Construction of the BIS MDT Chamber Module 0

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Abstract

Two BIS module 0 MDT chambers (Artemis and Beatrice) have been constructed at the University of Thessaloniki. In this note the chamber assembly steps and the quality assurance/quality control procedures are described. A precision better than the required specifications is achieved in construction.

1. Introduction

Monitored Drift Tube (MDT) chambers are used in the Muon Spectrometer of the ATLAS detector in order to measure the trajectories of charged particles in the magnetic field with a precision of the order of 50 µm over a distance of about 5 m. MDT chambers of different dimensions are arranged in the barrel region of the ATLAS muon spectrometer in three measuring stations at radial distances of 5, 7.5 and 10 m from the beam axis. In the azimuthal direction the measuring stations are segmented into eight large and eight small sectors, alternating with each other. Each azimuth sector is again segmented along the z direction (the beam axis) in stations with chambers of typical dimensions ranging between 1 and 2 m.. The BIS chambers, whose assembly is described here, are located in the small sectors of the inner station and have typically dimensions of 1 m in z direction and 1.7 m in azimuthal direction. Because of their location between the Tile Calorimeter and the Barrel Toroid coil cryostats and the restricted space in this area the design of the BIS chamber differs from the standard MDT chamber design [1]. In particular there is no spacer structure and therefore the suspension system of the chamber is located on the top multilayer (ML).

1.1. Description of the BIS chamber

A sketch of the BIS chamber is shown in Figure 1. The chamber consists of two multilayers (ML) composed of four layers of drift tubes each. The drift tubes are made from aluminum alloy; they have a diameter of about 30 mm and a wall thickness of 0.4 mm. The specifications and tolerances of the MDT tubes are described in [1]. Within a ML the tubes are close-packed with a wire pitch of 30.035 mm at 20°C. The two MLs are separated from each other by 6 mm thick cross-strips. The arrangement of the tubes in the two MLs is mirror symmetric with respect to the mid-plane (x–z plane) of the chamber. The chamber is supported on three mounting blocks, which are connected to the top ML via two pairs of Al profiles (support beams). The outside of the two MLs is covered by a layer of 30 mm thick insulating material and a 0.5 mm thick aluminum sheet for protection and thermal insulation. The assembled drift tube length (including the endplugs) is 1700 mm; there are 30 (36) tubes per layer leading to a total width (z-direction) of the chamber of 916 (1096) mm.

The deformation of the chamber along the tubes is monitored by a RASNIK system [2] (inplane alignment). The inplane alignment system for BIS consists of a single ray RASNIK and is mounted on the outside of the top ML between the support beams. It is embedded in the thermal

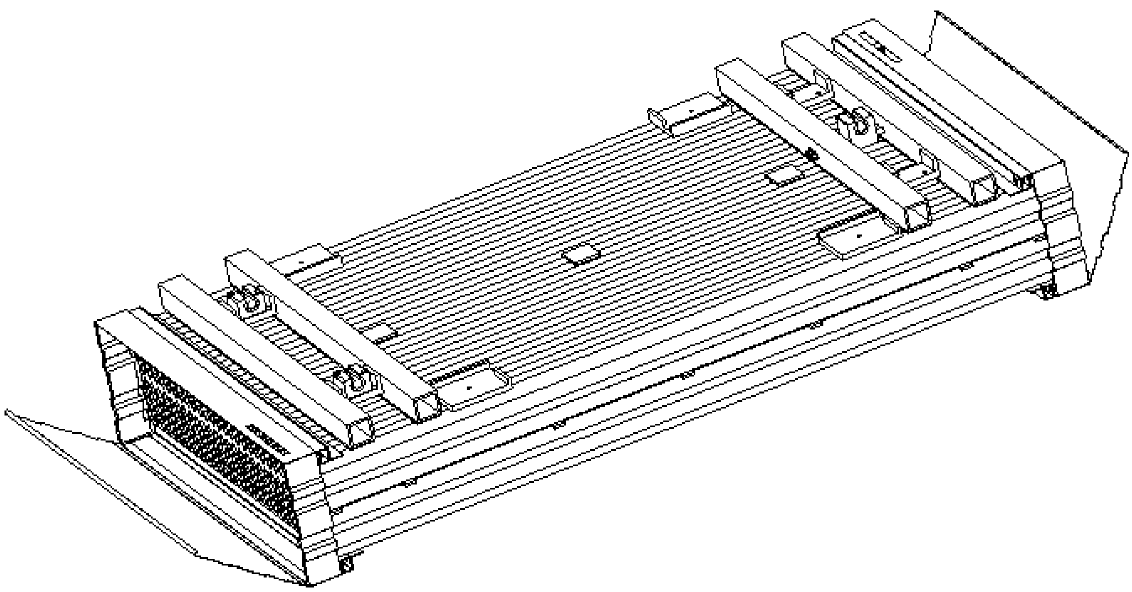


Figure 1: Sketch of a standard BIS chamber

insulation and protected by the aluminum cover.

The BIS chambers differ in some important aspects from the standard barrel MDTs, in particular:

- in the support system,
- the missing spacer,
- the Faraday cage,
- the location of the gas manifolds,
- and the thickness of the protection/insulation covers.

These differences necessitate a method of assembly different from the standard barrel MDT chamber assembly. Whenever possible standard assembly procedures and tooling were used [3,4,5].

2. Infrastructure and assembly tools

2.1. Clean room

The high demands in the mechanical precision of the MDT chambers require stable temperature and humidity during construction in a dust free environment. For that reason a clean room of class 50.000 ppm was constructed at the University of Thessaloniki. Temperature and humidity are controlled to within ±0.5 °C and 40±5% respectively. The room consists of two parts of 5x7 m^2 and 4x6 m^2 each where precision assembly and completion of the chamber are taking place (Figure 2).

The chamber assembly is taking place in the first part on a granite table of 2.7x2.2x0.4 m^3 and a flatness of ±3 µm (Figure 3). The room is equipped with a 0.5 t crane with a pivoting arm. All the assembly steps that require high and controlled precision are using the granite table. In the second part of the clean room the chamber is moved by the crane in order to be equipped with the Faraday cages and the gas manifolds. The clean room also serves as intermediate storage room. Chamber parts (tubes, support beams, etc.) are stored here at least 12 hours before they are used in the assembly. The clean room is equipped with 220/380 V mains, vacuum lines, compressed air, telephone, and ethernet connections.

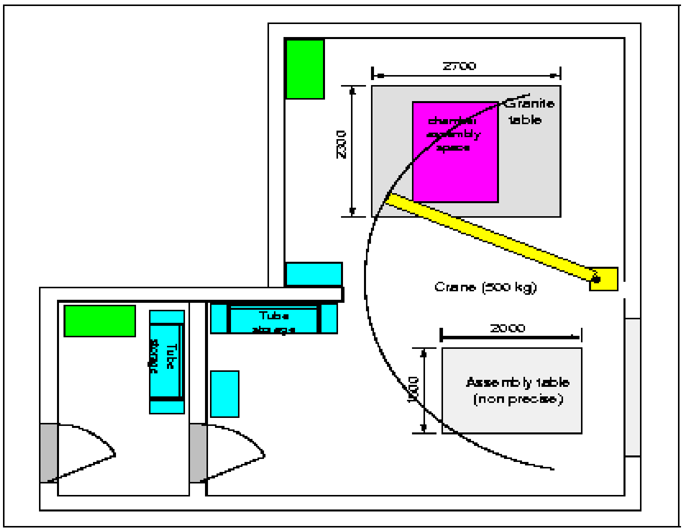


Figure 2: Layout of the clean room showing the location of the assembly tables and the crane.

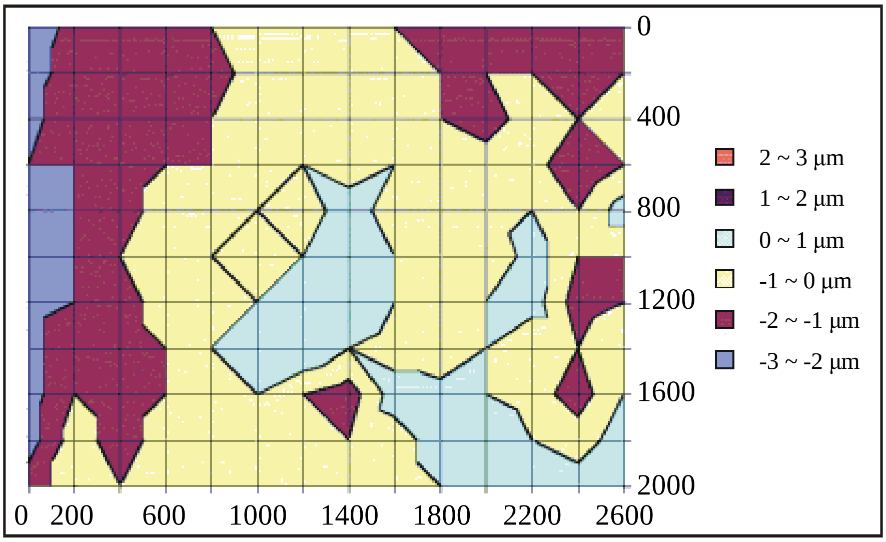


Figure 3: Granite table iso-lines showing the flatness of the table

2.2. Assembly tools

The main assembly tools used in the BIS construction are:

- six precision jigs for the placement of each tube layer equipped with a vacuum suction system;
- the stiffback to handle the under construction chamber;
- four sets of height blocks;
- six RASNIK systems to control at each step the position of the stiffback and its internal deformations;
- the inplane RASNIK system;
- templates for the tube positioning and orientation on the jigs;
- four placement templates for the positioning of the praxial alignment platforms;
- templates for the positioning of support beams and cross strips;
- bar code reader, connected to PC;
- mechanical feeler (mitutoyo) with 3 µm measurement precision connected to PC.

These tools are described below in more detail. The assembly sequence is controlled via a BridgeView 2 based computer program and all data are registered and stored in an MS ACCESS database.

2.2.1. Jigs

During the assembly the tubes to be glued are positioned on the table with an accuracy of better than 10 µm. This is ensured by a set of six jigs. The jigs are made of 1100 mm wide aluminum bars, 35 mm thick and about 100 mm high, with 12 mm stainless steel rods glued to them, see Figure 4. The tube positions are defined by the stainless steel rods which are glued on the Al bars. All jigs were assembled in the clean room with a precise template. The jigs themselves sit on two 30 mm diameter stainless steel rods and are held with clamps on the granite table. One is kept fixed and the other has the possibility to move along the Al bar (z-direction) in case of temperature variations.

The tubes are held down on the jigs by means of a vacuum suction system. For this purpose the middle four jigs have vacuum suction heads between the 12 mm steel rods. Because of the tube endplug shape the same system can not be used for the two outer jigs. The two outer jigs have no suction system; instead a row of suction heads, without rods, is placed 35 mm inwards of each of the end-jigs. The jigs are arranged on the granite table as shown in Figure 5.

In particular care was taken in the construction and positioning of the two end jigs where the precision surface of the endplugs is sitting.

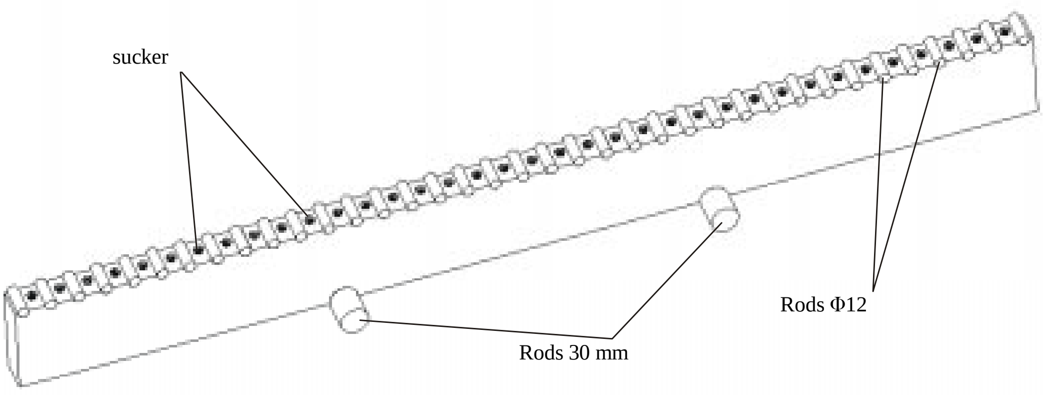


Figure 4: 3D drawing of a Jig module

To ensure the precise construction of the jigs, all jigs were measured after they were fixed on the granite table with a mechanical feeler by placing a precise steel rod of 30.035 mm diameter in each tube position (V-groove).

All jigs show an rms error in height (y-direction) from 3 to 7 μm and residuals from a straight line fit less than 10 μm. The measurements for the two outer jigs which are the most important in the chamber construction are shown in Figures 6 and 7.

The z-pitch variation of all the jigs was measured with a RASNIK system. This method cannot give the absolute value of the z-pitch but gives the relative difference of each z-pitch from a standard value (defined by the RASNIK setup) and therefore the residuals from the average z-pitch value. Figure 8 shows the spread of the z position of all grooves for jigs #1 and #6.

The alignment of the jigs was done with respect to a precise granite ruler fixed on the table.

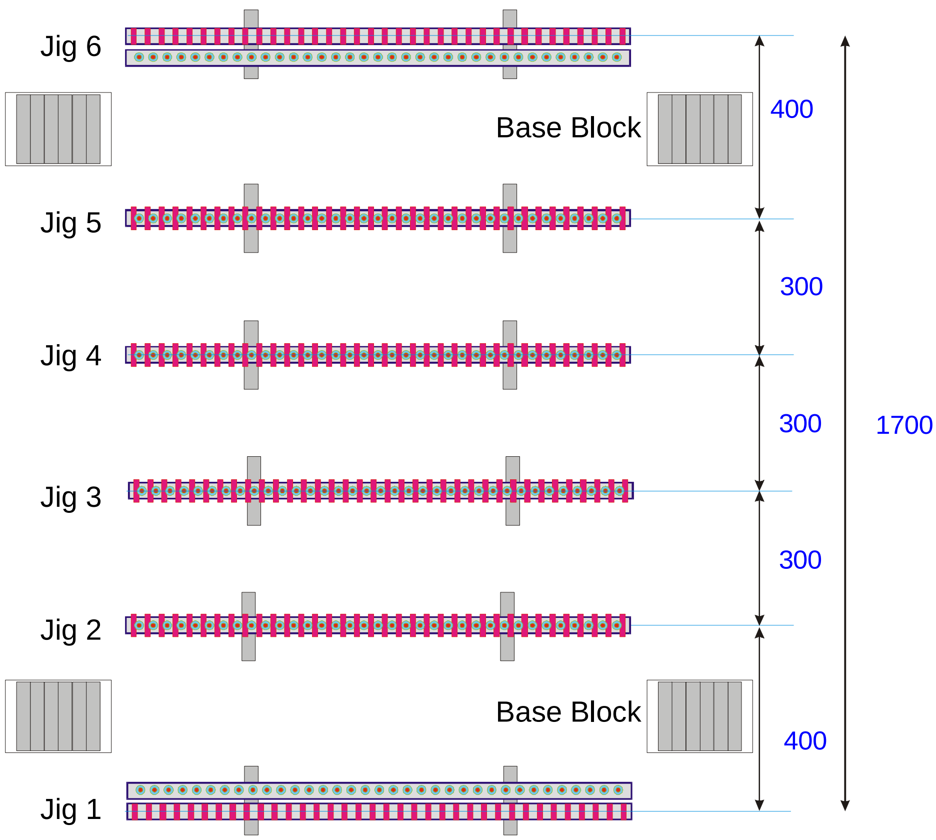


Figure 5: Arrangement of the jigs on the granite table

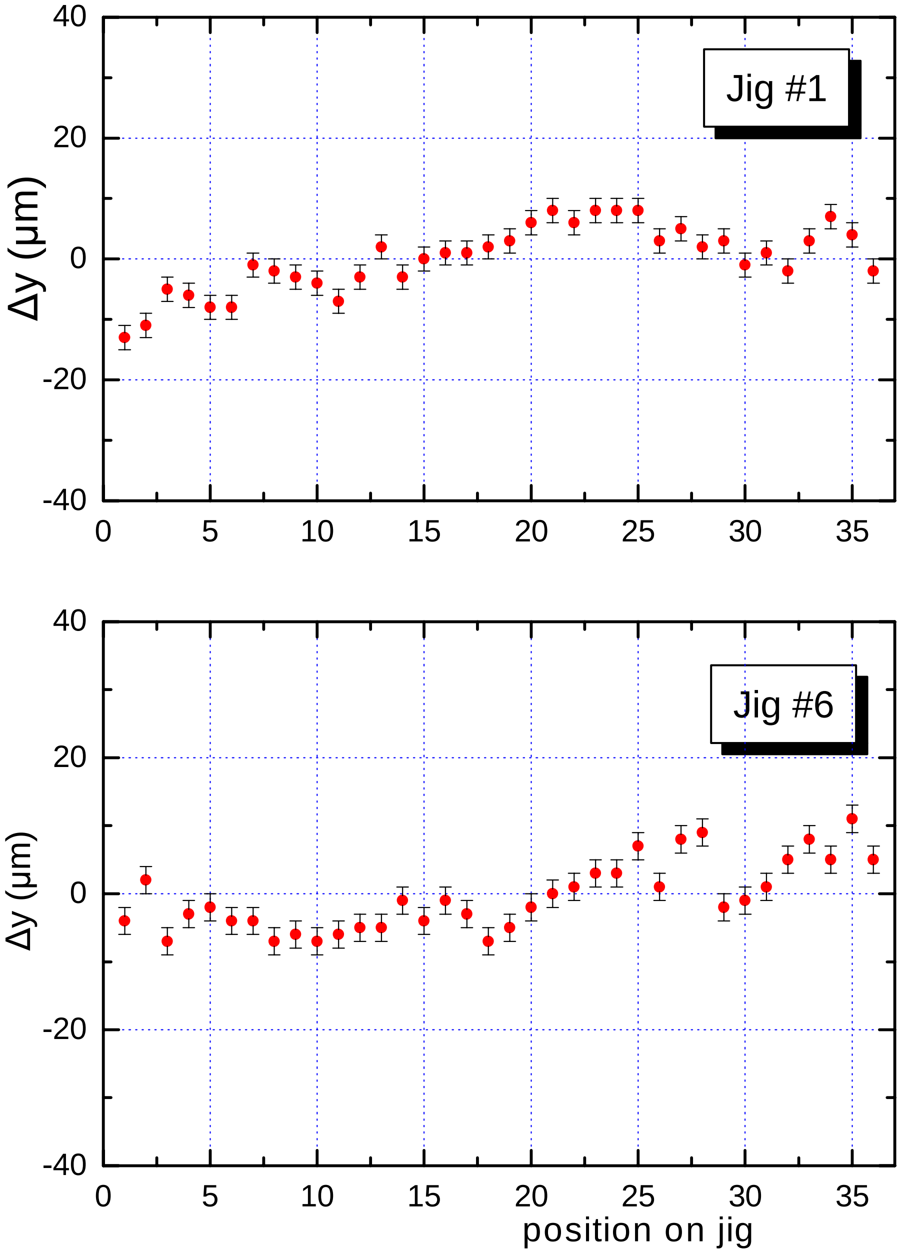


Figure 6: Relative height of the rod on jig #1 and #6 respectively, as measured with a mechanical feeler (mitutoyo), see text. The reference horizontal level is the granite table surface. The errors reflect the precision of the mechanical feeler.

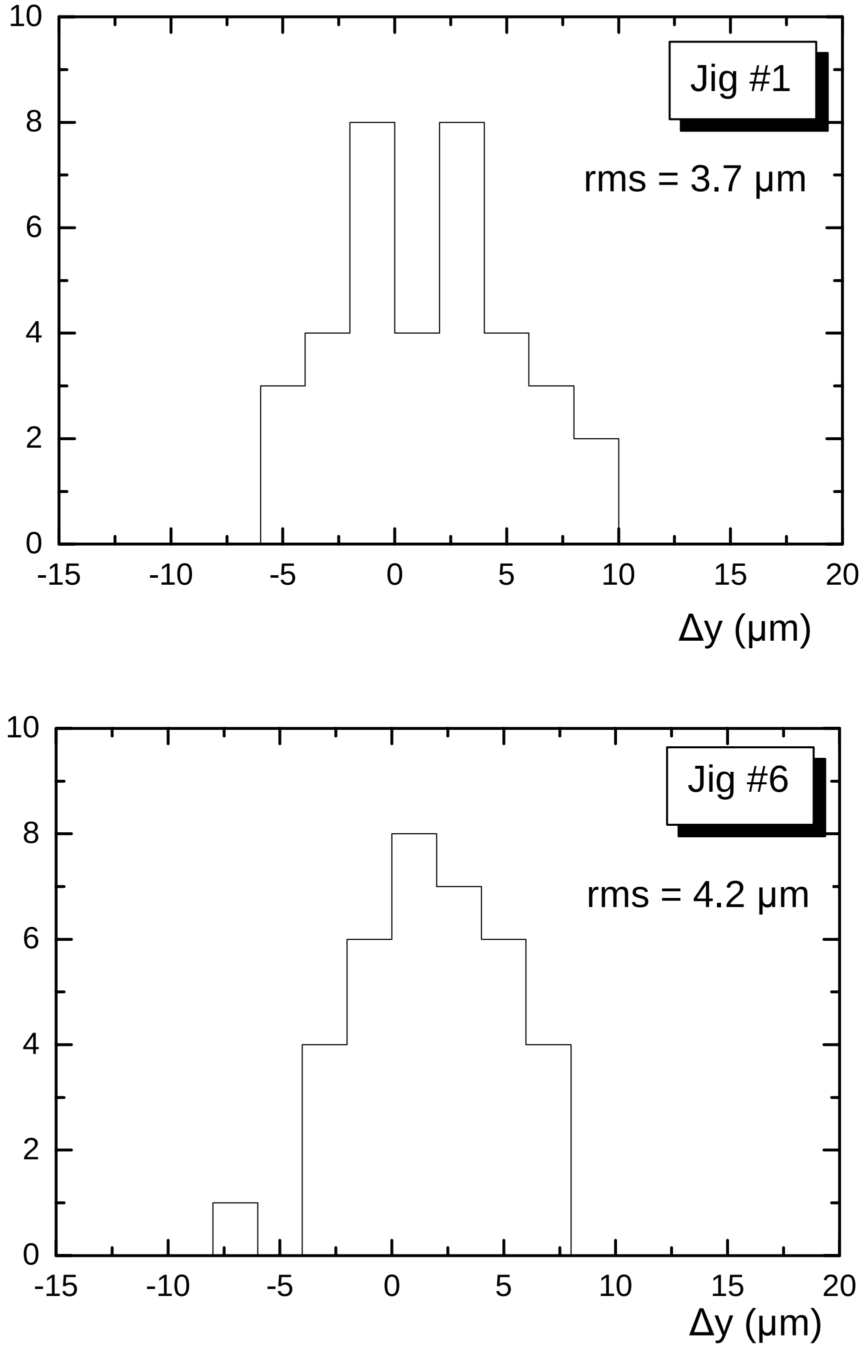
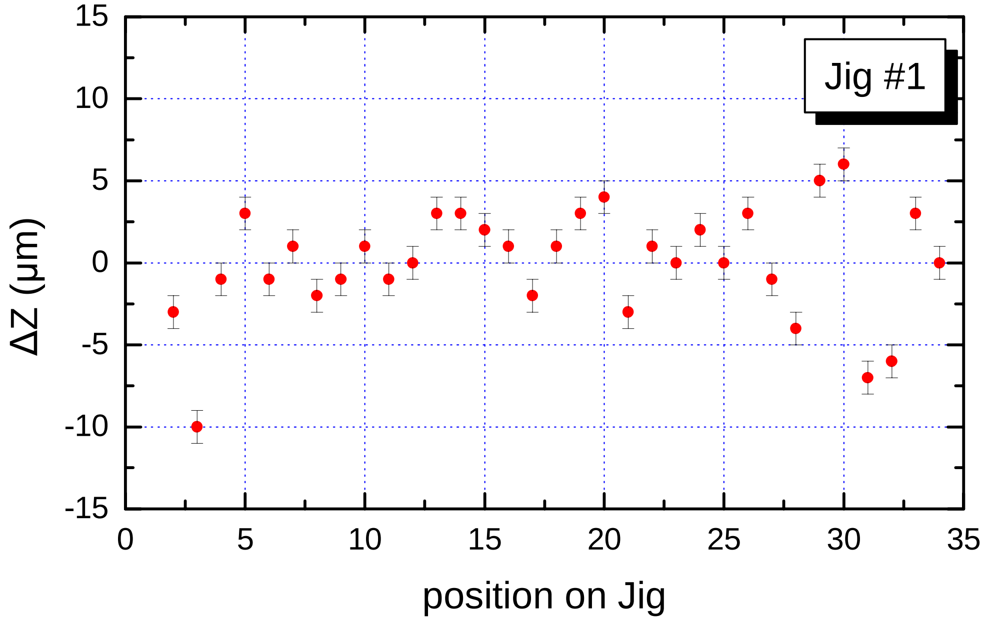


Figure 7: Distributions of the y residuals from a straight line fit for the jigs #1 and #6. The rms of the two distributions are 3.7 μm and 4.2 μm respectively to be compared to the 5 μm of the specifications.



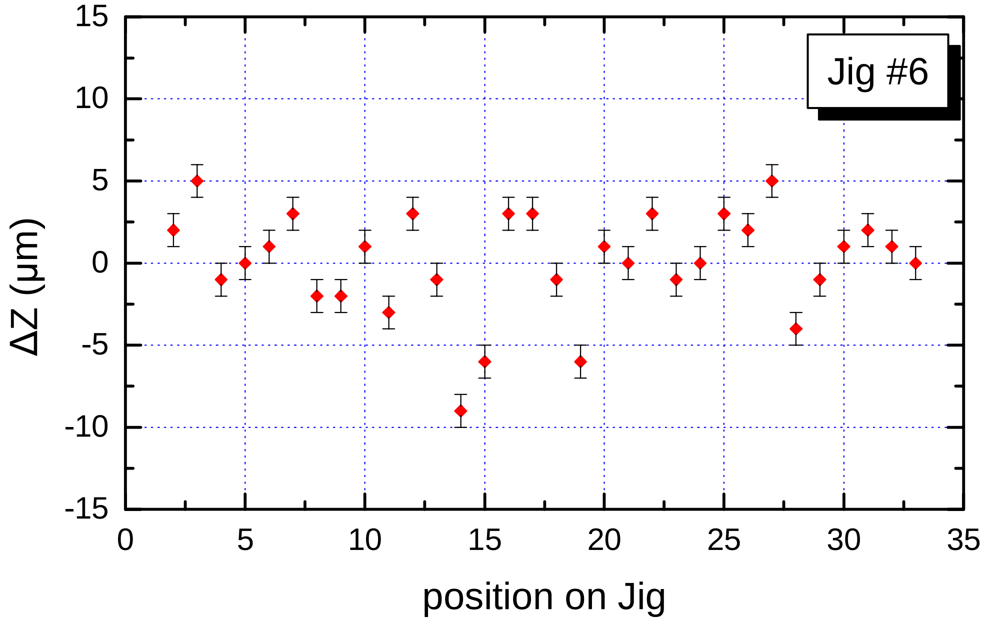


Figure 8: z-pitch variation for the jigs #1 and #6 as measured with RASNIK. The error is the rms of five measurements taken at each point.

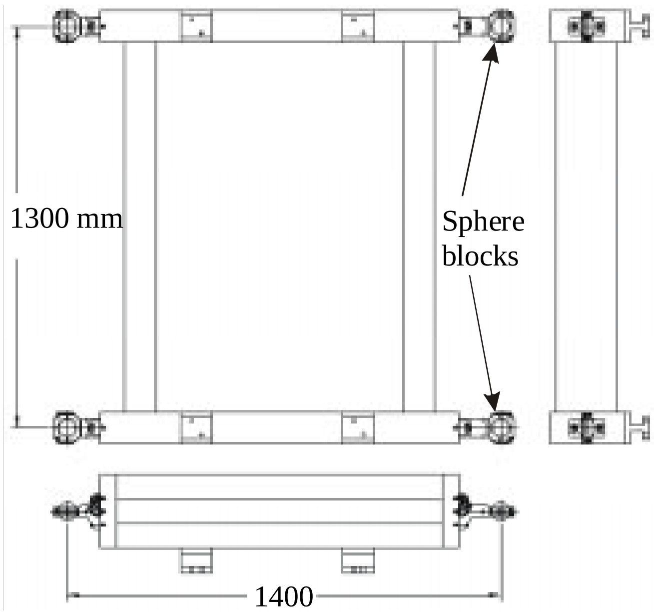


Figure 9: Sketch of the stiffback structure

2.3. Stiffback

The stiffback is an aluminum frame as shown in Figure 9 connected to the BIS support beams throughout the assembly sequence of each chamber. It is a rigid structure designed to deform not more than 10 microns under the full load of the chamber. A sketch of the stiffback is shown in Figure 9.

It consists of two cross-plates, 240 mm high and 1058 mm wide, connected to each other by two profile long-beams, 1250 x 100 x 200 mm. The two cross-plates are separated by 1300 mm from each other. Four brass arms located at the end of the cross plates hold four steel spheres, Figure 10. The spheres are the contact surfaces of the stiffback to the height blocks (via the sphere housing) that determine the correct height of the layer to be glued, as described below.

Two I-shaped support blocks are glued to the bottom of each cross-plate. The chamber is bolted to the stiffback to these four I-shaped blocks via the four U-shaped pieces glued to the support beams of the chamber (see figure 1). The stiffback structure is attached to the crane via a steel support frame.

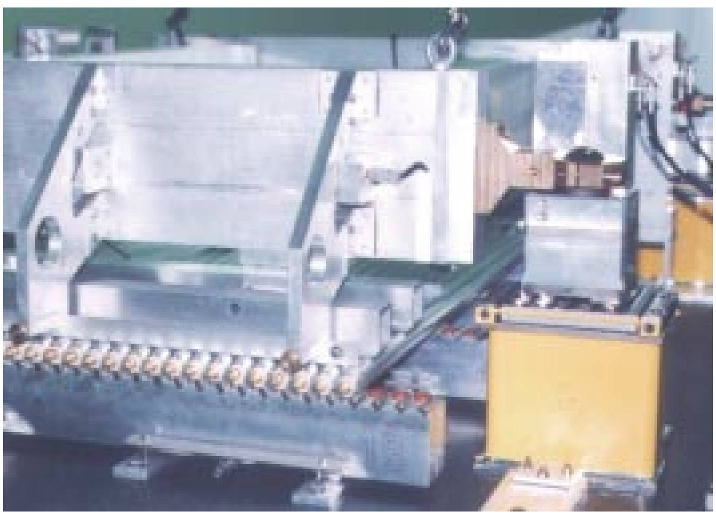


Figure 10: The stiffback with the brass arms in the sphere housing

2.4. Height blocks

The height for each of the eight layers of the chamber is determined by four towers placed on the granite table at the appropriate positions, see Figure 5. Each tower consists of a base block and height blocks corresponding to the layer height. The height blocks are combinations of calibrated steel rods of diameter 30.035 mm. Figure 11 shows the combination of the height blocks to achieve the required height for each of the eight layers.

Four sphere housings are used to position the steel spheres of the stiffback on the four towers, every time it is lowered in order to glue the next layer of tubes (see Figure 10). One of them sphere housings is considered as reference and it is fixed in both x and z directions. The housing located opposite to it in x direction is free to move in x direction only. These two housings define the reference side of the assembly setup. The other two are free to move in both x and z directions. Therefore the position of the stiffback is driven by the location of the spheres on the reference side.

By using the same piling-up pattern for the height blocks as for the tubes it is guaranteed the correct positioning of the stiffback in height (y) and in z at each step. The third dimension (x, along the tubes) is controlled via a stop connected to the fixed height block. The base blocks together with the first set of height blocks are once and forever aligned to the jigs and fixed to the granite table.

The height block combinations were measured on a CMM machine and found to deviate from the nominal values in x and y less than 10 µm.

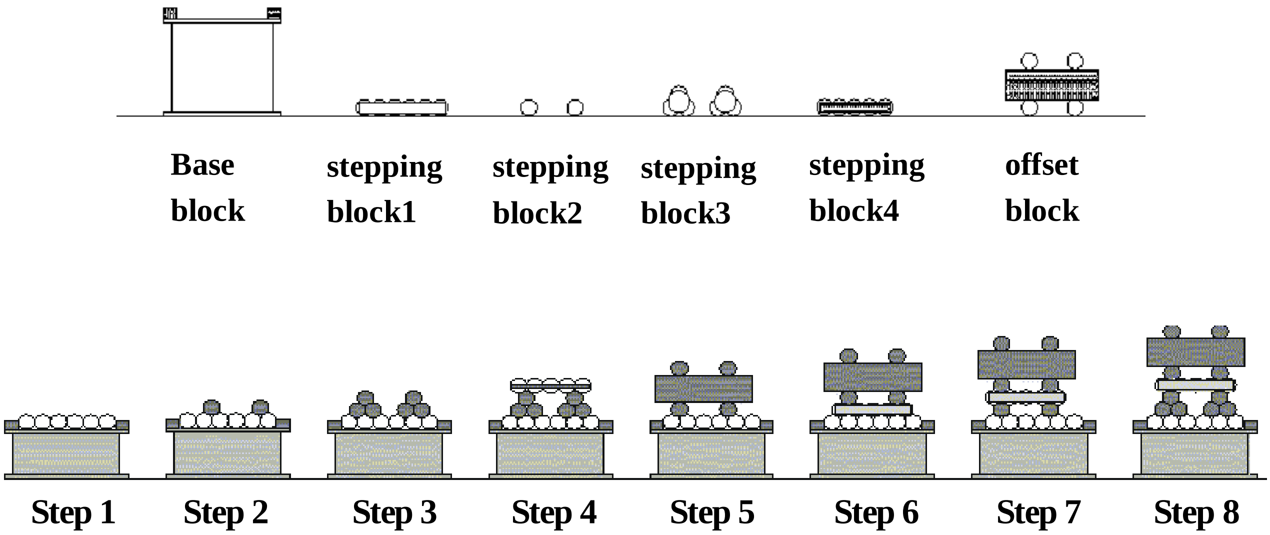


Figure 11: The height blocks and the combinations of them which correspond to the eight layers.

2.5. Templates

There are two templates for the positioning of the tubes on the jigs, one for each chamber side (RO and HV). The templates are placed on the end-jigs against the outer face. They define the tube position in the x direction and its orientation, see Figure 12.

The tube positioning template consists of a layer of 36 short aluminum cylinders glued together on the jigs. Each cylinder is 35 mm long, has an outer diameter of 30 mm, and a wall thickness of 5 mm. A 2.2 mm wide groove is machined at the bottom of each cylinder along its full length in order to define the tube orientation by requiring the tube ground pin to fit into the groove. The 36 cylinders are glued in an aluminum frame, see Figure 13.

There are also templates for the positioning of the support beams, the in-plane system and the praxial alignment platforms.

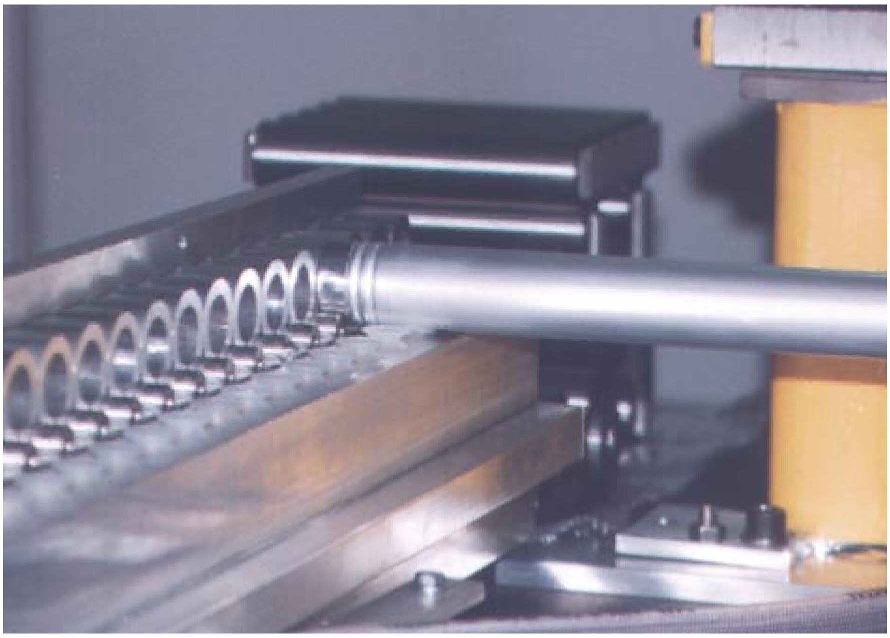


Figure 13: The tube positioning template on the jigs

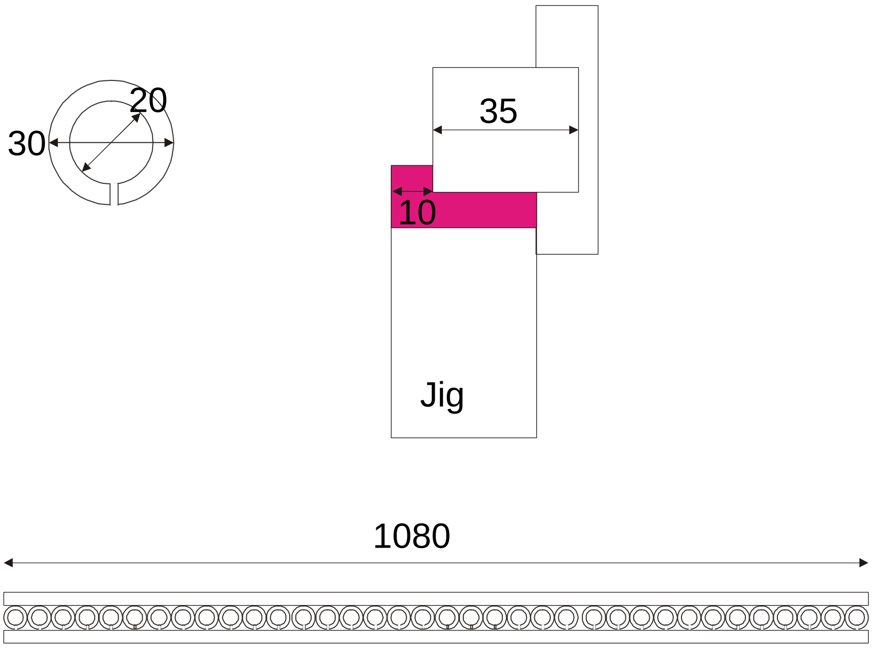


Figure 12: Tube positioning template

3. Assembly procedure

The assembly proceeds in two phases. Phase I comprises the precision gluing steps on the granite table. It takes eight working days. During Phase II the chamber assembly is completed on a non-precise table by adding the Faraday cages and by equipping the chamber with the auxiliary parts. Note that in the following, for convenience and in contrast to the general naming scheme, the tube layers are numbered 1–8 from top to bottom, following the gluing sequence.

3.1 Short Description of Phase I

On Day 1 the first layer of tubes is positioned on the jigs and glued. Then four praxial platforms are positioned with the help of four placement templates on top of the tube layer and glued. After glue curing the templates are removed and the praxial towers are placed on the platforms. The support beams are placed and glued via two templates on the first tube layer. The U-pieces are connected to the stiffback and glued to the support beams. The RASNIK in-plane monitor system is glued between the support beams (along x direction). The glue is cured over night while the vacuum system is on.

The following tube layers (2 to 8) are added, one per day. At every step the vacuum is switched off and the stiffback is lifted with the already glued tube layers. The four height blocks are configured as indicated in Figure 11. The next layer of tubes is placed on the jigs and the glue is applied between the tubes and at ±30 degrees from the vertical direction. The stiffback is lowered onto the height blocks and all RASNIK systems are read. The glue is cured over night.

On Day 5 the first multilayer is finished and the second multilayer starts by continuing the stacking procedure as described above after having glued the cross strips to the 5^{th} layer of tubes.

During the full duration of Phase I the on-line assembly control program is active. The QA/QC data as well as RASNIK information and environmental data (temperature, humidity) are stored in the local database.

On Day 9 the chamber is removed from the granite table which is ready to be used for the assembly of the next chamber.

3.2. Phase II

During Phase II the chamber is completed on the second (non-precise) table by adding the auxiliary equipment. The Faraday Cages are mounted and the T-sensors are placed on both chamber surfaces. The protective covers are fixed and the mounting blocks are added.

4. QA/QC during assembly

During the assembly procedure strict Quality Assurance / Quality Control (QA/QC) procedures are followed which guarantee the quality and the mechanical precision of the chamber.

One of the parameters is the tube position within the layer (planarity) measured by the height of the end-plugs. When the tubes are on the jigs and kept by the vacuum suction system the relative height of the precision surface of the end-plugs is measured with a mechanical feeler (Figure 14). When a tube is found to be out of the tolerance (± 15 μm) its position on the jigs is changed. Finally no tube was rejected due to wrong end-plug height and all the cases where the height was out of the tolerance was corrected by interchanging the tubes on the jigs. Figures 15 and 16 show the height of the end-plugs as measured at HV and RO sides for all layers for both BIS modules (Artemis and Beatrice) respectively. In all cases the rms was less than 10 μm.

The deformation along x direction of the glued tube layers is monitored with the inplane alignment system which is placed in the middle of the first tube layer. When the first layer is suspended from the stiffback the tubes sag along the x direction. This deformation becomes smaller and smaller as the layers are added and the chamber becomes stiff and rigid.

The sag of the first layer is compensated with the help of two strips of adhesive tape (30+30 μm), which is placed across the tubes in the middle of the second layer. Figure 17 shows the inplane RASNIK readings before gluing the second layer. The initial value (zero value) of the inplane is taken when the first layer is on the jigs and the vacuum is switched on (on Jigs with vacuum, J+Vac). The second measurement is taken when the vacuum is off and the first layer is laid on the jigs (On Jigs without Vacuum, J_wo_V). When the vacuum is switched on the layer returns to the initial position (J+Vac). When the stiffback with the first layer is suspended the sag is about 30 μm (susp). After the placement of the second layer of tubes on the jigs and the arrangement of the height blocks for the step 2, the stiffback is lowered. The inplane reading shows that the first layer is still sagged by the same amount since the two layers are not touching each other. After the addition of the adhesive tape in the middle of the tubes (across the second layer) the first layer is pushed and returned to the initial situation (2nd+60). The last measurement shows the inplane reading (in agreement with zero value) when the first layer is lowered on layer 2 and the adhesive tape with 60 μm thickness is placed.

The vertical stacking of the tube layers is controlled by monitoring the position of the four spheres of the stiffback using RASNIK monitors with long masks (220 mm), see Figure 18. A calibration procedure is made for the four RASNIK towers in order to refer the data according to nominal values of the height steps. Before the assembly, all the eight steps are performed with the stiffback without load. The reproducibility of the RASNIK measurements is within few microns.

Figure 19 shows the deviation of the sphere positioning from the nominal values in y and z directions for the four RASNIK towers (ROA, ROB, HVA, HVB) for module Beatrice.

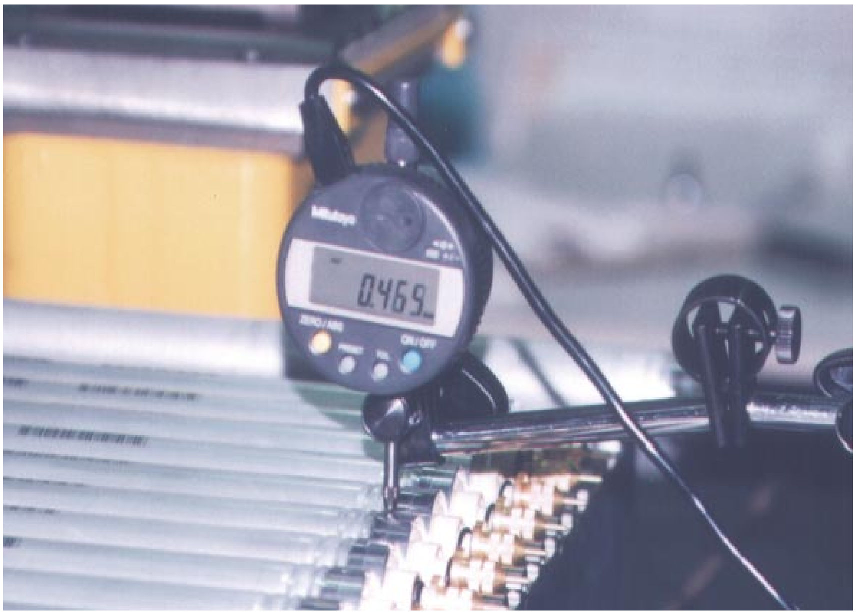


Figure 14: End-plug height measurements with the mechanical feeler (mitutoyo).

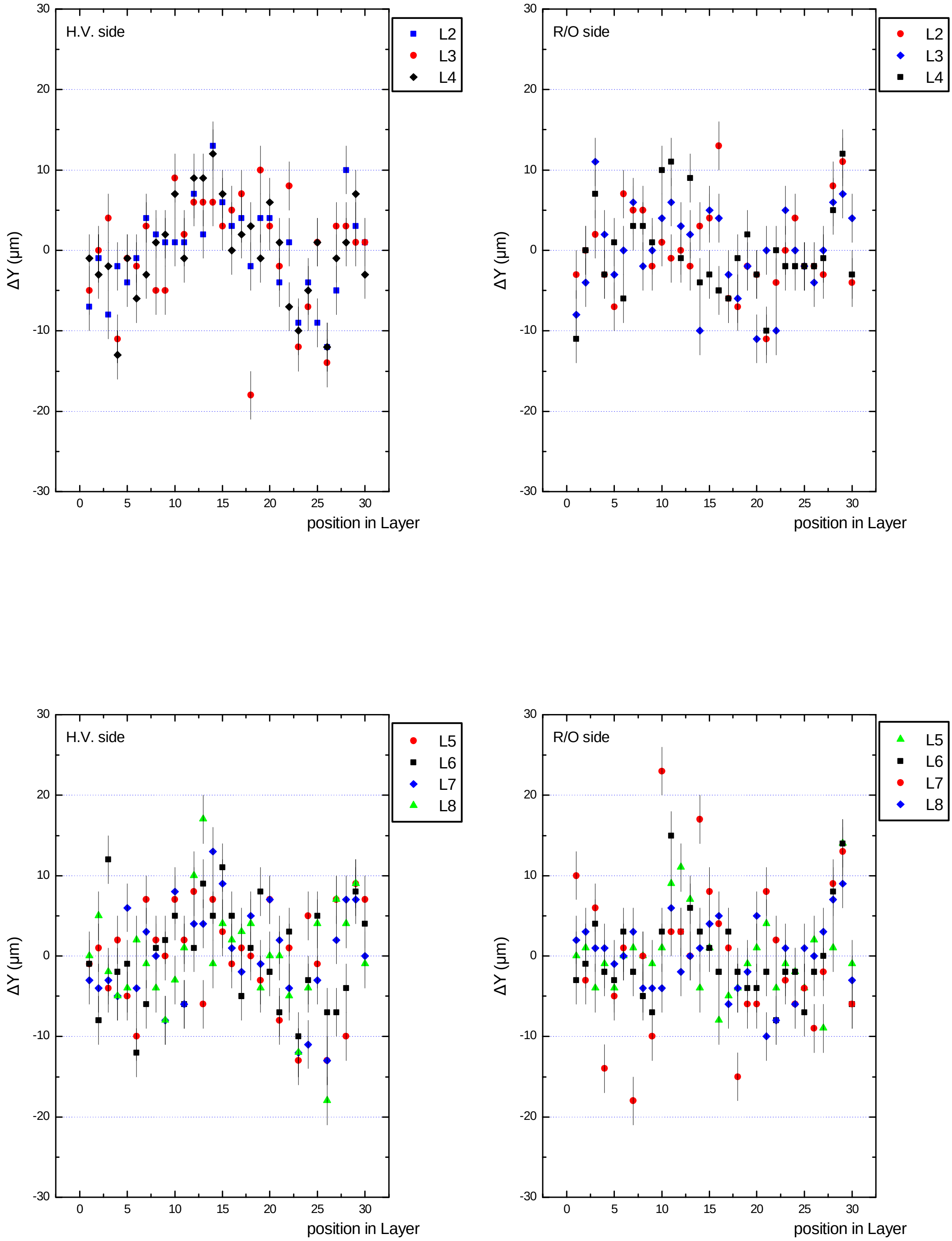


Figure 15: Residuals of the end-plug position on the jigs measured at HV and RO sides for all the layers of Artemis.

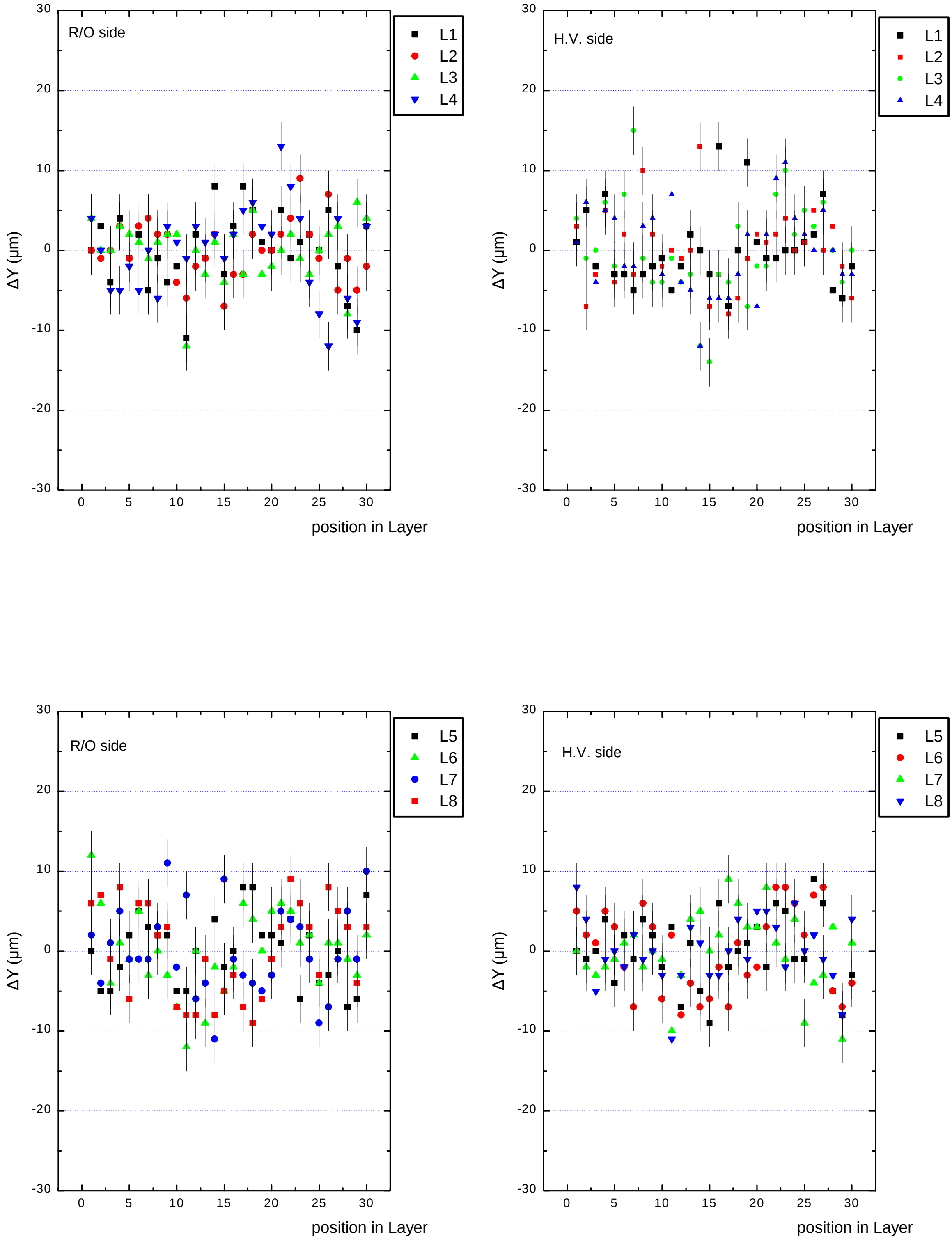


Figure 16: Residuals of the end-plug position on jigs measured at HV and RO sides for all the layers of Beatrice.

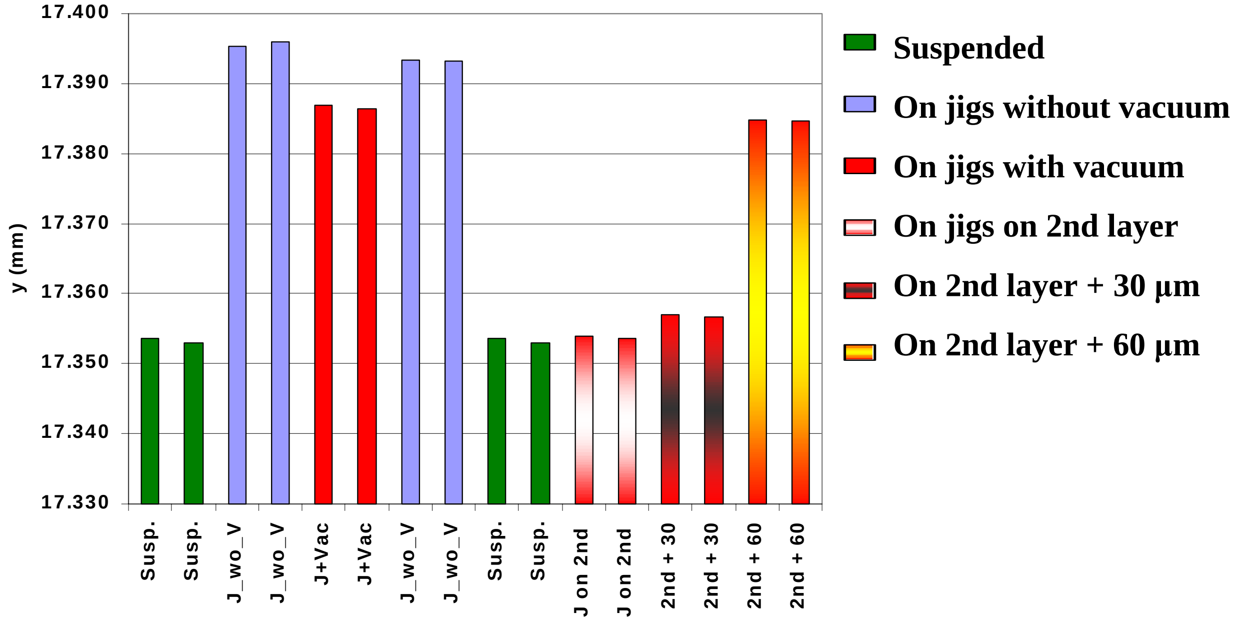


Figure 17: Measurement of the inplane RASNIK before gluing the second layer (Artemis).

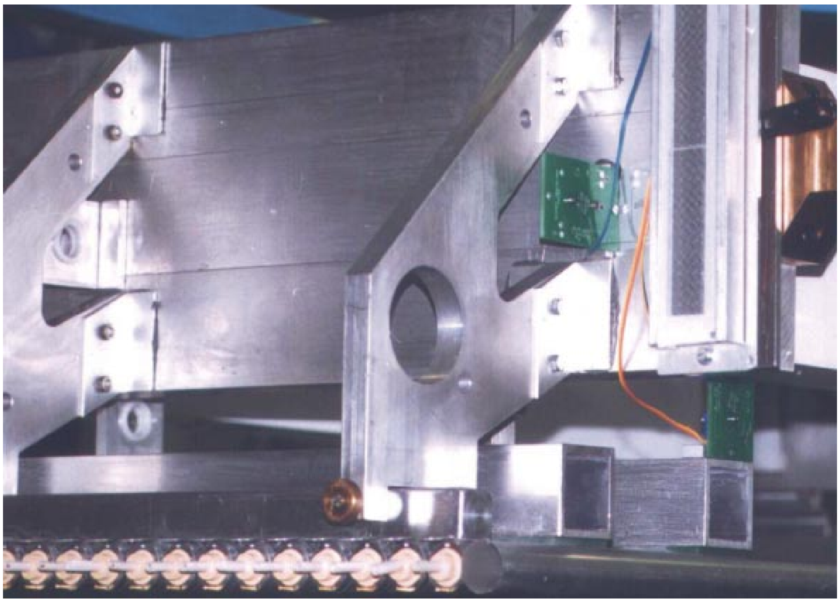


Figure 18: The long mask of the RASNIK system which is used for the monitoring of the stiffback position.

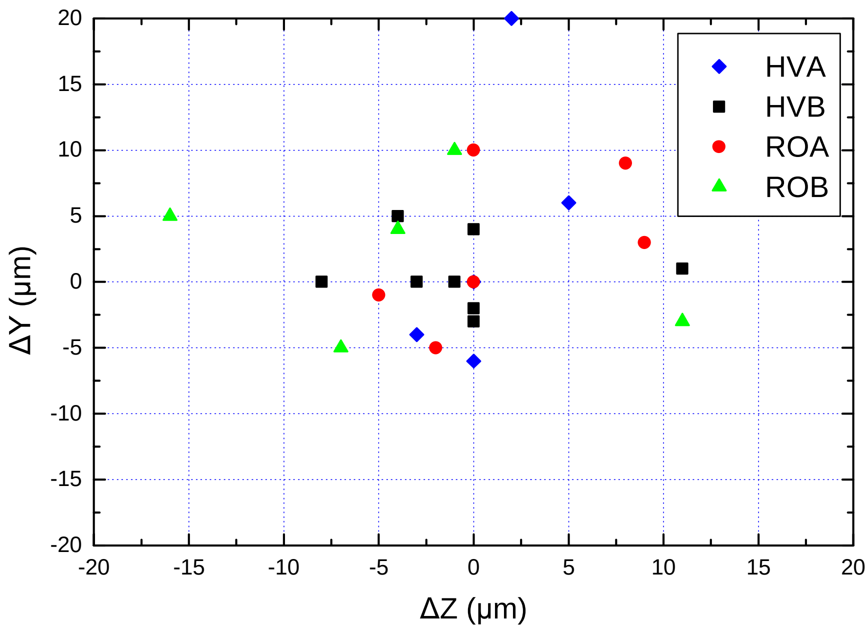


Figure 19: Measurements of the position of the four spheres during the assembly for the eight layers. The data show the deviation from the nominal values (Beatrice).

The tubes used for the BIS modules 0 were assembled at the University of Athens [6], tested at the NTU Athens [7], and delivered to Thessaloniki. Upon arrival at Thessaloniki the tubes were tested for wire tension and ohmic resistance.

The wire tension was measured with the JINR/Dubna technique which measures the wire oscillation frequency in magnetic field with a precision of 0.01 Hz. The average wire tension found to be in agreement with the NTU tests.

Figure 20 shows BIS Artemis during assembly.

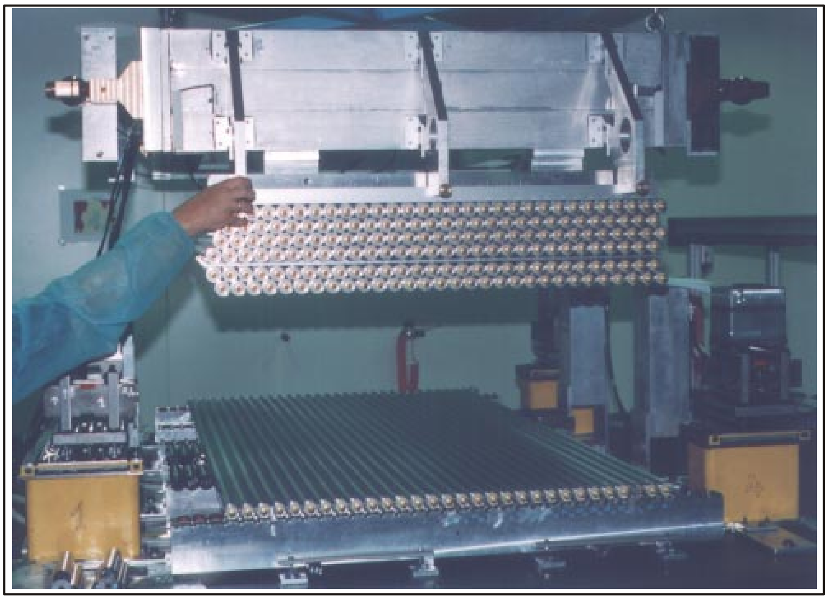


Figure 20: The six glued layers suspended via the stiffback and the seventh layer on the jigs (Artemis).

During the assembly of the 4th layer of the module Artemis the base block of the reference tower broke because of bad glue joints between the six rods. It was realized by the non-reproducibilityof the RASNIK measurements. A similar problem was developed on tower #2. The base blocks of the towers #1 and #2 ware replaced but their exact position was not possible to be reproducible. No problem has been encountered during assembly of Beatrice.

Both BIS modules have been tested at the X-Ray tomograph and found to be within specifications. The relative position of the two multilayers is obtained from the X-ray tomograph. The results from the X-tomograph for both Artemis and Beatrice are discussed in a separate note [8].

5. Conclusion

The assembly procedure of the BIS MDT chambers has been developed and tested during the construction of the BIS modules 0 Artemis and Beatrice. All the assembly steps were controlled by the online program and the data were recorded in a database. The QA/QC procedures during assembly show that the chambers are built within specifications.

References

[1] ATLAS Muon Spectrometer Technical Design Report, CERN/LHCC/97-22, May 1997.

[2] P. Duinker et. Al. Nucl. Instr. and Methods, A273 (1988) p. 814-819.

[3] G. Kaptsis, Ch. Petridou, J. Tsiafis and J. Wotschack, Mechanical design of the BIS module zero MDT chamber, ATLAS Internal Note, ATL-MUON-98-242.

[4] K. Economou, Ch. Petridou, D. Sampsonidis and J. Wotschack, Assembly and measurements of a mechanical prototype of the BIS MDT chamber, ATLAS Internal Note, ATL-MUON-98-243.

[5] Ch. Petridou, D. Sampsonidis, J. Wotschack, A. Zisis, Thermal studies on a mechanical prototype of a BIS MDT chamber, ATLAS Internal Note, ATL-MUON-98-263.

[6] MDT BIS module 0 tube assembly, D. Fassouliotis, P. Ioannou, C. Kourkoumelis and V. Birioukov, ATLAS Internal Note, ATL-MUON-2000-014.

[7] The QA_QC Results of the BIS-Module-0 Monitored Drift Tubes, E.N.Gazis, M. Dris, S. Maltezos, G. Stavropoulos, R. Avramidou, ATLAS Internal Note, ATL-MUON-2000-019.

[8] Analysis of the X-tomograph data of the BIS module 0 and comparison with QA/QC results, to be appeared as ATLAS Internal Note