Redesign of a Steam Strainer

Ann Jannesson

Solid Mechanics

Degree Project
Department of Management and Engineering
LIU-IEI-TEK-A--07/00239—SE
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Finspång, November 22, 2007
Abstract
This thesis was done at Siemens Industrial Turbomachinery AB in Finspång. Placed in the inlet to a steam turbine is a filter, a steam strainer, which separates particles and larger objects from the steam. These particles and objects will cause solid particle erosion in the actual turbine if they pass by. The strainer is exposed to large pressure drops when clogged, i.e., static loads which require a good creep resistance in the material. The temperature of the steam in the turbines is increased in order to deliver more energy; today’s turbines are dimensioned for almost 600 °C. The material in parameters, such as the strainer, should also be adjusted to the higher temperatures. Today’s temperature is suspected to be the cause of damage in the strainer because the present material might get brittle at higher temperatures.

The purpose of the thesis is to find a new material for the strainers and also to find a new concept for how to manufacture them. There are nine sizes of steam strainers but only five of them are exposed to the highest temperatures and pressure drops, which make only these five interesting to examine in this thesis. The concepts were chosen according to the method of Ulf Liedholm (1999), Systematic Concept Development. The thesis did not end up with only one concept because not all possible methods were tested but the suggestions are all based on a strainer built out of membranes as before. The discussed methods to join the membranes are EB-welding, laser welding and brazing.

An investigation to find if it was possible to improve the strength of the strainer by simple design changes and a calculation of what percentage of clogging the strainer would hold for was also done. The chosen material was a creep resistant, alloy special steel. Three suggestions on concepts were presented. The improvements in strength from simple changes in design were too small and too costly but are enclosed as an appendix in this report. Calculations on the strength were done without regard taken to fatigue caused by possible vibrations, so-called high cycle fatigue.

What would be interesting to do as a future work based on this thesis is, of course, to test the three manufacturing methods and evaluate them thoroughly but also to discuss other ways of improving the strength through design changes. These should be done regarding the flow. Also high cycle fatigue should be considered.

Keywords
Steam strainer, Steam turbine, Concept development, Material choice, Manufacturing process selection
Preface

This report is the result of my master’s thesis, the last part of my education to achieve a Master of Science in Mechanical Engineering at Linköping’s University. The project was done during the fall of 2007 in Finspång, Sweden, at Siemens Industrial Turbomachinery AB.

In order to complete this thesis I have had a great deal of help from a number of persons. At the company I would first of all like to thank Mattias Tallberg at DAC for taking the time to support me while constructing the FE-models. Then I want to thank my instructor, Michael Blomqvist at DATC, Christer Svensson at GTSL, Lennart Persson and Bo Andersson at STI and finally Bo Skoog at IEI, Linköping’s University.

This is an official version of the report, intended to be available on the Internet to anyone with an interest in it.

Finspång 2007-11-22

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Placed in the inlet to a steam turbine is a filter, a steam strainer, which separates particles and larger objects from the steam. These particles and objects will cause solid particle erosion in the actual turbine if they pass by. The strainer is exposed to large pressure drops when clogged, i.e., static loads which require a good creep resistance in the material. The temperature of the steam in the turbines is increased in order to deliver more energy; today’s turbines are dimensioned for almost 600 °C. The material in parameters, such as the strainer, should also be adjusted to the higher temperatures. Today’s temperature is suspected to be the cause of damage in the strainer because the present material might get brittle at higher temperatures.

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Sammanfattning

Examensarbetet utfördes i Finspång på Siemens Industrial Turbomachinery AB.


Syftet med arbetet är att välja ett nytt material till ångsilarna samt att finna nya koncept för hur ångsilen kan tillverkas. Nio storlekar på ångsilar finns men bara fem av dessa används vid högsta temperatur och tryck och därför har enbart dessa fem använts vid beräkningar i detta examensarbete.


En undersökning om det var ekonomiskt rimligt att förbättra hållfastheten genom enkla designändringar samt en beräkning över hur stor igensättning silen klarar gjordes.


Som framtida arbete med detta examensarbete som sprängbräda rekommenderas i första hand att testa de föreslagna metoderna för sammanfogning av membranen men även djupare diskussioner kring hur hållfastheten skulle kunna förbättras genom designförändringar borde tas. Dessa skulle kunna genomföras med avseende på flödet. Även högcykelutmattnings, HCF, borde undersökas.
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EBW and EB-weld........ Electron Beam Weld
EDM and ED-machined. Electron Discharge Machining
FE ................................ Finite Element, a method used calculating solid mechanics.
F/M-tree...................... Function/parameter-tree, this is a visual way of showing the different solutions, sub-solutions and suggestions on how to solve the problems in an explicit manner. This tree is used when developing a new concept.
HCF .......................... High Cycle Fatigue, i.e., fatigue at a great number of cycles, more than $10^5$ cycles.
HP ............................ High Pressure
IP ............................... Intermediate Pressure
KKL............................ Design criterion list, a list where the product specifications are assembled. This list is used when developing a new concept.
LCF ............................ Low Cycle Fatigue, i.e., fatigue at a small number of cycles, less than of $10^3$ cycles.
LP ............................... Low Pressure
SIT AB ......................... Siemens Industrial Turbomachinery AB
VAX turbines .............. Axial steam turbine that was introduced in 1982. Based on the steam moving in the axial direction of the turbine in contrary to the predecessor, the radial steam turbine, where the steam is introduced in the centre of the turbine and travels in the radial direction.
1 Introduction

In this section Siemens Industrial Turbomachinery AB is presented. Also, the steam turbine and steam strainer are introduced. The aim, purpose and limitations are noted and finally the present and previous solutions are shortly described.

1.1 The Company

Siemens is an international company with nine different business areas; Automation and Control, Power, Transportation, Medical, Information and Communication, Lighting, Financing and Real Estate, Affiliates and finally Other Activities.

The company where this thesis was done, Siemens Industrial Turbomachinery in Finspång, 30 km west of Norrköping, is a part of the area Power and produces gas and steam turbines.

1.1.1 History of Turbine Production in Sweden in General and in Finspång in Particular

It all began in 1883 when Gustav de Laval took out a patent for his steam turbine and then in 1893, De Laval Ångturbiner (De Laval Steam Turbines) was founded in Stockholm. Svenska Turbinfabriks AB Ljungström, STAL, was founded in 1913 in Finspång by the Ljungström brothers who had just constructed the Ljungströmsturbin.

STAL was in 1916 bought by what was then called ASEA and consolidated with AB de Laval Ångturbin. In 1959 it became Stal-Laval Turbin AB. Until this date De Laval and STAL were in a sense competitors even though STAL was specialized on stationary steam turbines and De Laval on turbines for warships and fast merchant vessels. After the fusion marine steam turbines were produced.

In 1944 STAL began developing gas turbines. Svenska Flygvapnet (the Swedish Air Force) was interested to buy three different jet engines and the response from STAL was the engines Skuten, Dovern and Glan, all named after local lakes. But when the jet engine Dovern was ready for mass production in 1951 Svenska Flygvapnet chose one from abroad. Stal-Laval modified the engines and in 1955 the stationary gas turbine GT35 was complete, based on the jet engine Glan.

Over the last 25 years the company has changed its name several times due to changes of owners but ended in 2005 up as today’s Siemens Industrial Turbomachinery AB (SIT AB).

(SIT AB, 2004)

Figure 1.1 illustrates this in a more explicit manner.
1.1.2 SIT AB in Numbers

Year of establishment: 2005
Number of employees at Siemens worldwide (2007): just over 475 000 in 190 countries
Number of employees at SIT AB (2007): about 2200 where 85 is in Trollhättan.
Turnover (2006): about 6 billion SEK
(Siemens AB, 2007)

1.2 Steam Turbine

Steam turbines are used to transform steam into kinetic energy. Steam is heated and put under high pressure. By letting it pass through the blades of the turbine the steam is expanded which releases enough kinetic energy to make the blades turn and produce mechanical energy in a generator.

There are mainly two kinds of steam turbines, axial and radial, Figure 1.2. In Finspång the radial turbine was developed during the 19th century and was also first to be developed. Not until in the 1980’s the axial turbine took over the market. The main difference is the direction of the steam flow. In the radial turbine the steam is brought to the centre to flow out in the radial direction while in the axial turbine the steam flows parallel to the axle passing the blades on its
way. It is the axial turbine that is dealt with in this report and will be referred to as turbine in the following texts.

There are three types of turbines, high pressure (HP), intermediate pressure (IP) and low pressure (LP). Most efficient are the last stage blades on the LP and the IP. But when the steam is too hot and at too high pressure, an HP is connected to use the steam at that state and then the steam is linked on in a closed circuit to an IP or LP turbine as in Figure 1.3. In this way the efficiency is raised and more energy is generated.

Figure 1.2:  

a) Axial turbine (IP/LP)  
b) Radial turbine  
(Internal material SIT AB, 2007)

Figure 1.3: HP and IP/LP turbines connected in series. The place for the steam strainer is marked. (Internal material SIT AB, 2007)
1.2.1 Steam Strainer

The core of this thesis, the steam strainer, is placed together with an emergency stop valve and a control valve in the pipe before the actual turbine to prevent particles and larger objects to pass into the turbine and cause possible fatal damage. The placing of the strainer is marked in Figure 1.3. The steam is very hot and the strainer is therefore exposed to considerable temperatures. The strainer is supposed to be cleaned annually since clogging causes pressure drop and losses in performance. The strainer is exposed to large forces due to large pressure differences when clogged. The design of the strainer is more described in section 1.5.1.

1.3 Aim and Purpose

The steam strainer is supposed to last throughout the life of the turbine (100 000 h) and since it does not, the purpose of this master thesis is to improve its strength to achieve this request. Above all it is the material that is assumed to be too brittle at the temperatures in question. But if the material is changed, the design must be altered since a more temperature endurable material is not possible to weld using conventional methods.

The aim is to form a new concept for material and design of a steam strainer for steam axial turbines. The new concept is supposed to deal with temperatures up to 585 °C and pressure drops of at most 165 bars, which is the pressure drop when the strainer is 100 % clogged. When the pressure exceeds 165 bars the safety valves open and the pressure never increases more. A clean strainer has a pressure drop of about 1.42 bars.

1.4 Limitations

The three types; HP, IP and LP are made in a range of different sizes within each type. The extreme cases in dimension for HP and IP are presented in Table 1.1. There is no reason to make calculations for the non-extreme versions, thus this report will focus on the extreme cases. Also, the LP turbines handle much lower pressures and temperatures and will therefore not be discussed at all.

*Table 1.1: The extreme cases that will be managed. The pressure drop is given as an absolute data.*

<table>
<thead>
<tr>
<th></th>
<th>HP/IP DN 150</th>
<th>HP/IP DN 400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum difference in pressure</td>
<td>165 bar (a)</td>
<td>165 bar (a)</td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>585 °C</td>
<td>585 °C</td>
</tr>
</tbody>
</table>
In service there are vibrations in the machine caused by the flow of steam, i.e., also in the steam strainer. These will be disregarded since they would make the project too extensive. Instead only low cycle fatigue (LCF) will be assumed to occur.

### 1.5 Present and Former Solutions

Different solutions of how to design the strainer in the best way according to needs and economy have been discussed throughout the years.

#### 1.5.1 Present Method

The design used today is a strainer built from a large number of membranes milled into their shape. See Figure 1.4. These are placed in a circular shaped structure by hand and welded and turned in the ends and heat treated still in the structure. The shape of the channels is developed to lead the steam on its way into the turbine.

![Figure 1.4:](image)

*a) The present design of the membranes. Between the channels are the borders, i.e., the elevations which support the next membrane.*

*b) The strainer as it is constructed today. The arrows represent the direction of the steam.*

*(Internal material SIT AB, 2007)*

Different shapes and dimensions of the channels in the strainer have been examined over the years and the company prefers to keep the dimensions and angle of the present shape if possible. The area of the channels is at most 0.8 mm wide and tilted 30° to simplify the flow of the steam. See Figure 1.4a. Wider channels of 1 mm have been used before but too large particles were then let into the turbine and a limit of 0.8 mm was decided. The plant in Görlitz, Germany,
produces a different type of strainer which does not have the 30° angle. This type of strainer is cheaper to produce but not as efficient. Since the calculations on the flow are not included in this project, no further research is done in this area and the guidelines set at SIT AB are followed.

The advantages of the present method using membranes are the cost and that it is relatively simple to manufacture. The disadvantages are that the material used does not resist the heat of the steam. And with a change of material it might not be possible to join the membranes by conventional welding.

1.5.2 Former Solutions Discussed

There are quite a number of solutions that have been discussed in the past. One of them is the so-called dovetail profile where the ends of the membranes have got a particular profile over which a ring is placed and squeezed to fit, Figure 1.5. This method uses the force of friction to keep the membranes in their positions.

![Figure 1.5: Example of what a cross section of the dovetail profile joint could look like. The darker part is the ring.](image)

Another way of fixing the membranes is to weld them together using electronic beam welding (EB-welding) and a supporting ring. This method is more described in section 2.5.

One totally different method discussed is to cut the whole strainer out of one piece. This should be done using laser cutting, water jet cutting or Electron Discharge Machining (EDM).

At the Siemens site in Görlitz a fourth method is used, namely membrane rings on top of each other. Every second membrane is wavy, the others are flat and in the space between the steam is allowed to flow.

![Figure 1.6: A close-up on how the membranes in Görlitz’ strainer are oriented.](image)
2 Theory

This section covers the theoretical background to the thesis. What material is used today? How is a strainer built out of the membranes? What does the environment of the strainer look like? The method systematic concept development by Ulf Liedholm (1999) is used to get a number of useable concepts and the theory is shortly noted in this section. Also the theory behind EB-welding and brazing is presented.

2.1 The Material

The material used today in the strainer is a ferrite stainless steel. The material’s Young’s modulus is dependent of the temperature and even at 300 °C it is as low as 164 GPa to compare with 217 GPa at 20 °C. The steel has a good corrosion resistance and the scaling temperature is 650 °C.

2.2 To Build the Strainer

The strainer is built out of membranes and there are two variants of each membrane, one plane and one conical, see Figure 2.1. The thickness of the plane is 2.5 mm and the one of the conical varies linearly between 2.5 and 1.9 mm with the thickest side out of the strainer, upwards on the figures below. When putting them together to get the strainer, an algorithm is used in order to get the correct diameter. The algorithm can for example look like PK or 3(PKK) + PK where P is the plane and K is the conical.

![Figure 2.1: a) A membrane showing where the cross section is cut. b) Cross sections of the plane membrane and c) the conical membrane.](image)

The dimensions of the strainers are listed in Table 2.1. For the two biggest strainers the number of channels are given as 8 (4+4) and 10 (5+5) which means
that there is a supporting weld on the middle and therefore the border on the middle is wider.

Table 2.1: The dimensions of the strainers in the HP turbines.

<table>
<thead>
<tr>
<th>Number of channels</th>
<th>Dout / Ain (mm)</th>
<th>Din (mm)</th>
<th>Dout (cm$^2$)</th>
<th>Ain (cm$^2$)</th>
<th>Aout (cm$^2$)</th>
<th>height (mm)</th>
<th>thickness (mm)</th>
<th>tout (mm)</th>
<th>Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>DN150</td>
<td>0,124</td>
<td>180</td>
<td>220</td>
<td>177</td>
<td>290</td>
<td>133</td>
<td>20 +0,06</td>
<td>1,6</td>
<td>4</td>
</tr>
<tr>
<td>DN200</td>
<td>0,124</td>
<td>230</td>
<td>270</td>
<td>218</td>
<td>371</td>
<td>133</td>
<td>20 +0,06</td>
<td>1,6</td>
<td>4</td>
</tr>
<tr>
<td>DN250</td>
<td>0,083</td>
<td>280</td>
<td>320</td>
<td>286</td>
<td>455</td>
<td>185</td>
<td>20 +0,06</td>
<td>1,6</td>
<td>6</td>
</tr>
<tr>
<td>DN300</td>
<td>0,062</td>
<td>330</td>
<td>370</td>
<td>385</td>
<td>595</td>
<td>252</td>
<td>20 h11</td>
<td>1,6</td>
<td>8 (4+4)</td>
</tr>
<tr>
<td>DN400</td>
<td>0,050</td>
<td>430</td>
<td>470</td>
<td>444</td>
<td>944</td>
<td>311</td>
<td>20 -0,25</td>
<td>1,2</td>
<td>10 (5+5)</td>
</tr>
</tbody>
</table>

2.3 The Environment of the Strainer

There are two types of strainers, one loose and one integrated. The integrated one is placed at the inlet of the turbine integrated with the safety valves. The separate is placed just before the safety valves. The integrated steam strainer is the one that is exposed to the most loads and will therefore be discussed in this report and further on will be called the strainer.

The strainer is placed together with an emergency stop valve and a control valve. These work independently of each other and act as safety devices to stop the steam flow in case of an accident. The strainer does therefore not need any safety function. The valves near the strainer require the strainer to be in the shape of a short pipe. In Figure 2.2 the casing in which the strainer is placed together with the safety valves is pictured. The arrows show the direction of the steam flow. Inside the casing the strainer is surrounded by the steam which penetrates from all sides, see Figure 1.4b.
2.4 Systematic Concept Development

A systematic and structured way of establishing a new concept is used. It is thoroughly described in Appendix A, but will be very briefly described here also. The main parts come from Liedholm (1999) which divides the method into three phases:

- **Concept Phase 1:**
  List the demands and requests in a design criterion list, the KKL. This is done by critically examining the problem and investigating the state of the art.

- **Concept Phase 2:**
  Use the KKL to make a function/parameter tree, the F/M tree. This is a tree structure that describes the functions and sub-solutions of the product.

- **Concept Phase 3:**
  From the previous two phases a number of concepts are generated. Since in this case there are only three interesting choices of concepts no further screening was done.

2.5 Principles of Three Possible Processes

Three possible processes, EB-welding, laser welding and brazing, are introduced here. All of them are favourable to be used together with shrink-fit rings.
2.5.1 Electronic Beam Welding

An electron beam is focused on the parts to be joined together. The beam is accelerated to approximately half the speed of light and melts the material into an extremely concentrated melt. The method is performed in vacuum to avoid the electrons being slowed down by molecules in the air and gives a deep penetration into the material, see Figure 2.3. The advantages compared to conventional welding are first of all the possibility to weld parts in difficult materials, for instance, heat resistant materials such as titanium, tungsten and molybdenum, but also in two different materials. This method leaves very little deformation in the parts since the area exposed to the beam is small and concentrated. The greatest disadvantage is the cost; EB-welding is expensive compared to conventional welding. (Svetskommissionen, 2007)

In this case, there are a few additional disadvantages. The EB-weld on the site in Finspång is designed to weld the actual turbines and has an oversized chamber. The welding is done in vacuum which has to be re-established every time the work piece is changed or replaced. The size of the chamber makes this a time consuming part of the work.

![Figure 2.3: Simplified sketch of EB-weld principles. (Svetskommissionen, 2007)](image)

2.5.2 Laser Welding

Laser welding is, like EB-welding, a method with high energy density. A laser beam is focused by systems of lenses or mirrors on the details to be welded. It gives a concentrated heating which heats the surface and leads the heat into the material. The material vaporizes and leaves a cavity deep inside the material. To protect the lenses and the weld itself a protective gas is used, usually helium or argon. The advantages for laser welding are that it is a fast method with a deep penetration and small deformation. The disadvantage is the need for a high
exactitude. The method also implies a major investment, but in this case, the investment is already done. (Svetskommissionen, 2007)

2.5.3 Brazing

The basic principle is that two metal pieces are put together closely and a filler metal is filling the cavity between them. This is all put in a furnace and heated during vacuum. The filler metal is melted but the two pieces to be joined are still solid. In this way an almost invisible joint is produced. The filler metal used at SIT AB is consequently Ni-based because of its excellent corrosion resistance, its resistance to high performance temperatures and its high strength. In order to give a satisfying joint the joint clearance should be within the range of 0.10-0.15 mm. If the clearance is wider precipitations of intermetallic phases will occur and the hardness of these precipitations are extremely high and will therefore cause a very brittle joint. A good way of getting the joint clearance small enough in this case could be by shrinking on supporting rings, see section 4.2.1. There are a number of different forms of the filler metal but the interesting forms in this case are paste, tape or foil, Figure 2.4. The paste is a mixture of metal and binder and would be applied as in the figure and drawn into the clearance by the capillarity force. The tape is similar to the paste but with an adhesive layer which makes the metal easier to apply. The foil has the advantage of being pure metal, no binders, unfortunately this also makes it hard to handle since the nickel itself has very low ductility. The brazing cycle is divided into six steps. First of all is a heating ramp to a temperature below the melting temperature of the filler metal, the preheat temperature. The second step is when the preheat temperature is reached and kept constant in order to let the temperature gradients even out, the soaking time. If a filler metal with binders or solvents is used, a soaking time at a lower temperature can be used to let the additives evacuate. The third and fourth steps are a short heating ramp followed by a soaking time at a higher temperature, the brazing temperature. When the soaking time is elapsed a cooling step follows until a temperature under the filler metal’s melting temperature is reached. Then, when the filler metal is solid, a forced cooling starts. (Internal material, SIT AB)

Figure 2.4: Two ways of applying the filler metal: a) As a tape of foil or b) as a paste both with shrink-fit rings.
3 Method

This section covers the method of how the thesis was performed. The concepts in question and two ways of improving the strength are presented. Also shown are calculations over how the material in the strainers is affected when the strainers have been used and are getting clogged.

3.1 Choice of Concept

Liedholm’s (1999) method, Systematic Concept Development, is used.

3.1.1 Phase 1 – Establishing the Design Criterion List

The first step in establishing the concept is to make a design criterion list, a so-called KKL.

Critical Inspection of the Problem

*What is the problem?* – With higher temperatures the material fails.

*Who has the problem?* – The customers, and if the customers are not satisfied they will not buy the turbines from SIT AB, and then SIT AB has got the problem too. With a 5 year warranty SIT AB is keen to have a strainer fulfilling the demands.

*What is the purpose/goal?* – The product is supposed to manage 100 000 hours in duty with a maximum temperature at 585 °C or 10 000 temperature cycles with a maximum temperature at 370 °C and a minimum temperature at 180 °C. At normal duty the pressure drop is 0.86 % but as a request the product should manage 100 % clogging, i.e., 165 bars of pressure drop. The product is recommended to be cleaned once every year.

*What side effects should be avoided?* – The flow through the strainer should not be affected, i.e., the shape and angle of the channels through the strainer should be kept the same.

*What limits are there for solving the problem?* – The dimensions of the parts that are connected to the parts around the turbine should not be changed. The dimensions where the steam flows are calculated and should not be changed.

Establishing the Design Criterion List – KKL

<table>
<thead>
<tr>
<th>Function</th>
<th>Demand/request</th>
</tr>
</thead>
<tbody>
<tr>
<td>To strain particles and larger objects from the steam</td>
<td>d</td>
</tr>
</tbody>
</table>

**Function determining properties**

- Roughly the same dimensions as today                  r
- Dimensions of part in contact with other detail close by d
Properties for time of use

- Manage steam at 585 °C for 100,000 hours
- Manage 10,000 cycles with $T_{\text{max}}=370$ °C and $T_{\text{min}}=180$ °C
- Possible to remove the product at steam blow
- Possible to change gaskets and other loose parts

Manufacturing properties

- Produced using the existing machine park/suppliers
- Possible to test

Distributing properties

- Manage storage in direct sunlight
- Manage outdoor storage in rain and snow
- Manage storage at -40 °C
- Manage storage at 50 °C

Delivery and planning properties

- Will be manufactured in very small batches
- Will be manufactured continuously

Economical properties

- Manufacturing cost about the same as before

3.1.2 Phase 2 – Establishing the Function Analysis

Starting from the KKL, an F/M-tree will be made.

The black box model

The first step in this phase is to determine the main function in a black box model. See Figure 3.1.

![Figure 3.1: The black box model](image)

Main function: Cleaning the steam.
Operator: Steam.
Input: Impure steam, 585 °C, containing particles and possibly larger objects.
3.1 Choice of Concept

Output: Clean steam, 585 °C.

Establish technical principles

There are a number of possible solutions on how to actually clean the steam and in this second step they will be examined to find out the best combination. First of all, three possible ways to separate the particles from the steam are mechanically with a strainer, with a magnet and by chemically cleaning. The magnet is found insufficient since there might be non-magnetic particles. The chemical solution is also disregarded from since there is really no reason to use chemicals un-called for. Remaining is the mechanical solution, the strainer.

Three possible methods to make a mechanical strainer is to cut it out of one piece, build it up from membranes or finally use a container filled with some kind of straining content. For the last suggestion the area of the flow was found to be too complicated to control and therefore disregarded from. Basically there are now three ways left to end up with a functional strainer; to make a cylindrical one out of one piece, to use longitudinal membranes as it is done today and finally to Figure 3.2.

![Figure 3.2: The F/M-tree with the chosen options in the coloured fields](image-url)

3.1.3 Phase 3 – Establishing the Concept

The final concepts are the following eight:

- A cylindrical strainer ED-machined out of one piece into the desired shape.
- A strainer laser cut from one piece into desired shape.
- A strainer water jet cut from one piece into desired shape.
- A strainer built out of the same kind of membranes used today but, of course, in another material and joined by EB-welding.
- A strainer built out of the same kind of membranes used today but, of course, in another material and joined by a dovetail profile.
- A strainer built out of the same kind of membranes used today but, of course, in another material and joined by brazing.
- A strainer built out of the same kind of membranes used today but, of course, in another material and joined by laser welding.
- A strainer built out of membranes shaped as rings placed on top of each other. These are then held together by some kind of supporting construction.

### 3.2 Improving the Strength

There are a number of ways in which the strength of the steam strainer can be improved. This can be done first of all by changing the material but also by changing the design to dissolve the stress concentrations. The change of material is more discussed in section 4.1.

#### 3.2.1 Influences on the Strength from Changes in Design

By small changes in the design major impacts on the strength can be achieved. Here, the modification is done by adding a small angle to the borders to smoothen out the stress concentrations, see Figure 4.7 and Figure 4.8.

The FE-models used in this section are based on the longest membrane without a welding support on the middle and with six channels. This is the one used making the strainer DN250, see Table 2.1. This one is chosen as a representative membrane. The algorithm for building a strainer out of these membranes is PKPK, i.e., every second membrane is plane and every second conical.

To achieve a reasonable model two membranes are modelled, one plane and one conical, and joined together into one final model, see Figure 3.3. This is not entirely correct since in reality only the ends are joined by welding or a similar method and the borders are only leaning on each other. But since the steam flows radially from the outside and into the strainer the membranes are squeezed together and will probably act as if they were welded on all contact surfaces. This is more discussed in section 5.2.

On the ends of the model, in Figure 3.3 marked 1 and 2, boundary conditions in the second direction are prescribed on the whole line. In the end marked 1 a boundary condition in the first and third direction is also applied. The one in the third direction is applied to the whole line while the one in the first direction is only applied to one node. The boundary condition in the first direction is to prevent the model from spinning during the calculations. The model is also under
3.2 Improving the Strength

a cyclic boundary condition, i.e., the model is restrained in the surfaces where the next membrane in a real strainer would have been if the whole strainer were modelled.

Figure 3.3: The unloaded model.

To confirm that the models correspond enough to reality to use them in this project a four-point bending test was performed and compared to a model loaded in the same way. The result of the model can be seen in Figure 3.4 and the actual test in Figure 3.5. The results are close enough to verify the other models.

Figure 3.4: The model of the bending test.
3.3 Effects of Clogged Strainer

In this section, first of all clogging is evaluated for different sizes of strainers. Secondly a recommendation is given on at what percentage clogging the strainers should be cleaned to keep the life of the turbine as long as possible. There are three different FE-models in this section and they are based on the strainers DN200, DN250 and DN400. Dimensions are found in Table 2.1.

3.3.1 Influence of Clogging

The load that the strainer is exposed to is directly proportional to the pressure drop over the strainer. The pressure drop on the other hand is depending on the percentage clogging of the strainer. The pressure on the outside of the strainer is 16.5 MPa, which is also the pressure drop if the strainer is 100% clogged. No higher pressures will be reached because of safety valves. At a high percentage clogging the load will however not be the problem since the strainer will probably be affected more because of vibrations as the flow velocity increases. But up to what flow velocity is it the load that matters? The equations presented in this section are gathered from SIT AB Internal material if nothing else is noted.

The pressure drop over the strainer, $\Delta p$, is calculated by

$$\Delta p = \zeta \cdot \frac{a^2}{2} \cdot \frac{1}{V_{\text{spec}}} \cdot \frac{1}{p_0} \cdot 100[\%] \quad (3-1)$$

where $\Delta p$ is given in percent, $a$ is the flow velocity through the strainer in m/s, $p_0$ is the maximum pressure drop over the strainer and also the pressure outside the strainer, $16.5 \text{ MPa} = 16.5 \cdot 10^5 \text{ N/m}^2$, $V_{\text{spec}}$ is the specific volume of steam flowing through the strainer at $p_0$, here given as $0.0212 \text{ m}^3/\text{kg}$. The factor $\zeta$ is the pressure loss coefficient and is empirically determined to 2.4 from research in the 1950’s. $\zeta$ is more discussed in section 5.4.
The flow velocity with respect to percentage clogging is calculated by

$$a = \frac{\dot{V}}{A} = \frac{\dot{V}}{A_{in,\%}} \cdot 10^{-4}$$  \hspace{1cm} (3-2)

where $\dot{V}$ is the volume steam flowing through the strainer in m$^3$/s and $A_{in,\%}$ is the area of the inlet through the strainer depending on the percentage clogging given in cm$^2$.

The relation between $A_{in,\%}$ and the inlet through a clean strainer, $A_{in}$ is

$$A_{in,\%} = \left(1 - \frac{\Delta cl}{100}\right) \cdot A_{in}$$  \hspace{1cm} (3-3)

where the $\Delta cl$ is the percentage clogging in the strainer.

The inlet $A_{in}$ for each DN size is listed in Table 3.1. In this table only strainers used in HP turbines are noted, see section 1.4.

**Table 3.1: Table over DN sizes and corresponding inlet through the strainer for strainers used in HP turbines.**

<table>
<thead>
<tr>
<th>DN [mm]</th>
<th>$A_{in}$ [cm$^2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>177</td>
</tr>
<tr>
<td>200</td>
<td>218</td>
</tr>
<tr>
<td>250</td>
<td>386</td>
</tr>
<tr>
<td>300</td>
<td>595</td>
</tr>
<tr>
<td>400</td>
<td>944</td>
</tr>
</tbody>
</table>

A well balanced flow velocity of the steam, according to SIT AB, is $a = 50$ m/s. When the strainers are clean the volume, $\dot{V}$, is chosen to achieve this speed. Use (3-2) and data from Table 3.1 with these values:

$$\dot{V} = 50 \cdot \frac{A_{in,\%}}{100^2}$$  \hspace{1cm} (3-4)

Equation (3-2) is plotted in Figure 3.6. The sound velocity in the steam at this pressure and temperature, which has been calculated by Markus Jöcker$^1$, $c = 681$ m/s, is also plotted. According to SIT AB, the flow velocity of the steam will stabilize at this speed because of properties in the steam. This will not be more discussed in this report.

---

$^1$ Markus Jöcker, Doctor of Engineering at KTH (Royal Institute of Technology), discussion November 13, 2007.
The velocity and pressure drop with respect to percentage clogging calculated with equations (3-1), (3-2) and (3-4) are presented in Table 3.2 where \( p_1 \) is the pressure inside the strainer in MPa. The pressure drop is visualized in Figure 3.7 and the ratio between inner and outer pressure in Figure 3.8.
3.3 Effects of Clogged Strainer

![Graph showing the ratio between pressures on the inner and outer side of the strainer](image)

**Figure 3.8:** How the ratio between the pressures on the inner and outer side of the strainer depends on the clogging in the strainer.

<table>
<thead>
<tr>
<th>$\Delta_{cl}$ [%]</th>
<th>$a$ [m/s]</th>
<th>$\Delta p$ [%]</th>
<th>$p_1/p_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>50,00</td>
<td>0,86</td>
<td>0,9914</td>
</tr>
<tr>
<td>5</td>
<td>52,63</td>
<td>0,95</td>
<td>0,9905</td>
</tr>
<tr>
<td>10</td>
<td>55,56</td>
<td>1,06</td>
<td>0,9894</td>
</tr>
<tr>
<td>15</td>
<td>58,82</td>
<td>1,19</td>
<td>0,9881</td>
</tr>
<tr>
<td>20</td>
<td>62,50</td>
<td>1,34</td>
<td>0,9866</td>
</tr>
<tr>
<td>25</td>
<td>66,67</td>
<td>1,52</td>
<td>0,9848</td>
</tr>
<tr>
<td>30</td>
<td>71,43</td>
<td>1,75</td>
<td>0,9825</td>
</tr>
<tr>
<td>35</td>
<td>76,92</td>
<td>2,03</td>
<td>0,9797</td>
</tr>
<tr>
<td>40</td>
<td>83,33</td>
<td>2,38</td>
<td>0,9762</td>
</tr>
<tr>
<td>45</td>
<td>90,91</td>
<td>2,84</td>
<td>0,9716</td>
</tr>
<tr>
<td>50</td>
<td>100,00</td>
<td>3,43</td>
<td>0,9657</td>
</tr>
<tr>
<td>55</td>
<td>111,11</td>
<td>4,24</td>
<td>0,9576</td>
</tr>
<tr>
<td>60</td>
<td>125,00</td>
<td>5,36</td>
<td>0,9464</td>
</tr>
<tr>
<td>65</td>
<td>142,86</td>
<td>7,00</td>
<td>0,9300</td>
</tr>
<tr>
<td>70</td>
<td>166,67</td>
<td>9,53</td>
<td>0,9047</td>
</tr>
<tr>
<td>75</td>
<td>200,00</td>
<td>13,72</td>
<td>0,8628</td>
</tr>
<tr>
<td>80</td>
<td>250,00</td>
<td>21,44</td>
<td>0,7856</td>
</tr>
<tr>
<td>85</td>
<td>333,33</td>
<td>38,12</td>
<td>0,6188</td>
</tr>
<tr>
<td>90</td>
<td>500,00</td>
<td>85,76</td>
<td>0,1424</td>
</tr>
</tbody>
</table>

**Table 3.2:** Speed, pressure drop and ratio between the outer and inner pressure presented with respect to percentage clogging.
3.3.2 Recommendation on Percentage Clogging

Previously the strainers have been guaranteed to manage 100% clogging. Now, an alarm at a certain pressure drop has been discussed. In this section a limit for how much the strainer can take without respect to vibrations will be calculated. This will be done with respect to ductile fracture, LCF and creep. The $\sigma_{el}$'s used are the effective stresses according to von Mises and calculated according to Dahlberg (2001) as:

$$\sigma_{vM}^M = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 - \sigma_x \sigma_y - \sigma_y \sigma_z - \sigma_z \sigma_x + 3\sigma_{xy}^2 + 3\sigma_{yz}^2 + 3\sigma_{xz}^2}$$ (3-5)

**Ductile Fracture**

First of all a safety factor, $\Gamma$, is calculated

$$\Gamma = \frac{R_{p0.2}}{\sigma_{el}} \geq 1.5$$ (3-6)

where $R_{p0.2}$ is the yield limit.

**LCF – Crack Initiation**

Regarding a cyclic load it is the stress difference that is important but in this case the minimum stress $\sigma_{min} = 0$ and therefore the difference in stress is equal to the maximum stress; $\Delta \sigma = \sigma_{max} = \sigma_{el}$. The criterion is

$$\Delta \sigma_{el} \leq R_{p0.2} \Leftrightarrow \Gamma = \frac{R_{p0.2}}{\Delta \sigma_{el}} \geq 1$$ (3-7)

**LCF – Crack Propagation**

If there is a crack initiation the safety factor for crack propagation, $\Gamma$, is

$$\Gamma = \frac{a_c}{a_N} \geq 3.0$$ (3-8)

Where $a_c$ is the critical crack depth and $a_N$ is the crack depth after N cycles.

**Creep**

Finally and maybe most important is to evaluate the creep. The safety factor $\Gamma$ need to be bigger than 1.

$$\Gamma = \frac{S}{\sigma_{el}} \geq 1.0$$ (3-9)

where
\[ S_i = \min \left\{ \left( \frac{2}{3} \right) R_{km,t}, R_{k,1\%t} \right\} \]  

(3-10)

Where \( R_{km,t} \) is the creep rupture strength, i.e., the stress that gives creep rupture after time \( t \) and \( R_{k,1\%t} \) is creep strain limit, i.e., the stress that gives 1% creep strain after time \( t \). Here the time \( t = 100000 \) h is used and all data are at temperature 585 °C.

If this condition is not fulfilled the next step is to check the following condition:

\[ \frac{S_i}{\sigma_{\text{dim}}} \geq 1.0 \]  

(3-11)

Where

\[ \sigma_{\text{dim}} = \max \left\{ \sigma_n, \left( \frac{\sigma_n + \sigma_b}{1.5} \right) \right\} \]  

(3-12)

Where \( \sigma_n \) is the mean stress over a load carrying cross section and \( \sigma_b \) is the bending stress over a load carrying cross section.
4 Results

In this section the result of the choices and calculations are presented and somewhat analysed. No final choice of concept is done but the costs for the three finalists are listed.

4.1 Choice of Material

The material chosen is a creep resistant, alloy special steel. Its main requirement is the creep resistance under mechanical long-time stressing at temperatures above 500 °C. Looking at the properties at room temperature this material is as good as, or worse, than other materials discussed during the progress of the project, but at higher temperatures the development of the chosen material is more uniform than the other. And since the strainer will be exposed to loads at as high temperature as 585 °C the properties at this level is the most important. Some examples on the properties of this material compared to other can be seen in Figure 4.1 and Figure 4.2 where the chosen material is called Mtrl A and the other, Mtrl B-D, are other materials discussed throughout the project. In Figure 4.3 the elongation limit for the material chosen, three other materials discussed and the present material is plotted.

Also, while dimensioning the strainer, this material managed quite high loads relative the other materials evaluated.

![Figure 4.1: The creep elongation limit for the material chosen, Mtrl A, and three other materials discussed. The materials Mtrl B-D are all creep resistant, martensitic stainless steel.](image-url)
Figure 4.2: The creep rupture limit for the material chosen, Mtrl A, and three other materials discussed. The materials Mtrl B-D are all creep resistant, martensitic stainless steel.

Figure 4.3: The elongation limit for the material chosen, Mtrl A, three other materials discussed and as Mtrl E, the material used today. The materials Mtrl B-D are all creep resistant, martensitic stainless steel.

4.2 Choice of Concept

In 3.1 the choices of concept have been narrowed down to three versions of membranes; the EB-welded profile, the laser welded profile and the brazed profile. They all have advantages and disadvantages such as cost and simplicity
that do not make any of them the perfect choice. Four strainers have been manufactured using EB-welding with satisfying results but tests of the other two concepts are to prefer to know which one is the most suitable.

4.2.1 Shrink-fit Rings

In order to produce a safe EB-weld, laser weld or brazing joint while manufacturing the strainer some kind of supporting ring is needed. The ends are machined after the welding no matter what type of joining process is used.

**Weld**

To weld the strainer, a ring with a cross-section as the ones in Figure 4.4 could be used. Figure 4.4a is welded twice in each end of the strainer with the welds perpendicular to each other, as the arrows in the figure. In this way there is non-welded material too to secure the joint but as the weld shrinks the material there are some stresses built into the material in this way. Figure 4.4b solves the problem with the stresses but leaves no non-welded material to support the load. The dashed arrow in the figure represents a possible supporting weld which could be done if needed. The advantage of the second alternative is that it will only need to pump vacuum in the chamber once, see section 2.5.

![Figure 4.4: Two suggestions on supporting ring to be used with EB- and laser welding. The arrows show where the welding should be placed.](image)

**Braze**

It is very important that the space between the surfaces to be brazed together is small, not bigger than 0.1 mm, and in order to get such a fine tolerance shrunken on rings are excellent. One suggestion on how this ring could be designed is shown in Figure 4.5. With a v-shaped cavity as shown in the figure the filler metal as a paste is easily placed. The ring in Figure 4.4a is also possible to use when brazing, see section 2.5.3.
Figure 4.5: Suggestion on how a supporting ring could be designed for brazing. The rings symbolize the filler metal before it is sucked into the joint by the capillarity attraction.

4.3 Changes in Design

Two variants in design are considered. With the original straight borders, as can be seen in Figure 4.6, it is possible to mill a number of membranes in the same pass which makes the manufacturing quite cheap. The alternatives, as seen in Figure 4.7 and Figure 4.8, are more complicated to manufacture. A more detailed examination of the changes is done but will not be presented here in the official version of the report. But briefly, they are improvements in strength but not worth the change in cost.

Figure 4.6: The original design of the membranes.

Figure 4.7: The first variant in design, M1.
4.4 Dimensioning with Respect to Load, Vibrations Excluded

If the strainers fail at 16.5 MPa pressure drop, it is interesting to know at which percentage clogging they will pass. The sizes DN200, DN250 and DN400 are used together with the same materials as shown in Figure 4.1, Figure 4.2 and Figure 4.3. A lot of the results are censored due to corporate secrecy.

4.4.1 Ductile Fracture

\[ \Gamma = \frac{R_{\rho 0.2}}{\sigma_{el}} \geq 1.5 \]  

(4-1)

The elongation limit for the interesting materials varies as (4-2) at 585 °C

\[ 206MPa \leq R_{\rho 0.2} \leq 280MPa \]  

(4-2)

Due to the secrecy the result will not be presented here.

4.4.2 LCF – Crack Initiation

With the explanation in section 3.3.2 the following equations are used.

\[ \Delta\sigma_{el} \leq R_{\rho 0.2} \Leftrightarrow \Gamma = \frac{R_{\rho 0.2}}{\Delta \sigma_{el}} \geq 1 \]  

(4-3)

Where

\[ \Delta\sigma_{el} = \sigma_{el}^{\max} - \sigma_{el}^{\min} = \sigma_{el} - 0 = \sigma_{el} \]  

(4-4)

The same \( \sigma_{el} \) as before is used and therefore the same data as in section 4.4.1 can be used. Also the same results occur. The levels where crack initiation might occur will not be used and therefore no calculations on crack propagation are done. But due to censorship the result will not be presented here.

4.4.3 Creep

\[ \Gamma = \frac{S_i}{\sigma_{el}} \geq 1.0 \]  

(4-5)

where
\[ S_r = \min \left\{ \frac{2}{3} R_{km,1} ; R_{k,1\%} \right\} \]  \hspace{1cm} (4-6)

For the different materials the \( S_r \) varies as:
\[ 44.67 \leq S_r \leq 61.33 \]  \hspace{1cm} (4-7)

All of these \( S_r \) are equal to \((2/3) \cdot R_{km,100\,000}\). In the case this condition is not fulfilled a second condition is used:
\[ \Gamma = \frac{S_r}{\sigma_{\text{dim}}} \geq 1.0 \]  \hspace{1cm} (4-8)

Where
\[ \sigma_{\text{dim}} = \max \left\{ \sigma_n; \frac{(\sigma_n + \sigma_b)}{1.5} \right\} \]  \hspace{1cm} (4-9)

where \( \sigma_n \) is the mean stress over a load carrying cross section and \( \sigma_b \) is the bending stress over a load carrying cross section.

And as before, no results are presented here.
5 Discussion

The choices made in this thesis are discussed together with the results. Important is to notice that the results of the dimensioning in section 4.4 are done with no regard to possible vibration damages.

5.1 Manufacturing Process

The choice of process is not finished in this report. The suggested concepts should be tested and more studies are required.

The changes in cost for each process are not to be ignored while making the choice. It has to be considered if maybe an expensive process is to prefer because of its advantages, such as in-house expertise.

The joints will have different size depending on manufacturing process. The cross section area of the EB-welding joint is almost the same as the one done with brazing. But if the filler metal in brazing has leaked into the clearance between the membranes this joint will be bigger and therefore stiffer. The membranes should not be able to move that much independently no matter what size the joint is so it will probably not matter that much in that point of view. But a stiff joint tends to be more brittle than a flexible one and that could be a disadvantage. The larger an object is the bigger the probability is that there will be imperfections in it. With this device it seems to be better with a small joint. But, not to forget, a small joint might be too fragile.

The supporting welds on the middle that is used today on the larger strainers are not discussed in the results. There will be a problem if shrink-fit rings are meant to be used since it will not be possible to shrink them that much. This gives the brazing method a disadvantage since a supporting ring is crucial. For the methods with EB- and laser welding it is easier just to make a weld on the middle. The direction of the weld might have to be angled or the border in the middle has to be redesigned. An investigation on how much load this middle support is taking could be done in order to choose an appropriate method.

5.2 The FE-Models

In this thesis models are modelled in I-DEAS (UGS, Corp. 2006) and analysed in Abaqus (Abaqus, Inc. 2006). They were relatively easy to learn and did not extend the thesis too much.

A model is a simplified version of reality. The closer it is to the truth, the more complicated it gets and complicated models are time consuming both regarding computation time and modelling time. The models used in this thesis are simplified mostly regarding load, support and joints.
First of all, the load itself is simplified. Instead of modelling a flow and a pressure drop a uniformed load is used. This was done because it would be too complicated to model the flow. Secondly; to model the load the end lines of the channels are used, see Figure 5.1 with the load on the lines marked A. In this particular model there are four lines on each membrane, therefore a fourth of each membrane’s total load is put on each line. This simplification was done because there are no suitable surfaces to load since the top of the model is rounded. Because of these two simplifications no reactions caused by the flow of steam are examined. And as has been remarked before, no vibrations are taken into account and therefore the limits are a little high.

The supports are done as boundary conditions in two lines, see Figure 5.1 marked B. The real strainer is hanging together with the valve cover in the casing which can be seen with a closer look at Figure 2.2b. The bottom end of the strainer has space to increase in length. Also, the casing is shaped to fit the strainer and will therefore support it in the radial direction for a short distance in the longitudinal direction. This is not taken into account at all in the models.

The membranes in the models are done as if they were stiffly joined in all contact surfaces. This is compared with reality where most of the contact surfaces are only supporting each other. But when the steam is flowing through the strainer it is squeezing the membranes together because the strainer is circular and some of the membranes are conical. And therefore this simplification is not unjustified. Although it is hard to see what difference the supporting weld on the middle of the two larger strainers did.

Figure 5.1: The model of the DN200 strainer in I-DEAS (UGS, Corp. 2006)
5.3 Changes in Design

Since the surfaces of the channels are angled, membranes are milled with a shank end mill after being arranged on a plate with holes for each membrane. Then they are all milled in one pass. This worsens the possibilities to alter the design as suggested in section 4.3. This far the modified versions have only been investigated with a distributed load on the top edge and it is not known how the membranes would react if loaded with the actual flowing steam. Probably the second modified version, M2, will have some problems with the quite thin and sharp edges on the bottom side.

Other changes in design could be discussed to improve the strength. Maybe the radius between the surface in the channels and the edges could be enlarged.

5.4 Dimensioning and HCF

As been pointed out before, vibrations and any other kind of HCF is disregarded from in the calculations in this report and therefore the limits in section 4.4 are probably to be reduced. The material will hold for these loads if there are no vibrations but when the flow velocity of the steam increases there will probably be some sort of self excitation.

The factor $\zeta$ used in Equation (3-1) in section 3.3.1 is a reason for discussion. The factor is based on experiments in the 1950’s and has been used for dimensioning for years. But in this case it might not be totally correct. It is developed to work with increase in flow velocity but because of increasing pressure and not because of decreasing flow area. But to find an appropriate factor for this case would be another thesis. And all the same, it has been used in this thesis because of lack of options and that it will probably not make that much of a difference.

5.5 Supporting Rings

In the discussed concepts supporting rings are included but with various cross sections, see Figure 5.2.

5.5.1 EB-Welding

It is not safe to EB-weld without a supporting ring since there is no extra material added and if the membranes are not as closely packed as they should be there will be a crack in the weld. Two ways of designing the ring for EB-welding are shown in Figure 5.2 a and b.

The first, a, is the one method that has been tested with EB-welding. It is also the one that at a first glance should have the best strength since the weld will not be straight through the membrane. It is hard to do any computations for the strength of the weld because it can vary a lot depending on a number of parameters such as material and cleanliness but the untreated material act like a safety device. But what have to be considered is that the part shrinks in the weld and two welds
perpendicular to each other might leave the part with built-in stresses. Also this type of supporting ring requires the work piece to be changed during the welding cycle which extend the machine time, see section 2.5.1.

The second suggestion on the ring, b, does not have the problem with built-in stresses since the weld is straight through the membrane but that is also a disadvantage. As said before it is very hard to compute the strength of the weld and in this case there is no non-welded material to trust. But compared to the previous suggestion the largest advantage is that the work piece does not have to be changed and the machine time will be shorter and therefore the cost would decrease. The edge on the inside of the strainer will be machined away after the welding. Also an extra supporting weld could be done perpendicular to the other, although this would require the same change of work piece as for suggestion a.

### 5.5.2 Brazing

When brazing a very small clearance where the filler metal goes is important. A supporting ring shrunk on is an excellent way of getting this small clearance. Two of the supporting rings in Figure 5.2 are possible to use when brazing, a and c.

The first suggestion requires filler metal in the form of tape or foil. The filler metal is placed around the strainer before the ring is shrunk on. The disadvantages are the cost and that the foil and tape are difficult to work with, see section 2.5.3.

The third ring, Figure 5.2c, is designed to be used together with filler metal in the form of a paste. There are two tracks on each end of the membrane which follows the ring around the strainer. The paste is placed in these tracks and when melted is it sucked in between the ring and the membranes by the capillarity force. As long as the soaking is good and the clearance is small this joint will allegedly work well.

![Figure 5.2](image)

*Figure 5.2: Three versions of possible supporting rings depending on choice of joining process.*

* a) For EB-welding or brazing with tape or foil  
 b) For EB-welding  
 c) For brazing with paste.*
6 Conclusions

A new material is chosen. It has average properties at lower temperatures but good properties at temperatures around 600 °C which is what it is requested for.

No final concept is chosen but three suggestions are made. All of them are based on the membrane system used today. The suggestions are EB-welding, laser welding and brazing. Tests have been done on the EB-welding method but no choice should be made before more tests are performed. EB-welding is expensive but the cost depends on the machine time which could be shortened by different designs of the supporting ring.

Different sizes of the strainer can handle loads of different percentage of clogging. These calculations are done without any regard to possible vibrations and as can be seen in section 5.4 there is an uncertainty of the factor $\zeta$. 

7 Recommendations on further work

First of all, the investigation of the most appropriate joining concept should be finished.

Secondly, a deeper examination on the strength improvements from design changes could be done, not only from a solid mechanics point of view but also fluid mechanics. How does the flow change because of the shape of the channels?
References

Literature

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Appendix A Method Used to Develop Concepts

A.1 Systematic Concept Development

Liedholm (1999) divides the development of the concepts into three phases. In short terms; the first provides a specification of the product properties from the main problem; in the second phase the decision of what the product is supposed to do and to produce is made and a function/parameter-tree (F/M-tree) is established; and finally in the third phase parameters are chosen from the F/M-tree and combined into sub-solutions. From these combinations the final concepts are chosen. (Liedholm 1999)

In his book Liedholm (1999) stresses that models are only simplifications of the reality. Simple models are easy to understand but far from the truth, complex models are closer to the truth but harder to understand. In the end there has to be some kind of a balance between these two.

A.1.1 Phase 1 – From Problem to Design Criterion List (KKL)

From the problem the product specification, including its properties, is collected. It is compiled in a design criterion list (the KKL) where the properties and the purpose of the product are defined. In the KKL the ground rules for the development process are given and it is supposed to be useful at evaluations. In the beginning the KKL will be vague because of the lack of knowledge but will be more specified as the project moves on. The KKL is made with the help of four steps described in Figure A.1. In the first step the problem is carefully reviewed by asking some simple questions.

- **What is the problem?** – Formulated to be possible to solve.
- **Who has the problem?** – One single person or a whole group?
- **What is the purpose/goal?** – What does the one who has the problem want?
- **What side effects should be avoided?**
- **What limits are there for solving the problem?** – Supplies, time, staff, etc.


The second step is to do a background research to check the state of the art. Maybe a similar problem has been solved before. In that case, how has that been done and at what cost? This kind of information might be found in patents, with competitors and in literature. It can also be useful to look for similar problems in totally different areas. As a third step, the project should be evaluated to be sure it is technically and economically viable. This check is not only supposed to be done in this third step but also as a regularly feature during the project’s course.
In case more knowledge or staffs is needed, an arrangement to acquire it will be formed. The fourth and final step is to actually establish the KKL. In the beginning of the project the KKL should be independent from the solution but will turn dependent as the project proceeds and the new knowledge is added to the KKL. (Liedholm, 1999)

**Figure A. 1: Concept phase 1, from problem to design criterion list, KKL (Liedholm, 1999, p. 7)**

There are a few things to consider while formulating the properties in order to receive the best result in the end.

- **Comparable/incomparable properties** – Choose comparable properties that are possible to rank. A property is incomparable if the only conclusion to be drawn is if it is fulfilled or not.

- **Demands/requests** – There should be a distinct line between demands and requests. Demands have to be fulfilled, if they are not, the solution is not an option. Requests on the other hand are properties that should be fulfilled if possible. Often, all the requests are not fulfilled by the best solution.

- **Standard** – Sometimes solutions are set by law or by standards within the business area.
- **Independent of the solution** – It is important to keep a clear mind and not be stuck with what is feasible, in that case possible solutions might be overlooked.

- **Functional/measurable** – When designing a product the functions and performance must be known. An objective judgment if one option fulfils the properties at all or better than another is desirable. The properties should be measurable in order to be objective.

- **Non-redundant** – Product properties should be formulated so that important goals, viewpoints or properties are not covered by several product properties in the KKL. Otherwise this might affect the evaluation in the end.

(Liedholm, 1999, pp. 9-12)

It is very important to fit all the product properties in the KKL and after it is established all the properties are checked to be well formulated and the list itself is checked. There are a number of checklists available to establish the KKL and the one below is just one example.

1. **Function**
   - What is the purpose of the product, what is its task?
   - Etc.

2. **Function determining properties**
   - What performance should the product have?
   - Is the manufacturing, assembly, distribution or use going to have an influence on the size or weight of the product?
   - What dimensions should the product have?
   - Etc.

3. **Properties for time of use**
   - In what environment will the product be used?
   - What is the product’s life?
   - Is maintenance necessary and possible?
   - Etc.

4. **Manufacturing properties**
   - Will the product be produced with the existing machine park? Will it be economically profitable to invest in new machines?
   - Should the manufacturing be done at another factory?
   - Etc.

5. **Distributing properties**
   - Will the product be stored, and in that case, what demands are put on the product?
   - Etc.

6. **Delivery and planning properties**
Appendix A Method Used to Develop Concepts

7. Safety/ergonomics properties
8. Aesthetics properties
9. Legal properties
   - What standards does the company have to follow?
   - Will the product imply patent infringement, and how will this be avoided?
10. Economical properties
   - What cost of manufacturing is allowed?
11. Scrapping and recycling properties
12. Ecological properties
(Liedholm, 1999, pp. 10-12)

A.1.2 Phase 2 – Function Analysis
In the second phase the product’s functions are listed together with the parameters necessary to realize them. The purpose is to make it clear what the product is supposed to do, find its functions and establish several different parameters/principle. This phase is also divided into four steps, presented in Figure A. 2. (Liedholm, 1999, p. 13)

First of all a black box is established, i.e., the main function with in- and output are defined. Also, an operator, a main function, input and output will be chosen. The operator is what transforms during the process. In this step the black box should be abstract and not showing anything about the solution. Secondly, all possible solutions to perform the main function are listed, those are the technical principles. They are established by three steps: To generate the technical principles, to evaluate them and to control the choice of operator. Most important is to remember, do not make it harder than it has to be! As the third step transformation systems are established, i.e., the transformations performed are mapped, then sorted after preparing-, performing- and completion phase. Finally they are ranked according to the order they are performed. The fourth and final step is to establish the function/parameter-tree, the F/M-tree, which is to show the different solutions, sub-solutions and proposals on how to solve the problems in an explicit manner. The function describes the system’s task while the parameters describe how the task is to be performed. The parameters are searched through idée generation and every new parameter forms its own new branch in the F/M-tree. A disadvantage with the F/M-tree is the size of it, it often tends to get too big and then it might be a good idea to list the lowest level in the tree in a morphological matrix instead, see Table A. 1 (Liedholm, 1999, pp. 13-20)
Figure A. 2: The four steps in the second phase, the function analysis

(Liedholm, 1999, p. 13)

Table A. 1: Example of a morphological matrix over how to boil potatoes

<table>
<thead>
<tr>
<th>Functions ↓</th>
<th>Parameters →</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peel the potatoes</td>
<td>Potato peeler</td>
</tr>
<tr>
<td>Heat the water and boil the potatoes</td>
<td>Stove</td>
</tr>
<tr>
<td>Strain the water from the potatoes</td>
<td>Colander</td>
</tr>
</tbody>
</table>
A.1.3 Phase 3 – Establish Concept

The object with this final phase is to establish the concepts that will make out the foundation of the continuous work. This third phase is also divided into four steps starting with the F/M-tree, see Figure A. 3. (Liedholm, 1999, p. 21)

First of all parameters have to be chosen and concepts have to be created. But there are two issues: How to limit the number of solutions and how to create suitable arrangement. It is very time consuming to examine all theoretically possible solutions and to limit these there are some possible strategies, Liedholm uses two of them. The first is to divide the parameters into three groups: good, approved and bad. The second is to group the functions with reference to importance. These strategies can be used one by one or together according to the situation. It is important to use compatible parameters and functions, i.e., if the parameter “electrical motor” is used in the function “transform energy” then the parameter “diesel tank” can not be used with the function “store energy”. A fairly
large number of concepts should be generated at this point, at least 10-20 of them. Now the concepts are to be inspected and improved. A way of understanding them is to describe their function in words. List the advantages and disadvantages. Most important are the functional properties but also possible future difficulties and possibilities. Now the evaluation and choice of concept has to be done. First of all, is the KKL fulfilled? Secondly, compare the remaining concepts in a so called evaluation matrix. This is a matrix where the properties are weighted according to importance. This matrix is described in the next passage, A.2 Concept Evaluation. Remember that this is only a guide, and the result is not obviously the best. Finally a few concepts are through to further development. At last, the final step: To correct and complement the KKL and plan further work. Investigate the KKL and make a few decisions: Should new properties be added? Should properties be adjusted or made more detailed? Should properties be cancelled? By now the KKL is probably dependent on the solution, but remember to keep the old version independent of the solution. A few concepts are now considered possible and further work can be planned. What resources are available; staff, time economic? Establish a long-term plan, e.g. in a Gantt diagram. Also establish a short-term plan for critical tasks such as; What parameters are most critical? In what order should the sub-systems be developed, sequentially and/or parallel? Which are the fundamental dimensions and performance? The long-term plan is to be adjusted as the project moves on, a short-term plan is to be established e.g. every week. (Liedholm, 1999, p. 22-28)

A.2 Concept Evaluation

There are a number of ways to evaluate the remaining concepts in a systematic manner but since there are only a few left in this case they are all taken into account in the further analyses.