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Industrial Electrical Engineering and Automation

Master Thesis on
Fast Charger Connector Solution

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Abstract

Volvo Construction Equipment are investigating new machine concept that involve fast charging with high power. This should be done automatically and independent on humans. The thesis set out to develop and design a complete system solution for this, including the connector and the automated system for connection. The thesis is based on previous projects presented at LTH in various mechatronics courses.

An analysis is done over the application in question. Specific details are not mentioned due to secrecy. The result of this work is that a single flexible arm is to be used, with one actuator. Mounted on this arm is the male connector. The flexible arm is guided, when extending, by a funnel leading to the female connector which is mounted on the vehicle side. The automated system is only developed as a concept due to limitations in time and resources.

The methodology used for the development of the connector is based on Ulrich and Eppinger's well renowned methodology for product development. From the application analysis it is decided that a plug-in connector is to be used. A final working prototype of the connector is developed and manufactured. Compared to the prototype previously presented at LTH in another project it is much smaller, around 50% in diameter. This is possible since a new concept is used for the male connector. The length and diameter of the male connector is ~20 cm and ~5 cm.

The prototype connector is tested for various current levels measuring the temperature in different critical places within the connector. The objective of the testing is to find at what current the connector levels out at a stable temperature around 100 degrees Celsius. This is found at 200A. This implies that it is possible to transfer 138 kW when charging with 3 phases AC and 400 V is done, and 512 kW when charging 2 phase DC with 640 V is done.

Sammanfattning

Volvo Construction Equipment undersöker nya maskinkoncept som innehåller snabb laddning med hög effekt. Detta ska genomföras automatiskt, självständigt från människor. Uppsatsen går ut för att utveckla och designa en komplett systemlösning för det här, vilket inkluderar kontakten och det automatiska systemet för kontaktering. Uppsatsen är baserad på tidigare projekt som är presenterade på LTH inom flera mekatronikkurser.

En analys görs över applikationen i fråga. Specifika detaljer nämns inte på grund av sekretess. Resultatet av det här arbetet är att en flexibel arm ska användas, med en aktuator. Monterat på denna arm är han-kontakten. Den flexibla armen guidas, när den sträcks ut, av en tratt som leder in till hon-kontakten som är monterad på sidan av fordonet. Det automatiserade systemet utvecklas endast som ett koncept på grund av begränsningar i tid och resurser.

Metodologin som används för utvecklingen av kontakten är baserad på Ulrich och Eppingers välkända metodologi för produktutveckling. Från analysen om applikationen bestäms det att en plug-in kontakt ska användas. En slutgiltig fungerande prototyp av kontakten utvecklas och tillverkas. Jämfört med den tidigare presenterade prototypen på LTH i ett annat projekt är den mycket mindre, runt 50% i diameter. Detta är möjligt eftersom ett nytt koncept är använt för han-kontakten. Längden och diametern på han-kontakten är ca 20 cm och 5 cm.

Prototypkontakten testas för flera strömstyrkor med fokus på temperaturen på olika kritiska ställen i kontakten. Målet med testningen är att hitta en ström för vilken temperaturen i kontakten stabiliserar sig på runt 100 grader Celsius. Den hittas på 200 A. Detta implicerar att det är möjligt att överföra 138 kW när laddning med 3 faser AC och 400 V genomförs och 512 kW när laddning med 2 faser DC och 640 V genomförs.

Acknowledgements

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I want to thank Mats Alaküla, Bobbie Frank for the possibility to continue working on a project I had already been a part of. It has been a great experience to develop a connector like this without any real equality in today's industry. Aside from my supervisor at Volvo CE I would also like to thank Joakim Unnebäck and Chongchul Kim for their input and help during visits in Eskilstuna and over the telephone, our discussions has been essential for my work. Thanks is also given to Bengt Simonsson and Getachew Drage, research engineer at LTH, for all help through discussions and hands on work during the project.

Lund, September 2016

Sebastian Palm

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1 Background and introduction

Volvo Construction Equipment (Volvo CE) are investigating a new machine concept that involve fast charging with high power. This should be done automatically and independent on humans. The application is classified, though the connector and the automated system for charging is not.

In today's industry there are a few examples of automated charging with high power. Though this area is quite unexplored. The range of power and size for the connectors in these examples are very limited. Few of the examples are designed with a broader market in focus. Some can only be used for one or maybe two scenarios, for example two different buses, but if a vehicle of different size should be used a new system would be needed.

With the electrification taking place in today's society there is a prominent advantage of having a low cost, simple, and flexible solution for automated fast charging. The solution should not rely on a specific vehicle and its capacity, neither on its size and geometry. Though to make the robotics and automation process simple, it could be an advantage to use the concept of automated driving for the electric vehicle and its possibilities.

At Lund University, Faculty of Engineering (LTH), several projects are already performed. This thesis will be based on some of them [1, 2, 3]. In these projects a connector prototype is tested and proved to work for currents over 300A, though the size and weight are not within the limits for Volvos application.

Fast charging is today one of the possible ways to go when trying to electrify heavy vehicles. The main problem with the electrification is the batteries and the size of them. If for example a truck is supposed to be fully electric it cannot justify having batteries for a full day of driving. There are a few solutions for this and one is fast charging, another is electrified roads. It is impossible to predict the future, but even if electrified roads is the best alternative these will not be up and running all over the country for a long time. This means that there is a need for a faster solution, fast charging. The idea is that if it is possible to charge for example a city distribution truck at every stop during the day the batteries can be designed much smaller since there is only a need to have enough energy in the batteries to get to the next stop. This system must be implemented without any extra stop time to make it economically justifiable and thus there is a need for fast charging.

1.1 Hypothesis

It should be possible to make a simple, low cost, and manufacturable connector, that carry currents over 300 A and is flexible both for AC and DC charging. It should also be possible to create an automated system with this connector that is fast, low cost, simple, and redundant.

1.2 Objectives

The outcome of the thesis should be a connector that fits on the targeted load receiver and that is possible to connect, but not charge. The connection should be solved as well. The cost of the complete system with connector and insertion device should be kept as low as possible due to the many charging points needed.

2 Concepts

2.1 Method

This thesis is not presented or performed according to one single method of product development. Several different methods are applied on the various areas. The methods are chosen due to the needs of the different areas. Ulrich and Eppinger (U&E) [4] describes a very thorough methodology though it is not perfect for all situations. It usually aims for an improvement of a product of around 20%. Since this thesis should take into account even the solutions very different from the ones in the industry and maybe completely new concepts some changes is made to the original Ulrich and Eppinger methodology.

2.1.1 **Requirements**

First demands and objectives are assembled. This is done by discussions with Bobbie Frank, Joakim Unnebäck, and Chongchul Kim from Volvo CE and Bengt Simonsson and Mats Alaküla from LTH. These demands are translated into measurable units by using the U&E methodology. The reason for this is to make it possible to evaluate the different concepts in screening and scoring processes.

2.1.2 **The cycle and network optimization**

The drive cycle is provided by Volvo CE. The first limitations are established and requirements discussed with Volvo CE and the supervisors. The batteries, costs regarding the network, limitations, regulations, already performed work on the cycle is performed, and etc. are studied. A simple network optimization matrix is created to calculate the best solution for placement and amount of charging stations. The final placement is decided based on the network optimization and on discussions with Volvo CE and supervisors.

2.1.3 **Concept generation**

The concept generation is divided into separate areas. One searching and evaluating the industry and the already existing concepts. One generation process focusing on the separate problems of the complete system and from this generating new or applying known solutions to these problems. From this combining different solutions into concepts for the system. One generating combinations from all the concepts.

2.1.4 **Concept screening and scoring**

To decide what concept is superior to the others a screening process is done, followed by discussions and further evaluation regarding each concept. When only a few concepts remain a more thorough scoring is performed, weighing the different properties by importance for success. The choice of final concept is made based on the scoring matrix, experience and discussions.

2.2 Requirements

Table 1 below shows a translation from statements made by Volvo to measurable units used for evaluation of the generated concepts. This method is taken from the well-known product development process described by U&E.

Table 1 Showing statement transformed to measurable unit

Statement	***Nbr***	***Requirement***	***Unit***
Connector should be able to handle 200 kW both AC and DC power.	1	Connector should be able to handle 200 kW without damage.	Binary
	2	Connector should have 3 phases, 1 ground, and 1 neutral.	Binary
Somehow the connection should be secured before full power is allowed.	3	Communication is needed through connector and/or wireless.	Number of communication possibilities
	4	Connector needs to comply with regulations and standards regarding high current connectors.	Binary
The lifespan of the system should be very long, at least 4 years, with small need for maintenance.	5	150'000 connections per vehicle, 1'000'000 connections per station. Leads to demands on no/very little damage per connection.	Number of connections without maintenance
The environment is very rough.	6	No problems should be related to the heavy duty environment. Mud, dust, temperature from -30 to 45 degrees Celsius, rain, and snow.	Binary
The accuracy of the vehicle is +/- 2,5 cm.	7	The system should be able to connect when vehicle is within +/- 2,5 cm of the thought position.	Binary
No pneumatic system on the vehicle but maybe at station.	8	No requirement on pneumatic system on vehicle	Binary
Connector placed at free area of vehicle, not possible to move already existing components.	9	Connector should be mounted either on front, back, under or on the sides of the vehicle.	Placement on vehicle
The connector need to get smaller.	10	The connector station is easily installed, without mayor changes to the surrounding.	Time
	11	The connector station is easily installed, without mayor changes to the surrounding.	Cost

	12	The connector on the vehicle should take up little space on the vehicle.	dm^3
The vehicle can move in a way that free area under/front/back can get very close to a target, sides can get around 40 cm from the frame.	13	The connector is mounted so that either it is easily accessible from front, back, under or sides (40 cm from the frame).	Time
The cycle-time is around 6 min, gives a charging window of 1 min. If two stations 2 min.	14	The station should be able to connect and disconnect within 10-15 seconds.	Binary
Connector must comply with regulations regarding accessibility to possibly powered connectors.	15	Connector must apply with regulations regarding accessibility to possibly powered connectors.	Binary
The system cost should be kept as low as possible.	16	The cost should be as low as possible for the whole system.	Price
The system should be simple.	17	The system should have as low amount of moving parts as possible.	Number of moving parts
	18	The system should be easy to maintain.	Time

2.3 Previous work

In previous projects on this area, at LTH, a prototype is developed and tested for currents well over 300A, see Figure 1. Three of the projects [1, 2, 3] present work done all the way through the product development process. Everything from theoretical work to concept development, prototyping, and testing is documented. Though the thought application is not the same as for Volvo CE, therefore most of the work cannot be directly used in this thesis.

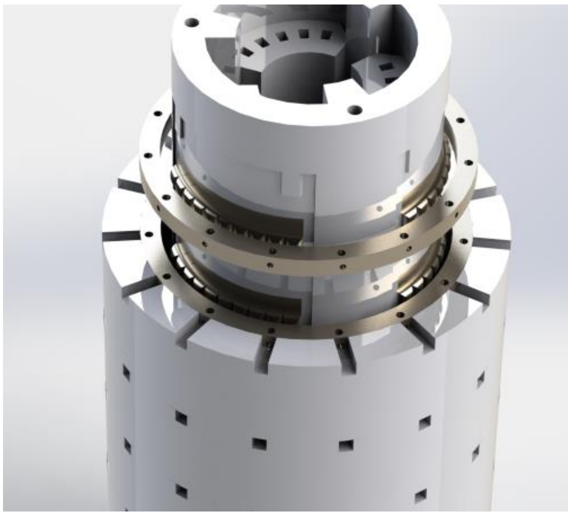

Figure 1 Illustration of previous prototype model

2.3.1 **Applicable for the thesis**

Regardless of the difference in applications between this thesis and the previous projects, the theory behind the connector and its features is the same. There is a need of a connector capable of transferring at least 300 A continuous current without developing heat levels that is damaging to the surrounding systems or to the connector itself. No electrical arcs should occur at any time for expected voltage levels.

One very important area when it comes to high current connectors is the need to ensure a good connection with low resistance. If the connection is faulting, excessive heat will be generated and not least the connector and its systems will take damage. There is no specific goal in resistivity set from Volvo CE. Though the thermal situations should not affect the system in a damaging way.

To keep the resistivity low and thereby the temperature, the connection between the male and the female phase must be secured no matter what circumstances. As mentioned in the previous project [1] a bigger surface does not necessarily mean a better and more secure connection. Partly due to a-spots, but also since a small stone located between the surfaces would either damage the phases and/or cancel out most of the contact area for the phases. Arguably this could cancel out a large portion of a phase without making the connection impossible. If that's the case it would lead to a heat generation much stronger than expected.

The solution presented in the report [2] for the problem of securing connection in different situations is to have one phase with an almost flat surface and one built up by individually flexible knobs. This is a good solution for this particular problem, though in a manufacturing point of view it is a nightmare. To individually connect 27 small knobs for each phase mounted in a frame is not possible without having a lot of manual labour. It should be possible to alter the design but keep the concept and thus make it more suitable for Volvo's application.

By using this solution to ensure the connection between the phases, a mechanical lock is also achieved. This due to the flat surface being slightly concave. The required force to pull out the plug when active is high. This is due to the pneumatic plug inducing a force of around 10N per knob when loaded with 3 Bar. To withdraw the connector the plug must be emptied, or the force needed to withdraw the connector would probably damage the connector.

The robotic arm presented as a final solution in the previous project is a SCARA-type robot. This robot is quite advanced and is overqualified for the application. It would be too expensive to use a robot like SCARA, though for the concept some parts and features might be used. A completely new concept for the automation is performed in the thesis.

2.4 Concept generation

The concept generation method is already described in the method chapter, though only the complete concepts is presented here. This is due to limit the size of the report and to keep the focus of the report on the bigger perspective. Short descriptions of all the concepts follows below.

In all concepts using plug-in connector, except for concept 1.G, the female connector is flexibly mounted within a housing permitting it to adjust for misalignment together with malposition in relation to the male connector. In the concept generation it will only be referred to as the female connector.

2.4.1.1 1.A

Plug-in connector mounted for vertical insertion on an extendable arm. The arm is mounted on a rotating plate to be able to insert the connector in a protective case when not in use. At least two actuators are needed for the arm. The male connector is mounted on the station and the female at the vehicle. A protective removable cover is mounted on the female connector which protects from dust, mud, and etc. See Figure 2 for illustration.

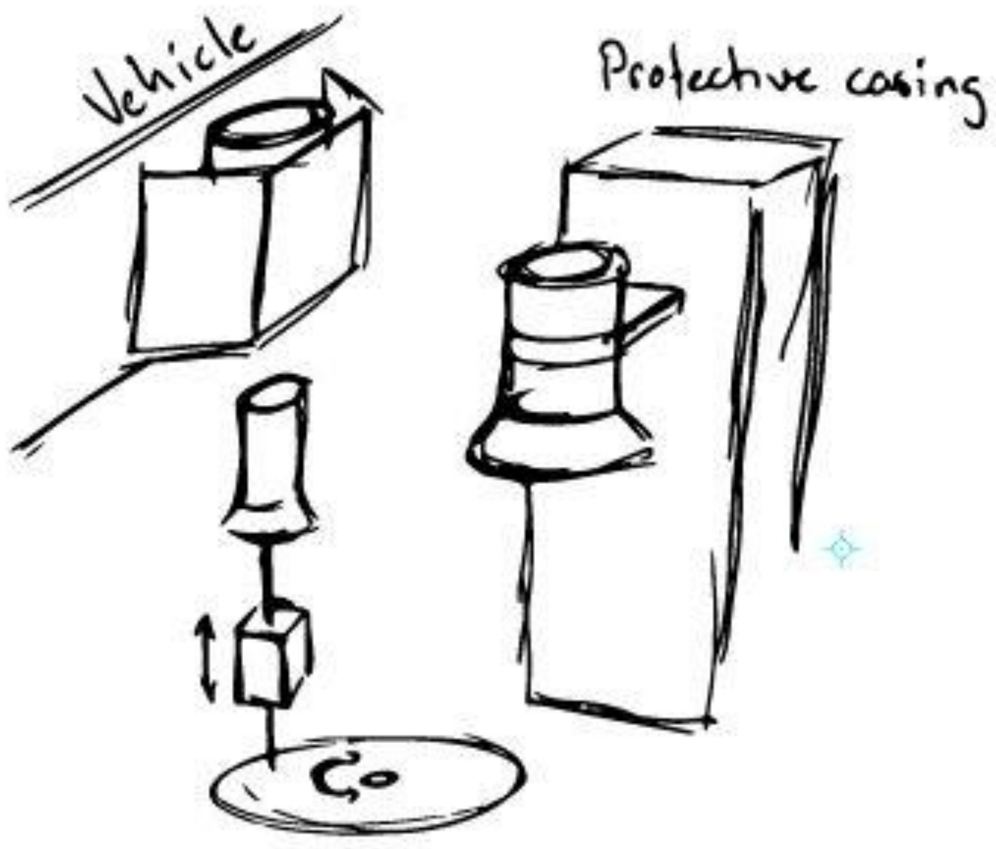

Figure 2 Illustration of concept 1.A

2.4.1.2 1.B

Plug-in connector mounted for vertical insertion on an extendable arm. When not in use the whole arm is hidden in a house for protection. A hatch is opened mechanically when the arm extends. At least one actuator is needed. The male connector is mounted on the station and the female connector on the vehicle. Like in concept 1.A the female connector has a removable cover for protection. See Figure 3 for illustration.

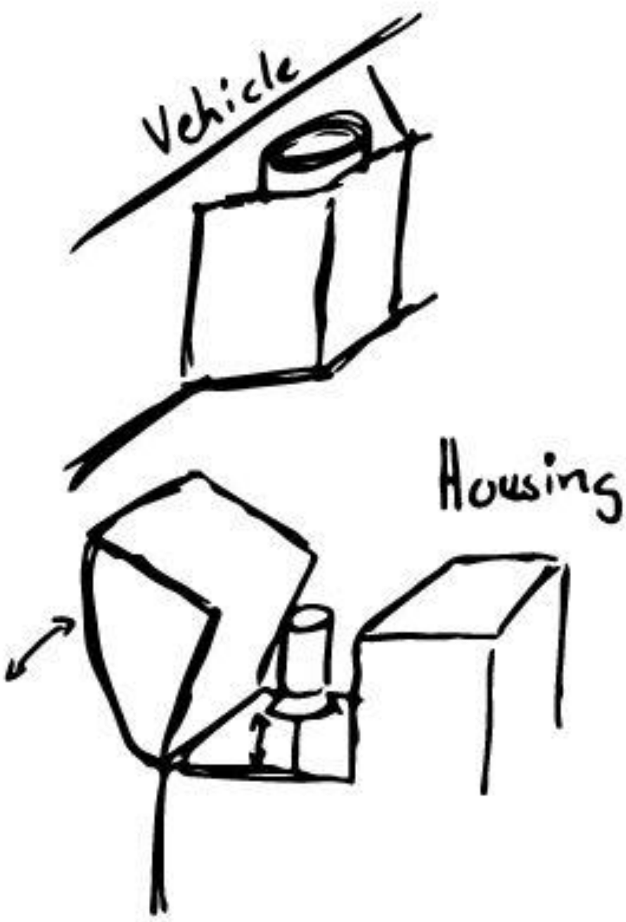

Figure 3 Illustration of concept 1.B

2.4.1.3 1.C

Plug-in connector mounted for horizontal insertion on a fix station. This concept uses the vehicle as actuator. The female connector is mounted on the vehicle and the male connector on the station. A removable cover is used for protection on the female and a mechanically retractable housing is protecting the male connector. See Figure 4 for illustration.

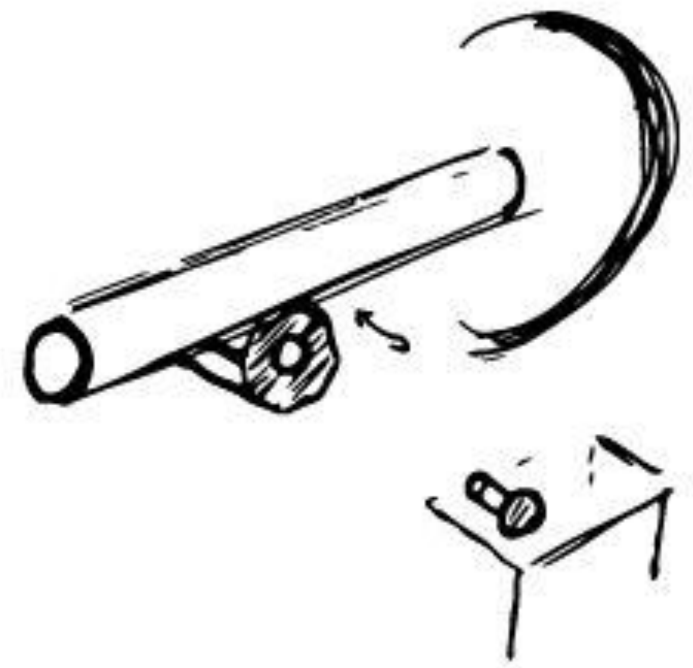

Figure 4 Illustration of concept 1.C

2.4.1.4 1.D

This concept also uses the vehicle as an actuator as concept 1.C does. Though the concept for the connector is not a plug in connector. There is 5 independently flexible spring loaded phases, constructed like blocks, in a row. The vehicle drives up to and pushes the female against these blocks and then hold the pressure. As protection some kind of retractable housing and/or brushes should be activated before connection is attempted. See Figure 5 for illustration.

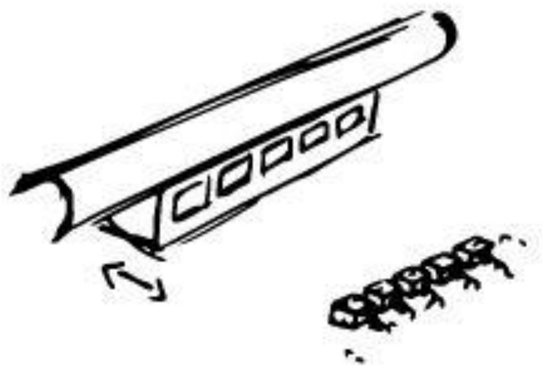

Figure 5 Illustration of concept 1.D

2.4.1.5 1.E

The vehicle has a feature called crab walk which means that it is possible to drive forward at an angle around 20 degrees. This concept uses this feature by having the vehicle approaching at a 20 degree angle, driving all the way until full connection is acquired with the plug-in connector. Then leaving by still driving forward but at an angle of 20 degrees in the other direction. The female connector is mounted on the vehicle, with a possibility of turning around an axis. A spring and a dampener is connecting the connector to the frame and ensures that it goes back to the original position after disconnection. The male connector is mounted in the same way but on the station. There will like in the other concepts be need of a protective housing for the male and a removable cover for the female connector. See Figure 6 for illustration.

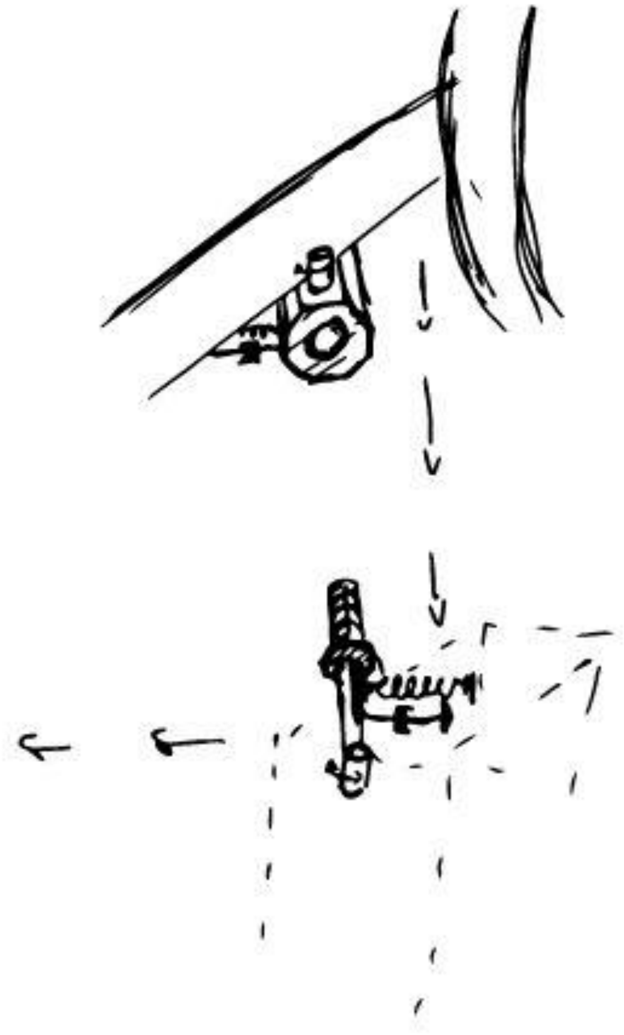

Figure 6 Illustration of concept 1.E

2.4.1.6 1.F

Like concept 1.E both the male and female connector are mounted with a spring and a dampener on with possibility for turning around one axis each. Though the connection is made under the vehicle. The female connector which is mounted under the vehicle collects the male counterpart when driving over the station. When connection is made the vehicle stops for charging and continues forward once charged sufficiently. The connector parts returns to their original position when disconnected. A sliding protection is covering the station when not in use, this is either mechanically removed when the vehicle passes over or removed with an actuator. The female connector has a protecting cover at its opening. See Figure 7 for illustration without the protective cover. It shows the connection and disconnection in three steps, one when the vehicle is approaching, one when charging is done, and one when the vehicle moves away.

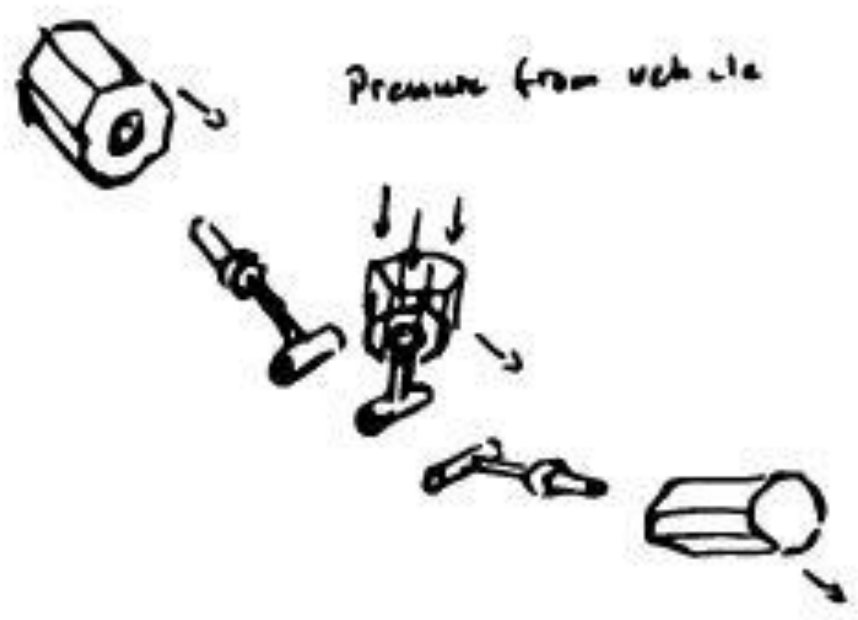

Figure 7 Illustration of concept 1.F

2.4.1.7 1.G

This concept is much like an already existing solution in today's industry from Staubli [5], though smaller and simpler. It is a plug-in connector mounted on an arm with two flexible sections. These flexible sections is permitting the same misalignment and malposition as the flexible mounting of the female connector does, in the other concepts. The female connector is mounted on the vehicle and the male connector on the station. The robotic arm need at least one actuator to connect with the vehicle. A retractable housing with a removable cover for the opening protects the male connector when not in use. A removable cover for the opening of the female connector is protecting it when not active. See Figure 8 for illustration.

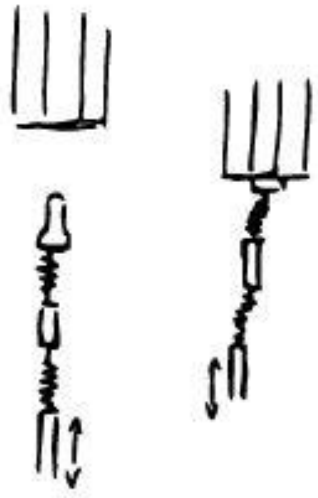

Figure 8 Illustration of concept 1.G

2.4.1.8 1.H

This concept is used by Alstom [6] the connection is made under the vehicle. Like concept 1.D it is no plug in connector, it is simply a few plates located in a row. They are mounted on an automated arm under the vehicle able to move down and up. The female is also very simple with plates located in the same order as for the male connector. There is no extra spring function, the only pressure built up is by the arm. Some protection needs to be implemented to ensure that the phases are kept clean before connection is made. See Figure 9 for illustration.

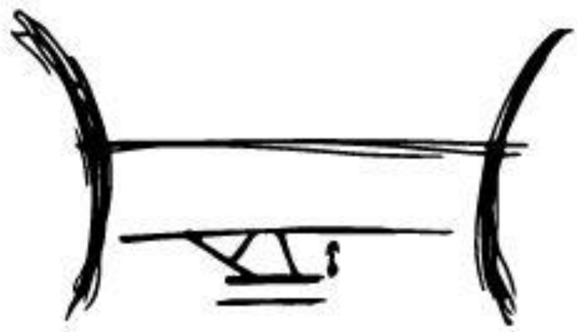

Figure 9 Illustration of concept 1.H

2.5 Concept screening

In this chapter the screening process and its results are presented. For the U&E method of screening to work, a reference concept is chosen. It can for example be a standard concept from today's industry, not the best or the worst, but a concept from the middle segment of performance. This present itself as a minor problem in cases where no real market is available. Though a reference concept is chosen. 1.H is chosen due to its simple function and since it actually is a viable option in the industry.

All concepts is compared to the reference concepts one by one. They are compared based on the requirements stated by Volvo. 0 mean that the concept at hand is about equal to the reference, "+" mean that the concept at hand is better than the reference, and "-" mean that the concept at hand is worse than the reference. Each concept gets 1 point for a "+" and -1 point for "-" and the total point is presented at the bottom of table. The screening table is presented in table 4.

The screening matrix result is seldom definite. Concepts tend to score good at some requirements and bad at some, resulting in many concepts scoring quite similarly. Therefore a discussion is needed. Each concept is weighed against each other regarding both by the performance in the screening process and by the experience of the student. The discussion of the concepts is presented after table 4.

Table 2 Showing the screening matrix

Req. Nbr	***1.H***	***1.A***	***1.B***	***1.C***	***1.D***	***1.E***	***1.F***	***1.G***
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	-	-	-	0	-	-	-
6	0	+	+	-	0	0	0	-
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	-	-	0	0	0
11	0	+	+	+	+	+	+	0
12	0	+	+	+	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	+	0	+	+	0
15	0	0	0	0	0	0	0	0
16	0	0	0	+	+	+	+	+
17	0	0	+	+	+	-	-	0
18	0	0	0	0	+	+	+	+
Sum	**0**	**2**	**3**	**2**	**3**	**2**	**2**	**0**
Develop	**No**	**No**	**Yes**	**Yes**	**Yes**	**No**	**Yes**	**No**

2.5.1.1 1.H

The reference in the screening is one of the better concepts presented on the market today. It's not the perfect reference concept, but it's the best alternative. This is due to a lack of alternatives. There are not many connectors which fit the application in mind, designed for around 300 A and still staying small. This might result in the screening process not being optimal.

2.5.1.2 1.A

This concept requires at least two actuators, one turning the robot into position and one to insert the connector. Instead of a turning plate on the bottom it would be possible to use a rail instead since it's not the turning motion that is important but the movement closer to the vehicle. One problem is how to make sure the turning-plate or rail is operational in the very rough environment. The station should not require the vehicle to use the crabwalk to be able to connect. It should only drive straight in and continue forward or back out when charged. This might imply that the vehicle have to drive over parts of the station depending on the design. This concept is not developed further.

2.5.1.3 1.B

In relation to 1.A this concept takes more advantage of the precision of the vehicle. There is one actuator to insert the connector. Flexibility can be created both in male and female. This concept is more reliable than the previous one. Should be quite easy to create a working protection to the station without introducing any more actuators. This concept requires either that the female connector is mounted on the front or the rear of the vehicle. If mounted on the side crabwalk motion is needed since the female connector cannot be mounted outside of the wheels. This concept is developed further.

2.5.1.4 1.C

This concept is without any actuators on the station. One problem with the design of this concept is to secure no harm comes to either part of the connector due to the environment. The concept requires the female connector to be mounted on the front or rear of the vehicle. There is a possibility to mount either the male and female with flexibility or both. There is a need to study the possibility of mounting the female connector so that the vehicle can move close to the station without hitting it, also the possibility of making sure it is possible to only use the vehicle as actuator. This concept is developed further.

2.5.1.5 1.D

Like concept 1.C this has no actuators but uses the vehicle instead. Unlike 1.C this concept does not have a plugin contact that is rotationally symmetrical. Instead a completely new design for the connector is needed. The concept is actually quite similar to the reference but no arm is needed for the connection. One major problem is to make sure that the connector is clean. The rough environment poses a real problem for this concept. No harm can come to the system or the vehicle if the vehicle misses the connector when driving towards the station. Like concept 1.C the placement and function needs further studies. This concept is developed further.

2.5.1.6 1.E

This concept solely uses the vehicle as actuator. This concept allows the vehicle to come in from one direction and continue in the same direction when finished charging by using crab walk. Though the concept does not only allow this, it require the feature. The female connector is mounted horizontally which makes it easier for the environment to affect the performance of the connector. Some kind of cleaning of the female connector is needed. This concept has a lot of moving parts which need to be designed to ensure no damage is taken from the environment. Even though this concept is favored in some aspects it is not developed further. One big concern is that the concept require crabwalk as a feature on the vehicle. If the automated system is to be used in more areas the amount of vehicles with crabwalk as a feature is very limited.

2.5.1.7 1.F

This concept use the same type of mounting of the connector parts, though with the female connector mounted under the vehicle. This eases the problem with cleaning the connector, since mud and small stones are allowed to fall out of the connector when the female part is returning to its original position. One feature which is problematic is the protection of the station. The vehicle is supposed to pass right over the station and automatically connect without any actuators. The protection over the station can thereby not be removed until the vehicle is over the station due to the environment. The protection of the connector parts cannot be removed until the connection is initiated since the bottom of the vehicle might be very dirty with dripping mud. This concept is developed further.

2.5.1.8 1.G

This concept is based on an already existing concept in the industry. Though the existing product is quite big and heavy, the thought size and weight is much smaller and lighter than that. This concept makes the volume taken up at the vehicle smaller than the others since no flexible mounting of the female connector is needed. Though some other problems present themselves with an automated flexible arm regarding precision and robustness when moved fast. Also the deformation when nod under load cannot be too big. There are some further studies needed on this concept and it is decided to develop it further.

2.6 Choice of concept

From the screening 4 concepts remain, these concepts are investigated further. A new table is established from the requirements stated by Volvo CE, see table 5. Only the most important requirements, in the perspective of comparing the concepts, is used in this matrix. After this a discussion follows, if the concepts should be tested further before a final concept is chosen.

Table 3 Showing a rated concept choosing matrix

	Concepts		**1.B**		**1.C**		**1.D**		**1.F**	
Nr	**Short description of requirement**	**Rate**	Points	Rated Points	Points	Rated Points	Points	Rated Points	Points	Rated Points
5.	Fatigue	**15 %**	4	0.6	4	0.6	5	0.75	4	0.6
6.	Heavy duty environment	**20 %**	5	1	3	0.6	2	0.4	4	0.8
10.	Easy to install (time)	**5 %**	3	0.15	5	0.15	5	0.2	3	0.15
11.	Easy to install (cost)	**10 %**	4	0.4	4	0.4	4	0.4	3	0.3
12.	Volume taken up at vehicle	**7 %**	5	0.35	4	0.28	3	0.21	3	0.21
14.	Time to connect	**10 %**	3	0.3	4	0.4	4	0.4	5	0.5
16.	The total cost of system	**15 %**	4	0.6	4	0.6	4	0.6	4	0.6
17.	Low amount of moving parts	**13 %**	3	0.39	5	0.65	4	0.52	3	0.39
18.	Easy to maintain	**5 %**	4	0.2	5	0.25	3	0.15	4	0.2
	Sum of points		35	**3.99**	39	**3.93**	34	**3.63**	33	**3.75**

The results from this matrix is not definite. The difference in points both the sum and the rated sum is not very big between the concepts. The only concept that tend to deviate from the others is 1.D which is mainly due to its problem with the environment. There is no simple way to make sure no mud or minor rocks are left on the phases when the vehicle approaches. The size of the connector is only approximated, the limitations in relation to the vehicle should be investigated before further development is done.

Concept 1.F require a lot of moving parts located under the vehicle. Testing of protection against everything this implies would be needed. There is also a limited volume available under the vehicle, before this concept is further developed the possible placement of the female connector should be investigated.

Concept 1.C have the same problems regarding using the vehicle as an actuator as concept 1.D. This concept is approximately the same size as concept 1.D though the design widely differs. Some studies should be performed regarding what placements is possible for this concept.

Concept 1.B is estimated to have the best protection against the heavy duty environment. It includes actuators compared to the other concepts, at least one. This feature makes it more complex, but a lot of the problems regarding precision of the vehicle does not apply. The main problem with this concept is the positioning of the station and the female connector. It would be preferable to mount the female connector on the side of the vehicle admitting it to continue forward after charging is done. The possible placement should be investigated.

Mock-ups is to be constructed for all of these 4 concepts. To ensure that no unforeseen problem occurs when mounted on the vehicle. The mock-ups should be very simple and only be used to see size and basic function. The mock-ups is to be mounted on the vehicle and tested for functionality. The result of this is discussed and then a decision is made regarding the final concept.

2.6.1 **Proof of concept**

As mentioned before the proof of concept focus on size and performance of the remaining concepts. Even though the flexibility on either the male or the female connector is a big part of the concept it is not necessary to include this feature in the proof of concept. This is partly due to limitations in time and resources, but also due to lack of result from including it. Establishing size and function with the mock-up is the most important. This can be done with a mock up without including the feature of flexibility.

Cardboard is chosen as a material for the mock-ups. This material comes in many different sizes and editions. This makes it easy to construct a model of approximately the right size, including the important functions.

One female and one male plug-in connector is constructed to represent concept 1.B, 1.C, and 1.F. See Figure 10 for illustration. Since the limitations is to be investigated for concept 1.F no mock up is constructed. Instead measurements is taken in relation to the vehicle, partly for what size an placement the connector can have and partly what size and placement the station can have.

Figure 10 Picture of mockup-model used for proof of concept

Due to confidentiallity the testing process and measurements from this cannot be presented further. Though the result from the proof of concept is that all 4 concepts are possible to mount and use on the vehicle. Concept 1.C and 1.D can be mounted either at the front of the vehicle or at the rear. It would be easier to implement it on the front though it is not clear if that is preferable. None of these concepts are chosen to be developed further. There are problems with the concept of solely using the vehicle as an actuator. Not least the precision, e.g. the insertion need a very precise positioning since the connector is striving for minimized size. A precision measured in mm would be needed and this is not possible with the vehicle today. Also there are problems concerning if the vehicle for some reason does not have the precision specified when it tries to approach the station. If this is the case there must be some insurance that the vehicle does not run the station over waiting for a signal from the connector that connection is true.

Concept 1.F does also use the vehicle as sole actuator. Though its station is designed to be under the vehicle, this might ease the problem described if the vehicle loses some precision. Though the problem regarding the need for protection due to the environment and having the vehicle running it over seems tough. No simple robust solution is generated for this problem. Either they become too complex, not robust enough or too expensive. It is decided not to develop this concept further.

2.7 Final concept

Concept 1.B is chosen as the final concept and is to be developed further. During the proof of concept some alterations to the concept are done. The female connector is mounted on the side of the vehicle, between the wheels. It is mounted horizontally perpendicular to the frame of the vehicle. The station is simple, as before one actuator is needed. The vehicle places itself beside the station. An arm extends automatically inserting the connector and charging is initiated.

It is decided that the flexibility of the system should not be located in the female connector mounting. The main reason for this is the risk of damages to the connector. If spring mounted when the vehicle drives over uneven ground, there is a risk that the vibrations become so great that the connector suffer some damages. To move the flexibility to the arm like the concept 1.G minimizes the risk of damaged due to vibrations in the vehicle. Other problems do occur instead, e.g. the static deformation when the arm is not in use if flexible, the need of good control of the robotic arm. These problems are further described later in the chapter Automated connection.

There are some very good points made around the use of a concept like 1.D or one like the reference. One of the major disadvantages with these concepts is their way of handling the rough environment. It is a very interesting area that does need some more studies before these concepts get discarded. If a wider perspective is used, that the connector is to be used in many different applications and both with AC and DC possibilities, it is probably better to continue the work on the plug-in connector. Though for the application in focus for the thesis the concepts are very good if the environment can be handled. It is decided that the thesis work should focus on solely the plug-in connector after the concept phase. This is due to limitations in time and resources.

3 Connector

In the previous chapter it is decided that a plug-in connector is to be used. An already existing solution is also presented through the previous work done on this field at LTH. Though it is not possible to use the prototype connector from the final project in the application of Volvo CE since it is too big and complex. As mentioned before concerning the previous work, the concept of the old prototype might be a good starting point for the connector.

3.1 Method

The development process for the connector does not follow a well-known methodology like the concept generation. There are a lot of work done around the concept of the connector in the project performed at LTH [1]. Therefore no new generation process is performed. The focus on the development of the connector will be on size, weight, and performance. First a concept using the same technology as the existing prototype is presented. Following this a new concept is taken into consideration. These concepts are compared with each other in aspects such as estimated performance, complexity, manufacturability, size, and etc.

A choice is made based on estimations and tests. The testing is limited due to recourses and time. The alternative chosen is further developed and simulated mechanically and thermally. The dimensions and sizes of the parts are decided based on thumb rules and experience from the student and the supervisors, simulations and tests are only used as a proof of concept. Thereafter a detailed CAD-model of both the male and the female connector is created. Drawings and Stp-files are created for manufacturing.

After the design is finalized the manufacturing is started. Most of the work is done at Volvo CE in their workshops, though some work is done in Lund. All brazing and assembling is done in Lund. The assembling is done in accordance with the final design.

3.2 Requirements for the connector

There are a lot of requirements for the connector for the application of Volvo CE. The connector should handle 300A current continuously. It does permit both charging with 3-phase AC and DC current, this should be integrated in the hardware design and not rely on different software. When used for AC, three phases, one neutral, and one security ground is needed. Two phases are needed for DC charging together with a security ground. This implements that 5 phases must be integrated within the design, all allowing to be used with 300A simultaneously. According to the standards of today two signal lines are needed in a high power connector [7]. Though it is not clear if it will be enough with a wireless communication like when inductive charging is done. It is decided that the connector should hold 2 conductive signal lines.

The connector should not generate excessive levels of heat. No damage is to be done to either the connector or systems around it due to temperature. The connector should not take any damage due to normal usage, even though the male and female connector are misaligned when insertion is attempted. Connection can be made over 1’000’000 times without any functional difficulties due to wear.

Both the female and male connector should be designed much smaller than the previous prototype presented earlier. This includes the whole system. Not only the connector, but the guiding system for the flexible arm and the mounting of the female connector. The prototype created is to be functional so that tests can be performed to ensure functionality. One very important feature of the connector is manufacturability. The connector should be easy to manufacture to keep down the costs. No rare and very specialized materials are to be used.

3.3 Connector concept

As mentioned before in this chapter there will be two main alternatives for the design of the connector. One very similar to the concept presented in previous projects and one new. These will be evaluated and compared to each other based on the requirements stated for the connector.

3.3.1 **Previous connector concept**

The previously manufactured prototype is shown in Figure 1. The concept behind this prototype is to mount three radially moveable segments in a frame. Each of these segments have 5 phases mounted in layers above each other. This creates a rotationally independent insertion for the connector. These segments can be moved radially through a pneumatic plug mounted in the centre of the connector. Each phase consists of 27 minor copper blocks, where 9 are mounted in the same row in each segment. These are independently flexible and separately connected to the phase cable. Two communication lines are mounted in the top of the connector which also is attached to the frame.

This concept is proven to work on currents over 300A when it is the size of the prototype. As a conclusion from the previous project, it is stated that much of the heat generation comes from the connection between cable and phase and not between the phases of the male and female connector. If this is true and the concept is altered to include a better and more robust connection between cable and phase it would be possible to reduce the number of blocks for each phase. This is estimated to be true. From the results presented in the previous project report [3] an estimation is made that around 15 blocks would be enough to handle 300A continuously without excessive heat generation. A CAD-model is created to use when evaluating the concepts.

3.3.2 **New connector concept**

The new concept originates from a technique for connecting phases by only using a mechanically developed pressure between the phases. The company behind this technique is BalSeal. The technique is based on canted spring coils, see Figure 11. These coils are mounted in a housing, i.e. a female phase, then the male presses back the canted spring and do thereby create a pressure between the male and female phase via the spring coil. Through discussions with a BalSeal representative, Robert Riegen, it is concluded that it would be possible to design a canted spring coil for the connector within reasonable limitations on size and cost. The limiting factor will not be the size of the spring, rather the possibility of designing a connector that can overcome all the requirements, e.g. while being rotationally independent be able to handle 300A simultaneously over all phases. An estimation is made that it would be possible to design a connector that is around 40mm in outer diameter on the male side.

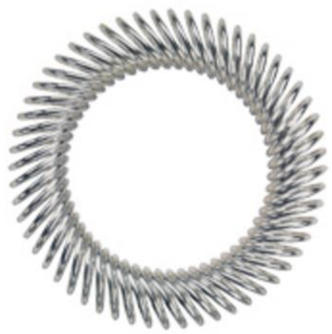

Figure 11 Showing the BalSeal canted spring coil [8]

3.3.3 **Test BalSeal concept**

After the discussion with the BalSeal representative some samples of coils designed to carry 300A continuously are provided. A test rig is constructed at Volvo CE and sent to LTH. The tests are performed to prove the concept, no scientific data is logged during the tests. It is also of interest to test if it is possible to use coils of stainless steel for the phases. This to minimize the wear due to the environment. This is to be compared to aluminium. Aluminium is used instead of copper since it is much easier to manufacture the test housing and pin for the coil. Figure 12 show the housing and the pin representing the connector in the tests.

Figure 12 Showing test rig used to confirm the possibility of using the BalSeal technique

The test rig consists of one adjustable transformer delivering a constant voltage and a current in a range from 0-8 A. This is connected to a larger transformer amplifying the current with a factor 100. A cable with an area of 50 square mm is used to carry the current. It is connected to a pin representing the male connector and a housing representing the female connector and holding the coil.

The test is as mentioned only a proof of concept. The temperature is kept under surveillance with a heat sensitive camera. The small coils do withstand the high current without damage. Though the temperature rate is higher than what is suitable for the application in the connector, the coils tested are much smaller than the ones thought for the connector. The result from the testing is that the concept is working. It is expected that the temperature rate will be lower when the coils are bigger and copper is used for the phases.

It is also concluded from the tests that stainless steel cannot be used for the phases. Stainless steel would ease the problem of wear due to the environment, but the temperature development would be too high. The phases designed to carry a high current continuously is to be constructed in some copper alloy, which is decided based on the requirements. Though for security ground and/or communication lines it would still be possible to use stainless steel.

3.3.4 **Modelling**

Before a choice is made weather to develop the new or the old concept concerning the connector an estimation of size is made. The focus lies on the male part of the connector. The major factor to the size difference between the concepts depends on the male side. The female connector will be similar to each other in design and size no matter what concept is decided upon.

A limitation is set for the current density in the connector to 10 A/mm^2 using rule of thumb. This is a quite high value when carrying current, though it should not be a problem. The rule of thumb is that the total loss of energy, heat development in this case, will not be affected extensively if the resistance is increased over a limited space. This is of course within a reasonable area of the spectrum, but 10 A/mm^2 is not an extreme value according to the supervisors of the project.

It is estimated earlier that only around 15 small blocks would be needed for each phase. A model is constructed in Solidworks from the same concept and design as the old prototype to see how small it could get if 15 blocks are used. See Figure 13 for illustration when compared to old prototype.

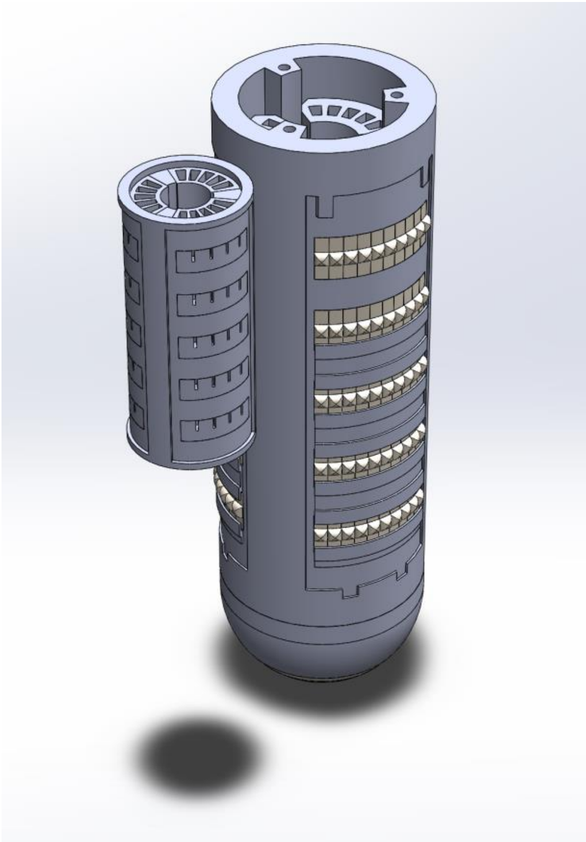

Figure 13 Showing both the old prototype model and the new estimated concept model

As presented the main concept with separately flexible blocks are altered in some details to ease the manufacturing process. Instead of connecting each block separately to the cable mounting them in the moveable section, a comb like structure is designed. This structure is mounted on a solid copper construction going through the section and connect to a cable at the top of the connector. This result in the knobs on each phase can move a bit if necessary, but a lot less time is needed for assembling the sections. See Figure 14 for illustration of the comb structure. This would be a promising concept to continue developing.

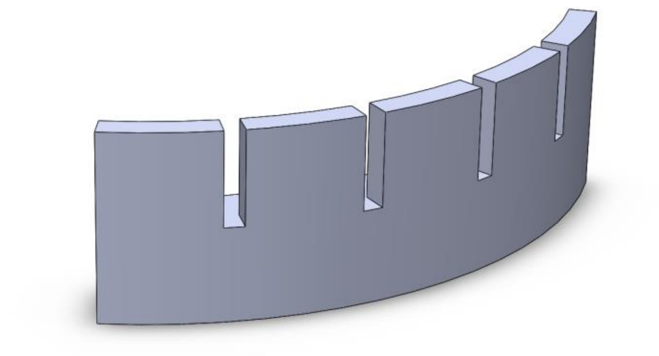

Figure 14 Showing a simple model of the comb-structure described above

The concept using the BalSeal technology is designed through the same rule of thumb as the other regarding the current density. Though in this concept there is no need for a pneumatic balloon. This creates new possibilities of making the connector smaller. The balloon itself has a diameter of around 20 mm. Through rough estimations in the modelling regarding the sizes and spaces between the phases a model is created. This model is shown in Figure 15. It is smaller than the other concept, around 20% smaller. There is no need for the comb structure or anything similar since the canted spring coil is to be used. Also no frame and radially moveable segments are needed due to the BalSeal technology. This implies that only one fastening is required for each phase if each phase is manufactured in one piece and not split up in three sections. Through this a simpler structure inside the male connector can be designed with only one bar of copper going through the connector connecting the cables to the phases.

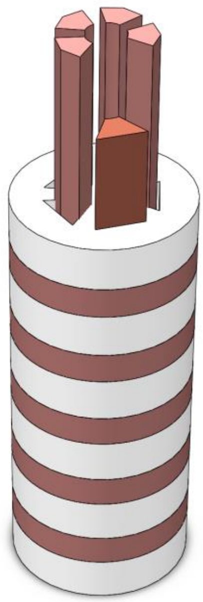

Figure 15 Showing model of male connector using new BalSeal concept

3.3.5 **Final connector concept**

It is decided to continue the development of the connector using the new technology from BalSeal. This is mainly based on the complexity of the concepts and the possible size of the connectors. One main requirement stated by Volvo CE is that the design should strive to minimize the connector size. The chosen concept is also simpler since no pneumatic system is needed to ensure connection. It is one less feature to take into account regarding everything from maintenance to cost.

There is no experience regarding the technology using coil springs, either from the student or from the supervisors. Therefore it is decided to rely on the BalSeal engineers regarding the design of the coil springs and the housing for these. Limiting factors such as outer diameter of the male connector, number of connections before failure, environmental factors, and current that are to be transferred are given and BalSeal design and manufacture the springs in-house.

The BalSeal technology can also be used as a mechanical lock. This by designing cavities in the male connector. With this technology the force for pushing the connector together and the force for withdrawing the connector can be decided separately, though with some correlation. It is recommended from BalSeal that if a latching connection is used this should be made out of stainless steel. This is because of the increased wear that comes with this technique. If stainless steel is used these spring coils cannot be dragged over any copper surface when inserting the connector. This is due to copper being much softer than stainless steel. If a steel coil is repeatedly dragged over a softer copper surface, this surface will be damaged. This must be taken into account when designing the male and female connector. It is estimated that a force of 50 N for withdrawal would be sufficient to ensure that the connector cannot disconnect by itself in any case, e.g. if mounted vertically the male connector will not be disconnected due to gravity. If someone grabs the male and disconnect it manually there will be an instantaneous reaction that cut all power through the charging station so that no harm can be done.

3.4 Material

3.4.1 **Phases and signal lines**

It is possible to manufacture the spring coils in various materials and with plating if needed. Though the amount of alternatives within the same metal or alloy group are limited. It is decided to have solid copper/beryllium springs without plating. This decision, to not use plating, is based on the certainty of wear in the rough environment. If a spring loses its plating after a certain number of connections and disconnections the performance is decreased. If a solid spring is worn down the same thickness as a plating it would still deliver approximately the same result since the material in contact does not change.

In perspective of conductivity it would be a better choice to use pure copper, though the environment is too demanding. Pure copper would probably be worn down long before 1´000´000 connections are done. The copper beryllium alloy can be designed as one of the highest performing alloys based on copper when focusing at tensile strength. The improvement in tensile strength is high. It can go from 400 MPa (pure copper) up to around 1350 MPa (2% beryllium, with some additional materials) [9]. Both the thermal and the electric conductivity is decreases with increasing percentage of beryllium at a high rate. With around 0.5 % beryllium the conductivity is at around 50% of the pure copper conductivity.

It is chosen to use the same or approximately the same material for the housing of the coil springs in the female connector and also for the counterpart on the male connector. This is decided based on partly the risk of chemical reactions if different materials are used and partly due to the increased mechanical properties. The loss in conductivity should not be a problem if the connector can be made small enough without increasing the current density too much. If the connector is designed to carry no more than 10A/mm^2 the heat generation should be okey even though a beryllium copper alloy is used.

As mentioned before one of the signal lines can be designed to act as a latching mechanism. If so the material recommendation, from BalSeal, is stainless steel. This is mainly due to the higher resistance to wear compared to copper alloys. It is good enough to use stainless steel concerning conductivity. The signal lines are not supposed to carry high current, therefore higher conductivity will not be needed. There is only need for one latching mechanism, though it is okay to use stainless steel for both signal lines if preferred. Actually the security ground do not need to be made in a copper alloy. It is established through the initial testing of the BalSeal concept that it works to use stainless steel for 300 A if not used for long periods of time. The test is performed on a BalSeal spring with an inner diameter of around 10 mm. The protective ground should be able to handle 300 A and more, but only for a short time since the power should be cut instantaneously if current goes through the ground.

3.4.2 **Insulating material**

The previous prototype use a 3D printed PA plastic as an insulating material. This is used both for the male and for the female connector. This material proved to be good both due to its insulating and mechanical properties. For the new prototype it is decided that either the same or a similar plastic is to be used. The material should be 3D printable due to the need of a simple prototype manufacturing. It is important that the material can handle high temperatures over 150 degrees Celsius, since the heat generation from the connector can be extensive. The material should also not expand in a way that might damage the connector or interfere with the function of the connector due to heat. Volvo CE provides a plastic 3D printable material called ULTEM 1010 Resin [10]. This is chosen as insulating material both for the male and the female connector.

3.4.3 **Cables**

There are lots of different cables to choose from. Different brands and different recommended areas of use. One common thing when looking at industrial cables for around 300 A is that the cables tend to grow in thickness. This often implies that the cables are very stiff as well and cannot be bent around sharp corners. This introduces a new problem since the cables must be able to be connected to the connector phases without making the connector big. The cables also must be able to follow a robotic arm without putting any damaging strain on the robot or the cable itself.

There are some alternatives for industrial cables that have an extra high requirement on flexibility. These cables are more expensive. One of these cables are manufactured by Methodone Electronics Inc. This cable, Power Flex 1000 with a diameter of around 21 mm, can carry 300 A continuously but still bend around a radius of 62 mm [11].

These cables are, as stated, more expensive than normal cables for the industry, though this might not be a large cost in the big picture. If only the part from the connector to the charging station, along the robotic arm, uses this kind of cable it will mean around 10 to 15 m of flexible cable per connector. This is not a big cost if they survive the whole lifetime of around 1’000’000 connections.

3.5 Male connector

This chapter present the male connector prototype design. There are some comparisons to the old prototype. During the initial design some simple analyses are performed concerning the structural integrity and thermal situation of the connector and its phases. All analyses are performed in ANSYS Workbench provided by LTH. Though these where only used as a complement to the already performed testing of the BalSeal testing and they are not used as a base for any dimensioning.

3.5.1 **Design**

In Figure 16 a CAD-model of the final design of the male connector is shown. The total length of the connector is 230 mm and the widest diameter is 50 mm. This is significantly smaller than any connectors researched for this kind of power transfer. There are many features within the connector that are similar the previously presented prototype at LTH, but this is much less complex. The different parts of the male connector is presented below. After the main parts and features are presented the assembling will be described. Drawings of all components not 3D-printed is found in [Appendix].

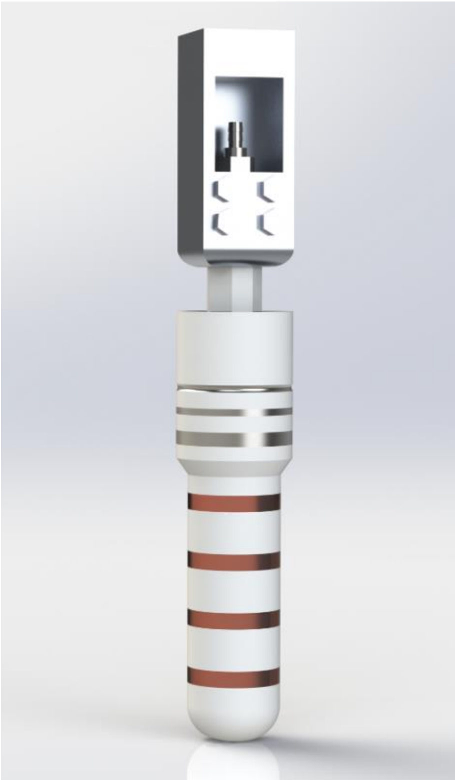

Figure 16 Showing a rendering of new male connector final design

3.5.1.1 Phases

All 4 phases are designed in the same way with the same features. They can be seen in Figure 16 as the copper rings on the thinner part of the connector. This part has an outer diameter of 40 mm. They are constructed of rings which are equal for all phases. These rings are fastened by brazing to four bars with different lengths. One model of a ring and a bar is shown in Figure 17. These bars have a thicker part in the bottom, which fits well with the inner surface of the rings. It is also this part that is fastened to the ring. The bar has one flat surface facing inward in the connector and one curved surface concentric with the ring. On the top of the bar the outer surface is flat and a threaded, M5, hole is goes through the bar. Both the rings and the bar is an alloy of copper beryllium.

The bars are designed to have around 8 A/mm^2 through them when 300A is run though each phase. This is estimated to be a low enough number to not have excessive heat generation. This design, if the thumb rules regarding current density and heat generation is estimated correctly, allows the connector to use 300 A for all phases when charging with 3-phase AC is done. When charging with DC Only two phases are used. Allowing the connector to use two of its phases coupled in parallel for each charging phase. By using this method the current density is cut in half compared with only using two of the available four phases.

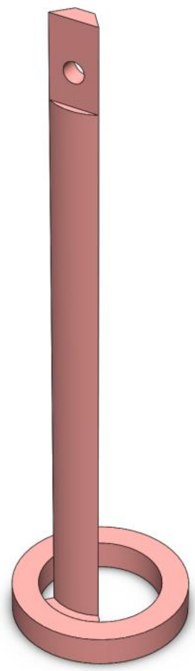

Figure 17 Illustration of phase ring brazed to copper bar

3.5.1.2 Security ground

The security ground is located together with the signal rings on the 50 mm part of the connector. The concept is the same regarding ring and bar though the measurements are different. It is made of stainless steel instead of copper as the phases. The reason for this can be found under the heading Materials in this report. It needs to have the same material as the signal lines if located at the same section of the connector. As can be seen in the drawings the cross section area of the ring and bar for the security ground is lesser than for the phases. This is not a problem since if there is current going through the security ground all phases are cut in the charging station. There will not be enough heat generated during this short time even if the current is high.

3.5.1.3 Signal rings

There are two signal rings, both located on the 50 mm section of the connector. Both are made of stainless steel. One has a flat outer surface and one has a cavity. The cavity is for a locking feature when inserted into the female. The cavity is designed so that a force of around 50 N is needed to withdraw the connector once inserted. No bars are designed for the signal lines since cables can be brazed directly on the inner surface of the rings. For illustrations look at drawings.

3.5.1.4 Plastic skeleton

This connector have a plastic skeleton keeping all the other parts in their place. The skeleton consists of various parts, they will be presented from the bottom to the top. The skeleton is designed to have as few different parts as possible. The design allows the entire inside of the connector being filled up with plastic. The plastic is Loctite 9497, that is a high temperature epoxy adhesive. The plastic can withstand temperatures up to 180 degrees Celsius and still have 20% tensile strength left and also it conducts heat well [12]. As many other epoxy plastics it is highly insulating which is very important. Both the ULTEM-plastic and the Loctite has a low coefficient of thermal expansion which is good. There will be no high tension build up between the plastics once heated up.

The bottom part of the plastic skeleton can be seen in Figure 18. It is designed so that a M10 nut can be locked at the bottom along the axis of the hole going through the whole plastic skeleton. The bottom part also keeps one phase in place. The radii on the outer surface of the bottom part is designed by the requirements from BalSeal to ensure that the spring coils will work properly.

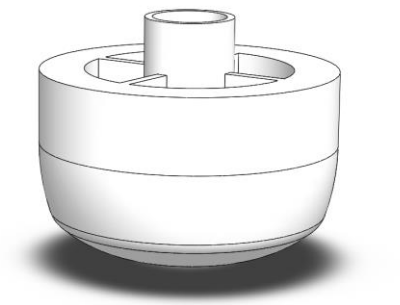

Figure 18 Illustration of 3D-printed bottom part of male connector

The next three parts are similar in their design. They are designed to keep the rest of the phases in place, one on top of each plastic part. They can be seen in Figure 19.

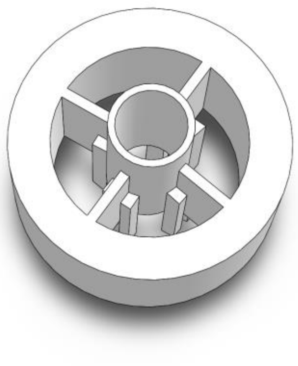

Figure 19 Illustration of 3D-printed skeleton part

After the phases the connector shifts from 40 mm to 50 mm in outer diameter. This plastic piece is designed to have a smooth transition between the diameters, also this parts outer surface ensures that the BalSeal spring coils will work properly for the signals and the protective ground when inserted. This part is shown in Figure 20.

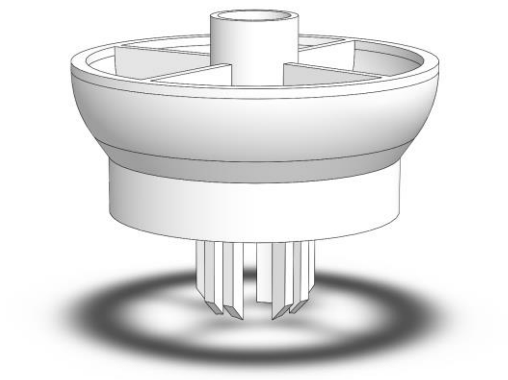

Figure 20 Illustration of 3D-printed skeleton part

Between the security ground and the signal rings there are two minor pieces designed to keep the rings in place. They are shown in Figure 21

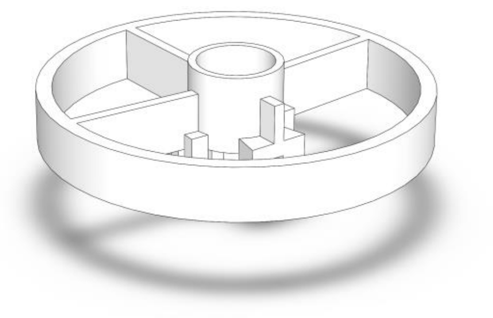

Figure 21 Illustration of 3D-printed skeleton part

On the top of the connector a larger part is designed. This part ensures that the bars coming up through the connector from the phases are separated according to the design. It protects the fastenings between the cables and the bars. It also enables plastic to be filled up over the connections between bars and cables so that no part of the connector is not insulated, except the phase's surfaces. See Figure 22 for an illustration.

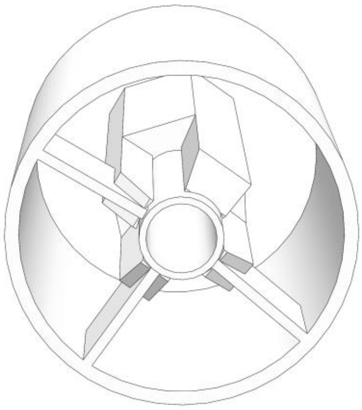

Figure 22 Illustration of 3D-printed skeleton part

3.5.1.5 Assembling

The connector is designed with a hole going through the middle. This is to enable a steel rod threaded in both ends to squeeze the skeleton together to have everything in place then filling up the connector with epoxy. The rod is also used for its mechanical properties, it is there to stiffen the connector, making it much more durable. Figure 16 shows how the rod also can be used to mount the connector on e.g. a robotic arm only by using a nut.

The rod is hollow to enable a pneumatic system to be attached and blow the female connector clean before inserting the male. This is implemented as a safety precaution against the rough environment. The inside of the female connector should be protected from much of the environment, but the ambient air will have dust etc. blowing around in it.

Once assembled the connector is hollow aside from the cables and bars going through it. Loctite 9497 has a medium viscosity which practically means that it will not float out in all cavities inside the connector by itself. A vacuum chamber is used to eliminate bubbles inside the plastic and assure that the resin reaches all cavities.

The design of the bars connecting the phase rings to the cables are a trade-off between the cross section area and the need of space between the phases. The placement is not a rotationally symmetric due to the bar connected to the security ground not being similar to the others. There are around 4.5 mm at the least between the phases. This is estimated to be enough, though tests are performed on the working prototype to ensure that it is.

3.6 Female connector

The female connector prototype design is presented here. As for the male connector a presentation will first be made of the separate parts and features, followed by the assembling of the parts. The design of the complete connector will be compared with the old prototype.

3.6.1 **Design**

The female connector is like the male connector built up in layers, with the phases mounted inside 3D-printed plastic parts, though these are solid not hollow. Drawings of all components not 3D-printed is found in [Appendix].

3.6.1.1 Phases

As mentioned before, the springs and some parts of the housing for the springs are designed by BalSeal. Due to confidentiality not all of these measurements can be published. The design of the coil springs are depending on the requirements from the environment and the application, along with the outer diameter of the male connector, 40 mm for the phases and 50 mm for the security ground and the signal lines. The material of choice is the same alloy of copper and beryllium as for the male connector.

Each phase consist of a housing ring which a spring coil fits into. There is a block that is brazed to the outside of the housing ring. This block has a hole going through it for fastening of a cable. An illustration of this can be seen in Figure 23.

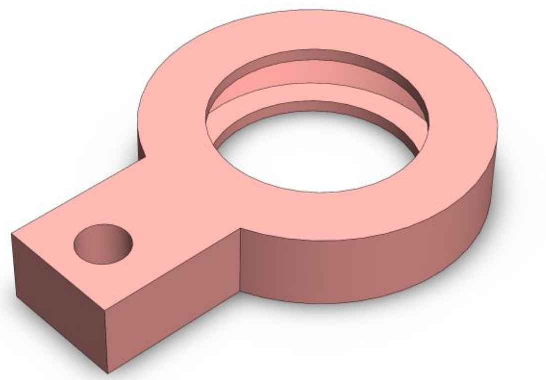

Figure 23 Illustration of female phase-ring brazed to the block connecting to cable

3.6.1.2 Security ground

The concept for the security ground is the same as for the phases, though the measurements are different. The spring coil is designed for 50 mm and the cross section area of the ring and the block is much smaller than for the phases. The material is stainless steel. An illustration of the security ground is seen in Figure 24, though without the block that is brazed to the outside of the ring.

Figure 24 Illustration of female security ground-ring

3.6.1.3 Signal lines

The two signal lines and the security ground are equal, there are no difference on the female connector. Both are made of stainless steel. The spring coils are designed for 50 mm.

3.6.1.4 3D-printed parts

There are a number of different parts 3D-printed to keep the housing rings in place, there is also a funnel and a housing for the female connector. The parts are presented from the outside and inwards. All parts are 2D-printed in the same ULTEM material as the male connector is.

The housing for the female connector can be described as an octagonal tube with a funnel in one end. There are 4 walls going from the tube all the way in, keeping the other parts in position, also dividing the inside into 4 parts, one for each phase and its connection to the cables. The signal lines and security ground shares space with one phase each. See Figure 25 for illustration. The bottom part also have the possibility to fasten a lid via 8 bolts to keep all the other parts in place in the female connector.

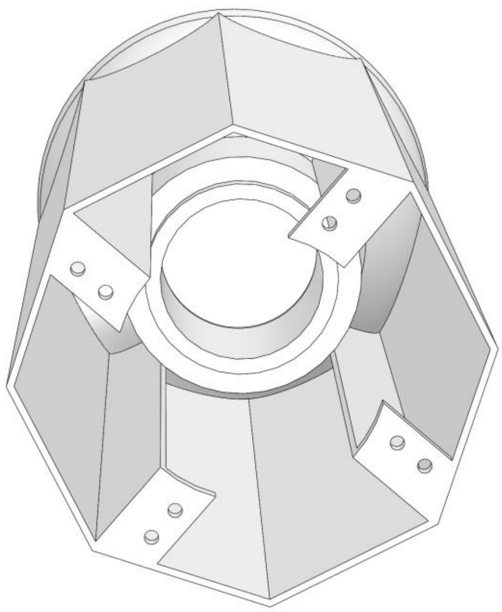

Figure 25 Illustration of female connector housing

The funnel is there as a guiding system for the robotic arm. It is designed as a test prototype due to limitation in time. The project did not allow for any research on how to design this to be sure it could guide the connector no matter the position and misalignment. If the connector is developed further, more research should be done on this feature. See Figure 26 for illustration of the funnel.

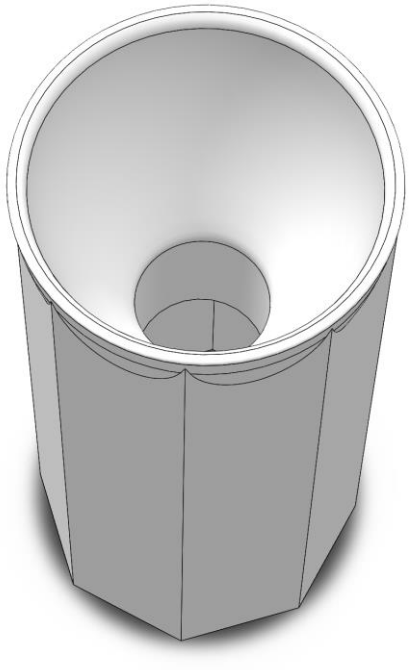

Figure 26 Illustration of the female connector funnel

Continuing downwards from the funnel, the parts holding the two signal lines are located. These are constructed so that the housing rings and their attached cable connection slides down into them from the top. The plastic covers the bottom and the outside of the housing rings. The plastic makes sure the position of the ring is right in relation to the ring below and so that the ring is in the middle of the connector. There are 4 small holes going through the plastic in the outer border symmetrically around the middle axis. These are there to make it possible to keep the cable connections separated with 90 degrees. See model of the part in Figure 27.

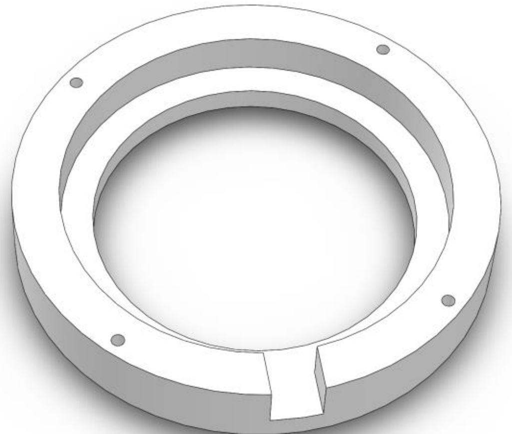

Figure 27 Illustration of female 3D-printed plastic part where a signal ring is mounted

The plastic part fitting with the security ground is similar to the one described above, but with a variation. It is designed to fit the 50 to 40 mm variation in the male connector. The housing ring is fitted in the same way. The transition between the diameters is designed to be smooth. See Figure 8 for a model of the part.

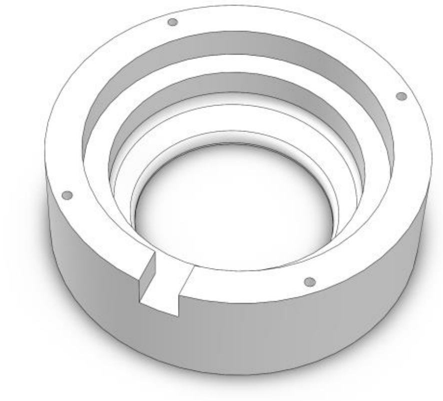

Figure 28 Illustration of the 3D-printed plastic part where the security ground ring is mounted

Concept wise the plastic parts for the phases are the same as for the signal lines only different in size. There need to be a bigger distance between the phases than between the signal lines. The distance is designed to be 10 mm to ensure no sparks develop between the phases. According to the experience from the supervisors this distance is enough for voltages higher than 640 V, which is the normal voltage for DC charging.

3.6.2 **Mounting of female connector**

There is no way of easily mounting the prototype as it is today on the vehicle, though with a few simple additions to the plastic housing it should be very easily mountable in the frame. The size of the connector that is to be mounted on the vehicle is much smaller than the previous prototype. There are no flexibility implemented in the female connector mounting, this is as described previously because the flexibility is implemented in the robotic arm. Hence there are no need for any more space than what is already given by the design of the housing. It is not possible to describe more about the mounting due to confidentiality.

3.6.3 **Assembling of connector**

The 3D-printed parts are delivered from Volvo CE together with all the metal parts. The spring coils are delivered from BalSeal separately. Some work is done to a lot of the 3D-printed plastic parts to make them fit properly. A lot of the work is grinding and the main reason for this is that there is no experience with the material used in the printer, therefore it is hard to predict how much the material bleeds.

The brazing of both the copper and the stainless steel is done at LTH at a workshop, all parts are brazed with silver in accordance with recommendations from the supervisor. After the brazing is done, all copper parts need to go through a heat treatment. This is since they are heated up to almost 1000 degrees Celsius during the brazing. The heat treatment is done according to recommendations from Harald Phil, which is the provider of the copper material [13].

Once almost the whole male connector is assembled, it is clear that no cables over 35 mm^2 will be possible to use. Even though this smaller size of cables are used the top plastic part of the connector breaks. It is still possible to use the part but there is need of grinding down deformations due to the damage. It is noted that some alterations must be made if the connector is to be further developed. The female connector is assembled without issues but the bleed should be taken into account for some very minor changes.

The connector can be seen below before assembling in Figure 9 and assembled in Figure 10.

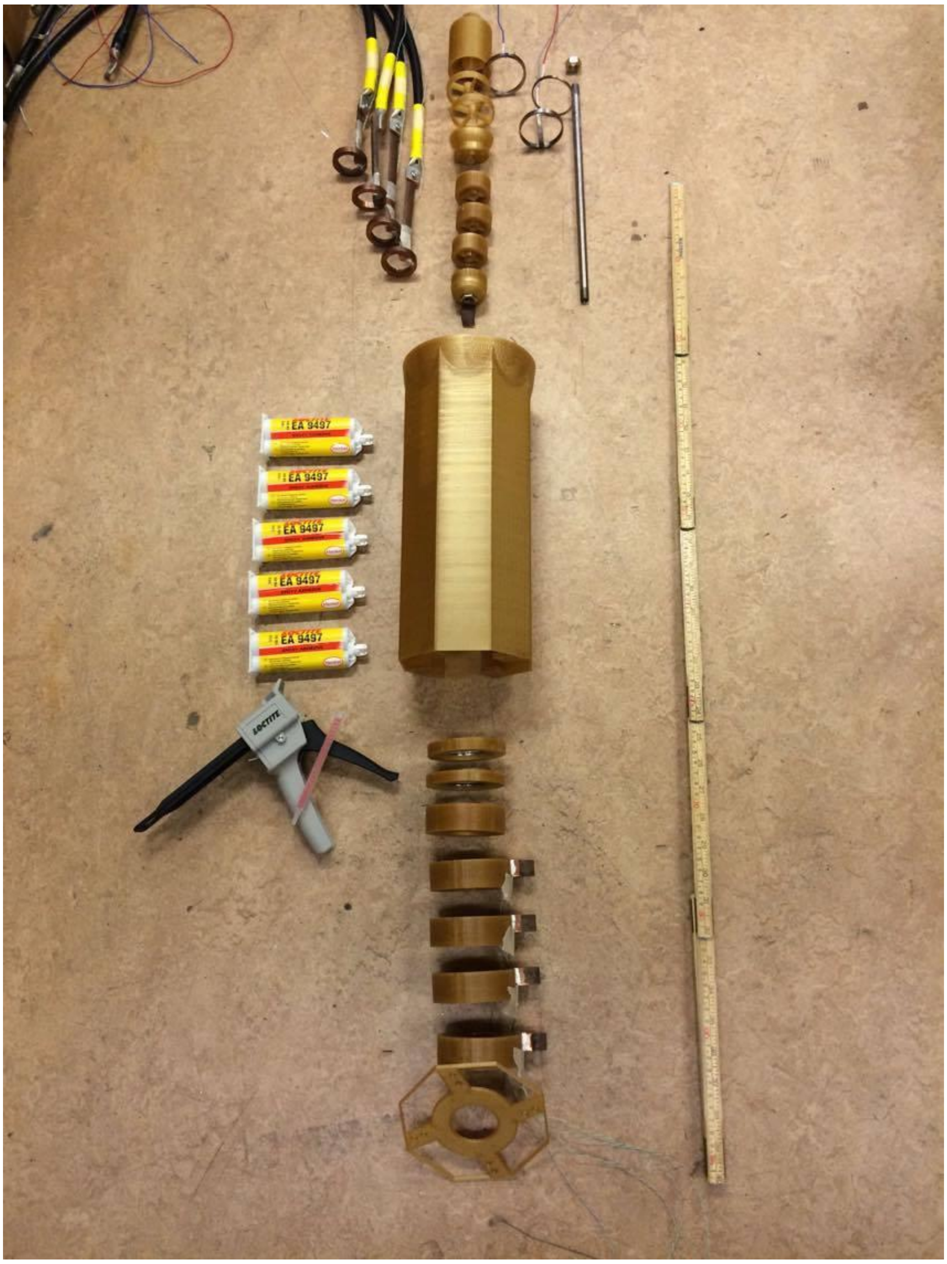

Figure 29 Showing picture of connector parts lined up for assembling

Figure 30 Showing picture of connectors assembled

4 Automated connection

The objective is that the vehicle drives into the charging station and stops, automatically the station connects with the vehicle and initialize the charging. When finished charging it should disconnect automatically and the vehicle can drive away.

From the network optimization previously presented in the report there is to be one charging station for the vehicles in the cycle. The charging station should include two chargers so that two vehicles can charge at the same time. Between each vehicle coming in for charging there will be a setup window where no charging is done. The setup time for each vehicle is 20 seconds, which implies that there will be about 20 seconds from that one vehicle stops charging until the next vehicle should start charging. Practically once the vehicle starts moving out of the station the next one will start moving in for charging. This gives the automated station about 5-7 seconds to connect once the vehicle has parked respectively disconnect if charging is done. There will be a Wi-Fi-communication between the vehicles and the charging station, which simplifies the process since each part will know what the others are doing if needed.

The concept generation also decides that the station should be simple with one robotic arm with a flexibly mounted male connector. This should connect with the vehicle from the side along a horizontal axis perpendicular to the vehicle. The flexibility in the arm should allow for a malposition of +/- 2.5 cm in all directions, along with some misalignment.

There must come no harm to any part if there are any errors in positioning or alignment larger than what is specified. The system must be robust. This is very important since the vehicles are fully automated and large enough to easily run over a charging station at least if no precautions are taken. A lot of work on this matter can be done by using the wireless communication.

The station will be placed in a very rough environment. As for the connector there must be a good resistance against mud, dust, water, etc. At prototype level the charging station will be located inside a tent to simplify observation of the automated system. This means that most of the weather conditions are not the biggest problem. The main problem is dust in the surrounding air and dripping mud from the vehicle.

4.1 Limitations and new objective

The initial objective is to design and construct a prototype ready for testing. This objective is revised after about half of the project is done. It is revised due to limitations in resources and time. The final design and manufacturing of the connector is delayed. Through discussions among the student and the supervisors it is decided that the automated system should only be designed at a conceptual level.

4.2 Robotic arm

There are several problems associated with having a flexible automated robotic arm. Increasing flexibility usually means that the arm is increasingly tough to control. It would be possible to have an arm with a spring in the middle allowing the connector to move, though there are problems with this. The control would be hard to design, but most likely possible. There would have to be a trade-off among ease of inserting the connector, stationary deformation when the connector is hanging in the air, and also the need of a good controller when trying to move the arm fast. There is only around 5-7 seconds for either insertion or withdrawal of the connector. There is also a need of some kind of protection from the environment. The arm cannot be hanging freely in the air without protection from for example dripping mud from the vehicle.

4.2.1 **Concept design**

The idea is to only use one actuator moving the robotic arm horizontally along an axis perpendicular to the thought position of the vehicle when parked for charging. This actuator can move the arm fast and with precision. The distance that needs to be travelled for the connector is around 1.1 m to insert it.

The arm is divided in two main parts that are connector to each other. One arm which is very simple, it is simply described as a rod or a bar that is connected to the connector at one end via a spring. This spring is flexible enough to allow the required malposition and misalignment in relation to the vehicle when inserting the connector.

To work around the problem with a flexible arm when moving it fast, without having an extensive control model, a mechanical solution is designed. The second part of the arm is the solution. This can be described simply as a tube. The tube is wide enough to fit the other arm inside it but only barely, thus eliminating the negative effect of moving the arm fast since the connector is closed fitted inside the tube. The tube should move along with the other arm for the first 70 cm or so, this is the part that needs to be covered fast if connection is to be made in 5-7 seconds. After this part is covered a mechanism releases the tube and leaves it stationary in that position. The next 30-40 cm are covered more slowly since this is the part where the flexible mounting of the male connector is adjusting for malposition and misalignment by being guided by the funnel on the female connector. See Figure 11 for illustration of arm.

When charging is done the arm is retracted with the tube still stationary, once the male connector is inside the tube again the tube starts moving with the arm. This solution with the second part of the arm would not only solve the problem concerning the flexibility, it would also act as a protection for the male connector. A lid should be mounted in the end of both the tube and at the opening of the female connector, where both should be automatically opened when connection is attempted. These solutions should be enough to protect the system from the environment.

The station itself holding the charging control, the actuators, along with more should also be protected by some housing. Though there are not many requirements on size and durability on this yet, but that should be investigated further if the station concept is to be developed.

Figure 31 Illustration of arm including the surrounding tube

5 Testing

The tests are performed at LTH, at a workshop. The room temperature is 22-24 degrees Celsius during all tests. Various current tests are performed to determine the thermal situation during continuous usage of the connector.

The equipment used is a data acquisition unit named LXI Data Acquisitions Unit, Agilent 34972A, which collects and log the readings from all the sensors. These numbers are later translated in MATLAB, provided by LTH, into diagrams showing temperature over time.

8 different thermocouple k-element sensors are used. These are glued with a highly thermally conductive glue to every phase on both the male and the female connector. Two of the sensors in the male are connected in the edge of the brazing between the rings and the bars, phase number 1 and 4. Two are glued closer to the top of the connector, phase number 2 and 3. The reason for this is that it will give a better description of where in the connector the most heat is generated.

During the tests when loaded with current all phases are connected in series with each other. This is done since there is no need to load them separately. It is the current through the connector that drives the temperature to rise. This also simplifies the testing drastically.

A rotary transformer is used to vary the current level going through the phases. This delivers a current between 1 and 8 A. This is in turn connected to another transformer magnifying the current with a factor 100. See Figure 12 for illustration. In all tests the phases are referred to by a number, number 1 is at the top, the rounded, end of the connector. Then the other numbers follows in order.

Around 7 m of cable is used. The cable has an area of 35 mm^2. This is lower than what was decided but due to limitations in the space inside the male connector 50 mm^2 cables or higher could not be used. If the cables themselves generates too much heat it is decided that fans are to be used to cool them off so that the connector still might give a reading disregarding the effect of using smaller cables.

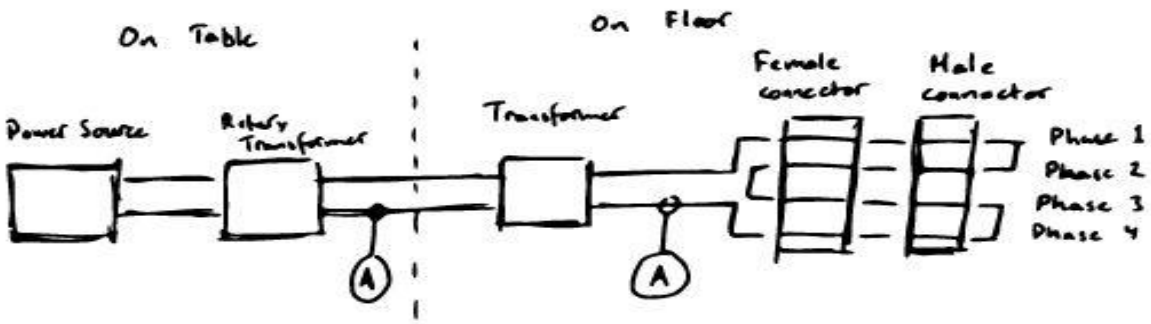

Figure 32 Illustration of the test rig

5.1 Test, current

When testing the current both continuous current and cyclical load is tested. The aim for the connector is to be able to carry 300 A through all phases continuously. Though the testing is starting on a lower current to make sure nothing unexpected happened. The starting level is set to 200 A. Continuous testing is very time consuming, an estimation is made to begin testing for 1 h to see the behaviour of the connector and find a good level for longer testing.

5.1.1 **Test 200 A, 1h, continuous**

The first test results can be seen in Figure 13 and Figure 14. The test is performed for 1 hour with 200 A going through the connector. It is clear that the temperature rate decreases over time. The temperature after 1 h is maximum 90 degrees Celsius. This is below any dangerous levels of temperature inside the connector. The cables are measured via a thermal camera and are stabilizing around 80 degrees. The male connector seems to be overall at a higher temperature than the female connector. Also the phases seem to vary up to 10 degrees between each other on respectively connector.

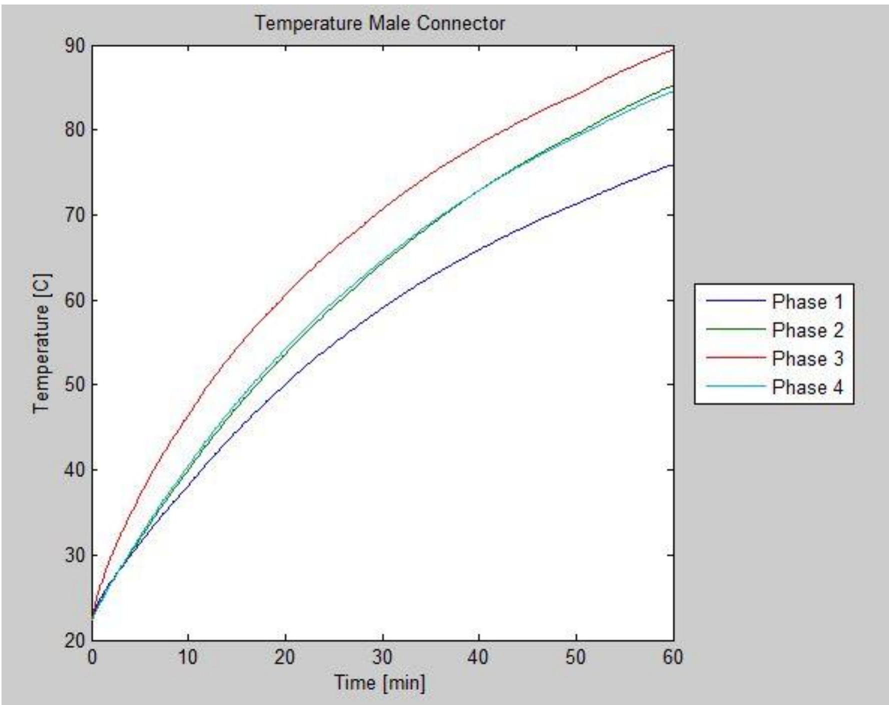

Figure 33 Showing test results test 1

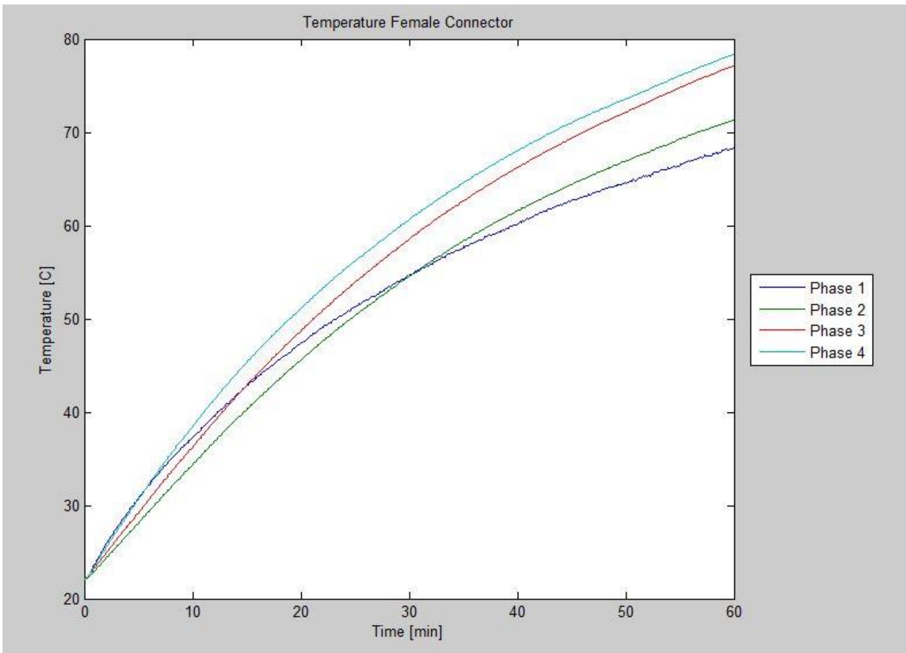

Figure 34 Showing test results test 1

5.1.2 **Test 250 A, 1h, continuous**

The second test results can be seen in Figure 15 and Figure 16. For the second test the current is increased to 250 A and the test is performed for 1 hour. One interesting thing to note is that while the temperature rate is higher in the beginning, the temperature seems to level out towards a stable temperature faster than the previous test. The maximum temperature is on the same spot as in test 1 in the male connector. Just as in test 1 the phases vary both between the connectors and within the connectors. The temperature in the cables during this test goes up to 120 degrees Celsius.

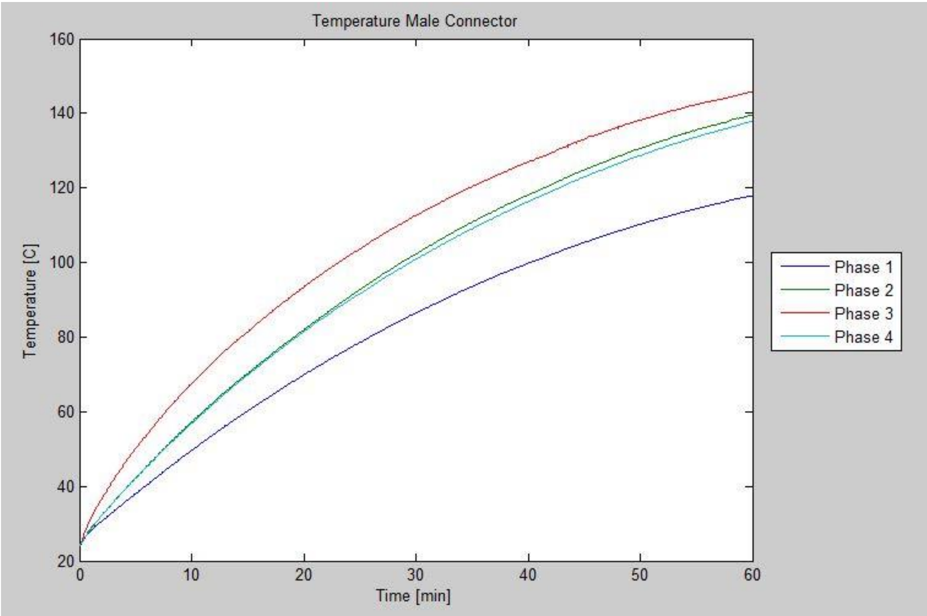

Figure 35 Showing test results test 2

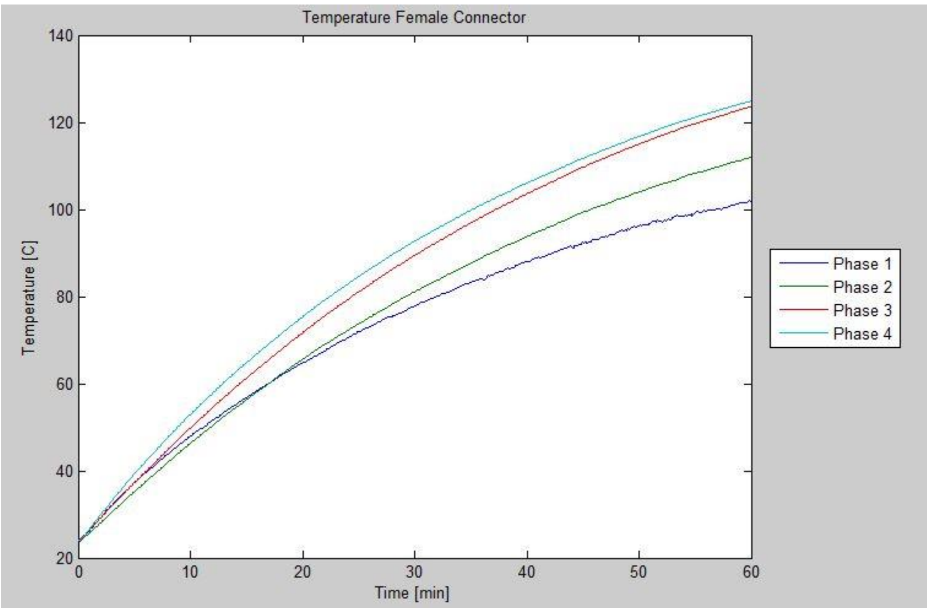

Figure 36 Showing test results test 2

5.1.3 **Test 200 A, 3h, continuous**

The third test results can be seen in Figure 17 and Figure 18. It is decided that test 3 is to be done at 200 A for 3 hours since the temperature started to reach 150 degrees Celsius at test 2. A clear stagnation in the temperature rate is seen after one hour. The maximum temperature seems to level out at around 107 degrees inside the male connector. Still there is a clear difference in temperature between the connectors and within them. The cables also stabilize in temperature at around 90 degrees. A noise is noticed at the sensor for the female phase 1.

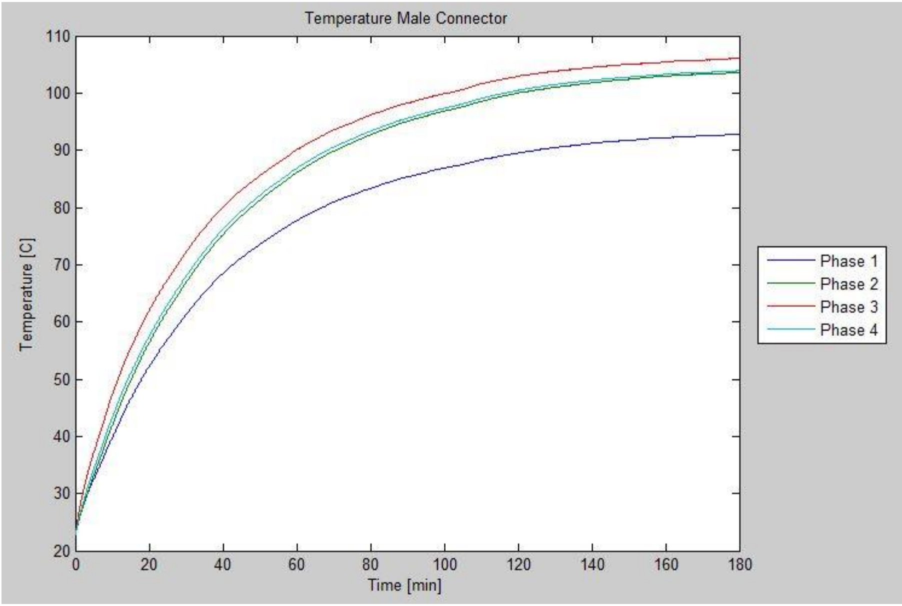

Figure 37 Showing test results test 3

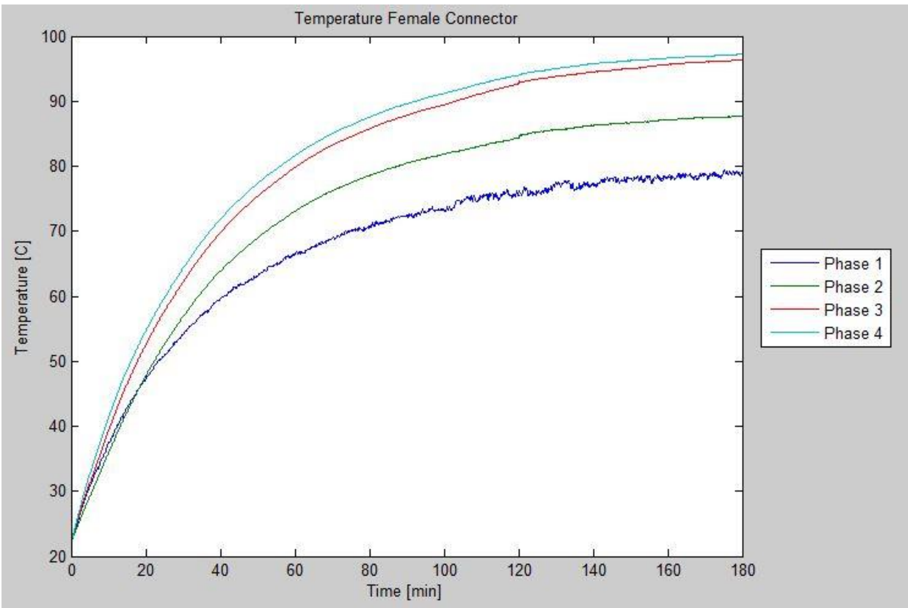

Figure 38 Showing test results test 3

5.1.4 **Test 200A, 2h, cycle**

The fourth test results can be seen in Figure 19 and Figure 20. Since the continuous test at 200 A is successful it is decided that a cycle test is to be performed at this current to discover any similarities or dissimilarities, when the connector is used as it will be in the application at Volvo CE. The test is performed for 2 hours. The cycle is 74 s of charging and 20 s setup time. This test is performed for 2 h. The result seems to have the same characteristics as for continuous testing, though the maximum temperature is lowered by around 10 degrees. The clear point of the temperature rate stagnation seems to be moved forward as well.

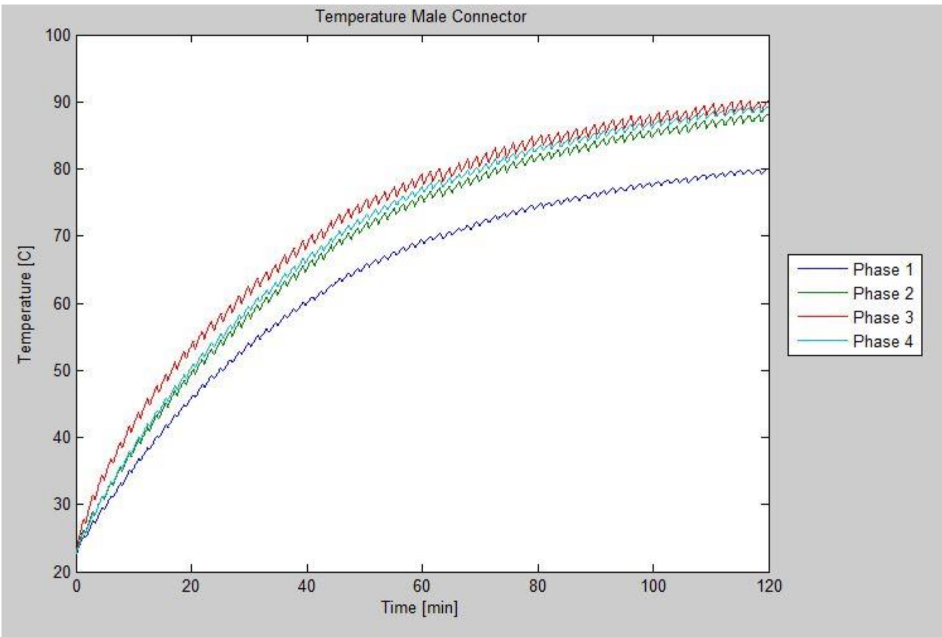

Figure 39 Showing test results test 4

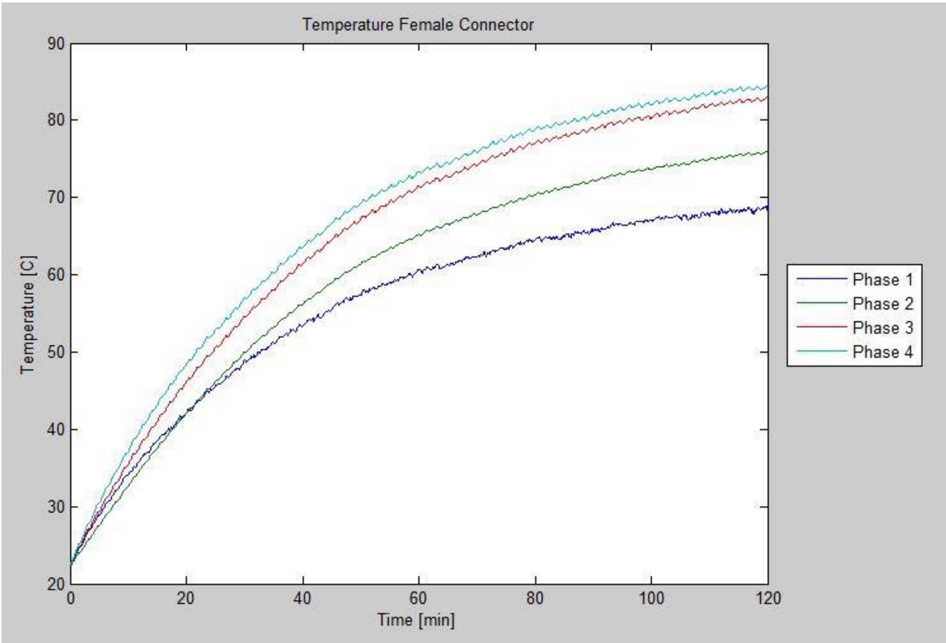

Figure 40 Showing test results test 4

5.1.5 **Test cooling, connected and disconnected**

After the test continuous testing at 200 respectively 250 A a cooling test is performed for 1 hour each. It is hard to draw any conclusions between these since they have different starting temperatures. The one seen in Figure 21 is when the connector is still connected and the one seen in Figure 22 is when the connector is disconnected before cooling. Both alternatives reaches about the same temperature after one hour, close to 35 degrees Celsius.

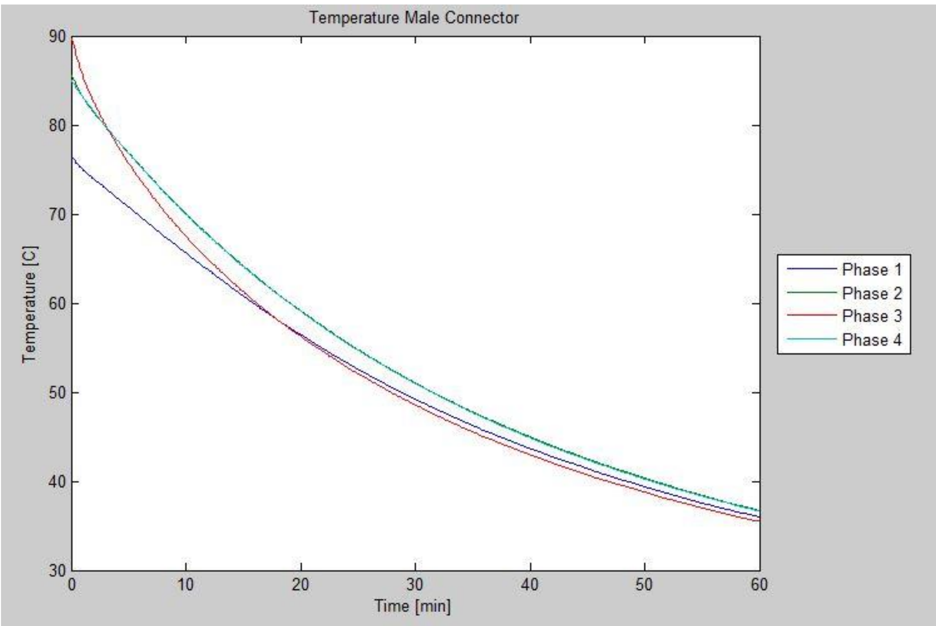

Figure 41 Showing test results test cooling connected

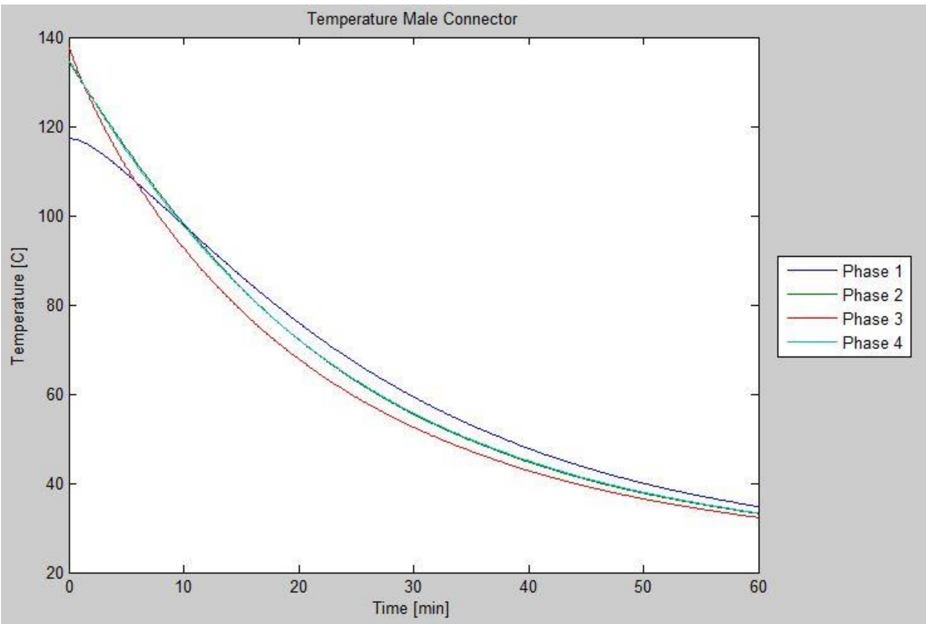

Figure 42 Showing test results test cooling disconected

5.1.6 **Test 150A, 3h, continuous**

The last test performed is a continuous test where all phases are loaded with 150 A for 3 hours. This is to simulate the application at Volvo CE where the total power transferred is 200 kW. As mentioned in this case when DC charging it is possible to use the phases coupled in pairs. Thus 150 A is run through all 4 phases. The result is that after three hours the maximum temperature is around 70 degrees. The temperature rate is close to zero, around 2-3 degrees Celsius per hour. See Figure 23 and 46 for illustration.

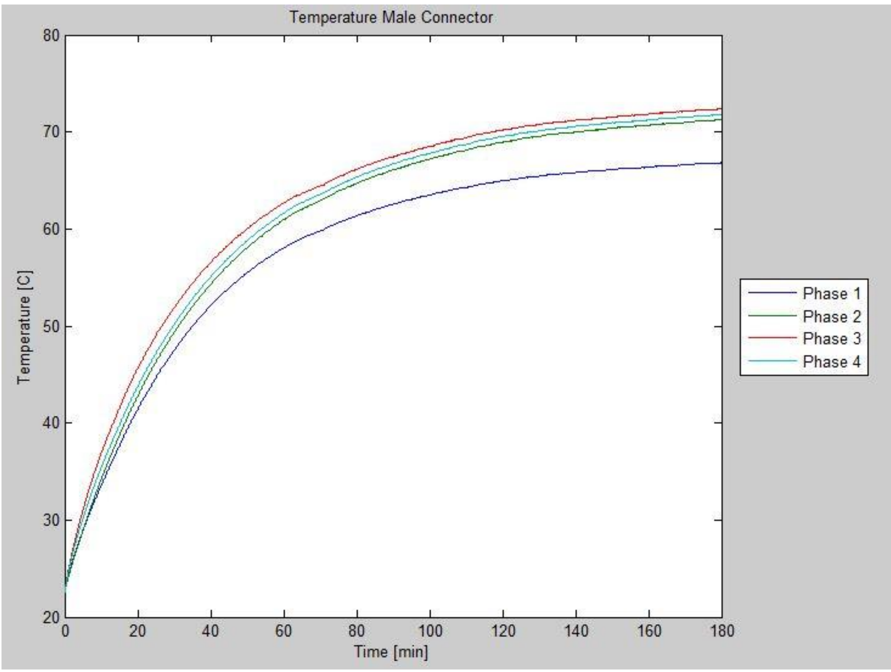

Figure 43 Showing test results test 5

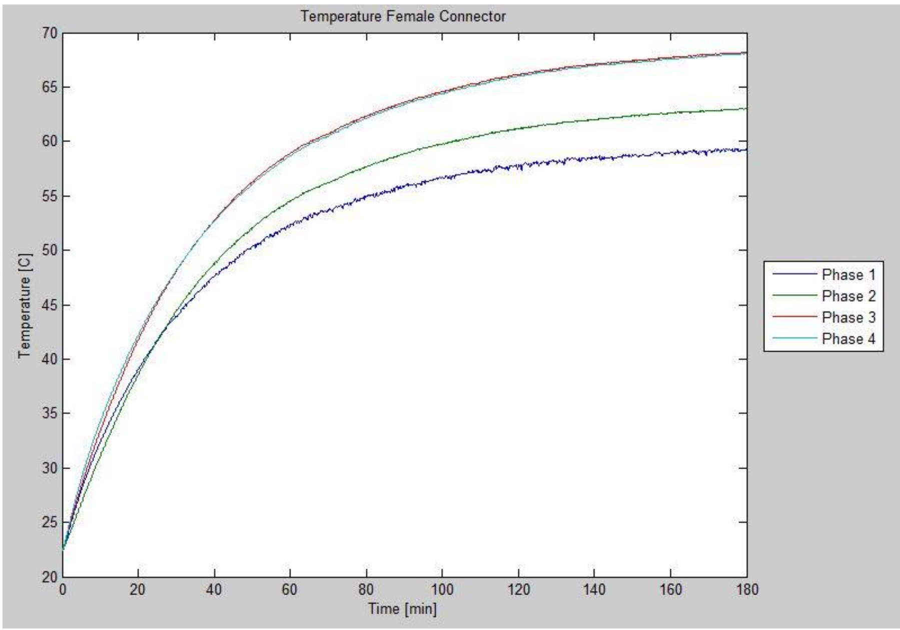

Figure 44 Showing test results test 5

5.2 Test, resistance

A test is performed to establish that there is enough insulation between the phases inside the male connector. Only the male connector is tested since that is where there is least distance between the phases. The test is performed by using a multimeter, FLUKE 1587 insulation multimeter. It is connected to the phases and puts a DC voltage of 1052 V over them. Then it measures the resistance in the insulation in between. The test is performed for all possible combinations of the phases 1&2, 1&3, 1&4, 2&3, 2&4, and 3&4 and the result is the same for all of them. The resistance is >2.2 GΩ. This is more than enough for a connector which is supposed to carry 640 V DC at the most.

6 Discussion and conclusion

6.1 Concept development

Most of the discussions regarding the concept work is already presented in the chapter since it is used as a base for the decisions made. Though there are still some things worth discussing further.

The methodology chosen for this thesis is very applicable. It is a well proven base for product development within the industry. Though there are other methodologies that would have worked just as well, maybe even better. For example an iterative process might have given an equal result. There is a greater need of resources when applying this method though it helps you solve many of the child deceases fast and early in the process. There are a few problems that never would have occurred if this methodology was chosen.

If the connector is to be developed further it would be recommended that an at least partly iterative process is applied. For example on the size problem with the cables or with the funnel used as a guiding system. This would require resources but it would probably give the fastest result.

6.2 Connector

The connector developed in this project is around 50% of the size of the old prototype. One of the main objectives for the development was just this, the size needed to be reduced. Most of the reduction is made on the width of the connector and most is made on the male connector. The reduction in size is mainly possible due to the new concept developed by BalSeal, without their spring coils it would have been tough to design a connector this small.

Another objective for the project is to make the connector easier to manufacture. The connector using the BalSeal technology takes away the need for connecting 150 separate blocks to small bundles of cable. Instead a spring coil is mounted in a housing. The cables are connected on one point per phase. The prototype developed in this project is much easier to assemble and the parts are easier to manufacture.

There is an objective stating that 300 A should be carried continuously without damage to the connector or the surrounding systems for both AC and DC charging. This is not achieved in this project. The connector is not dimensioned to carry more than 200 A continuously. During the test on 250 A the temperature on one sensor reaches 150 degrees Celsius after 1 h. The temperature rate is very low at this point, but it is still too high to assume what temperature will be the highest.

Through discussions among the student and the supervisors it is concluded that the temperature probably should be kept under 100 degrees Celsius during lab tests if the connector should be considered stable enough for the application. It is also the conclusion that if the male connector were to be increased by 3-4 cm in diameter, it would not only allow larger cables to be used but also it would be likely to be able to carry around 300 A continuously and still remaining under 100 degrees Celsius.

Even though the connector did not achieve the objective regarding current, it is still a big step forward on the area of connectors. There are no counterpart with around the same size transferring 200 A. This transfers to around 138 kW for AC three phase charging and 512 kW DC two phase charging.

Though regarding the requirements for the application at Volvo CE, the connector is very well designed. The temperature after 3 hours continuous testing is just above 70 degrees Celsius. It is known from the cyclic test that the temperature will be lower, maybe even 10 degrees lower if the connector is used in the cycle thought in Volvo CE's application. This implies that it might not even be necessary to implement the extra flexible cables presented in the thesis. This should of course be tested further, but since the temperature in the testing only got to 70 degrees and 35 mm^2 are used it might be possible to use these in the application as well.

6.2.1 **Male**

The male connector is quite simple to assemble. However there are problems with 3D-printing a skeleton which does not have tolerances fine enough to use as a mould for the epoxy. There are small gaps between the phases and the skeleton, which allows the plastic resin to sip through. For the prototype in this project these are sealed before filling up the male connector.

If the connector is developed further there should be more of the skeleton that keeps the bars going through it in place during the assembling. In this prototype it is more or less only the last top part that is making sure the bars are separated by enough space. It would be simpler to have this feature on more places in the skeleton.

The brazing and the following heat treatment is time consuming. If the connector is further developed it should be considered to manufacture a solid piece instead of two. This might be possible without having a high demand on complex equipment.

6.2.2 **Female**

There are not many changes made to the concept of this connector compared to the previous prototype. The main change is the fastening of the cables and the phase rings are adjusted for the BalSeal concept instead. This is due to the simplicity of the female connector concept. The phases can be mounted separately and it is very simple to disassemble and assemble the connector. This is important because one of the coil rings might break. If it was not possible to disassemble the connector it could be very hard to get a new coil spring inside its housing.

6.3 Automated connection

It is unfortunate that there were complications and delays in the project regarding the connector. It would have been very interesting to develop the concept further and make a simple prototype to test the system. Today it is common to try to make robotic arms as light as possible thus increasing the flexibility and instability as a negative consequence, therefore it would have been exciting to focus on making the arm stiff for one distance and flexible for another. Especially when this is solved by a mechanical solution instead of control.

6.4 Testing

Testing the current without the full level of voltage is made upon the assumption that this will not affect the thermal situation notably. This is a common assumption made when looking at the temperature in current carrying constructions. This decision is also based upon the experience of the supervisors at LTH. This assumption should not affect the test negatively.

The choice of using the LXI Data Acquisitions Unit is made based on experience in using the hardware and its availability at LTH. It is simple to use since it is logging all numbers on a USB-stick in the form of a matrix.

The number and placement of the sensors is made upon limitations of space and time. It would be nice to have more sensors showing the development within the male connector plastic, this to ensure that no hotspot is located in the plastic. Though it is not possible to motivate the time and effort to ensure that the sensors are exactly where they are supposed to be within the plastic. Also it would probably not give any surprising results. Theoretically the warmest parts should be in contact with the phases. This is the reason two of the sensors in the male connector is placed at the bars instead of in contact with the phase-rings. It is also shown that this is where the temperature in the connector is the highest. This is probably because it is close to the connection between the bars and the cables. This connection is theoretically the most heat generating part of the connector since it is the toughest part to have a good connection in. This is also implied by the testing since phase number 3 is generally 5-10 degrees higher than the rest of the sensors in the male connector. In theory it would naturally be higher than phase one since there are four phases quite close to the sensor compared to number ones single phase in the bottom of the connector.

From test one it is not clear what temperature the connector will reach when it levels out towards a stable state. The temperature rate is still too high. Though during the last part of the test it is showing a tendency of slowing down the temperature rise.

Test two shows a more stagnating curve even if the temperature in total is higher than in test one. It can be concluded that the connector cannot handle 250 A continuously without reaching damaging levels of temperature. During the test the temperature reaches around 145 degrees Celsius at one sensor and this is too high. The connector should only reach around 100 degrees Celsius as a maximum if it is to be used at a larger scale to ensure that it will not damage surrounding systems.

Test three is done as a result of the test two resulting in a high temperature, test one stopped at around 90 degrees and might level out around 100 degrees, thus test three is performed at 200 degrees over 3 hours. The result is a graph with a clear stagnation in the temperature rate. Even if it at steady state is not achieved the temperature rate is very low at the end of the test.

The next step is to test the connector for a cyclic load over time. The behavior is the same for the overall graph as for the rest of the tests, though the temperature is around 10 degrees lower on all the sensors compared to the continuous test. The difference between the phases are also lower than for the continuous test. This is theoretically understandable since the temperature moves slower through the plastic material than for the copper, the temperature should thus become more even through the connector when small pauses are introduced. Also it can be concluded that this is the worst case scenario for the connector since both the same male and the female connector is used in every cycle. In the application a new vehicle will arrive for every new cycle, this should lower the total temperature even further.

The one conclusion that can be drawn from the cooling test is that the connector has a higher temperature rate when disconnected from one another. After one hour the temperature is about the same even though the starting temperature is different.

Test 5 proves that the connector is very applicable for the Volvo CE situation. The maximum temperature when continuous current is used is not in a dangerous region for the surrounding systems. As discussed this might even enable that less expensive and smaller cables can be used. It is seen as a success that the connector can be used for the application, even if not all requirements are fulfilled.

Regarding the test concerning resistance it is performed as a proof that the plastic used is enough to insulate the phases. This is very important since the phases are located at quite a close distance from each other inside the male connector. The result 2.2 GΩ between all phases is good. There is no chance that there will be a problem with normal use of the connector regarding the insulation in the connectors.

There are numerous tests that would be very interesting to perform. Such as lifetime test, by inserting and retracting the connector over 1’000’000 times and study the result. Looking at the tensile strength and maximum bending moment etc. would be very interesting as well. Also the maximum capacity both for current and voltage would be interesting to test. For example over 1 s, how much current can pass through each phase with no damage? Or how much voltage induces an arc through the air? These are all interesting tests to perform though it is something for the future since there are limitations in time and resources for the thesis.

As a conclusion to the thesis work it is overall a success. Even though the objective is not fully reached it is still a big improvement on today’s connectors in the industry. At least when focusing on size and current capacity. The requirements on size could probably have been a bit lighter since there are more space to work with on the load receiver, though it is good to have a minimum size of the connector to refer to. The concept is working without any discovered defects and it would theoretically work for 300 A for AC charging as well if simply scaled up a few centimetres in diameter.

7 References

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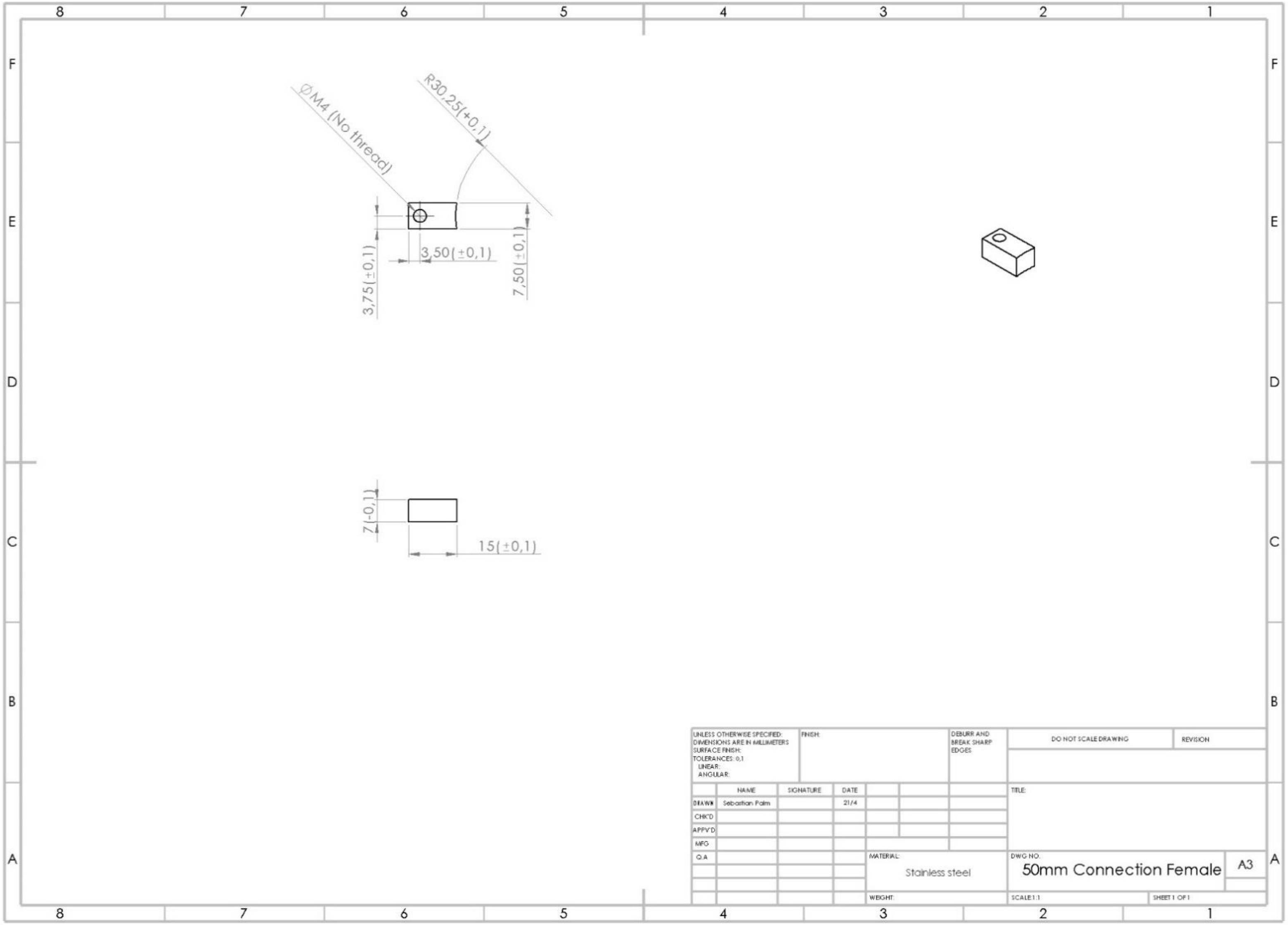
[13] Haraldphil.com, *Material data sheet Hovadur CCNB:* http://www.haraldpihl.com/attachments/036_HOVADUR%20CCNB.pdf

Appendix A Technical drawings of all metal components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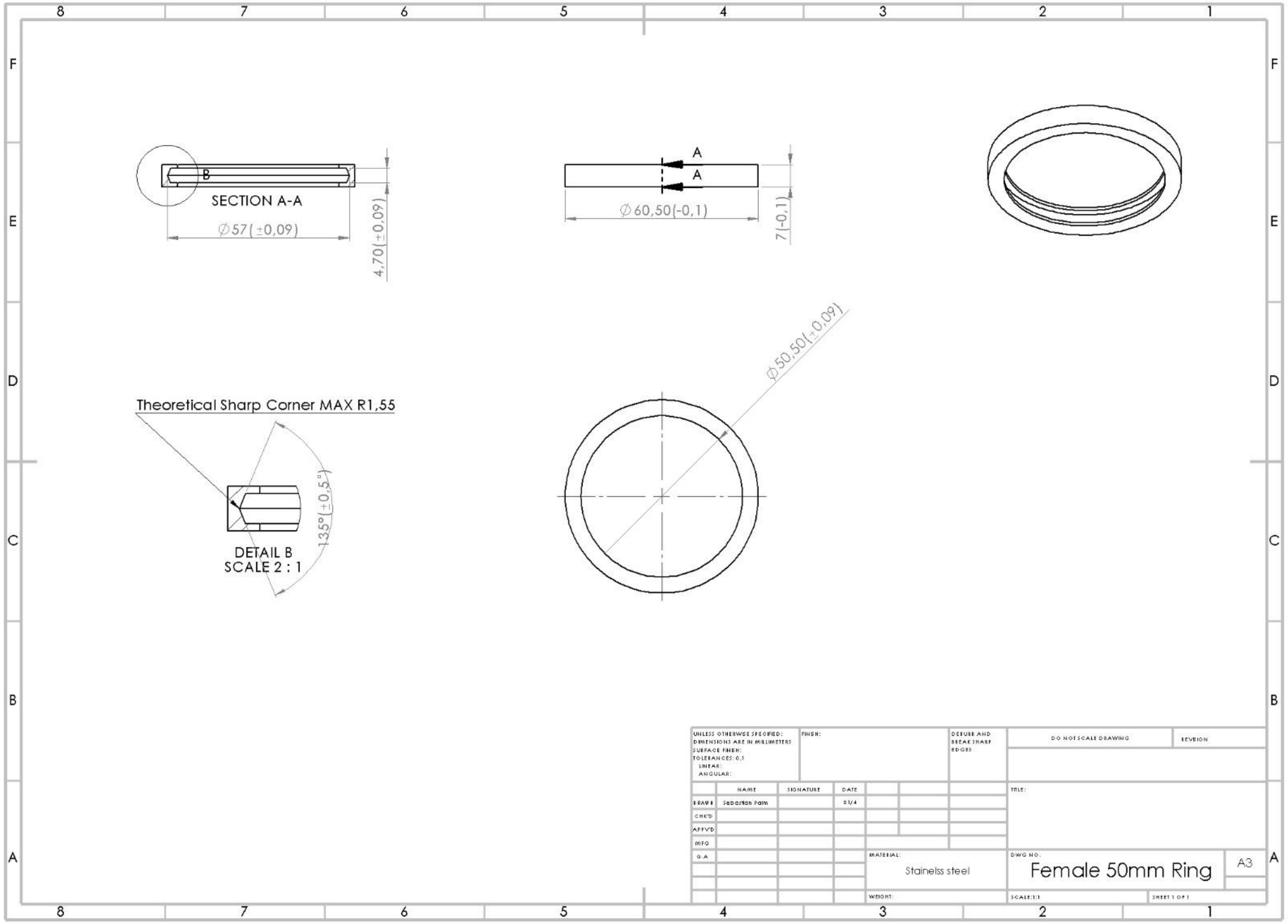
R30,25(+0,1)
3,50(±0,1)
3,75(±0,1)
7,50(±0,1)
7(-0,1)
15(±0,1)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: 0,1
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Sebastian Palm
21/4
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
Stainless steel
WEIGHT:
TITLE:
DWG NO.
50mm Connection Female
A3
SCALE:1:1
SHEET 1 OF 1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B
∅57(±0,09)
4,70(±0,09)
A
A
∅60,50(-0,1)
7(-0,1)
∅50,50(±0,09)
Theoretical Sharp Corner MAX R1,55
135°(±0,5°)
DETAIL B
SCALE 2 : 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: 0,1
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
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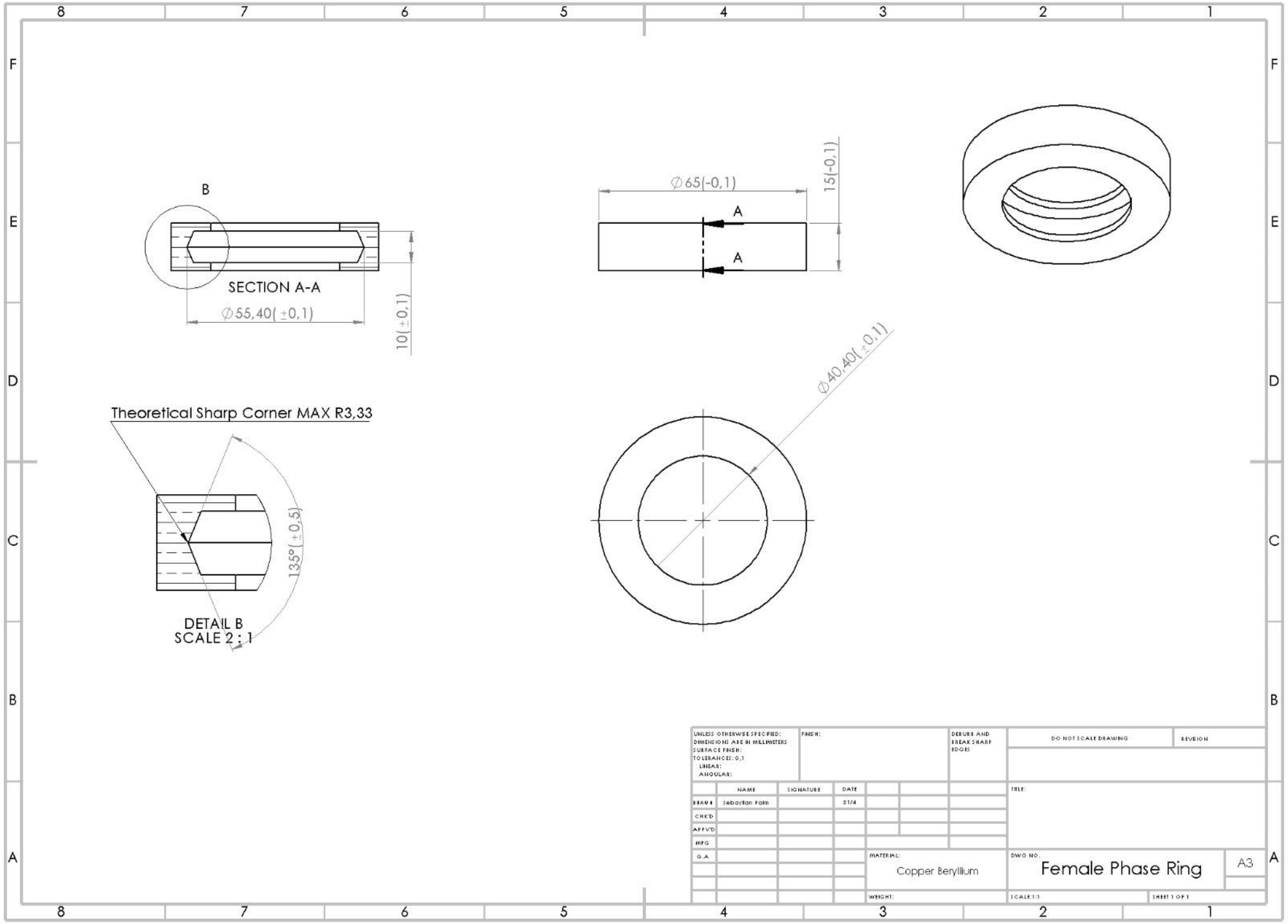
NAME
SIGNATURE
DATE
DRAWN
Sebastian Palm
21/4
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
Stainelss steel
WEIGHT:
TITLE:
DWG NO.
Female 50mm Ring
A3
SCALE:1:1
SHEET 1 OF 1



B
SECTION A-A
⌀55,40(±0,1)
10(±0,1)
⌀65(-0,1)
15(-0,1)
A
A
⌀40,40(±0,1)
Theoretical Sharp Corner MAX R3,33
135°(±0,5)
DETAIL B
SCALE 2 : 1
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DIMENSIONS ARE IN MILLIMETERS
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TOLERANCES: 0,1
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Sebastian Palm
21/4
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
Copper Beryllium
WEIGHT:
TITLE:
DWG NO.
Female Phase Ring
A3
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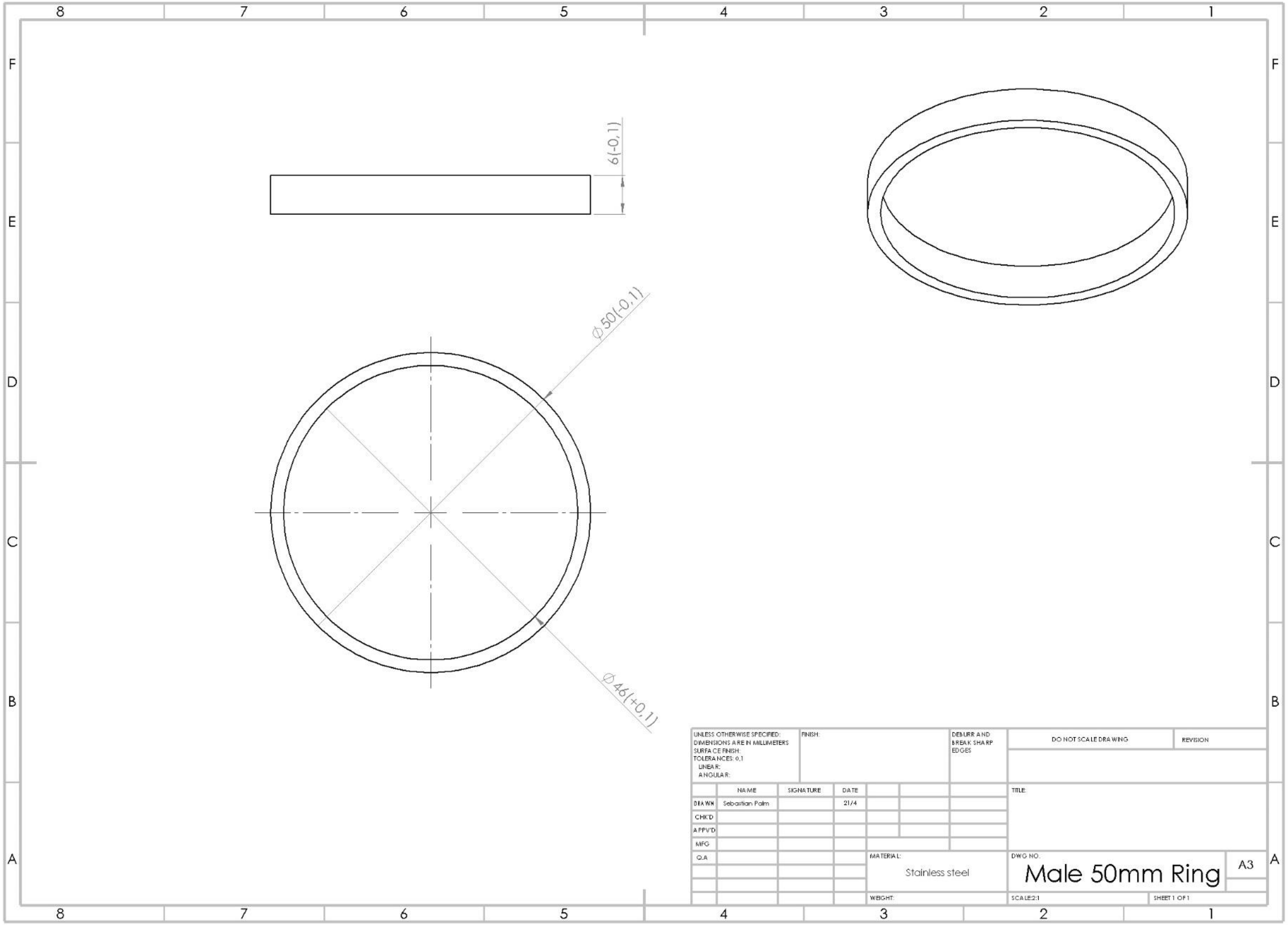
SHEET 1 OF 1


6(-0,1)
Ø50(-0,1)
Ø46(+0,1)
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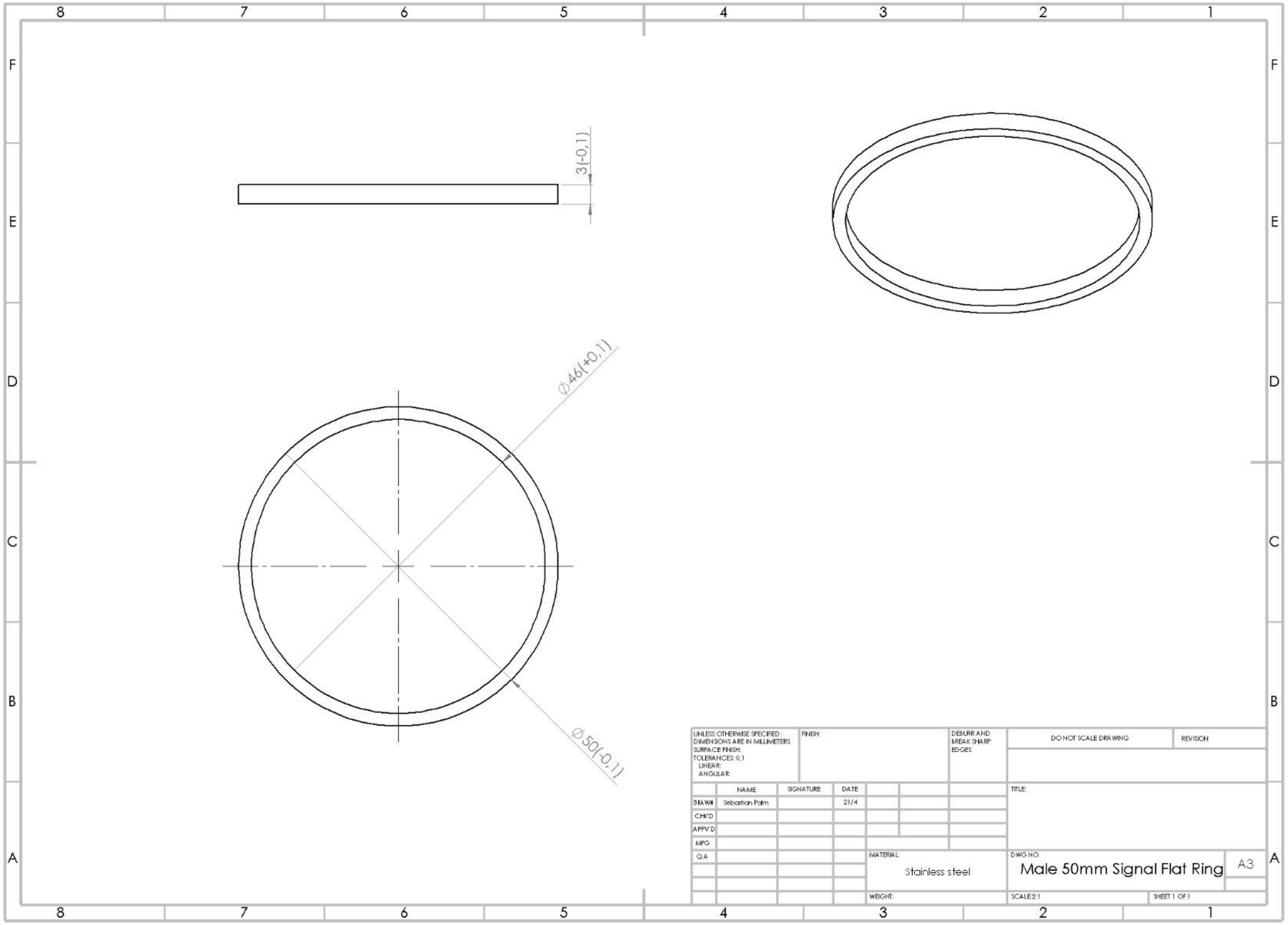
TOLERANCES: 0,1
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Sebastian Palm
21/4
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
Stainless steel
WEIGHT:
TITLE:
DWG NO.
Male 50mm Ring
A3
SCALE:2:1
SHEET 1 OF 1


3(-0,1)
Ø46(+0,1)
Ø50(-0,1)
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TOLERANCES: 0,1
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Sebastian Palm
21/4
CHK'D
APPV'D
MFG
Q.A
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WEIGHT:
TITLE:
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Male 50mm Signal Flat Ring
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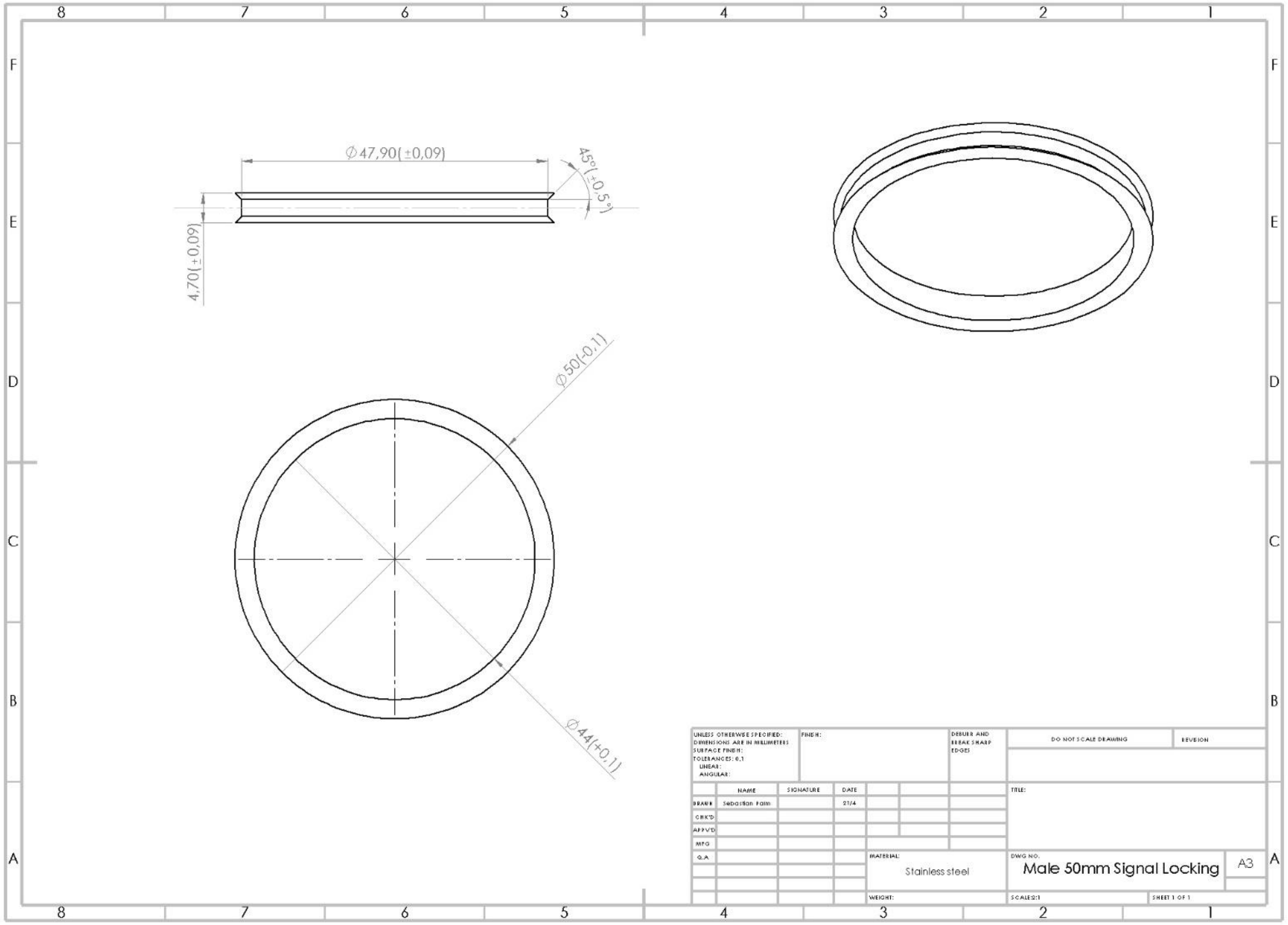
SCALE:2:1
SHEET 1 OF 1



Ø47,90(±0,09)
45°(±0,5°)
4,70(±0,09)
Ø50(-0,1)
Ø44(+0,1)
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LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Sebastian Palm
21/4
CHK'D
APPV'D
MFG
Q.A
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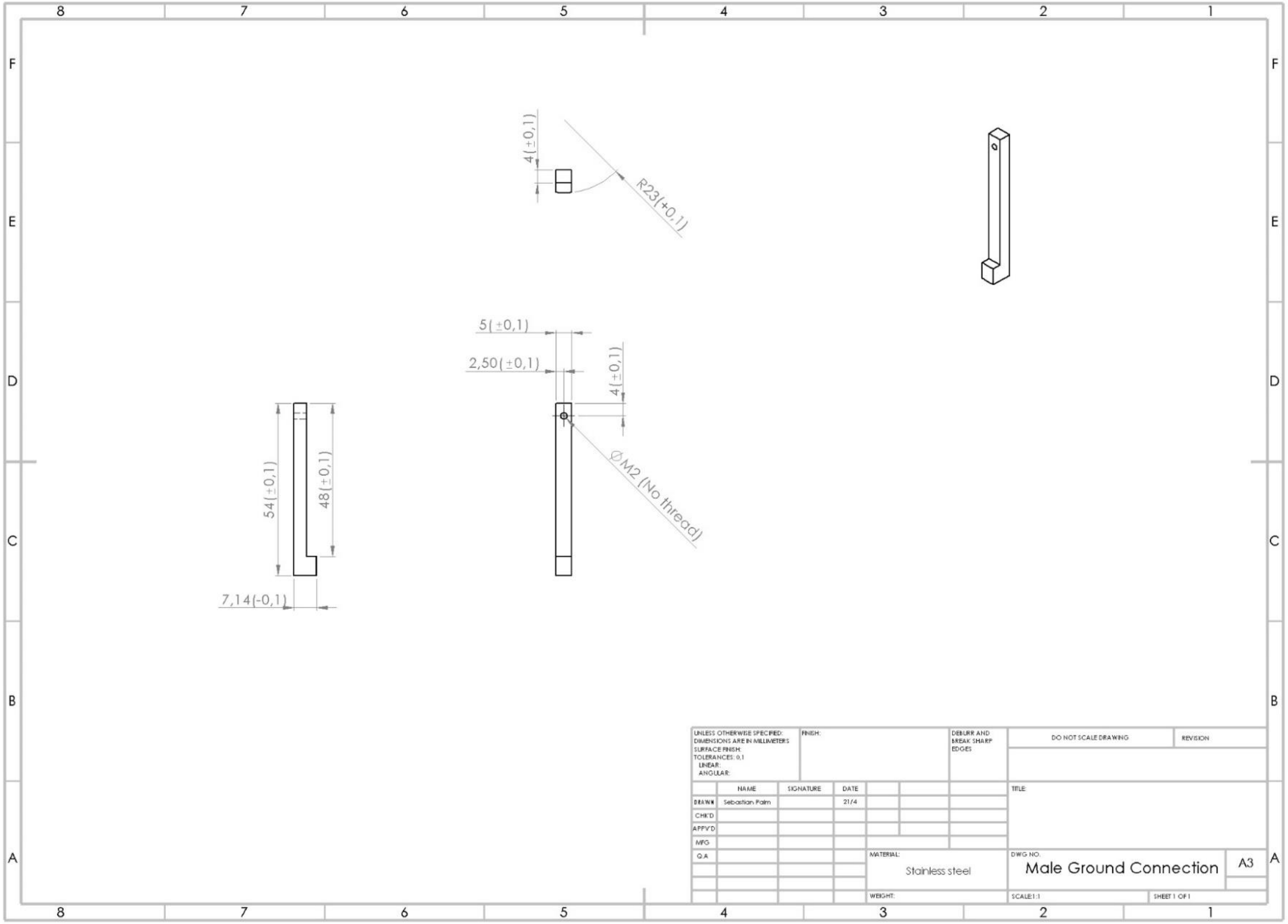
MATERIAL:
Stainless steel
DWG NO.
Male 50mm Signal Locking
A3
WEIGHT:
SCALE:2:1
SHEET 1 OF 1


4(±0,1)
R23(±0,1)
5(±0,1)
2,50(±0,1)
4(±0,1)
∅M2 (No thread)
54(±0,1)
48(±0,1)
7,14(-0,1)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
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LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
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Sebastian Palm
21/4
CHK'D
APPV'D
MFG
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Stainless steel
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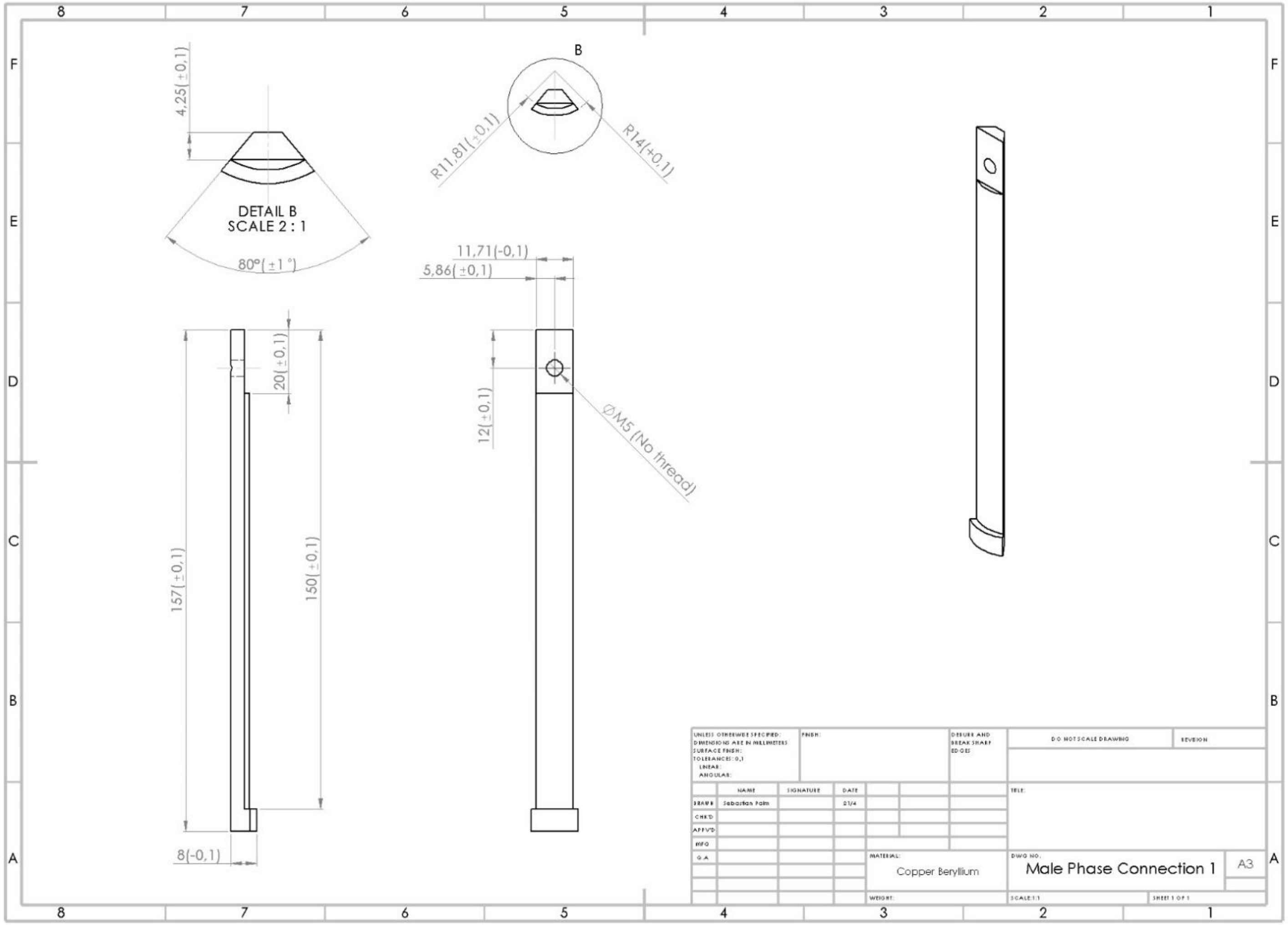
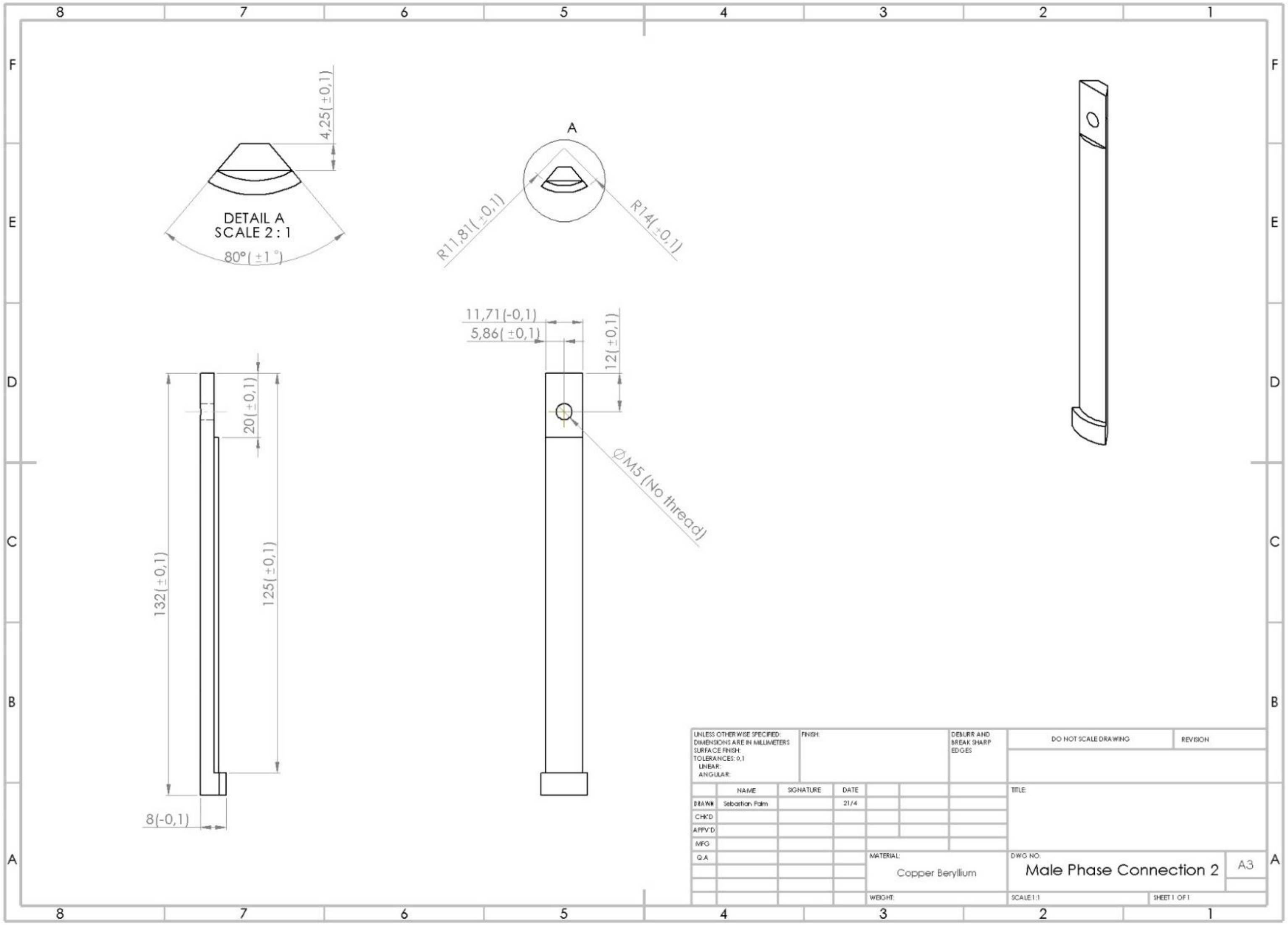
Male Ground Connection
A3
WEIGHT:
SCALE:1:1
SHEET 1 OF 1



4,25(±0,1)
B
R11,81(±0,1)
R14(±0,1)
DETAIL B
SCALE 2 : 1
80°(±1°)
11,71(-0,1)
5,86(±0,1)
20(±0,1)
12(±0,1)
ØM5 (No thread)
157(±0,1)
150(±0,1)
8(-0,1)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: 0,1
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Sebastian Palm
21/4
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
Copper Beryllium
DWG NO.
Male Phase Connection 1
A3
WEIGHT:
SCALE:1:1
SHEET 1 OF 1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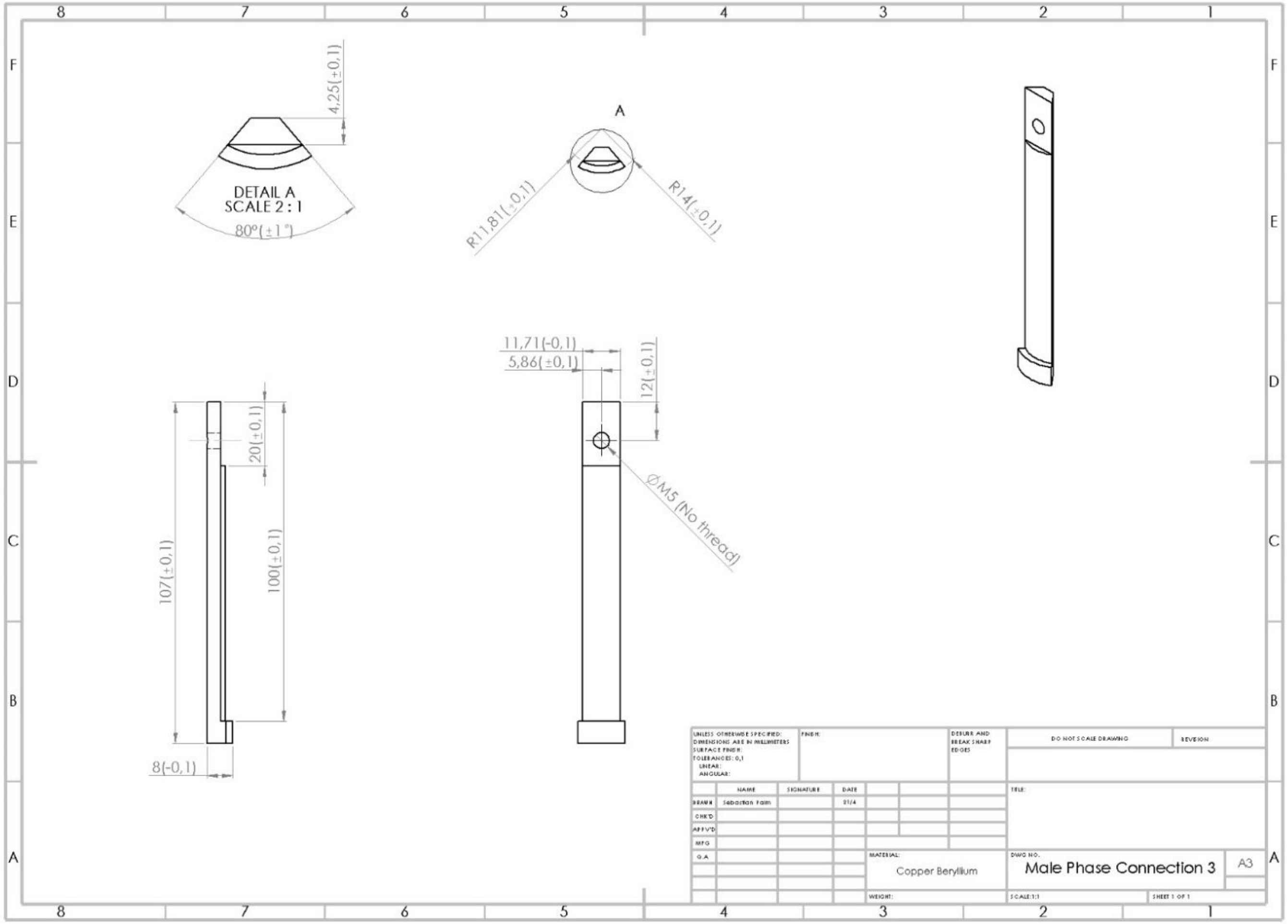
SCALE 2 : 1
4,25(±0,1)
80°(±1°)
A
R11,81(±0,1)
R14(±0,1)
11,71(-0,1)
5,86(±0,1)
12(±0,1)
20(±0,1)
132(±0,1)
125(±0,1)
8(-0,1)
ØM5 (No thread)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: 0,1
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Sebastian Palm
21/4
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
Copper Beryllium
WEIGHT:
TITLE:
DWG NO.
Male Phase Connection 2
A3
SCALE:1:1
SHEET 1 OF 1



4,25(±0,1)
DETAIL A
SCALE 2 : 1
80°(±1°)
A
R11,81(±0,1)
R14(±0,1)
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5,86(±0,1)
12(±0,1)
20(±0,1)
107(±0,1)
100(±0,1)
8(-0,1)
ØM5 (No thread)
UNLESS OTHERWISE SPECIFIED:
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SURFACE FINISH:
TOLERANCES: 0,1
LINEAR:
ANGULAR:
FINISH:
DEBURR AND
BREAK SHARP
EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Sebastian Faim
21/4
CHK'D
APPV'D
MFG
Q.A
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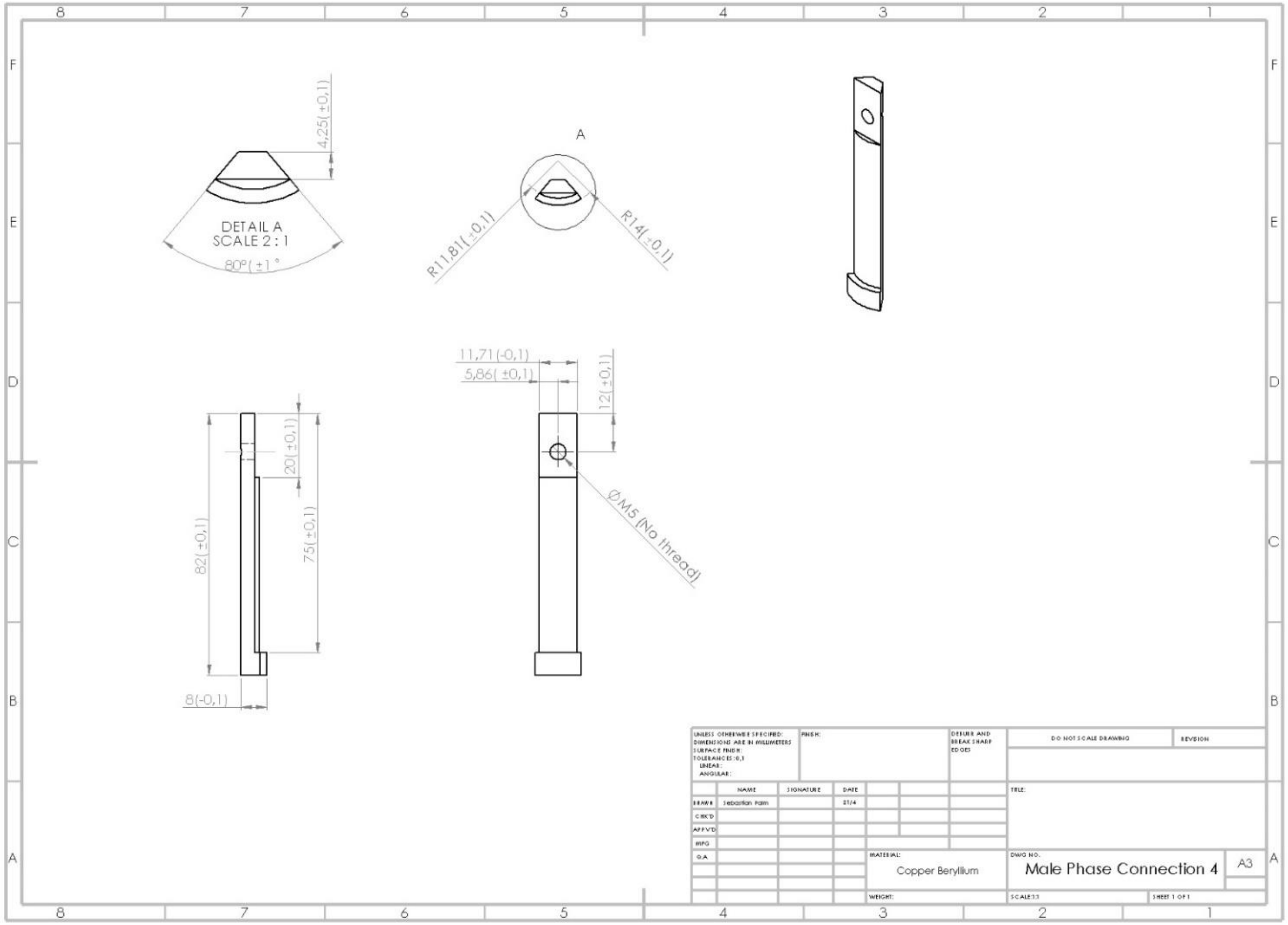
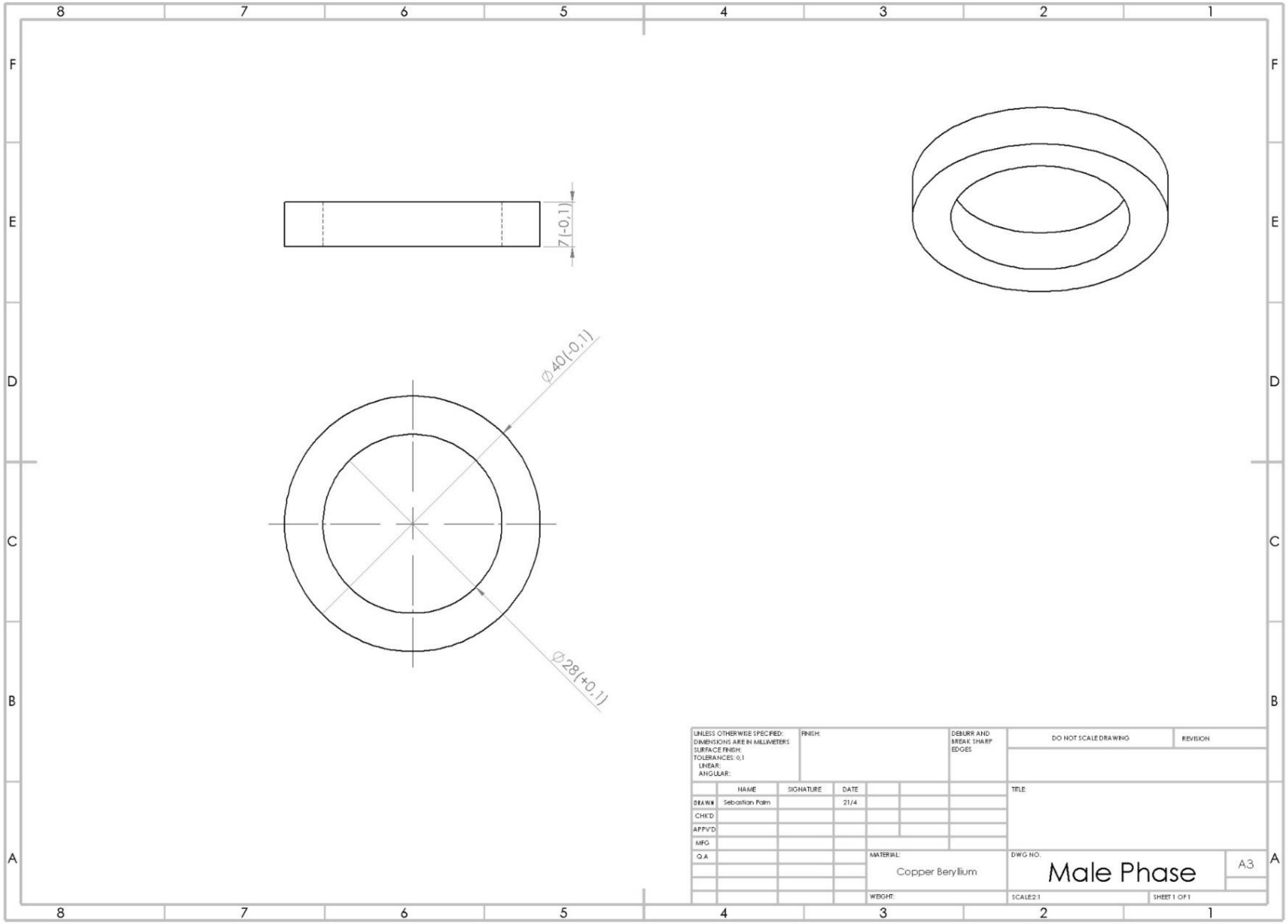
DWG NO.
Male Phase Connection 3
A3
WEIGHT:
SCALE:1:1
SHEET 1 OF 1



DETAIL A
SCALE 2 : 1
4,25(±0,1)
80°(±1°)
A
R11,81(±0,1)
R14(±0,1)
11,71(-0,1)
5,86(±0,1)
12(±0,1)
20(±0,1)
82(±0,1)
75(±0,1)
8(-0,1)
ØM5 (No thread)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:0,1
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Sebastian Palm
21/4
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
Copper Beryllium
WEIGHT:
TITLE:
DWG NO.
Male Phase Connection 4
A3
SHEET 1 OF 1


7 (-0,1)
Ø40(-0,1)
Ø28(+0,1)
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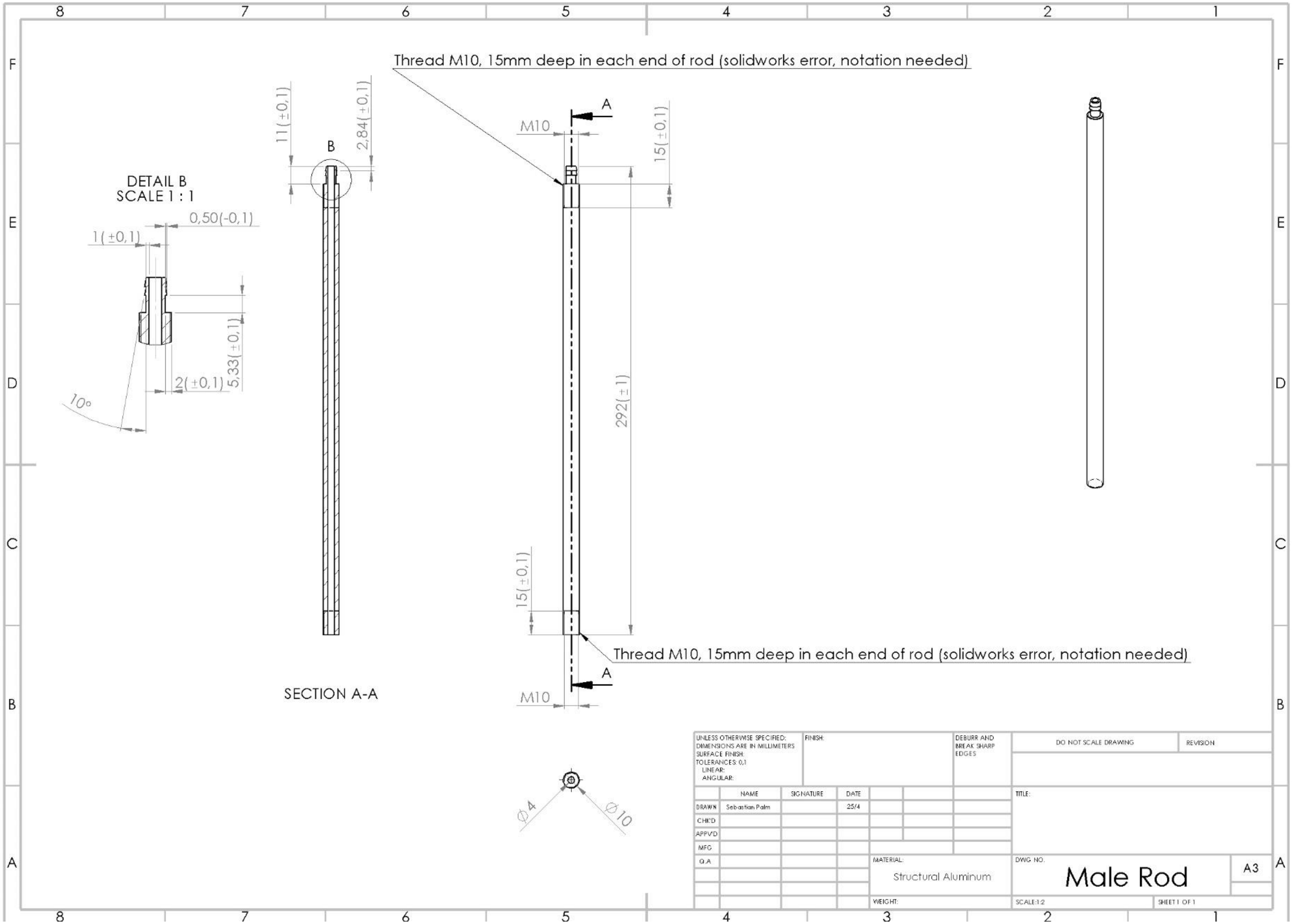
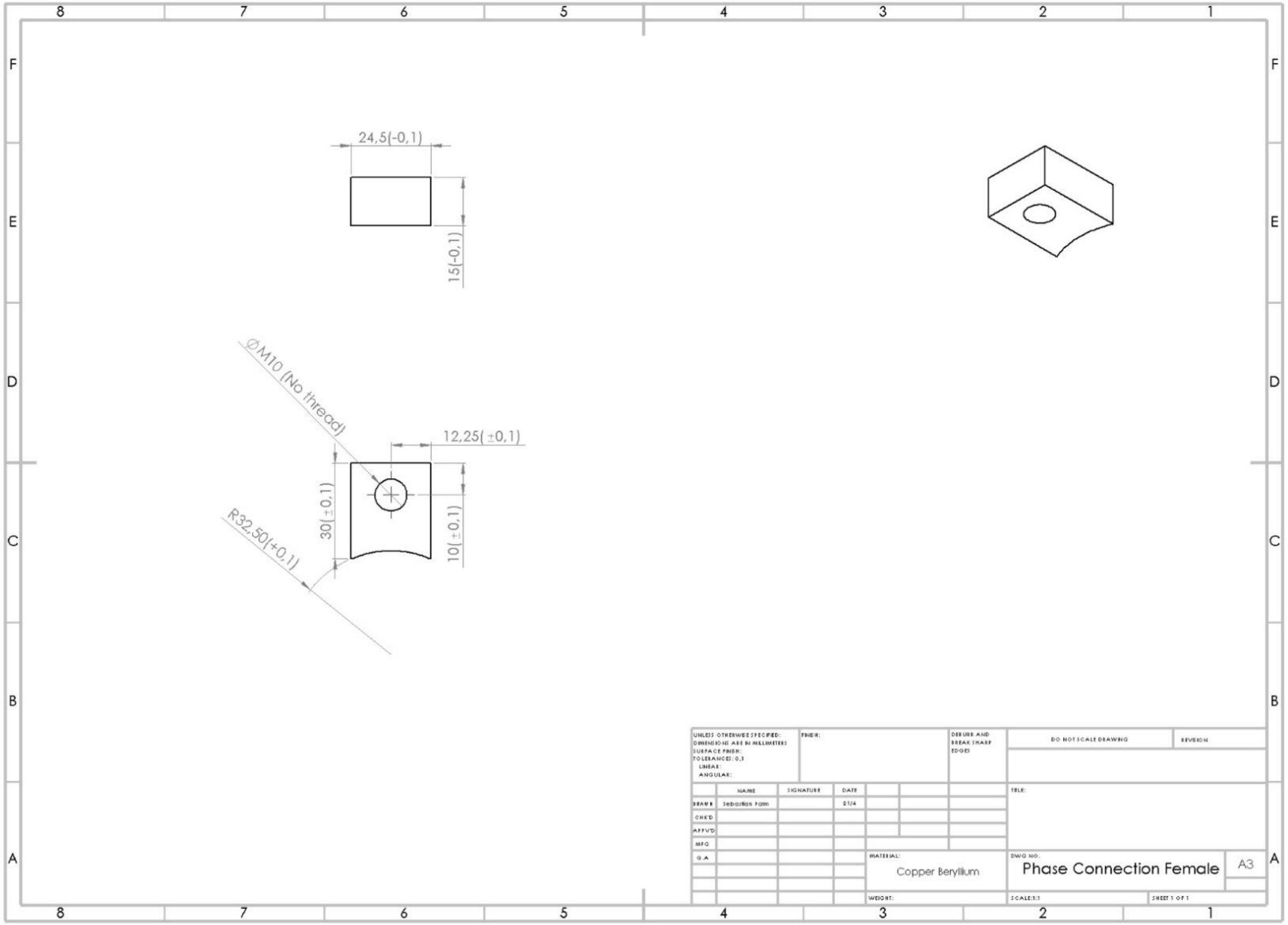
SURFACE FINISH:
TOLERANCES: 0,1
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Sebastian Palm
21/4
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
Copper Beryllium
WEIGHT:
TITLE:
DWG NO.
Male Phase
A3
SCALE2:1
SHEET 1 OF 1


Thread M10, 15mm deep in each end of rod (solidworks error, notation needed)
DETAIL B
SCALE 1 : 1
1(±0,1)
0,50(-0,1)
5,33(±0,1)
2(±0,1)
10°
11(±0,1)
2,84(±0,1)
B
SECTION A-A
A
M10
15(±0,1)
292(±1)
15(±0,1)
Thread M10, 15mm deep in each end of rod (solidworks error, notation needed)
A
M10
⌀4
⌀10
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: 0,1
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Sebastian Palm
25/4
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
Structural Aluminum
WEIGHT:
TITLE:
DWG NO.
Male Rod
A3
SCALE:1:2
SHEET 1 OF 1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15(-0,1)
ØM10 (No thread)
12,25(±0,1)
30(±0,1)
10(±0,1)
R32,50(+0,1)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: 0,1
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Sebastian Palm
21/4
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
Copper Beryllium
TITLE:
DWG NO.
Phase Connection Female
A3
WEIGHT:
SCALE:1:1
SHEET 1 OF 1