Thesis 15 ECTS credits advanced course

STUDY OF TRUNNION CAPS

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STUDIE AV ÖVERFALL TILL FÄSTE
Summary
This thesis compiles information of a kind of bracket named “Trunnion cap” which is used at some of the loaders and trucks that are developed at Atlas Copco Rock Drills AB in Örebro, the information is needed to create a technical guideline for design of new trunnion caps. The thesis is limited to investigate trunnion caps that are used to attach steering cylinders on six different vehicles, MT436B, MT5020, MT6020, ST1030, ST14 and ST1520. It investigates what angles the force generated by the steering cylinders acts from, which varies from a range of 6 to 96 degrees depending on which vehicle and frame it is. The forces generated by the steering cylinder have also been calculated regarding the maximum pressure which is between 21.5 and 30 MPa for the different vehicles.

Any kind of useful information from customers has also been searched partly by asking employees at Atlas Copco customer centres around the world if they are aware of any occasions were trunnion caps or bolts to trunnion caps have broke down. The results indicate that no problems exist today and that old problems had to do with lack of service. Even the internal databases for service reports have been searched for failures that regard parts to trunnion caps but no relevant information was found.

The tolerances for the holes in the trunnion caps and to the pins that are assembled to the trunnion caps has also been identified with a result that vary, some assemblies have a tight fitting while others have a loose fitting.

Finally has the availability of bolts with property class 8.8 and 10.9 been investigated where it has been noticed that the lead time for bolts with property class 8.8 more often is shorter than it is for bolts with property class 10.9.
Sammanfattning

Detta examensarbete sammantäcker och tar fram information om en typ av fäste som kallas “Trunnion cap” som används på några av de truckar och lastare som utvecklas på Atlas Copco Rock Drills AB i Örebro. Informationen behövs för att skapa en konstruktionsriktlinje för trunnion caps.

Arbetet är begränsat till att undersöka de trunnion caps som används vid infästning av styrcylindrar på sex olika fordon, MT436B, MT5020, MT6020, ST1030, ST14 och ST1520. Det undersöker från vilka vinklar kraften som genereras av styrcylindern verkar från. Dessa vinklar verkar inom ett intervall från 6 till 96 grader. Själva kraften har också beräknats med avseende på maximalt styrtryck vilket varierar från 21,5 till 30 MPa beroende på fordon.

Värdefull information från kunder har också eftersökt delvis genom att fråga anställda vid några av Atlas Copcos marknadsbolag runt om i världen om de är medvetna om några tillfällen då trunnion caps eller bultar till trunnion caps har havererat. Svaren på denna fråga tyder på att inga problem existerar idag men att de problem som funnits tidigare berott på bristande service. Även Atlas Copcos interna databaser för servicerapporter har genomgåts på rapporter som rör delar till trunnion caps, dock utan att någon relevant information hittats.

Examensarbetet har även sammantäckt de toleranser som hålen i trunnion caps:samt axeln som monteras dit har. Resultatet varierar då några sammantällningar har grepppassning medan andra har spelpassning.

Slutligen har även tillgängligheten på bult med hållfasthetsklass 8.8 och 10.9 undersökt där det har noterats att ledtiden för bult med hållfasthetsklass 8.8 i allmänhet är kortare än för bultar med hållfasthetsklass 10.9.
Preface

I want to thank all those people who helped me during my work with this thesis, my mentors and the employees at Atlas Copco Rock Drills AB.

I would also like to thank the clients of this thesis, Mikael Petersson and Martin Hellberg who despite the short notice still managed to create an assignment for the thesis.

Last, but more important, I would like to thank my partner Katarina Lanneborn who has encouraged me during the whole thesis even when she herself had much to do.
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Introduction

This thesis is a part of a bachelor degree programme in mechanical engineering, at Örebro University. It is worth 15 European Credit Transfer System (ECTS) credits, which correspond to about 10 weeks. It is performed at Atlas Copco Rock Drills AB in Örebro.

The Atlas Copco group\textsuperscript{1} is divided in Compressor technique, Construction and Mining Technique (CMT) and Industrial Technique where this thesis is performed at the product company in Örebro at the Research and Development (R&D) department at Underground Rock Excavation, CMT, see figure 1.

The R&D department at the product company in Örebro uses an internal software named “TPX/DEMO” to work with Bills Of Material (BOM) lists and “Pro/ENGINEER”\textsuperscript{2} to create 3D-designs. Each machine type has its own BOM-list, where all installations and options are shown by article numbers. By using these lists it is possible to find out what article numbers different parts and drawings have.

To store and handle parts and assemblies from “Pro/ENGINEER” the R&D department uses a system called “Pro/INTRALINK”\textsuperscript{3} and to handle drawings they use an internal system named “Archive”.

Atlas Copco also uses a business system named “Movex Explorer”\textsuperscript{4} (version 12) where information about suppliers, prices, lead time and more about articles can be found.

To find article numbers for different fasteners, bearings and other articles engineers at Atlas Copco uses an internal database named “Mechanical Articles - GSD” (GSD) where different types of articles are sorted in folders by size or other categories.

\textsuperscript{1} Atlas Copco presentation
\textsuperscript{2} www.ptc.com
\textsuperscript{3} www.ptc.com
\textsuperscript{4} www.lawson.com
At Atlas Copco Finite Element Analyses (FEA) are performed at the Rocktec department see figure 1. In this thesis the Computer-Aided Engineering (CAE) program “Ansys”\(^5\) will be used.

**Background**

In Örebro Atlas Copco manufactures and develops different Mine Trucks (MT) and Scoop Trams (ST). These machines are all articulated and the frame is divided into two parts, power-frame and load-frame. The power-frame is the part where the engine is attached and on the load-frame a dump box or bucket is attached depending on which kind of machine it is.

The MT have a dump box and they have their power-frame in the front while the ST have their power-frame in the back and a bucket in the front. Between the power- and load-frame two steering cylinders are assembled and they are both attached with a shaft (pin) and sometimes with two trunnion caps which are a kind of bracket. As the machine turns the angle between the force acting from the steering cylinder and the direction of the bolts (see centreline of holes in figure 2) to the trunnion caps is changing. Figure 2 shows the angle \(\alpha\). The results section shows exactly how the different parts are assembled and what the angle value for each vehicle is.

\(^5\) www.ansys.com
Two different solutions are used when designing the attachments for articulated parts such as steering and tipping cylinders. The first solution is to use trunnion caps and assemble a shaft on the frame. The second solution is to use an expanding shaft to attach the cylinder in a hole in the frame, see figure 3.

![Figure 3: Attachment solutions](image)

According to the R&D department there are problems with the trunnion cap solutions, where the bolts to the trunnion cap are broken or loosened due to the lack of service or the bolts not are retightened by the customers.

**Aim**

The aim of this thesis is to find any information that can be useful when creating a technical guideline for design of trunnion caps, if possible due to time. The thesis will lead to a guideline.

**Tasks**

The tasks for the thesis are:

1. To identify what parts are used to the trunnion caps on different vehicles and to create assemblies of parts to FEA.
2. To define the range of angles from the force that is acting on the trunnion caps.
3. By help from the Rocktec department at Atlas Copco and FEA analyse how forces and different angles of the forces affects bolts and trunnion caps with respect to deformation and stresses.
4. To analyse which property class (grade) on bolts that is most suitable for different trunnion caps with respect to availability.
5. To find what tolerances holes and pins have in trunnion caps on different vehicles.
6. Find any relevant information from customers.
Delimitations
The thesis will only analyse trunnion caps and bolts that belongs to steering cylinders on the vehicles MT436B, MT5020, MT6020, ST1030, ST14 and ST1520 beginning with MT5020, MT6020 and ST1030. The range of angels that will be analysed is between the minimum and maximum angle of the force acting on the trunnion caps, maximum four angels per machine will be analysed. All FEA will be performed by the Rocktec department at Atlas Copco and all steering cylinders are double-acting.

The vehicles

MT436B
The MT436B is shown in figure 4 and its technical data\(^6\) are given in table 1. The maximum pressure in the steering system occurs when the vehicle for example hits a rib. Also it is used in the force calculation and in the FEA.

<table>
<thead>
<tr>
<th>MT436B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Load capacity</td>
<td>32 650 kg</td>
</tr>
<tr>
<td>Operating weight of vehicle</td>
<td>30 600 kg</td>
</tr>
<tr>
<td>Length</td>
<td>10.180 m</td>
</tr>
<tr>
<td>Height</td>
<td>2,680 m</td>
</tr>
<tr>
<td>Width</td>
<td>3,065 m</td>
</tr>
<tr>
<td>Working pressure in steering system</td>
<td>170 bar</td>
</tr>
<tr>
<td>Maximum pressure in steering system</td>
<td>215 bar</td>
</tr>
</tbody>
</table>

Table 1: Technical data MT436

\(^6\) www.atlascopco.se
**MT5020 and MT6020**

The MT6020 vehicle is basically a modified MT5020. Therefore there are many similarities between the two vehicles. The power-frames, the steering system and the steering cylinders are identical as well as the assembly of trunnion caps on the load-frame. In the FEA the load-frame from MT6020 has been used.

The MT5020 is shown in figure 5 and its technical data are given in table 2. The maximum pressure in the steering system occurs when the vehicle for example hits a rib. Also it is used in the force calculation and in the FEA.

<table>
<thead>
<tr>
<th>MT5020</th>
<th></th>
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<tbody>
<tr>
<td>Load capacity</td>
<td>50 000 kg</td>
</tr>
<tr>
<td>Operating weight of vehicle</td>
<td>42 000 kg</td>
</tr>
<tr>
<td>Length</td>
<td>11,220 m</td>
</tr>
<tr>
<td>Height</td>
<td>2,815 m</td>
</tr>
<tr>
<td>Width</td>
<td>3,200 m</td>
</tr>
<tr>
<td>Working pressure in steering system</td>
<td>207 bar</td>
</tr>
<tr>
<td>Maximum pressure in steering system</td>
<td>241 bar</td>
</tr>
</tbody>
</table>

Table 2: Technical data MT5020

The MT6020 is shown in figure 6 and its technical data are given in table 3. The maximum pressure in the steering system occurs when the vehicle for example hits a rib. Also it is used in the force calculation and in the FEA. The MT6020 is Atlas Copcos largest minetruck.

<table>
<thead>
<tr>
<th>MT6020</th>
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</thead>
<tbody>
<tr>
<td>Load capacity</td>
<td>60 000 kg</td>
</tr>
<tr>
<td>Operating weight of vehicle</td>
<td>43 900 kg</td>
</tr>
<tr>
<td>Length</td>
<td>11,227 m</td>
</tr>
<tr>
<td>Height</td>
<td>2,829 m</td>
</tr>
<tr>
<td>Width</td>
<td>3,440 m</td>
</tr>
<tr>
<td>Working pressure in steering system</td>
<td>207 bar</td>
</tr>
<tr>
<td>Maximum pressure in steering system</td>
<td>241 bar</td>
</tr>
</tbody>
</table>

Table 3: Technical data MT6020
ST1030
The vehicle is one of Atlas Copcos most popular loaders regarding the number of sold vehicles. The ST1030 is shown in figure 7 and its technical data are given in table 4. The maximum pressure in the steering system occurs when the vehicle for example hits a rib. Also it is used in the force calculation and in the FEA.

<table>
<thead>
<tr>
<th>ST1030</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Load capacity</td>
<td>10 000 kg</td>
</tr>
<tr>
<td>Operating weight of vehicle</td>
<td>26 300 kg</td>
</tr>
<tr>
<td>Length</td>
<td>9,745 m</td>
</tr>
<tr>
<td>Height</td>
<td>2,355 m</td>
</tr>
<tr>
<td>Width</td>
<td>2,260 m</td>
</tr>
<tr>
<td>Working pressure in steering system</td>
<td>224 bar</td>
</tr>
<tr>
<td>Maximum pressure in steering system</td>
<td>241 bar</td>
</tr>
</tbody>
</table>

Table 4: Technical data ST1030

ST14
The ST14 is shown in figure 8 and its technical data are given in table 5. The maximum pressure in the steering system occurs when the vehicle for example hits a rib. Also it is used in the force calculation and in the FEA.
## ST14

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Load capacity</td>
<td>14 000 kg</td>
</tr>
<tr>
<td>Operating weight of vehicle</td>
<td>38 000 kg</td>
</tr>
<tr>
<td>Length</td>
<td>10,825 m</td>
</tr>
<tr>
<td>Height</td>
<td>2,550 m</td>
</tr>
<tr>
<td>Width</td>
<td>2,640 m</td>
</tr>
<tr>
<td>Working pressure in steering system</td>
<td>280 bar</td>
</tr>
<tr>
<td>Maximum pressure in steering system</td>
<td>300 bar</td>
</tr>
</tbody>
</table>

**Table 5: Technical data ST14**

![Figure 8: ST14](image)

### ST1520

The ST1520 is shown in figure 9 and its technical data are given in table 6. The maximum pressure in the steering system occurs when the vehicle for example hits a rib. Also it is used in the force calculation and in the FEA.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Load capacity</td>
<td>15 000 kg</td>
</tr>
<tr>
<td>Operating weight of vehicle</td>
<td>41 300 kg</td>
</tr>
<tr>
<td>Length</td>
<td>11,320 m</td>
</tr>
<tr>
<td>Height</td>
<td>2,650 m</td>
</tr>
<tr>
<td>Width</td>
<td>2,648 m</td>
</tr>
<tr>
<td>Working pressure in steering system</td>
<td>224 bar</td>
</tr>
<tr>
<td>Maximum pressure in steering system</td>
<td>235 bar</td>
</tr>
</tbody>
</table>

**Table 6: Technical data ST1520**

![Figure 9: ST1520](image)
Methods

Identifying concerned parts

In order to understand the magnitude of stresses and deformations from the results of the FEA and to see what revision the drawings from each part have, all drawings of parts in the trunnion cap assembly must be identified. All parts can be found by running the BOM-list number for each vehicle in “TPX/DEMO” and then search the power- and load-frame to find the article number for them.

There are then two alternatives to find the article number for every part in the trunnion cap assembly, one is to use “TPX/DEMO” and “archive” to search for the different parts on drawings and in BOM-lists for every frame assembly. A much faster alternative that also has been chosen in the thesis except for the bolts is to check out the article numbers for the frames from “Pro/INTRALINK” and open them in “Pro/ENGINEER”. When each assembly is opened in “Pro/ENGINEER” it is easy to mark the wanted parts in the assembly and find the article number for them in the model tree in “Pro/ENGINEER”. As soon as an article number is found the drawing for it can be opened by running the number in “archive”.

The reason to not use the faster alternative for the bolts is that since a double check was made on the bolts on the load-frame to MT5020 and MT6020 it was discovered that the BOM-list in “DEMO/TPX” did not match the parts in the model tree in the assembly in “Pro/ENGINEER”.

The drawings for the steering cylinders need to be identified as well in order to know the height of the area on the pin that is affected by the force from the steering cylinders. To simplify the thesis it is going to be the height of the ends of the cylinder that are used and not the height of the bearing in the cylinder.
Identifying the angles

The first part of the thesis is to determine the range of angles that the force from the steering cylinder is acting from on the trunnion caps and the bolts to the trunnion caps for each vehicle. By finding the Atlas Copco article number for frames and cylinder sets, as described in the section “Identifying concerned parts”, and check them out from “Pro/INTRALINK” it is possible to use the function “pin” in “Pro/ENGINEER” to create a virtual joint between the power- and the load-frame when assembling them. When the joint is created the maximum and minimum angles between the frames can be set. For this procedure the angles when the vehicle reaches it maximum turning radius in both directions are chosen.

To be able to use the cylinder as a cylinder, the piston and the piston rod can be assembled with the function “cylinder” in “Pro/ENGINEER”. The cylinder can then be assembled to the frames with the function “pin” and the desired angles can be measured, see figure 10.

![Figure 10: Measuring the angles](image)

Since the maximum and minimum angle between the cylinder and the bolts not always occurs when the vehicle is at its maximum or minimum turned position a trial and error analysis is needed to be able to define these angles. The analyses will be performed by using the “pin-function” in “Pro/ENGINEER” and rotate one frame around the joint and measure the angles in the different positions. The wanted angles have been found when they no longer decrease or increase. The angles that shall be investigated are the minimum and maximum angle and also the angle that is in 50% of the range.

If any trunnion cap has force acting at 0˚ or 90˚ even those angles shall be investigated.
Forces

Calculating the forces generated by the steering cylinders
To be able to calculate the forces generated by the steering cylinders, it is necessary to know the diameter of the piston (named bore in the drawings from Atlas Copco) and the piston rod, which can be found on the drawings for every steering cylinder. The drawings for all steering cylinders except the steering cylinder to ST1030 can be found in the same way as described in the section “Identifying concerned parts”. To find the drawing for the steering cylinder to ST1030 it is needed to contact the hydraulic group at the R&D department.

It is also needed to know the pressure in the cylinder. In this thesis the maximum pressure is used which occurs when a vehicle for example hits a rib in the mine. Both the maximum pressure and the working pressure for each vehicle are given by the hydraulic group.

The forces $F$ are calculated by using formula (1), were $p$ is the pressure in the cylinders and $A$ is the area of the surface acting in the cylinders.

$$F = p \cdot A \quad (1)$$

Since all cylinders are double-acting two different forces are needed to be calculated, one for when the cylinder extends and one when it retracts. To calculate the force for extension the area from the piston should be used and when calculating the force for retraction the area from the piston subtracted with the area from the piston rod should be used.

Identifying the pretension in bolts
All information on what torque the bolts of the trunnion cap should be tightened with is defined on the drawing for the steering cylinder assembly for each vehicle. The drawings can be found in the same way as described earlier in the section “Identifying concerned parts”.

---

7 Mattias Awad
8 Hydraulik 1
Create the material to the FEA

All FEA will be performed by the Rocktec department at Atlas Copco but the assemblies of current parts to them will be created in the thesis. The objectives of the FEA are to see what the maximum deformation of the trunnion caps is and to see what stresses that occur when pretension of bolts is applied only. In addition other objectives are to see what deformations and stresses that occur in bolts and trunnion caps when the forces from the cylinders are applied as well. The Rocktec department will provide any areas of parts, where the stresses are higher than the yield strength.

Initially the idea was to use only trunnion caps, trunnion bases, related plates, bolts and pins, see figure 11, for each frame and vehicle and then set those ends at the related plates that are welded to the frame to “fixed support” when perform the FEA by “Ansys”. After a discussion with an engineer⁹ at the Rocktec department at Atlas Copco it was decided that almost the whole frame should be used to ensure that the stiffness in the assembly is as close to the reality as possible. Therefore the assemblies that will be created in the thesis to the Rocktec department will consist of one frame and one pin. The frame will be stripped and some parts will be simplified by the FEA engineer⁹ at the Rocktec department who also decides what to simplify in each frame.

The assemblies that will be created and all the including parts will be exported from “Pro/INTRALINK” to a folder for each vehicle to the address “G:\Common\Mahesh Grampurohit\Trunion Caps” in the Atlas Copco computer network.

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⁹ Mahesh Grampurohit

Figure 11: Related parts to trunnion cap
Finding relevant information from customers

Relevant information is any kind of failure reports or useful information from customer centres. The information can be useful when writing the technical guideline. Atlas Copco has a database where all failure reports are logged and where it is possible to search reports by using the Atlas Copco article number for the concerned part. When any kind of failure has been fixed and the report is more than one year old it is removed to an archive in the database. By searching the database and the archive with the article numbers of the concerned parts it will be obvious if there is any relevant information to find. Another way to find information is to ask the customer centres around the world if they have any information of failures that not reported in the databases. In order to have a quicker response and more authority, the service department is asked to send the question by mail to the customer centres.

Calculating the safety factor of bolts

When designing bolted joints the R&D department uses an internal document named “General Bolted Joint Design” (Atlas Copco Document id: 2.10.00/10.02), see appendix 1. The document is used as a guideline and it contains information on what to think of and how to calculate the factor of safety. Below the heading “Design Parameters for Metric and UN Bolts” in the document it shows that, the safety factor is the clamp load (pretension) divided by the actual load. Also it shows the minimum factor of safety should be equal to three.

Earlier calculations on the safety factor for bolts in trunnion caps to steering cylinders have been made on both MT436B and MT5020 but only when working pressure in the cylinder occurs. The calculations are made on the assumption that the bolts are only exposed to a tensile force and that they share the force generated by the cylinder equally. The thesis is focused on the maximum pressure in the cylinders and in the FEA the force generated by maximum pressure is going to be used, therefore new calculations of safety factors when using maximum pressure is needed.

Identifying tolerances for pins and holes

Another issue is whether the pin should have a tight or loose fitting when designing the trunnion cap assembly. The thesis will not investigate which one of the solutions that is most suitable for the assembly, but it will identify what tolerances the different assemblies have today.

The tolerances on the holes can be identified by searching the BOM-lists for the Atlas Copco article numbers for each frame and vehicle as described in the section “Identifying concerned parts”. The tolerances might not be found in the top level for each frame but they should not be too deep in the BOM-lists for the frames since the holes are drilled after welding of all plates. The tolerances on the pins can be identified by looking at the drawing for each pin found in the same way as described earlier.

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10 Niklas Forsberg
Identifying the availability of different bolts

If it is possible to choose between two or more different lengths of a bolt when designing a trunnion cap it would be preferred to select the one with minimum numbers of days in lead time. The lead time for different articles can be found by running the article number in a command named “mms002” in “Movex Explorer”. The lead time that can be found in “Movex Explorer” regards the articles and prizes that Atlas Copco and their suppliers have agreed on and it is therefore not valid for other companies. The bolts that are holding the trunnion cap are included in the frame which means that it is the supplier that manufactures the frames that also buys the bolts to the trunnion caps.

To choose a bolt with a shorter lead time in “Movex Explorer” will not help the suppliers but since it happens that the production sometimes has to replace the bolts of different reasons\textsuperscript{11} or that the supplier runs out of bolts with the right grade or surface treatment with the risk of delaying a delivery it can still be an issue to find out what the lead time is for different bolts for Atlas Copco.

To find the article numbers for different bolts the internal database “Mechanical articles - GSD” can be used, bolts with the wanted size and surface treatment may be searched and the article number noticed. The thesis will investigate bolts with sizes from M16 to M30 with lengths between 50 and 180 mm.

The decision on what lengths and sizes to investigate is based on the sizes and lengths used today. The thesis will investigate lengths that cover a range of bolts longer and shorter than used today. The same thought is used on the sizes except that the thesis will not investigate sizes larger than M30.

\textsuperscript{11} John Andersson
Results

Parts to trunnion caps and to the FEA

MT436B power-frame
The power-frame to MT436B that is used in the thesis is named “5575 7021 55” and it is the left hand side that is used in the FEA. The assembly that was created for the analysis including the power-frame and the pin is named tc_mt436pf. Figure 12 shows the power-frame, where the main parts of the trunnion assembly are highlighted. In figure 13 the main parts of the trunnion assembly and their names are shown.

![Figure 12: MT436B power-frame](image)

![Figure 13: Trunnion assembly on power-frame MT436B](image)
*Trunnion base (upper left hand side)*

The Atlas Copco article number for the trunnion base, see figure 14, is “5571 8873 00” and its drawing is found in appendix 2. The part is welded on the power-frame, after welding, a trunnion cap is assembled with the trunnion base and finally a hole with the desired tolerance is drilled. Therefore the appearance of both the trunnion base and the trunnion cap is a bit different on the manufactured power-frame than on the drawings for each part. In the geometric model that is used in the FEA the radius “23 R” (mm) given in appendix 2 is the same as the radius for the pin from this assembly.

![Figure 14: Upper trunnion base power-frame](image1.png)

*Trunnion base (lower left hand side)*

The Atlas Copco article number for the trunnion base, see figure 15, is “5571 1354 00” and its drawing is given in appendix 3. The part is welded on the power-frame, after welding, a trunnion cap is assembled with the trunnion base and finally a hole with the desired tolerance is drilled. Therefore the appearance of both the trunnion base and the trunnion cap is a bit different on the manufactured power-frame than on the drawings for each part. In the geometric model that is used in the FEA the radius “R23” (mm) given in appendix 3 is the same as the radius for the pin from this assembly.

![Figure 15: Lower trunnion base power-frame](image2.png)
Trunnion cap
The Atlas Copco article number for the trunnion cap, see figure 16, is “5571 8876 00” and its drawing is found in appendix 4. In the geometric model that is used in the FEA the radius “R23” (mm) on the drawing is the same as the radius for the pin from this assembly.

![Figure 16: Trunnion cap MT436B](image)

Pin
The Atlas Copco article number for the pin, see figure 17, is “5571 1313 00” and its drawing is found in appendix 5. The same pin is assembled on both power- and load-frame. The pin has a hole drilled in both axial and radial directions. The purpose of the holes is to provide a bearing assembled in the steering cylinder with grease. There are no instructions for how to assemble the pins, but in the FEA they are assembled to the power-frame so that the hole in the radial direction is pointing in a 90° angle from the direction of the bolts in the trunnion caps. The steering cylinder is assembled between the two trunnion caps.

![Figure 17: Pin MT436B](image)
**Bolt and washer**

The Atlas Copco article number for the bolt is “5540 4780 00” and for the washer it is “0300 0276 78” their technical specifications are given in figure 18.

<table>
<thead>
<tr>
<th>Bolt</th>
<th>Washer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
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</table>

![Figure 18: Bolt and washer, power-frame MT436B](image1.png)

**MT436B load-frame**

The load-frame of MT436B which is used in the thesis is named “5575 7024 00”. The left hand side is used in the FEA. The assembly that was created for the analysis including the load-frame and the pin is named “tc_m436lf”. The load-frame is shown in figure 19, where the main parts of the trunnion assembly are highlighted. In figure 20 the main parts of the trunnion assembly and their names are shown too.

![Figure 19: Loadframe MT436B](image2.png)
Hydraulic assembly on loadframe MT436B

**Trunnion base**
The Atlas Copco article number for the trunnion base, see figure 21, is “5571 9121 00” and its drawing is given in appendix 6. The part is welded on the load-frame, after welding, two trunnion caps are assembled with the trunnion base and finally two holes with the desired tolerance are drilled. Therefore the appearance of both the trunnion base and the trunnion caps is a bit different on the manufactured load-frame than on the drawings for each part. In the geometric model which is used in the FEA the radius “R23” (mm), given in appendix 6 is the same as the radius for the pin from this assembly. On MT436B the same trunnion base is used in both upper and lower position.

**Trunnion cap**
On the load-frame the same trunnion cap is used as the one on the power-frame, see appendix 4, where the Atlas Copco article number is “5571 8876 00”.

Figure 20: Trunnion assembly on loadframe MT436B

Figure 21: Trunnion base loadframe MT436B
Pin
To the load-frame the same pin is used as the one to the power-frame, see appendix 5, where the Atlas Copco article number is “5571 1313 00”. There are no instructions for how to assemble the pins but in the FEA they are assembled to the load-frame so that the hole in the radial direction is pointing in a 90° angle from the direction of the bolts in the trunnion caps. The steering cylinders are assembled between the trunnion caps.

Bolt and washer
The Atlas Copco article number for the bolt is “5531 0097 00” and for the washer it is “5559 9240 00” the technical specification for the bolt is shown in figure 22, a drawing of the washer is found in appendix 7.

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<th>Technical specification</th>
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<td>Bolt</td>
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<tr>
<td>5559 9240 00</td>
<td>Washer</td>
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MT436B steering cylinder
The Atlas Copco article number for the steering cylinder is “5573 0297 00”, the height of the area acting on the pin in the trunnion cap assembly is between 61,5 mm and 65,5 mm. A drawing of this cylinder is given in appendix 8.
**MT5020 and MT6020 power-frame**

The power-frame of MT5020 and MT6020 is named “5590 0061 36”. The left hand side is used in the FEA. The assembly that was created for the analysis including the power-frame and the pin is named “5590006136_tc_pf”. The power-frame is shown in figure 23 where the main parts of the trunnion assembly are highlighted. In figure 24 the main parts of the trunnion assembly and their names are shown.

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**Figure 23: Power-frame MT5020 and MT6020**

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**Figure 24: Trunnion assembly on power-frame MT5020 and MT6020**
**Trunnion base**
The Atlas Copco article number of the trunnion base, see figure 25, is “5590 0003 02” its drawing is found in appendix 9. The part is welded on the power-frame, after welding, a trunnion cap is assembled with the trunnion base and finally a hole with the desired tolerance is drilled. Therefore the appearance of both the trunnion base and the trunnion cap is a bit different on the manufactured power-frame than on the drawings for each part. In the geometric model which is used in the FEA the radius “R28” (mm), given in appendix 9, is the same as the radius for the pin from this assembly. To MT5020 and MT6020 the same trunnion base is used in both upper and lower position as well as on the right hand side and the left hand side.

![Figure 25: Trunnion base power-frame](image)

**Trunnion cap**
The Atlas Copco article number for the trunnion cap, see figure 26, is “5590 0002 97” and its drawing is found in appendix 10. In the geometric model which is used in the FEA the radius “R28” (mm) on the drawing is the same as the radius for the pin from this assembly.

![Figure 26: Trunnion cap power-frame](image)
Pin

The Atlas Copco article number for the pin, see figure 27, is “5590 0006 76” and its drawing is found in appendix 11. The pin has a hole drilled in both axial and radial directions. The purpose of these holes is to provide a bearing assembled in the steering cylinder with grease. The pin is assembled to the power-frame so that the hole in the radial direction is pointing to the centre of the machine in a 90° angle from the direction of the bolts in the trunnion caps.

Bolt and washer

The Atlas Copco article number for the bolt is “5541 0250 00” and for the washer it is “5540 1129 00”. Their technical specifications are shown in figure 28.
**MT5020 and MT6020 load-frame**

The load-frame of MT5020 and MT6020 used in the thesis is named “5590 0060 00”. The left hand side is used in the FEA. The assembly that was created for the analysis including the load-frame and the pin is named “5590006000_tc”. The load-frame is shown in figure 29, where the main parts of the trunnion assembly are highlighted. In figure 30, the main parts of the trunnion assembly and their names are shown.

![Figure 29: Loadframe MT5020 and MT6020](image1.png)

![Figure 30: Trunnion assembly on loadframe MT5020 and MT6020](image2.png)
**Trunnion base**
The Atlas Copco article number of the trunnion base in figure 31, is “5572 6637 00” and its drawing is found in appendix 12. The part is welded on the load-frame, after welding, a trunnion cap is assembled with the trunnion base and finally, a hole with the desired tolerance is drilled. Therefore the appearance of both the trunnion base and the trunnion cap is a bit different on the manufactured load-frame than on the drawings for each part. In the geometric model used in the FEA the diameter “56” (mm), found in appendix 12, is the same as the diameter of the pin from this assembly. To MT5020 and MT6020 the same trunnion base is used in both upper and lower position as well as on the right hand side and the left hand side.

![Figure 31: Trunnion base loadframe MT5020 and MT6020](image)

**Trunnion cap**
The Atlas Copco article number of the trunnion cap, see figure 32, is “5574 9887 00” and its drawing is found in appendix 13. In the geometric model that is used in the FEA the radius “R28” (mm) on the drawing is the same as the radius for the pin from this assembly.

![Figure 32: Trunnion cap loadframe MT5020 and MT6020](image)
**Pin**

On the load-frame the same pin is used as the one to the power-frame, see appendix 11, with the Atlas Copco article number “5590 0006 76”. The pin is assembled to the load-frame so that the hole in the radial direction is pointing in the same direction as the head of the bolts. The steering cylinder is assembled between the two trunnion caps.

**Bolt and washer**

The Atlas Copco article number for the bolt is “5541 0386 00” and for the washer it is “5540 1130 00”, their technical specifications are shown in figure 33.

![Figure 33: Bolt and washer, loadframe MT5020 and MT6020](image)

**MT5020 and MT6020 steering cylinder**

The Atlas Copco article number for the steering cylinder is “5590 0006 62”, the height of the area acting on the pin in the trunnion cap assembly is between 125 mm and 127 mm. A drawing of the cylinder is given in appendix 14.
**ST1030 power-frame**

The power-frame to ST1030 is named “5580 0073 76”. The left hand side is used in the FEA. The assembly that was created for the analysis including the power-frame and the pin is named “5580007376_tc”. The power-frame is shown in figure 34, where the main parts of the trunnion assembly are highlighted. In figure 35 the main parts of the trunnion assembly and their names are shown.
**Trunnion base**
The Atlas Copco article number for the trunnion base, see figure 36, is “5575 4191 00” and its drawing is found in appendix 15. The part is welded on the power-frame, after welding, a trunnion cap is assembled with the trunnion base and finally a hole with the desired tolerance is drilled. Therefore the appearance of both the trunnion base and the trunnion cap is a bit different on the manufactured power-frame than on the drawings for each part. In the geometric model which is used in the FEA the radius “R19”, shown in appendix 15, is the same as the radius for the pin from this assembly. To ST1030 the same trunnion base is used in both upper and lower position as well as on the right hand side and the left hand side of the power-frame.

![Figure 36: Trunnion base power-frame](image)

**Trunnion cap**
The Atlas Copco article number for the trunnion cap, see figure 37, is “5575 4204 00” and its drawing is found in appendix 16. In the geometric model that is used in the FEA the radius “R19” (mm), shown in appendix 16, is the same as the radius for the pin from this assembly.

![Figure 37: Trunnion cap power-frame](image)
**Pin**

The Atlas Copco article number for the pin, see figure 38, is “5580 0065 68” and its drawing is found in appendix 17. The pin consists of two different parts, one pin and one plate welded on top of the pin. The pin has holes drilled in both axial and radial directions. The purpose of the holes is to provide a bearing assembled in the steering cylinder with grease. The pin is assembled to the power-frame so that the hole in the radial direction is pointing in the same direction as the head of the bolts. The steering cylinder is assembled between the two trunnion caps.

![Pin power-frame ST1030](image)

**Bolt and washer**

The Atlas Copco article number of the bolt is “5540 6239 00” and for the washer it is “5540 1128 00”, their technical specifications are shown in figure 39.

![Bolt and washer, power-frame ST1030](image)
**ST1030 load-frame**

The load-frame to ST1030 is named “5575 7009 56”. The left hand side is used in the FEA. The assembly that was created for the analysis including the load-frame and the pin is named “5575700956_tc”. The load-frame is shown in figure 40, where the main parts of the trunnion assembly are highlighted. Figure 41 shows the main parts of the trunnion assembly with their names.

![Figure 40: Loadframe ST1030](image)

![Figure 41: Trunnion assembly on loadframe ST1030](image)
**Trunnion base (upper)**
The Atlas Copco article number for the trunnion base, see figure 42, is “5575 2981 00” and its drawing is found in appendix 18. The part is welded on the load-frame, after welding, a trunnion cap is assembled with the trunnion base and finally a hole with the desired tolerance is drilled. Therefore the appearance of both the trunnion base and the trunnion cap is a bit different on the manufactured load-frame than on the drawings for each part. In the geometric model that is used in the FEA the radius “R19” (mm) shown in appendix 18, is the same as the radius for the pin from this assembly. To ST1030 the trunnion base “5575 2981 00” is used in the upper position on the right and left hand side of the load-frame.

![Figure 42: Upper trunnion base loadframe ST1030](image)

**Trunnion base (lower)**
The Atlas Copco article number for the trunnion base, see figure 43, is “5575 2948 00” and its drawing is found in appendix 19. The part is welded on the load-frame, after welding, a trunnion cap is assembled with the trunnion base and finally, a hole with the desired tolerance is drilled. Therefore the appearance of both the trunnion base and the trunnion cap is a bit different on the manufactured load-frame than on the drawings for each part. In the geometric model which is used in the FEA, the radius “R19” (mm) shown in appendix 19 is the same as the radius for the pin from this assembly. To ST1030 the trunnion base “5575 2948 00” is used in the lower position on the right and left hand side load-frame.

![Figure 43: Lower trunnion base loadframe ST1030](image)
**Trunnion cap**
On the load-frame the same trunnion cap is used as the one to the power-frame, see appendix 16, its Atlas Copco article number “5575 4204 00”.

**Pin**
The Atlas Copco article number for the pin, see figure 44, is “5580 0065 48” and its drawing is found in appendix 20. The pin consists of two different parts, one pin and one plate welded on top of the pin. The pin has holes drilled in both an axial and radial directions. The purpose with the holes is to provide a bearing assembled in the steering cylinder with grease. The pin is assembled to the load-frame so that the hole in the radial direction is pointing away from the articulated part between the load- and the power-frame in an angle of 49° from the direction of the bolts. The steering cylinder is assembled between the two trunnion caps.

![Figure 44: Pin loadframe ST1030](image)

**Bolt and washer**
The Atlas Copco article number for the bolt is “5540 6239 00” and for the washer it is “5540 1128 00”. The trunnion cap on the power-frame has the same bolt and washer.

**ST1030 steering cylinder**
The Atlas Copco article number for the steering cylinder is “5580 0042 58” but on that drawing no dimensions are to be found. Instead the drawing from the supplier given by the hydraulic group is used. The height of the area acting on the pin in the trunnion cap assembly is 66 mm. A drawing of the cylinder is found in appendix 21. Its supplier’s number is “3713427”.

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ST14 power-frame

The power-frame to ST14 is named “5580 0031 17” and it is the right hand side that is used in the FEA. The assembly created for the analysis including the power-frame and the pin is named “5580003117_tc”. The power-frame is shown in figure 45, where the main parts of the trunnion assembly are highlighted. In figure 46 the main parts of the trunnion assembly and their names are shown.
**Trunnion base**
The Atlas Copco article number for the trunnion base, see figure 47, is “5575 7003 98” and its drawing is found in appendix 22. The part is welded on the power-frame, after welding, a trunnion cap is assembled with the trunnion base and finally, a hole with the desired tolerance is drilled. Therefore the appearance of both the trunnion base and the trunnion cap is a bit different on the manufactured power-frame than on the drawings for each part. In the geometric model which is used in the FEA the diameter “53” (mm), shown in appendix 22, is the same as the diameter for the pin from this assembly. To ST14 the same trunnion base is used in both upper and lower position as well as on the right and left hand side of the power-frame.

![Figure 47: Trunnion base power-frame](image)

**Trunnion cap**
The Atlas Copco article number for the trunnion cap, see figure 48, is “5575 7003 87” and its drawing is found in appendix 23. In the geometric model which is used in the FEA the diameter “53” (mm) shown in appendix 23 is the same as the radius for the pin from this assembly.

![Figure 48: Trunnion cap power-frame](image)
Pin
The Atlas Copco article number for the pin, see figure 49, is “5580 0037 26” and its drawing is found in appendix 24. The pin consists of two different parts, one pin with the Atlas Copco article number “5580 0024 90”, see appendix 25, and one plate bolted on top of the pin. The pin has holes drilled in both an axial and radial directions. The purpose of the holes is to provide a bearing assembled in the steering cylinder with grease. The pin is assembled to the power-frame so that the hole in the radial direction is pointing in an angle of 90° from the direction of the bolts. The steering cylinder is assembled between the two trunnion caps.

![Figure 49: Pin power-frame ST14](image)

Bolt and washer
The Atlas Copco article number for the bolt is “5540 2801 00” and for the washer it is “5540 1130 00”, their technical specifications are shown in figure 50.

![Figure 50: Bolt and washer, power-frame ST14](image)
ST14 load-frame

The load-frame to ST14 is named “5580 0021 54”. The right hand side is used in the FEA. The assembly created for the analysis including the power-frame and the pin is named “5580002154_tc”. The load-frame is shown in figure 51, where the main parts of the trunnion assembly are highlighted. In figure 52 the main parts of the trunnion assembly and their names are shown.

Figure 51: Loadframe ST14

Figure 52: Trunnion assembly on loadframe ST14
**Trunnion base**
On the load-frame to ST14 two different trunnion bases are used. The Atlas Copco article numbers for them are “5580 0022 68”, shown in the left part of figure 53, and “5580 0022 67”, shown in the right part of the same figure. The drawings of them are found in appendix 26 and 27.
“5580 0022 68” is located in the upper position on the left hand side of the load-frame as well as in the lower position on the right hand side, “5580 0022 67” is located in the opposite positions. The trunnion base is welded on the load-frame, after welding, a trunnion cap is assembled with the trunnion base and finally, a hole with the desired tolerance is drilled. Therefore the appearance of both the trunnion base and the trunnion cap is a bit different on the manufactured load-frame than on the drawings for each part. In the geometric model used in the FEA the radius “R26.5” (mm) shown in appendix 26 and 27 is the same as the radius for the pin from this assembly.

![Figure 53: Trunnion base load-frame ST14](image)

**Trunnion cap**
To the load-frame the same trunnion cap is used as the one to the power-frame, see appendix 23, Atlas Copco article number “5575 7003 87”.

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Pin
The Atlas Copco article number for the pin assembly, see figure 54, is “5580 0037 27” and its drawing is found in appendix 28. The pin consists of two different parts, one pin with the Atlas Copco article number “5580 0024 89”, see appendix 29, and one plate bolted on top of the pin. The pin has holes drilled in both axial and radial directions. The purpose of these holes is to provide a bearing assembled in the steering cylinder with grease. The pin is assembled to the load-frame so that the hole in the radial direction is pointing away from the articulated part between the load- and the power-frame in an angle of 49˚ from the direction of the bolts. The steering cylinder is assembled between the two trunnion caps.

Figure 54: Pin loadframe ST14

Bolt and washer
The Atlas Copco article number for the bolt is “5541 0656 00” and for the washer it is “5540 1130 00”. It is the same washer as the washer to the trunnion cap on the power-frame for ST14, see figure 50. The technical specification for the bolt is shown in figure 55.

Figure 55: Bolt load-frame ST14

ST14 steering cylinder
The Atlas Copco article number for the steering cylinder is “5580 0109 51”, the height of the area acting on the pin in the trunnion cap assembly is 79 mm. A drawing of the cylinder is found in appendix 30.
**ST1520 power-frame**

The power-frame to ST1520 is named “5575 7013 87” and it is the right hand side that is used in the FEA. The assembly created for the analysis including the power-frame and the pin is named “tc_st1520pf”. The power-frame is shown in figure 56, where the main parts of the trunnion assembly are highlighted. In figure 57 the main parts of the trunnion assembly and their names are shown.

![Figure 56: Power-frame ST1520](image)

![Figure 57: Trunnion assembly on power-frame ST1520](image)
**Trunnion base**
The Atlas Copco article number for the trunnion base is “5575 7003 98”, it is the same as the trunnion base on the power-frame for ST14, see figure 47 and appendix 22. The part is welded on the power-frame, after welding, a trunnion cap is assembled with the trunnion base and finally a hole with the desired tolerance is drilled. Therefore the appearance of both the trunnion base and the trunnion cap is a bit different on the manufactured power-frame than on the drawings for each part. In the geometric model which is used in the FEA, the diameter “53” (mm) shown in appendix 22 is the same as the radius for the pin from this assembly. To ST1520 the same trunnion base is used in both upper and lower position as well as on the right and left hand side of the power-frame.

**Trunnion cap**
The Atlas Copco article number for the trunnion cap is “5575 7003 87”, it is the same as the trunnion cap to the power-frame for ST14, see figure 48 and appendix 23. In the geometric model that is used in the FEA the diameter “53” (mm) shown in appendix 23 is the same as the diameter for the pin from this assembly.

**Pin**
The Atlas Copco article number for the pin, see figure 58, is “5580 0064 75” its drawing is found in appendix 31. The pin consists of two different parts, one pin and one plate welded on top of the pin. The pin has a hole drilled in both an axial and radial directions. The purpose of the holes is to provide a bearing assembled in the steering cylinder with grease. The pin is assembled to the power-frame so that the hole in the radial direction is pointing away from the head of the bolts in the assembly. The steering cylinder is assembled between the two trunnion caps.

![Figure 58: Pin power-frame ST1520](image)
**Bolt and washer**
The Atlas Copco article number for the bolt is “0147 1963 65” and the article number for the washer is “5540 1130 00”, it is the same washer as the one for the power-frame on ST14, see figure 50. The technical specification for the bolt is shown in figure 59.

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*Figure 59: Bolt power-frame ST1520*

**ST1520 load-frame**
The load-frame to ST1520 is named “5575 7014 24” and it is the right hand side that is used in the FEA. The assembly that was created for the analysis including the load-frame and the pin is named “tc_st1520lf”. The load-frame is shown in figure 60 where the main parts of the trunnion assembly are highlighted. Figure 61 shows the main parts of the trunnion assembly and their names.

*Figure 60: Loadframe ST1520*
**Trunnion base (upper)**

The Atlas Copco article number for the trunnion base, see figure 62, is “5575 7003 96” its drawing is found in appendix 32. The part is welded on the loadframe, after welding, a trunnion cap is assembled to the trunnion base and finally, a hole with the desired tolerance is drilled. Therefore the appearance of both the trunnion base and the trunnion cap is a bit different on the manufactured loadframe than on the drawings for each part. In the geometric model that is used in the FEA the radius "R27" (mm), shown in appendix 32, is the same as the radius for the pin from this assembly.
**Trunnion base (lower)**

On the load-frame to ST1520 two different trunnion bases are used in the lower position, the Atlas Copco article numbers for them are “5575 7003 88”, shown in the left part of figure 63, and “5575 7003 90”, shown in the right part of the same figure. The drawings of them are given in appendix 33 and 34.

“5575 7003 88” is located on the left hand side of the load-frame and “5575 7003 90” is located on the right hand side. The trunnion base is welded on the load-frame, after welding, a trunnion cap is assembled with the trunnion base and finally, a hole with the desired tolerance is drilled. Therefore the appearance of both the trunnion base and the trunnion cap is a bit different on the manufactured load-frame than on the drawings for each part. In the geometric model that is used in the FEA the diameter “53” (mm), shown in appendix 33 and 34, is the same as the radius for the pin from this assembly.

![Figure 63: Trunnion base load-frame ST1520](image)

**Trunnion cap**

The Atlas Copco article number for the trunnion cap is “5575 7003 87”, it is the same as the trunnion cap to the power-frame for ST14, see figure 48 and appendix 23. In the geometric model that is used in the FEA the diameter “53” (mm), shown in appendix 23, is the same as the radius for the pin from this assembly.
**Pin**
The Atlas Copco article number for the pin, see figure 64, is “5580 0064 68”, and its drawing is found in appendix 35. The pin consists of two different parts, one pin and one plate welded on top of the pin. The pin has a hole drilled in both axial and radial directions. The purpose of these holes is to provide a bearing assembled in the steering cylinder with grease. The pin is assembled to the load-frame so that the hole in the radial direction is pointing towards the articulated part between the load- and the power-frame in an angle of 55° from the direction of the bolts. The steering cylinder is assembled between the two trunnion caps.

![Figure 64: Pin loadframe ST1520](image)

**Bolt and washer**
The Atlas Copco article number for the bolt is “5541 0656 00” and for the washer it is “5540 1130 00”, it is the same bolt and washer as to the trunnion cap on the load-frame for ST14, see figure 50 and 55.

**ST1520 steering cylinder**
The Atlas Copco article number for the steering cylinder is “5574 6758 00”, the height of the area acting on the pin in the trunnion cap assembly is 105 mm. A drawing of the cylinder is given in appendix 36.
Angles

The maximum turning angle is found in a drawing for general arrangements for each vehicle and the name (article number) of each drawing is found by searching in every vehicle BOM-list in “TPX/DEMO”. By using the method described in the section “Work method”

In the thesis the angles from the force acting on the trunnion cap were able to be located. It is worth to clarify that the angles are measured between the centreline of the bolt to the trunnion cap and the force acting from the steering cylinder, see table 7. As mentioned earlier in the results it is the left hand side of the frames that are analysed on MT436B, MT5020, MT6020 and ST1030 and the right hand side on ST14 and ST1520.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Maximum turning angle for vehicle (degrees)</th>
<th>Angles between steering cylinder and centreline of the bolt (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frame</td>
<td>Minimum</td>
</tr>
<tr>
<td>MT436B (LH)</td>
<td>42.5</td>
<td>Powerframe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loadframe</td>
</tr>
<tr>
<td>MT5020 and MT6020 (LH)</td>
<td>44</td>
<td>Powerframe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loadframe</td>
</tr>
<tr>
<td>ST1030 (LH)</td>
<td>42.5</td>
<td>Powerframe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loadframe</td>
</tr>
<tr>
<td>ST14 (RH)</td>
<td>44</td>
<td>Powerframe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loadframe</td>
</tr>
<tr>
<td>ST1520 (RH)</td>
<td>42.5</td>
<td>Powerframe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loadframe</td>
</tr>
</tbody>
</table>

Table 7

Forces

Forces generated by the steering cylinders

The forces that are generated by the steering cylinders are calculated by using the formula (1). The results are given in appendix 37.
Pretension in bolts

The information on what torque the bolts of the trunnion cap should be tightened with is found on the drawing for the steering cylinder assembly for each vehicle. Every drawing refers to an Atlas Copco specification named “5506 9351 00”, see appendix 38, where the pretension (named clamp load in the specification) is calculated for different bolt sizes when tightened to 75 % of the yield strength. Table 8 summaries the pretension for the bolts of the trunnion caps for all vehicles.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Frame</th>
<th>Bolt, article nr</th>
<th>Size</th>
<th>Grade</th>
<th>Torque with molybaste (Nm)</th>
<th>Pretension (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT436B</td>
<td>Powerframe</td>
<td>5540 4780 00</td>
<td>1 1/8</td>
<td>10,9</td>
<td>1048</td>
<td>305 600</td>
</tr>
<tr>
<td></td>
<td>Loadframe</td>
<td>5531 0097 00</td>
<td>1 1/8</td>
<td>10,9</td>
<td>1048</td>
<td>305 600</td>
</tr>
<tr>
<td>MT5020 and MT6020</td>
<td>Powerframe</td>
<td>5541 0250 00</td>
<td>M24</td>
<td>10,9</td>
<td>630</td>
<td>218 900</td>
</tr>
<tr>
<td></td>
<td>Loadframe</td>
<td>5541 0386 00</td>
<td>M30</td>
<td>10,9</td>
<td>1253</td>
<td>347 900</td>
</tr>
<tr>
<td>ST1030</td>
<td>Powerframe</td>
<td>5540 6239 00</td>
<td>M20</td>
<td>10,9</td>
<td>365</td>
<td>151 700</td>
</tr>
<tr>
<td></td>
<td>Loadframe</td>
<td>5540 6239 00</td>
<td>M30</td>
<td>10,9</td>
<td>365</td>
<td>151 700</td>
</tr>
<tr>
<td>ST14</td>
<td>Powerframe</td>
<td>5540 2801 00</td>
<td>M30</td>
<td>10,9</td>
<td>1253</td>
<td>347 900</td>
</tr>
<tr>
<td></td>
<td>Loadframe</td>
<td>5541 0656 00</td>
<td>M30</td>
<td>10,9</td>
<td>1253</td>
<td>347 900</td>
</tr>
<tr>
<td>ST1520</td>
<td>Powerframe</td>
<td>0147 1963 65</td>
<td>M30</td>
<td>10,9</td>
<td>1253</td>
<td>347 900</td>
</tr>
<tr>
<td></td>
<td>Loadframe</td>
<td>5541 0656 00</td>
<td>M30</td>
<td>10,9</td>
<td>1253</td>
<td>347 900</td>
</tr>
</tbody>
</table>

Table 8

Relevant information from customers

Service reports

The database for service reports were searched for failure reports by running the Atlas Copco article number for trunnion bases, trunnion caps, bolts, pins and steering cylinders for all vehicles. The reason for running the number for the steering cylinder is that if the trunnion cap or the bolts to the trunnion cap brakes it is likely to think that even the cylinder might take damage.

When the article numbers are searched the hits are few and in the database for unsolved or new failure reports only three reports were found, all were related to steering cylinders. One report was for MT6020 and two for ST1030, they were all about oil leakage in the cylinders.

In the archive there were more hits but still all of them except one were related to steering cylinders and concerned oil leakage in the cylinder or problem with seals.
The single failure report (report number: CHLR77GQEHH) which did not concern leakage and were the word “trunnion” is mentioned belongs to a ST1030. The report were found when the article number “5580 0042 58” was searched, and it had the following problem description:

“In this cylinder, the piston rod is flexed lightly caused by the cut of the screw of the trunnion the front zone (in load frame). the operator has problem with steering movement very slow, he stops the machine and he observes that the cylinder this damage and the screws of the cut trunnion. The customer repaired the cylinder to put the machine again due to that does not have the resources in the mine to change it for another. Besides it requests us to replace cylinder for one new.”

Since no other information or attachments are found in the failure report and due to the poor description it is not possible to conclude what the initial reason to the failure was.

Customer centres
To find any information that might not have been reported to the database for service reports the technical service department at Örebro asked the following persons if they were aware of any occasions where either the steering trunnion cap or bolts holding the caps have broke down on any machine in their region

- Jose Flores, Regional responsible South America
- Cesar Angeles, Warranty coordinator Peru
- Jim Carrol, Regional responsible Asia
- Dale Harnish, Service Manager USA
- Richard Lotheringen, Training Manager South Africa
- Marc Vancaillie, Service Manager Zambia
- Sukanto Chattopadhyay, Service Manager India
- Shao Fu Wu, Service engineer China
The following answers are received before the end of the thesis:

**Dale Harnish:**

“I am not aware of any trunnion cap problems in recent years. Most of the old problems had to do with the bolts not being properly torqued by relying on impact wrenches rather than torque multipliers. Once the mines were convinced that they needed torque multipliers, that problem went away.

Another problem was that the caps had to be pulled down evenly. If one side was tightened up too far, the bolt in the other side was put in a bind and gave a false torque reading. This problem was solved by education on proper tightening of the caps. I have never seen anything in the service manuals telling proper tightening procedures on the caps. It probably should be there somewhere.

In my area, the customers like the trunnion caps. I like them especially for tear down. They are much easier to remove after a long time, than the colleted pins. Being able to buy pre machined trunnion caps has also eliminated the problem of not being able to replace lost or damaged trunnion caps easily.

I like trunnion caps and want them to stay. I feel it gives us an advantage over the competition.”

**Richard Lotheringen:**

“Throughout RSA and Africa, I see this from time to time on steering cylinders, but I would say it is due to poor maintenance, being a combination of not checking / tightening bolts properly - using incorrect bolt grade etc.

On st 1030’s for instance you will not find any units in Africa without bucket problems, relating to the CAP bolts not being torqued with a torque multiplier.”

**Sukanto Chattopadhyay via Subir Karmakar:**

“Except accidental failure, no such failure of steering trunnion cap or bolts holding the caps observed in our region.”
Safety factor for bolts

The safety factor for each bolt and frame are calculated by using the formula from the “General Bolted Joint Design” mentioned in the chapter “Work method”. The results are given in appendix 39. The information of the quantity of bolts for each trunnion cap assembly is given too (note that the power-frame for MT5020 and MT6020 is the only frame were eight bolts are used to the trunnion cap).

The safety factor is calculated for the extension force as well as for the retraction force although the bolts never are exposed to the whole extension force in these installations. The safety factor is well above the recommended value for all frames except for the load-frame to MT5020 and MT6020 at the extension force.

Tolerances for pins and holes

The tolerances for the pins and the holes are found by using the method described in the section “Work method” and the results are given in table 9.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Frame</th>
<th>Frame article nr (assembly)</th>
<th>Hole diameter in trunnion cap (mm)</th>
<th>Pin article nr</th>
<th>Pin diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT436B</td>
<td>Powerframe</td>
<td>5575 7018 78</td>
<td>63.50 - 63.53</td>
<td>6571 1313 00</td>
<td>63.40 - 63.43</td>
</tr>
<tr>
<td></td>
<td>Loadframe</td>
<td>5571 1283 90</td>
<td>63.50 - 63.53</td>
<td>5571 1313 00</td>
<td>63.40 - 63.43</td>
</tr>
<tr>
<td>MT5020 and MT6020</td>
<td>Powerframe</td>
<td>5590 0061 36</td>
<td>76.07 - 76.12</td>
<td>6690 0006 76</td>
<td>76.12 - 76.20</td>
</tr>
<tr>
<td></td>
<td>Loadframe</td>
<td>5574 9808 00</td>
<td>76.10 - 76.15</td>
<td>6690 0006 76</td>
<td>76.12 - 76.20</td>
</tr>
<tr>
<td>ST1030</td>
<td>Powerframe</td>
<td>5580 0073 76</td>
<td>50.68 - 50.70</td>
<td>5580 0065 67</td>
<td>50.75 - 50.80</td>
</tr>
<tr>
<td></td>
<td>Loadframe</td>
<td>5575 7009 56</td>
<td>50.66 - 50.71</td>
<td>5580 0065 47</td>
<td>65.17</td>
</tr>
<tr>
<td>ST14</td>
<td>Powerframe</td>
<td>5580 0084 63</td>
<td>64.95 - 65.05</td>
<td>5580 0024 90</td>
<td>65.17</td>
</tr>
<tr>
<td></td>
<td>Loadframe</td>
<td>5580 0021 54</td>
<td>64.84 - 64.91</td>
<td>5580 0024 89</td>
<td>65.17</td>
</tr>
<tr>
<td>ST1520</td>
<td>Powerframe</td>
<td>5575 7004 11</td>
<td>63.35 - 63.45</td>
<td>5580 006474</td>
<td>63.45 - 63.50</td>
</tr>
<tr>
<td></td>
<td>Loadframe</td>
<td>5575 7014 21</td>
<td>63.35 - 63.45</td>
<td>5580 0064 67</td>
<td>63.45 - 63.50</td>
</tr>
</tbody>
</table>

Table 9

As shown in table 9 the different designs of trunnion caps do not follow any kind of guideline or at least not the same one. While the solution for the frames to MT436B only consists of loose fittings the solution for the frames to ST1520 consists of tight fittings. For the vehicles ST1030, ST14, MT5020 and MT6020 the solution differ between the load-frame and the power-frame, the reason of that has not been investigated.
Availability of different bolts

Bolts with different surface treatment are available on the market but for bolts with a property class (grade) of “10.9” Atlas Copco uses a surface treatment named “flZnmc-480 h” and for bolts with a property class of “8.8” the surface treatment “FZB” is used\textsuperscript{12}. According to the document “General Bolted Joint Design” appendix 1 bolts with the property class “8.8” should be used as far as possible, but on all vehicles the thesis investigates bolts with a property class of “10.9” has been used to the trunnion caps. Therefore a table of lead time for bolts with both property class “8.8” and “10.9” has been created, see appendices 40 and 41.

The bolts were found in the GSD-database as described in the section “Work method”, the article numbers were noticed as well as the grade of recommendation which is found next to the article number under the heading “SG”. The number “1” means that the article is recommended to use, while the number “2” means that the article should be used only restrictively, worth noting is that every bolt searched in the thesis with a property class of “10.9” should be used restrictively according to the GSD-database. When all the wanted article numbers were found the lead time was found by running every number in the command ”mms002” in “Movex Explorer”.

In general, the lead time for bolts with the property class “8.8” is less than the time for bolts with property class “10.9”.

\textsuperscript{12} Johan Ericsson
Discussion and further recommendations

MT436B

During the identification of all parts of the vehicles it was discovered that, on the steering cylinder installation, named “5573 2647 00”, for MT436B there are no instructions on how to assemble the pins to the frames regarding the hole in the radial direction. In the installations from all the other vehicles there are instructions on how to assemble the pin and the pin is always rotated so that the hole is placed where the pin is exposed to the minimum bending loads.

As mentioned in the results, the assemblies to the FEA are assembled so that the hole in the radial direction is pointing in a 90 degrees angle from the direction of the bolts in the trunnion caps. It would be interesting to see what differences in stresses in the pin that might occur if the pin is rotated in another direction.

Regarding the placement of the hole in the radial direction a solution similar to the pins to the Scoop Trams could be used to minimize the risk of assembling the pin incorrectly. The pins to the Scoop Trams have a plate either welded or bolted on top of the pin. Most of the plates have a geometry that looks like a flat cylinder where a part of the circumference is chamfered; see figures for pins in the results.

MT5020 and MT6020

When I looked at a manufactured power-frame for MT5020 and MT6020 I discovered that, the trunnion cap named “5590 0002 97” did not look the same in the reality as on the drawing in appendix 10. In fact the drawing is a bit unclear at some points, for instance the information “MIN R25 (4X)” shown in the area “D3” at the drawing specifies the minimum radius but not the maximum. The manufactured trunnion cap does not even have a radius, see figure 65.

The question is how much this affects the deformation and stresses in the trunnion cap, but in the end it is a matter of quality, does the supplier supply what is asked for.

As well as the pins for the trunnion cap assembly to MT436B the pins to MT5020 and MT6020 can be optimized to reduce the risk of incorrect assembly.
The FEA
Since the FEA not is finished by the end of this thesis the results from there should be investigated to see if it is possible to conclude which angles of the force acting from the steering cylinder that might be preferred. Especially it is interesting to look at the analyses of MT5020 and MT6020 because of the different solutions of trunnion caps on the load- and the power-frame.
Is it preferable to use smaller and more bolts instead of larger and few?
Do the stresses in the bolts increase or decrease more in any of the two solutions?
Is it possible to find out something more from the FEA results?

In the thesis no calculations of stresses in the trunnion caps have been made, but if someone would want to check the reliability of the results from the FEA such calculations should be performed.

Information from customers
Some of the information given in the specification for this thesis indicated that, it has been several times where trunnion caps or bolts to trunnion caps have broken. In the database for service reports no such information where found and the answers given from the people at different customer centres indicates that there have been problems but that they were caused by poor or incorrect maintenance. But since only three answers arrived before the end of this thesis it would be incorrect to make any conclusions even if the reports and answers so far indicates that there are no problem with the trunnion caps today.
**Tolerances for pins and holes**

As shown in the results there are different tolerances both between vehicles and sometimes even between the power- and the load-frame for the same vehicle. In order to know what ISO tolerances suit this kind of design better, more investigations should be done.

What is interesting with the solutions that used a loose fitting is the question of what happens with the trunnion base and the pin when pretension to the bolts is applied. Known from earlier studies and from assembling is that a deflection of the trunnion cap will occur, but the trunnion base is welded to a plate at its edges and therefore the possibility of deflection is limited.

There are at least two questions that need answers in a further investigation of tolerances for pins and holes:

- Will it still be a gap between the pin and the trunnion base after pretension of the bolts if a loose fitting is used?
- If there is a gap after pretension of the bolts how does this affect the bolts when forces from the cylinder are applied in different angles?

In the FEA all dimensions for the holes in the trunnion cap assemblies have been changed, so they have the same dimension as the pin for each assembly.

**Fatigue failure**

An issue that has not been regarded in this thesis is the fatigue failure of the different trunnion cap assemblies. In order to investigate after how many load cycles the bolts or the trunnion caps will fail, it would be necessary to measure and use the pressure that mostly occurs in the steering cylinder. The maximum pressure only has a possibility to occur in very special situations such as when the vehicle for example hits a rib. This kind of measurements could take place in different environments that the vehicles act in. There is one report found where the steering pressure is measured on a MT5010 (the MT5020 predecessor) with three different load cases and where the vehicle stands on asphalt. The Atlas Copco document number is “TD2006-0138”.

Similar measurements could be performed for the other vehicles and perhaps on a different ground.
Other issues

The bolts used in the trunnion cap assemblies are specified with one Atlas Copco article number in “Pro/ENGINEER” and for some assemblies another article number in “DEMO/TPX”. The vehicles and frames where the article number differs are:

- MT5020 and MT6020, load-frame (“0147 1960 26” in “Pro/ENGINEER” and “5541 0386 00” in “DEMO/TPX”).
- ST1030, load-frame (“0147 1963 56” in “Pro/ENGINEER” and “5540 6239 00” in “DEMO/TPX”).
- ST14, load-frame (“0147 1963 65” in “Pro/ENGINEER” and “5541 0656 00” in “DEMO/TPX”).

The differences between the specified numbers in “Pro/ENGINEER” and “DEMO/TPX” only concern the surface treatment, the size and grade is still the same. The bolts that are specified in “Pro/ENGINEER” all have a surface treatment of “oiled ag corr” while the bolts specified in “DEMO/TPX” have a surface treatment of “flZnnc-480 h”.

In the trunnion cap assembly to the power-frame to ST1520 a bolt with the Atlas Copco article number “0147 1963 65” is used in both “Pro/ENGINEER” and “DEMO/TPX”. The bolt has a surface treatment of “oiled ag corr” and can be found at position 31 in an assembly with the article number “5575 7004 11”, the same position (31) is used even for another article. Since all bolts with the property class 10.9 should have a surface treatment of “flZnnc-480 h”12 this one should be switched.
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Retrieved 2011-06-13

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