ALIGNMENT OF THE MSGC BARREL SUPPORT STRUCTURE

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ABSTRACT

The MSGC barrel is a sub-part of the tracking system of the CMS experiment at the LHC. The mechanical support structure of the MSGC barrel consists of ladder-like support beams carrying the detector modules and of four disks supporting the ladders. The required alignment precision of the modules, a few tens of micrometers, is designed to be obtained by precise part manufacture and by careful measurement of the alignment during the assembly of the structure. In the paper the use of digital photogrammetry for the measurement of the alignment of the disks and for the structural verification is presented. Digital photogrammetry was chosen from a number of potential methods after a careful evaluation.

The use of photogrammetry for the structural verification of a prototype is presented. The displacements were measured both of unloaded and loaded disk by using photogrammetry and linear displacement transducers for verification. The displacements obtained from the two measurement methods corresponded well, not only to each other, but also to the results given by finite element analysis.

The structural verification will be done and the alignment procedure will be tested with a full-sized prototype of a half of the MSGC barrel. Preparations for the photogrammetry measurements are presented and the design of the required supplementary equipment is shown.

1 INTRODUCTION

Micro Strip Gas Chamber (MSGC) detectors are used in the CMS tracking system at radii 690 mm to 1200 mm. The central part, Z = ±1205 mm, is known as the MSGC barrel with six concentric layers of detectors. In the barrel the MSGC detectors are supported by horizontal ladder-like support structures, called rods, that are supported by four vertical disks (Fig. 1). The disks are joined together by horizontal cylinders and panels. Parts are mainly made of carbon fibre/epoxy composites. The rods and the disks are assembled from water-jet cut carbon fibre C-profiles and flat sheets. The manufacture method bases on gluing pre-cut pieces in a precision jig; it is called a "jigsaw puzzle" method. The cylinders and panels are sandwich structures with carbon fibre skins and Nomex honeycomb core. Accurate joining of components is ensured by aluminium and plastic inserts glued into the composite structures.

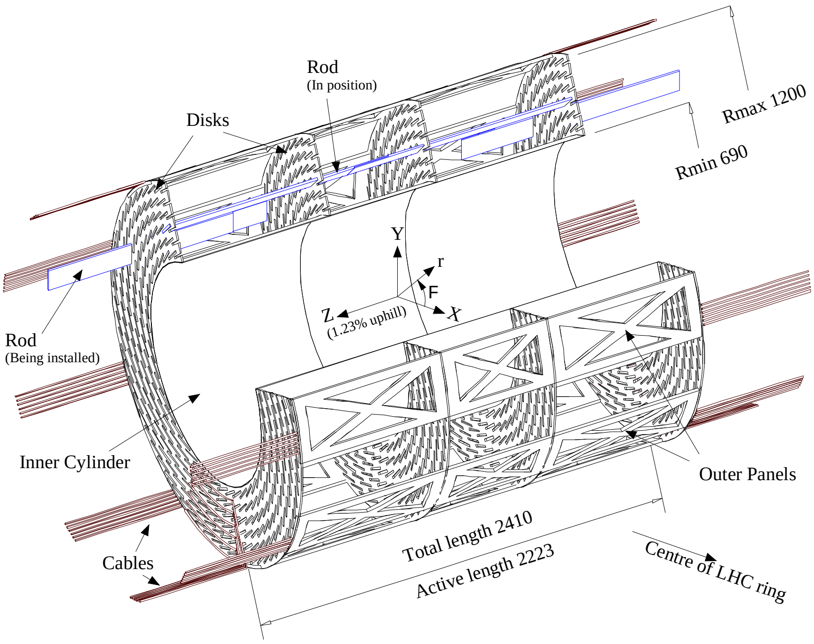

Figure 1. *The MSGC barrel. Note the co-ordinate system.*

The micro strips, the particle detecting elements, have to be aligned with respect to each other in order to achieve sufficient tracking efficiency. The whole MSGC barrel shall also be aligned as a rigid object with respect to the CMS tracking system, but this paper concentrates on the internal alignment of the MSGC barrel (i.e. parallelism of the micro strips within the barrel volume). The alignment accuracy of the micro strips, excluding the errors in the micro strip substrate, is the sum of the positioning accuracy of the module in the rod and the positioning accuracy of the rod within the whole support structure. The modules are positioned accurately when mounting them in the rods; the positioning is performed under a microscope, if needed, to achieve sufficient accuracy. The alignment of the rods is ensured by accurately positioned fixations in each disk and by aligning the disks accurately with respect to each other in the barrel assembly.

To position the disks accurately with respect to each other requires the use of an alignment measurement system during the assembly of the barrel. The required positioning accuracy of the disks is derived from the alignment and the positioning requirements of the micro strips by taking into account the errors during the sub-assemblies (Table 1). The measurement system does not have to be an on-line system, but it has to be adapted to this type of geometry and flexible, because some details in the geometry may change subsequently.

Table 1. *The position measurement requirements for a disk, derived from the alignment and positioning requirements. The co-ordinate system as in Figure 1. [1, 2].*

Direction	Required measurement accuracy
X	50 μm
Y	50 μm
Z	100 μm

In this paper, the photogrammetry refers to the digital photogrammetry measurement service that the CERN-EST/SU-group uses and develops. A normal measurement procedure with the photogrammetry is first to attach reflective targets to the points to be measured in the structure, then to take multiple photos from different viewpoints with a CCD-camera and to analyze the recorded data by a computer. In addition to the targets at the points to be measured, supplementary targets are normally used to provide overlap of the targets in preceding pictures, and to fill the target space homogeneously. When a sufficient amount of picture data is recorded, the corresponding points in different pictures are recognized, and the locations of the points to be measured are calculated by a computer. The recognition of the corresponding points is simplified by applying coded targets. The locations of the points are obtained, either relatively with respect to each other, or absolutely, if the system is calibrated during the measurement by measuring standard reference bars.

Until today, the photogrammetry has been used to measure two prototypes of the MSGC barrel R&D project: the B1-prototype and the two-layer disk prototype. The measurements of the B1-prototype were carried out to measure the absolute co-ordinate values (i.e. the dimensions of the B1-prototype) while the measurements of the two-layer disk prototype were performed to measure relative values (i.e. the displacements).

The B1-prototype was manufactured to study experimentally the developed design of the MSGC barrel support structure. It is a box-shaped object with dimensions: 930 mm x 520 mm x 680 mm (Fig. 2). The prototype was measured by using the photogrammetry to verify the manufacturing accuracy of the prototype. The obtained standard deviation of the measured values was about 20 μm [3].

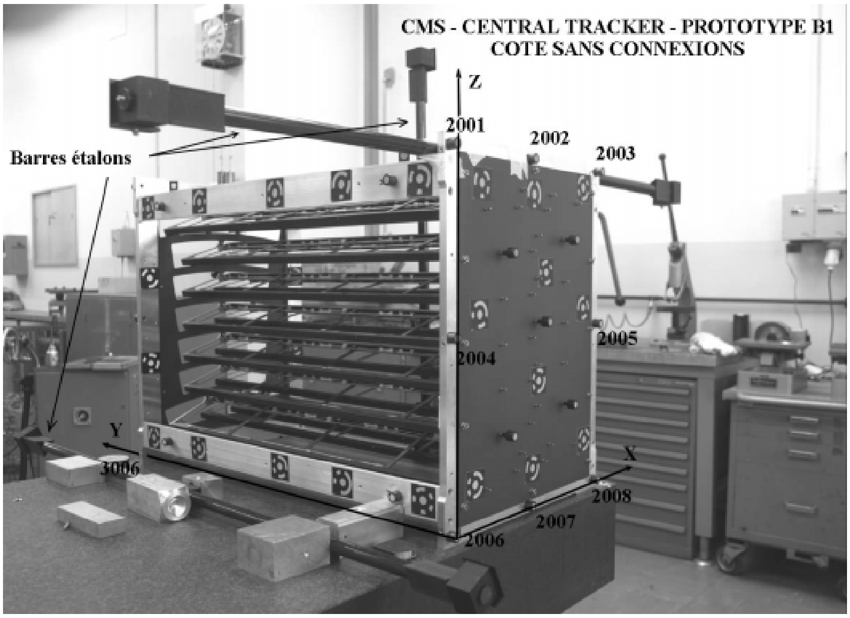

Figure 2. *The B1-prototype prepared for the photogrammetry measurements. Note the three standard reference bars around the prototype. [3]*.

2 STRUCTURAL VERIFICATION OF A TWO-LAYER DISK PROTOTYPE

The two-layer disk prototype was constructed to study the manufacturing aspects of the "jigsaw puzzle" method and to compare the structural finite element analyses of the disk with experimental results. The prototype is scale one but comprises only supports for the two innermost detector layers instead of the six layers of the final structure. The main interest was to study the displacements under loading and the long-term behaviour of the loaded structure.

2.1 Measurement set-up

During the measurements, the prototype was freely supported by a rigid steel structure at two points at the inner periphery of the disk as shown in Figure 3. The displacements were measured using linear displacement transducers and photogrammetry. Eight transducers were attached into a support frame that was temperature stabilized to minimize its thermal distortions. The transducers measured the displacements at the inner radius in eight radial directions (Fig. 3). Adhesive photogrammetry targets were attached to the surface of the disk and to the disk supports. The experiments were carried out in an air-conditioned laboratory where the temperature was constant to ±2ºC during the experiments.

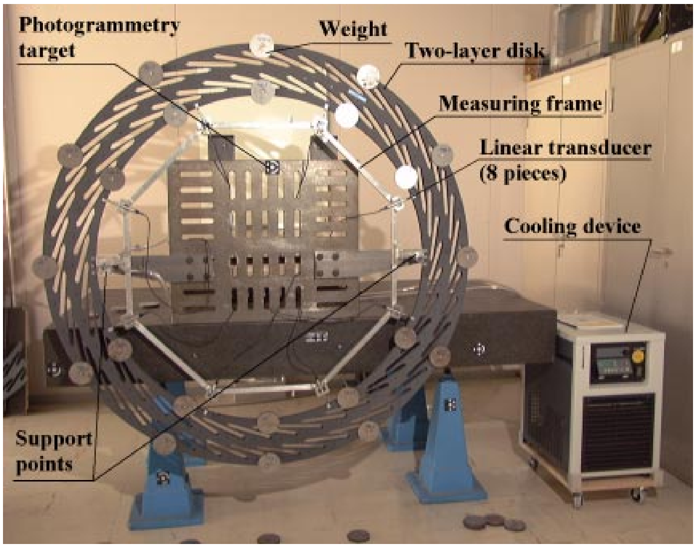

Figure 3. *The two-layer disk prototype and the measurement set-up. The weights equal 0.5 kg each. The temperature stabilized measurement frame supports the linear displacement transducers. The outer diameter of the disk is 1546 mm.*

First, stiffness measurements were carried out to study the elastic behaviour of the disk and to verify the repeatability of the measurements. The stiffness measurement was performed as follows: first, the unloaded disk was photographed, then weights, altogether 22 kg, were applied close to the inner and outer peripheries with a spacing of 30° to represent the corresponding load of the rods and the measurements were repeated, and finally the weights were removed and the structure was re-measured to verify its elastic behaviour [4].

The long-term load test was carried out to detect a possible creep of the disk. The loads were left on the disk for six weeks, and the photogrammetry measurements were performed five times: first when the disk was unloaded, then of the loaded disk three times during the loading period and finally again of the unloaded disk. The transducers measured the displacement of the disk continuously and the results were written down frequently.

2.2 Measurement results

The accuracy of the photogrammetry measurements done on the prototype was estimated to be around 30 μm. The accuracy of the linear displacement transducers alone equals about 1 μm, but in this case the accuracy of the total system was evaluated to be around 20 μm due to thermal fluctuations and positioning tolerances of the transducers. [4].

The displacements measured with the photogrammetry and the linear displacement transducers gave similar results and, when taking into account error limits, corresponded with the values obtained by finite element analyses (Fig. 4) [4]. The displacement of the disk in the long-term measurement equaled the results of the stiffness measurements, no creep was observed. [5].

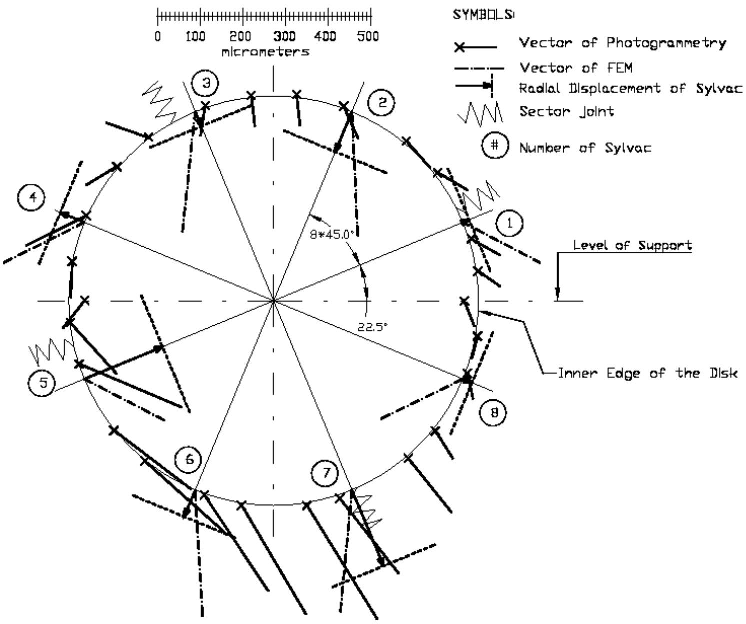

Figure 4. *A comparison of the stiffness measurement results between the measurement methods and FE-analysis. "Sylvac" refers to the linear displacement transducers. [4].*

3 ALIGNMENT AND SURVEY OF THE BIG WHEEL PROTOTYPE

The Big Wheel prototype, shown in Figure 5, is a full-sized prototype of about one half of the MSGC barrel support structure. It consists of two disks and one cylinder whereas the whole barrel is put together from four disks and three cylinders. The final verification of the MSGC barrel concept, design, and structure will be carried out by using the Big Wheel prototype. Possible subsequent modifications of the design will then only be modeled and simulated on a computer. Therefore, one of the main goals of the prototype is to compare the experimental results with the simulation results and, if necessary, modify the simulation model to better correspond to the real structure.

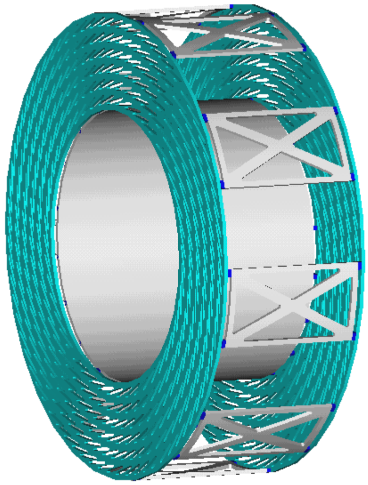

Figure 5. *The Big Wheel prototype.*

3.1 Alignment concept

After a fairly extensive study, the photogrammetry was chosen to be a method to survey and to align the final MSGC barrel support structure [2]. Photogrammetry has proven to be a flexible and accurate method to measure objects with a complex geometry. The photogrammetry leaves flexibility to make changes in the structure. It is like a flexible co-ordinate-measuring machine with looser geometry restrictions. According to the measurements carried out on the B1-prototype, the repeatability of the photogrammetry is sufficient for the alignment task. The measurements on the two-layer disk prototype showed that also the accuracy is sufficient, even though the accuracy will not be as good when the final structure is measured due to its larger size. Compared with many other methods, the flexibility of the photogrammetry was found very competitive: adding the number of measured points is easy, modifications to the structure do not compromise the measurement set up and the targets used are light, simple and inexpensive [2]. Furthermore, the cost and the respond time for the project are competitive as the devices and the services exist already at CERN.

Several factors, such as target visibility, target types and target network, affecting the accuracy of the photogrammetry have been taken into account already at the design phase of the MSGC barrel to gain an accuracy as good as possible. The final feasibility and precision of the alignment measurement procedure will be verified with the Big Wheel prototype.

In the barrel wheel structure the rod fixations in each disk are the actual objects to be aligned and surveyed. However, when the final structure is equipped with all the connectors, cabling, cooling and gas pipes, it cannot be guaranteed that these points are visible any more. The best visibility would be obtained at the outer periphery, especially if the targets were sticking out from the structure. Spherical targets at the outer periphery were found ideal, because they are visible in every direction without pointing them. Small spherical targets, with a diameter of 10 mm, have been tested at CERN before, but due to larger scale of the object to be measured they would not illuminate sufficient area on the CCD-matrix of the camera. Therefore larger spherical targets were designed and manufactured to maintain the accuracy. The new targets have a 20-mm retro-reflective sphere on a high precision foot that is plugged radially at the outer periphery of the disk (Fig. 6).

Due to the inaccuracies in the targets, in their feet, and in their attachments to the disk, the accuracy requirements cannot be met directly. Therefore the system is first calibrated by measuring the locations of the spherical targets with respect to references in the disk. A precision target holder was designed and manufactured to attach the reference targets, already used in the B1-prototype, to the rod fixations (Fig. 7). Each holder fixes two reference targets per rod slot in a known position between the rod fixations. 25 reference targets holders are planned to be used in a disk. The geometrical centre of the detecting layers is derived in the disk by using the reference targets. When the centre is known, the disks can first be adjusted concentric and then achieve the rotational alignment. The photos are taken and the locations of the spherical targets are computed with respect to the references. The locations of the targets in the outer periphery are saved in a database. When the reference targets are not visible and only the spherical targets can be measured, the places of the reference targets can be calculated using the database.

A cross-shaped target bar, shown also in Figure 6, will be placed in the open volume inside the wheel to provide areas to attach targets that are overlapping in preceding pictures and to provide a well-spread target network. The target bar is made of carbon fibre to provide good dimensional stability. It does not have to be accurately fixed, but it has to be stable.

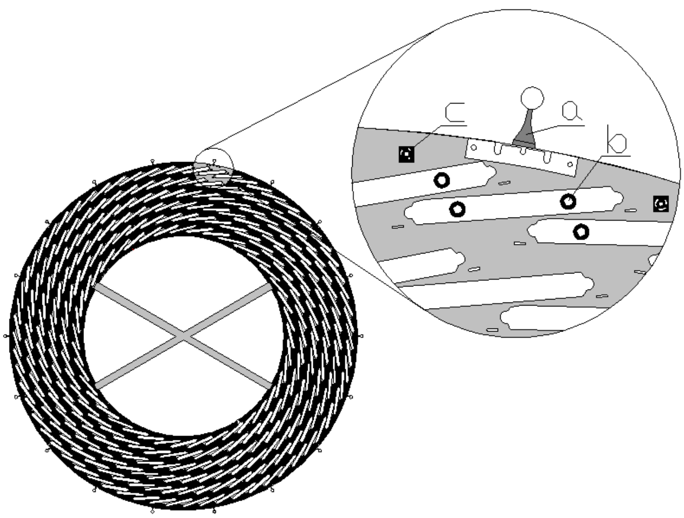

Figure 6. *A magnification of the disk with: a spherical target (a), a reference target (b) in a rod slot and a coded sticker target (c) attached to the disk. Note also the cross-shaped target bar attached to the disk.*

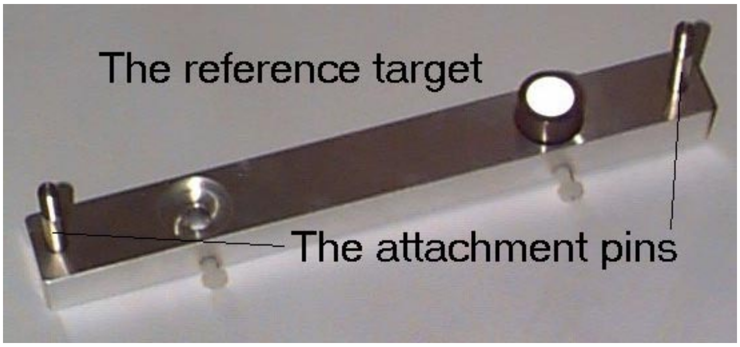

Figure 7. *The reference target holder will be attached to the disk by the attachment pins.*

The Big Wheel will be assembled on a support structure shown in Figure 8. The needs of the photogrammetry have been taken into account during the design of the support frame: the visibility is good due to the skeleton structure, the Big Wheel is raised up from ground level to enable photo-taking, and free space is reserved to stick targets onto the frame.

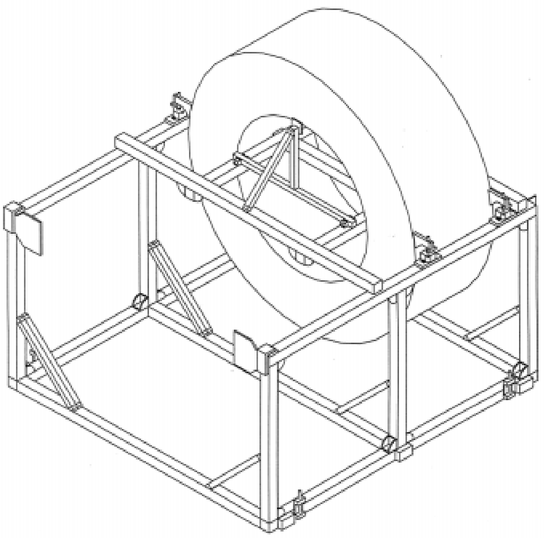

Figure 8. *The Big Wheel on its support frame.*

3.2 Alignment procedure

The individual components will be surveyed before the assembly of the structure. The cylinder between the disks will be measured by using a co-ordinate-measuring machine (CMM) at CERN. The connection elements in the ends of the cylinder fix the tilt of the disk with respect to the other, which states planarity requirements on the planes spanned by the connection elements. The planarity should be better than 40 μm; it will be achieved by shimming the elements according to the measurements obtained with the CMM.

Survey of the disk with photogrammetry will be performed simultaneously with the calibration of the targets at the outer periphery. The reference target holders will be installed in different rod slots and their positions are measured. Load tests on the disk will be performed in a similar way as on the two-layer disk prototype.

Figure 9 shows different steps from the survey of the components to the aligned Big Wheel. After the survey (step 1), the assembly of the structure will take place. One disk and the cylinder is first fixed together and lifted on the supports (step 2). Then the other disk is applied on the supports and aligned roughly. The photogrammetry targets are attached to the rod slots, to the outer periphery and wherein supplementary targets are needed (step 3). Then the pictures are taken and the final alignment is done (step 4). The operator who performs measurements will define the need of supplementary targets and the photo-taking process (viewpoints and number of photos) more exactly. The measurements are repeated until the required alignment is achieved. Finally, the panels are fixed at the outer periphery and the alignment is verified once more.

The whole structure will be load tested in order to study stiffness, possible creep, drift or other effects on the alignment of the structure. The structure will be loaded by using steel bars as weights. The stiffness and long-term measurements will be performed, like was done with the two-layer disk prototype. The photogrammetry measurements will also be verified by linear transducers.

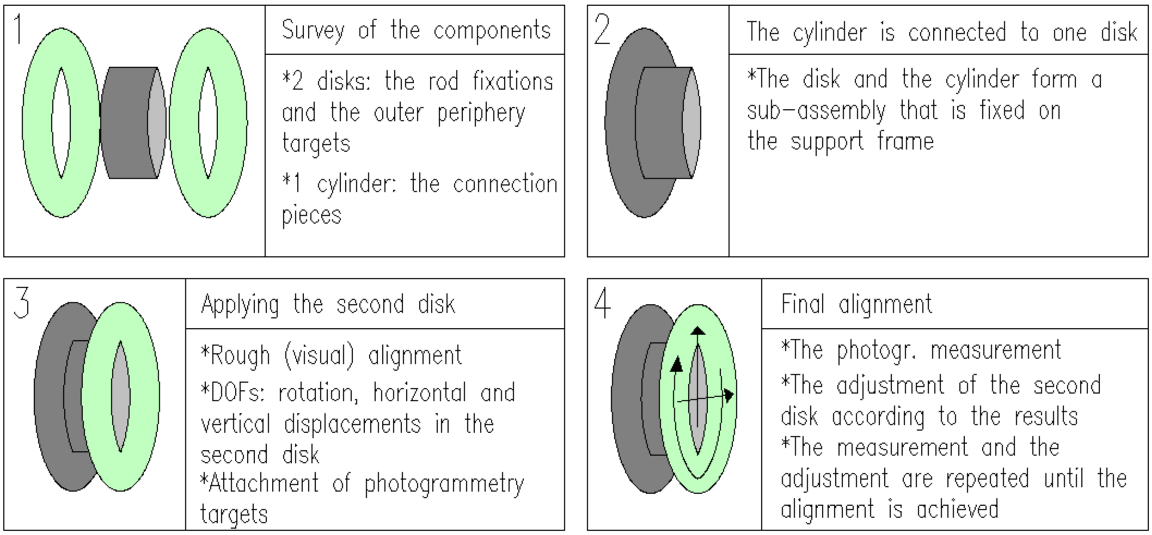

Figure 9. *The Big Wheel assembly procedure. The assembly begins with survey of components, proceeds with connecting the disks together through the cylinder and is ready when the Big Wheel is stated to be aligned.*

4 CONCLUSIONS

The two-layer disk prototype measurements performed with the linear transducers and the photogrammetry corresponded with the FE-analysis of the structure within error limits of 30 μm.

The digital photogrammetry provided by CERN-EST/SU-group is found to be a good alignment method for the Big Wheel prototype alignment. All the measurements carried out on the prototypes have shown that the photogrammetry is an accurate, flexible and inexpensive method. Moreover, continuous development of the targets and the procedure to be used encourage using photogrammetry.

The final evaluation of the system will take place when measuring the Big Wheel prototype. If the photogrammetry satisfies the requirements on accuracy and usability, it will also be used in the alignment of the final MSGC barrel.

5 ACKNOWLEDGEMENTS

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