disturbances in the fluid flow. Purpose of an centralizer is to restrict those imperfections by allowing free fluid flow.

1.4.2 Proper use of centralizers

When it comes to placing centralizers on the casing, there are mainly 4 different placements[16];

- Over the stop collar: Typically optimal centralizer placing, since it enables centralizer to move in both directions.
- Between stop collars: Optimal for rigid centralizers, and other centralizers designed to perform when being pushed down through the hole.
- Over couplings: This placement removes the need for a stop collars, but complicates assembly of the system, and can lead to some unwanted dynamic loads on the centralizer.
- Between couplings and stop collars: This placement have to be done with great precision for optimal behaviour of the centralizer, but it uses only one stop collar, reducing the costs.

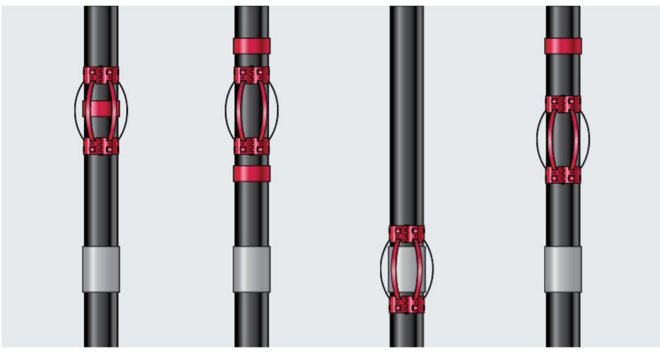


Figure 3: Centralizer placing

Next important thing to evaluate is number of centralizers and distance between them. This is an difficult task, since we can't be 100 percent sure how the rig will behave under the surface. Too many centralizers and the casing will stuck in the bore hole, too few, and we won't get wanted standoff, leading to a bad cementing job. Simultaneously, companies have to think about practicality, and ease of assembly.

To obtain satisfactory results drilling companies are often using sophisticated numerical software, such as CentraDesign (Pegasus Vertex,inc.), to find optimal solutions.[17]

1.5 Innovation

The Smartalizer is slimmer than traditional bow spring centralizers, allowing it to travel through narrow passages with ease. Unlike traditional bow spring centralizers, which exert a large amount of radial forces on the structure while within the borehole, this increases the drag coefficient between the topdrive and the borehole. The Smartalizer aims to reduce this by delivering a small standoff on the way down in the well, this reduces the drag significantly compared to a casing with or without centralizer. The importance of this gets more and more prominent the deeper the well goes since with every centralizer connected to the casing increases the drag coefficient. The Smartalizer also reduces the risk of sticking because it prevents the casing dragging along the bore hole.

The Smartalizer will avoid the norm by not exerting the massive forces that a traditional bow spring centralizer would apply to the formation. The maximum force allowed to press against the formation while running casing is regulated by the API 10D standard. For this reason, solid bow spring centralizers do not deliver the optimal restoring force to achieve a 100% standoff. The Smartalizer however can overcome the limitation in restoring force the centralizer can deliver by only deliver restoring force when the centralizer is activated in its final position. A normal bow-spring centralizer cannot be used in large inclination wells due to the limiting force it can apply. But the Smartalizer opens up the use cases for a bow spring centralizer to be used in horizontal wells, this will achieve a lot greater standoff than any other type of centralizer type in horizontal wells.

1.5.1 Possibility for rotation

One more benefit of this design is that this centralizer can be made with intention to rotate by adjusting the press connection between the collar and bow spring, so the casing inside the centralizer can rotate too, which assures better fluid-displacement efficiency in highly deviated well bores.[14]

1.6 Possible challenges

Possibly the biggest challenge with this product is that it is something unique and there is not much research done so far, so the whole project has to go through many demanding and resource-intensive tasks before it gets available in the industry. Have in mind that these challenges mentioned here are only theoretical until necessary tests are done.

- Assembly: The final model will need to be mounted and pretensioned before transport and any on-site actions are taken. Fortunately, there are not too many parts included in assembly procedure, but the whole operation needs to be done delicately and precisely, many parts are designed with small proportions and close tolerances so there is no place for mistakes. The bow springs needs to be stretched before they are locked in place with elastic connectors and the locking ring. The stretching procedure and the pretensioned system after that means that there is a great tension in the system, so it must be done in safe environment, any failures can lead to serious injuries and can be fatal.
- Transport: When pretensioned, the system needs to be transported to the site in special packaging secured from any possibly external influences. Because of that, the transport itself is a bit more demanding compared to other conventional centralizers, which can be transported with very few precautionary measures taken.
- Moving through the well: Here, the whole system is put to the real test. The centralizer will meet some considerable friction forces, hits and rattles on its way down the well. The centralizer must be rigid enough to withstand all these resistances without unlocking until it is in desired placing. Eventual fail, and unwanted system activation could spoil the whole project.

The problem like with every other operation below the ground is that it is impossible to see what is going on. All presumptions are made by calculations and geometrical examinations. Once the system is deployed in the well there are no other possibilities than to rely on those calculations made earlier and possible ongoing measurements.

One more problem related to movement through the well is side force which could squeeze the springs so they stretch and lose contact with elastic connectors. If that side force suddenly disappears it could lead to a furious spring retraction , and big impact on elastic connectors which could damage them, or, more likely, damage locking ring.

Lastly, the bow spring should be released and retract uniformly to assure that wanted result is achieved. Uneven retraction could lead to skewed standoff.

2 Method

When reasoning, there are three orthodox approaches, two of which are relevant for this actual project, and which are used. Those two different approaches cant be viewed as opponents to each other, since they supplement each other, and this is shown through this project.

2.1 Theoretical

Once given the task, inductive approach is taken and assumptions are made based on earlier experiences. After that, the research on current topic, centralizers, and all necessary researches on relevant subject, such as oil exploitation, and others, which can be useful for further project development are done. There is a lot focus on existing challenges that can be overcome with this new solution in future oil drilling. With good theoretical foundation, solid hypothesis can be made now, and with given requirements, this is a good base for model development.

2.2 Practical

Based on hypothesis and expectations, design modeling is started by doing basic calculations to get an insight on which forces and stresses this exact model is dealing with, and this establishes good foundation for designing process. Then, the drafts are made, rough models, which should meet all requirements if all the calculations are correct.

To test all calculations the ANSYS is used, a simulation program which does a number of calculations each second with the highest possible precision. In case all expectations are met, the model is refined and developed further till an final model.

So in this part of project development the deductive approach is taken.

2.3 Source of error

The most important source of error to consider are human themselves. Firstly, it is important to keep a neutral angle, which can get challenging with the time. After a lot of researching people tend to get some thoughts about the project, so it gets difficult to resist the urge to make biased reports on the subject, specially if the researcher has some interests in the project, or simply just want it to succeed. All statements should be questioned, and possible risks should be marked. The time is a big factor in every project, so people choose to cut out important actions, necessary for further development in order to buy more time. The time pressure is source of error difficult to bypass.

Then, there are often many people involved in the project, and everyone should contribute the project with reliable data. To be sure, the researcher should double check the essential information given, the errors can occur in most subtle places, often easy to overlook. Those small errors are the reason of many big engineering disasters. Taking different approaches to different experiments could also lead to biased results.

The retracting centralizers are relatively new technology, and there are still very few articles about it, so doing quantitative research is challenging, and so is the qualitative research, since there are not many research articles to compere to each other. Using too few cases in research process can lead to sampling errors, luckily the supervisors form Moonshine Solutions AS have a lot of experience from the field and know exactly what is expected from this system.

This project depends on stable numerical experiments, as such its is susceptible to math errors. To make sure that all calculations are accurate, the researcher should repeat those calculations in different occasions without impressions from earlier experiments. It is even preferable with more people doing these numerical experiments independently, to secure not biased results.

All precautionary measures are taken to minimize the chance of error, but it can never be fully neutralized.

3 Design process

Shigley's design process is a six-step process that controls the entire design from start to finish, its purpose is to come to a valid result most efficiently and organized. It can be used in new projects or improvements to existing projects.

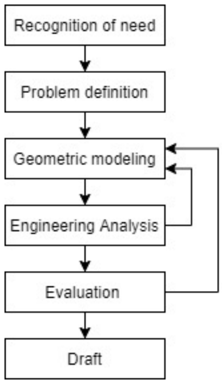


Figure 4: Shigley's design process

The process starts with Recognition of needs figure [4] is the initialization of the process, this is where the individuals initiate the process and set goals and objectives with the project. In our case this is already done by Moonshine Solutions AS, they have found a problem that they want to solve and established the grounds for further development.

The next step is Definition of problem this is where one shall cover the dominating specifications of the product, so it functions properly. In this instance, the problem is already defined by the previous work done by Moonshine Solution AS. The limiting constrains are dependent on functional and physical characteristics and is sat by standards and working principle. This will be elaborated on in the design criteria chapter.

The synthesis phase is where inspiration and research are collected from external sources and thereby ideas that potentially can solve the problem are sketched up. This idea will then go through a feasibility test and then the designs will be compared with limitations. From this, the design will be chosen as an option or be discarded. When there is couple of viable options they will be drawn up in Computer-Aided Design (CAD) software. In this project, this will be done by Autodesk Inventor due to the ease of use and it is commonly used in the industry.

The Analysis and optimization phase is where simulating the physical forces is done to evaluate the material and dimensions. This is done by a combination of numerical calculations and Finite Element Method (FEM). ANSYS will be used to preform the FEM analysis in this project.

3.1 Modeling process

Top-down modeling

The top-down modeling approach is a computer aided design (CAD) method where the modeler knows what the structure should look like but does not know the precise dimensions. Therefore, all dimensions will be dependent on each other and be parametrically constrained, this gives room for editing the design fluently down the line, all dependent parts will then automatically adjust. Due to the iterative nature of the design process, it is necessary to have a fully constrained parameter-driven model. This gives the ability to change dimensions in the process. When the calculations and FEM analysis is completed the design will most likely need some dimensional changes, therefor this method will be beneficial.

Initially using a top-down approach is more time-consuming than the bottom-up approach but it is beneficial when not knowing the final result. And it gives room for iterations.

4 Design considerations

The design goals and limitations will be discussed in this chapter, which will lay the groundwork for the further creation of potential design solutions. Limitations from a wide range of sources will be added and clarified.

4.1 Transferring forces

In the requirements from Moonshine Solutions, it is stated that porous aluminum is used as the actuating mechanism. The porous aluminum has a relatively low tensile strength; therefore, a large portion of the forces must propagate through the casing instead of the aluminum. To overcome this different types of mechanical advantage can be utilized and combined.

4.2 Aim and objectives

As with every other project, the aim is to make a optimal concept which firstly will satisfy the company it is done for, but also all the organisations and people which could have special interest in the projects outcome. To do that the task is divided into several smaller tasks, or objectives, by completing all these objectives, the main task will be accomplished.

4.2.1 Defining the task

Before even starting the project its obligatory to make sure that the task is well understood, and the team agrees on what the final goal is. When that is done all given conditions are evaluated and categorized to simplify the remaining work.

4.2.2 Choosing the right design

The main task, and most important work in this project is choosing the right design which meets all juridical and individual requirements. Visualising different models through drafts, makes it easier to represent different ideas, show theirs advantages and disadvantages, so its easier for managers to choose the optimal design. (INCLUDE OUR SIMPLE DRAWINGS OF IDEAS) More about the designing process in the chapter 5.3.

4.2.3 Parameter optimization

Aesthetically appealing design is important factor when selling new technology, but it can become useless if its unable to sustain all loads it will encounter at some point. So, when desired design model is chosen, doing adequate calculations on all related parts is obligatory to find an starting point for the model dimensions. When that is done the model is visualised in an CAD program, and all dimensions that have some affiliation and depend on each other are put together and parametric connection is made, so when some changes are done to an dimension, other dimensions which are connected to that one dimension will adapt to these changes. This makes all future modelling work simpler by cutting down the time necessary to do all these changes individually. Next step in project progression is simulating possible loads on these models in ANSYS for most precise results. More on simulating process in next sub chapter.

4.2.4 Simulations

Using computer aided calculations minimizes the chance of calculation fails and gives results with extreme accuracy, as long as the right criteria is provided. As already mentioned, these calculation programs are able to do millions of calculations over a short period of time, which significantly reduces time and manpower needed for the job, still, a qualified supervision is necessary. The CAD models are run through a number of simulations until the desired results are achieved. After every simulation the results are analyzed in detail, and those times there is place for improvement, parameters are readjusted and the simulation process is repeated. The good thing with simulation programs is that boundaries given for an CAD model can be saved, and used for another model where necessary changes are done, so yet again, the whole process of model readjustment is reasonably effective.

4.3 Design criteria

When designing this system there are two main sources of design constraints. One coming from the company Moonshine Solution AS and their specifications for the dimensional and functional constrains, and the other coming from the Norwegian standards used in the petroleum industry.

The main standard that is used in this thesis is the one in the association with centralizers, API specification 10D "Specifications of bow-spring casing centralizers", and one standard associated with casings API Specification 5CT "specification for Casing and Tubing"

4.3.1 Moonshine Solution

The configuration of the Smartalizer must be made to fit on the (OD) of a 13 3/8" (339.725 mm) casing body. But the template should be able to size up or down to work into various casing dimensions in the future. The maximum outer dimension of the centralizer in for a 13 3/8" casing should be no larger than the casing coupling which is according to API specification 5CT Table C.35 is 14 3/8". this gives 1" (25.4 mm) larger than the casing (OD). Therefore should the mechanism not protrude out more than ½" (12.7mm) from the casing outer diameter OD.

The length of the mechanism should be as small as possible to be able to hold the axially dimension.

4.3.2 Axial Forces

A bow-springs positioned on a 13 3/8" (339.725 mm) casing must minimum deliver a restoring force of 5 427 N at 67% standoff ratio according to API Specifications 10D Table 1.in prior work where the bow-springs was constructed to exeed these specifications. The bow springs were then stretched in the axial direction. This results in a radial deformation, the deformation lowers the OD of the Smartalizer until it reaches the allowable outer diameter. From this analysis, the pretension load was then determined to be 18.333 kN per bow-spring. To achieve the restoring force with the weight of a 12,9 m 13 3/8" casing. Six bow springs would be necessary, this results in an axial force of 110 kN. That will be the force the mechanism must hold.

4.3.3 Aluminum segment

According to the patent of Moonshine Solutions, it will be necessary to use a segment that causes an action that will release the pretension stored in the bow-springs. There are a couple of options that can be used to achieve this goal. In the patent nr: US2010/0078173 produced by Moonshine Solution AS there is mentioned an SMA (shape memory alloy) that is activated when the right temperature is achieved. There are some problems with using temperature-sensitive materials, these are materials that are reliant on highly precise temperature control, this would be very challenging due to the natural temperature gradient along with the depth of the borehole. So that option is if not impossible it is very hard and requires a good understanding of the material sciences.

One option is to alter the PH value from the natural 9-9.5 PH in OBM (oil based mud) or 7-9 PH in WBM (water based mud) to a PH value of 13 by adding sodium hydroxide (NaOH) to the fluid. This fluid will cause a chemical reaction with a segment of aluminum. The chemical reaction is normally very time-consuming, but by altering the amount of surface area exposed to the reactance a faster reaction time can be acquired. For this reason, a porous aluminum segment is chosen.

Porous aluminum is produced by casting aluminum into salt crystals. This results in pores in the aluminum structure when the salt is washed away. In this process, the internal structural integrity is significantly decreased compared to a solid block of aluminum. It reduces the tensile strength from 1600-240MPa dependent on the treatment to 26-7.2 MPa dependent on the pore size. As seen in the attached table for aluminium, below the pore size can be range from 0.2mm to 4 mm, in this case, it is advantageous to develop a mechanism that takes advantage of the structural strength of the material. For this reason, the material with the highest strength is preferred, as seen in the table below the strength of the material increases with smaller pore size, therefor a grade of 0.2-0.35mm is chosen, it has the highest tensile strength of $26N/mm^2$ this grade also has the highest surface area and therefore results in a faster reaction time.

When sodium hydroxide reacts with aluminum and water, hydrogen gas is produced. The aluminum absorbs the oxygen atom from sodium hydroxide, and then absorbs the oxygen atom from the water, releasing the two hydrogen atoms, resulting in hydrogen gas and sodium aluminate.

2 Al + 2 NaOH + 2 H2O → 2 NaAlO2 + 3H2

As a result of this, the aluminum loses mass and thereby its strength. The reaction time is greatly dependant on the exposed surface area and temperature. After experiments that have been conducted for Moonshine Solution AS, a solution of 1 % sodium hydroxide is sufficient to break down the aluminum.

4.3.4 Chain reaction

When a casing is in the borehole it will not be in contact with the altered solution on all sides due to the varying amount of standoff. This implies that the activation chip would need to be placed strategically around the circumference. As a consequence of the uncertainty of the material properties, it is necessary to construct a mechanism that releases a chain reaction that causes all the activation segments to release the remaining holding force when one of the segments breaks.

5 Design iterations

5.1 Moonshine Solutions existing design

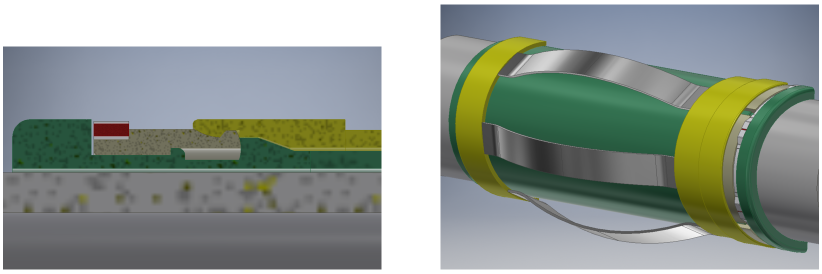


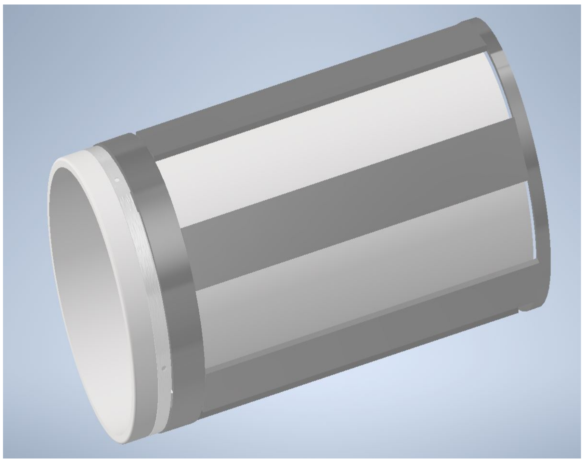
Figure 5: Moonshine Solutions Design

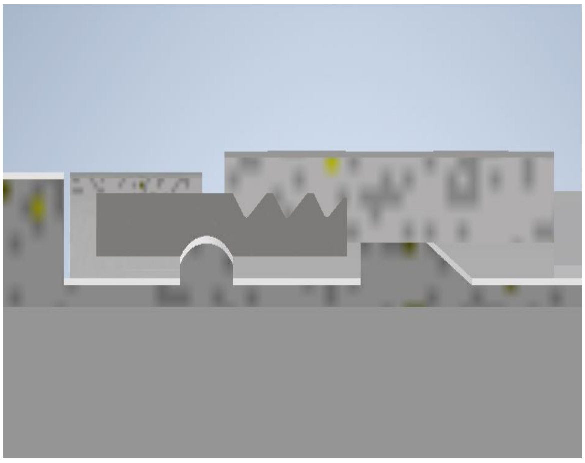
In the thesis proposal from Moonshine Solutions AS, they had a design based on the concept of using a lever action to reduce the forces acting on the aluminum segment. Here will the forces from the pre tensioned bow springs be held back by multiple curved leavers placed around the circumference of the centralizer. The leavers will be held back by a bond with strategically placed aluminum segments around the circumference. This holds back the actuating force. But the design has some problems, by making a curved ridged leaver and then trying to bend it on a ridged cylinder. Collisions between materials will occurred and prevent the lever from actuating. After discussing the design and doing the calculations with Moonshine Solutions AS it was discarded due to the high radial forces and difficult tolerances necessary to make the levering mechanism work. But the idea of using a bound to hold back the forces were taken further since it satisfies the chain reaction criteria mentioned in chapter 4.3.4.

5.2 Fundamental Design

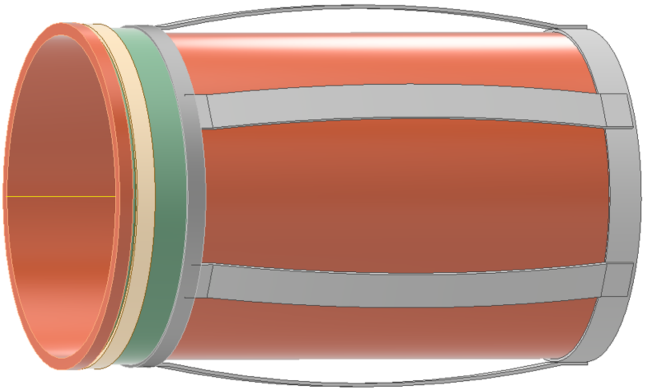
This design is mainly based on the design developed by Moonshine Solutions AS. But it introduces some essential changes to improve its function. The original model had a serious flaw in the ring which purpose was to hold and release bow springs. The system was based on lever principle, where the holding ring was supposed to overbalance to one side resulting in spring releasement. But as the ring is solid it is unable to just tip over, it must twist for the system to work, which is unpredictable reaction to induce. To overcome this challenge, four locking brackets are introduced in this model instead a solid ring. The brackets are a desirable solution since it makes it possible to change quantity of them as well as quantity and angle of locking tooth in intention to manipulate the occurring stresses in the system.

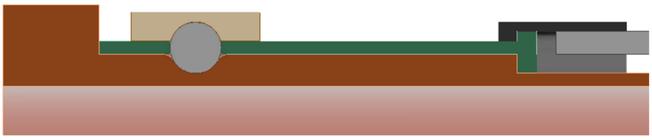
Further, we can see aluminium pins instead of aluminium brackets and self-locking system for the ease of mounting. Self-locking detachable ring is somewhat difficult to set up. Still, it is uncertain if the solvent is strong enough to dissolve aluminium pins effectively.





5.3 Thread Design





This is a design that takes a different approach then the other iterations suggested. This takes advantage of an over-hauling screw principle. The forces from the bow springs are translated through a ledge. This allows the collar witch the ledge is connected, to rotate around the circumference of the casing. On the inside of the rotating part, some slots/ threads will transfer most of the forces through the body, the forces transferred depends on the pitch angle. The pitch angle is so large that mechanism will self-deploy if it is not held back. To hold back the restoring force a bond is used. equivalent to the bond used in the original proposal from Moonshine Solution AS. This is used on the outside of the rotating part; the bond will hold back steel balls that protrude through the rotator and into the body. The rotation will apply a force that will push the balls out of their socket in the body. This will in turn divide some of the force into the body and some of the force radial. The bond stops the radial force from releasing the balls and thereby actuating the mechanism.

The advantage of this design is that it greatly reduces the forces on the aluminum. But the drawback is the added complexity of the system.

6 Final Design

In this chapter, the engineering of the final Smartalizer proposal is deliberated on. This is done in the correct order according to Shingley's design process, this will go under the Synthesis phase where all prior information and specifications are taken into consideration and combined to create the prototype. At the end of the chapter materials, technical drawings, and discussion on the final results will be covered.

Takeaways from the prior iterations

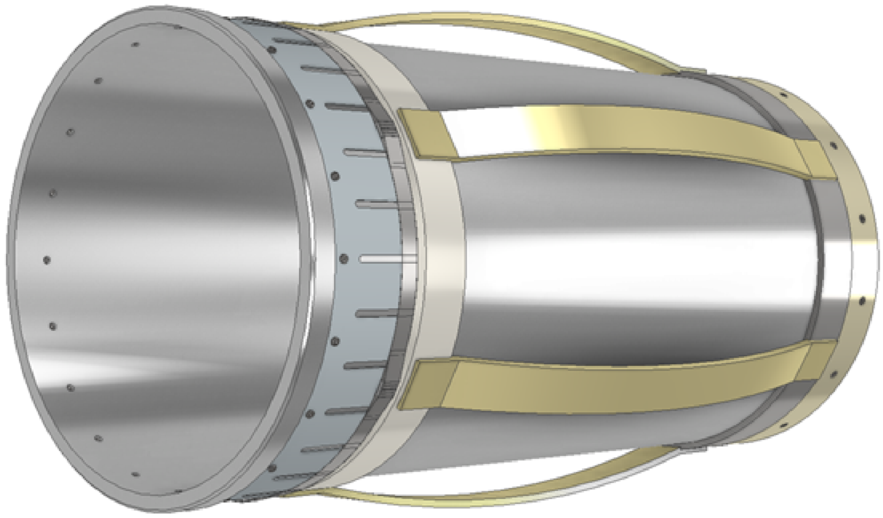


Figure 7: Final Design

- The idea of using a bond to fulfill the chain reaction criteria is a good idea and therefore will also be applied in this mechanism.
- The idea with leavers will cause to many loose parts in the annulus, this can possibly restrict the flow.
- Reduction of the complexity is desirable to keep the costs down.

As a result of these conclusions the final design where produced. This utilizes the bonds around the circumference to hold back the forces from actuating the mechanism. By making a compliant segment the reduction of loose parts is achieved. To reduce the forces acting radially an angle dividing the forces axially and radially can be designed so the desired force can act on the aluminum.

6.1 Working principal

A summary of the mechanism's inner workings will be provided in this chapter. As the centralizer is inserted into the bore hole, the mechanism is defined in a static position. When the mechanism is triggered and the potential energy in the bow springs is released, a description of the dynamics of the activation is given.

6.1.1 Step 1

The centralizer has arrived in the well annulus at its predetermined spot. The fluid pill is pushed into the annulus and down the casing. The fluid will than react with one or more of the carefully spaced aluminum segments around the circumference of the centralizer.

Figure 8: Step 1

6.1.2 Step 2

The section in contact with the fluid initiates a chemical reaction that gradually degrades the aluminum's structural integrity, causing the radial forces from the bow springs to exceed the aluminum yield strength. The locking ring will disengage from the elastic connector as a result of this.

Figure 9: Step 2

6.1.3 Step 3

The collar will decouple from the elastic connector by bending the connector radially this will cause the collar to slide down axially on the body, releasing the potential energy in the bow springs and raising the casing into a desired standoff position.

Figure 10: Step 3

6.1.4 Step 4

The collar is now decoupled from the elastic connector and can slide down axially on the body, this releases the pretension in bow springs which results in lifting the casing into a desirable standoff.

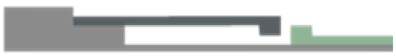


Figure 11: Step 4

6.2 Modeling Phase

ITEM	QTY	
1	1	Body
2	1	Elastic Connector
3	1	Collar
4	1	Bottom Collar
5	6	Bow Spring
6	1	Locking Ring
7	25	EN IOS 4168 – M6 x10

With a few variations, the Smartalizer is designed in the direction of mechanical energy flow through the device. Due to unforeseen stress concentrations that could not or were not calculated in the numerical analyses, this step will be iterative as the design is evaluated in FEM analysis in ANSYS. Here are the benefits of using a top-down parametrically guided architecture, where dimensional variations in one parameter necessitate an automated updating of dependent constraints to prevent model coalitions of errors.

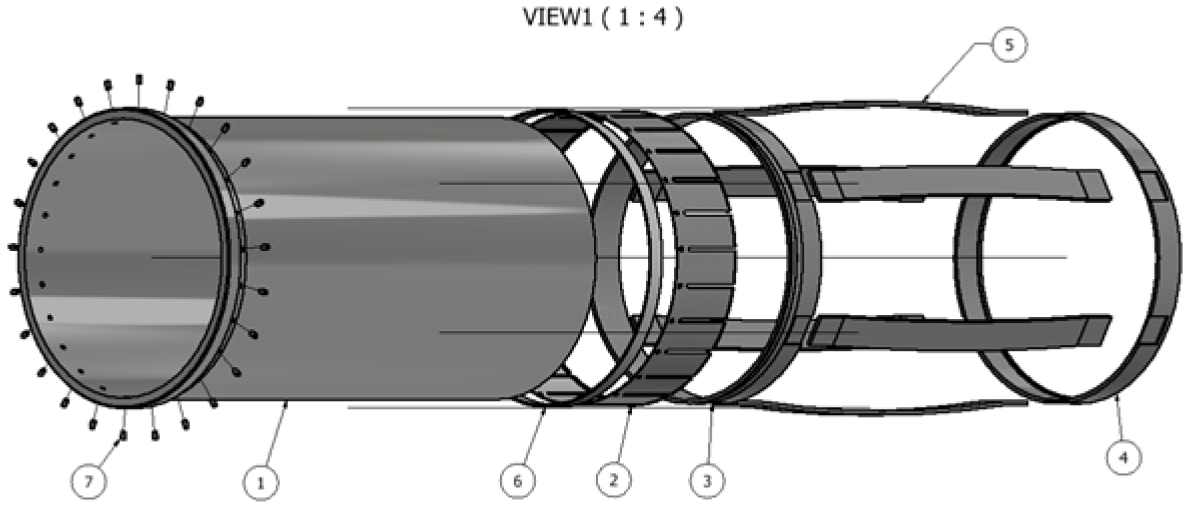


Figure 12: Exploded view

6.3 Bow Spring

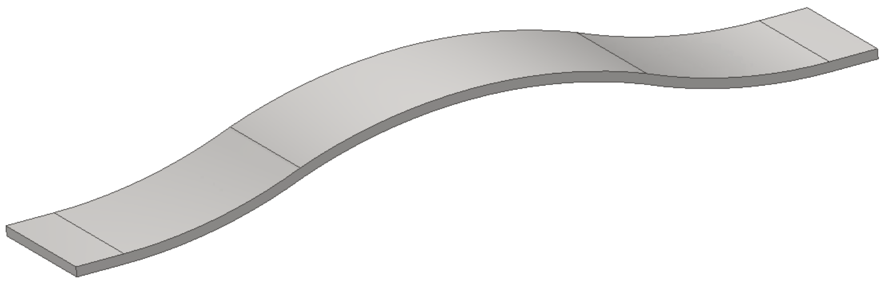


Figure 13: Bow Spring

A bow spring is similar to a leaf spring, which is used in the suspension of heavy-duty vehicles. Their aim is to deform and absorb forces in the vertical direction. This would result in a lateral deformation of the same magnitude. In this application, The bow springs is purposefully deformed and then locked in place, this stores a considerable amount of potential energy due to the spring's inherent tendency to compress back to its original state. When the bow springs are deformed in the radial direction, they will have an equal deformation in the axial direction. This reduces the total outer diameter of the Smartalizer and increases the length of the spring in the axial direction. That enables the Smartalizer to have a lower outer diameter than the borehole it is inserted into.

The bow springs are partially developed by prior work done by Moonshine Solutions AS. From the FEM analysis provided the dimension and reaction forces can be taken into the initial conditions. The development and optimization of this part is not in the scope of thesis but it can be seen that the applied load to an individual bow spring is 18 333N and will achieve a deformation of 12mm radially and 5.5mm axially in both directions. From this the force acting on the collar can be determined to be 110 000N because the use of 6 bow springs. In the Von Mesis stress analysis it can be seen that the stresses in the material is very large and and results in a maximum stress on 833MPa, this gives an minimum safety factor of 0.78 when using the low Steel alloy 4140 normalized but multiple steel alloys is propose that can reduce these stresses. In the future this would need some attention to minimize the stresses and achieving a larger deformation in the redial direction is probably desired. But in this thesis, the values of the reaction forces and axially deformation will be taken further in the development of the locking mechanism.

6.4 Feature List Mechanism

To give a clear understanding of the mechanism the illustration below is showing the cross-section of the Smartalizer mechanism. This shows the body, elastic connector, collar, and locking ring, and how they interact with each other. The different feature markers show the parts that must be calculated. This will be referred to in the following chapters.

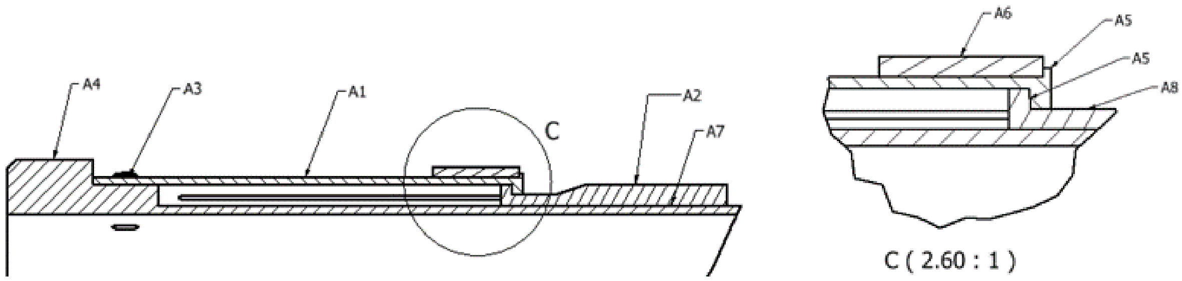


Figure 14: Feature

A1: Elastic connector	A5: incline
A2: Bow spring connector	A6: Porous Aluminum
A3: Set screw	A7: Casing thickness
A4: body height	A8: Collar thickness

Table 1: Feature List

6.5 Collar

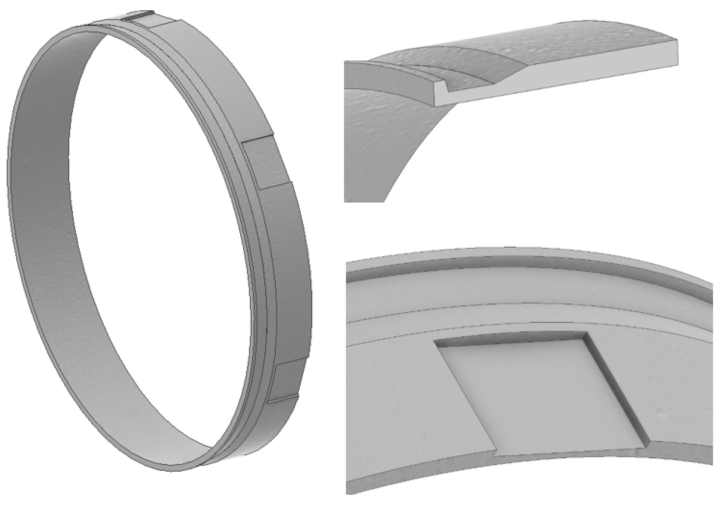


Figure 15: Collar

From discussions with the head of development in Moonshine Solutions AS, it is required to use six bow springs equally spaced around the circumference of the centralizer. This results in a accumulated reaction force from the bow springs of approximately 110 000 N.

As figure (14) shows the connection A2 is where the bow springs will transfer the force from the bow springs to the collar. This could be done by either bolting or welding. But due to the limited space [12] and the benefit of trying to keep the part count down, welding the material seems to be the better option. Evaluation of the welds comes with some uncertainty in weld quality. A factor that greatly affects the weld quality are the material choices.In the bow springs the material is a type of spring steel with low carbon values that make it easy to achieve a good weld. The area available for welding is dependent on the bow spring dimensions, this might change with further development of the bow springs but in the given bow spring model. These dimensions are given 30 mm axially on both sides of the spring as seen in figure [12] and 40 mm vertically.

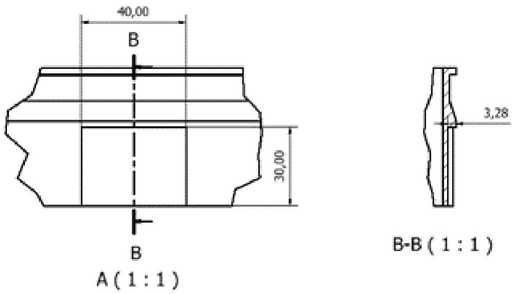


Figure 16: weld area

Calculating stresses in the weld,

$$\tau = \frac{F}{2 * h * l} \tag{1}$$

Where

- F: Load from the bow spring
- h: Possible weld end crater, which max value can not exceed keyway's depth.
- l: Effective length of a weld

From this calculation it is possible to see that welding area that connects the bow spring to the collar is sufficient. In this case only longitudinal edges of bow spring are welded to the collar, and the stresses present in the weld do not exceed 176MPa. If desired the edge of the top spring can also be welded to the collar to distribute the load further. This exact calculation will be applied to the bottom collar too since it has the same dimensions. This transfers the forces from the weld to the collar, and the collar must be able to withstand the normal stresses in feature (A8), where the collar has the lowest cross-sectional area.

the values for this calculation of the normal stress is the axial force of $F = 110kN$ from the six bow springs and the material chosen for the collar is stainless steel with a Tensile Strength of $\sigma = 250MPa$. The OD of the body in feature A7 figure [2] is measured to be $343.72mm$ this will be the inner diameter (ID) of the collar. From this the required thickness to withstand the normal stress can be found.

Parameters:

- Axial Force = $110kN$
- Inner Diameter ID = $343.72mm$
- Material YS = MPa

Finding the thickness of the material. Finding the necessary outer area of the collar.

$$A_{OD} = \frac{110kN}{250MPa} + \frac{\pi}{4} * (343.72mm)^2 = 9.332 * 10^4 mm^2 \tag{2}$$

Necessary outer diameter (OD) to withstand the normal forces

$$OD = \sqrt{\frac{A_{OD}}{\frac{\pi}{4}}} = 344.53mm \tag{3}$$

thickness (t) of the material

$$t = \frac{OD - ID}{2} \rightarrow t = \frac{344.53mm - 343.72mm}{2} = 0.4mm \tag{4}$$

Due to the large diameter of the casing, the area that the force is subjected to will be relatively large with a small wall thickness. From the calculations the dimensions required are very small, this would not be practical to manufacture so a dimension larger than this is chosen.

6.6 Aluminum Segment

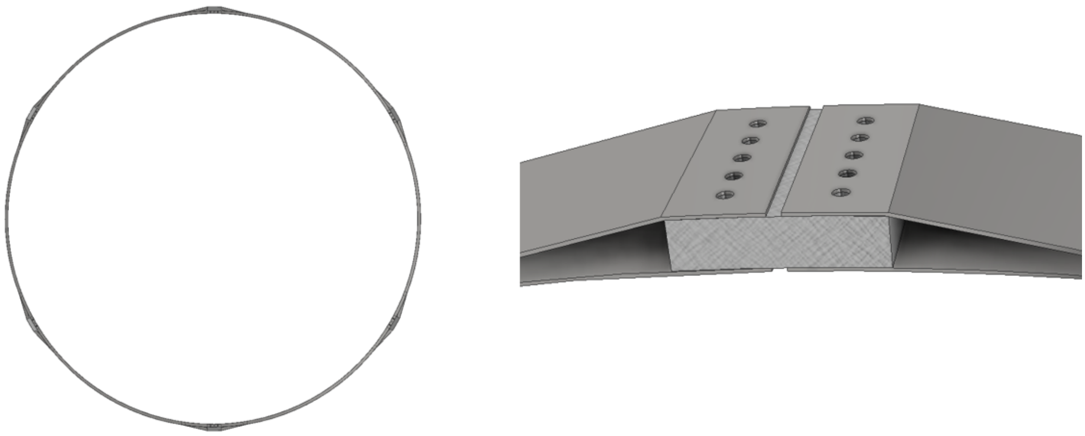


Figure 17: Aluminum Segment, Locking Ring

The locking ring of the Smartalizer consists of steel bounds connected with segments of porous aluminum. It is necessary to have multiple segments of aluminum around the circumference of the casing, this is done to make sure that at least one of the segments will come in contact with the sodium hydroxide when the casing is leaning against the borehole in an angled well, this ensures that the mechanism will be activated in all scenarios.

The elastic connectors will exert a force outward on the locking ring. This will create hoop stress on the ring. As the ring is held together by the aluminum segments this will be the weakest link in the system and therefore the hoop stress must not exceed the maximum allowed stress in the aluminum. To find the stresses it is first necessary to find the cross-sectional area of the aluminum. The size of the segments is constrained by the dimensional limitations. The length and width of the aluminum are constrained by dimensional restrictions. Height is restricted by the maximum OD of the Smartalizer this gives ½ inch (12.7 mm) in from the casing wall. By measuring the OD of the elastic connector and subtracting the maximum OD of the Smartalizer height constrain. The available height is determined to be $3mm$, the length of the aluminum segment should not be longer than $20mm$. This is done to mitigate differential pressures along the cross-section. The segment is deliberately placed symmetrically above the angle where the radial forces will apply. This is done to evenly distribute the forces on the cross-section. The cross-sectional area of the aluminum segment is calculated to be

$$A = L * H \rightarrow A = 20mm * 3mm = 60mm^2 \tag{5}$$

due to the uncertainty of the inhomogeneous material, a safety factor of two is chosen to ensure that the material can hold the radial forces. From these values, the allowable force is determined by rearranging the calculation of hoops stress.

$$\sigma = \frac{F}{A * 2} * SF \rightarrow F = \frac{\sigma * A * 2}{SF} = 1560N \tag{6}$$

After finding the allowable forces acting radially, the angle of the ledge on the collar and elastic connector can be determined. This is done by finding the angle that devides the forces up to the maximum radial force does not exceed the 1560N that was determined above. This is done in the following chapter

6.7 Elastic Connector

The elastic connector is the main part of the locking mechanism. This serves the purpose of transferring the pretension forces from the collar to the body. It consists of a cylinder that has been cut with multiple slits in it. This results in long compliant sections that will still have a large normal stress capability, but by dividing it up into sections can the moment of inertia of the individual sections be so low that they can bend radially out. On the tip of each section there is a ledge with an angle on it. This is where the forces will be transferred from the collar. The collar will transfer all the forces from the six bow springs through this ledge, the angle must divide the forces radially and axially. This angle is decided from the allowable forces to act on the locking ring radially. Here the friction forces from the steel on steel connection must also be taken into consideration. In addition to the bending force of the elastic connector.

Friction force on the ledge

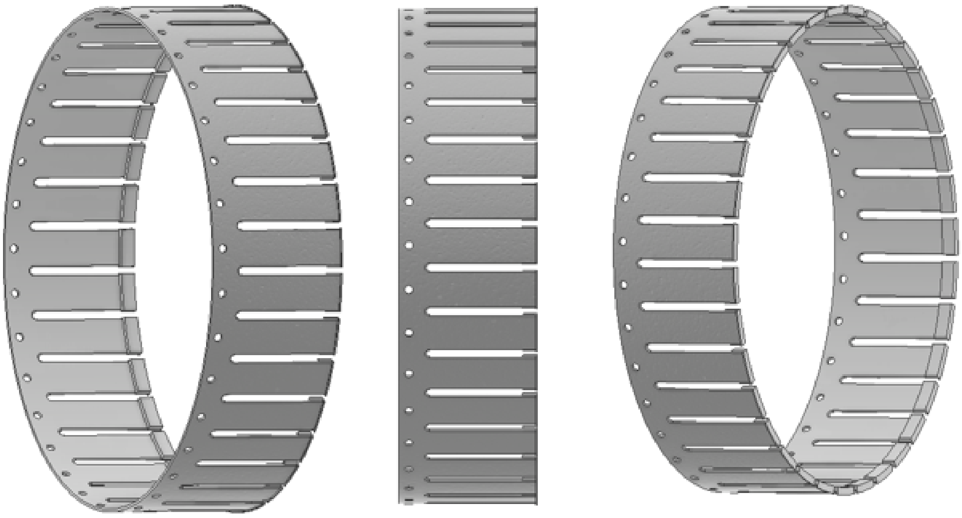


Figure 18: Elastic Connector

The friction coefficient between steel on steel connection is dependant on the condition of the material. It varies from dry steel on steel static connections with a friction coefficient of 0.78 to lubricated steel on steel static connections with a friction coefficient of 0.10. The normal force on the material is also a factor that depends on the angle between the two surfaces.

$$F_{friction} = F * sin(\theta) * \mu \tag{7}$$

This parameter is dependant on two variables; the friction factor and the angle between the two faces.

Normal stress

The elastic sections normal stress is calculated.The inner diameter ID is calculated by measuring the distance between the body and the elastic connector.The cut-out parts of the elastic connector have the smallest total cross-sectional area. The area of the cutout sections is determined by subtracting the outer diameter from the inner diameter, then subtracting the cutouts where n is the number of sections and $nlen$ is the length of the spacing between the sections.

$$A_{total} = \pi * (OD^2 - ID^2) - \frac{n * n_{len}(OD^2 - ID^2)}{4OD} = 6.48 * 10^3 mm^2 \tag{8}$$

Normal stresses in the connector when the thickness is 1.5 mm

$$\sigma = \frac{F}{A_{total}} = 17MPa \tag{9}$$

It can be shown that despite the material's thin thickness, the large diameter allows it to withstand a large force. A thickness of 1.5 mm was chosen, and the above calculations were performed. Although the material can withstand much more than this, using a thinner material would be impractical when machining the material. This also ensures a high level of safety.

Bending force

The bending forces of the one individual section are calculated by finding the bending force required to bend the compliant section out the length of the ledge. To find this the equation for bending a beam is evaluated. The distance the ledge has to bend to release the ledge is D=2.5 mm. The elasticity module of the material is E= 210 GPa and the moment of inertia is dependant on the height and width. The width is dependent on the number of sections and the spacing between the sections and the thickness of the material. Here multiple variables are dependent on each other. It is beneficial to have so many slits that one of the sections can be approximated to be a rectangle. This simplifies the moment of inertia calculations.N=35 sections are chosen and the spacing between them is 5 mm. First, the width b is found by taking the circumference of the circle then subtracting the spacing times the number of spacings, then dividing it by the number of elastic connectors.

$$b = \frac{OD * \pi - n * n_{len}}{n} \tag{10}$$

$$I = \frac{1}{12} * b * h^3 = 9.121mm^4 \tag{11}$$

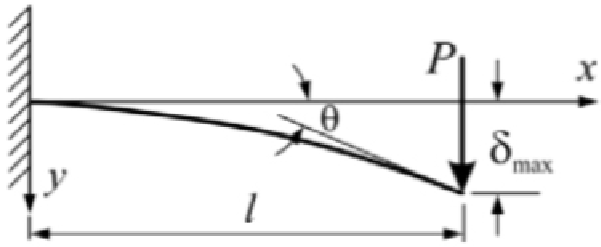


Figure 19: Bending Beam

To avoid this force from being to large a length of 80 mm where chosen.

$$\delta = \frac{F * l^3}{3 * E * I} \rightarrow F = \frac{\delta * E * I * 3}{l^3} * n = 842N \tag{12}$$

This produces a cumulative bending force of 811N, which must be taken into account when calculating the angle between the two connecting faces.

Bending stress

The sections will experience a bending moment from the bending force, this results in bending stress, this stress must not exceed the material's yield strength. The length=L of the bendable section is determined by the materials allowable stress=σ and the moment of inertial= I. To determine the moment of inertia. The cross-sectional area of the compliant section is approximated to be a rectangle instead of an arching structure. But will realistically have a higher moment of inertia.

finding the moment of one section

$$M = \frac{\delta * E * I * 3}{l^3} * l = 2.245Nm \tag{13}$$

Bending stress in elastic section

$$\sigma = \frac{M * \frac{t}{2}}{I} = 185MPa \tag{14}$$

This shows that the bending stress in that material will be approximately 185MPa. In reality this stress will be higher due to the arching of the moment of inertia area.

Finding the angle of the surface between the elastic connector and collar

Above in chapter 6.6, the allowable radial forces for the aluminum sections were calculated. From this and when accounting for the friction and bending forces the angle of the ledge can be determined by iterating the equation for the angle θ.

$$\theta_{n+1} = acos(\frac{F_{al} + F_{bend} + F * sin(\theta) * \mu}{F}) = 77.46 \tag{15}$$

The next step is to evaluate the transferring of force from the elastic connector (2) to the body(1) figure [12] this is done by several set screws as seen in feature (A3) figure. These will serve two purposes. They will fasten the body (1) to the casing wall and as mentioned above they will transfer forces from elastic connector (2) to the body (1). The number of screws that is theoretical necessary is relatively low. But when analyzed in FEM analysis it could be seen that transferring the forces directly from the individual “fingers” to a set screw would be beneficial due to stress concentrations in the cut-out corners. Thereby the same number so screws as fingers were chosen.

7 Simulations

The simulation section is a part of the analysis and optimization in Shinley’s design process. This is where the CAD 3D model made in inventor is imported to ANSYS and converted into a finite element model, then the structural analysis is carried out. In the analysis for this mechanism, the Von Mises stresses and the displacement is of interest. This chapter is divided into multiple sub-sections where one part is evaluated at the time. This gives the ability to have a greater accuracy due to the limitations in the computing power available and the limitations due the student license.

In this chapter all parts in the part list (12) will be evaluated with the calculated forces from chapter 6.

7.1 Bow Springs

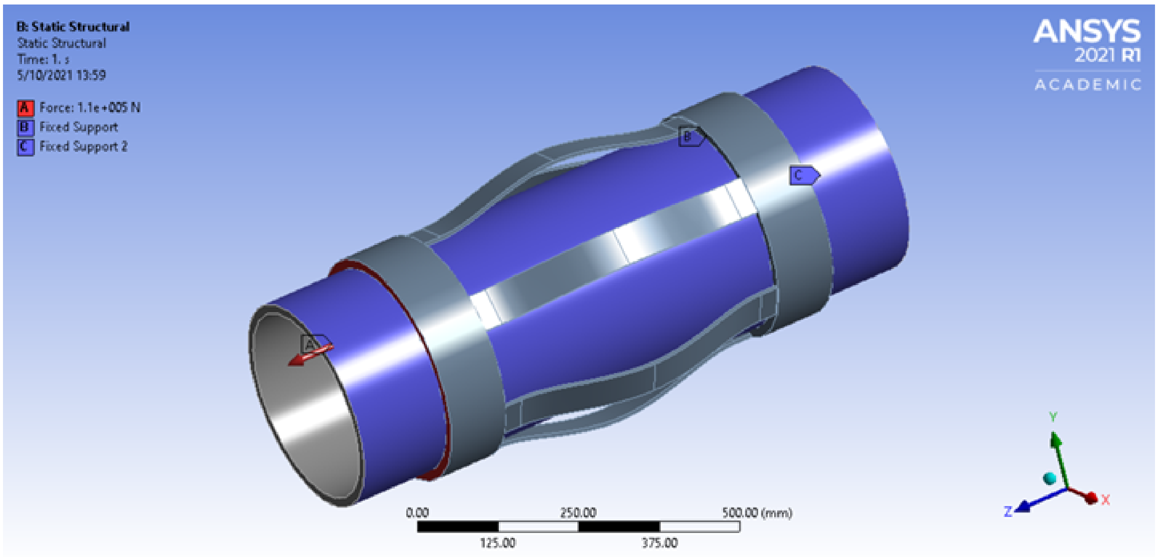


Figure 20: Bow spring simulations

The bow spring simulations are done by Moonshine Solutions AS in the prior work. The simulations are done in multiple iterations, one on a singular bow spring that is tensioned and the other where the six springs are connected with the upper and lower collar. These simulations are the basis of all dimensioning reaction force parameters. It can be seen that the bow springs are stretched in the z-direction with a force of 110 000 N. This results in a deformation of 23 mm lowering the outer diameter. This is the pre-tensioning of the bow springs and is what allows the Smartalizer to go through the annulus without exerting large forces on the borehole. In the stretched position the bow springs will be held back by the elastic connector then locked in place by the locking ring on the outside.

As can be seen from the simulation, the Equivalent (Von-Mises) stress is 1171MPa, which is greater than the material yield strength. As a result, some geometry adjustments and a different material choice would be needed. Multiple types of spring steel are suggested to do this but that is not in the scope of this thesis. The locking mechanism that is subjected to the reaction forces of the bow spring is the main focus. In the further development of the Smartalizer, these parameters would need to be evaluated further to make the machine as optimal as possible.

As the centralizer consists of six bow springs each one will thereby experience 18 333N in the axial direction. This is a crucial design parameter further up the chain when evaluating the top and bottom collar that connects the bow springs to the rest of the system.

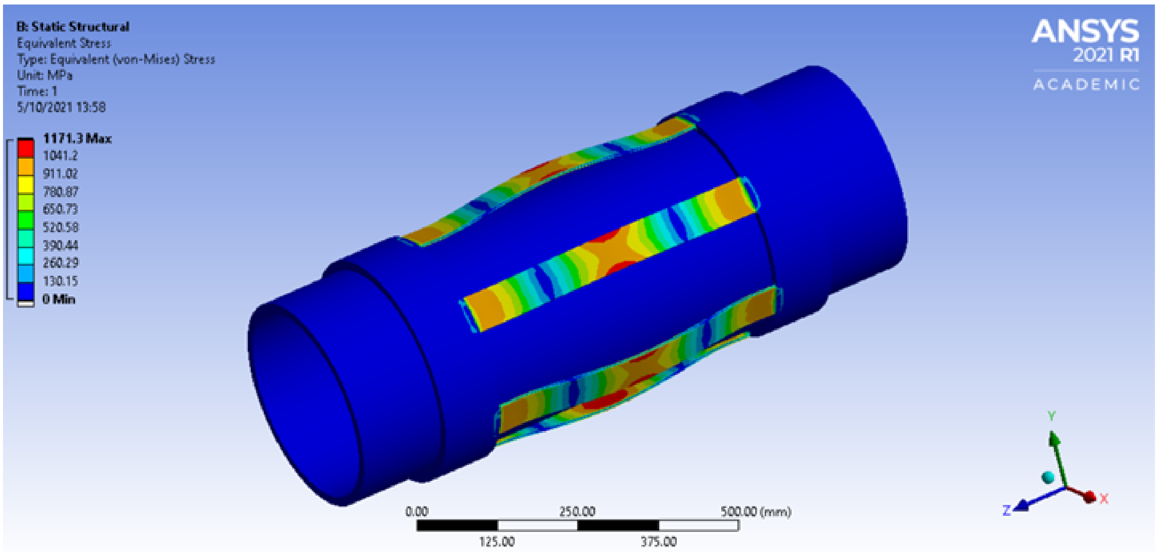


Figure 21: Von Mises stress bow springs

7.2 Upper and lower collar

Upper and lower Collar The reaction forces from the six bow springs are tensioned as simulated above. This resulted in a transfer force of 18.333kN from each bow spring. The bow springs are welded to the upper and lower collar along the sides and there is possibility to weld the top ends to the collar if needed. These welds are not simulated but the forces are applied on the edges to most accurately simulate the stresses on the collar, the stresses in these welds are also calculated in chapter (6.5). To get the most accurate simulation a mesh size is chosen to be 10 mm.

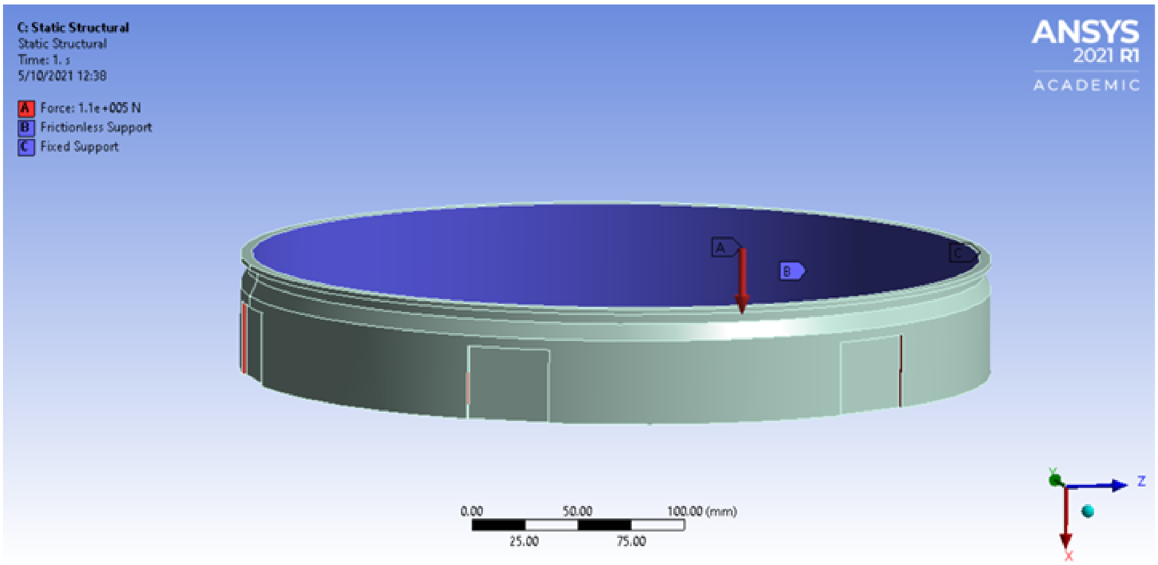


Figure 22: Collar ANSYS

The following parameters are used for this simulation

- The mesh used in the simulation is 10 mm with regions of courser mesh to get a more uniform mesh for a more accurate result
- The six bow springs are welded to the collar, this will exert a force of 18.33kN on each connector.
- There is fixed support on the ledge where the elastic connector will attach
- on the inside of the collar there is frictionless support, this simulates the outside of the body and prevents the collar from deforming radially inwards.
- Material: Low alloy steel 4140

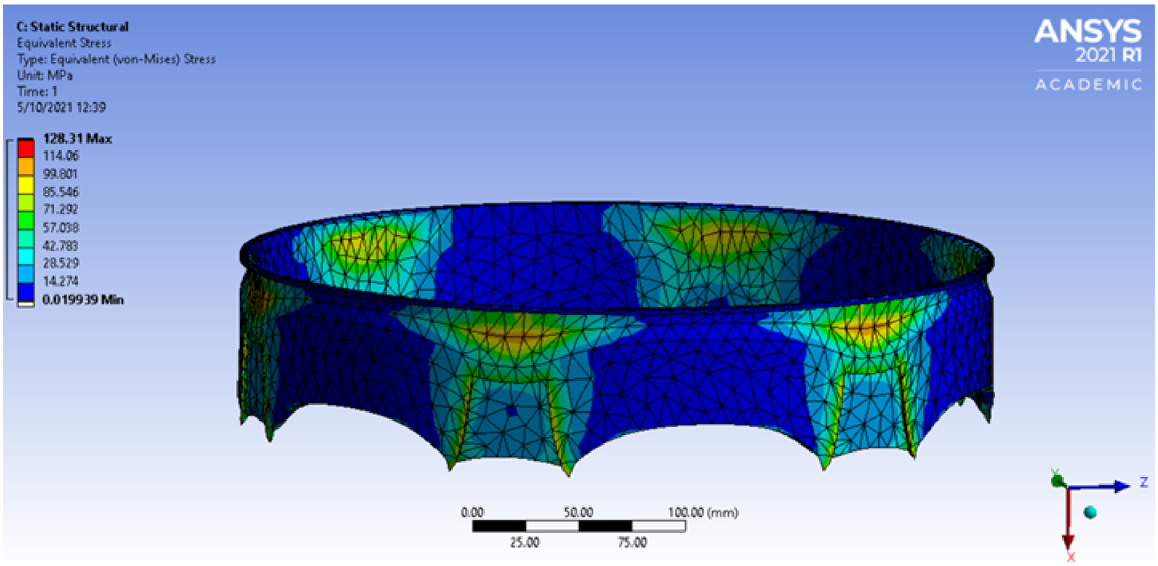


Figure 23: Collar ANSYS

There is some stress concentration above where the bow springs are connected, as seen in the simulations, but this area has a maximum Von Mises stress of 128MPa. This is well below the material's yield stress. As a result, the safety factor is high, the material selection can therefore be reconsidered, and a less expensive steel alloy can be used. The deformation of the material is negligible and therefore causes no reason for concern. The collar will transfer the forces to the elastic connector by the ledge with an angle of 77 deg from the calculation in chapter (6.7).

7.3 Elastic Connector

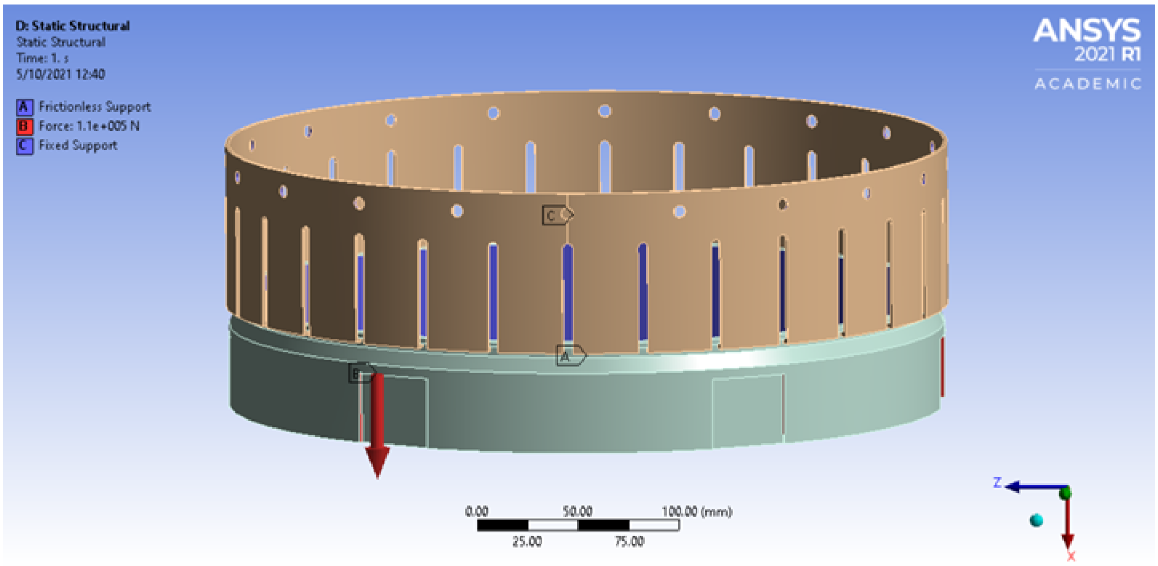


Figure 24: Elastic Connector ANSYS

The collar is simulated at the same time as the elastic connector. This is done to ensure that the forces are transferred as accurately as possible across the contact faces. However, since the collar mesh is set to be coarse, the elastic connector mesh size can be fine without reaching the mesh cap. The forces on the collar will directly transfer through the ledge where the collar connects to the elastic connector.

The following parameters are used for this simulation

- The mesh used in the simulation is 10 mm for the elastic connection and 30 mm for the collar.
- The six bow springs are welded to the collar, this will exert a force of 18.33kN on each connector.

- fixed support is attached in the holes where the set screws will connect to the body.
- on the inside of the collar there is frictionless support, this simulates the outside of the body and prevents the collar from deforming radially inwards.
- Material: Low alloy steel 4140

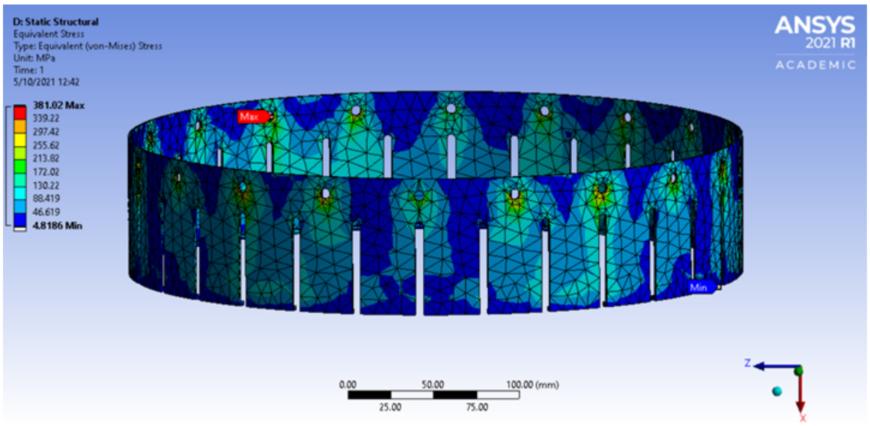


Figure 25: Elastic Connector ANSYS

There is some stress concentration around the holes where the setscrews connect the elastic connector to the body. this part is made from low alloy steel 4140 which has a high tensile strength so this stress is still within the bounds of the material with a good safety margin.

7.4 Body

The body of the Smartalizer is the part that will take all the forces from the bow springs before and after the machine is deployed. Before the machine is deployed the body will experience normal stresses from the pretension of the bow spring. These forces must all be held in place by the body.

Scenario 1 locked position

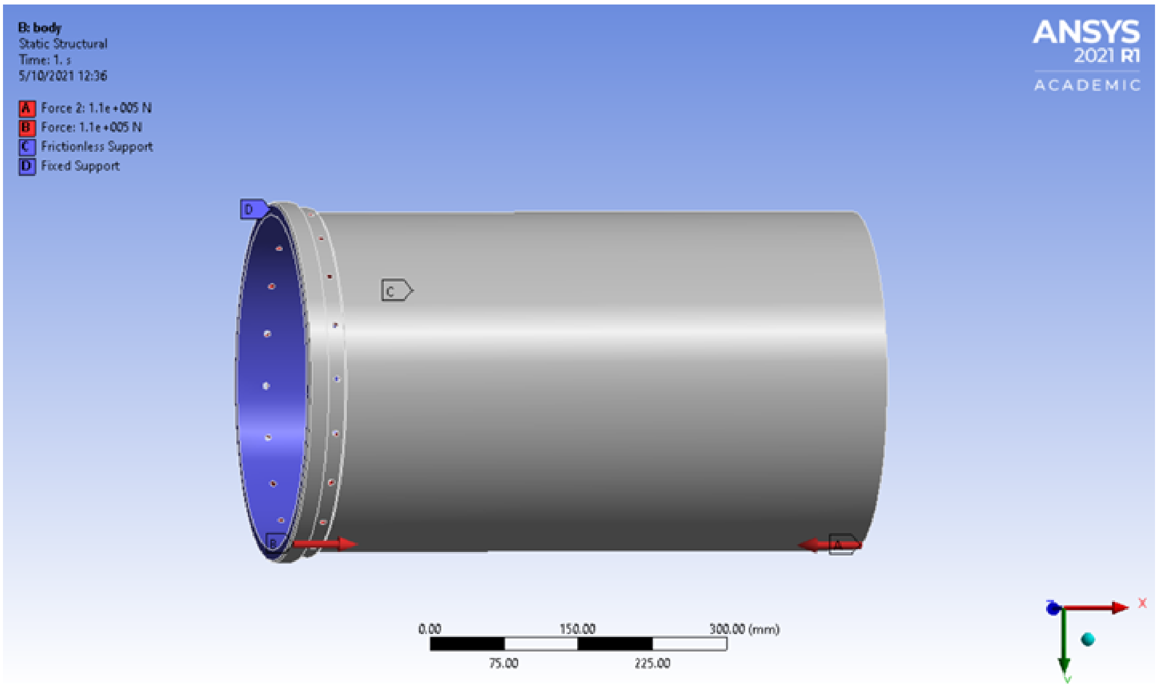


Figure 26: Body ANSYS

The purpose of this simulation is to find the stresses that occur in the body when the mechanism is in its locked position. At this time it will experience the reaction forces from the bow springs on the lower edge of the body as well as the force that is transferred through the setscrews connecting the elastic connector to the body. This is done by having frictionless support on the inside face of the body, this stops the body from deforming inward where the casing would be. The force parameter from the bow springs is applied on the bottom edge and the set screws connecting the elastic connector to the body. The calculations done earlier on the body show that this part should not experience large normal stress. But the simulations are done to ensure that no unexpected stress concentrations are occurring.

The following parameters is applied to the body

- 110 kN force on the bottom and on the top where the set screws connect to the body.
- A frictionless support is applied to the inside of the body to simulate the casing wall.
- A fixed support is applied to the top of the body that is facing the casing coupling.
- Material Stainless Steel 316

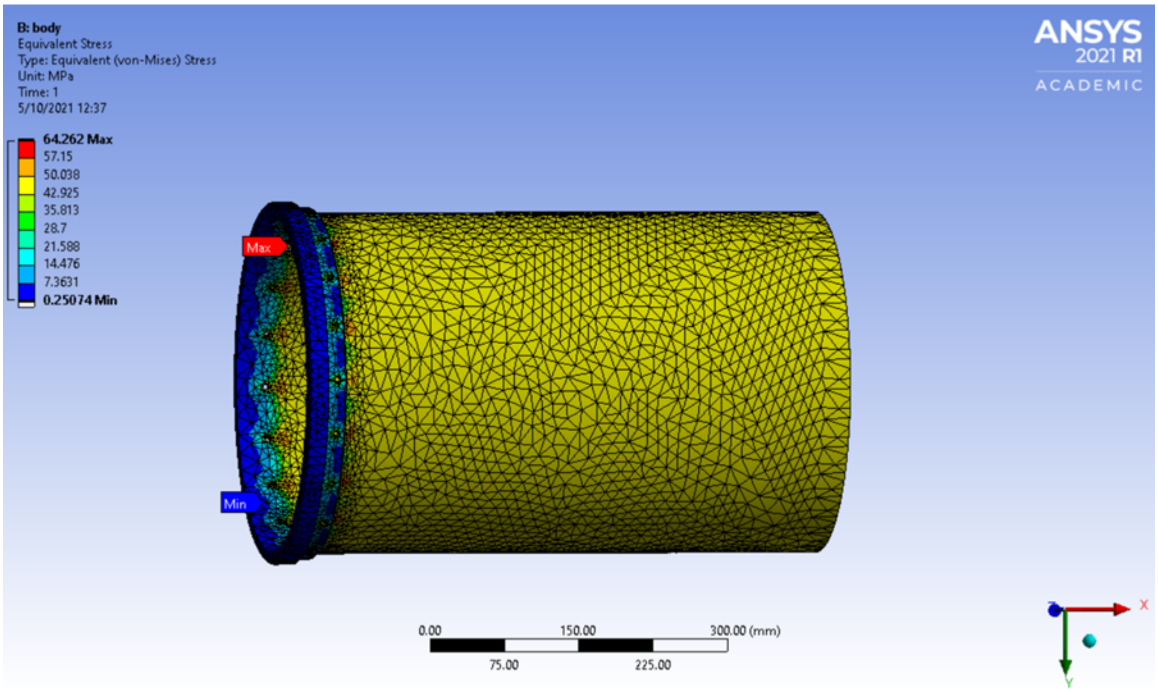


Figure 27: Body ANSYS Von mises stress

As expected from the manual calculations, the body does not experience high stress and the deformation is so small that it is negligible.

7.5 Design improvements

When designing this mechanism a large emphasis was set on making it as simple as possible. By reducing the part count in the mechanism significantly from approximately 8 parts in the proposal to 4 parts in the final design. Manufacturing of the individual parts is also taken into considerations which reduces the machining time by reducing the number of steps required in the manufacturing. The order of assembling this part is straightforward and reduces the risk when pretensioning the mechanism. This mechanism enables the possibility for rotating the casing when cementing, this is often done to accomplish a better cementing job.

8 Conclusion

This thesis deals with subjects witch still to this day are kept secret to the majority, and as such is tough to investigate, so this project was dependent on good support from the client. There was few attempts of designing similar innovative products earlier, but unfortunately none of them is documented, and for some reasons companies have given up on them. Hopefully, this rapport will be of good use for future development of the subject. The thesis shows all the fundamentals of the designing process, and covers different branches of engineering.

8.1 Further work

The project is still in the starting phase and as such it is to expect that it will go through many more analyses and changes before it eventually becomes available on the market. This centralizer arises some important questions in oil industry, and challenges maybe one of the biggest concerns for the environment, bad cementing jobs in the oil wells. This product will ensure more reliable well and lower the risk of down time.

But, as mentioned, the product needs to go through many tests in the future, so far most of the data comes from the theoretical calculations, actual models are needed to confirm the hypothesis set up earlier. This applies to the aluminium segments too, and the locking ring itself. The aluminium segments are manufactured as highly porous brackets and as such contain high number of insecurities in the properties. Some other solutions may be more suitable for the task.

The bow springs are yet to be designed. So far there was not much focus on the bow springs, this made designing and dimensioning process a bit more challenging. The final design will for sure go through some changes when the actual bow springs get implemented in the existing design. Designing bow springs will be a challenging task, the ratio between length, width and thickness needs to be precise to achieve desired functionality of the bow springs. Then, when bow springs are designed, the distance between the two collars will be adjusted. Implementation of different parts to the functional assembly will often need some modification to the parts, and The Smartalizer is no exception.

The locking system and functionality are shown and discussed through this report and will serve as foundation for the future development of the Smartalizer.

9 References

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List of Figures

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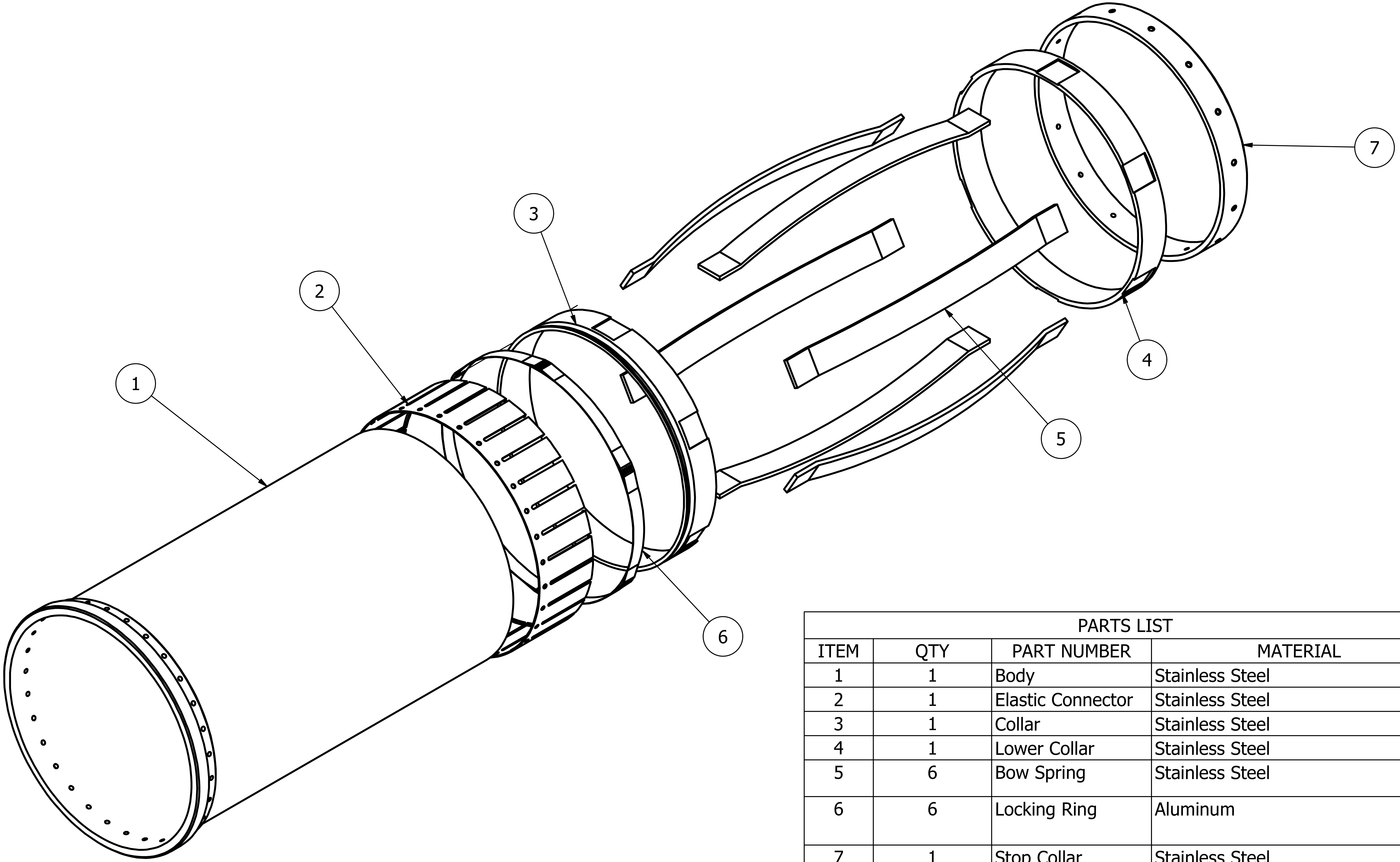
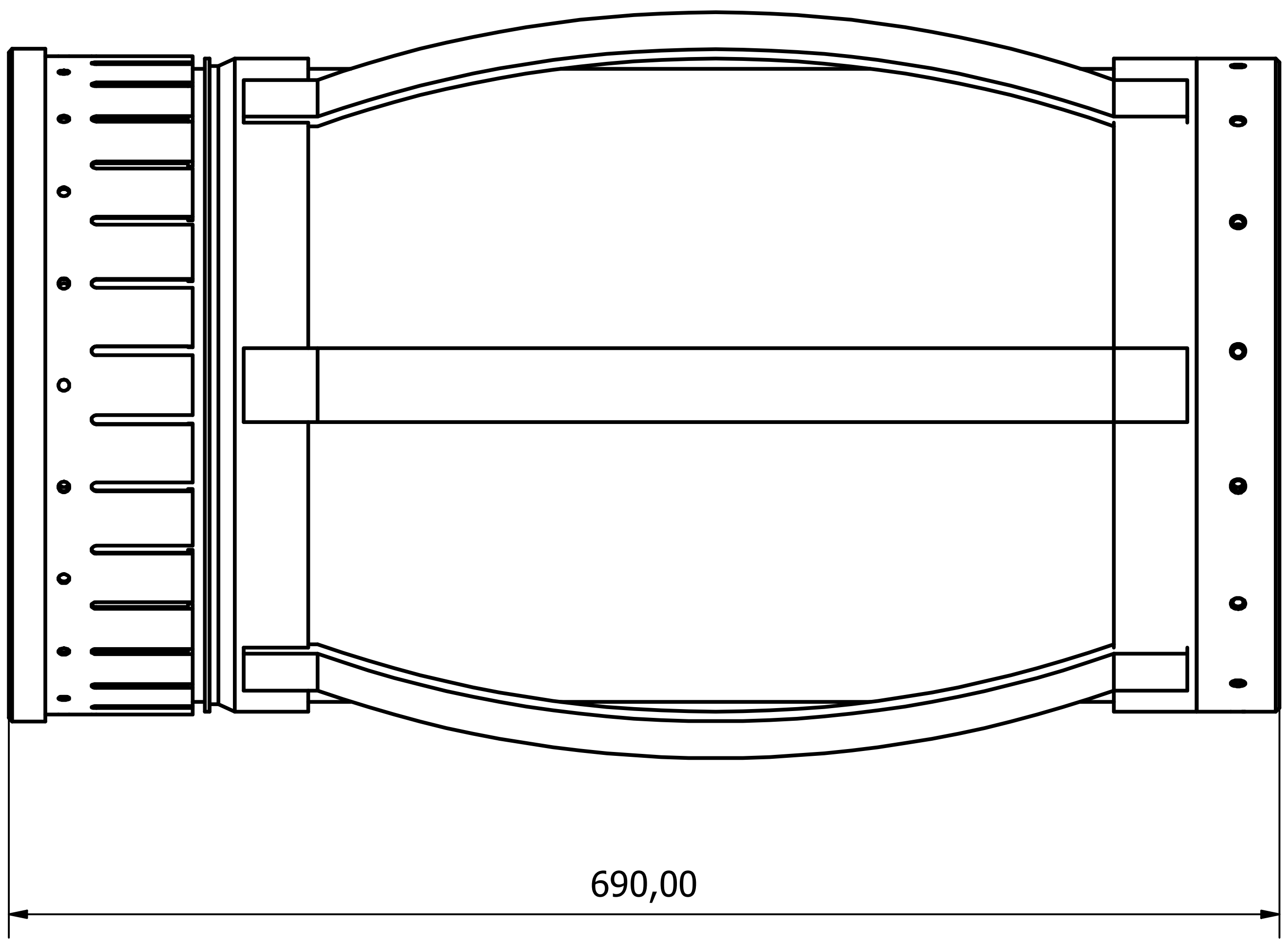
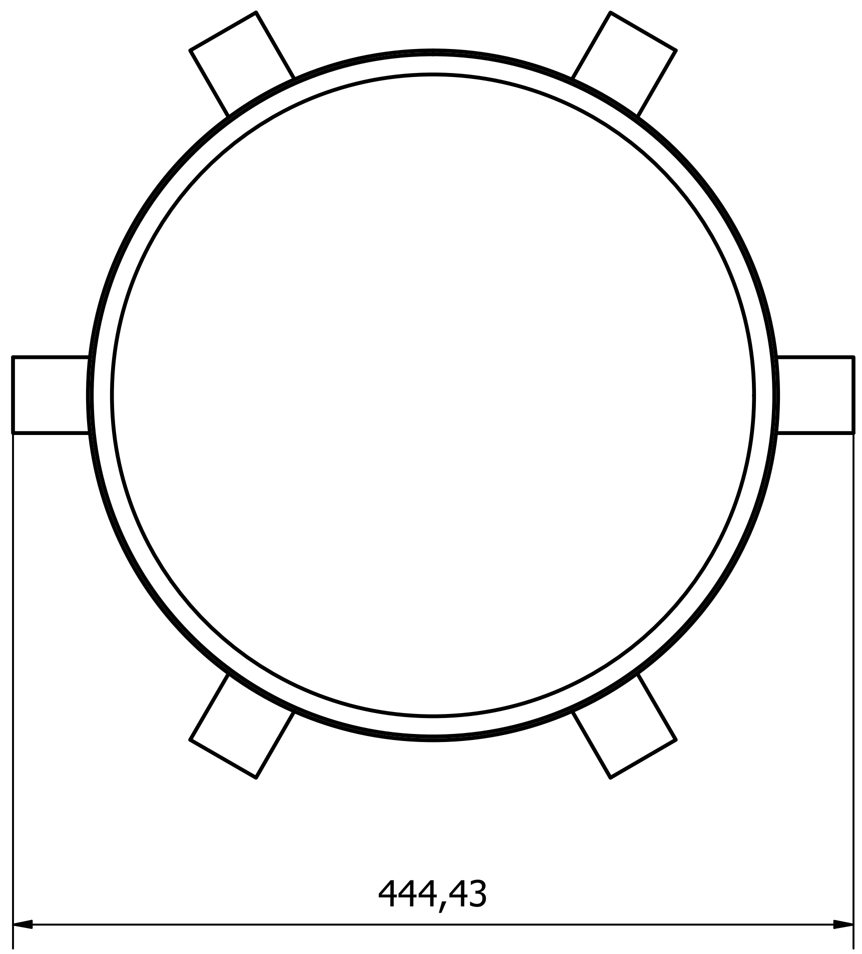


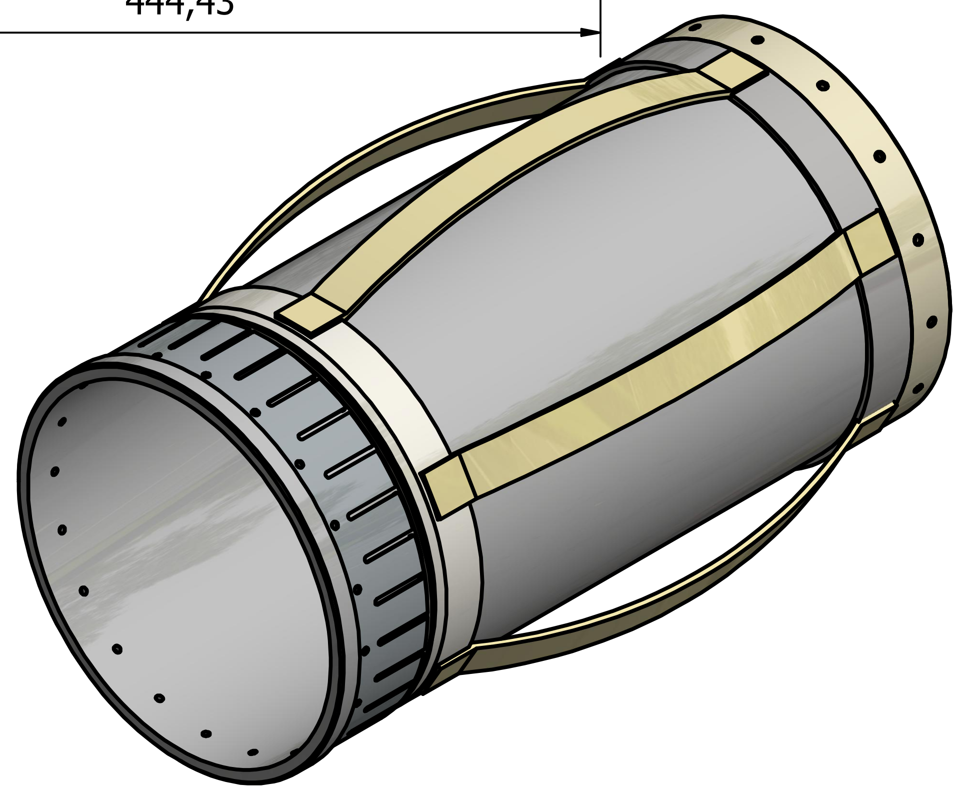
PARTS LIST			
ITEM	QTY	PART NUMBER	MATERIAL
1	1	Body	Stainless Steel
2	1	Elastic Connector	Stainless Steel
3	1	Collar	Stainless Steel
4	1	Lower Collar	Stainless Steel
5	6	Bow Spring	Stainless Steel
6	6	Locking Ring	Aluminum
7	1	Stop Collar	Stainless Steel

Designed by	Weight	Material	Scale	Date
Didrik Arnevig	45.933 kg		1 : 5	5/24/2021

Moonshine Solutions	Smartalizer		
	Smartalizer assembly	Edition	Sheet 1 / 1

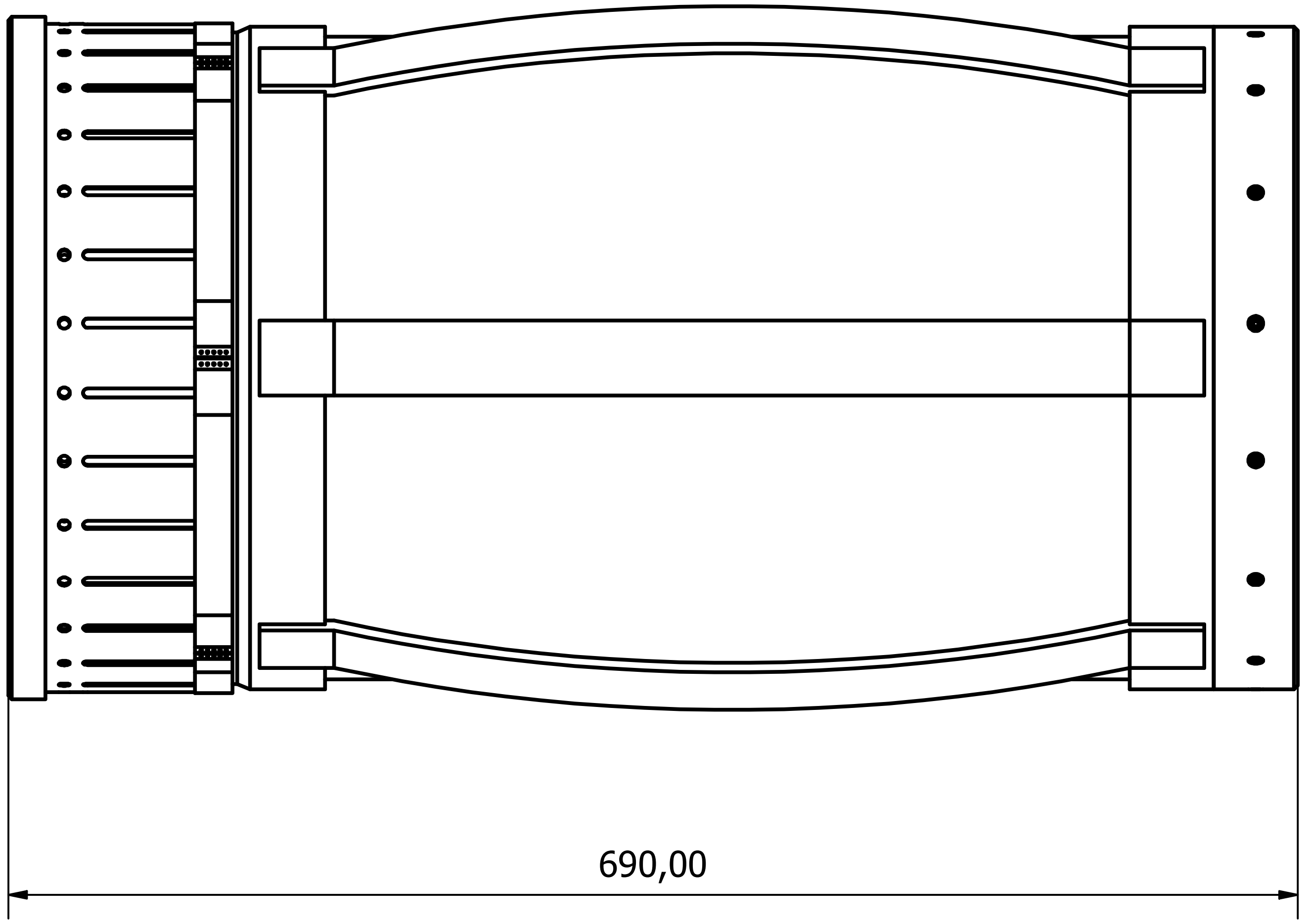


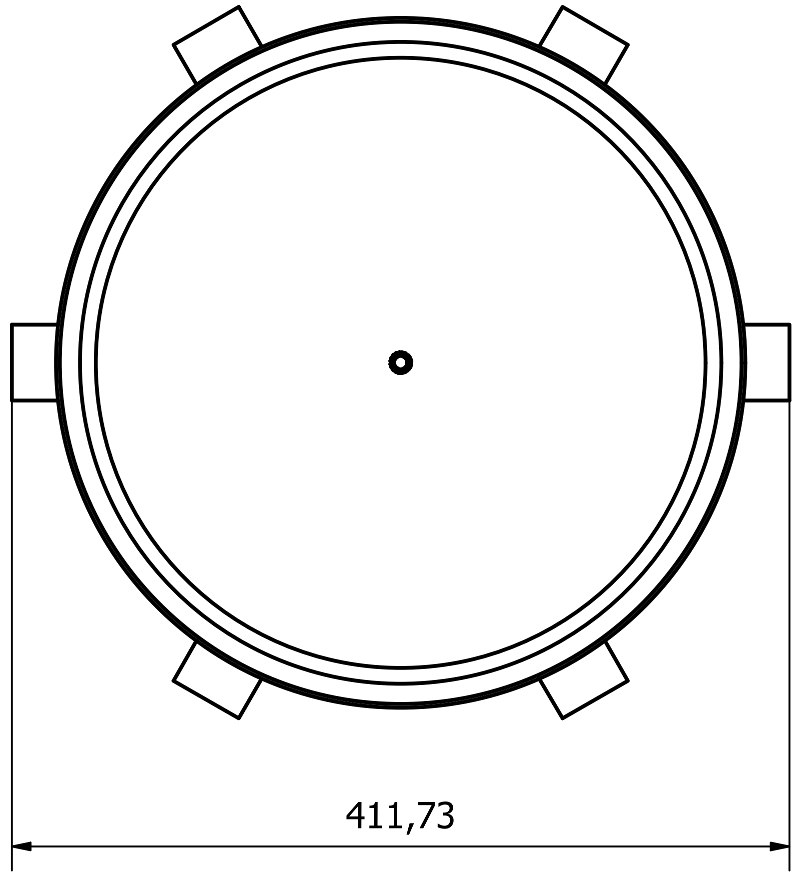


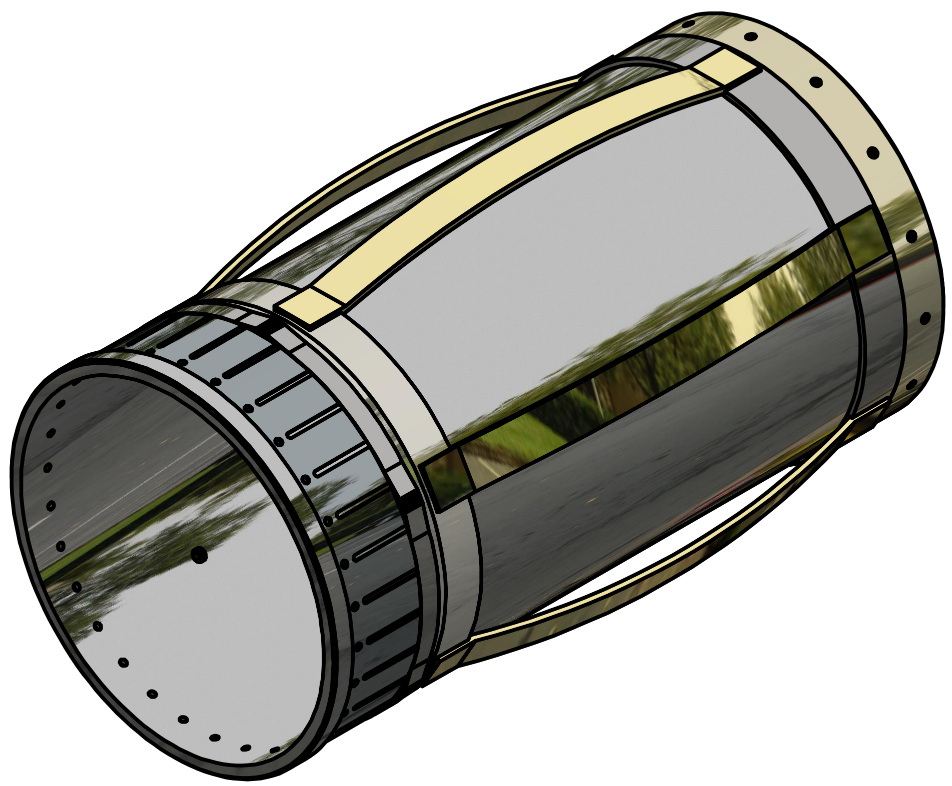


Designed by	Weight	Material	Scale	Date
Didrik Arnevig	N/A		1 : 6	5/24/2021

Moonshine Solutions	Smartalizer after actuation		
	model_display_2_etter	Edition	Sheet 1 / 1

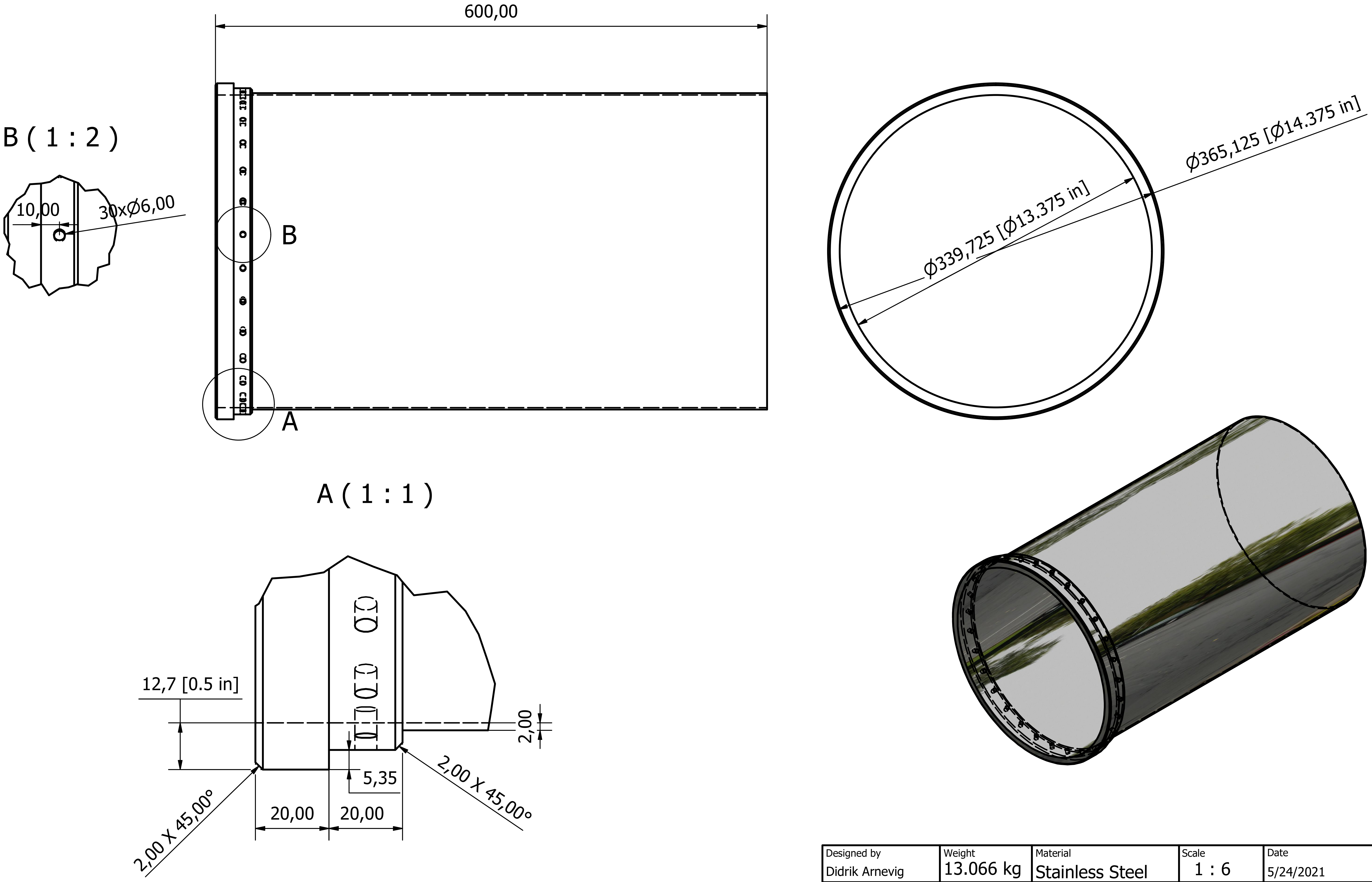






Designed by	Weight	Material	Scale	Date
Didrik Arnevig	45.933 kg		1 : 6	5/24/2021

Moonshine Solutions	Smartalizer before actuation		
	model_display_før	Edition	Sheet 1 / 1



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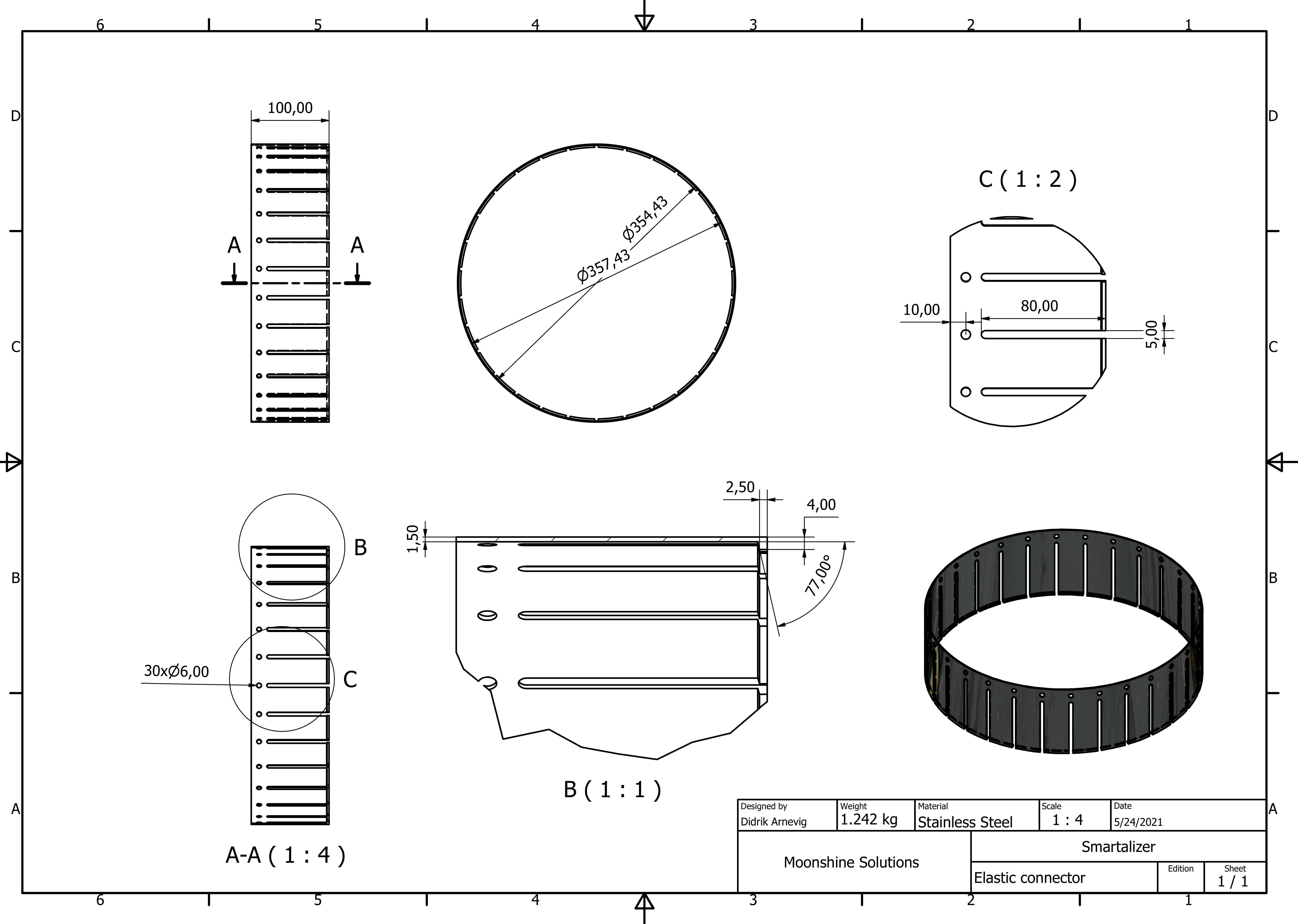
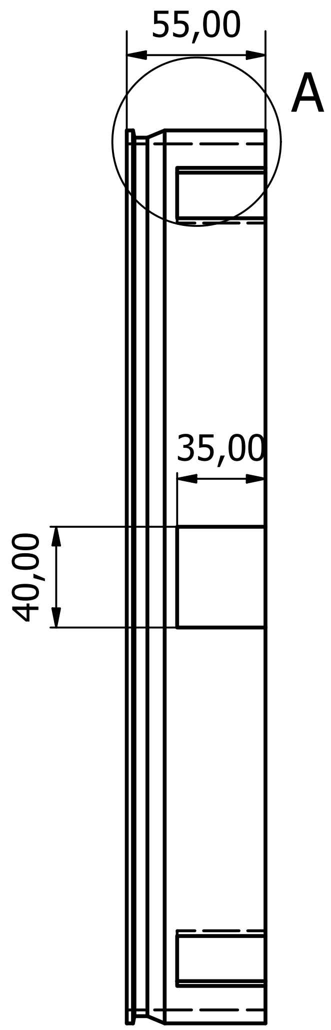
Didrik Arnevig	13.066 kg	Stainless Steel	1 : 6	5/24/2021

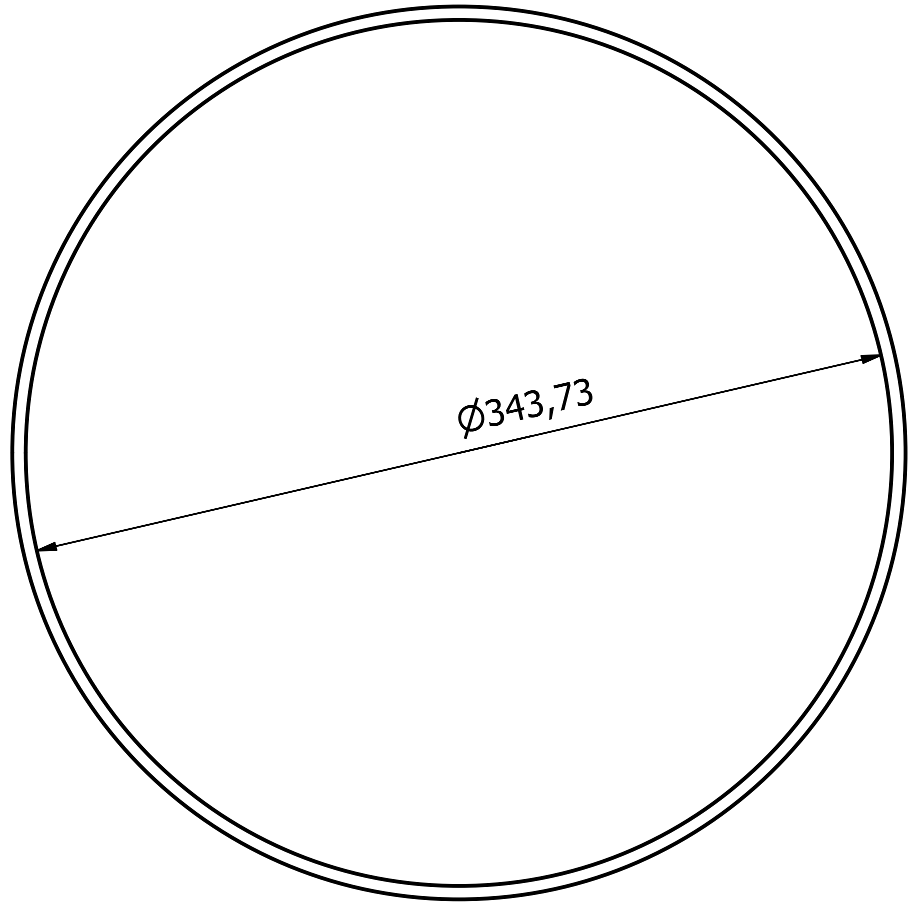
Moonshine Solutions	Smartalizer		
	Body1_ferdig	Edition	Sheet 1 / 1

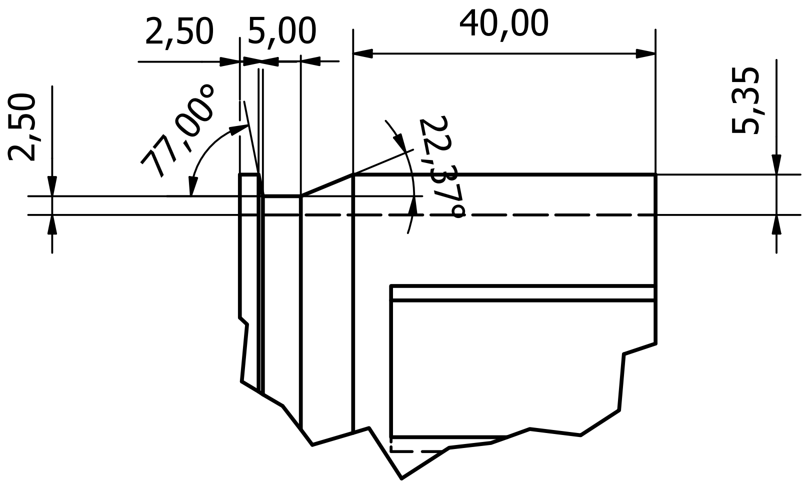


Designed by	Weight	Material	Scale	Date
Didrik Arnevig	1.242 kg	Stainless Steel	1 : 4	5/24/2021

Moonshine Solutions	Smartalizer		
	Elastic connector	Edition	Sheet 1 / 1







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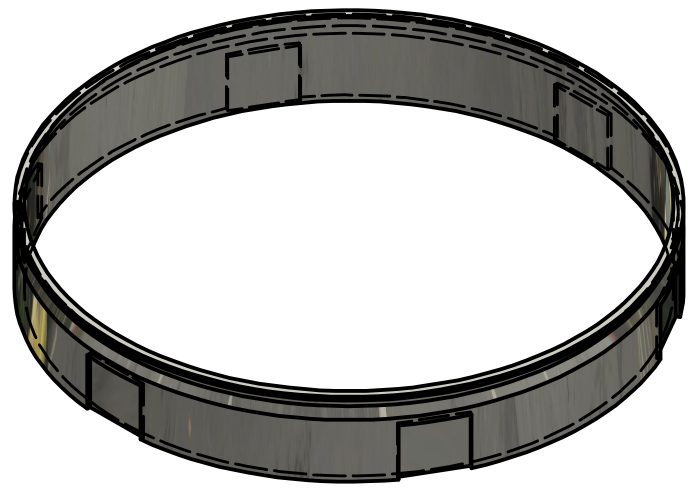
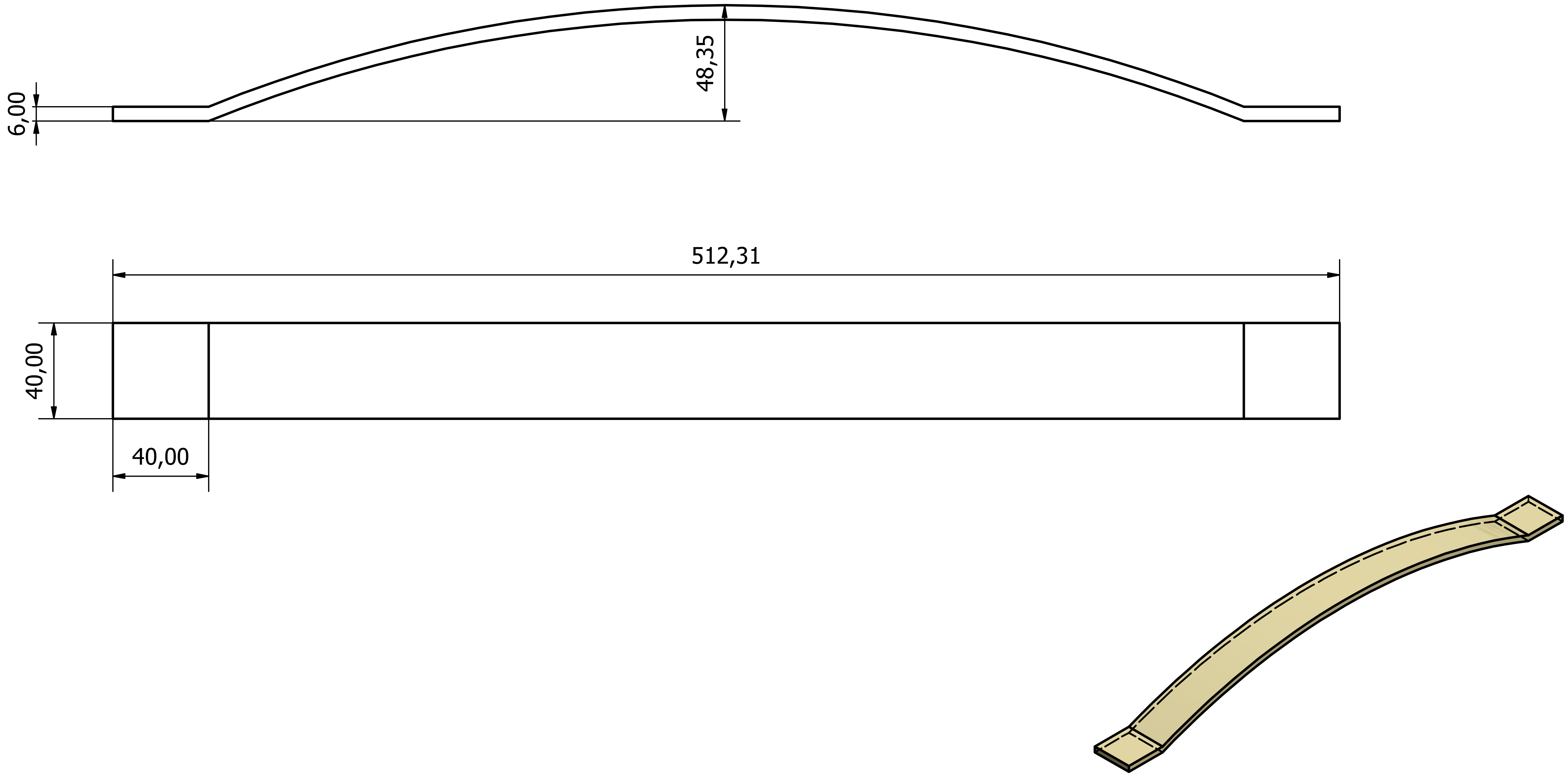


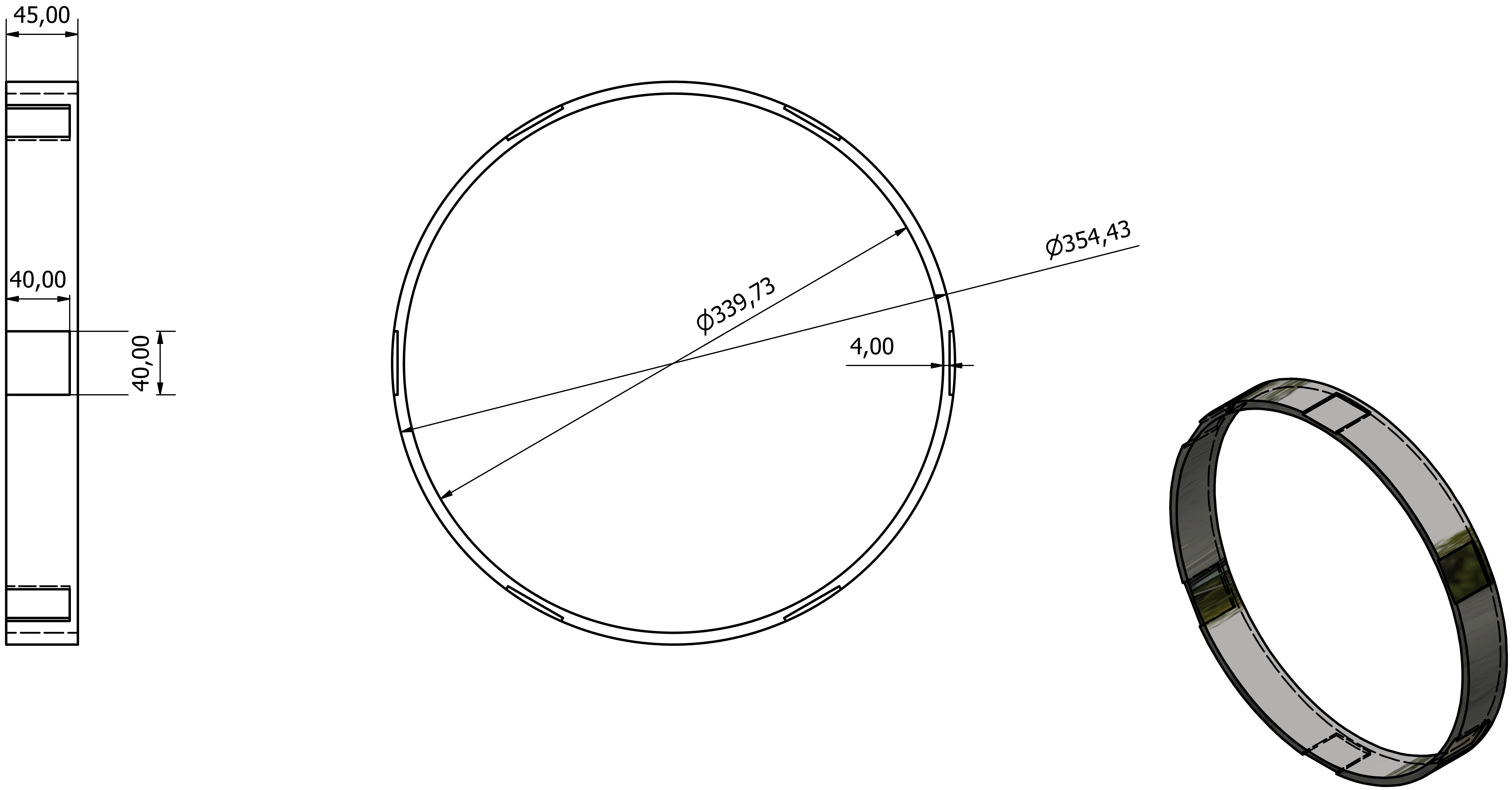
Designed by	Weight	Material	Scale	Date
Didrik Arnevig	2.161 kg	Stainless Steel	1 : 4	5/24/2021

Moonshine Solutions	Smartalizer		
	Collar	Edition	Sheet 1 / 1



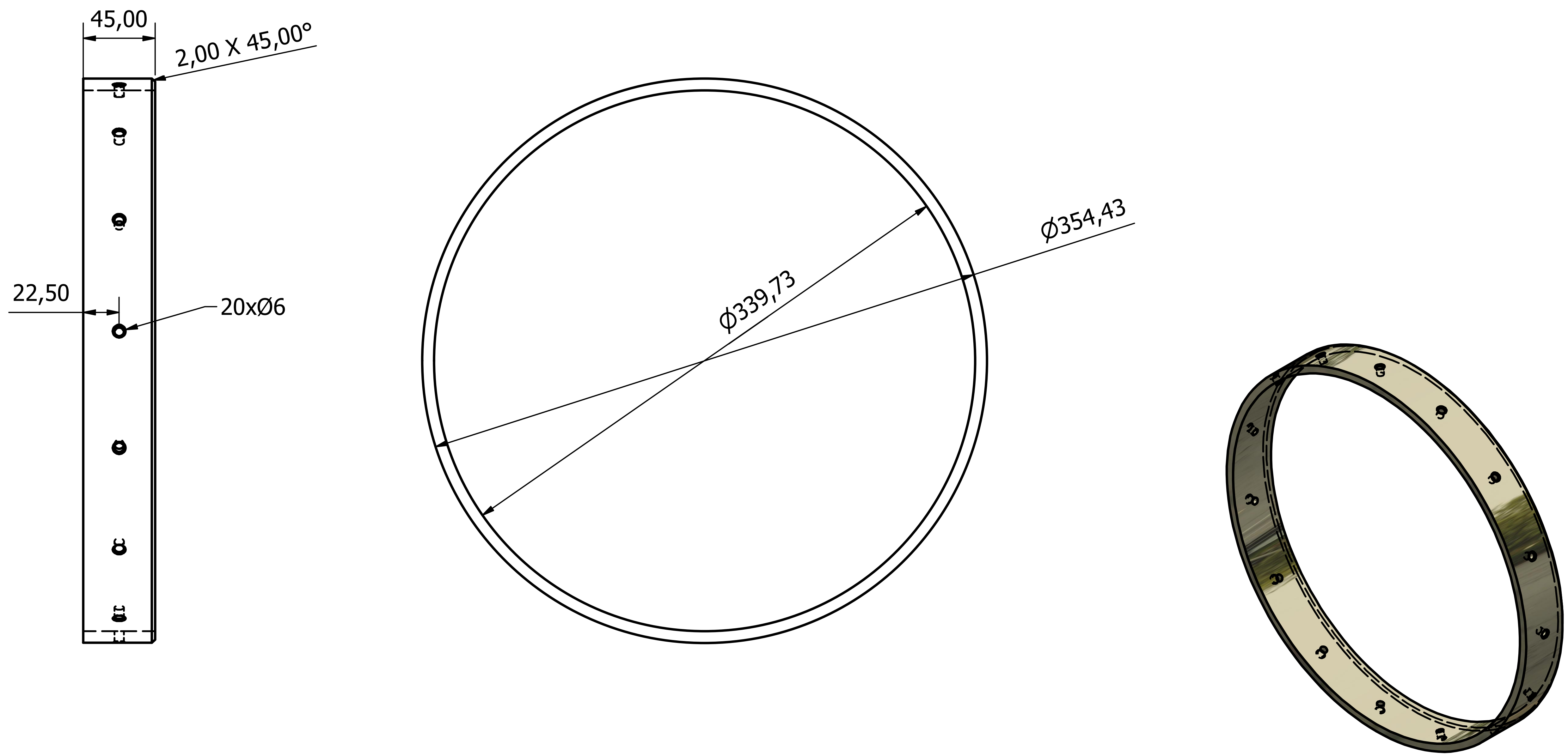
Designed by	Weight	Material	Scale	Date
Didrik Arnevig	0.984 kg	Stainless Steel	1 : 4	5/20/2021

Moonshine Solutions	Smartalizer		
	BowSpring_1	Edition	Sheet 1 / 1

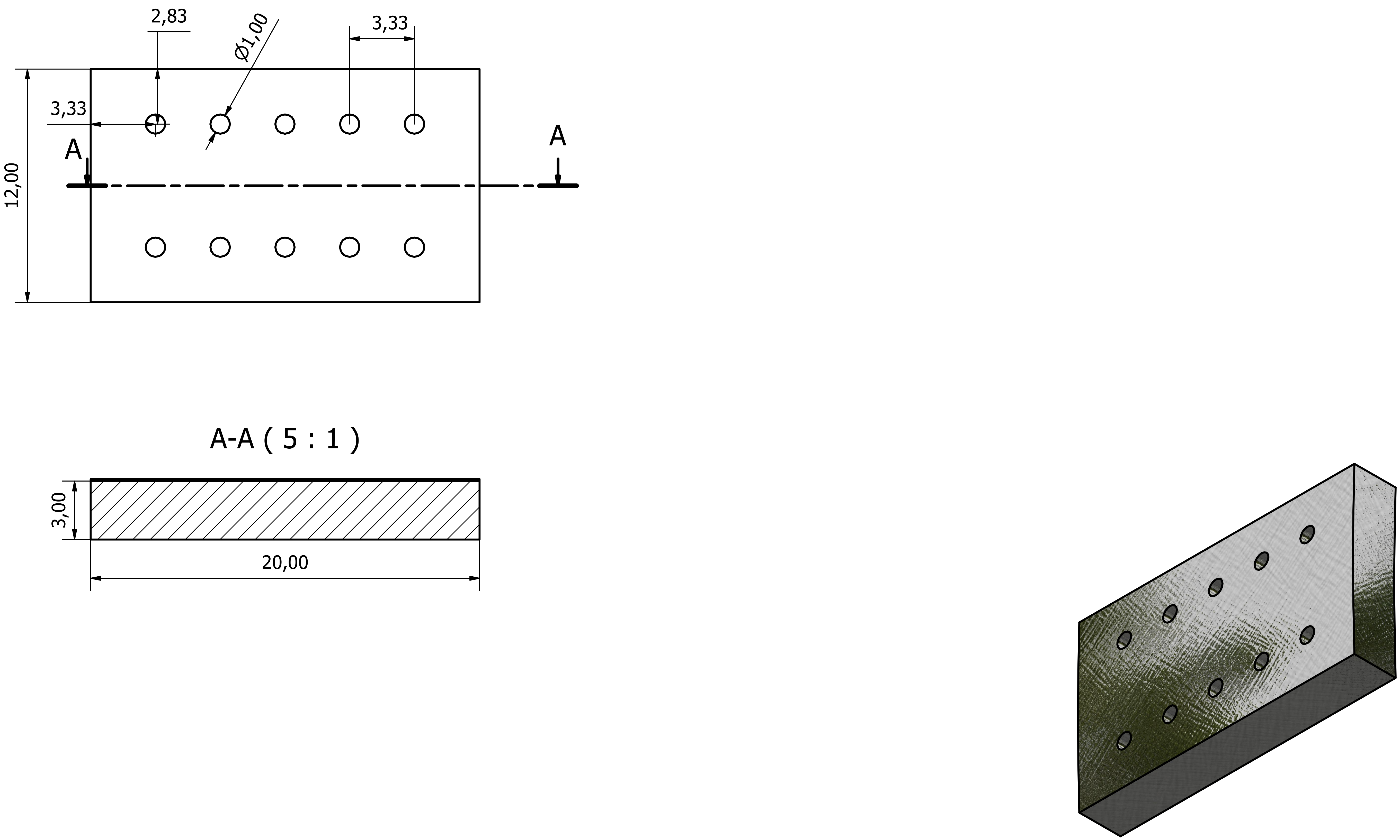


Designed by	Weight	Material	Scale	Date
Didrik Arnevig	2.657 kg	Stainless Steel	1 : 4	5/24/2021

Moonshine Solutions	Smartalizer		
	Lower collar	Edition	Sheet 1 / 1



Designed by: Didrik Arnevig	Weight: 2.841 kg	Material: Stainless Steel	Scale: 1 : 4	Date: 5/24/2021
Moonshine Solutions	Smartalizer			
	Stop collar		Edition:	Sheet: 1 / 1



Designed by	Weight	Material	Scale	Date
Didri	0.001 kg	Generic	5 : 1	5/24/2021

Moonshine Solutions	Aluminium segment	Edition	Sheet 1 / 1

LIVALLCO STÅL AB
SMITH & STENSSON

Fjäderstål
51CrV4

Beteckningar

Svensk standard	SS 2230
ASTM / ASME standard	
Likvärdig kvalitet	
W.stoff nr	1.8159

Applikation

51CrV4 är ett låglegerat stål som används i seghärdat tillstånd. Detta stål kan också induktionshärdas, eller nitrerhärdas. Det används för detaljer som kräver ganska hög hårdhet samt styrka och seghet. Typiska användningsområden är axlar, vevstakar, växlar, kolvstänger. Kan härdas hårdare än Ck75.

Sammansättning

C	0,47 - 0,55
Cr	0,90 - 1,20
Mn	0,70 - 1,1
P	max. 0,025
S	max. 0,025
Si	max. 0,40
V	0,10 - 0,25
Fe	rest.

Dimension / Format

Plåt	1-10 mm
Rundstål	Ø 2 -710 mm
Platt/4-kant	Ja
6-kant	-
Smide	Ja
Rör	-

Mekaniska egenskaper

Sträckgräns	min. 700 N/mm²
Brottgräns	900 - 1100 N/mm²
Slagseghet	

Mekaniska egenskaper är endast riktvärde för seghärdat rundstål i Ø 50 mm

För mer detaljerad teknisk information, kontakta LIVALLCO STÅL AB
Tel. 0302-150 10   info@livallco.se

LIVALLCO STÅL AB
SMITH & STENSSON

Fjäderstål
C67S / C75S

Beteckningar

Svensk standard	SS 1770 / 1774
ASTM / ASME standard	
Likvärdig kvalitet	
W.stoff nr	1.1231 / 1.1248

Applikation

Högkolhaltigt stål som används huvudsakligen till fjädrar med medelhöga påkänningar. Över 150°C mister den sina elastiska egenskaper.

Sammansättning

C	0,70 - 0,80
Mn	0,60 - 0,80
Si	0,15 - 0,35
P	max. 0,035
S	max. 0,035
Fe	rest.

Dimension / Format

Plåt	1,5- 6 mm
Rundstål	-
Platt/4-kant	Ja, även band
6-kant	-
Smide	Ja
Rör	

Mekaniska egenskaper

Sträckgräns	min. 1275
Brottgräns	1320 - 1870
Slagseghet	

Mekaniska egenskaper är endast riktvärde för seghärdat bandstål

För mer detaljerad teknisk information, kontakta LIVALLCO STÅL AB
Tel. 0302-150 10 info@livallco.se

inner diameter $ID := 354.43\ mm$

thickness $t := 1.5\ mm$

Section spacing $n_{len} := 5\ mm$

Number of sections $n := 30$

Bending distance: $\delta := 2.5\ mm$

Elastic connector length: $l := 80\ mm$

Total force of bow spring: $F := 110\ kN$

Steel on steel friction: $\mu := 0.2$

Force on aluminium: $F_{al} := 1560\ N$

Material:

Elasticity module: $E := 210\ GPa$

yied strength: $\sigma_{max} := 250\ MPa$

Outer diameter: $OD := ID + 2 \cdot t = 357.43\ mm$

outer: $O := OD \cdot \pi = \left(1.123 \cdot 10^{3}\right)\ mm$

Areal of connector cross section: $A_{tot} := \pi \cdot \left(OD^2 - ID^2\right) - \frac{n \cdot n_{len} \cdot \left(OD^2 - ID^2\right)}{4 \cdot OD} = \left(6.485 \cdot 10^{3}\right)\ mm^2$

Normal stress: $\sigma := \frac{F}{A_{tot}} = 16.962\ MPa$

section width: $b := \frac{OD \cdot \pi - n \cdot n_{len}}{n} = 32.43\ mm$

Moment of inertia: $I := \frac{1}{12} \cdot b \cdot t^3 = 9.121\ mm^4$

Bending force: $F_{bøying} := \frac{\delta \cdot E \cdot I \cdot 3}{l^3} \cdot n = 0.842\ kN$

Bending moment of segment: $M := \frac{\delta \cdot E \cdot I \cdot 3}{l^3} \cdot l = 2.245\ N \cdot m$

Bending stress: $\sigma := \frac{M \cdot \frac{t}{2}}{I} = 184.57\ MPa$

Angle of ledge: $\theta = acos\left(\frac{F_{al} + F_{bøying} + F \cdot sin(\theta) \cdot \mu}{F}\right)$

$\theta := 80\ deg$

$\theta := \operatorname{acos}\left(\frac{F_{al} + F_{bøying} + F \cdot \sin(\theta) \cdot \mu}{F}\right) = 77.362\ deg$

$\theta := \operatorname{acos}\left(\frac{F_{al} + F_{bøying} + F \cdot \sin(\theta) \cdot \mu}{F}\right) = 77.468\ deg$

$\theta := \operatorname{acos}\left(\frac{F_{al} + F_{bøying} + F \cdot \sin(\theta) \cdot \mu}{F}\right) = 77.463\ deg$

$\theta := \operatorname{acos}\left(\frac{F_{al} + F_{bøying} + F \cdot \sin(\theta) \cdot \mu}{F}\right) = 77.463\ deg$

$$F_{al} := \cos(\theta) \cdot F - F_{bøying} - F \cdot \sin(\theta) \cdot \mu = 1.56\ kN$$

Item	Parameter	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
1	Pore size, mm	0,20 – 0,35	0,30 – 0,50	0,40 – 0,63	0,40 – 1,00	0,63 – 1,60	0,63 – 3,00	0,63 – 4,00
2	Filter grade, µm	40 – 50	50 – 60	70 – 90	150 – 200	300 – 400	500 – 600	600 – 700
3	Volume porosity, %	55-65						
4	Specific surface area, m2/m3	approx. 10'000	approx. 8'000	approx. 6'000	approx. 4'000	approx. 3'000	approx. 1'200	approx. 1'000
5	Compressive strength, N/mm2	39	35	28	24	21	20	19
6	Tensile strength, N/mm2	26	21	16,4	15,3	8,3	7,6	7,2
7	Density, g/cm3	1,00 – 1,20						
8	Cell structure	all pores are open, d min = filter grade, D max = pore size						
9	Operating temperature, °C	from -200 to +250…550						
10	Melting-point, °C	approx. +600						
11	Hardness, HB	67 – 71						
12	Thermal conductivity, W/(m*K)	30 – 50						
13	Aluminium alloy	AlSi7Mg						
14	Cleaning, maintenance	backwash, ultrasound, mechanical and chemical cleaning						
15	Permeability coefficient K, m2 ≥	7,00E-12	8,50E-12	3,10E-11	7,50E-11	1,45E-10	2,25E-10	2,60E-10