

Thesis – Sector Assembly Tests

ATLAS New Small Wheel

Advise for the ATLAS New Small Wheel sector assembly test

Version: 2



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Preface

As a Dutch student from the study Engineering, Design and Innovation I, Daan Zaalberg, perform the bachelor internship during my graduating year of the study. It was a great opportunity to graduate at CERN.

The Thesis is written to explain my work I did at CERN but most of all it is to keep the information I figured out available for future projects and for the final assembly procedure.

The thesis is written for the colleagues at CERN who have to work with the sector assembly. Also for the University of Amsterdam to explain my work and to graduate the study Engineering Design and Innovation

First of all I want to say thanks to my supervisor at CERN Patrick Ponsot, who supported me during my thesis and project as well for Stephanie Ulrike Zimmermann for the support during my bachelor Special thanks to Patrick Werneke who arranged the possibility to get me at CERN.

Also I want to thank Job van der Grinten as my coach during my graduation internship. But I could not do the graduating without the other teachers of the university of Amsterdam who gave me all the information I needed to be a good engineer.

In the end I want to say thanks to my colleagues for the good lunches and support during my project, my roommate for support during the project and my father who supported me during my stay at CERN.

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Abstract

During the thesis, I worked on the sector assembly where the different plates of the New Small Wheel detector will be connected together. The main question is:

“How to minimize the deformation in the total sector while assembling the small Thin Gap Chamber on the MicroMegas?”

To find the answer on the question is done desk research and simulations. At the end, the results will be checked with a sector assembly test with laser survey. The most important factor during the assembly is to minimize the deformation during the complete assembly steps. The imported parts of the sector are the spacer-frame, MicroMegas detectors (MM) and the small-strips Thin Gap Chambers (sTGC). All the different detectors (MM and sTGC) have their own connection with the spacer-frame. The deformation in the wedges and frame is within the tolerance. The total deformation is 706 μ m. The individual deformation is less than the total acceptable deformation. The deformations get higher when the sector is in a swing. The advice is to minimize the swing when the sector is hanging on two points during the complete assembly with cables. A pillar is designed to fix the sector in Z direction and stop from swinging. Finally, to reach a higher precision on the connection points from the sTGC connections tolerances are changed, also the assembly station is updated.

To prove that the deformation of the sector assembly is within the tolerances a survey measurement with a laser tracker was done during the sector assembly. The behaviour of the deformation is as expected. With a total deformation of 1300 μ m, the extent is higher because of using dummy detectors and small mistakes during the assembly. For the serial production, the assembly must be done precise and with care to avoid mistakes.

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Glossary and abbreviations

KM	Kinematic mount, 3 point connection but deformation is still possible.
NSW	New Small Wheel
MM	MicroMegas
MM-DW	MicroMegas double wedge (the MM quadruplets/modules with the spacer frame)
sTGC	Small-strips Thin Gap Chamber
M0	Module zero (test module with special test planes).
Wedge	Complete plane of a detector (for MM is that SM1+SM2 modules and then the one sTGC)
Module	Component SM1 and SM2 will be named as module
Interface	Connection points for the tooling and wedges
Quadruplet	Is a module
SM1	Small module 1 (Inner module of the MM)
SM2	Small module 2 (Outer module of MM the biggest one)
Grabber mount	Connection point for manipulation and movement of the sector
Survey	Meeting
Assembly	Mounting, Connection of different parts

1 Introduction

1.1 Project Background

To finish the study engineering design and innovation I did my bachelor thesis at CERN on an already running project. CERN is the European Organization for Nuclear Research. [1] The setup of CERN is a beam pipe mounted in a 27km ring at 100m under the ground and which has four detectors installed. In the beam pipe, the so-called Large Hardon Collider (LHC), the particles have a velocity that is almost the speed of light and have a collision in all the detectors. The detectors will detect how the particles behave at the moment of the impact. To get better and new results the energy of the beam has been progressively increased from 8 TeV to 13 TeV [2]. In addition the luminosity of the beam will be increased by a factor 5 beyond 2025 . [2] To reach the high luminosity of the beam the LHC and the detectors must provide some updates.

The project for the bachelor thesis is about the ATLAS detector, the biggest detector in the setup. The ATLAS detector looks for Higgs particles and dark matter. The detector is build up out of different peelings of detectors layers according to Figure 1 Atlas detector structure

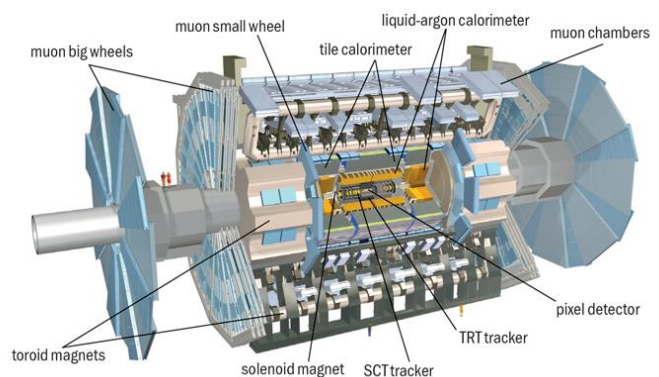


Figure 1 Atlas detector structure [3]

The project is about the muon small wheel on both sides of the inner detectors. The New Small Wheel (NSW) is part of the muon detectors that detect the muon particles. The Muon detectors are the outer detectors of the ATLAS experiment. The muon detectors work by the difference in voltage fields. When a particle goes through the tension field the tension will change and the differences will be detected. [4] Because of the higher luminosity update the two SWs will be replaced. In the large shutdown in 2019-2020 the old (Small Wheel) SW will be replaced by the NSW. The NSW project is in the finale phase with detailing, assembling and testing.

The assembly of the NSW consists of a mainframe with different sectors. Each NSW has a 10 meter diameter and is built with eight small and eight larger sectors which are overlaying together around the main axes. Because of the overlay the sectors forms a closed surface. Each sector exists with four detector wedges: two small Thin Gas Chambers (sTGC) and two MicroMegas (MM). These are mounted on an aluminium frame with electronics, services and cooling systems. All the wedges consist of different modules/quadruplets. The sTGC wedges will be attached together by kinematic mounts and the MM modules are bolted on the aluminium frame using reference pins and sliding washers. The kinematic mounts and sliding washers will allow expansion and shrinkage of the detector without stresses. A module is one detector plate with four layers for detecting the particles. For the sector assembly some new tooling is designed. The tooling tries to avoid the stress during the assembly of the sector.

New tooling's that are designed for the assembly are a trolley to move the sTGC wedge and a frame to hang the MM double wedge and sector. The spacer frame and the MM wedges are already assembled together when they arrive. The MM hangs in the assembly-tooling frame and the sTGC is positioned in place by the trolley. Than all of the parts can be assembled to one part (see Figure 3 Tooling for assembly of the sectors). The sector is different orientated during assembly then the final

position on the NSW. Under gravity the wedges and spacer frame will deform while hanging in the assembly station. A high deformation can damage the sector and minimize the efficiency.

The NSW detector will only detect the Muon particles and is part of a bigger muon detector complex. A muon particle is an electric loaded particle. The principle of the muon detectors is a voltage field in a gas. When a particle comes into the tension field, a detector measure the voltage drop in the gas chamber. [6]

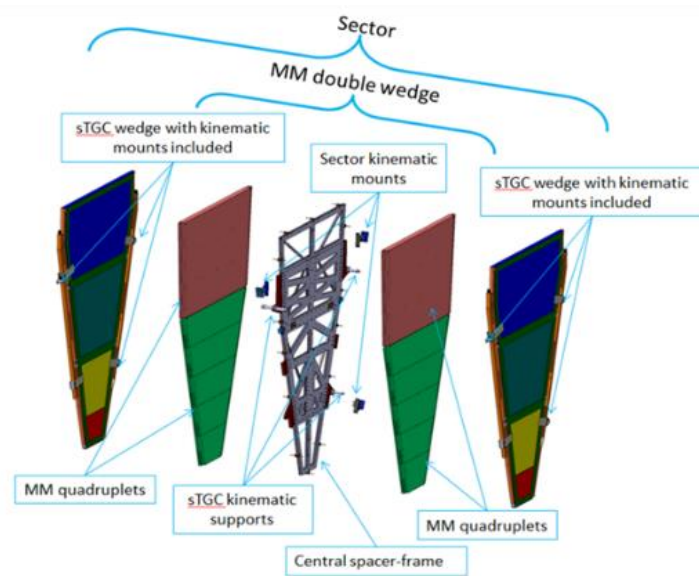


Figure 2 Structure Sector Assembly [4]

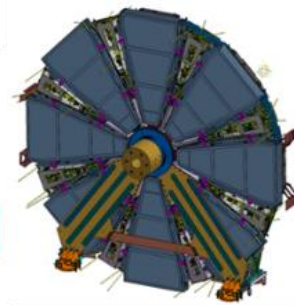


Figure 3 Tooling for assembly of the sectors [5]

1.2 Project Issue

The issue of the project is the high precision on the large size of the detectors and during the assembly, there are several factors that will increase the deformation in the sector.

Main question:

“How to minimize the deformation in the total sector while assembling the small Thin Gap Chamber on the MicroMegs?”

For answering, the main questions there are a few sub questions to analyse the problem:

- What are the involved components for the sector with the deformation?
- What is the design and working of the existing assembly tooling?
- What is the assembly procedure with the sector wedge situations?
- What are the external influences and environments?
- What are the critical stress points?

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At first the problem will be analysed in detail according to all the sub questions with desk research. After analysing, a solution will be investigated with supporting ANSYS simulations. The solution will be tested with dummies and prototypes to proof that the solution works during the first sector assembly. After the testing, a conclusion for the total project and the answer on the main question will be given.

The complete sector assembly will get a close look to minimize the deformation on each step in the assembly.

2 Problem Analyses

In the problem analyses, the problem is worked out in detail to get a good overview of the problem. Each sub chapter has a conclusion. In the end all the conclusions will be combined to get the overall conclusion.

The general tolerances for the assembly are: The mechanical tolerance for the wedges are $\pm 400 \mu\text{m}$ in the XY plane and $\pm 200 \mu\text{m}$ in the Z direction. With electronic and optical sensors, the both sTGC wedges will be aligned with an angular tolerance of 0.1 mrad. [7]

2.1 Key components with and the deformation

All the components that are involved in the project will be in the part list with the assembly drawing in Appendix A. The total weight and dimensions of the Small sectors are:

Table 1 Specs about the total sector [8]

Specs about Small Sector	Value	Unit
Weight total	1029.4	Kg
Weight double wedge MM	618.4	Kg
Weight 2x sTGC	386	Kg
Weight KM	25	Kg
Length (L)	3565	mm
Wide (W)	404	mm
Height a (Ha)	1821.5	mm
Height b (Hb)	500	mm

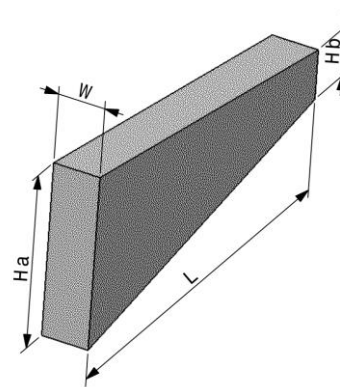


Figure 4 dimensions Small Sector [27]

Frame

The frame is the basic structure of the sector.

The frame is in the middle of the sector

wedges. The structure of the sector is an open structure so the frame is as light as possible.

To reach this lightweight the frame is made of aluminium. To connect all the components to the frame there are interface supports. There are several types of interface: one for the MM and one for the sTGC, Kinematic Mounts, and grabber mounts. [9] The frame will give the structure to the total sector. The ANSYS simulations done for the frame in the position on the NSW are within the tolerances. [10]

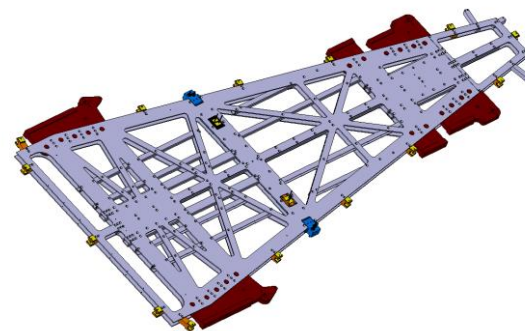


Figure 5 Support frame [16]

All the services, cooling and wedges are mounted to the frame. The frame is made from aluminium AW-6082 and weighs 130 Kg. Most of the services will go into the open areas of the frame. This way the weight and size will be minimized.

The structure of the spacer frame is strong in the vertical position. When the spacer frame is in horizontal/flat position it will bend more. The stress and deformation when the frame hangs into the assembly station is critical. The deformation is given in the picture below figure 6. In the worst-

case situation during the assembly, the maximum deformation in the frame will be 0.23 mm, see the figure 6 below. The 230 μm is the total deformation of the frame.

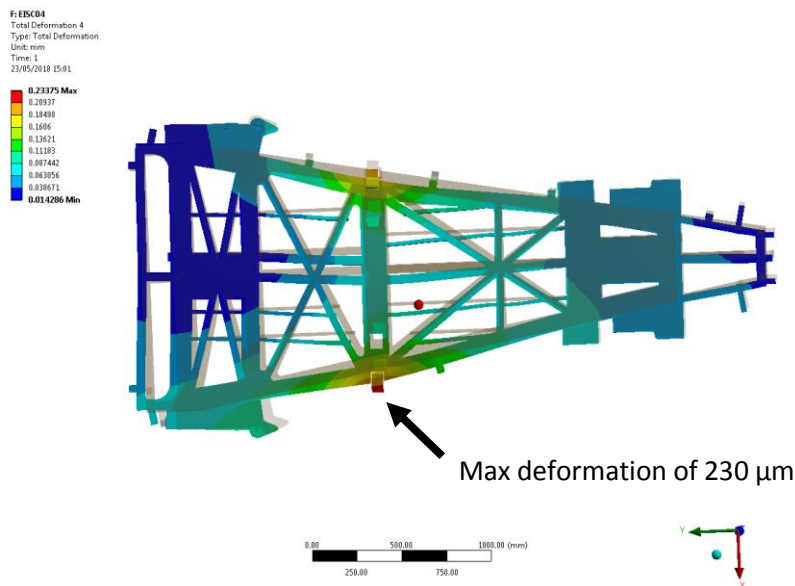


Figure 6 Left view frame deformation

Support interface sTGC, KM, grabber mount.

The interfaces are on both sides of the frame. See appendix A for the position of the interfaces. There are three different interfaces. Two are a combination of the grabber mount interface and the sTGC KM interface. One is the connection for the KM. The three different interfaces are on both sides of the spacer frame, so six for the complete sector

The KM is the connection between the sectors and the frame on the NSW. With the KM connection, the sector is able to deform without getting high stress. The orientations of the KM will be different for each sector. But three out of the four interfaces for the KM will always be used.

The grabber mount is for the movement of the sector. They are attached to the interface of the sector. With four M10 bolts the grabber mount is connected to the interface of the frame. The support interface is the connection point for all the connections from outside to the spacer frame. The position of the grabber mount is shown in the assembly in appendix A. The orientation of the grabber mount is the biggest on the front (SM1) and the smallest on the back (SM2). The pictures of the grabber mounts are in Appendix B.

The connection threads on the top of the grabber mounts are important for the assembly. The cable will be connected between the thread and the lifting beam of the assembly station. To see the deformation in this part a calculation and simulation has been made. After the calculation, a conclusion could be made that the deformation is too small to be reckoned with. This is important to keep in mind for the project. The maximal deformation is 0.00646 mm. The simulations are in the Appendix B. The material used for the grabber mounts is aluminium AW-6082.

MM

The MM detector consists of four parts (quadruplets). Two parts on each side of the frame. The quadruplets are connected to the spacer-frame. The structure of the MM is built with different plates which are connected to each other with bolts. The explanation of the MM is in the Appendix C. Because of the working and the structure of the MM a high precision is needed. The required relative positioning tolerance is $200\text{ }\mu\text{m}$ But the possible mechanical tolerance we can get is $400\text{ }\mu\text{m}$. This has been accepted because of using an active optical alignment system which can give precision higher than $200\text{ }\mu\text{m}$. [11]

During the first test with the MM they bent the MM module in a horizontal position and while bending they looked at the performance of the detector. The result was that the MM still got a good performance with a deformation of 0.5 mm . Appendix C shows the explanation about the deformation experiment. [12]

The MM connection points are based on the principle of the kinematic mount. The connection in the Z direction is around the sides of the frame. In the middle of the frame are two points which will constrain the MM in the X and Y direction. Between the connection points and the MM are sliding washers. In the worst situation the deformation of the total MM on the assembly station is 0.3 mm , see the figure 7 below. The 0.3 mm is between the tolerances of the $400\text{ }\mu\text{m}$ in the plane of the MM. [13]

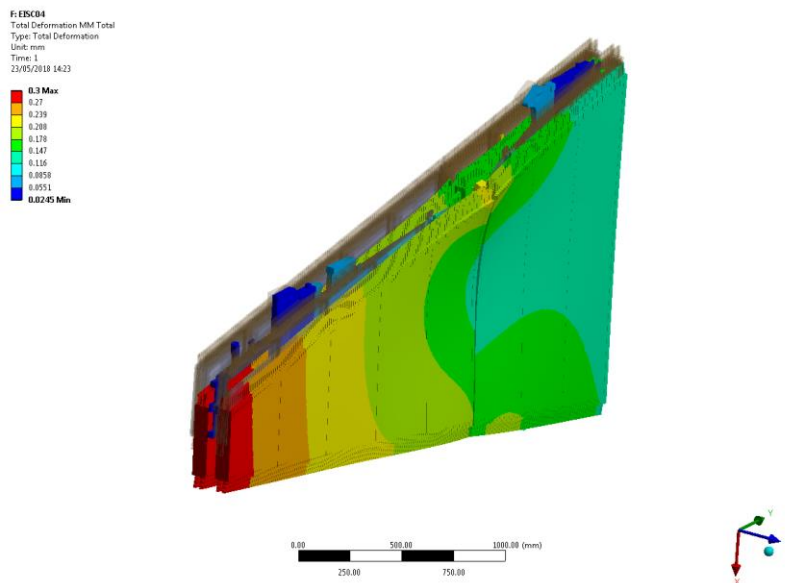


Figure 7 ISO view MM deformation with frame

sTGC

The sTGC is used as a trigger detector. The structure of the sTGC is different from the MM.. The different planes of the sTGC are glued together. Because the sTGC is glued together, it is seen as one solid part.[14]

The sTGC wedges are in a epoxy glass fibre frame with on the end of the frame a connection point for the Rods of the sTGC. Background information of the sTGC is in Appendix D.

The sTGC has the same working principle as the MM. But as it is used as trigger system, the required resolution is lower. Important is the relative position of both sTGC detectors which means identical behaviour of their support fixed on spacer-frame. The maximum deformation of the sTGC is in the situation of EISC04. The deformation in the sTGC is 0.21 mm. The position of the sTGC wedges are between the required 0.1 mrad angular alignment precision. The deformation is on its normal position with connection points according to the orientation on the EISC04.

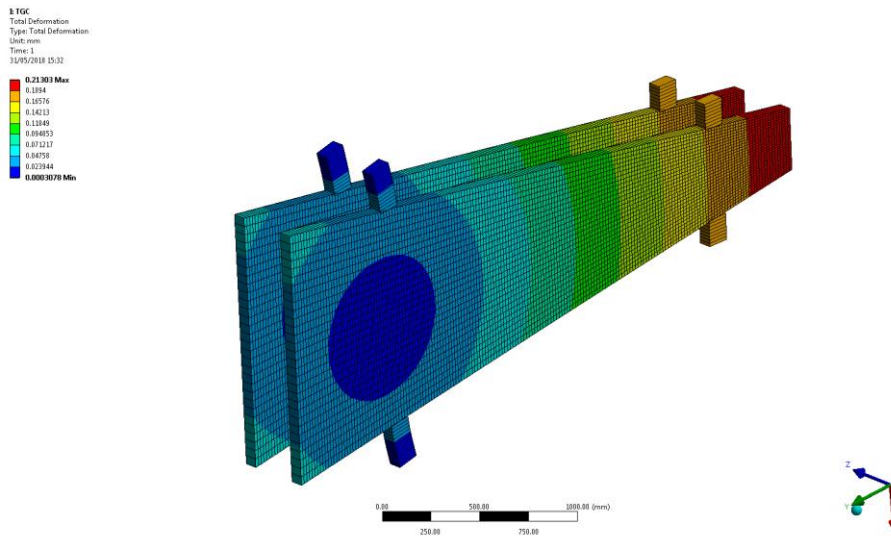


Figure 8 sTGC deformation ISO view

KM sTGC

The KM mounts will fix the sTGC to the MM-DW but the sTGC wedges are able to deform with minimum of stress. The sTGC KM mounts are connected to the spacer frame interface with rods. The rods are connected to the sTGC support frame into bearings so it allows rotation. The rods are different for each configuration. Appendix E gives more background information about the KM according to the orientation and working. See figure 10 for the orientation in the assembly station.

The fixed rod and the guided pin have tolerances that won't fit into the bearings. (see Figure 9 Fixed point with the bearings for the situation). By changing the tolerances a higher precision could be reached. All of the designs that are made for the rods are designed with tolerance which makes it difficult to fit into the bearings. See Appendix E for the fixed and the fork they used welding's. But

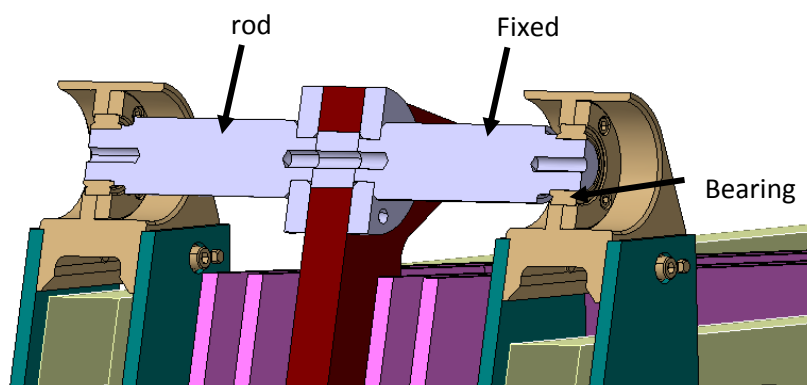


Figure 9 Fixed point with the bearings

the welding's will deform the rods more because of the heat brought in the material during welding. Without welding an additional clamp in the milling machine is not needed and there is no deformation because of the welding. Because of the small tolerance between the rod and the bearing it is hard to slide them together. There must be found a solution to slide them together.

The position of the vertical sector is not optimal for the EISC 04, 06, 12, 14 because of the position of the sTGC KM. The deformation will be higher in the end of the sTGC because there will be no constrain. Appendix E shows the working of the sTGC and the placing in the sectors. According to the simulation is to see that there is 760 μm in the total sector see appendix document K.

All the KM's are missing the washer in the Z direction. Without the washers, the sTGC will fall off the frame. Imported is that the fork must be able to move with the washer and the fixed point must be blocked. With all the parts combined, the deformation will be 0.7068 mm, see Appendix K.

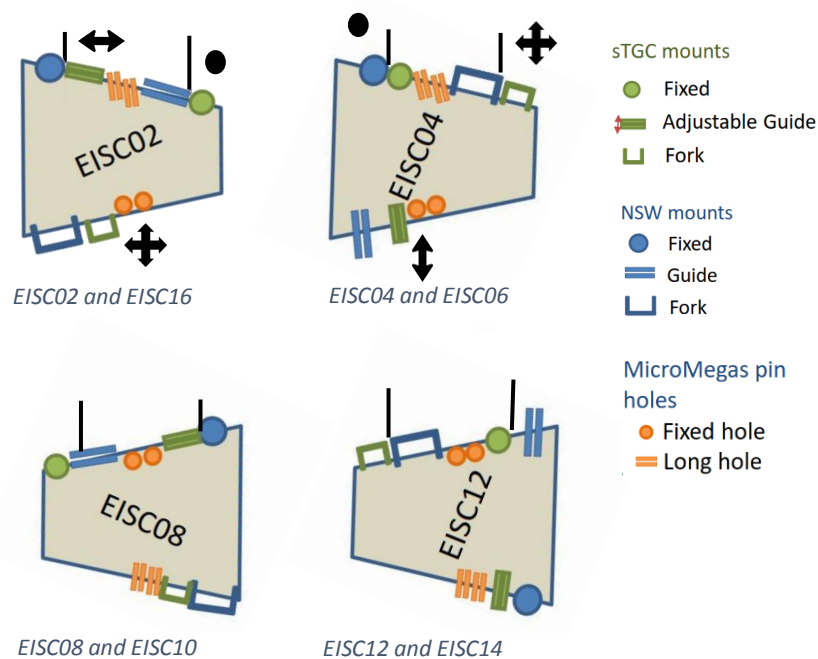


Figure 10 Configuration of the sectors

2.2 Assembly tooling

Assembly frame

The assembly frame is a frame to mount the sector during assembly. The upper beam of the assembly frame is also the lifting beam for the crane. With adjustment screws the upper beam can be positioned on the two pillars. The sector hangs on two steel cables, which are connected to the grabber mount. With cable adjustment screws, the height can be changed. [15]



Figure 11 assembly frame with trolley [16]

The assembly station frame is for the final sector. The frame is made from steel s235 walled H barks with in the top two connecting points for the spacer frame. Thread tensioners on both connection points can level the frame. It is possible to align the cables with the thread. This way the deformation of the beam has no direct influence on the sector. The beam is placed on top of the assembly station. This will fix the Y and Z directions and still leaves the possibility to move in the X direction. [16]

The total weight of a small sector is 1029.4 Kg the weight is 60% on SM2 and 40% on SM1. This results in:

$$1029.4 * 0.6 = 617 \text{ Kg for the cable under SM2 } 617 * 9.81 \approx 6 \text{ kN}$$

$$\text{For SM 1 is that } 1029.4 * 0.4 = 411 \text{ Kg the force is than } 411 * 9.81 \approx 4 \text{ kN}$$

B: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
25/07/2018 14:15

0.53199 Max
0.47288
0.41377
0.35466
0.29555
0.23644
0.17733
0.11822
0.05911
0 Min

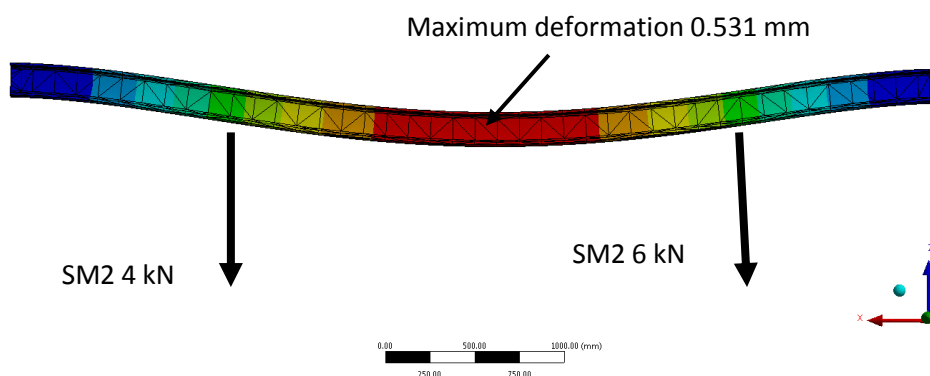


Figure 12 top beam with the load of the sectors

The H beam will deform 2.5 mm under the load of the total sector. Because the sector will be placed in the middle of the frame, the deformation on both sides is the same. Therefore, the deformation in the beam is not an issue for the assembly. The tread tensioners can modify the deformation in the H beam so it is not an influence on the sector. See figure 12 for the deformation of the lifting beam

Adjustable steel cables do the connection of the sector into the frame. With screw tread the length can be changed. The already designed lifting beam will have the cables under an angle because of the connection point on the sector and on the beam.

To calculate the angle of the cables the different points of the trapezium are known. The bottom line is the sector the top line of the trapezium is the lifting beam. The slanted beams are for the cables of the assembly station see in Appendix F.

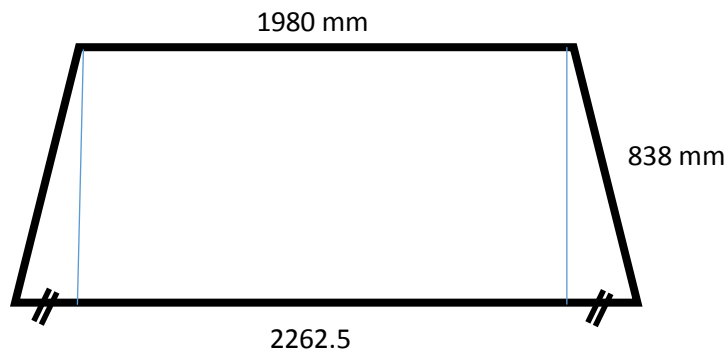


Figure 13 Position of the cables on the assembly station

The angle for each cable is 9.6 degrees. This number will be used in the simulations.

In the appendix F you find the research report about the deformation of the current situation with 9.6 degree angle. The highest deformation is 0.8358 mm in the total deformation. The MM will deform with 0.36 mm in total deformation. As reference for the deformation of the sector are the results of the simulation done in appendix K. The result, the angle of 9.6 degree will give the sector a higher deformation from $\approx 60 \mu\text{m}$ for the MM and in the complete sector it is $\approx 135 \mu\text{m}$. To minimize the stress the cables must be in a vertical position and be connected to the grabber mounts. The deformation will minimize with almost 10%.

Trolley

The trolley is used to move around the sTGC. The sTGC's are hanging in the trolley's. With the trolley the sTGC wedges can be driven against the MM's. The trolleys can fit in each other to get the good position of the sTGC in front of the MM. The sTGC are precisely connected and are not able to swing or move in the trolley. With a bolt the position of the sTGC can go up and down. The trolley shown in Figure 11 assembly frame with trolley

To fix the sTGC to the trolley two clamps with bolts will be used on both sides of the sTGC Christmas tree. Extra pins are used on MM trolley. On sTGC we have rotating plates to avoid rotation of the wedge. With two extra pins on the sides of the trolley the sTGC wedge is not able to rotate around the axis. A horizontal position without support will give the sTGC too high deformation so the sTGC must stay in a vertical position during the assembly.

The movement of the trolley is in X and Z directions. The wheels of the trolley are able to go in all directions. According to the approval of the sTGC group, the structure of the sTGC will not deform more than the tolerances.

2.3 Assembly approach

The steps that are needed for the assembly are investigated in this sub question. For each step an ANSYS simulation has been done or calculations by hand are made find the problems during assembly.

The steps that are needed to assemble the total sector are:

1. Survey MM before transport
2. Hanging the MM in to the frame (levelling)
 - Riding MM to assembly frame
 - Hanging MM in assembly frame
 - Survey MM while hanging
3. Pre-alignment of 2sTGC for the MM double wedge.
 - sTGC to assembly frame
4. Installation of the 3 sector kinematic supports and connection sTGC.
 - Installation of sTGC
5. Installation of the 3 sector kinematic mounts.
 - Placement of sector KM and position them
6. Mount and alignment sTGC to MM and positioning rotation
 - Positioning of the total sector with an alignment system
7. (storage of assembly on the NSW)
 - Storage on the storage frame
 - Placement with the placement tool.

When step 5 is finished anew assembly can start on another lifting beam in parallel.

During the assembly, the following situations apply:

Table 2 Risk for the high deformation while assembling

#	Situation	When and where	Risk for high deformation
1	Only the frame horizontal	Before adding MM	Low
2	MM-DW horizontal	Still on the assembly table of the MM	Low
3	MM-DW	After installing the MM	Normal
4	Complete sector	After adding the sTGC with assembly station	High

The situations with the MM-DW and with the sTGC are the most critical. This is because the frame then gets the most weight with the different wedges on it. The frame alone is not a problem.

2.4 Influents from temperature/ wind and human.

The difference in temperature can deform the sector. For the simulation with temperature is used the large sector, the behaviour of the large sector and the small sector will be the same only the deformation in the small sector will be lower. The temperature in the assembly hall will be around 22 °C.

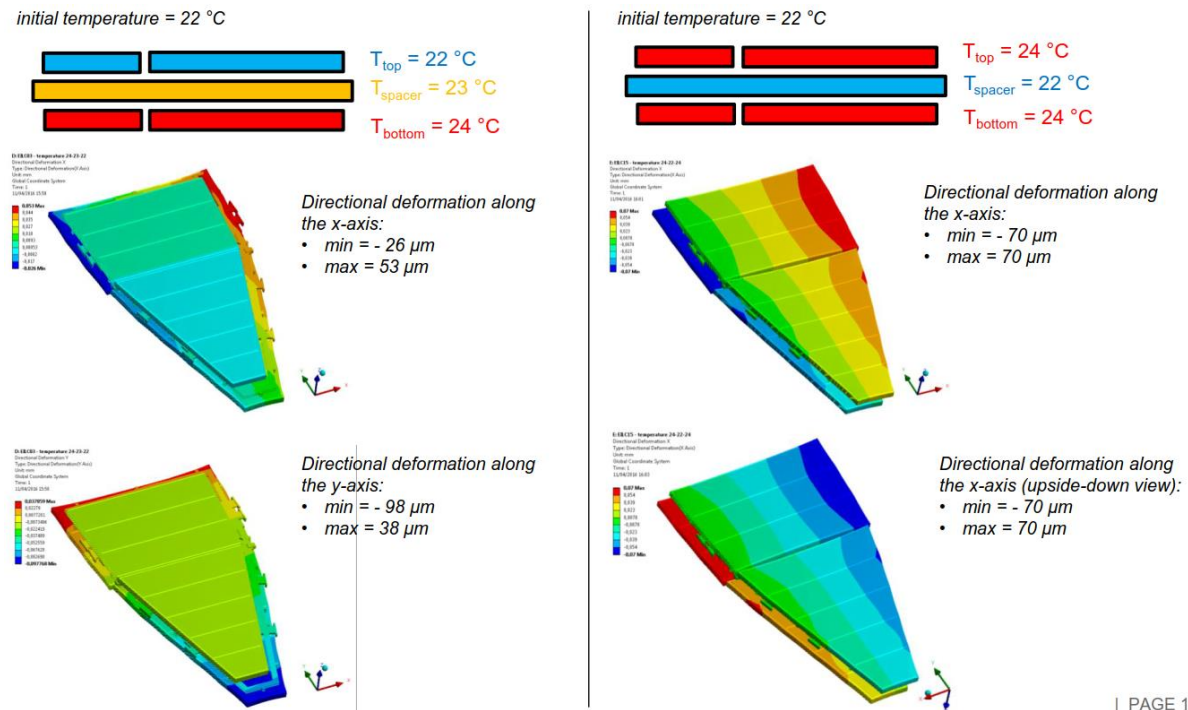


Figure 14 Deformation sector by temperature [28]

The results of the sector deformation according to the temperature are in the picture above. The deformation according to the temperature is -98 μm for the large sector. The picture below is in a worst case situation. In reality, there will be no only high temperature different between the wedges.

Other reasons for deformation of the sector could be:

- Human factors by bumping in to the sector.
- An airflow in the building with give the sector a higher swing.

2.5 Possible behaviour of the sector

To find the critical deformation in the sector it is important to know the behaviour on the NSW. Most of the calculations are already done for the complete sector into the original positions.

The orientation and the possible movements are from the lifting beam and while connected into the sector assembly tooling. The possible movements are a swing from left to right as seen in Figure 15 Situation for the sector in a swing “EISC02” Another possible movement is that the sector is not horizontal.

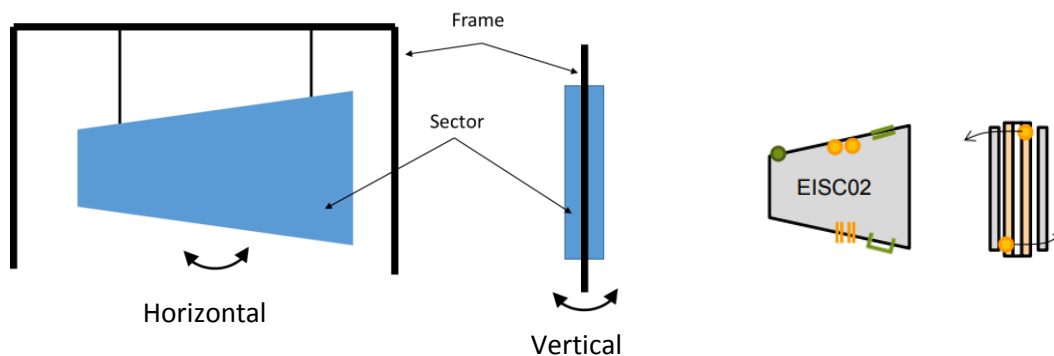


Figure 15 Situation for the sector in a swing

With the research about the complete sector behaviour, it is possible to see the weak points. During the sector assembly there will be looked at the deformation in the sectors under a swing. In earlier research was concluded that the sector could not be in a flat position without supports. In appendix K are the results of the sector assembly. Important is the deformation in the wedges. The deformation in the MM on the plane must be lower than $400\mu\text{m}$. An angle of 0.4 degree has an deformation from $460\mu\text{m}$.

By fixing the sector and so stop it from swinging the deformation because of the swing can be stopped. Minimization the swing will result in minimizing the deformation. Because there will be an swing in the sector.

To see what the consequences are of a vertical angle is done a simulation seen in appendix K. The results of this simulation were almost the same. As the sector in normal position. Even when the sector will lean a little bit to the front the deformation will be less then $10\mu\text{m}$.

Imported to know is the real behaviour of the sector during the first sector assembly and to check the calculation results. For survey of object, CERN is using photogrammetry and laser measurements. Both of the survey technologies need an survey target. Table 2 in chapter 2.3 will give all the moments for a survey. Together with the survey group is chosen between the photo and laser measurement. The best choice is the laser because this survey technic is also just down in ATLAS. The precision of the laser survey with $50\mu\text{m}$ will be used as an input for the design of the survey targets supports

For the best survey results it is important to have the survey targets on the same plane. To get all the targets on the same plane support are needed. For the best survey the sector must be hanging as still as possible.

By this survey the deformation can be guaranteed and the simulations and calculations can be checked. This imported step has been added to the assembly procedure.

2.6 Conclusion of problem analyse

The conclusion of the problem analyse will give all the problems

All the individual wedges are within the tolerances. The worst situation of the combined wedges is the sector EISC04. This is because of the orientation of the sTGC KM. The orientation of the sector in the assembly station is always with the fixed point on top. To minimize the deformation in the sTGC KM mounts the rods can be improved. The fixed point can not slide in easy in the bearing because of the small tolerances. There must be found a solution to keep the small tolerances and slide in in easy

Missing or wrong parts:

- Washers to connect the sTGC KM in Z direction. To minimize the deformation the fork will need a distance between the washer and the bearing. This way the rod is still able to move in all directions.
- Wrong tolerances on the fixed rod and the guided rod. With the existing tolerances the rod and the pin are too wide and will not fit into the bearings.
- By removing, the welding in the rod a higher tolerance can be reached. This will also minimize the deformation.

The assembly station can also get some improvements because the cables are connected to the sector under an angle of 9.6 degree. Changing the cable to a vertical position will minimize the deformation with almost 10%.

During the assembly an swing from more than 0.4 degree is the biggest swing allowed. If the swing is higher than 0.4 degree the deformation in the individual MM-DW and sTGC will be more than 400 μm . Because of the human influence and airflow, the sector will have a swing.

The simulations give a good approach for the behaviour of the deformation during the assembly. To see the real deformation for the first sector assembly an extended survey is needed. For the serial production of all the sectors a simple survey need to be done to guarantee that the sector deformation is within the tolerances limits. For this survey a laser will be used and supports are needed to place the target into position. The swing of the wedge needed to be blocked for the survey with the laser.

3 Solution

The problems out of the chapter 2 are used as input for the solutions. Different solutions will be given and the best will be used.

3.1 Minimize swing

The high swing could be a problem for the sector deformation. The way to minimize the swing without a big change is to minimize the factors for a swing. The worst reasons are airflow and human mistakes by bumping into the sector. To minimize the airflow the doors and windows must be closed all the time. For human mistakes, a mark is needed to keep people out of the sector assembly area.

If the swing after minimizing the factors is still more than 50 μ m the lowest grabber mounts needed to be fixed in Z direction to stop the sector from swinging. The solutions for that are:

- Cable to the ground (temporary for the first test)
- Clamp (for the serial assembly)
- Trolley (will mount the sector in the middle and give an over constrain)
- Extra beam between the frames horizontal (will block the movement around the sector for service assembly).

An cable that fixes the Z direction is the best solution for the first sector assembly. With the cables, it is easy to modify the sector to get the perfect position of the sector. For the cables straps can be used. The straps are connected to the grabber mounts and to the assembly station.

For the future a pillar is designed that is able to fix the Z direction. It can be used for all the small sectors with two screws. With the two screws in the plates the grabber mount can be blocked.

The position of the pillar is in front of the two grabber mounts. The pillar under SM1 is higher than the one under SM2. For the small and large sectors, the pillars will have a different length.

The pillar will be connected with four bolts in the concrete. The two plates on top of the pillar are removable. This way it is easy to install the sector into the assembly station. The pillar will fit between the two trolleys. And only fix the sector in Z direction on the two grabber mounts. Detailed drawing in appendix J.

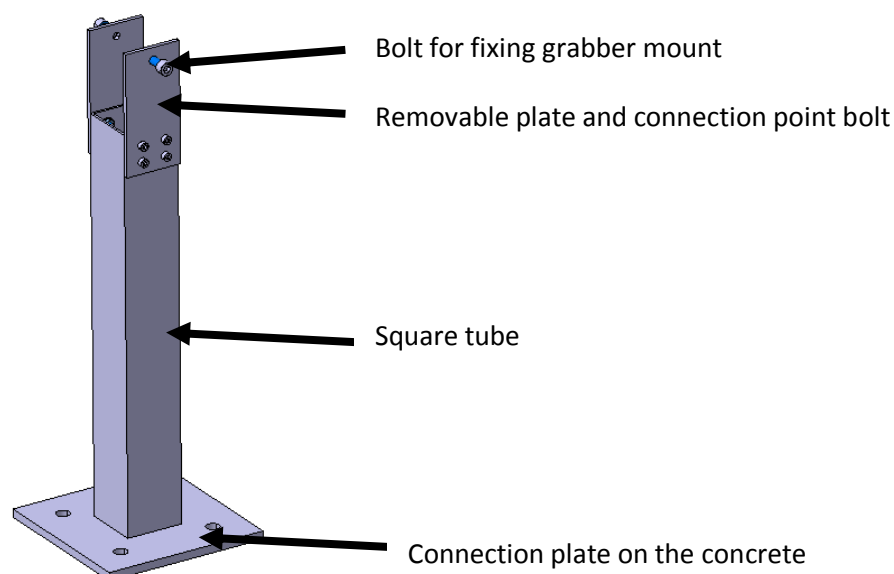


Figure 16 Pillar to avoid swing

3.2 Update assembly station

To get the cables vertical, the position of the grabber mounts has to change or the position of the cables in the lifting beam has to change.

The best way to solve this is to drill new holes in the lifting beam since the position of the grabber mount will be used by other tooling. The position for all the tooling is already agreed, so it will be difficult to change all the tooling.

The position of the new holes must be 284.5 mm to the outside of the frame. The dimension must be added to the old connection point dimension to get the cables horizontal. The length of the cables has still the good length so they don't need to change.

3.3 Survey with laser

For the best result of the laser survey, there are needed supports with a precision of 50µm.

After each assembly step there must be done a survey. For the survey moments during the assembly see table 2 in chapter 2.3. The table shows that the frame, MM and sTGC are needed to be surveyed. There for the following design is made for the rods

The first concept of the supports are in the picture below. All of the supports are in one plane with the MM or sTGC wedge.

- MM length of the support 105 mm
- sTGC length of the support 202mm

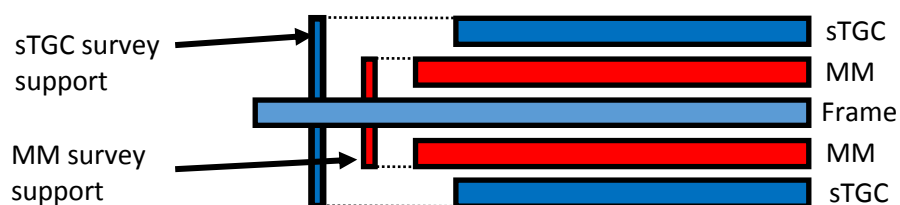


Figure 17 First concept survey supports

After a meeting with the survey group a new design was created. This new design will save time and more accurate supports for the survey targets. With the new design there is only one survey target needed to measure the sTGC and the MM. For the survey of the spacer frame is chosen for a small support to hold the target.

The length of the survey supports could be in the middle of the sTGC and the MM and still get a good result. See the picture below. And the small MM spacer frame survey can be used as an reference survey in the begin of the MM-DW assembly

- Rod length 150mm
- MM spacer frame support length 85mm

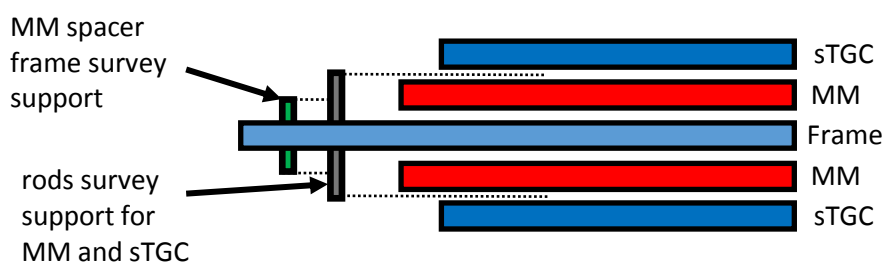


Figure 18 survey concept after meeting survey group

With new tolerances designed, the MM survey points can be placed on the MM pins (see Appendix C for position of MM pins) now. This is used for the first reference survey. Difference in tolerance is 50mm, according to the survey rods. For MM support of the pins this means that they have to be between the rod and the frame with a tolerance of 50 mm. By using one of the sTGC and the MM time could be saved during the assembly. The reference for the survey is the frame on a flat underground with the MM survey points and the rods. After this, each step will be surveyed to measure the deformation in each step of the assembly.

All the positions of all the survey points, while the sector is placed in the assembly station, are mentioned on the picture below Figure 18.

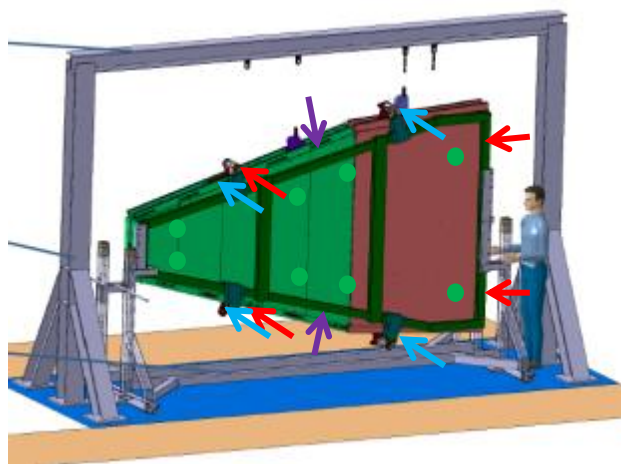


Figure 19 MM survey target position

Location of the MM-DW survey targets (blue color)

Location of the reference survey targets frame (purple color)

Location of the MM survey targets connected with magnets (green color)

Location of the sTGC survey targets (red color)
(possible to add targets on 2 others sTGC KM support)

3.4 Optimisation design

Before the sector assembly the designs needed to be updated and the missing part has to be designed. The sTGC KM mounts need to be improved to get a higher precision.

To control the total assembly there must be a routine survey of the sector. The routine survey can guarantee the high precision and quality of the sector. For the survey of the sector supports, rods survey stickers, points and a laser tracker system available at CERN are required. It is required that the sector hangs without movement for an accurate survey. To reach this situation a possible third connection point must be created.

To get a better result of the rods a few changes must be made.

The welding's in the rods has to be removed for a higher precision and less production time. Also the design is difficult to machine in the workshop. The design should be simplified by changing the design and dimensions of holes and slots. In the end the tolerances of the connection pin and the fixed points will be improved. Rods must be 29.9mm +/-0.03 and the pins 15mm +/-0.02 change to fit into the bearings. The chamfer will have effect on the forces between the bearing and the rod. For easy sliding of the rods, a chamfer or a cone there must be added to the rods. The cone will be

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removable and connected with a M10 thread into the end of the rod. The chamfer will have effect on the forces between the bearing and the rod.

A continuous possibility to measure the swing is required. With a digital leveller, it can be quickly measured if there is a lot of rotation.

All the information about each sector must be saved. This is required for trouble shooting at a later stage when something is wrong in the cavern. So each sector has its own documents.

3.5 The new assembly procedure

The assembly procedure must be optimized from the first assembly approach. To get the complete procedure, all the steps are verified in 3D with CATIA. Together with the parts list this will give the final assembly approach for the test. After the first sector assembly test the procedure can be updated.

It is imported that the assembly must be done in one day and the deformation must be checked by each assembly step. Of course the first assembly of the sector will take longer. But with the new experience the next assembly will go faster.

The survey moment is an imported step in the assembly procedure. After each step a survey moment will be done to see the deformation.

Also the position of the sectors is defined in the assembly procedure. Each sector must have the fixed point on top. This way the deformation during the assembly will be less. The new assembly procedure, to minimize the deformation during the assembly, is to find in the Appendix K

4 Implementation of the solutions

To realise the first assembly of the sector all the missing parts will be fabricated. All the other parts must be available in time. The first sector assembly is done with the MM-DW, the SM1 and SM2 chambers connected to spacer. For the sTGC a M0 and a wood mock-up will be used. There is almost no difference in results of the simulation between the behaviour with the different weight of the prototypes and the dummy's. The simulations for the real sector can be used for the results from the sector with dummy's and M0. The difference in the simulations is 20 μm . This value is acceptable so the simulations are done for the real sector and can be used for the first assembly test. For the assembly test new holes are drilled in the lifting beam of the assembly station.

To get a realistic first sector assembly some modification had to be made on the wedges. Therefore, the wedges were weighed individual and compared to each other. To have the balance on the sector and to get a result that is realistic to the real serial production some extra weight of 14 Kg to 15 Kg was added on the SM1 and SM2 M0. For the sTGC it was 35 Kg (see Appendix G for the background information).

The best solution is to add metal strips to the surface of the MM wedges. It will be mounted with special bolts on the screws on the MM. In the Appendix G pictures of the extra weight are being showed.

All the parts are made or they got an update if needed. When everything was complete, the first assembly started.

4.1 Minimize the swing.

The result of the first sector assembly was a visible swing because of the airflow in the building. To stop the sector from swinging straps are added to the grabber mounts and the assembly frame. See the picture below figure 20.

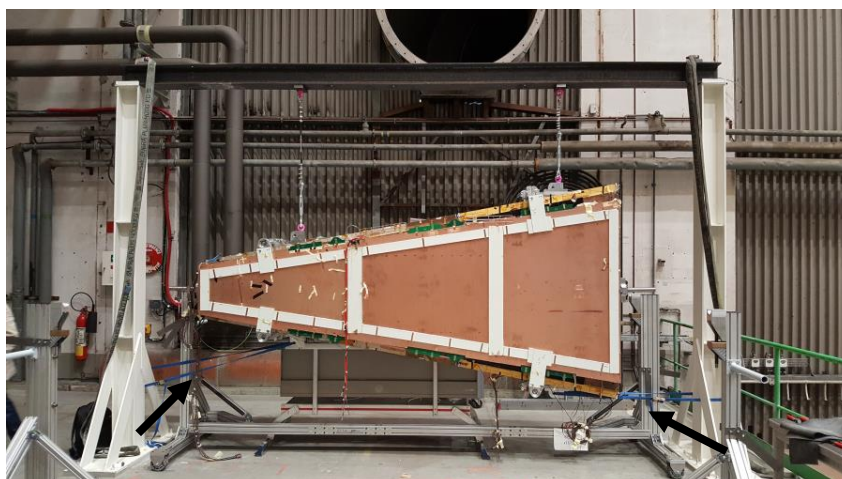


Figure 20 Sector assembly with support cables

With the straps, there was no visible swing anymore. For the MM-DW and assembly of the sTGC where the cables an perfect solution. It was easier to install the sTGC because the sector was not

moving. With the cables, it is easier to work on the sector and the deformation because of the swing is blocked.

But for the laser survey the cables were not enough. The laser was not able to make a good result because the sector was still moving too much. To stop the sector from swinging for the survey an extra support is added to the back of the sector. With this support, the sector was hanging still and the survey could be done. With this extra support the working of the pillar is proved.

The extra support had the same function as the pillar. With the support the working of the pillar is confirmed. For in the future the pillar will get in production and stop the sector from swinging during the serial production of the small sectors.

4.2 Survey during the assembly

The sector survey is according to chapter 3.3 “Survey with laser”. For the two types of supports the survey points are made in the workshop. You will find the result below with pictures of the location. For more detail the drawings are in Appendix I.

In the picture below figure 21 and 22 you will find the survey supports that are used as reference points.

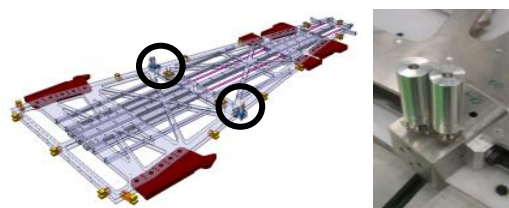


Figure 22 Spacer frame supports survey points

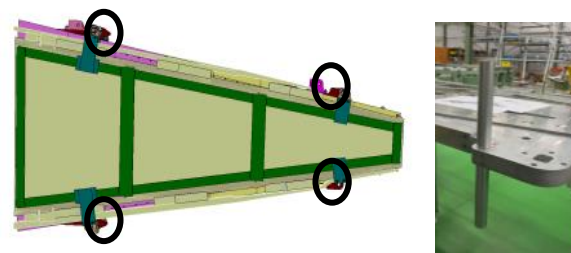


Figure 21 Support reference survey point

The survey points worked well. It is important to minimize the swing during the survey moments. Surveys were performed before and after each assembly step including the survey points. The survey points will be used to check the sector deformation when simulation and reality. After the first surveys, the position of the target changed because of the orientation of the supports and rods. That is why all the rods had a number and on one side a stripe. The stripe must always point to them middle of the sector. An improvement for new supports and rods will be an air hole. Because of the precision, it is sometimes hard to slide the target into position. The air in the hole cannot get out and that stops the target from going in. That's why the holes are made deeper so the air was easier to compress and go out. For the best design is it better to make a small hole on the side of the hole to the outside. This way the air can go out and does not compress.

4.3 Optimisation of the design

The new pin and the fixed point result in good tolerances. Without the cone the fixed point is hard to slide in to the bearing.

The fixed point had an cone with M10 to slide in easy. (See the picture of the cone figure 23) The drawing is to be found in Appendix I. This design worked well in combination with the new tolerances.

The pin had no chamfer and it was hard to slide it in place. For the future, a chamfer to the pin will be added. Because the pin is the last part to connect the sTGC to the MM it is hard to slide it in anyway (see appendix L). Because of the optimisation of the design, the assembly is easier and a higher precision can be reached.

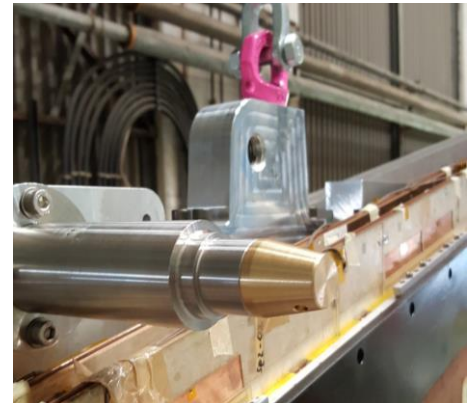


Figure 23 Fixed point with the cone

4.4 Results of the survey

The survey is done with a laser and the position target is corresponding with the position explained in chapter 3.3. The surveys are done after each step. With as a reference the MM-DW in flat position. The MM-DW in vertical position and the complete sector in vertical position hanging on the assembly station. The results are in appendix H

The results are compared with the simulations. The simulation should be an approach for the deformation of the sector (see appendix K for the simulations).

The results of the survey are in Appendix H. The results are higher than the simulations. But the behaviour of the deformation is as expected. The results are $\approx 25\%$ higher than the simulations. During the survey the sTGC two target are placed wrong. The sTGC B and D, this results in high results in Z direction.

The MM-DW should have according to the simulations a deformation of $300\text{ }\mu\text{m}$ in the XY plane. The result was the double in the XY plane. In Z direction it is around $1000\text{ }\mu\text{m}$. This is because of the extra from the dummy and a sector who was under an angle. This two things in combination with the first prototype with a lot of modification results in a higher deformation.

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5 Conclusion

The conclusion will give the answer on the main question “How to minimize the deformation in the total sector while assembling the small Thin Gap Chamber on the MicroMegas?”

To give a good answer on the main question first the answers on the sub question.

The deformation done with simulation in the important parts is for the MM 360 μm and for the sTGC 730 μm . The sTGC KM could have a better design to minimize the tolerances. This results in a better result of the hanging sector.

The tooling is an assembly frame with two trolleys for the sTGC. The MM-DW is hanging with two cables on the lifting beam of the assembly frame. The cables are under an angle. By changing the angle the deformation can be minimized with 10%.

The assembly procedure of the sector assembly is made step by step. The important thing about the sector assembly is the extra added survey moments, to see the deformation in the sector before installing on the NSW.

During the assembly, airflow and human will give the sector a swing which results in a deformation. A swing form 0.4 degree will be a problem for the sector when it is hanging on the assembly station. This will be solved with the pillar.

The conclusion on the main question is to minimize the swing in the sector assembly. Minimizing the swing will give as result less deformation. To optimize the assembly are changes the sTGC KM and the assembly station. To proof that the deformation is remains under the tolerance limit each time a survey moment to the assembly procedure. The pillar makes the MM-DW hanging more stable in the assembly station what makes the assembly easier.

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6 Recommendation

The recommendation is to make the pillar before the serial production of the Small Sector. This will minimize the swing and deformation. The pillar needed to drill in the concrete to give the best result. The position of the pillar must be strait below the cable. For the large sector avoiding the swing is even more imported because the sector is bigger and will have higher deformation.

The washers to fix the fork rods in Z direction needed to be made of plastic. Aluminium or stainless steel will stick together. With the plastic washer, the fork sTGC KM is always able to move. A washer from polyethylene should be strong enough for fixing the sTGC on the fork.

Change the design of the guided pin to get it in easier. On the top an chamfer and the end a little bit longer. This way it is easier to install the pin.

As final recommendation be careful and precise during the complete assembly because to see in the results of the survey there are made a lot of mistakes during the assembly. For the serial production is this not expectable.

For future research is good to disassemble the sector. To see what the critical points are to understand the behaviour of the sector better. When the first sector with the final wedges is available there must be done a more extensive survey. This is important to understand the complete behaviour of the sector. This must be done before the serial production of the sectors. This will be an hard study and the results out of this thesis can be used as a input for the final sector survey.

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8 Appendix

Table of contents for the appendix below.

In the appendix are two extra-added documents the assembly procedure and the sector deformation study.

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Appendix L	See added document

Appendix A

Assembly drawing

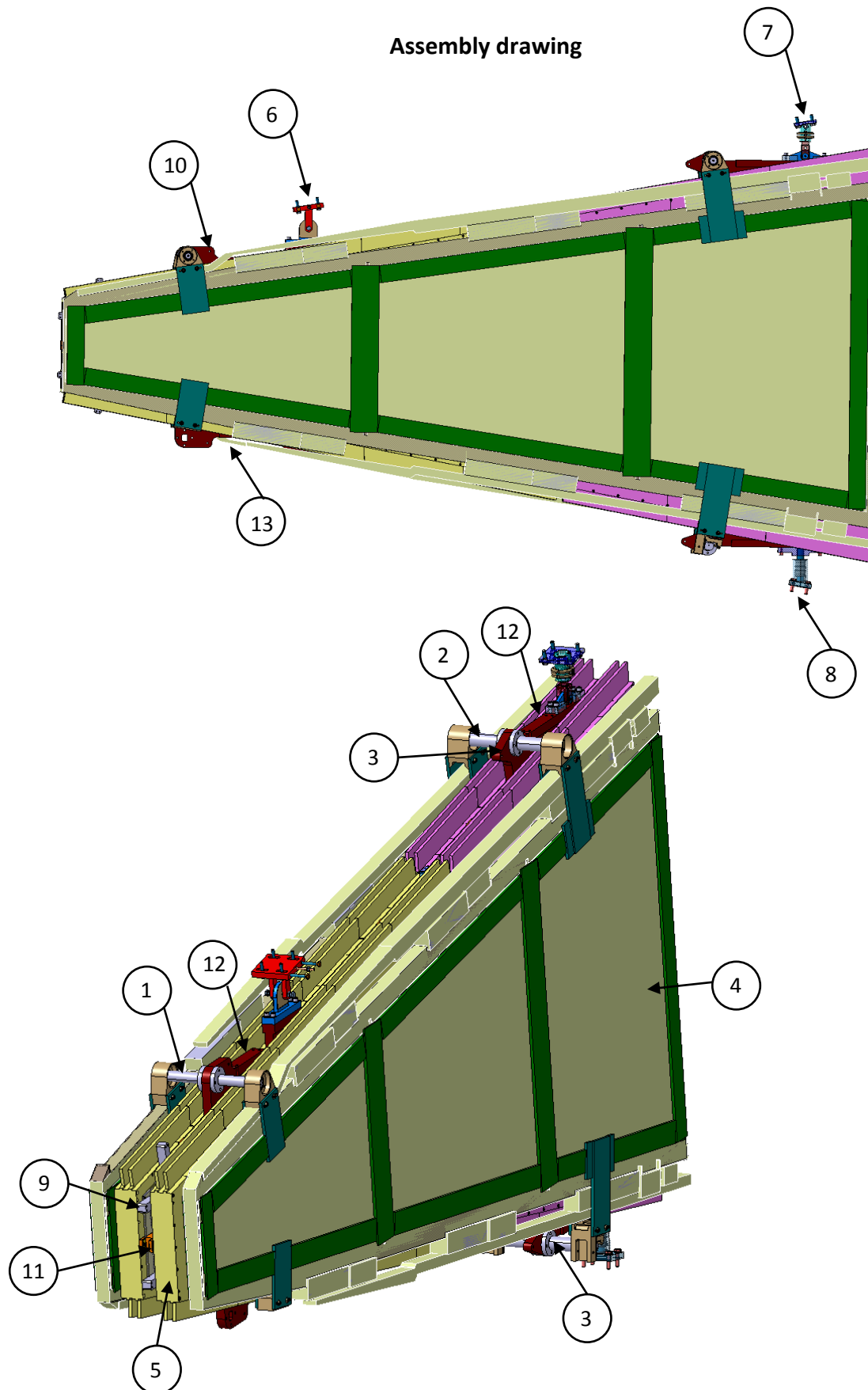


Table 3 global part list sector

#	Part	Description
1	KM sTGC Fork	Connection between frame and sTGC
2	KM sTGC Fixed	Connection between frame and sTGC
3	KM sTGC Guided	Connection between frame and sTGC
4	sTGC	Trigger detector
5	MM	Susceptible for deformation
6	KM Fork	For hanging the sector into the NSW
7	KM fixed	For hanging the sector into the NSW
8	Km Guided	For hanging the sector into the NSW
9	Protection support	Protection for the Sector if needed
10	Hole for survey point	Reference point for the survey rods
11	MM connection	All around the frame for connection MM
12	Grabber mount	Grabber mount connection point
13	Frame interface	Connection points from the frame

SS Kinematic mounts – Side C: HO

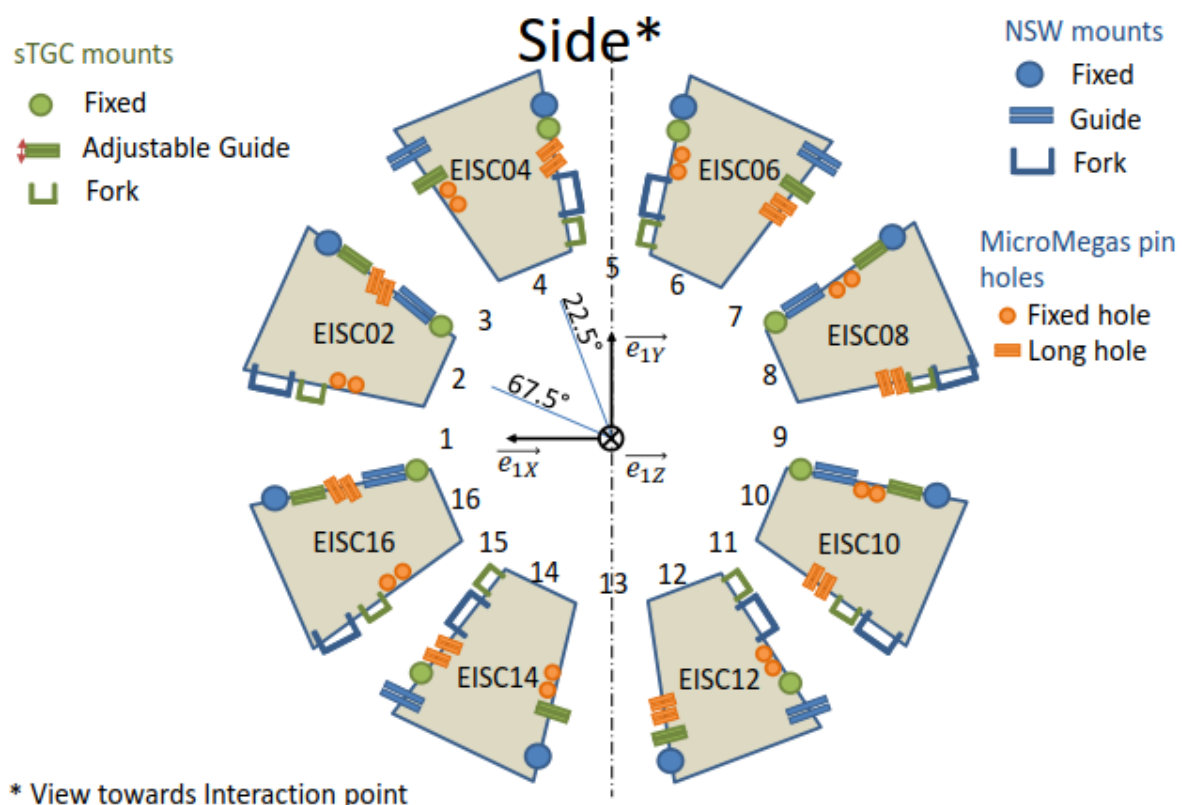


Figure 24 All the different orientations of the small sector on the NSW

Appendix B

Grabber mount

The force used in the simulation is based on the total weight of one sector.

SM1 4kN

SM2 6kN

The force is placed in the hole at the top of the grabber mount and moving upwards. The fixed points are in the bottom holes where the bolts should be.

The material is Aluminium AW-6082.

Conclusion of the final simulation: is that the deformation is too small to be reckoned with in further calculations.

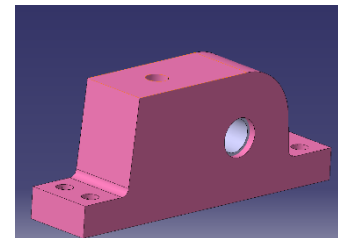


Figure 25 Grabber mount small

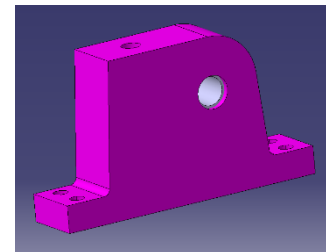


Figure 26 Grabber mount large

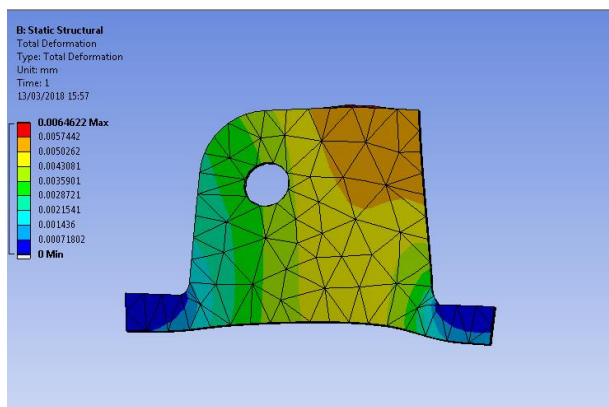


Figure 27 grabber mount large simulation

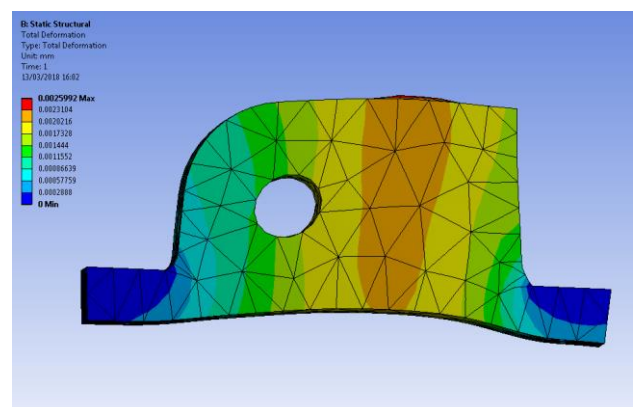


Figure 28 Grabber mount small simulation

Appendix C

MicroMega

The MM quadruplet exists of five layers:

Between the read out planes a gas chamber is placed with an electrical field. The eight services board and cooling pipes are on the outside of the wedges.

1. Drift panel (aluminium honeycomb with a thin copper layer at the RO side)
2. Read out (RO) panel 2x (the first layer consists of strips of copper. The second layer consists of strips made of resistive ink, the third layer are small pillars to hold the last layer of consists of a stainless steel mesh. All of the layers double)
3. Drift panel (aluminium honeycomb with both sides copper layer)
4. Read out panel stereo double (equal to the first panel but the two layers of strips are crossing each other.)
5. Drift panel (aluminium honeycomb with a thin copper layer at the RO side) [17]

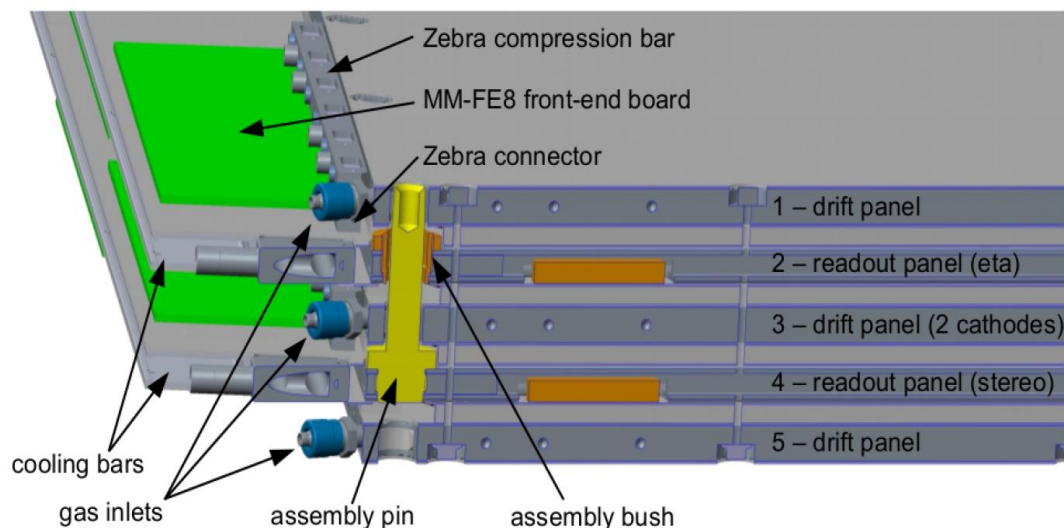
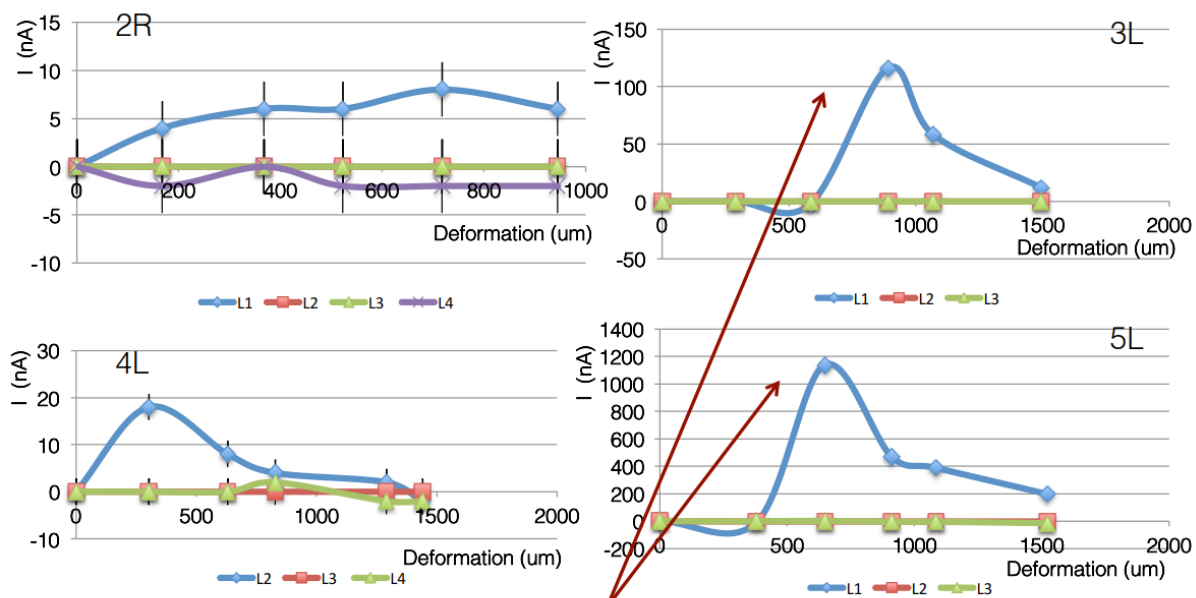


Figure 29 MM structure [26]

The RO can measure a difference in the electricity when a particle crossed through the gas chamber.

Because of the alignment of the RO layers the MM wedge is not allowed to bend too much. To know the maximum deformation to the sector there is an experiment performed. In the experiment, the wedge is put under pressure (weight). While the pressure increased, they measured the performance of the detectors. The maximum deformation for MM quadruplet is 1 mm when not in use. When the quadruplet is installed at the sector the maximum deformation is 0,5 mm for a performance of the detector. [12] The results of the test are in Figure 30



- In 2 cases uncontrolled increase of dark current has been observed (at ~0.5 mm deformation)

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P. Iengo - MM performance under deformation

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Figure 30 Results of MM experiment [12]

The quadruplets are held together with 18 clamps that fix the MM quadruplets in the Z direction. 9 clamps for SM1 and 9 for SM2. Two of these clamps are in the middle of the frame for both of the quadruplets. Movement in the X and Y directions is still possible. The alignment of the MM is done by a fixed point and a slotted point. [13]

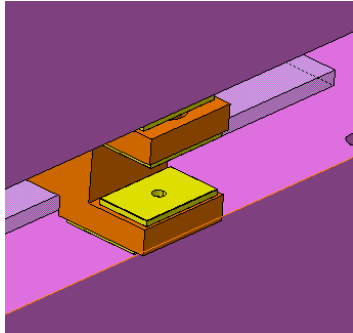


Figure 33 Fixed Z direction MM

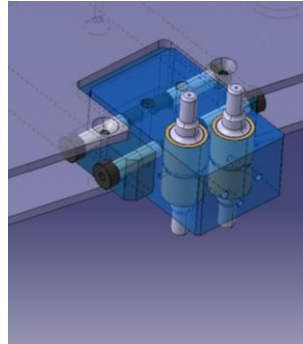


Figure 31 Pins MM connection

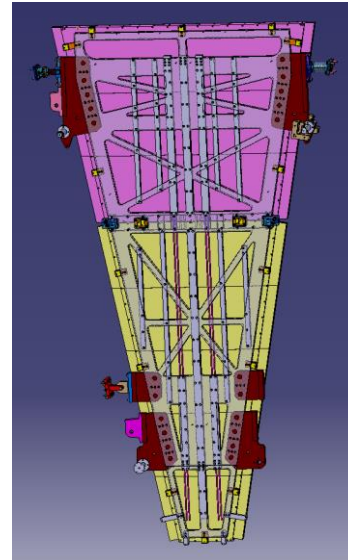


Figure 32 global organisation connection points

The MM wedges are connected by two pins on the frame. The tolerances of the connection are:

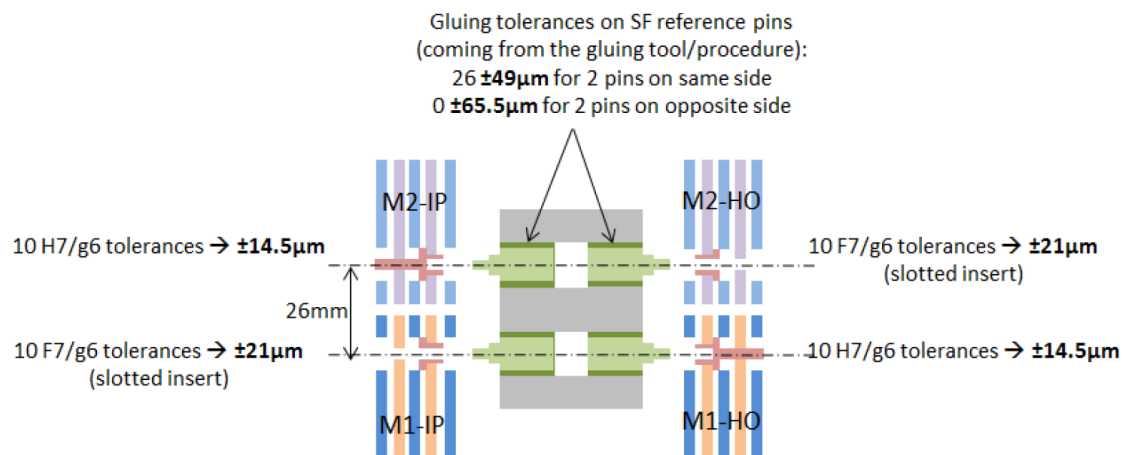


Figure 34 tolerances of the MM [13]

M1-M1	101 μm	Between the 2 Quadroplets
Ip side	84.5 μm	Between quadruplets in one wedges
OH side	84.5 μm	Between quadruplets in one wedges
Worst case	156.5 μm	M1OH-M2OH

Thesis Daan Zaalberg	Sector Assembly Tests ATLAS NSW	
CERN	Version 2	26-07-2018



Appendix D

sTGC background

The sTGC is a detector of the NSW sector for detecting a trigger. The sector is build up out of three quadruplets. Each quadruplet consists of four layers. Only if the sTGC gives a trigger the coincidence will be saved. By this method the data will be minimized. The 2 sTGC weights 350Kg.

Reference plan is on the bottom side of the sTGC because of the marble assemble table.

Between the layers is n-pentane gas, sealed by glue and CO₂.

1. Pads (cathode plates with paper honeycomb glued together with a carbon coating and RO)
2. Wires (wires supported by pillars on the adjacent layers)
3. Strips (read out plane with strip pitch on top of the strips a carbon coating) [14]

Four layers are glued together to form the quadruplet.

The particles will go through the quadruplet and the position of a particle is located by measuring the ionization. [4]

Because of the ordering of the wires, the sTGC wedges are allowed to bend and still get a good result. Because of the glue and the honeycomb, the sTGC gets a strong structure.

The sTGC can be flexible. That is why it is important to calculate the deformation of the sTGC. The deformation requirements are less than the requirements for the MM so the sTGC will fit in the maximal deformation.

The critical point is between the layers. It is not allowed that the layers touch each other, otherwise there will be a short-circuit and the sTGC quadruplet stops detecting.

Appendix E

sTGC KM background

The kinematic mounts make the constrain between the frame and the sTGC. They fix the sTGC in six directions. The sTGC is still able to deform without stress. The constrain between the frame and the sTGC has three connection points. In the table 4 below the three different sTGC mounts with the fix directions are shown. The different supports on the frame for the KM are shown in figure 38.

With push and pull screws it is possible to align the sTGC. The screws are in the guided KM.

Table 4 Kinematic mounts [18]

Mount	Name	Fix directions	Distance
Mount 1	Fixed	3 (X,Y,Z)	0
Mount 2	Adjustable guide	2 (Y,Z) or (X,Z)	
Mount 3	Fork	1 (Z)	+/- 3mm

The weight of the sector will be shared at the three kinematic mounts. The support of the KM will constrain two sTGC wedges on the main frame. There are two different types of guides according to the position of the sector on the NSW. There is a guide for Y,Z and for X,Z direction.

- Fix=4771 N
- Guided tangential = 2281 N
- Guided radial = 3319.4 N
- Fork 22.5 N [19]

The mount of the sTGC kinematics is calculated with FEA for displacement. In sector EISA06 the result was a displacement from $\approx 300 \mu\text{m}$. After the physical testing the high displacement was acceptable. Also after the Eurocode factor 1.35. [20]

The bearings that are used are Radial spherical plain bearings with transit passage because they allow the rotation.

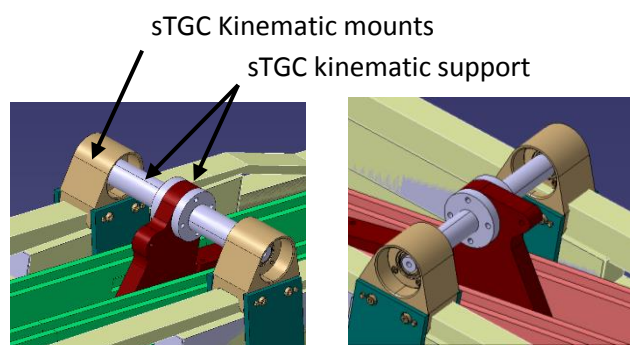


Figure 38 fixed mount sTGC

Figure 38 fork mount sTGC

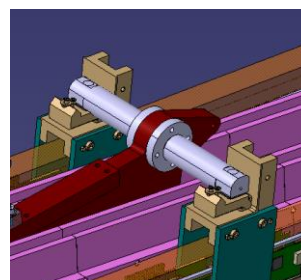


Figure 38 Guided mount sTGC X direction

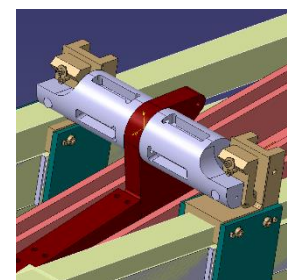


Figure 38 Guided mount sTGC guided mound Y direction

GE 15 TXGR

lubricant

Practically maintenance-free - dry lubrication

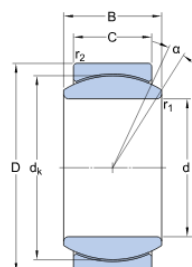
execution

Steel / PTFE fabric

sealing solution

-

Dimensions



d	15	mm
D	26	mm
B	12	mm
C	9	mm
α	8th	°
d_k	22	mm
r_1	minute 0.3	mm
r_2	minute 0.3	mm

Figure 39 Bearing small for the guided pin [21]

GE 30 TXG3E-2LS

lubricant

Practically maintenance-free - dry lubrication

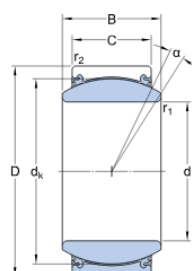
execution

Steel / PTFE fabric

sealing solution

Three lip seals

Dimensions



d	30	mm
D	47	mm
B	22	mm
C	18	mm
α	6	°
d_k	40.7	mm
r_1	minute 0.6	mm
r_2	minute 0.6	mm

Figure 40 Bearing for fixed and fork rods [22]

Original dimensions of the rods and pin:

- Rods: 30 H5 mm
- Pins: 15 f7 mm [23]

Tolerances of the bearings are standard for all this type of bearings:

- Bearing fork and fixed point: 30 0/-0.010 mm
- Bearing pin 15 0/-0.008 mm

Appendix F

Assembly station

The position of the cables is at an angle of 9.6 degrees. The difference between the position of the holes and the grabber mounts is 282.5 mm

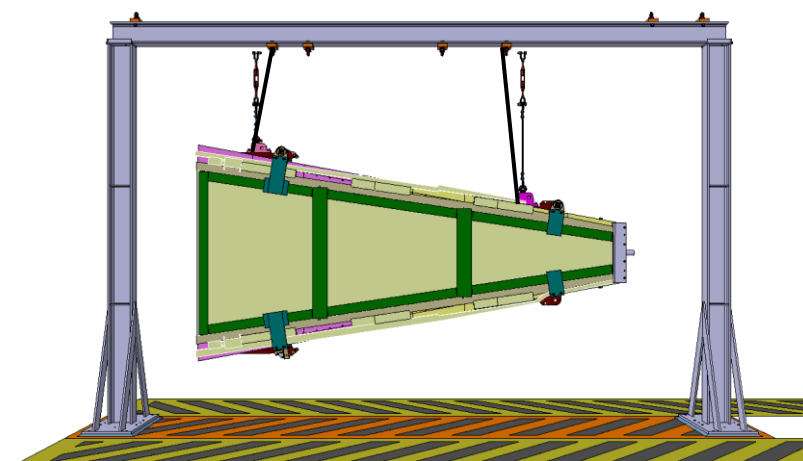


Figure 41 assembly station with cables under an angel

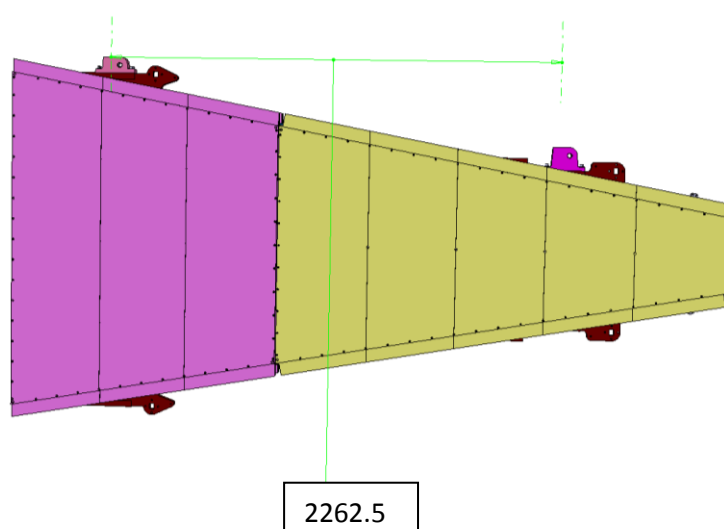


Figure 43 distance between the grabber mounts

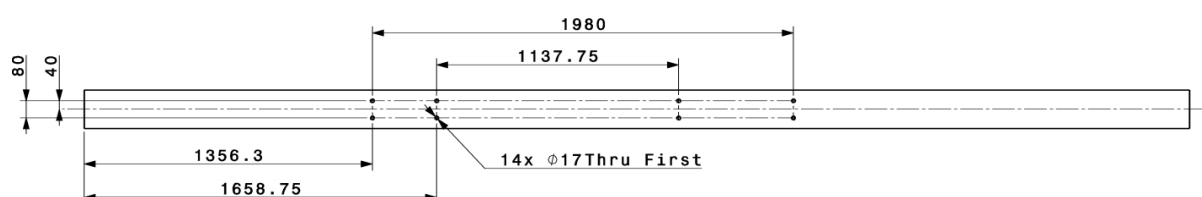
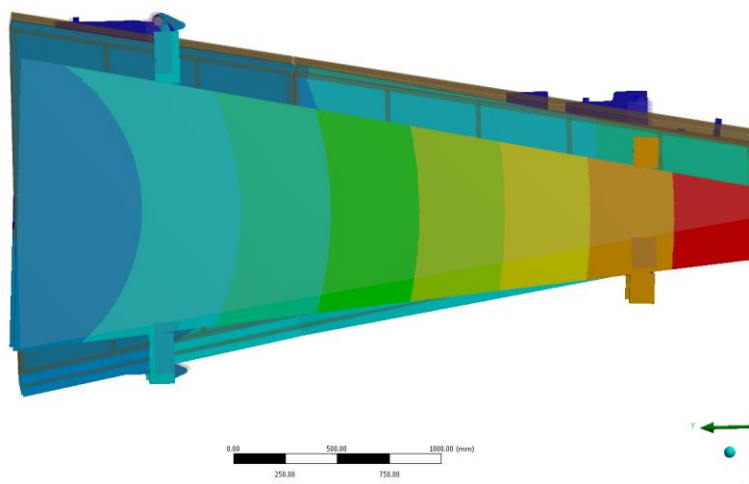


Figure 42 Dimension for the lifting beam [31]

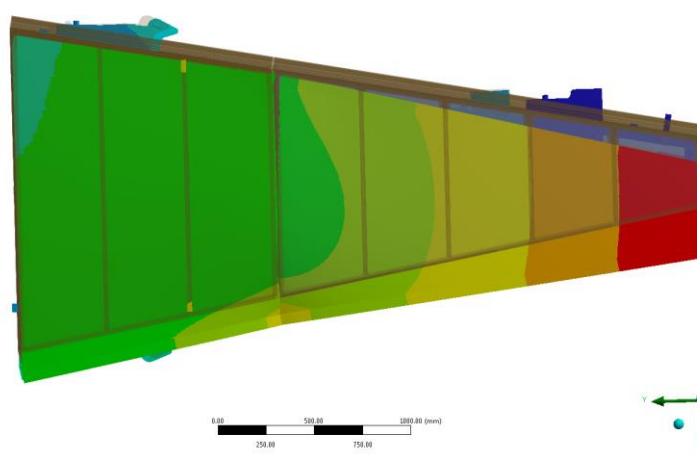
Deformation in the sector with the 9.6 degree angle in the cables. This is a total deformation from peak to peak as an approach for the sector behaviour. A simulation is done for the complete sector, MM_DW and the frame is done to see the deformation with the cables under an angle of 9.6 degree.

F:\ESC04
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
04/06/2018 10:45
0.8350 Max
0.7461
0.6564
0.5667
0.4769
0.3872
0.2975
0.2078
0.1181
0.02837 Min



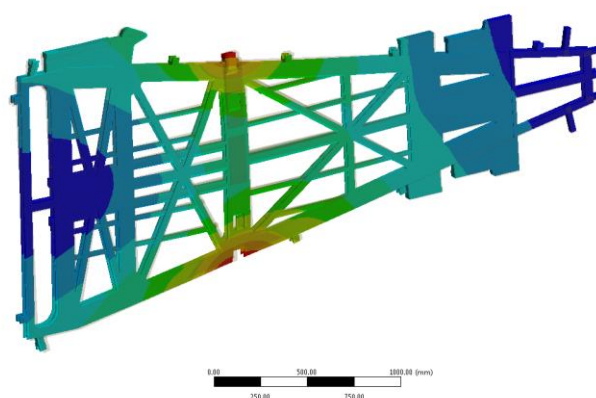
Maximum deformation
0.835 mm

F:\ESC04
Total Deformation MM Total
Type: Total Deformation
Unit: mm
Time: 1
04/06/2018 10:46
0.36 Max
0.324
0.287
0.25
0.213
0.176
0.139
0.102
0.0653
0.0284 Min



Maximum
deformation 0.36 mm

F:\ESC04
Total Deformation 4
Type: Total Deformation
Unit: mm
Time: 1
04/06/2018 10:55
0.2407 Max
0.22446
0.19995
0.17544
0.15093
0.12642
0.10191
0.077396
0.052885
0.028375 Min



0.248 mm

Appendix G

Extra weight on the sector for first sector assembly test

To add weight on the MM's of about 14 to 15 Kg on the different wedges strips from steel where used as the best solution. Below you will find the drawing of the strips. The strips will be connected on the sides of the M0 (SM1 and MS2). For each module this is 2x 7.8 kg with one on the top and one at the bottom.

Table 5 Results and calculations extra weight

Components	Weight	Size	Kg/M^2	Weight added
Frame	130 Kg			
SM1 dummy	94.5 Kg	2.02 M^2	46.78218	0
SM2 dummy	97 Kg	2.12 M^2	45.75472	0
SM1 Prototype	80.4 Kg	2.02 M^2	39.78897	14.1 Kg
SM2 Prototype	82.5 Kg	2.12 M^2	38.91509	14.5 Kg

Aluminium 2755 Kg/m3

Plate			
	Weight	Size	Thickness
SM1 prototype	14.1 Kg	2.02 M^2	2.54 mm
SM2 prototype	14.5 Kg	2.12 M^2	2.48 mm

Stainless steel 7930 Kg/m3

Plate			
	Weight	Size	Thickness
SM1 Prototype	14.1 Kg	2.02 M^2	0.88 mm
SM1 Prototype	14.5 Kg	2.12 M^2	0.86 mm

Strip			
	Weight	Size	Thickness
SM1 Prototype	14.1 Kg	0.7 M^2	2.54 mm
SM1 Prototype	14.5 Kg	0.76 M^2	2.41 mm

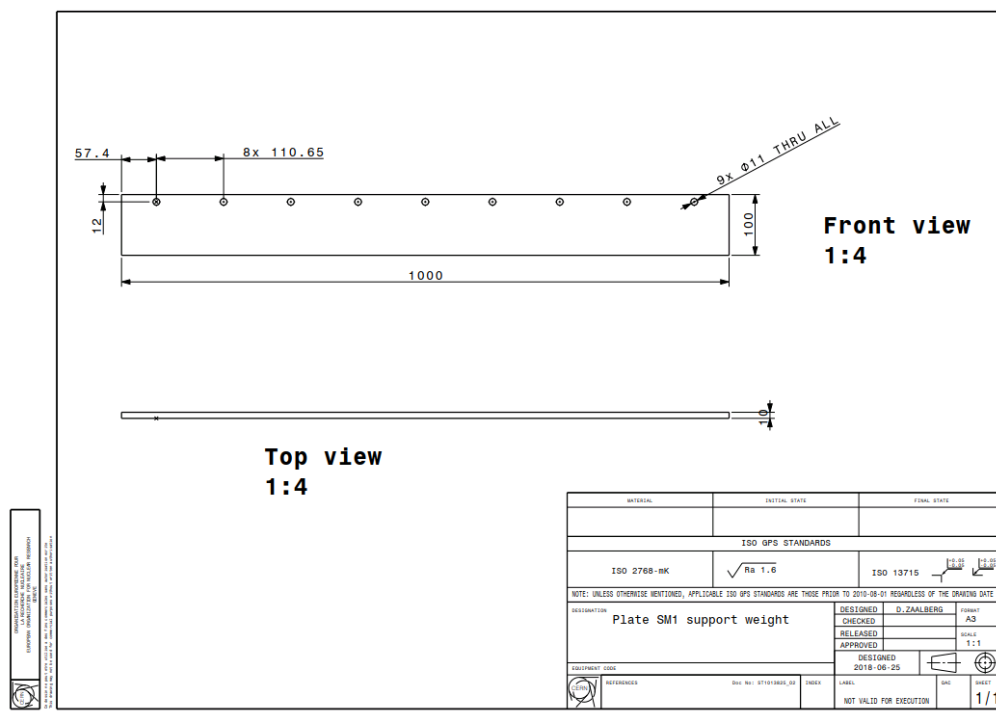


Figure 44 Weight support plate plat is 7.8Kg

The connection of the four plates for the extra weight. With the special bolts and nuts. The bolt will connect the MM together. The Head of the nut will have a thread. With the thread, it is possible to connect the weight to the MM M0.



Figure 45 Connection of the extra weight to the M0

The sTGC consist of a wood mock-up and a M0. The weight of the both can be seen in the table below. The extra added weight is 35Kg.

Table 6 Real weight of the sTGC

Components	Weight	Weight added
Wood sTGC	122.0 Kg	0.0 Kg
M0 sTGC	157 Kg	35.0 Kg
8 plates		4.375 Kg

In the figure 46 below is the extra weight of the sTGC to be seen. The total weight is separated into 4 plates to simulate the reality.



Figure 46 extra weight on the sTGC

Prototype

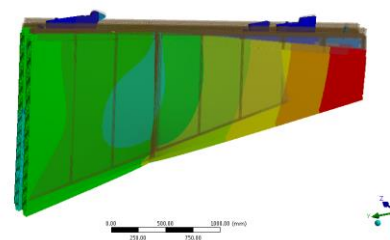
SM1_1_D	19.74	Kg
SM1_2_RO	21.79	Kg
SM1_3_D	20.68	Kg
SM1_4_RO	21.79	Kg
SM1_5_D	19.79	Kg
Other	45.45	
	149.24	

SM2_1_D	21	Kg
SM2_2_RO	21.8	Kg
SM2_3_D	12	Kg
SM2_4_RO	11.9	Kg
SM2_5_D	11.2	Kg
Other	48.3	Kg
	126.2	

SM1	94.5	
Diff	54.74	

SM2	97	
Diff	29.2	

1.18004
 Total Deformation (mm) Total
 Type: Total Deformation
 Unit: mm
 Time: 1
 18/06/2018 13:40
 0.32 Max
 0.344
 0.340
 0.335
 0.330
 0.325
 0.320
 0.315
 0.310
 0.305
 0.300
 0.295
 0.290
 0.285
 0.280
 0.275
 0.270
 0.265
 0.260
 0.255
 0.250
 0.245
 0.240
 0.235
 0.230
 0.225
 0.220
 0.215
 0.210
 0.205
 0.200
 0.195
 0.190
 0.185
 0.180
 0.175
 0.170
 0.165
 0.160
 0.155
 0.150
 0.145
 0.140
 0.135
 0.130
 0.125
 0.120
 0.115
 0.110
 0.105
 0.100
 0.095
 0.090
 0.085
 0.080
 0.075
 0.070
 0.065
 0.060
 0.055
 0.050
 0.045
 0.040
 0.035
 0.030
 0.025
 0.020
 0.015
 0.010
 0.005
 0.000
 0.000E+00 Min



Maximum deformation 0.32 mm

Dummy

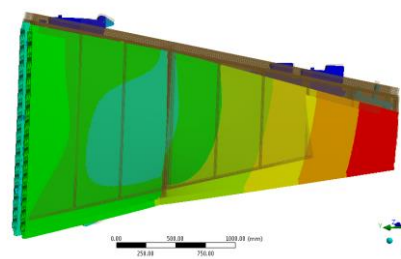
SM1_1_D	11.06	Kg
SM1_2_RO	11	Kg
SM1_3_D	11	Kg
SM1_4_RO	11	Kg
SM1_5_D	11	Kg
Other	39.45	
	94.51	

SM2_1_D	11	Kg
SM2_2_RO	11	Kg
SM2_3_D	12	Kg
SM2_4_RO	11.9	Kg
SM2_5_D	11.2	Kg
Other	39.9	Kg
	97	

SM1	94.5	
Diff	0	

SM2	97	
Diff	0	

1.18004
 Total Deformation (mm) Total
 Type: Total Deformation
 Unit: mm
 Time: 1
 18/06/2018 13:40
 0.3 Max
 0.281
 0.277
 0.273
 0.269
 0.265
 0.261
 0.257
 0.253
 0.249
 0.245
 0.241
 0.237
 0.233
 0.229
 0.225
 0.221
 0.217
 0.213
 0.209
 0.205
 0.201
 0.197
 0.193
 0.189
 0.185
 0.181
 0.177
 0.173
 0.169
 0.165
 0.161
 0.157
 0.153
 0.149
 0.145
 0.141
 0.137
 0.133
 0.129
 0.125
 0.121
 0.117
 0.113
 0.109
 0.105
 0.101
 0.097
 0.093
 0.089
 0.085
 0.081
 0.077
 0.073
 0.069
 0.065
 0.061
 0.057
 0.053
 0.049
 0.045
 0.041
 0.037
 0.033
 0.029
 0.025
 0.021
 0.017
 0.013
 0.009
 0.005
 0.001
 0.000
 0.000E+00 Min



Maximum deformation 0.3 mm

Figure 47 Differences between the dummy and the real sector.

The differences in the maximum deformation is 20 μm . The conclusion is that, the prototype and dummy is a good replica from the real sectors.

Appendix H

Results of the survey

Accuracy of the survey

To show the results clearly, the deformations are shown with a 100x upscale. Shown in the tables the deformation in X and Y direction. [24]

The MM-DW on table is a reference point and the MM-DW in assembly station is the new situation. The results for the MM-DW in vertical position hanging are in pictures below figure 48,49

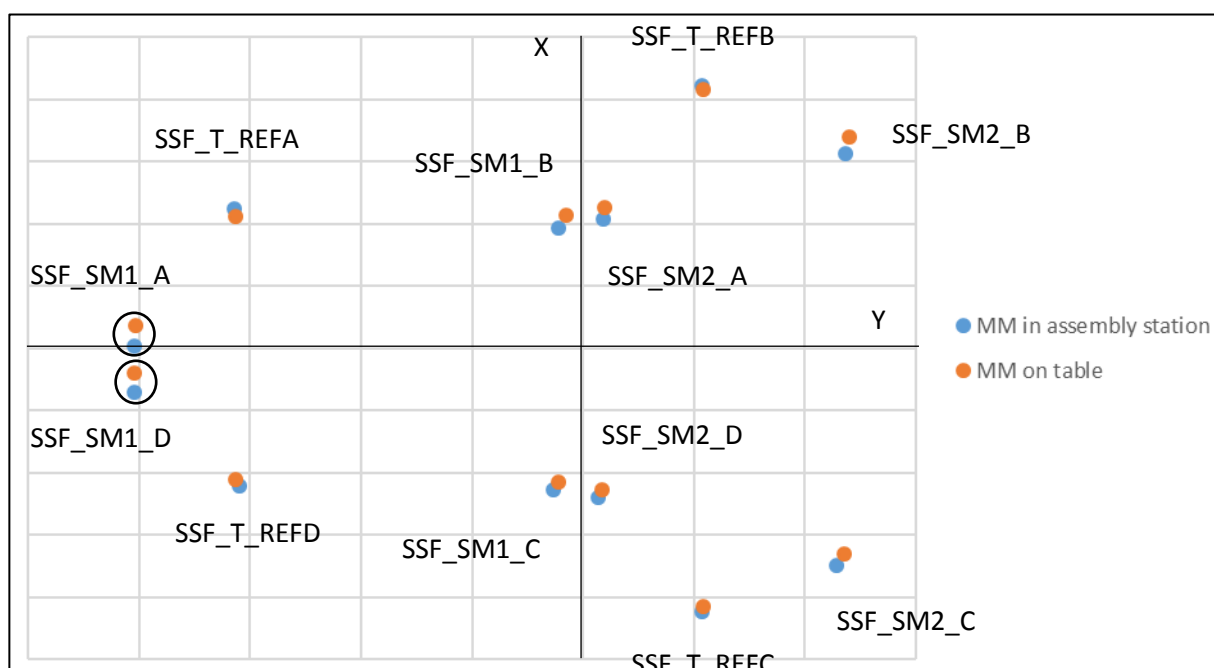


Figure 48 Result of the MM-DW in vertical position XY

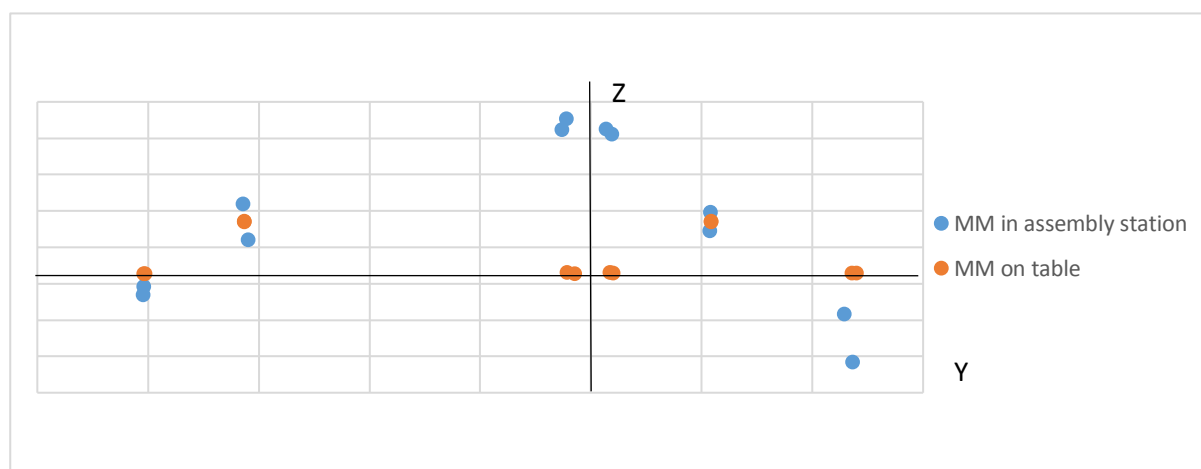


Figure 49 Results of the MM-DW in vertical position YZ

Table 7 Results MM-DW survey

	X	Y	Z	
Survey target on Alignment rod for assembly				
SSF_T_REFA	-191.8	152.7	-252	um
SSF_T_REFB	-168.3	-37.7	128.4	um
SSF_T_REFC	119	-54.2	-128.4	um
SSF_T_REFD	241.1	-60.7	252	um
Points on MM Quadruplets				
SSF_SM1_A	-637.9	-25	-291.2	um
SSF_SM1_B	-263.2	-229.7	1960.7	um
SSF_SM1_C	-395.7	-364.7	2130.8	um
SSF_SM1_D	-678.9	-58.9	-183.4	um
SSF_SM2_A	-232.3	-154.3	1965.4	um
SSF_SM2_B	-367.6	-359.9	-562.2	um
SSF_SM2_C	-536.8	-179.7	-1224.8	um
SSF_SM2_D	-393.9	-67.5	1908	um

The deformation is higher than expected. The behaviour of the deformation is according to the simulations. Results are in table 7. The results in the table are corresponding with the results in figure 48 and 49.

It is shown that the deformation in the whole sector is higher than in the simulations. The overall deformation can be explained because of the dummy wedges. During the previous assembly's and tests, the MM-DW was not perfect. The mistakes that are made during the first MM assembly are resulting now in an overall higher deformation.

Also the Z direction of the SM1 and SM2 are higher than expected. (SM1_A, SM1_D, SM2_A, SM2_D, SM2_C). This is to explain by the reason that the MM-DW is heavier than the final MM-DW. Also the sector is under a angle what will give a higher deformation. These two things in combination with the first prototype of the MM-DW with modifications to make it work will result in higher deformation.



The results below are from the sTGC in the orientation of EISC04. The reference point is from the sTGC supported in the trolley. The results are below in figure 50 and 51. [25]

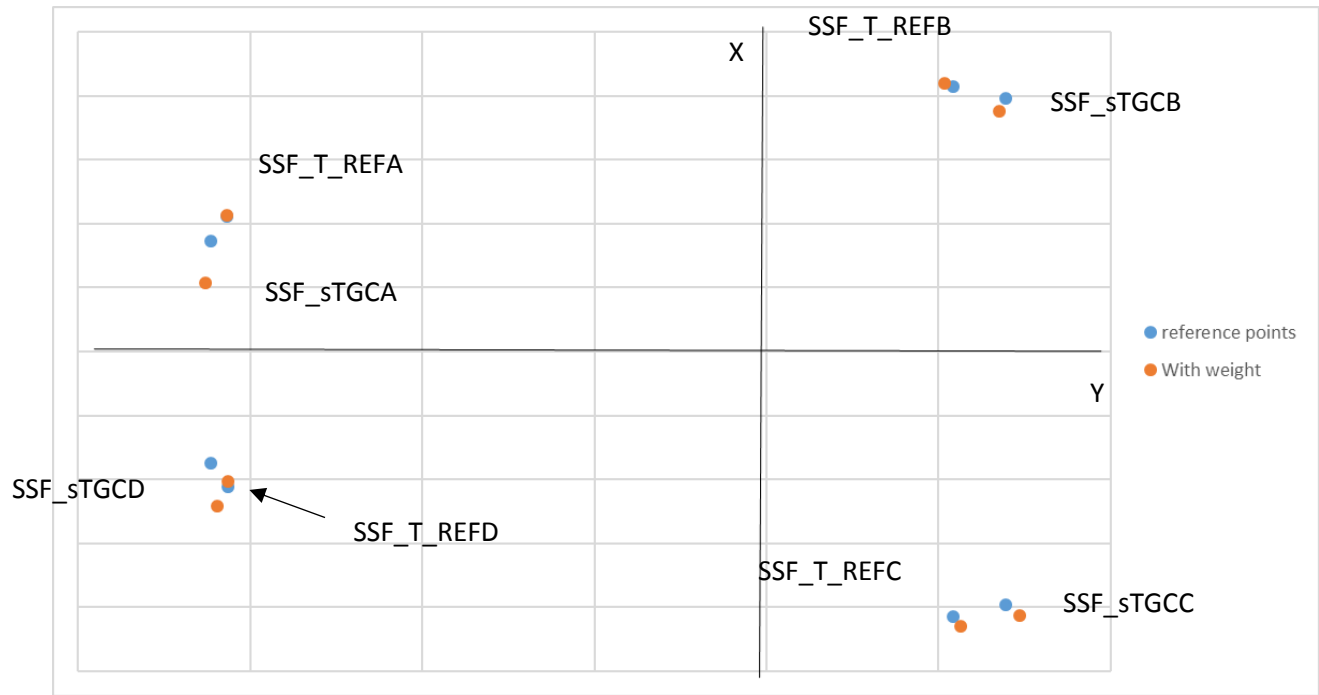


Figure 50 sTGC results EISC04 XY

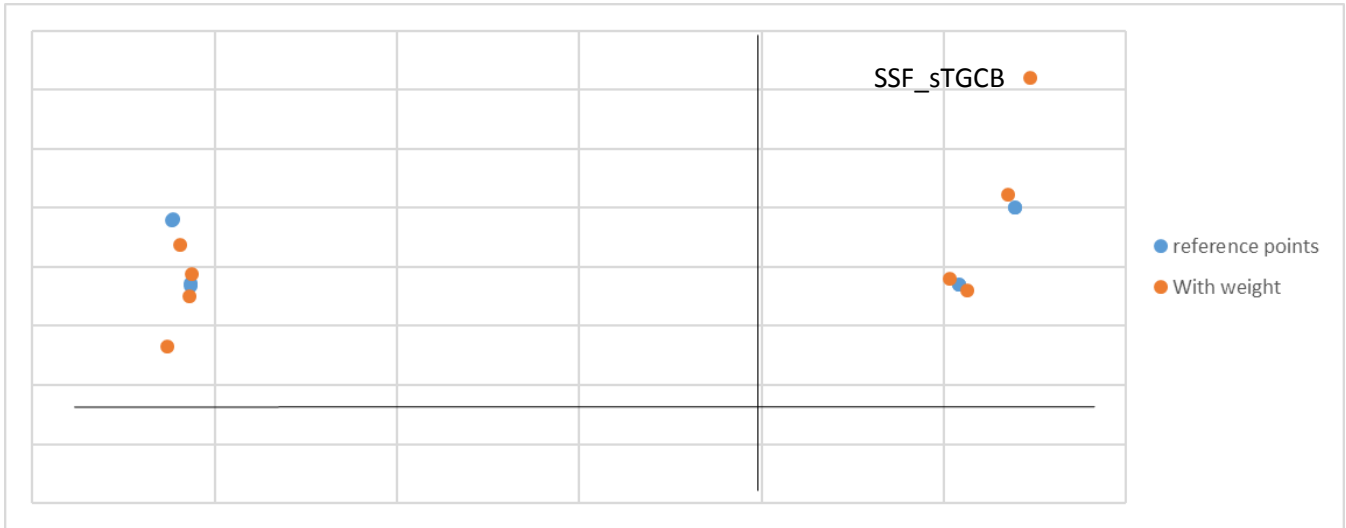


Figure 51 sTGC results EISC04 YZ

The results from the sector before and after hanging the sTGC

Table 8 results survey of the sTGC

SSF reference points	X	Y	Z	
SSF_T_REFA	-144.7	-28.4	-87.3	um
SSF_T_REFB	295.9	-227.8	44.4	um
SSF_T_REFC	-101.4	247.5	-44.4	um
SSF_T_REFD	-49.8	8.8	87.3	um
sTGC reference points				
SSF_STGCA	1346.7	-197.5	215.8	um
SSF_STGCB	317.4	-415.4	-1095.6	um
SSF_STGCC	394.9	183.4	-111.9	um
SSF_STGCD	1319.8	138.5	1067.3	um

The behaviour of the sTGC in position EISC04 is as expected. Unfortunately was survey point B not placed well, therefor the result for that survey point is not. The miss placing of the survey point is because it was difficult to get it in because of the friction between the sTGC and the target.

The deformation in the STGC is perfect as expected see table 9. The higher numbers comes out of the orientation of the angle of the sTGC hanging in the trolley and the sector hanging on the MM_DW. By changing the angle of the sTGC with the adjustable guide, it is possible to reach the same results as in the simulation

To see the deformation in the sTGC, one has to compare the distance from the points to each other before hanging and while hanging. This is the Internal displacement during the assembly looking at the distance between the points before the weight and during the weight. Comparing the results with the simulations the deformation should be 730um. So there is a difference of 27% between the real and the simulation

Table 9 Deformation results in the sTGC (results in mm)

	X	Y	Z
AB	-1.0293	-0.2179	-1.3114
AC	-0.9518	0.3809	-0.3277
AD	-0.0269	0.336	0.8515

The table below shows the movement of the sTGC. This are the new results minus the old results from table 10. This results in good behaviour and good connection between the sTGC and the MM-DW. This means that the small deformation in the sTGC can be corrected and it is possible to align the both sTGC.

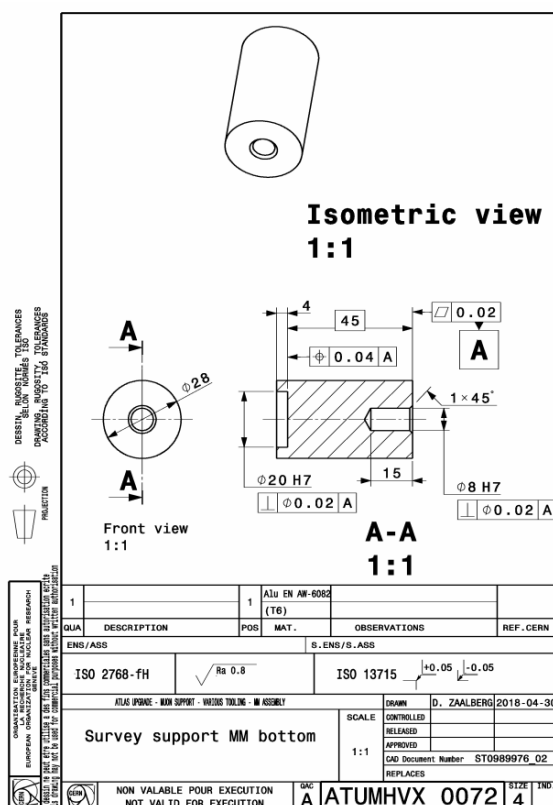
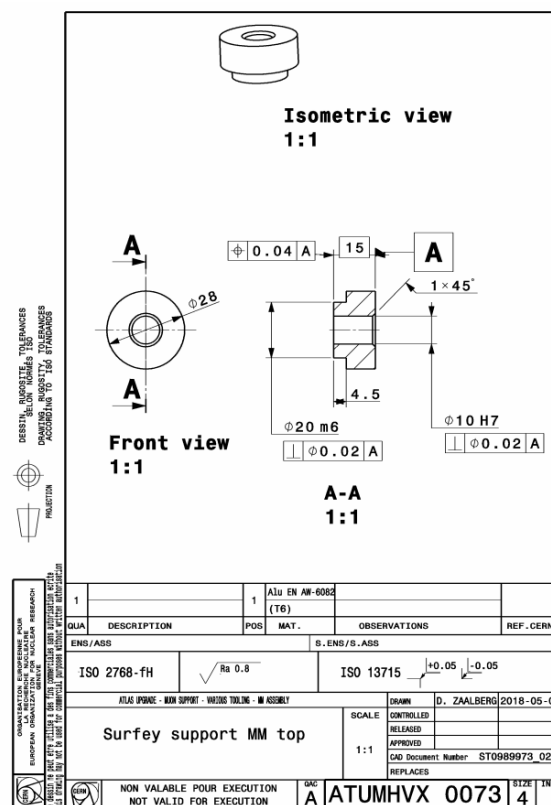
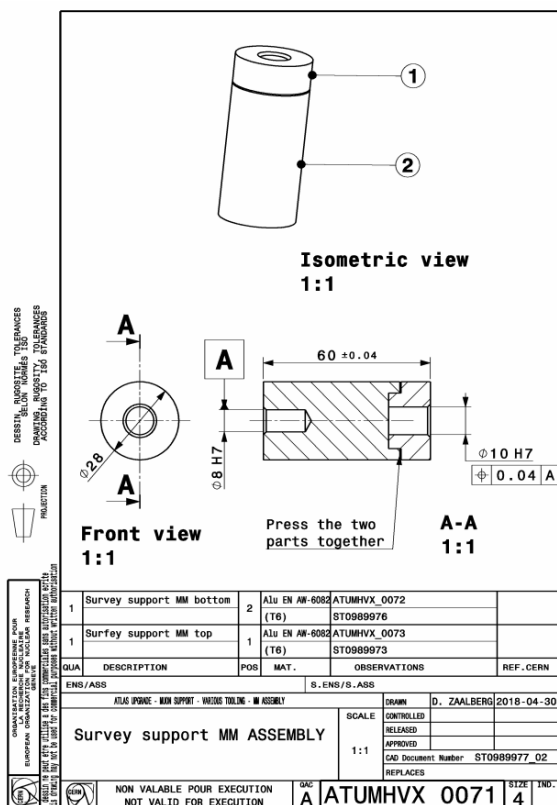
Table 10 Results after adjusting the guided

sTGC after adjusting guided			
SSF reference points	X	Y	Z
SSF_T_REFA	8.1	-10.6	-7.1
SSF_T_REFB	-13	-1.3	3.6
SSF_T_REFC	16.8	-6.3	-3.6
SSF_T_REFD	-11.9	18.1	7.1
sTGC reference points			
SSF_STGCA	1404.2	339.9	40.5
SSF_STGCB	-37	88.4	67
SSF_STGCC	-10.4	1182.6	18.6
SSF_STGCD	1446.9	782.8	-15.6

Appendix I

Drawings of survey and support parts for assembly

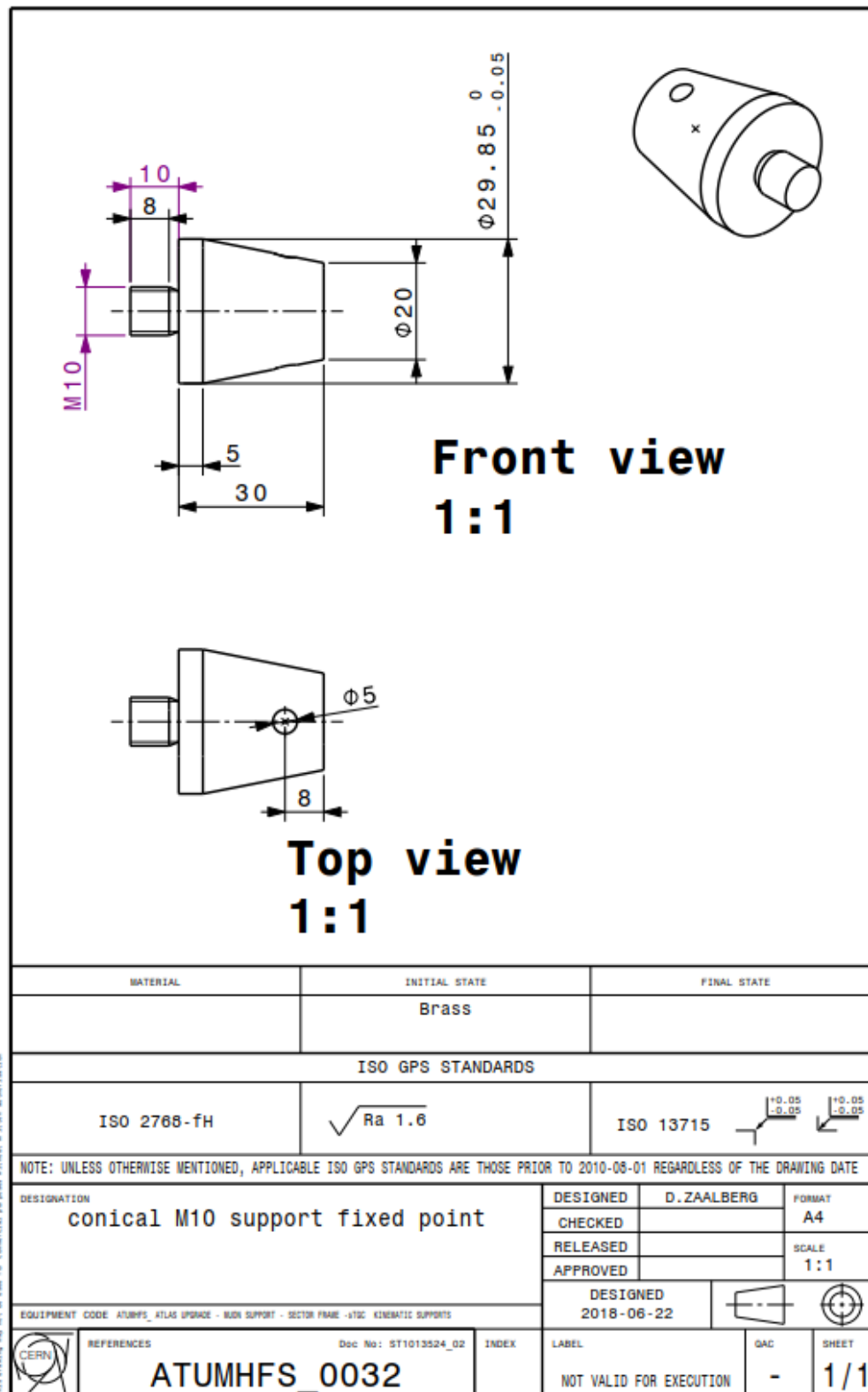
Support for survey for MM pins



Thesis Daan Zaalberg	Sector Assembly Tests ATLAS NSW	
CERN	Version 2	26-07-2018

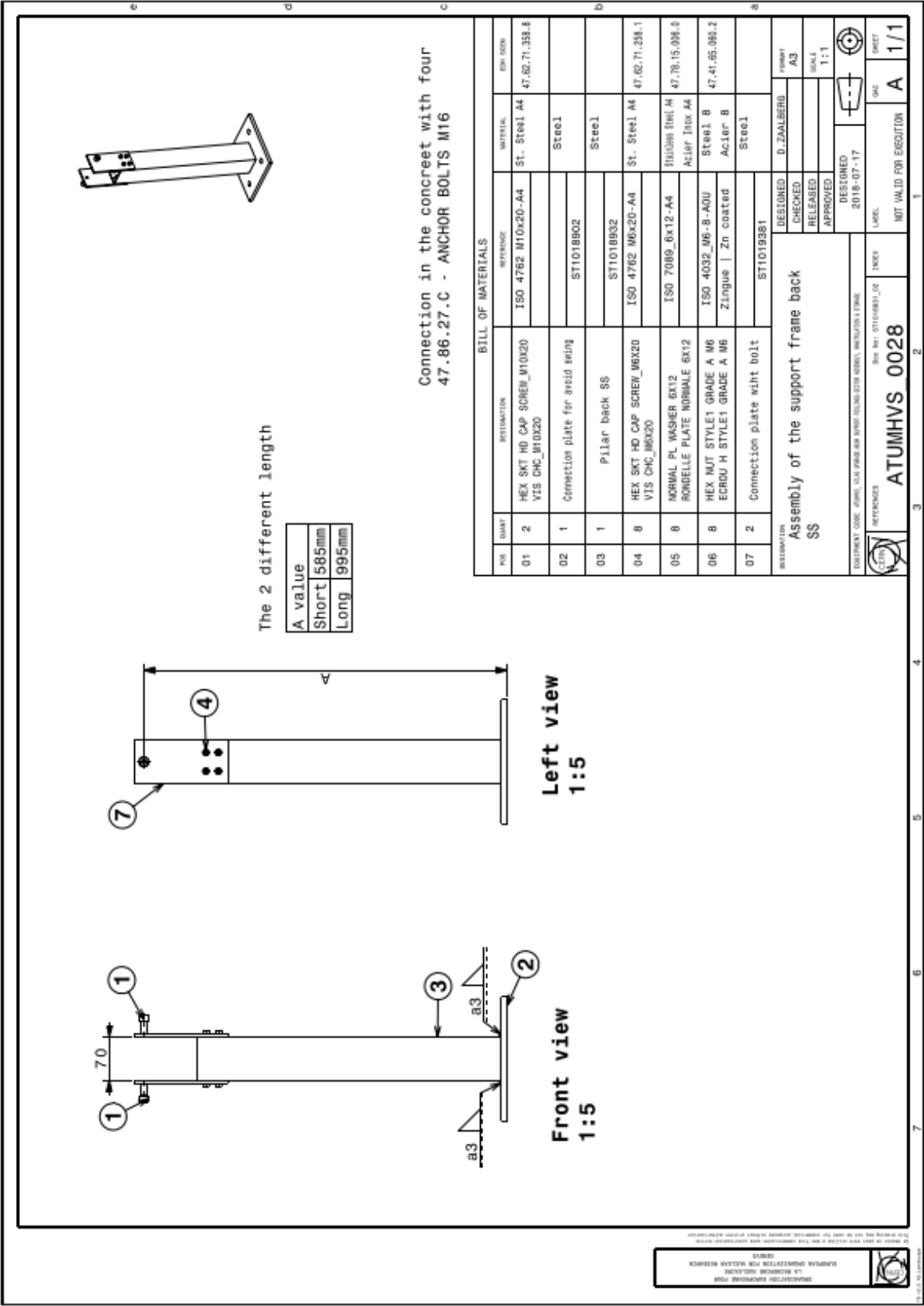


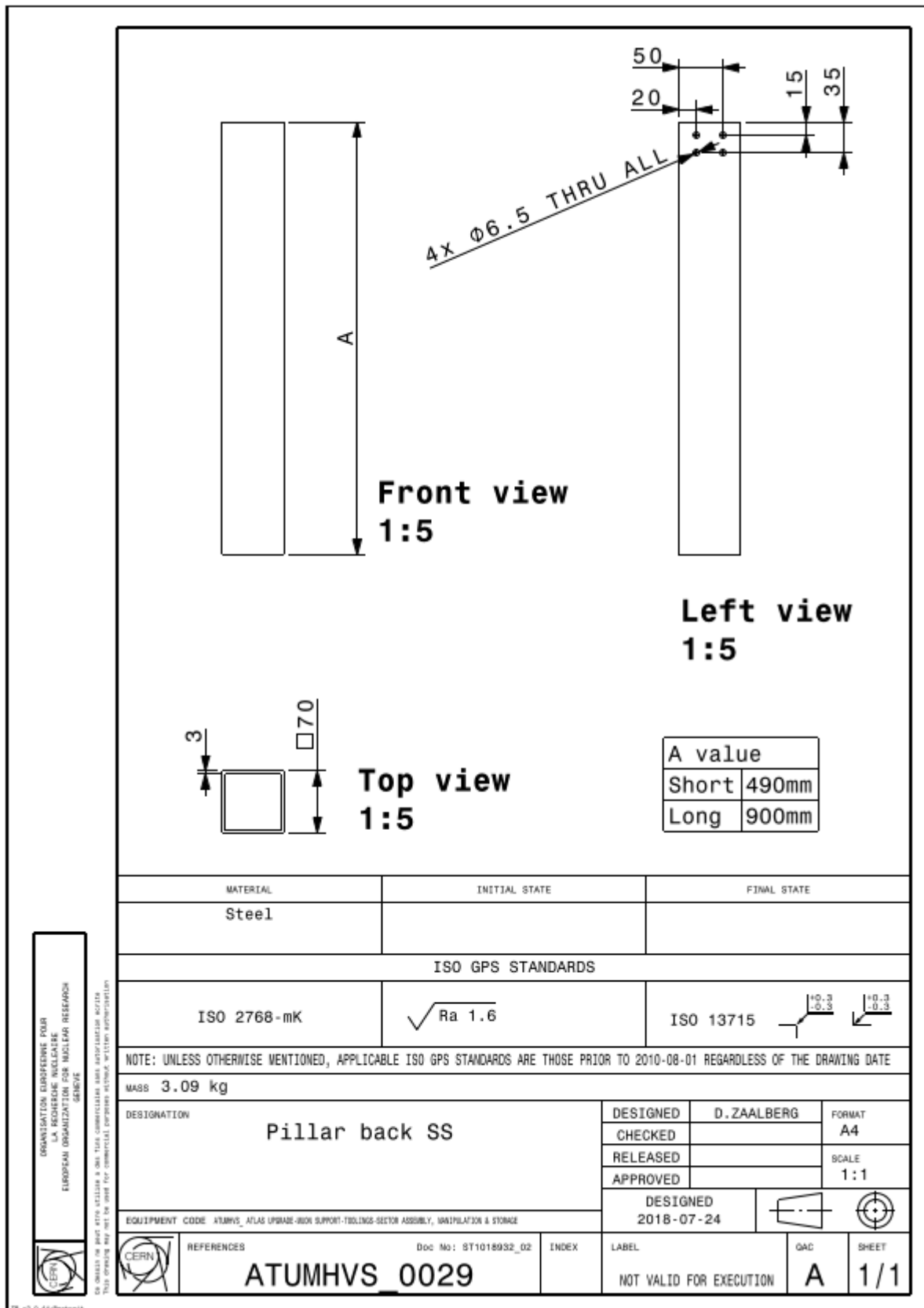
Cone for connection of the fixed rod

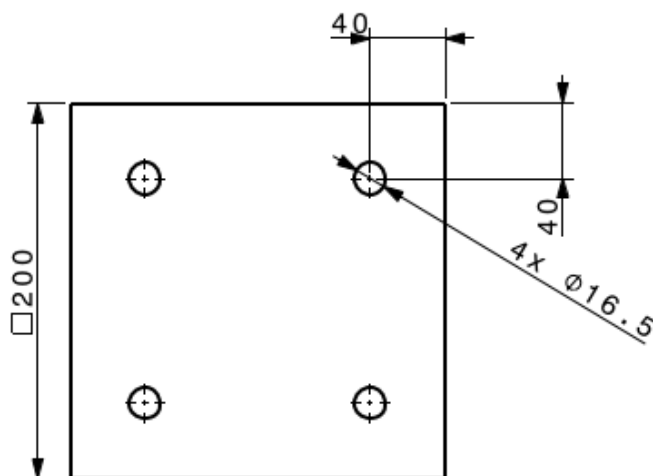


Appendix J

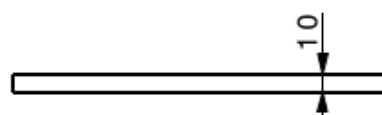
Design and drawings of the pillar to avoid swing







Front view
1:3



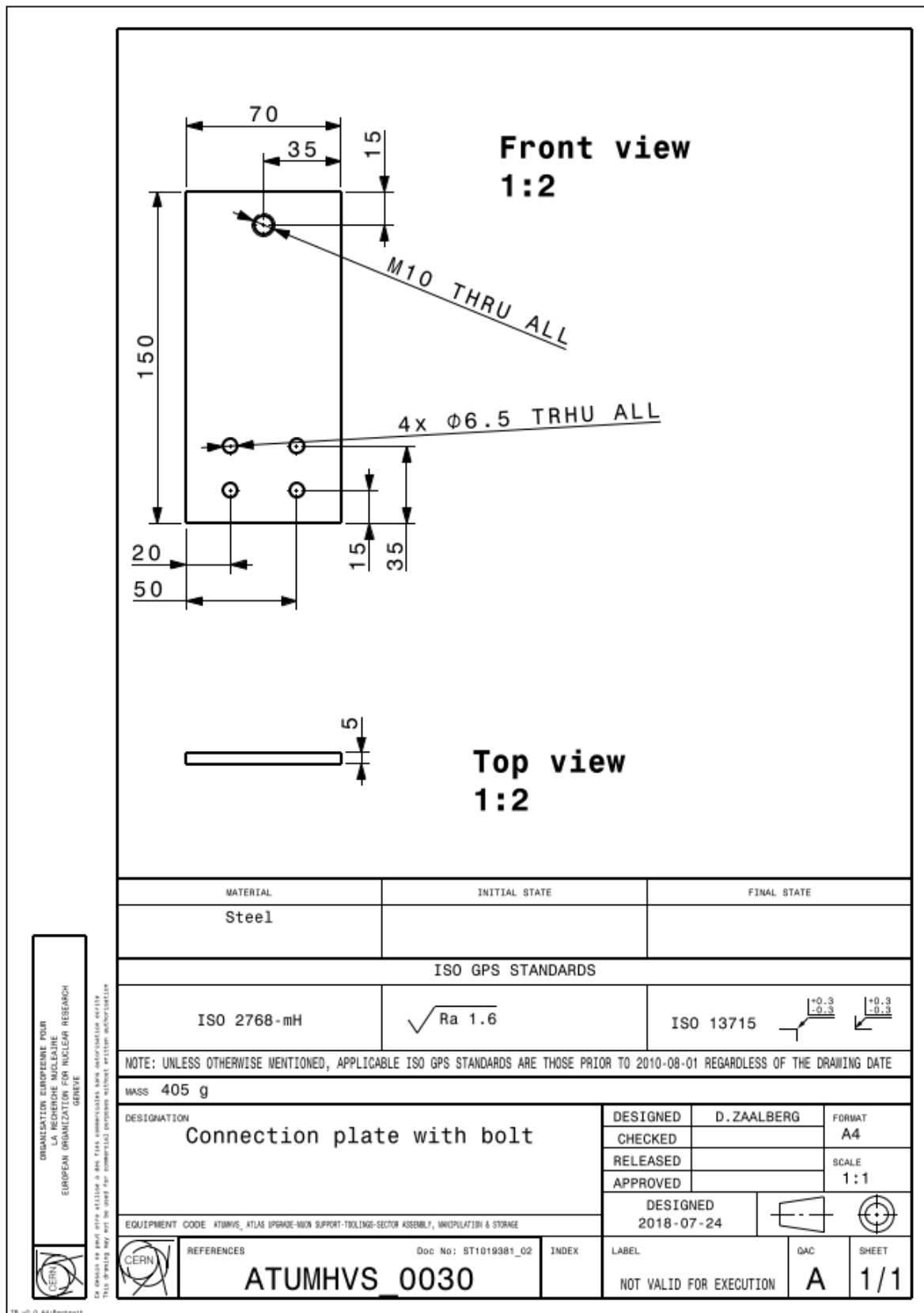
Top view
1:3

MATERIAL	INITIAL STATE	FINAL STATE
Steel		
ISO GPS STANDARDS		
ISO 2768-mK	$\sqrt{Ra\ 1.6}$	ISO 13715 $\begin{matrix} +0.3 \\ -0.3 \end{matrix}$ $\begin{matrix} +0.3 \\ -0.3 \end{matrix}$
NOTE: UNLESS OTHERWISE MENTIONED, APPLICABLE ISO GPS STANDARDS ARE THOSE PRIOR TO 2010-08-01 REGARDLESS OF THE DRAIVING DATE		
MASS 3.07 kg		
DESIGNATION Connection plate to avoid swing		DESIGNED D.ZAALBERG
		CHECKED
		RELEASED
		APPROVED
EQUIPMENT CODE ATUMHVS, ATLAS UPGRADE HIGH SUPPORT TOOLING-SECTOR ASSEMBLY, MANIPULATION & STORAGE		DESIGNED 2018-07-24
REFERENCES ATUMHVS 0031		FORMAT A4
		SCALE 1:1
CERN		DESIGNED 2018-07-24
Doc No: ST1018902_02		INDEX
INDEX		LABEL
NOT VALID FOR EXECUTION		QAC A
		SHEET 1/1

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CERN

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This drawing may not be used for commercial purposes without written authorization

TB-v0.0 A4-Portrait



Appendix K

ANSYS simulation results sector assembly

Version: 1



Student

Name: Daan Zaalberg

Number: 500709165

24-07-2018, Meyrin

Internship organisation

Company: CERN

Supervisor: Patrick Ponsot

Study

Name: Hogeschool van Amsterdam

Study: Engineering design and innovation

Supervisor: J. van der Grinten

VERSION	CHANGE	DATE	CHECK BY	CHECK DATE
1	D. Zaalberg	24-07-2018	P. Ponsot	25-07-2018

1 Simulations for the deformation

The document is an appendix from the thesis Sector Assembly test for New Small Wheel. The simulations are done with ANSYS.

1.1 Purpose of the simulation

The simulation will show the behaviour of the sector while assembling the sTGC to the MM-DW.

With this simulation will an approach of the deformation be simulated. If the tolerances are above the tolerances of the 400 μm there has to be found a solution. The orientation of EIS04 is the sector with the highest deformation. In this document, only the EISC04 will be handled.

When all the simulations are conformed and the deformation is within the tolerance limits the green light can be given for the first sector assembly. In the Appendix C of the thesis is concluded that a higher deformation than 0,5mm will have effect on the efficiency of the sector That's why it is important to see the deformation before the test in real.

1.2 Set up of the simulation EISC04 and EISC06

The sector mesh is a simplified version of the real one. The same materials will be used as in reality. The connections between the wedges and the frame are done with joints and fixed in the directions needed.

The sector hangs on two cables on the assembly frame. For the two cables, there will be used two remote displacements. The remote displacements have one coordinating system placed in the middle of the interface for the cable. The fixation of the coordinate system is shown in the picture below (Figure 1).

In the situation with different degrees of freedom, the Y rotation is fixed on the grabbermounts. By turning, the gravity around the Y axis a swing is made with the simulation.

For the simulation with the sector under a swing, the Y rotation is blocked. This way it is possible to see the deformation in the sector. Otherwise, ANSYS will show the swing displacement. The simulations are relative.

Configuration	X	Y	Z
Fixed	Fixed	Fixed	Fixed
Guided	Free	Fixed	Fixed
Fork	Free	Free	Fixed

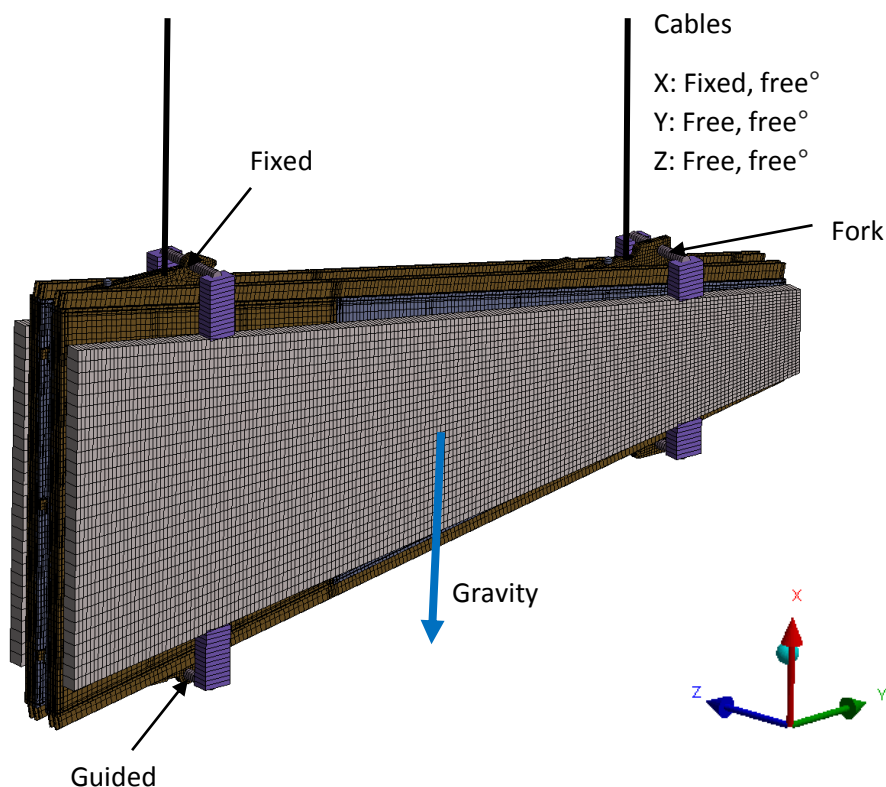


Figure 1 sector configuration for simulation

0 degree swing

Total deformation

Deformation of all the components, because of the MM connection to the spacer frame there is a difference between the left side and the right side of the sector. The MM quadruplets are mounted on both sides. The fixed and guided are reversed on both sides. Good to see the deformation according to the KM orientation.

The highest deformation is in the top of the sTGC 0.7068 mm of deformation. The deformation is based on the deformation in the sTGC, KM and MM quadruplets.

The deformation is mainly due to the relative displacement between the sTGC and MM wedges, not in the wedges. The deformation of 0.706 mm is not a big problem according to the quality of the MM's. When the sector is in normal position the deformation because of the KM orientation would be less and within the tolerance of 400 μm .

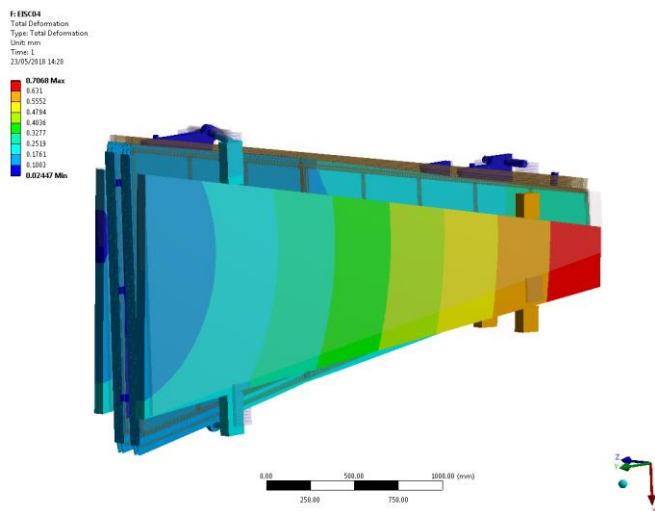


Figure 2 Total sector 0 degree angle, ISO view left side total deformation

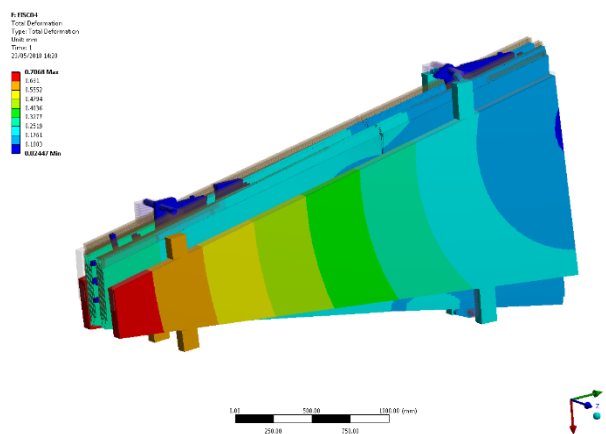


Figure 3 Total sector 0 degree angle, ISO view right side total

MM total deformation

The MM has a deformation of 0.3 mm. This deformation is in the complete MM-DW. Good to see is the bending in the MM (Figure 4 till 7). The bending is because of the MM orientation into the spacer frame.

The highest deformation is in the top part of the SM1.

The difference in deformation between SM1 and SM2 is 80 μm .

The bending is around the entire axis (X,Y,Z). In different quadruplets is the deformation around the 0.15 mm. But the complete MM had a deformation form 0.3 mm from peak to peak.

The deformation is acceptable for the sector assembly.

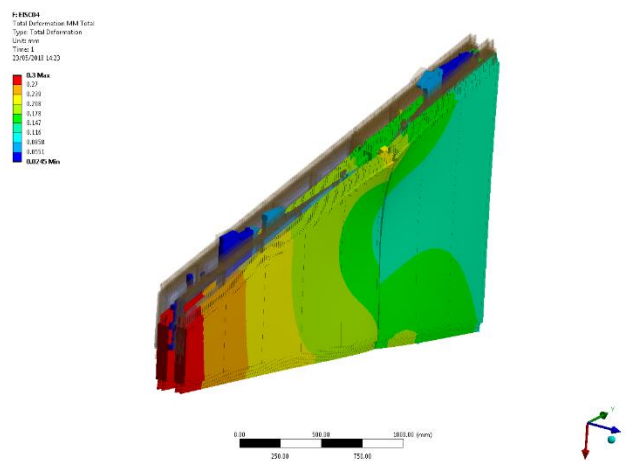


Figure 4 MM-DW 0 degree angle, ISO view total deformation

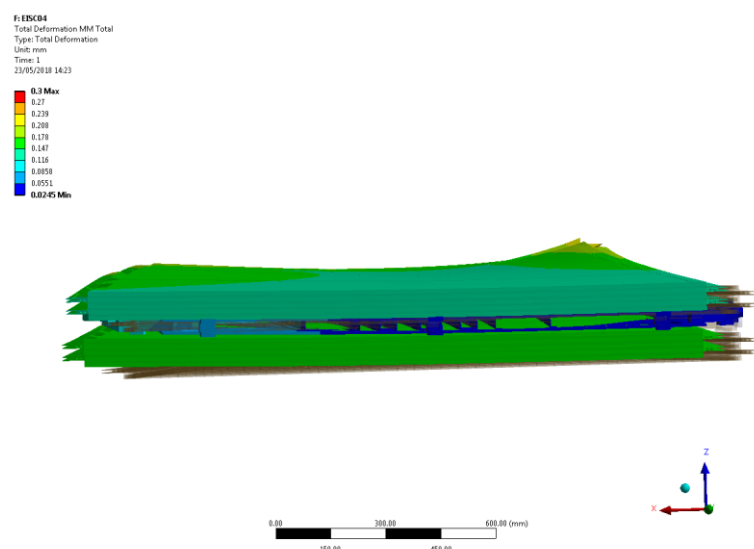


Figure 5 MM-DW 0 degree angle, back view total deformation

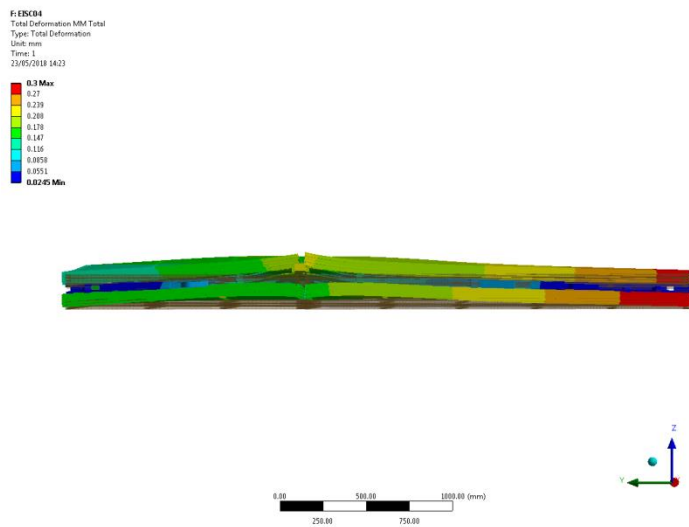


Figure 6 MM-DW 0 degree angle, top view total deformation

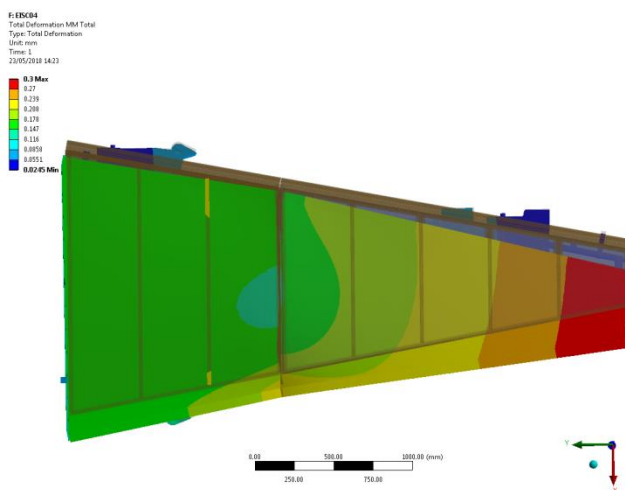


Figure 7 MM-DW 0 degree angle, left view total deformation

Frame total deformation

The behaviour of the MM equivalent to the deformation of the spacer frame. The deformation in the spacer frame is 0.23 mm. The largest deformation is on the connection pins for the MM.

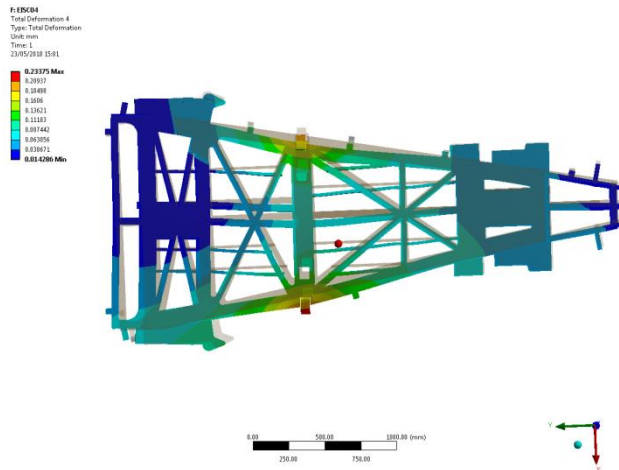


Figure 89 Spacer frame 0 degree angle, left view total deformation

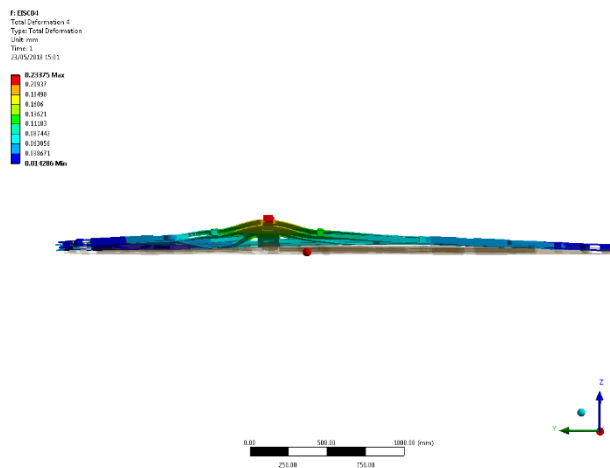


Figure 8 Spacer frame 0 degree angle, front view total deformation

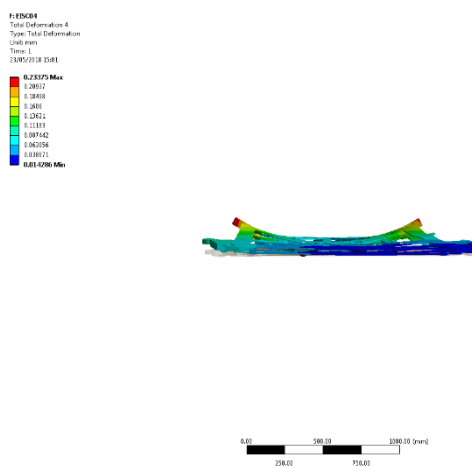


Figure 10 Spacer frame 0 degree angle, back view total deformation

sTGC and KM total deformation

The sTGC is a complete glued part, with different layers. Because of the glue the sTGC will look as a solid part. The fixed point on top and the guided point on the bottom will give the sTGC a higher deformation of 0.7 mm. The higher deformation in the sTGC while assembling is not a problem. If the deformation gets higher it is possible to compensate it by an adjustment in the guided fork. Good to see is the small difference in the two wedges because of the bending in the MM. The difference in the two sTGC is between 10 μm and 15 μm . This is because of the bending of the spacer frame under the weight of the MM. This will not be a problem for the deformation in the sTGC. In the end of the sTGC assembly the sTGC needs to be adjusted on the guided fork.

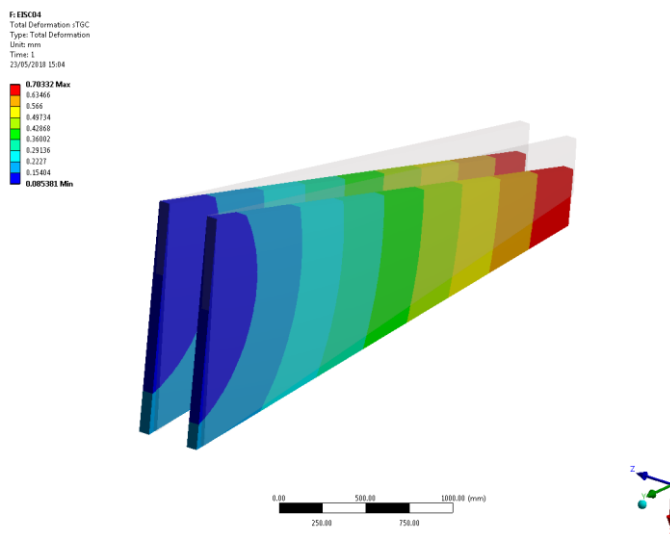


Figure 1112 sTGC 0 degree angle, ISO view total deformation

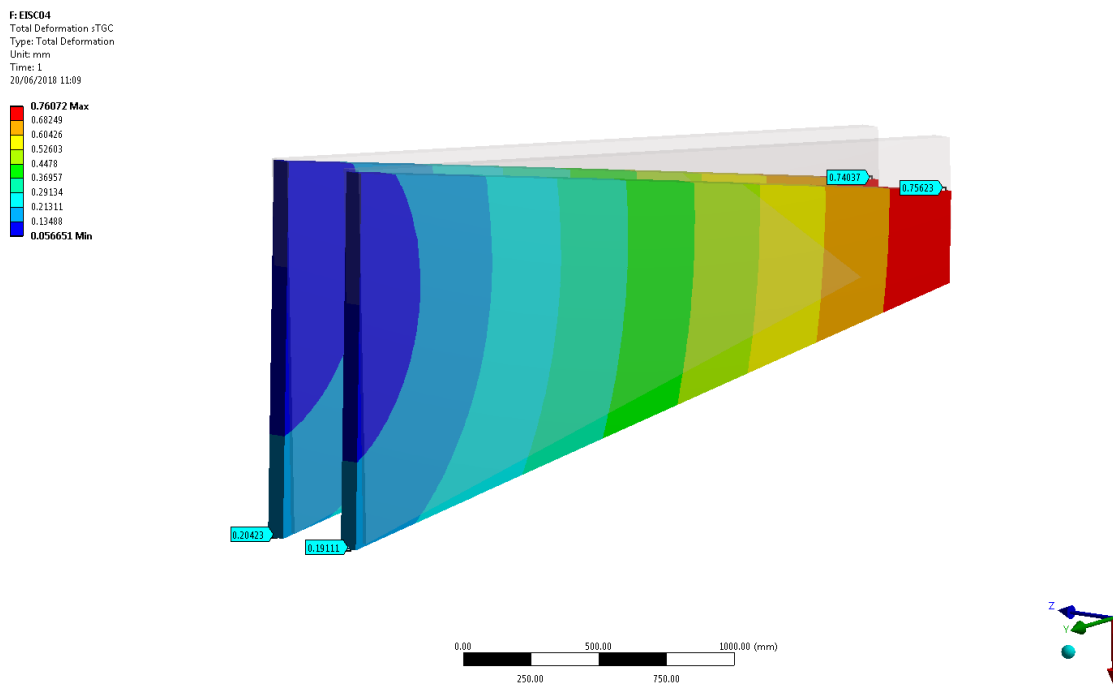


Figure 11 sTGC difference in the wedges.

To understand the behaviour of the sTGC KM the orientation is important. On top is the fixed and on the bottom is the guided KM. The expectation of the deformation is that the fixed point will bent down because of the gravity and the guided will bent to the left because of the moment in the sTGC. The KM are very simplified.

In the pictures below the result of the simulations. The behaviour of the sTGC KM is the same as expected with a deformation of 0.2 mm in the fixed and 0.22 mm in the guided.

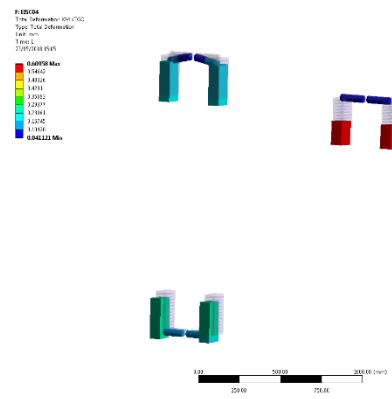


Figure 13 sTGC KM 0 degree angle, ISO view total deformation

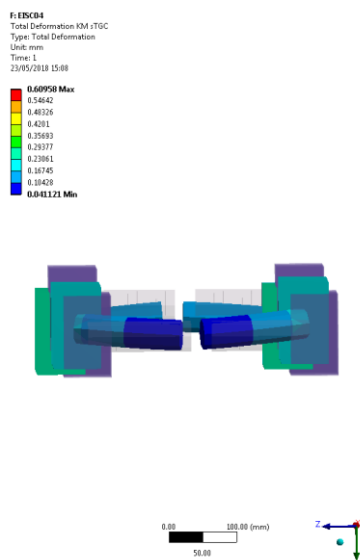


Figure 14 sTGC KM 0 degree angle Top view total deformation

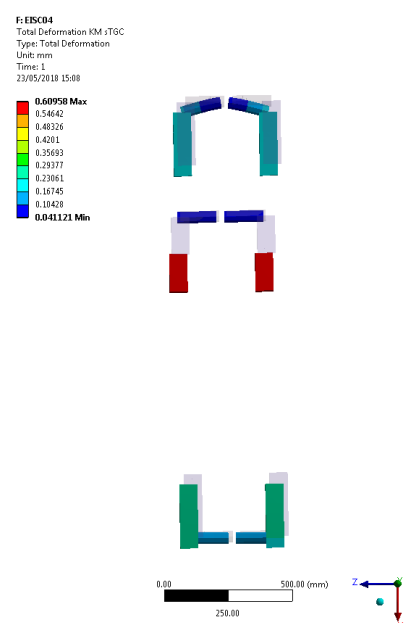


Figure 15 sTGC KM 0 degree angle back view total deformation

1.3 1 degree swing

Total deformation

The deformation is an approach to the reality. These situation sexists for a short time and is the worst-case situation. But in this simulation is shown that the back of the sector will deform more. The deformation is 1 mm. With a horizontal bending on the long side of the sector. With a twist around the X axis because of the orientation of the STGC KM

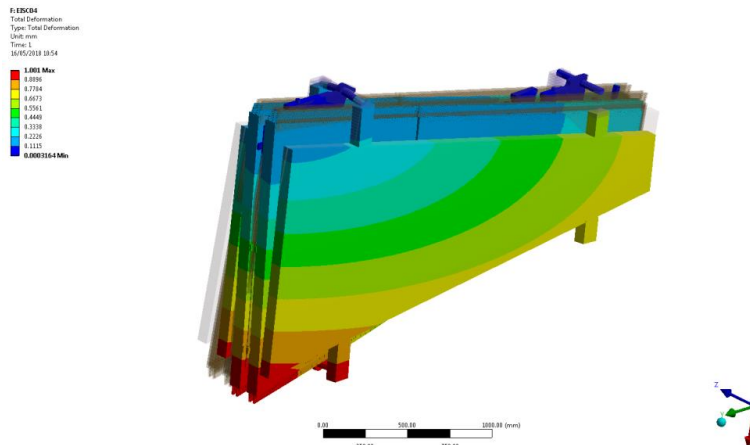


Figure 16 Total sector 1 degree angle, ISO view left total deformation

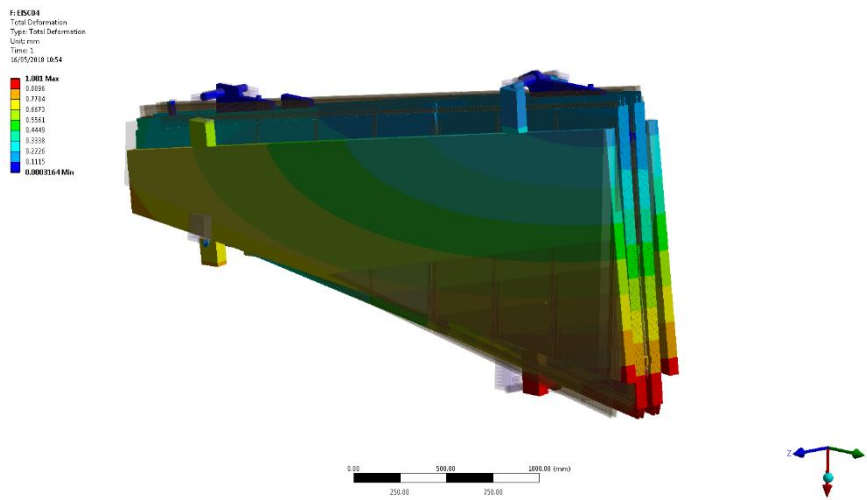


Figure 16 Total sector 1 degree angle, ISO view right total deformation

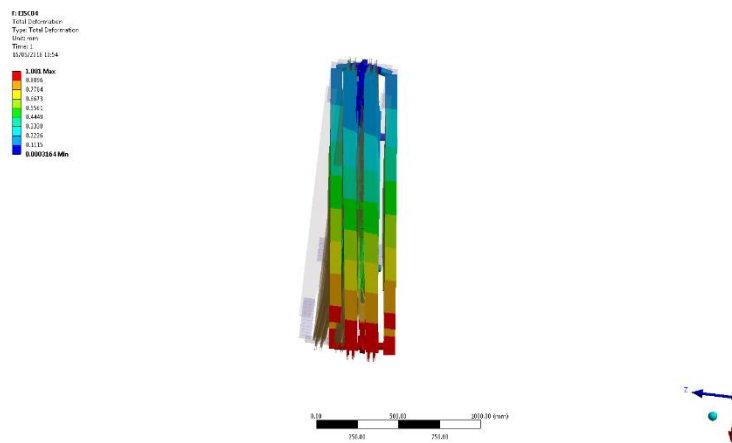


Figure 18 Total sector 1 degree angle, back view total deformation

MM total deformation

The maximal deformation in the MM is 1mm. The deformation in the end of SM2 is because of the swing.

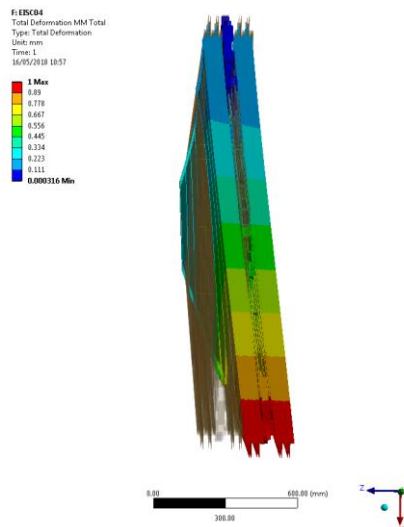


Figure 19 MM-DW 1 degree angle, back view total deformation

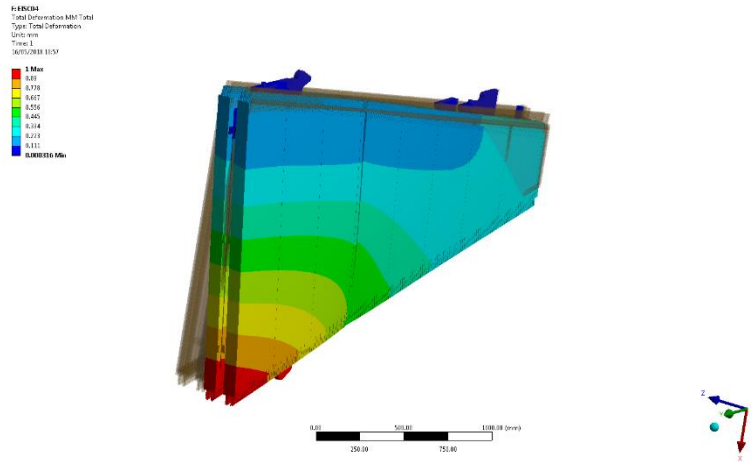


Figure 2014 MM-DW 1 degree angle, ISO view total deformation

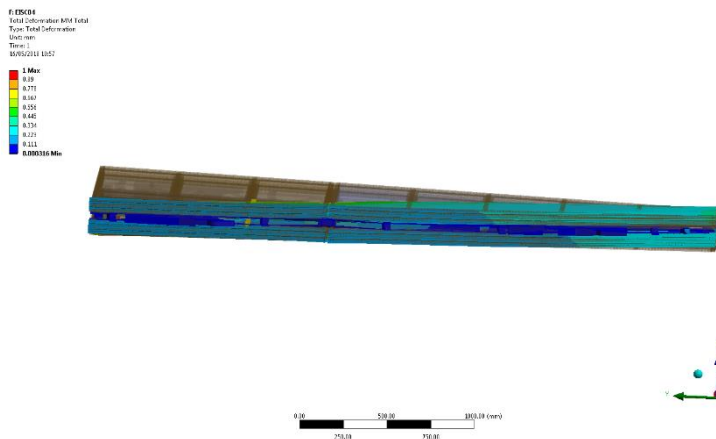


Figure 2115 MM-DW 1 degree angle, top view total deformation

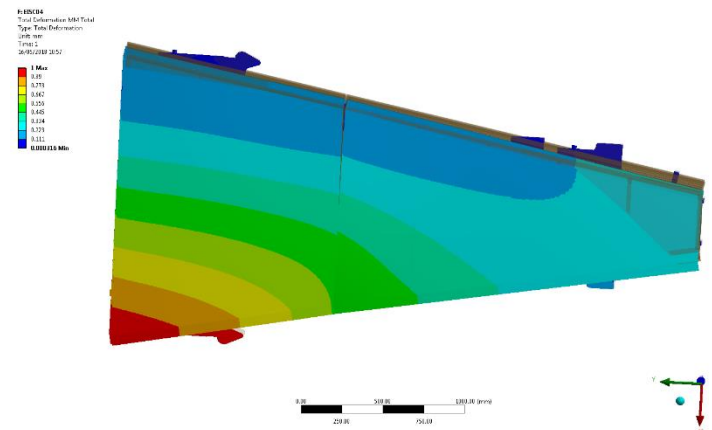


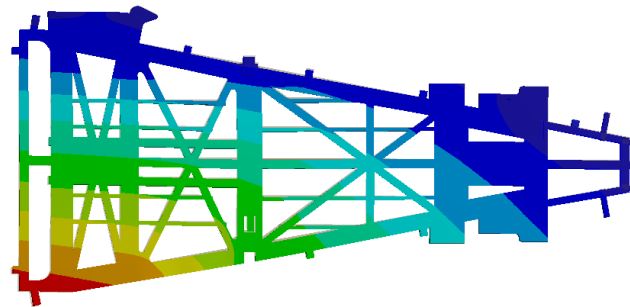
Figure 2213 MM-DW 1 degree angle, left view total deformation

Frame total deformation

Maximal deformation is 0.96 mm

F: EISC04
Total Deformation 4
Type: Total Deformation
Unit: mm
Time: 1
05/06/2018 16:04

0.96221 Max
0.85531
0.74841
0.6415
0.5346
0.4277
0.3208
0.2139
0.107
9.6222e-5 Min



0.00 500.00 1000.00 1500.00 2000.00 (mm)

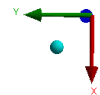
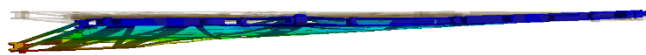


Figure 2317 Spacer frame 1 degree angle, front view total deformation

F: EISC04
Total Deformation 4
Type: Total Deformation
Unit: mm
Time: 1
05/06/2018 16:04

0.96221 Max
0.85531
0.74841
0.6415
0.5346
0.4277
0.3208
0.2139
0.107
9.6222e-5 Min



0.00 25.00 50.00 75.00 100.00 (mm)



Figure 2416 Spacer frame 1 degree angle, top view total deformation

F: EISC04
Total Deformation 4
Type: Total Deformation
Unit: mm
Time: 1
05/06/2018 16:04

0.96221 Max
0.85531
0.74841
0.6415
0.5346
0.4277
0.3208
0.2139
0.107
9.6222e-5 Min

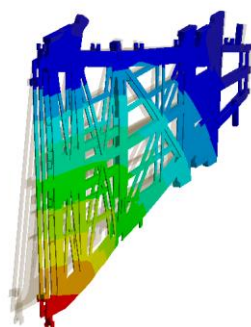


0.00 250.00 500.00 (mm)



Figure 19 Spacer frame 1 degree angle, back view total deformation

0.96221 Max
0.85531
0.74841
0.6415
0.5346
0.4277
0.3208
0.2139
0.107
9.6222e-5 Min



0.00 350.00 700.00 (mm)



Figure 2518 Spacer frame 1 degree angle, Iso view total deformation

sTGC deformation and KM

maximal deformation is
0.94mm

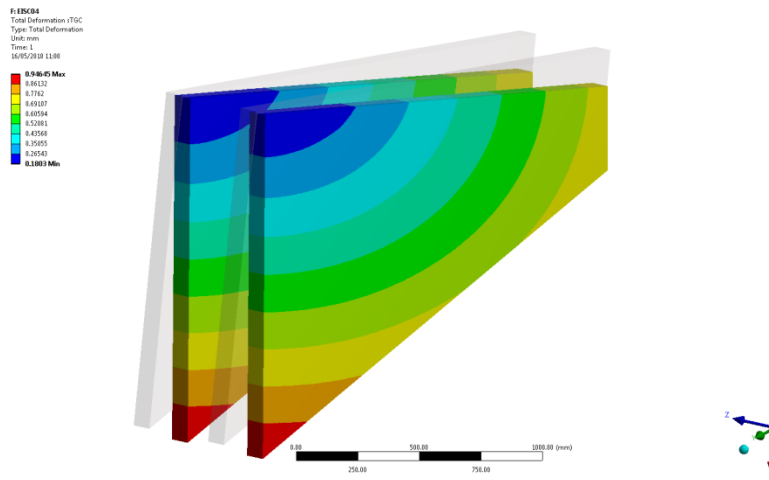
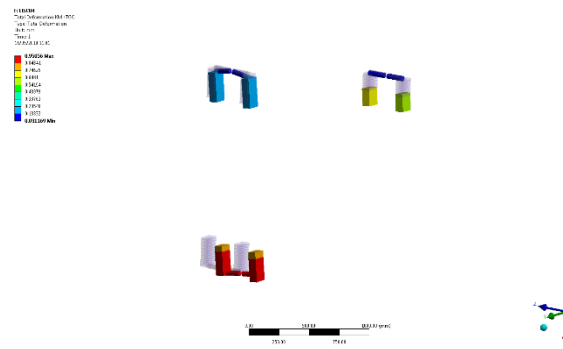


Figure 2722 sTGC 1 degree angle, ISO view total deformation



Maximal deformation of KM is
0.95mm

Figure 28 sTGC KM 1 degree angle, ISO view total deformation

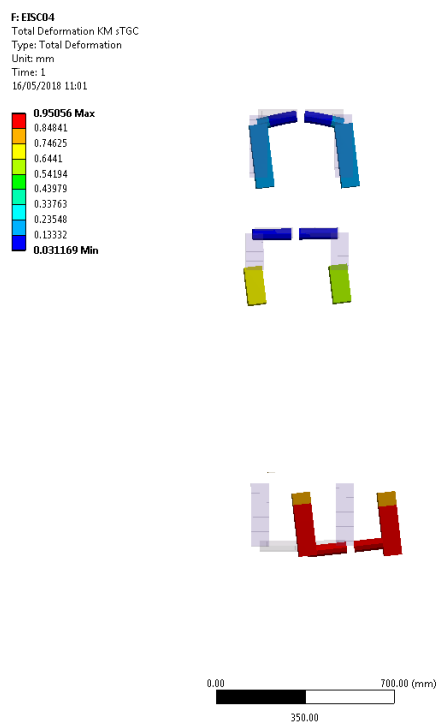


Figure 21 sTGC KM 1 degree angle, back view total deformation

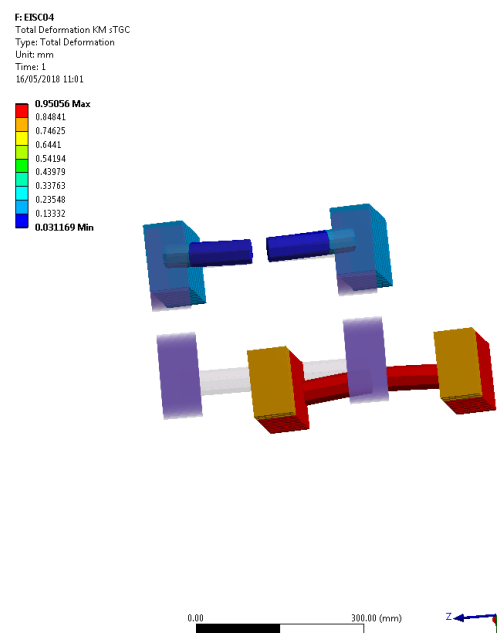
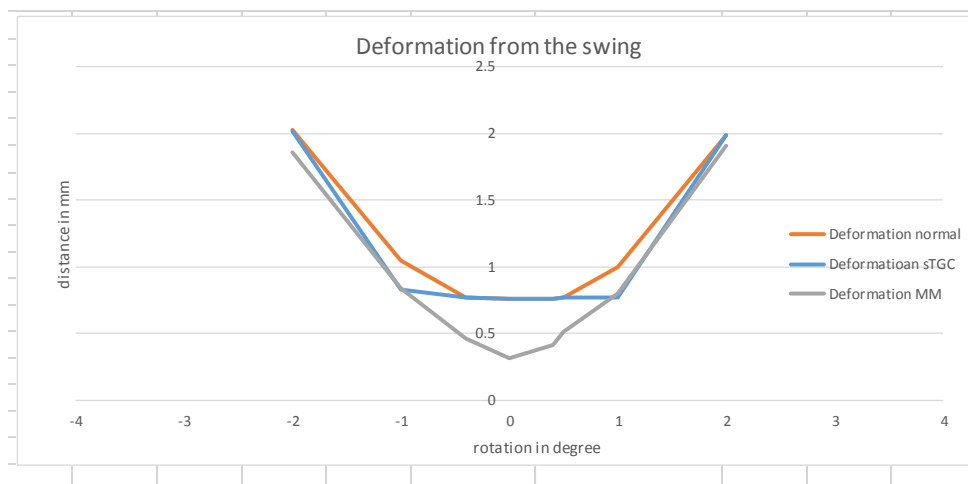


Figure 3020 sTGC KM 1 degree angle, back view total deformation

1.4 Conclusion

The way of swinging is according to the 1 degree simulations.

EISC04															
Degree	-5	-4	-3	-2	-1	-0.4	0	0.4	0.5	1	2	3	4	5	
Deformation normal				2.029	1.052	0.775	0.759	0.765	0.768	1.001	1.99				mm
Deformation sTGC				2.02	0.832	0.775	0.759	0.765	0.768	0.77	1.99				mm
Deformation MM				1.86	0.845	0.463	0.319	0.412	0.515	0.805	1.91				mm



By fixing an extra point in Z direction the deformation would be minimized. But to fix an extra point while lifting is very difficult. It is easier is to reduce the triggers for a possible swing. At the first assembly sector must become clear what the swing in reality is. So while the first assembly is good to keep attention to the degree of the swing and to keep in mind the what the consequences are.

According to the simulations, there is no problem for the sector EISC04 and EISC06. Good to keep in mind is that there could be a possible swing witch will give higher deformation.

A swing of 0.4 degree results at the bottom of the sector in a displacement in Z direction of 18 mm. The 18 mm is from the middle axis to the position with 0.4 degree angle.

1.5 Swing horizontal

The vertical swing is when the sector is complete vertical during transport and in the assembly station. The same simulation is used as the one for the swing. Different is the orientation of the gravity.

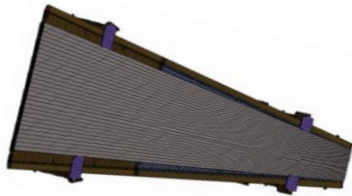


Figure 3223 -5 degree total sector

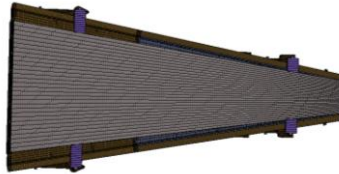


Figure 33 0 degree total sector

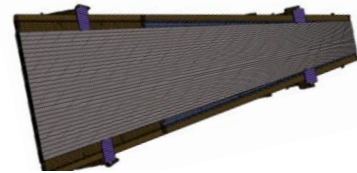


Figure34 5 degree total sector

-5 degree

With the -5 degree the deformation for the sector EISC04 is less because the sTGC is more to the original position on the NSW. Because of the -5 degree the orientation and the stress on the sTGC KM is more in an optimal position. The guided will take more force than before. The highest

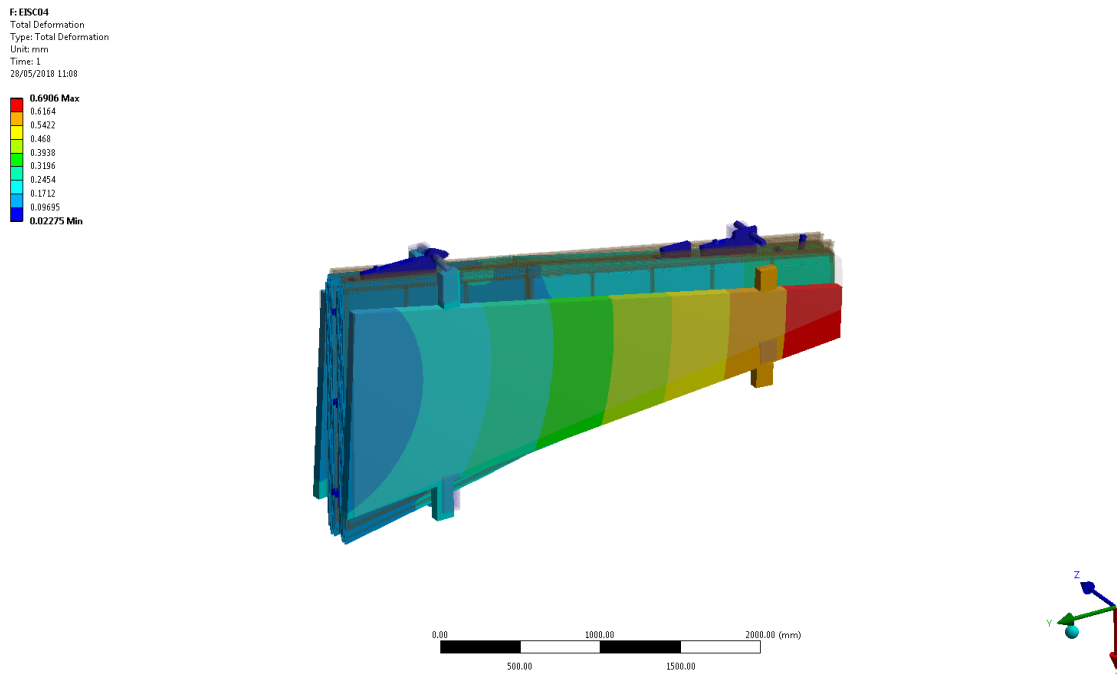


Figure 3524 -5 degree angle deformation total sector, left iso view

deformation in the total deformation is 0.690 mm and in the MM it is 0.291 mm.

0 degree

The 0 degree has the same results as the simulation before. Some changes according to fixations on the axis are done in this version. But the results turned out the same.

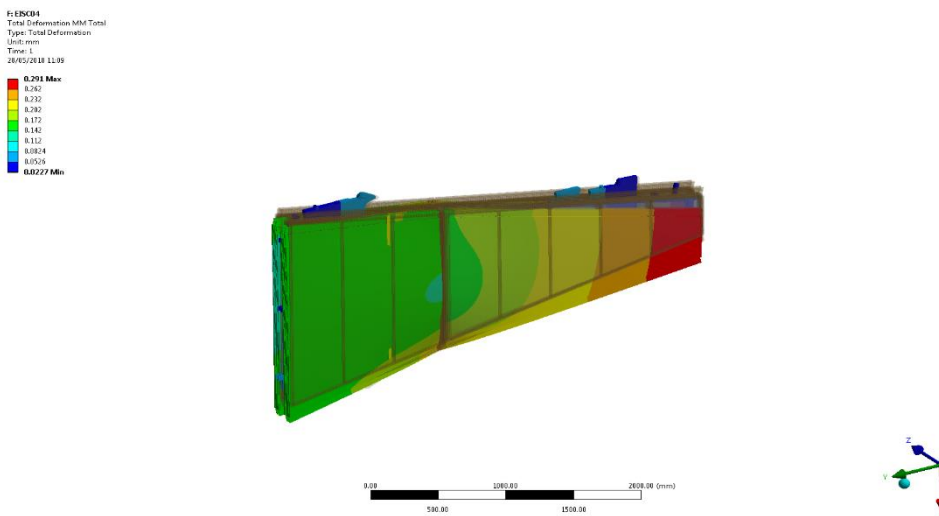


Figure 36 -5 degree angle deformation MM-DW, ISO view

F: EISC04
 Total Deformation
 Type: Total Deformation
 Unit: mm
 Time: 1
 28/05/2018 11:20

0.7068 Max
 0.631
 0.5552
 0.4794
 0.4036
 0.3277
 0.2519
 0.1761
 0.1003
 0.0247 Min

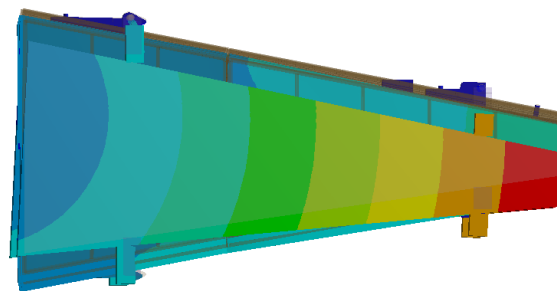


Figure 257 0 degree angle deformation total sector, left ISO view

F: EISC04
 Total Deformation MM Total
 Type: Total Deformation
 Unit: mm
 Time: 1
 28/05/2018 11:20

0.3 Max
 0.27
 0.239
 0.208
 0.178
 0.147
 0.116
 0.0858
 0.0551
 0.0245 Min

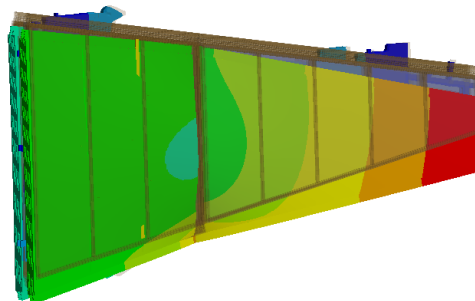


Figure 268 0 degree angle deformation MM-DW, left ISO view

5 degree

The deformation is 18um higher than the 0 position.

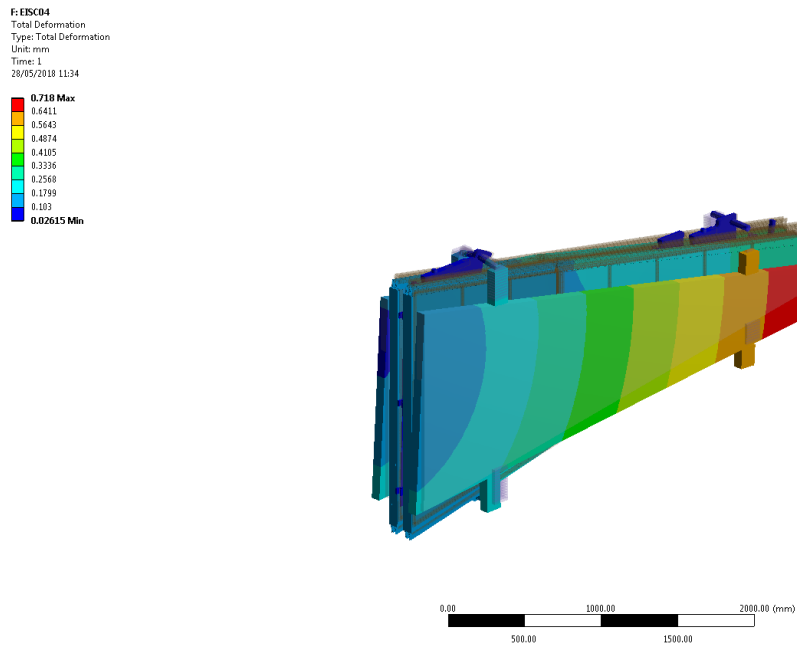


Figure 3927 5 degree angle deformation total sector, left ISO view

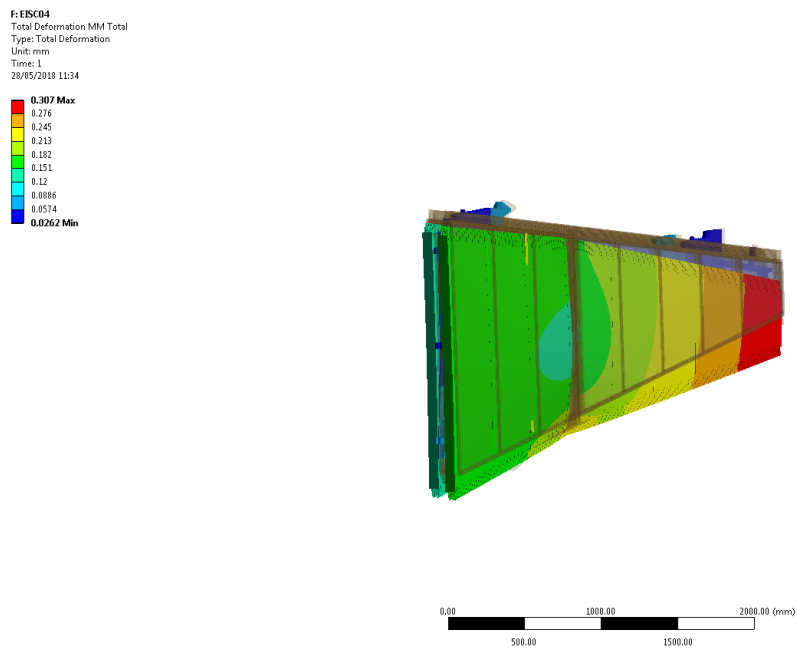


Figure 40 5 degree angle deformation MM-DW, left ISO view

According to this change of angle there is no problem with the horizontal angle, the deformation with -5 angle and +5 angle is within the 10% of the original 0-degree position.

Appendix L

Sector assembly procedure

Version: 1



Student

Name: Daan Zaalberg

Number: 500709165

24-07-2018, Meyrin

Internship organisation

Company: CERN

Supervisor: Patrick Ponsot

Study

Name: Hogeschool van Amsterdam

Study: Engineering design and innovation

Supervisor: J. van der Grinten

VERSION	CHANGE	DATE	CHECK BY	CHECK DATE
1	D. Zaalberg	24-07-2018	P. Ponsot	25-07-2018

This is a proposal for the procedure of the sector assembly. The procedure is for connecting the MM and the sTGC together. The procedure starts with preparing the modules to a complete sector. The assembly procedure has an overlapping with the MM and sTGC assembly procedure. For the assembly procedure of the MM and sTGC this document is not valid. This procedure will give only the imported things for the sector assembly procedure.

On the last page you find a complete part list as needed for the assembly.

Every assembly step is explained and also includes a list of needed parts and supporting images and figures from the first assembly sector.

The procedure starts with the preparing of all the parts. It will continue with the transport from all the parts to B191. The end of this assembly procedure is the storage and survey of the sectors.

Assembly procedure

All the necessary parts should be checked and ordered according the part list on page 19.

Preparation of the MM assembly

Part	Amount
MM double wedge	1
Survey support rods	4
Survey points	4
Transport basket	1
Grabber mount small	2
Grabber mount large	2
M10x45 screw	16
M 10 washer	16

Work sequence:

1. Survey of the spacer frame on the table (Figure 1).
2. MM-DW assembly on the spacer frame (Figure 2).
3. Survey measurement of MM-DW in BB5 vertical and horizontal for reference. (Figure 3 and Figure 4) and position of the survey points (Figure 5)
4. Connect two grabber mounts on the interface with the M10 x 45 bolts and M10 washers. (Figure 6)
5. Turning the MM-DW with the crosses and the turning tooling. (Figure 7 to 10)
6. Vertical survey moment with the complete MM-DW. Use Figure 5 to survey points position
7. Change cross for transport (Figure 11).
8. Place MM-DW in trolley use the bar to stop the sector from swinging (Figure 12 and 13).
9. Place MM-DW into the transport basket; use the bar to stop the sector from swinging (Figure 13 and 14).
10. Transport the MM-DW to B191, use lifting arm to load into the truck (Figure 15 and 16).
11. Place sTGC's into the trolleys in B180 and move them to B191 (Figure 19 to 21). Drive slowly max 3km/h!
12. Check that the other parts are available according to the part list. (Figure 38)



Figure 1 Spacer frame on the assembly table



Figure 5 Survey point for reference



Figure 4 MM-DW on the spacer frame

Notes to figure 4:

Labelling of all the supports for the survey to place them back in the exact the same position. The long survey supports are called ref. A,B,C, and D, the pins are called Pin A,B,C,D. The A starts on the right front and goes clockwise to D.

The survey target fits well in the survey rods. (Figure 4).

The distance between the two supports (pin) is 270 um. The ref. bars and the pins will give an good first survey that can be used as an reference. The position and different survey points are shown in figure 4



Figure 2 Survey point on the MM-DW

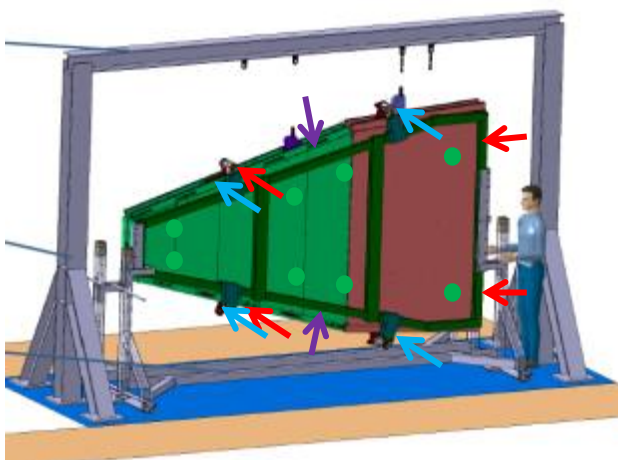


Figure 3 MM survey target position

Location of the MM-DW survey targets (blue color)

Location of the reference survey targets frame (purple color)

Location of the MM survey targets connected with magnets (green color)

Location of the sTGC survey targets (red color)
(possible to add targets on 2 others sTGC KM support)

Connection of MM DW into the assembly frame

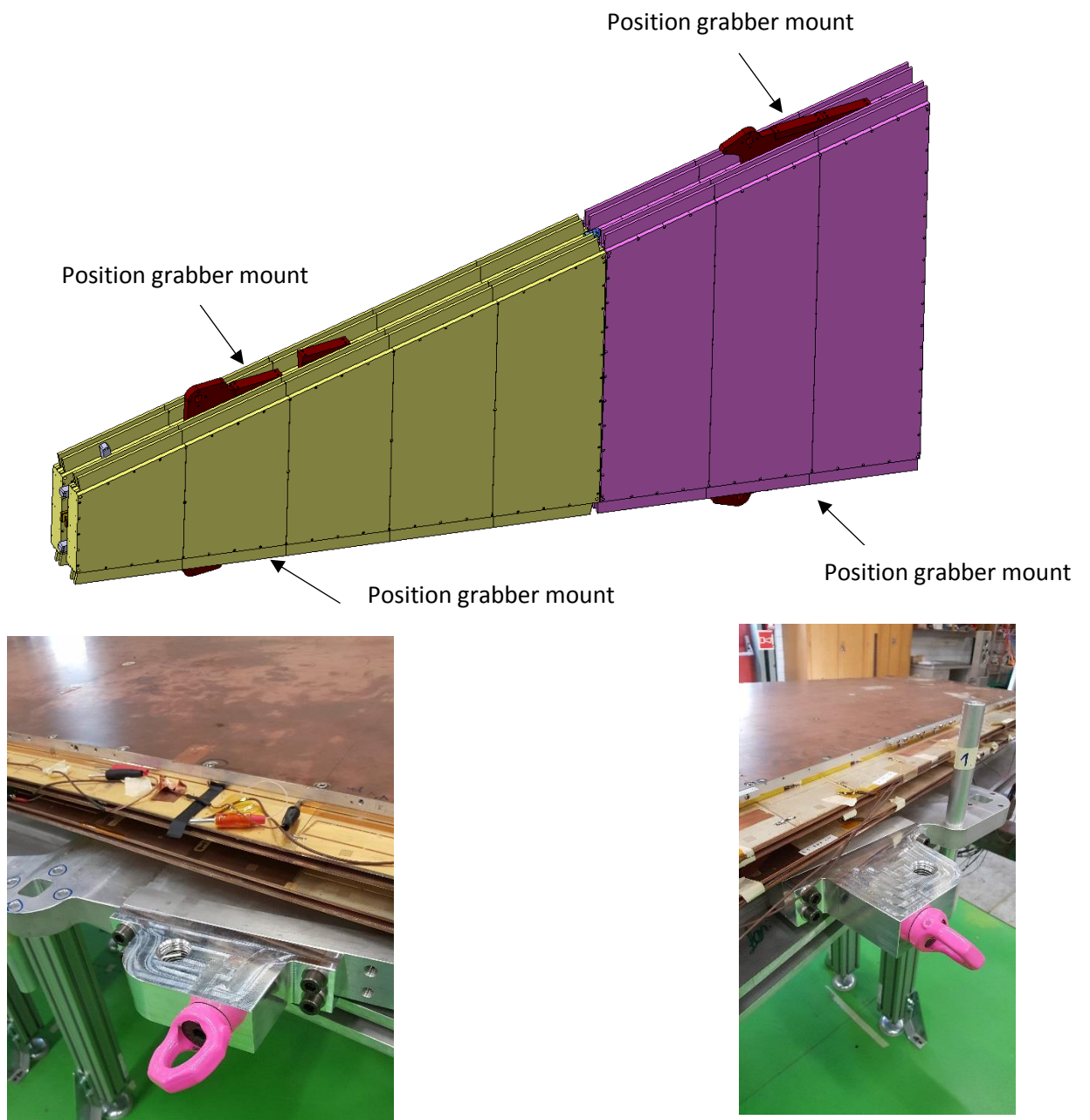


Figure 6 Grabber mount position

Turning of the MM-DW

Turning the MM-DW to a vertical position with the special tooling. After turning, remove all the support bars for turning and positioning of the survey targets on the MM SM1 and SM2 for the vertical survey of the MM-DW.



Figure 8 MM-DW with bars on the table before turning

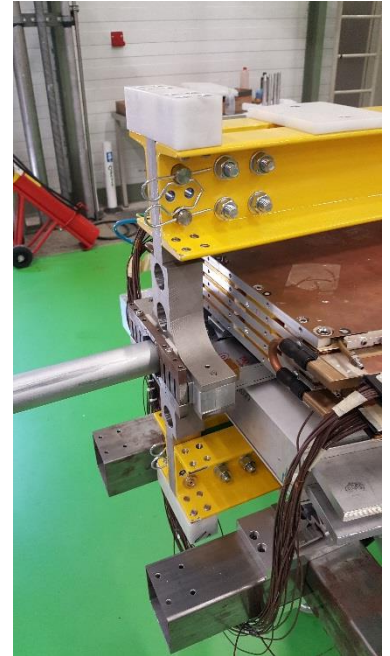


Figure 7 Connection of the bar to the MM-DW



Figure 10 MM-DW while turning



Figure 9 MM-DW in vertical position

Transport MM to B191 in parallel

Preparing the cross for transport

The first connection cross was not strong enough, because of the moment force in the cross the bridge deformed. The solution was an extra connection to clamp the two beams together. For the future, the design of the cross must be changed with extra supports to stop the moment force. To avoid the sector from turning there is an extra bar to slide in on the trolley and the transport basket. An extra cable must be used to connect the grabber mount to the transport basket. This way the sector is blocked during the transport

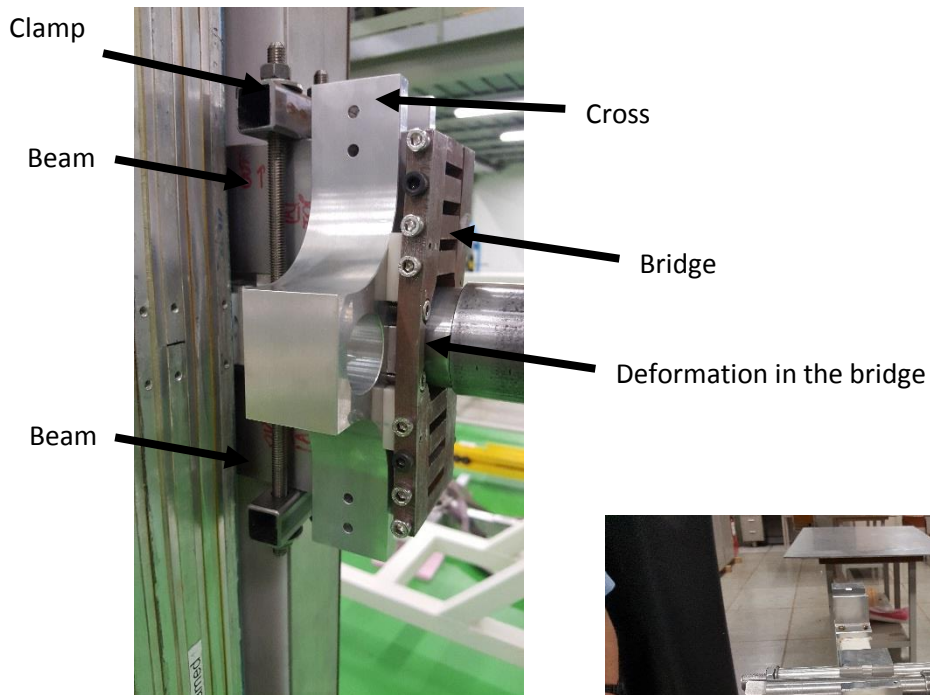


Figure 14 New cross for transport



Figure 13 Connection of the cross into the transport basket with fixing bar



Figure 11 Trolley next to transport basket



Figure 12 MM-DW in transport basket

Delivering with a truck in B191

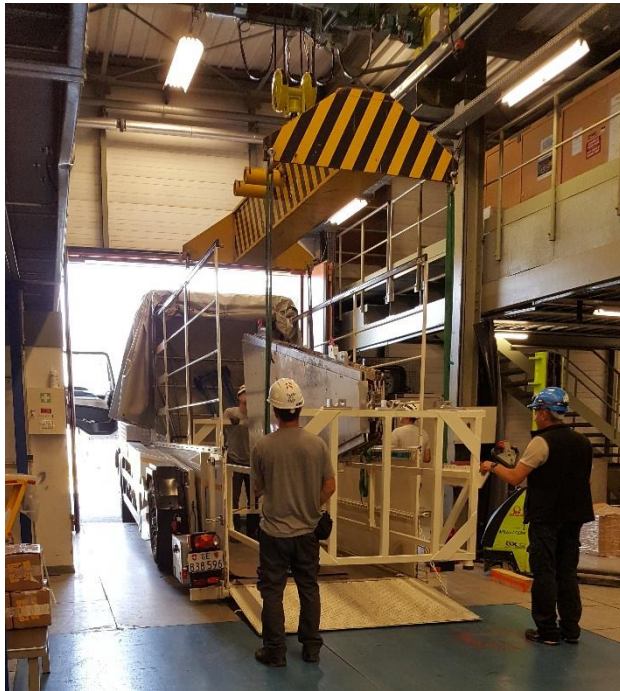


Figure 16 BB5 loading into transport truck



Figure 15 B191 loading out of transport truck

Position of the transport basket next to the assembly station in B191. See Figure 17 and 18



Figure 18 Transport basket hanging in lifting tool



Figure 17 Position of the transport basket

Transport sTGC to B191



Figure 19 Storage of the sTGC



Christmas tree

Figure 20 Place sTGC into the trolley with the Christmas tree.



Figure 21 Transport of the sTGC to B191

Connection of the MM DW into the assembly frame. (MM DW wedge arrives in the transport basket from BB5.)

Part	Amount
MM double wedge	1
Lifting beam and assembly station	1
Adjustable cables assembly station	2
Survey rods and points	4 sets

1. With the crane pick up the lifting bar from the assembly station.
2. Connect the cables with the adjustment system with the grabber mount and with the lifting bar (See Figure 22).
3. Before lifting, the cables must be under low tension. (MM will hang horizontally) (Figures 23, 29 and 27).
4. Lift the lifting bar and check if the MM is horizontal with a water leveller
5. Place with the lifting bar and the crane the MM's into the assembly station (Figure 26).
6. Align the lifting bar with the screws on the assembly station (Figure 25).
7. Connect the pillars to avoid swing (Figures 24 and 30).
8. Place survey rods and points for position (Figure 5). For the setup (Figure 27).
9. Survey measurement of the MM-DW (Figure 27).

The orientation in the assembly station is shown in the Figure 22.

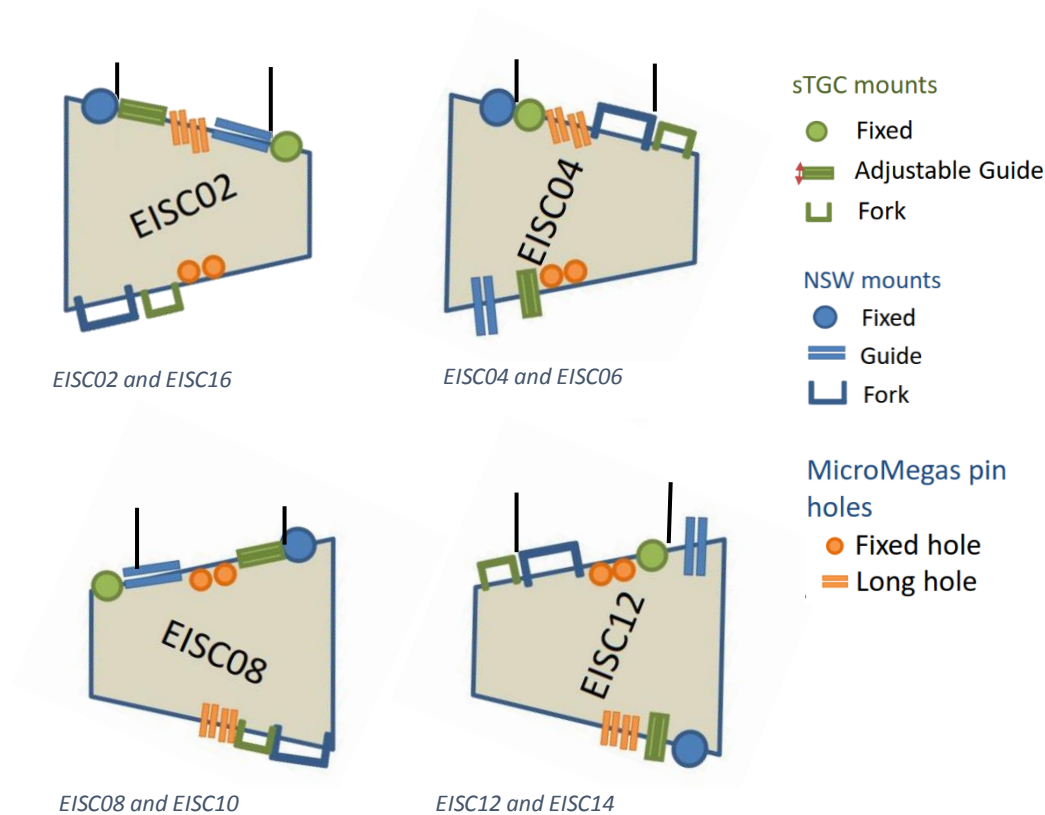


Figure 22 Configuration of the sectors



Position of the MM-DW in the transport basket. The grabber mounts needs to be attached the steel cables to be attached with adjustments parts.

Figure 23 attach cables on the grabber mounts



Align and place the MM-DW into place with the lifting bar. The outside holes are for the SS and the inner holes are for the LS connection.

Figure 26 Lifting sector into the assembly station



Connect the lifting bar to the assembly frame with two bolts on the sides.

Figure 25 positioning the lifting bar to the assembly station with screws



Connection of the pillar to avoid swing

Figure 24 Here the pillar must be installed and connected to the grabber mounts

For the survey of the MM-DW in the assembly station are the same target points used as for the MM-DW survey in BB5.



Figure 27 Survey of the sector



Cable and grabber mount SM1

Figure 29 Cables attached to the grabber mount



Cable and grabber mount SM2

Figure 28 Cable attached to the grabber mount

Fixing of the pillars

Fixing of the pillars to avoid swing. On the same position of the grabber mounts (Figure 24 for the position of the pillar). The pillar is shown in Figure 30.

Connect the bottom plate with nuts into the bolts under the grabber mount in the concrete.

Put the two removable plates into place and connected it with the four bolts.

Turn on in parallel the both screws to the grabber mount.

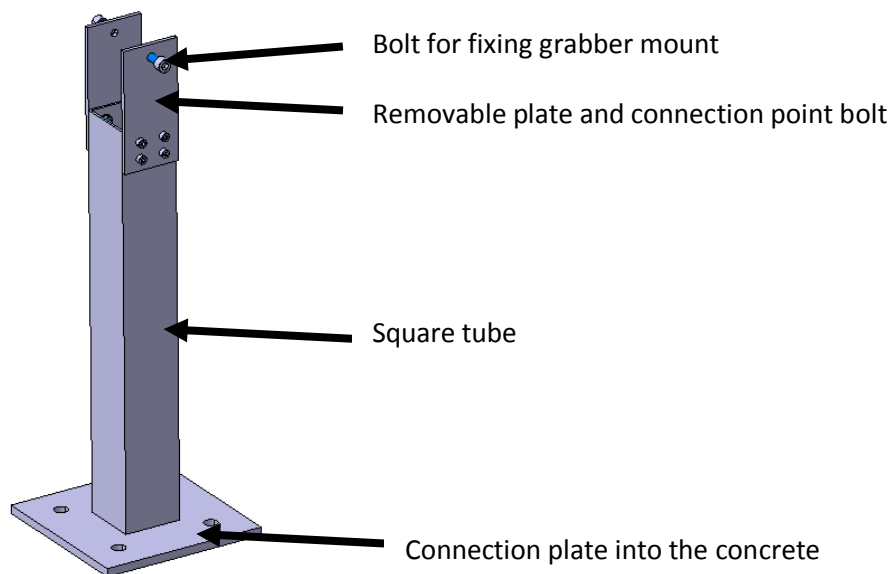
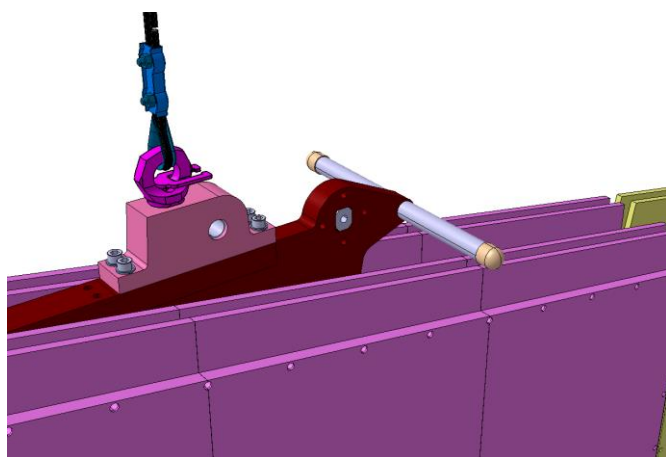


Figure 30 Pillar to avoid swing

The connection of the sTGC to the MM-DW (sTGC arrive on the trolleys from B181)

Part	Amount
sTGC trolley's	2
MM double wedge	1
sTGC wedge	2
Cube round	1
Cube square	1
Fixed point with cone	2
Fork rod	2
Guided rod	2
M8x75 screw	12
M8 washer	24
M8 lock nut	12
Thread bar M10x50	4
Washer M10x32.4	4
M10 nut	8
Survey rods and points	4 sets

1. Place the cube inside the interface. The round cube for the fixed and the square-cube for the guided. Figure 31
2. Connect the sTGC KM support to the frame interface. Use Allen screw M8x75mm, on both sides of the screw with M8 washers. In addition, a lock nut M8 (The guided without a pin) See Figure 32 and 33 for the connection and position.
3. Connect the cone into the fixed point Figure 34
4. Positioning both sTGC with the trolley in front of the MM-DW. Figure 35
5. Change the height of the MM or the height of the sTGC if necessary, so the sTGC could slide into the MM-DW perfectly.
6. Drive both sTGC next to the MM-DW. Figure 36
7. Slide in the pin of the guided.
8. Connect the bolt into the fixed point with the washer M10x32.4 and fix the rot with 2 nuts. Figure 35
9. Connect the bolt into the fork with the washer M10x32.4 with two nuts. Figure 35
10. Remove the trolley and adjust the sTGC.



Putting the cube into place with the pin in the middle.

Figure 31 Cube in the interface

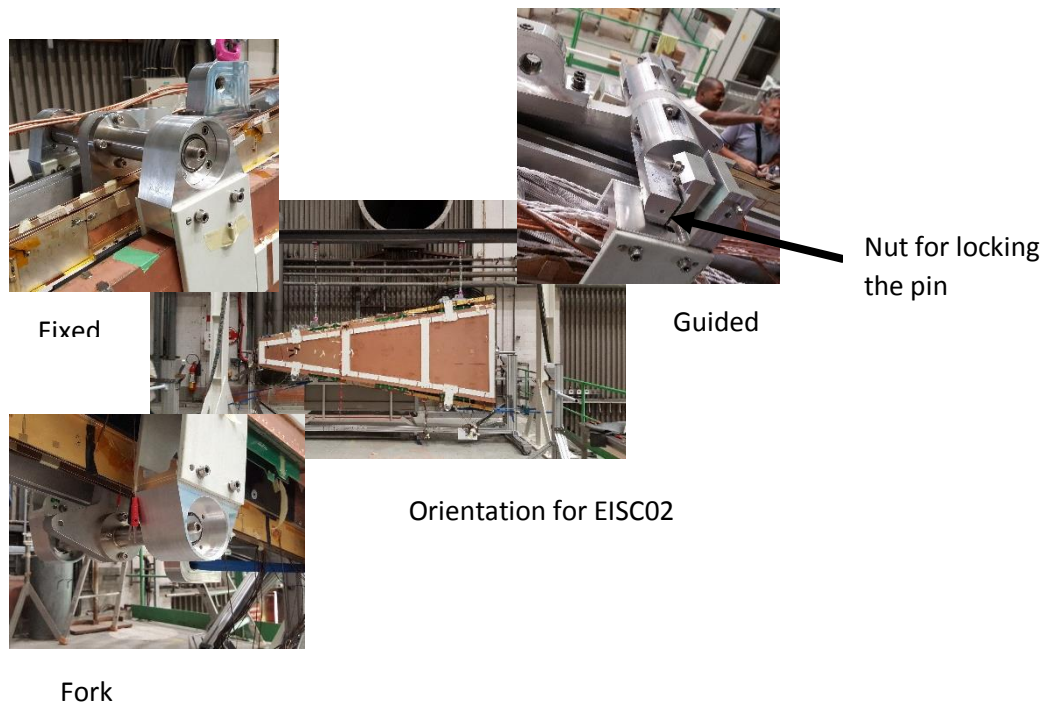


Figure 32 Orientation of KM EISC02

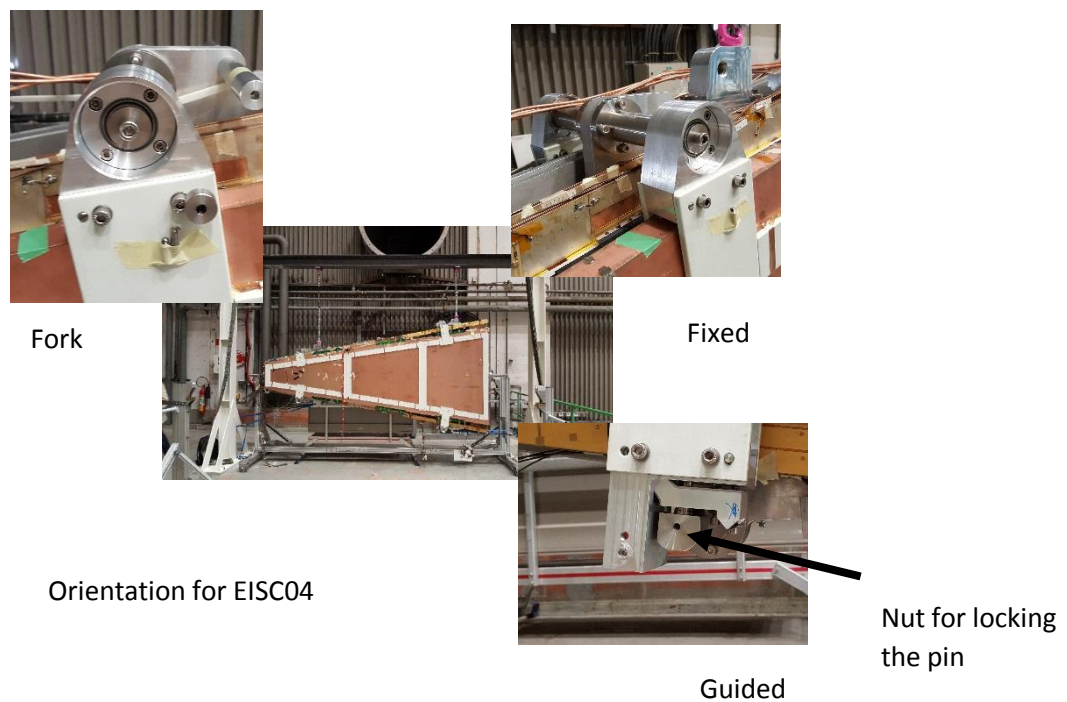
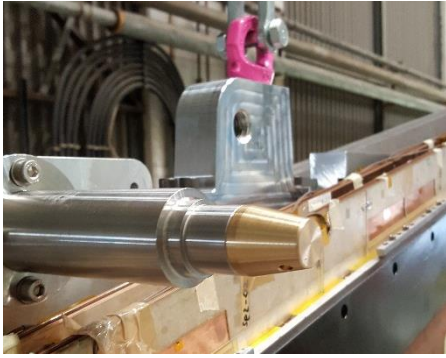


Figure 33 Orientation of KM EISC04



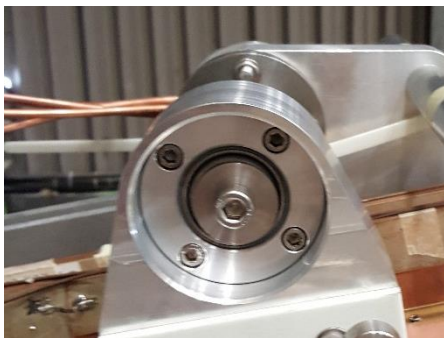
Fixed point with the cone before installing sTGC

Figure 34 cone of the fixed point



Move the trolley into place and adjust the position with the screws on the trolley

Figure 36 Positioning of the sTGC in front of the MM-DW



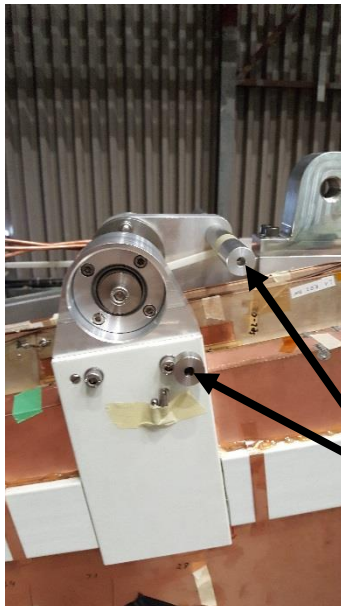
Washer to attach the sTGC in Z direction.

Figure 35 Washer form steel fixed point fork from plastic

Survey the total sector and alignment sTGC

Part	Amount
Complete sector	1
Survey points	4x MM-DW 6x sTGC survey points
Assembly frame for survey	1

1. Lift up the lifting bar with the crane and move it into the sector lifting area for survey measurement.
2. Place all the survey points for the sTGC see Figure 37 for survey points and Figure 5 for the total position of the survey.
3. Survey measurement by survey group.
4. Align with push and pull screws the both sTGC in the same position.
5. Final survey before storage.



Survey supports for the survey moment. Also the two survey points on top of the sTGC are needed for aligning the sTGC.

Figure 37 Survey point

Table 1 Movement of the adjustable guided

Guided	Adjustment	adjustment	
Horizontal EISC02	2 mm (2 turns)	X = 1.1 mm Y = 0.6 mm	On end of SM1
Vertical EISC04	2 mm (2 turns)	X = 1.45 mm Y = 0.7 mm	On the end SM1

Storage

Part	Amount
Complete sector	1
Storage beams	1

1. Remove survey points that are not needed any more.
2. Lift the bar and place the complete sector into the storage area.

The part list depends on the configuration of the sector. The guided is vertical or horizontal. The other parts are universal for the complete sector. You can see what parts are needed for the first sector assembly test. Also the availability is shown. The parts under missing have to be ordered.

Part list for first sector assembly tests (EISC02 & EISC06)		Daan Zaalberg			25/04/2018		Modified by Daan Zaalberg - 22/05/2018	
Parts	No. CDD	No. Smartear	EDH number	Material	Needed	Availabl	Missing	Subscription
sTGC fixed support	ATUMHFS_0030	ST0992030_02		Stainless steel	2	1	1	
sTGC fixed support - Pin diameter 10mm g6 x 68mm				Stainless steel	2	0	2	
sTGC fork support	ATUMHFS_0031	ST0992081_02		Aluminium	2	1	1	
sTGC vertical guide - Pin	ATUMHFS_0004	ST0688193_02		Stainless steel	6	2	4	guided horizontal+vertical
sTGC vertical guide - Rod/pin SYMM	ATUMHFS_0009	ST0758749_02			1	0	1	
sTGC vertical guide - Rod SYMM	ATUMHFS_0010	ST0758750_02		Aluminium	1	0	1	
sTGC vertical guide - Rod/Pin	ATUMHFS_0007	ST0758696_02			1	1	0	
sTGC vertical guide - Rod	ATUMHFS_0008	ST0758695_02		Aluminium	1	1	0	
sTGC horizontal guide	ATUMHFS_0028	ST0991802_02		Stainless steel	1	0	1	
sTGC horizontal guide assembly	ATUMHFS_0029	ST0992013_02			1	0	1	
sTGC horizontal guide - Rod/Pin	ATUMHFS_0001	ST0754658_02			1	1	0	
sTGC horizontal guide - Rod	ATUMHFS_0003	ST0754659_02		Stainless steel	1	1	0	
sTGC vertical guide - Insert (square hole)	ATUMHFS_0024	ST0748551_02		Stainless steel	2	2	0	1x guide
sTGC fixed support - Insert (round hole)	ATUMHFS_0025	ST0754846_02		Stainless steel	2	2	0	1x fixed
Spacer-frame				Aluminium	1	1	0	1x prototype
MM dummy double wedge				Detector	2	2	0	2x dummies & 2x M0s bolted on the spacer-frame at BBS
sTGC dummy wedges				Detector	2	2	0	1x wood dummy, 1x prototype made of M0s
Grabber mount 1	ATUMHVV_0015	ST0794117_02		Aluminium	2	2	0	
Grabber mount 2	ATUMHVV_0016	ST0794563_02		Aluminium	2	2	0	
Protection interface short	ATUMHVX_0070	ST0807196_02		Aluminium	4	0	4	2 will stay at BBS for MM integration tests
Protection interface long	ATUMHVX_0069	ST0807216_02		Aluminium	4	0	4	2 will stay at BBS for MM integration tests
Support for reference point MM assembly	ATUMHVX_0071	ST0989977_02						
Support for reference point MM bottem	ATUMHVX_0072	ST0982428_02		Aluminium	4	0	4	
Support for referance point MM top	ATUMHVX_0073	ST0989976		Aluminium	4	0	4	
alignment rod for assembly (2 pieces / alignment rod)	ATUMHVX_0068	ST0981375_02		Aluminium	8	0	8	4 will stay at BBS for MM integration tests
Bearings for sTGC D30mm				Stainless steel	4	4	0	available in Steel for first assembly okay
Bearings for sTGC D15mm				Stainless steel	2	2	0	available in Steel for first assembly okay
Allen Bolt M8x75mm			47.62.71.321.1	Stainless steel	12	0	12	Mounting flanges
Lock nut M8			47.56.20.080.1	Stainless steel	12	0	12	Mounting flanges
Flat washer M8			47.78.06.080.1	Stainless steel	24	0	24	Mounting flanges
M10 nut			47.43.77.100.6	Stainless steel	8	0	8	Dubble nut per treaded bar
Threaded bar M10x50			47.38.77.100.3	Stainless steel	4	0	4	4x Fixing rods
Washer fixed M10x34.2	ATUMHFS_0026	ST0974455_02		Stainless steel	8	0	8	Fixing rods fixed point
Washer fork M10 with clearance	ATUMHFS_0027	ST0974442_02		Stainless steel	2	0	2	Fixing rods fork point
Grub screw M5x10			47.62.87.179.0	Stainless steel	4	0	4	Fixing pins guide points
Allen Bolt M10x45			47.62.71.360.4	Stainless steel	16	0	16	Grabber interface 4x
Washer M10			47.78.06.100.4	Stainless steel	16	0	16	Grabber interface 4x
fit bolt- ISO 7379 - DIN 9841 M6 8x40			https://eu.shop	Stainless steel	2	0	2	bolt for alignment rot (not urgent for now)

Figure 38 Part list