Design and development of a testing device for a new invented Doctor Blade

Design och utveckling av testripp för nyuppfunnet käppningsblad

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Abstract
This thesis project is about designing and developing an already existing testing device for a new invented Doctor Blade. A doctor blade is a blade used for creping tissue paper of a rotating cylinder, Yankee Cylinder. The old testing device was incomplete in a way that a rotating cylinder was missing, hence the tested blade is not loaded properly. The old testing device already contained the doctor blade holding device and the pulling device (pulling the creping blade). These two devices are transferred to the new testing device without any redesign within them. The adding of a rotating cylinder/roller required some new redesign regarding the testing device.

The main beam (beam carrying all elements) is replaced with a larger one in order to fit the roller and is elongated in order to run longer tests. The new beam has a larger cross section in order to minimize the risk of bending.

The main beam is supplied with five small beams, welded onto it, three for attaching the holding device and two for attaching the roller. The dimensions of these small beams are chosen in order to put the roller on the right position according to the creping blade.

An electric motor is added to the new testing device in order to drive the roller with a chain. This required two sprockets, one for the motor and one for the roller shaft. The sprockets are chosen with a pitch diameter ratio matching the gearing required.

FMEA-analysis is done on the whole design where five failure modes were chosen to be included, bending of the main beam and motor beam, screw joints of the same beams and sprocket-chain mechanism. Some FEM-analysis was required in order to detect the bending of the beams and measuring the loading on the screw joints. The screw joint loading achieved from the FEM-analysis is used for the theoretical screw joint calculations.

The FMEA-analysis implied that four of the analyzed failure modes have acceptably low risk factor and do not require any further actions. However one received a high risk factor, the chain-sprocket mechanism, the risk of clamping fingers. This is solved by adding a protecting house/shell made of sheet metal.

Measurements were done on the old and the new testing device regarding the required force for pulling the creping blade and the pressure distribution between the creping blade and the beam (and roller in the new testing device).

The improvement of the pulling force values is rather due to the new designed doctor blade than due to the new testing device. The new testing device is however more appropriate than the old one hence the added roller and the tests shows that it is functional as well.

Keywords: Doctor Blade, testing device, design, FMEA-analysis, FEM-analysis. 2013-12-17
Sammanfattning


Huvudbalken (balken som bar alla delar) ersattes av en större balk för att den nya valsen ska få plats. Nya balken är även längre i syfte att kunna köra längre tester. Tvärsnittsareaen hos den nya balken är större i syfte att minimera risken för böjning.

Fem små balkar är fastsattsade i den nya huvudbalken, tre för fästning av hållaranordningen och två för fästning av valsen. Placeringen av dessa fem balkar valdes i syfte att placera valsen i rätt position enligt kräppningsbladet.


FMEA-analys utfördes på hela testriggen dör fem olika haveriorsaker inkluderades, böjning av huvudbalken och motorbalken, skruvförbanden på dessa två balkar och till sist kugghjul-kedja mekanismen. FEM-analys krävdes för beräkningar av böjningen på balkarne och för belastningen på skruvförbanden. Belastningen på skruvförbanden uppnåd från FEM-analysen användes senare i de teoretiska beräkningarna av skruvförbanden.


Mätningar gjordes på den gamla och den nya testriggen på dragkrafter och tryckfordelning mellan kräppningsblad och balk (vals i den nya testriggen).

Förbättringen av värden på dragkrafterna beror mer av det nydesignade kräppningsbladet än av den nya testriggen. Hursomhelst är den nya testriggen lämpligare än den gamla med tanke på tillförseln av valsen och dessutom så visar testerna att den är funktionell.

Nyckelord: Kräppningsblad, testrigg, design, FMEA-analys, FEM-analys. 2013-12-17
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1 Introduction

A new invention was made by the company CS Production. This invention is for the tissues making industry and will hopefully reduce some losses and increase the productivity of the paper machine. The invention is patented by the company.

This new product will not only be constructed and developed, it also needs to be tested and evaluated before mass production. Therefore, this big project was divided into two smaller projects. While the first one will focus on the design and development of the new invention, the second one will focus on the testing arrangement. This thesis is handling the second part, the design of the testing apparatus.

1.1 Background

In the tissue industry, creping is the manufacturing process that gives the paper its different properties. The process begins with a wet paper sheet transferred to a heated rotating Yankee cylinder (figure 1). In order to get the paper attached to the Yankee cylinder, an adhesive coating is first applied to the cylinder surface. When the sheet is applied to the Yankee cylinder it dries before reaching the doctor blade. By applying a force that is great enough to make the paper sheet detach from the cylinder the sheet will begin to crepe and obtain its final properties. The coating has very important role in the making of paper. There are more reasons for the coating to be applied then just to make the paper stick to the cylinder. The coating also protects the cylinder and the doctor blade from mechanical wear (chatter marks). It improves the drying of the paper, protects the cylinder from corrosion and enables angle change for the doctor blade. The coating also reduces the mask effects of additives (reducing the effect of the chemicals in order to get better creping)\textsuperscript{1}.
The impact angle from the doctor blade is important factor to get a good crepe. Low impact angle gives the paper a high bulk and large impact angle results in low bulk paper (figure 2). High bulk paper is soft paper, high volume per weight (low density). Although low impact angle can cause poor creping since the creped paper sheet needs to slide over the top side of the creping blade easily. Therefore the right angle giving a good balance between good crepe and high bulk is required. Depending on the paper and coating a good doctor blade are normally used for about four to six hours before it is worn out and needs to be changed. When changing a doctor blade the blade is released from the Yankee cylinder and pulled out by hand. Keep in mind that a blade can be up to seven meters long depending on the size of the machine, and therefore requires three to five operators to change it while the Yankee is still active and are running at full speed \[1\].
1.2 The new inventions and patent description

The inventor was mainly focusing on the large time losses caused by the current changing of the doctor blade which required the production to stop and the risks achieved by operating closely to the large, spinning, Yankee cylinder. Hence the smart idea where the fixed doctor blade was replaced by a smaller, continuously fed doctor blade was born and patented.\cite{2}

The older, fixed doctor blade will in fact be replaced by two parts. The first part is the carrier blade which contains a slot where the second part, the smaller creping blade will slide in. The total height of the two blades, when the small blade is in the slot, is about the same height of the original fixed doctor blade. These blades are described more closely in the second report as written parallel to this one, Design and development of a new invented Doctor Blade.\cite{9}

Another concerning issue is the need of an even contact pressure by the doctor blade on the Yankee cylinder. The edge of the doctor blade which is in contact with the Yankee cylinder needs to have the same sharpness along the whole cylinder’s length. Hence the wear on the tip while sliding through the length of the cylinder the blade needs to be twisted with an angle (figure 3). This is achieved by twist the whole holding device in a way that increases the angle between the doctor blade and the vertical tangent of the cylinder linearly along the length of the Yankee cylinder.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2}
\caption{Different impact angles giving different bulks.\cite{1}}
\end{figure}
Figure 3. The unworn creping blade at the start of the Yankee cylinder length and the worn out and twisted creping blade at the rest of the cylinder length.

The twist angle depends on the wear rate and the velocity of the sliding doctor blade. Hence the wear rate depends on many parameters and is almost impossible to calculate the angle hence cannot be calculated. The angle will probably be specific for each paper machine. Hence the paper producers will have to make their own tests to find out the wear rate and the twisting angle needed. This will be possible hence the holding device is constructed so that different twisting is possible.

The new doctor blade holding device is also patented [3] and includes mechanisms for the pressure regulation and the twist. This holding device will be constructed in the testing device that this thesis is all about.

1.2.1 Doctor blade holding device patent summary
Possibility to, in sections, individually adjusts the contact pressure between the doctor blade and the Yankee cylinder along the length of the cylinder. This is achieved by arranging pivotable pressure arms evenly distributed over the length doctor blade, and each one of them is provided with its own pressure vessel. These pressure arms press on a clamp ledge which in turn is pressing on the doctor blade closely to the upper edge. The clamp ledge can either be one piece or divided in smaller parts. For optimization of the functionality a possibility to, in a simple way, adjust the angle between the doctor blade and the cylinder is required. Another purpose of the invention is to enable an easy blade change with minimum time wasted [3].
1.3 Project description
This project is mainly a design project. The company CS Production already had a simple testing device which they didn’t think was not complete enough. In order to promote the new doctor blade they needed to prove the functionality and sustainability of the blade. To do that a more complete and more real life like testing device is needed.

The old testing devise already included the doctor blade holding device with pivotable pressure arms that were described earlier in the patent summary. This holding device will be transferred to the new testing device without disassembling it (figure 4).

![Figure 4. CAD-picture showing the doctor blade holding device (yellow part) mounted in the old testing device.](image)

It also includes a pulling device which slowly pulls the sliding creping blade (figure 5), which also will be transferred to the new testing device. The pulling device contains two driving wheels pressed against each other with the creping blade clamped in between them.

![Figure 5. CAD-picture showing the pulling device (yellow part) mounted in the old testing device.](image)

The old testing device is incomplete in the way that a rotating cylinder/roller is missing, hence the load impact on the doctor blade will differ from the one in a real paper machine with a Yankee.
cylinder. Instead of a roller the doctor blade is pressed against a fixed steel beam (figure 6). Therefore, the main task of this project is to construct a roller into the incomplete testing device and find solutions for all the necessary changes in the construction to make it fit and function as required.

![Figure 6. CAD-pictures showing that the doctor blade (yellow part) is pressed against a beam.](image)

To observe any improvements of the new testing device and compare it with the older version, measurements will be done on both the new and the old testing device. The measurements will be about the force needed to draw the sliding creping blade. The value of this force is essential due to the functionality when installed in a real paper machine.

Mechanical strength calculations will be done on some screw joints and the main beam to make sure that the testing structure will be stable and functional.

An FMEA analysis will be made on the testing device to make sure that it does not include any risks regarding safety and lack of functionality.

### 1.3.1 Main questions
- Functionality of the new testing device?
- Any risks with within the design?
- Sustainability of the most important screw joints?

### 1.4 Goals and purposes
The main goal with this project is to construct a testing arrangement where the invented doctor blade can be tested. The testing arrangement should load and affect the doctor blade in a way that simulates the conditions in a real paper machine as much as possible.

The purpose is to achieve test results showing whether the doctor blade is functional and sustainable before starting to produce it. The test results will be used for marketing of the new product.
2 Method
Hence this is a design project where a development of an existing device will be done. The main work is about CAD-design, drawing generation and mechanical strength calculations. In order to observe eventual improvements by the new device, measurements on old and new devices will be done and compared.

2.1 Measurements on old and new testing devices
Measurements were made on the force needed to pull the sliding creping blade (while it is under pressure) and on the pressure distribution by the pressure arms on the doctor blade. These measurements were made with the already existing sandwich doctor blade and not with the new improved doctor blade that is constructed and described in the first report, Design and development of a new invented Doctor Blade [9]. The same, old, sandwich blade was meant to be the one used for measurements in the new testing device in order to compare only the testing devices, and not the doctor blades, but unfortunately the old doctor blade was somehow damaged before the new testing device was built. Therefore the new doctor blade will be used instead for the new measurements.

2.1.1 Force measurements on the sliding blade
The force measurement of the sliding blade was measured by a newton meter [4] that was attached in between to blades, where one is the creping blade and the other one is the same kind of blade pulled by the pulling device (figure 7). The newton meter is connected to a weight indicator showing the value of the forces [4]. The measurements were done with different pressures in the pressure vessels, starting with 1 bar and increased by 0,5 bar up to 5 bar.

Figure 7. CAD-pictures showing the placement of the Newton meter (yellow part).
2.1.2 Measurements on the pressure distribution

The pressure distribution was measured by measuring the pressure between the doctor blade and the beam (roller in the new testing device). These measurements were made for each pressure arm individually (26 pressure arms). This was made by having a very thin metal sheet wedged between the creping blade and the beam/cylinder. The metal sheet was then manually pulled upwards with a dynamometer (figure 8). The values from the dynamometer were then used to draw up a chart showing the pressure distribution.

![Figure 8. Thin metal sheet (colored in yellow) clamped between the creping blade and the beam and pulled upwards by a dynamometer.](image)

2.2 Design of new testing device

As mentioned earlier the main problem with the old testing device is the missing roller. Hence the main task of this project is to reconstruct the old testing device with an added roller. This adding of a roller requires a number of new parts and new dimensioning of the beams. All parts and assemblies will primarily be constructed in the CAD-program ProEngineer. When the design is finished, drawings will be made and handed to the company (CS Production) which will manufacture the parts and assemble the testing device.

2.2.1 The new beam

The 100x100 beam (figure 9) in the old testing device was replaced by a hollow 100x180 beam with 10mm thickness (figure 17). The material for these beams is SS 1412 steel. Both the roller and the doctor blade holding device will be mounted on this beam. The selection of this beam was according to the requirements and to what existed at the company stock.
The new beam is modified so that the doctor blade holding device and the roller with its shafts and bearings fits. Two very short 50x100 beams will be welded onto the upper half of the front of the beam. Two holes will be drilled into the front of these short beams where the bearings will be bolted (figure 17). At a height right under these two beams, three other short beams are welded onto the main beam. Four threaded holes are drilled into the bottom side of each one of these short beams where the doctor blade holding device will be bolted (figure 17).

The 100x180 beam has two rows of six threaded holes on the back side for bolting into the rack. This beam is also the one which the pulling device is attached to, as it was attached to the 100x100 beam in the old testing device. The new beam is extended further (about 2m total from the roller to the pulling device) for running longer tests before the force meter reaches the pulling device.

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The main requirement regarding the rollers position is that the contact between the creping blade and the roller needs to be at the middle of the roller, where the tangent of the outer diameter of the roller is vertical. The angle between the doctor blade and the roller tangent also needs to be 20°. This is fulfilled by first adjusting the angle to 20° by simply rotating the whole pivotable holding device. When the angle is right the position is then adjusted by changing the height of the two short beams and the length of the three short beams. The screw holes in the bearings are elongated, which is appropriate since the risk that the positions of the roller/creping blade will not be as planed when assembling.

### 2.2.2 Roller and shafts

The roller will be machined (turned) out of a 1600mm long SS 2172 alloy steel cylinder down to Ø105. Two Ø80 holes will be machined into each side of the roller for the shafts. These holes will be heated and then cooled to shrink onto the Ø80 shafts (figure 19). Tolerances are chosen as recommended for shafts mounted by temperature difference (high attachment force) with a diameter larger than 24mm [5]. All tolerances are chosen according to ISO 286-2:1988.

The shafts have Ø25 extension to insert into the bearings. Tolerances are chosen as recommended for shafts mounted by hand with a diameter of 18 up to 30mm [5].

The right shaft will have a further Ø20 extension for the sprocket (figure 19). Tolerances are the same as for the shaft-bearing attachment since the diameter is within 18 and 30mm range too. The sprocket will be attached to the shaft with a wedge and hence two keyways will be machined into the shaft and the sprocket. The keyway is dimensioned according to SMS 2305.

### 2.2.3 Motor and gearing

The 100x100 beam from the old testing device (figure 9) will be reused in the new testing device as a carrier for the motor which drives the roller (figure 23). A small plate will be welded at the edge of the beam for extension. Four new holes will be drilled close to the right edge of the beam, two into the plate and two into the top side of the beam, for bolting the motor.
In order for the motor to drive the roller it also needs a sprocket. The required line speed of the roller (requirement from the company) is 50 m/min which gives an rpm value according to equation 1 and 2.

$$105 \times \pi = 330 \text{ mm} (\text{roller circumference})$$  \hspace{1cm} \text{Equation 1}

$$50000/330 = 151.5 \text{ rpm}$$  \hspace{1cm} \text{Equation 2}

The rpm value of the motor is 22.5 rpm. This gives us a required gearing according to equation 3.

$$151.5/22.5 = 6.73$$  \hspace{1cm} \text{Equation 3}

This gearing value needs to be matched by the ratio between the two sprockets where the motor sprocket will be the bigger one.

During the FMEA-analysis (described later) it was observed that the sprockets and the chain need a protecting shell preventing any accidents. This protecting shell is designed as two parts, a house and a cover (figure 24). These will be made from a 2mm sheet metal. The house-part will be welded onto the right side of the 100x100 beam and the cover will be bolted into the house part. The house contains two holes for the shafts. The upper hole, for the roller shaft, is elongated in case of any misfits when assembling.

### 2.2.4 Pulling device

As mentioned earlier the pulling device already existed in the old testing device and will be transferred to the new testing device, colored in yellow (figure 24). The pulling device needs to be bolted onto a horizontal plate and cannot be attached to the main beam directly. Hence a new simple part, a L-plate, was constructed and added (colored in blue). This L-plate is a steel plate with
11mm thickness and it is welded onto the beam. Four holes are drilled into the horizontal part of the plate for bolting the pulling device. The length of horizontal part and the height are chosen in order to hold the pulling device (pulling wheels in the pulling device) at the same height and distance from the beam as the creping blade.

2.3 FMEA – Failure Mode and Effect Analysis

In a FMEA-analysis one finds out what failure can occur, the causes of the failure and what the consequences are. There are three types of FMEA-analysis that can be made: system-, construction- and process-FMEA. In this thesis a construction-FMEA is applied where potential failures and risks in the testing device will be evaluated. Component’s and material’s failure and consequences are analyzed and fixed [8].

For each failure mode analysis an assessment is performed on occurrence, severity and possibility to detect. Occurrence (O), severity (S) and detection possibility (D) are each graded with a number between 1 and 10 according standard template (appendix A). The three grades are multiplied with each other and the product will be the risk factor, equation 4.

\[ O \times S \times D = \text{Risk factor} \]  

Equation 4

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-99</td>
<td>OK - GREEN</td>
</tr>
<tr>
<td>100-199</td>
<td>should be fixed - YELLOW</td>
</tr>
<tr>
<td>( \geq 200 )</td>
<td>must be fixed – RED</td>
</tr>
</tbody>
</table>

A complete table with the different failure modes with respective descriptions, grades and risk factors can be found in (appendix A). Most of them got a risk factor lower than 100 and does not require any further actions. One failure mode got a risk factor of 200 which indicates that it must be fixed. The failure mode is finger clamping in between the chain and sprockets which has severe consequences. The solution for this is to add a protection shell.

2.3.1 FEM-analysis of the beam

A FEM-analysis of the beam is done where the bending of the beam (caused by the weight of the pulling device) was investigated. The beam and the L-plate were imported into ABAQUS/CAE (figure 10).
A Tie constraint was applied between the surfaces who are supposed to be welded together, the front of the beam and the back of the L-plate. Boundary condition was applied on the 12 screw holes at the backside of the beam where they were fixed in all direction, as if they were bolted into the rack (figure 11).

A load was applied to correspond to the weight of the pulling device. The total volume of the pulling device (measured automatically in ProEngineer) is 0,00995m³. The density was chosen to a relatively high value of 8000 kg/m³ for the steel in the pulling device. This gives a total weight of the pulling device according to equation 5.

\[ 0,00995 \times 8000 = 79,6 \text{ kg} \Rightarrow \text{Force} \approx 800 \text{ N} \]  

\[ \text{Equation 5} \]

This load is then distributed on the four holes in the L-plate where each hole is loaded with a 200N force. The weight of the beam is also added as a pressure on the bottom surface of the beam (figure
The volume of the beam is 0,02m$^3$ and the density is chosen to the same value as for the pulling device, 8 000 kg/m$^3$. The magnitude of the pressure is calculated according to equation 6 and 7.

$$0,02 \times 8000 = 160 \text{ kg} \Rightarrow \text{Force} \approx 1570 \text{ N}$$

Equation 6

The area of the bottom surface of the beam is 0,3m$^2$ (measured automatically in ProEngineer).

$$1570 \div 0,3 \approx 5233 \text{ Pa} \approx 0,0052 \text{ MPa}$$

Equation 7

**Figure 12.** Loading of the beam during FEM-analysis of the bending of beam.

### 2.3.2 Screw joint calculations

In order to perform calculations on the screw joints a tensile force in the screws is required. This tensile force is calculated in a FEM-analysis. The obtained tensile force will be used in the theoretical screw joint calculations.

#### 2.3.2.1 FEM-analysis of the screw joints

The beam and the L-plate are imported and fixed as they was in the previous FEM-analysis. The loading corresponding to the weight of the beam and the pulling device is retained with an addition of two loading corresponding to the weights of the roller and the holding device (figure 13).
Figure 13. Loading of the beam during FEM-analysis of the reaction forces at the screw holes.

The total volume of the holding device is $0.013 \text{ m}^3$ (measured automatically in ProEngineer) giving the total weight according to equation 8.

$$0.013 \times 8000 = 104 \text{ kg} \Rightarrow \text{Total force} \approx 1021 \text{ N} \quad \text{Equation 8}$$

This force is divided over and applied to the 12 holes in the 3 short beams where the holding device is bolted.

The total volume of the roller, shafts and bearings is $0.009 \text{ m}^3$ (measured automatically in ProEngineer) giving the total weight according to equation 9.

$$0.009 \times 8000 = 72 \text{ kg} \Rightarrow \text{Total force} \approx 707 \text{ N} \quad \text{Equation 9}$$

This force is also divided over and applied to the 2 short beams where the bearings are bolted.

From this simulation one can observe the reaction forces on the fixed region, which in this case are the screw holes. Those reaction forces correspond to the tensile forces in the screws that the screw joint calculations are done to.

Those reaction forces are indicated as the colored regions around the holes in figure 27. The highest magnitude of these forces is about 350 N. This value is chosen to be used in the screw joint calculations and is referred to as $F_\text{L}$.

2.3.2.2 Theoretical screw joint calculations

In order for the screw joint to be functional it should remain tight (with no gap) after loading. The screw is pretensed (preloaded) with $F_\text{F}$ when bolted, meaning that the screw is already under tension before the load, $F_\text{L}$, is applied. This preload ($F_\text{F}$) equals the clamping force on the flanges ($F_\text{C}$) and the load on the screw ($F_\text{S}$) when the screw joint is not loaded. The screw itself is then extended and the flanges are pressed a little bit. The clamping force ($F_\text{C}$) should have a positive value in order for the screw joint to be clamped. A negative value means that a gap exists in the screw joint, making it nonfunctional.
When an external load, $F_L$, is applied it affects both the tension in the screw and the pressure force in the flanges. The tension in the screw ($F_s$) increases with $F_{La}$ and the clamping load in the flanges decrease (unloads) with $F_{Lab}$. Equation 10, 11 and 12

$$F_L = F_{La} + F_{Lb} \quad \text{Equation 10}$$

$$F_s = F_F + F_{La} \quad \text{Equation 11}$$

$$F_c = F_F - F_{Lb} \quad \text{Equation 12}$$

As mentioned earlier the clamping force (equation 12) needs to have a positive value in order for the screw joint to be functional. This means that the part of the external load ($F_{Lb}$) that corresponds to the decrease of the clamping load must not exceed the preload ($F_F$) in the screw.

The external force ($F_L$) is divided into $F_{La}$ and $F_{Lb}$ according to the relationship between the two spring constants of the screw ($c_s$) and the flanges ($c_f$). Equations 13 and 14.

$$F_{La} = c_s c_s + c_f * F_L \quad \text{Equation 13}$$

$$F_{Lb} = c_f c_s + c_f * F_L \quad \text{Equation 14}$$

The spring constants are calculated by dividing the clamping length ($L_c$) with the elastic modulus and the area of the affected region (from a suspension point of view) (figure 14). Equations 15 and 16.

$$1c_s = L_c A * E_s \quad \text{Equation 15}$$

$$1c_f = L_c A * E_f \quad \text{Equation 16}$$

The affected area is calculated according to *Fritsche’s principle*. Equation 17.

$$A = \pi 4 [ (D_S + k_m L_c 2)^2 - D_h 2] \quad \text{Equation 17}$$

$D_S$ is the diameter of the disk and $D_h$ is the diameter of the hole (figure 14). $K_m$ is a correction factor, which is $1/5$ for steel. This gives an affected area of 524 mm$^2$. 
The Elastic modulus for both screw and flanges ($E_s$ and $E_i$) is chosen to a value of 210GPa for steels.

By having the clamping length ($L_c$), affected area ($A$) and the elastic modulus, $c_s$ and $c_i$ can easily be calculated using equations 15 and 16. The obtained values are $c_s=0,498\text{MPa}$ and $c_i=4,07\text{MPa}$.

The pretention load of the screw ($F_p$) is usually chosen to a value of 70% of the yield strength of the screw material. The yield strength of the screw material is 640MPa. The average diameter of a M10 screw is 9,026mm. These values give the pretention load ($F_p$) according to equation 18. \[ F_p=0,7\times640\times10\times(0,009026^2)\times\pi=28700 \text{N} \] Equation 18

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**Figure 14. Different dimensions and lengths in the screw joint.**
3 Results
In this chapter the results of all work done in the method will be presented. It will include measurement results and comparison between, figures showing the new constructed and used parts and results of the calculations that were made.

3.1 Measurements results
The results of the measurements that were done on the pulling force of the sliding blade and the pressure distribution will be presented here in form of tables and charts.

3.1.1 Force measurement on the sliding blade
The values of the measured pulling force of the sliding blade for the different pressures (in the pressure vessels of each pressure arm) are presented in table 1 and figure 15.

Table 1. Pulling force required for the different pressures.

<table>
<thead>
<tr>
<th>Pressure [bar]</th>
<th>Pulling force [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Old device</td>
</tr>
<tr>
<td>1</td>
<td>304</td>
</tr>
<tr>
<td>1,5</td>
<td>638</td>
</tr>
<tr>
<td>2</td>
<td>962</td>
</tr>
<tr>
<td>2,5</td>
<td>1277</td>
</tr>
<tr>
<td>3</td>
<td>1581</td>
</tr>
<tr>
<td>3,5</td>
<td>1994</td>
</tr>
<tr>
<td>4</td>
<td>2308</td>
</tr>
<tr>
<td>4,5</td>
<td>2661</td>
</tr>
<tr>
<td>5</td>
<td>2897</td>
</tr>
</tbody>
</table>

Figure 15. Chart showing the relationship between pressures and pulling force required.
As the chart indicates the relationship between the increasing pressure and the pulling force is practically linear. This was expected hence the relationship between the pressure and the friction between the doctor blade and the beam should be linearly depended as well.

As mentioned earlier the new doctor blade is used for the measurements on the new testing device hence the old one was damaged. Therefore these results cannot be used to compare the new testing device to the old one. These results are more of an evidence showing that the new device is working properly. However one can see that the values of the forces are much lower than those measured on the old testing device with the old doctor blade, meaning that the new doctor blade was designed effectively, minimizing the friction on the creping blade.

### 3.1.2 Measurement on the pressure distribution

As mentioned earlier the pressure between the doctor blade and the beam (roller in the new testing device) is measured at all 26 pressure arms. Unlike the measurements on the pulling force only two different pressures (1 and 2 Bars in the pressure vessels) were used for the pressure distribution measurements. This is hence the improbability of that the pressure distribution will differ at different “pressure vessel”-pressures. Anyway two different pressures were used just to make sure of that. Note that the values in the table 2 are not pressure, they are values of the force required to pull the metal sheet upwards and the unit is hence N. A chart showing these values is drawn for better visualization (figure 16).

<table>
<thead>
<tr>
<th>Arm nr</th>
<th>1 Bar [N]</th>
<th>2 Bar [N]</th>
<th>Arm nr</th>
<th>1 Bar [N]</th>
<th>2 Bar [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0,6</td>
<td>1,8</td>
<td>14</td>
<td>0,6</td>
<td>2,2</td>
</tr>
<tr>
<td>2</td>
<td>0,2</td>
<td>0,8</td>
<td>15</td>
<td>2,6</td>
<td>3,8</td>
</tr>
<tr>
<td>3</td>
<td>0,7</td>
<td>2,3</td>
<td>16</td>
<td>1,2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>0,5</td>
<td>2,2</td>
<td>17</td>
<td>1,1</td>
<td>2,2</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>2,2</td>
<td>18</td>
<td>1,1</td>
<td>2,7</td>
</tr>
<tr>
<td>6</td>
<td>1,2</td>
<td>2,2</td>
<td>19</td>
<td>1,2</td>
<td>2,4</td>
</tr>
<tr>
<td>7</td>
<td>1,4</td>
<td>2,7</td>
<td>20</td>
<td>1,1</td>
<td>2,8</td>
</tr>
<tr>
<td>8</td>
<td>0,5</td>
<td>1,8</td>
<td>21</td>
<td>0,7</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1,3</td>
<td>22</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>1,4</td>
<td>2,6</td>
<td>23</td>
<td>0,8</td>
<td>1,8</td>
</tr>
<tr>
<td>11</td>
<td>0,8</td>
<td>1,8</td>
<td>24</td>
<td>1,6</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>1,2</td>
<td>2,4</td>
<td>25</td>
<td>0</td>
<td>0,2</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>1,6</td>
<td>26</td>
<td>0,6</td>
<td>1,8</td>
</tr>
</tbody>
</table>
Figure 16. Chart showing the pressure distribution over the 26 pressure arms.

One can easily notice that there are some pressure arms standing out from the rest. Arms 15 and 24 are the ones that stand out the most with their high values. Arms 2 and 25 have stands out in the opposite, low values. These arms and their pressure vessels will be inspected and corrected for the new testing device.

3.2 The new design
In this chapter a series of CAD-pictures showing the new constructed elements with respective descriptions are collected. The part in focus will be highlighted for better understanding of the figures. Drawings of the parts, with complete dimensions can be found in appendix B.

3.2.1 The new beam
The new beam shown in figure 18 (colored in red) is bigger and consequently has higher strength and bending resistance than the 100x100 beam used in the old testing device. A more explanatory drawing can be found in appendix B.
3.2.2 Roller and shafts

The roller is the main new part in the new testing device (figure 18). It did not exist at all in the old testing device.

The roller, shafts, bearings and the sprocket are assembled as shown in figure 19. Recommended tolerances for the holes in the roller and the bigger shaft diameter (Ø80) are H8/u8. H8 tolerance for an Ø80 hole is (80 +0.46) and u8 for an Ø80 shaft is (80 +0.102+0.148). Recommended tolerances for the bearings and the Ø25 part of the shafts are H7/j6. However SKF delivers the bearings with a H8 tolerance. H8 tolerance has a bit wider range than the H7 (H7 ⇒ 250+21 and H8 ⇒ 250+33). Hence...
the shaft tolerance is also chosen to a higher one, j7, which for an Ø25 shaft is (25−8+13). Finally, the recommended tolerances for the sprocket and the Ø20 part of the shaft are H7/j6. H7 tolerance for an Ø20 hole is (200+21) and j6 for an Ø20 shaft is (20−4+9). The right shaft has a further extension (with a 5mm smaller diameter) containing a keyway for the sprocket. The keyway is 3,5mm deep and 6mm wide [7]. More explanatory drawings can be found in appendix B.

![Figure 19. CAD-picture showing the roller (red), shafts (yellow), bearings (green) and the sprocket (blue) in an explode mode.](image)

The bearings are of type (SY 25 TF), a Y-bearing from SKF with an inner diameter of 25mm (figure 20).

![Figure 20. CAD-pictures of the bearing.](image)

The sprockets are from Kedjeteknik. The sprocket for the shaft was chosen first (figure 22). The designation and dimensions of the sprocket are; wheel number 14/455, pitch 9,525mm and pitch diameter 42,81mm.
3.2.3 Motor and gearing
In order to match the gearing required (equation 3) the motor sprocket needs to have a pitch diameter according to equation 19.

\[ 42.81 \times 6.73 = 288.24 \, \text{mm} \]

Equation 19

A sprocket with pitch diameter of 288.08mm (almost perfect!) was found and chosen (figure 22). The wheel number of the sprocket is 95/455A and the pitch is 9.525mm. The keyway in the sprocket is 2.8mm deep and 6mm [7]. A matching chain was also found on Kedjeteknik. Chain number 455 and estimated needed length 1320mm.

As mentioned earlier the 100x100 beam from the old testing device is reused in the new testing device for holding the motor (figure 23). In order to have the motor sprocket coincident with the
shaft sprocket the beam needs to be moved to the right. This requires new holes at the back side for bolting to the rack. A small plate is welded to beam (close to the right edge) putting the motor sprocket straight under the shaft sprocket. Four holes are drilled for bolting the motor (2 into the extension plate and 2 into the top side of the beam). A more explanatory drawing can be found in appendix B.

![Figure 23. CAD-picture showing the 100x100 beam mounted into the new testing device holding the motor.](image)

The protecting shell is added and colored in yellow in figure 24. The cover is placed at a distance from the house (which it supposed to be bolted into) for better visualization. A more explanatory drawing of the shells can be found in appendix B.

![Figure 24. The protection shell (colored in yellow) protecting the sprockets and the chain.](image)
3.2.4 Pulling device

The pulling device is transferred from the old testing device to the new one. A new part, a L-plate, is constructed and added (figure 25). The pulling device is tilted with an angle of 20° in order to match the angle of the creping blade. This was already done in the old testing device. The length of the horizontal part of the L-plate is 140mm and the distance between the bottom side of the plate and the top side of the main beam is 119mm. A more explanatory drawing of the L-plate can be found in appendix B.

![Figure 25. CAD-picture showing the pulling device (yellow part) attached to the L-plate (blue part) which is in turn welded onto the beam.](image)

3.2.5 Conclusions – New design

The main beam is replaced by a bigger (higher cross section), thicker and longer beam. A bigger, higher cross section is chosen in order to fit, in addition to the holding device, the roller. And also minimize the risk of bending hence the beam is elongated from the left side. The number of screw hole on the back side of the beam is increased from 4 (in the old testing device) to 12 holes, divided on 2 rows, because of the increased load (roller) on beam.

The five short beams welded onto the main beam (two for the roller and three for the holding device) have the same cross section dimensions. Hence they can be cut from one long beam with the same cross section dimensions.

The roller requires two shafts in order to be inserted into the bearings. These shafts are pressed into the holes at the sides of the roller after heating it (expanding it). The right shaft is further elongated in order to hold the chain sprocket. The sprocket is attached to the shaft by keyway and wedge. The bearings are ordered from SKF.
The motor is carried by the 100x100 beam (main beam in the old testing device) and it is placed so that sprockets lie at the same vertical plane. The ratio between the two sprocket’s pitch diameter corresponds to the gearing. The gearing needed is calculated by dividing the required roller speed with the speed of the motor. The sprockets are ordered from Kedjeteknik.

A protecting house for the sprockets and chain is constructed in order to eliminate the risk of clamping fingers etc. The house is made of a metal sheet and consists of two parts, the house and the cover.

The pulling device is bolted onto the new L-plate. The dimensions of the L-plate are chosen in order to place the pulling device at the right position.

### 3.3 FMEA – Failure Mode and Effect Analysis

FMEA analysis was made on the most critical part of the device. A summary of the complete table (found in appendix A) is shown in table 3. Five different potential failure modes are included in the analysis.

<table>
<thead>
<tr>
<th>Pos.</th>
<th>Function</th>
<th>Potential failure mode</th>
<th>Risk factor</th>
<th>Action</th>
<th>New risk factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>180x100 Beam</td>
<td>Carrier of pulling device, roller and holding device</td>
<td>Bending</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Screw joints failure (six screws on the backside)</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100x100 Beam</td>
<td>Carrier of motor</td>
<td>Bending</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Screw joints failure (four screws on the backside)</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chain &amp; sprockets</td>
<td>Driving the roller</td>
<td>Clamping fingers</td>
<td>200</td>
<td>Protecting shell</td>
</tr>
</tbody>
</table>

### 3.3.1 FEM-analysis of the beam

FEM-analysis is used as the detection method of the bending of the main beam. Eventual bending is caused by the weight of the pulling device and the beam itself. The FEM-analysis showed that a very small bending was achieved, about 2mm vertically at the edge where the pulling station is mounted (figure 26).
Giving that the beam is almost 4m long, this small deformation is hardly critical and will not cause any problems for the testing device regarding its functionality.

### 3.3.2 Screw joint calculations

Figure 27 shows blue regions around these holes meaning negative reaction force, and red regions around the lower six holes meaning positive reaction force. Negative reaction force means tension in the screws and the positive reaction force means compression in the screws. The reaction force on the upper row screw holes (upper six) is ranged between 300 and 350 N. Hence a value of 350N is chosen for the theoretical screw joint calculations.

Using 350 N as $F_L$ (as mentioned earlier) in equation 14 the value of $F_{lb}$ is obtained, which is about 312 N. According to equation 12, this is the value that was not supposed to exceed the pretension force ($F_t$), which is 28 700 N. This means that the screw joints are holding the beam with a very high safety margin.
3.3.3 Conclusions – FMEA
The FMEA-analysis indicated that almost all (except one) analyzed risks had a risk factor within the safe zone and required no further actions. Although there was one risk (clamping risk in the sprocket/chain mechanism) that had a high risk factor and required a solution. This risk is eliminated by adding a protecting house.
4 Discussion

The company CS Production required that the new main beam should be longer than the old one in order to run longer tests. This requirement increased the risk of bending of the beam, due to the weight of the pulling device and the beam itself. Therefor a beam with larger cross section area was needed. This led to replacement of the old beam (100x100mm with 5mm thickness) with a higher and thicker cross section, 180x100mm with 10mm thickness. According to the FEM-analyze the new beam seems to resist bending (only 2mm at the end of the beam, see figure 26) and be functional as required. This small deformation is achieved even when the measured volume, density of steel and the calculated weights of all parts were rounded up for higher safety margin.

The number of screw holes at the back side of the beam is chosen to twelve (M10 screws). The old beam had only four holes (also M10 screws). Giving that the loading on the new beam is approximately twice as high as the loading on the old beam in the in the old testing device the twelve screw joints is considered reasonable and giving a high safety margin. Either way screw joint calculations were done, in order to show it in numbers. The calculations revealed that these twelve screw joints can be loaded with a load hundred times the current load before failure.

The holes in the beam are threaded instead of having a nut. This is hence the difficulties of holding the nuts in the inside of the beam while screwing. The holes in the three short beams carrying the holding device are also threaded (M8) hence the holes are close to the side walls of the beams so the nuts cannot fit at the inside of the beam.

At the beginning it was planned that the holes in the two short beams (carrying the roller) would be elongated (vertically) in order to adjust the vertical position of the roller in case of misalign during the assembly. Then it was noticed that the bearings already had elongated holes so eventual adjustment could be done anyway. Unlike the holes in the three short beams (carrying the holding device) the holes in the two short beams (carrying the roller) are not threaded hence the nuts fits at the inside of the beams.

The sprocket in the roller shaft is constrained tangentially with a wedge. Hence the keyway in the sprocket is through the whole length of the sprocket it is possible to adjust the axial position of the sprocket with a few millimeters if needed.

In order to achieve the required speed of the roller a gearing needed to be applied hence the speed of the motor is much lower. This was solved by choosing two sprockets with matching pitch diameter ratio. With some luck two sprockets with almost perfect pitch diameter ratio was found at Kedjeteknik (required ratio = 6,73 ≈ found ratio = 6,729).

Five different failure modes on three different elements were included in the FMEA-analysis, the main beam, the motor beam and the sprocket-chain mechanism. Two different failure modes on the main beam and on the motor beam were included, bending of the beams and the screw joints for bolting into the rack.

These failure modes were graded by choosing an appropriate level of each of the three categories, severity, occurrence and detection. Bending of the main beam was graded with an eight on severity according to the criteria “Item inoperable, with loss of primary function”. Too large bending puts the
pulling device out of position, hence the loss of primary function. This failure mode either occurs or not, hence the occurrence was graded with the lowest grade, 1. Finally the detection was graded with a 3 according to the criteria “High chance the Design Control will detect a potential cause/mechanism and subsequent failure mode” giving the total risk factor of 24, which is acceptably low.

The screw joints got the highest grade possible, 10, regarding the severity, hence a screw joints failure will cause a collapsed testing device. However with the low grades on occurrence (according to the screw joint calculations) and detection (Design Controls will almost certainly detect a potential cause/mechanism and subsequent failure mode) the total risk factor is remained acceptably low.

Bending of the motor beam received the following grades, 2 on severity, 1 on occurrence and 3 on detection giving the total risk factor of 6. The screw joints was grades in the same way as the screw joints of the main beam hence the same criteria could be applied.

The detection method for bending of the main beam is simply a FEM-analysis. The beam and the L-plate were imported into Abaqus/CAE for investigation. The beam was fixed at the screw joint on the back side and loaded with loads corresponding to the different elements carried by the beam at respective positions in order to simulate the real life loading. The bending occurred to be negligibly small. This was considered negligible after discussion with the supervisor. And was confirmed during the first test run of the testing device where we noticed that it did not affect the functionality.

Screw joint calculations were made on the M10 screws joining the main beam with the rack. The theoretical screw joint calculations required a known external load. This external load was achieved from the FEM where the reaction forces on the fixed regions (screw holes) were measured. Theoretical screw joint calculations were applied and resulted in a confirmation of what was expected, which was that the screw joints are over-dimensioned and failure will most unlikely occur. Hence the motor beam was loaded with much higher load in the old testing device it was concluded that the same amount of screw holes (four M10 screws) could be used again in the new testing device.

The FMEA-analysis implied a high risk of accident at the sprockets/chain region. This risk was eliminated by adding a protecting shell/house. This protecting house will be welded onto the side of the motor carrying beam. The house contains two holes for the two sprocket shafts (motor shaft and roller shaft). The upper hole, for the roller shaft, is elongated in order to be able to adjust the vertical position of the roller if needed.

The improvement of the pulling force values is rather due to the new designed doctor blade than due to the new testing device. Therefor there is not much I can say about it here in this report more than that they show that the new testing device is functional and can withstand pressures up to 5 bar in the pressure vessels.

The pressure distribution measurements were used to indicate any defected pressure arms or vessels. This was successful and there was 4 defected pressure vessels detected and replaced.
5 References


### Appendix A

**Complete FMEA-table including all different failure modes with respective descriptions [8].**

<table>
<thead>
<tr>
<th>Pos.</th>
<th>180x100 Beam</th>
<th>180x100 Beam</th>
<th>100x100 Beam</th>
<th>100x100 Beam</th>
<th>Chain &amp; sprocket</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FUNCTION</strong></td>
<td>Carrier of pulling device, roller and holding device</td>
<td>Carrier of pulling device, roller and holding device</td>
<td>Carrier of motor</td>
<td>Carrier of motor</td>
<td>Driving the roller</td>
</tr>
<tr>
<td><strong>POTENTIAL FAILURE MODE</strong></td>
<td>Bending</td>
<td>Screw joints failure (six screws on the backside)</td>
<td>Bending</td>
<td>Screw joints failure (four screws on the backside)</td>
<td>Clamping fingers</td>
</tr>
<tr>
<td><strong>POTENTIAL CAUSES</strong></td>
<td>Wrong beam dimensions</td>
<td>Screws too small</td>
<td>Wrong beam dimensions</td>
<td>Screws too small</td>
<td>Hands too close to the sprockets</td>
</tr>
<tr>
<td><strong>POTENTIAL EFFECTS</strong></td>
<td>Pulling device ends in lower position</td>
<td>Breakdown</td>
<td>Motor ends in a lower position</td>
<td>Breakdown</td>
<td>Personal injuries</td>
</tr>
<tr>
<td><strong>DETECTION METHOD</strong></td>
<td>Visual inspection and FEM-analysis</td>
<td>Visual inspection and screw joint calculations</td>
<td>Visual inspection</td>
<td>Visual inspection</td>
<td>Visual inspection</td>
</tr>
<tr>
<td><strong>SEV</strong></td>
<td>8</td>
<td>10</td>
<td>2</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td><strong>OCC</strong></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><strong>DET</strong></td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td><strong>Risk factor</strong></td>
<td>24</td>
<td>10</td>
<td>6</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td><strong>Recommended Action(s)</strong></td>
<td>Protecting shell</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SEV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td><strong>OCC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>DET</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Risk factor</strong></td>
<td>24</td>
<td>10</td>
<td>6</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Rank</td>
<td>Effect rate</td>
<td>Criteria</td>
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<td></td>
<td></td>
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<tr>
<td>------</td>
<td>---------------------</td>
<td>--------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Hazardous- without warning</td>
<td>Very high severity ranking when a potential failure mode affects personal safety, safe item operation and/or involves non-compliance with government regulation without warning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Hazardous- with warning</td>
<td>Very high severity ranking when a potential failure mode affects safe item operation and/or involves non-compliance with government regulation with warning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Very High</td>
<td>Item inoperable, with loss of primary function.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>High</td>
<td>Item operable, but at reduced level of performance. Customer dissatisfied.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Moderate</td>
<td>Item operable, but Comfort/ Convince item(s) inoperable. Customer experiences discomfort.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Low</td>
<td>Item operable, but Comfort/ Convince item(s) operable at reduced level of performance. Customer experiences some dissatisfaction.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Very low</td>
<td>Fit &amp; finish/Squeak &amp; Rattle item does not conform. Defect noticed by average customers.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Minor</td>
<td>Fit &amp; finish/Squeak &amp; Rattle item does not conform. Defect noticed by most customers.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Very minor</td>
<td>Fit &amp; finish/Squeak &amp; Rattle item does not conform. Defect noticed by discriminating customers.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>None</td>
<td>No effect.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Standard rating criteria for OCCURRENCE.

<table>
<thead>
<tr>
<th>Rank</th>
<th>CPK</th>
<th>Failure Rate</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>≤ 0.33</td>
<td>&lt; 1 in 2</td>
<td>Very High:</td>
</tr>
<tr>
<td>9</td>
<td>≥ 0.33</td>
<td>1 in 3</td>
<td>Failure almost inevitable</td>
</tr>
<tr>
<td>8</td>
<td>≥ 0.51</td>
<td>1 in 8</td>
<td>High:</td>
</tr>
<tr>
<td>7</td>
<td>≥ 0.67</td>
<td>1 in 20</td>
<td>Repeated failures</td>
</tr>
<tr>
<td>6</td>
<td>≥ 0.83</td>
<td>1 in 80</td>
<td>Moderate:</td>
</tr>
<tr>
<td>5</td>
<td>≥ 1.00</td>
<td>1 in 400</td>
<td>Occasional failures</td>
</tr>
<tr>
<td>4</td>
<td>≥ 1.17</td>
<td>1 in 2000</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>≥ 1.33</td>
<td>1 in 15 000</td>
<td>Low:</td>
</tr>
<tr>
<td>2</td>
<td>≥ 1.50</td>
<td>1 in 150 000</td>
<td>Relatively few failures</td>
</tr>
<tr>
<td>1</td>
<td>≥ 1.67</td>
<td>≤ 1 in 1 500 000</td>
<td>Remote: Failure is unlikely</td>
</tr>
</tbody>
</table>
Standard rating criteria for DETECTION [8].

<table>
<thead>
<tr>
<th>Rank</th>
<th>Detection rate</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Absolute uncertainty</td>
<td>Design Control will not and/or cannot detect a potential cause/mechanism and subsequent failure mode; or there is no Design Control.</td>
</tr>
<tr>
<td>9</td>
<td>Very remote</td>
<td>Very Remote chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
</tr>
<tr>
<td>8</td>
<td>Remote</td>
<td>Remote chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
</tr>
<tr>
<td>7</td>
<td>Very low</td>
<td>Very Low chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
</tr>
<tr>
<td>6</td>
<td>Low</td>
<td>Low chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
</tr>
<tr>
<td>5</td>
<td>Moderate</td>
<td>Moderate chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
</tr>
<tr>
<td>4</td>
<td>Moderately high</td>
<td>Moderately High chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
</tr>
<tr>
<td>3</td>
<td>High</td>
<td>High chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
</tr>
<tr>
<td>2</td>
<td>Very high</td>
<td>Very High chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
</tr>
<tr>
<td>1</td>
<td>Almost certain</td>
<td>Design Controls will almost certainly detect a potential cause/mechanism and subsequent failure mode.</td>
</tr>
</tbody>
</table>
Där ej annat anges gäller tolerans enligt SS-ISO 2768-1

<table>
<thead>
<tr>
<th>Itemref</th>
<th>Quantity</th>
<th>Title/Name, designation, material, dimension etc</th>
<th>Article No/Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L-järn 90x140x11</td>
<td>00713</td>
</tr>
</tbody>
</table>

Designed by

CS Production

L-JARN Dragstation

Date: 15-May-13

Scale: 0,100