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MDT chamber assembly procedure and construction of a full scale BML

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1 Introduction

The detector being developed by ATLAS for large area precision tracking in the muon spectrometer is based on chambers made of an assembly of high pressure drift tubes [1]. The mechanical assembly precision is a crucial issue and suitable assembly methods and jigs have been investigated by the Collaboration [2,3,4].

The method described here was first applied to the construction at Frascati of a 0.8 x 0.5 m^2 prototype in 1995 and the mechanical precision achieved was within the specifications [5].

A large assembly table has then been realised with technical improvements with respect to the original design described in a previous ATLAS note [2], by a common design work with the Nikhef and Protvino groups.

A 4 x 1.5 m^2 chamber has been built at Frascati in 1996. The improved design of the assembly jigging and the construction procedure are described in this note.

At present, a number of groups (Boston, Dubna, Freiburg, Frascati, MPI, Nikhef, Protvino and Thessaloniki) are working jointly on the optimisation of the method and on the finalisation of the design. For final verification, the construction of two full scale chamber prototypes, at MPI and at Frascati, is planned during the year 1997.

2 MDT chamber specifications

To achieve the high resolution required, ATLAS has chosen to use high pressure drift tubes as a basic element detector [1], which can provide an intrinsic resolution of 80 μm. A full chamber, of the required dimensions and with the required number of channels, consists of an assembly of tubes glued to a support structure.

The baseline design foresees two superlayers of 3 or 4 layers of tubes, on the two sides of the spacer support.

To achieve the required tracking precision, the position of the wires with respect to a reference on the chamber must meet the specification of 20 μm rms precision in projection.

In addition the alignment of the chambers in a tower has to be controlled at about 30 μm level. Therefore the alignment sensors have to be placed within 20 μm precision.

All these requirements imply a mechanical assembly procedure achieving quite stringent precision.

Another crucial implication is the demand on the precision of wire positioning inside the tube. This issue will not be discussed here.

The precision on the wire positioning achieved in the tubes used to build the chamber,

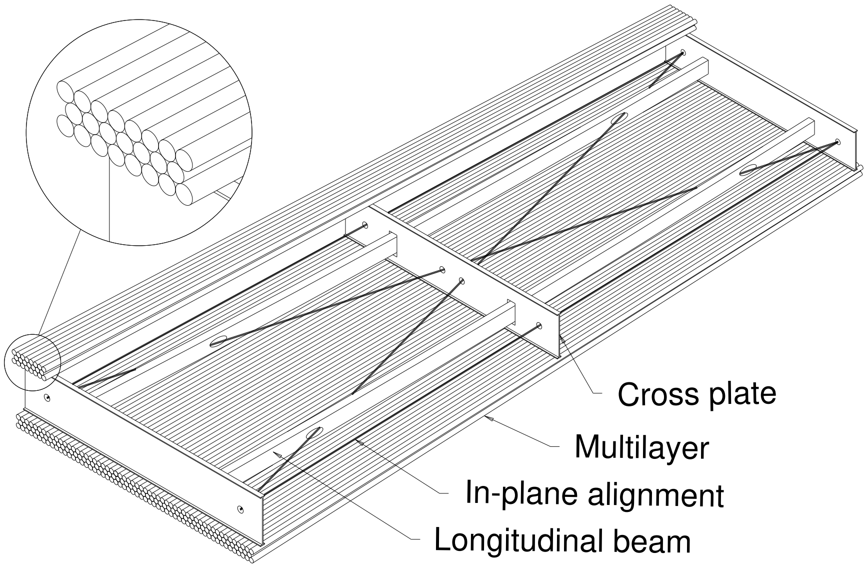

Figure 1: MDT chamber with part of top multilayer removed to show the chamber support. Also shown is the arrangement of the in-plane alignment rays used to monitor internal deformations of the chamber.

has however to be considered, in order to understand the actual mechanical precision achieved in the assembly of the chamber.

The general mechanical characteristic of the tubes are shown in Table 1, and a drawing of a barrel chamber is reported in figure 1, where the support structure (simply called spacer) plus one multilayer of tubes are shown.

The spacer is made of 3 cross plates connected by two longitudinal beams. The mechanical characteristics of the spacer are dictated by the requirements of having enough stiffness in the direction transversal to the tubes, and of being appropriately flexible in the direction along the tubes, to sag, under gravity, following the sag of the wires.

The orientation of the end-cap chambers in the apparatus (vertical) can make the requirements different.

The basic operation to be performed to assembly the chamber is to glue tubes on the two sides of the spacer. This operation is done with the plane of tubes and the spacer in the horizontal plane position (no scheme for doing it in the vertical plane, for example for the end-cap chambers, has been considered so far).

After gluing the tubes to one side, the chamber is turned up-side down to proceed to the gluing of tubes to the other side of the spacer.

In this position the gravity causes a deflection of the cross plates opposite to the one undergone when gluing the tubes to the first side. This deflection must be limited to a few microns, to preserve the precision positioning of the tubes . The cross plates for the barrel chambers are stiff enough, by design, to not allow a significant deformation when

Table 1: Mechanical parameters of the drift tubes. Errors and limits are engineering tolerances.(From ref. 1

Parameter	Design value
Material	Al–Mn alloy (ALUMAN 100)
Outer diameter	$30^{+0.}_{-0.030}$ mm
Wall thickness	$400 \pm 20\ \mu m$
Eccentricity	$< 10\,\mu m$
Length[a]	1.4–6.3 m
Weight	0.1 kg/m
Wire diameter[b]	$50\,\mu m$
Wire material[c]	Gold-plated W–Re wire
Wire tension	$\sim 60\%$ of elastic limit
Wire supports	One for tubes with $L > 3$ m
Tube/Wire concentricity	$100\ \mu m$

[a] Depends on location of chamber.
[b] Final choice will depend on performance studies.
[c] Other materials are being explored.

they are supported by the longitudinal beams, which support the cross plates in internal points close to the *Bessel* points.

In the assembly of the chamber the cross-plates are positioned by precise supports at their ends.

In the case of the present prototype the cross plate was considered stiff enough and no other means of support were used. For different chambers, and in particular for the end-cap chambers, that is not the case.

The application of the assembly method presented here to all the chambers in general will be discussed elsewhere [6].

The positioning of the tubes in between the locations, where they are attached to the cross-plates, have to meet a looser specification, that is 100 μm tolerance on the wall position with respect to the wire position.

3 Assembly concepts

To build a precise assembly of tubes, the tubes are first precisely positioned and then glued.

The tolerances on the tube parameters (see table 1), while extremely good, are however not enough to achieve the required precision by simply staking the tubes together, because of the building-up of the fluctuations. A jigging has to be used to control the tube position, before gluing.

The jig for the BML construction allows for the positioning of each tube individually, as advocated in the first proposal by the Nikhef group, leaving space between the tubes, to avoid misplacements caused by the contact with neighbouring tubes.

The basic idea of the assembly method presented here is to control the tube positioning by:

- a *tube jig* for positioning the tubes of one layer. It consists of combs on a flat table in which the tubes are constrained via vacuum suction in the correct position within the layer.
- a *spacer jig* for precise positioning of the spacer, to which the layers of tubes are glued, while resting in the correct position on the jig. The *spacer jig* is made of supports for the spacer, allowing for precisely controlled displacements in the horizontal and vertical position.

The assembly of the chamber consists of successive steps in which a single layer at a time is glued to the spacer.

The tube jig guarantees the precision within one layer, and the spacer jig guarantees the precise positioning of one layer with respect to the others. Once all the layers of one multilayer on one side are completed, the chamber is turned up-side down and the procedure is repeated on the other side. With this assembly method a gap can be left between tubes in both the horizontal and vertical direction. Each tube can be positioned individually in the chamber.

The basic idea that lead us to develop this assembly scheme is that of reducing to the essential the precision steps and the precision hardware needed, and the manipulation of tubes.

The precision combs on the table ("bottom" combs) are needed in any scheme. In addition, in other schemes "top" combs are used to position more layers together. The realization of "top combs" is intrinsically more difficult than "bottom combs", since they do not lay along all the length on the flat table, but are only supported at their ends. Therefore they must be made in one piece and be high to be stiff enough. For large chambers (the width of the chambers is up to 2.16 m), given the precisions aimed at, that can be a difficulty not easily overcome. In addition the alignment of top combs in position and in angle is also not easy. In the scheme presented here there are no top combs.

The spacer jig is needed in any scheme. Once a convenient spacer jig is designed, the displacements in the horizontal and vertical direction, which in addition are needed in this scheme with respect to other schemes, can be achieved by the insertion of high precision calibrated rods, by which both the horizontal and vertical positioning can be controlled.

The manipulation of tubes during the assembly is reduced to the bare minimum. Only

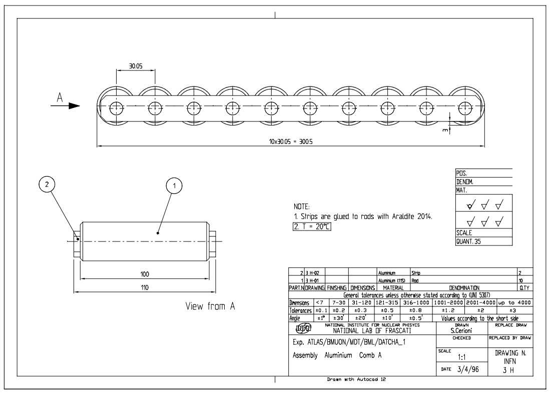

Figure 2: A group of 10 rods glued together. A comb consists of 5 such groups.

single tubes have to be handled when a tube layer is built on the granite. Complete layers are handled only when solidly attached to the spacer in their final position. This reduces possible deformations of the layers during successive operations.

The concept of the present assembly method has been described in detail in a previous note [2]. In the following, the hardware designed and realized for the construction of the BML prototype is described.

4 Assembly jigging

4.1 Tube jig

The tube jig is made of combs on which single tubes can be layed down and against which the tubes are positioned by vacuum suction.

Being the combs layed on the flat surface of a granite table, they can easily be realized in a modular way.

We used the highest modularity, i.e. a sequence of single high precision Al rods (fabricated in the Frascati workshop) put together in contact. The precision both in the horizontal and vertical coordinate is controlled through one parameter, namely the diameter of the rods.

For convenience the rods were glued to two lateral bars, in groups of 10. A drawing is shown in figure 2.

A full length comb consists of 5 such groups.

The whole tube jig is shown in figure 3.

The combs are aligned on one side (reference side) by using a granite ruler 2 m long. Being the length of the tube 4 m, the ruler allows to align half the combs directly, and

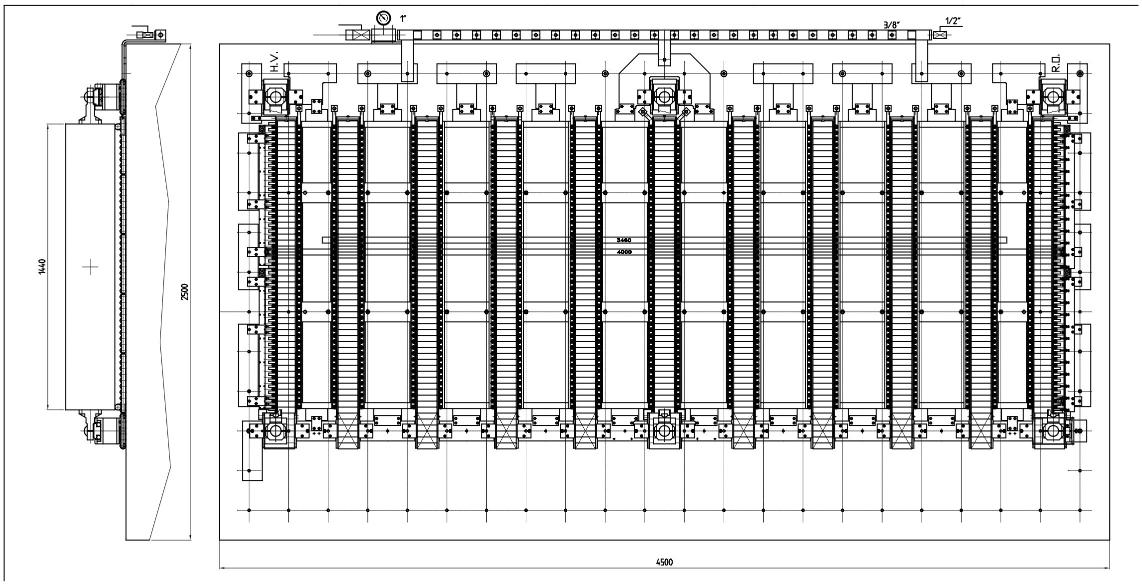

Figure 3: The whole jig for the BML.

then to align one more comb at a time with the previous ones, by moving by one step the ruler to include each time a new comb.

The combs at the two ends are made of rods with a prolongation of smaller diameter, to allow the insertion of one piece attached to the tube, which controls the azimuthal rotation of tubes.

On the two sides of the combs a line of vacuum suckers pulls the tubes against the rods. The area of each sucker is about 0.6 cm^2 and the under pressure applied is 0.5 bars.

One full comb has been given to the MPI group, that had it measured by the German company Gogl.

The results show a precision of less than 2 μm rms.

The diameter of the rods determines the pitch of the tube placement. It gives an average gap between tubes of about 65 μm.

4.2 Spacer jig

The basic concept is that the spacer itself has not to be precise. Only the displacements have to be precisely controlled.

This is achieved by attaching to both sides of the cross-plates, a precision sphere (see figure 3). During the assembly operation, the positions of the spheres with respect to the combs, are controlled by means of 6 precision supports also visible in figure 3.

The spacer position is controlled through six points (the six spheres): to provide kine-

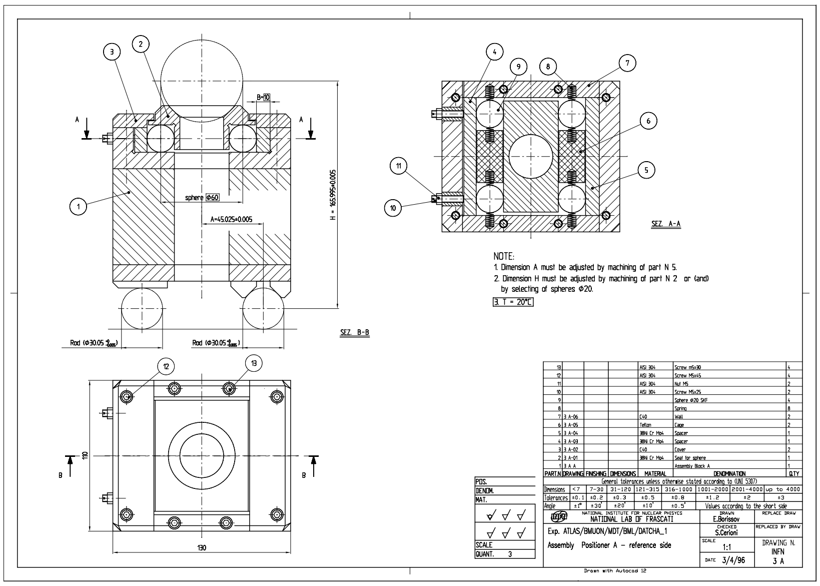

Figure 4: Drawings of the precision blocks supporting the spheres.

matic constraints, one point is completely fixed, the other at the end in the same side (reference side) is only fixed transversally and in height while is free to move longitudinally, the remaining four are fixed only in height and free to move in the plane.

The drawings of the blocks are shown in figure 4. The pictures of one block is shown in figure 5.

They have been fabricated in the Frascati workshop and then have undergone a grinding process in an external shop, to achieve a few microns precision. The displacements are controlled by inserting below the blocks high precision steel rods, produced by an external shop.

The full sequence of operations, necessary to mount the six layers, has been simulated on the plane of a 3-D coordinate measuring machine (see figure 6) and the results are shown in figure 7 and 8.

The measured positions are in agreement with the design position within less than 10 μm.

The use of spheres to control the position of the spacer guarantees a very high reproducibility level in the displacements of the chamber and also the achievement of the highest precision when the chamber is rotated.

The same side of the jig is used as reference side after the rotation.

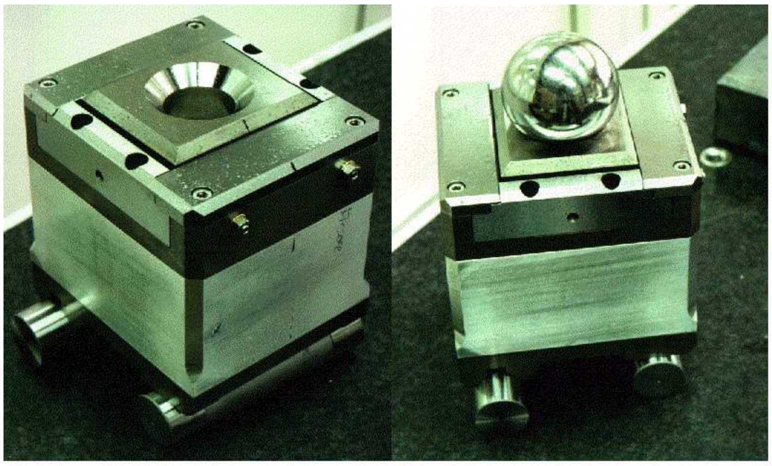

Figure 5: Picture of a precision block without and with the sphere.

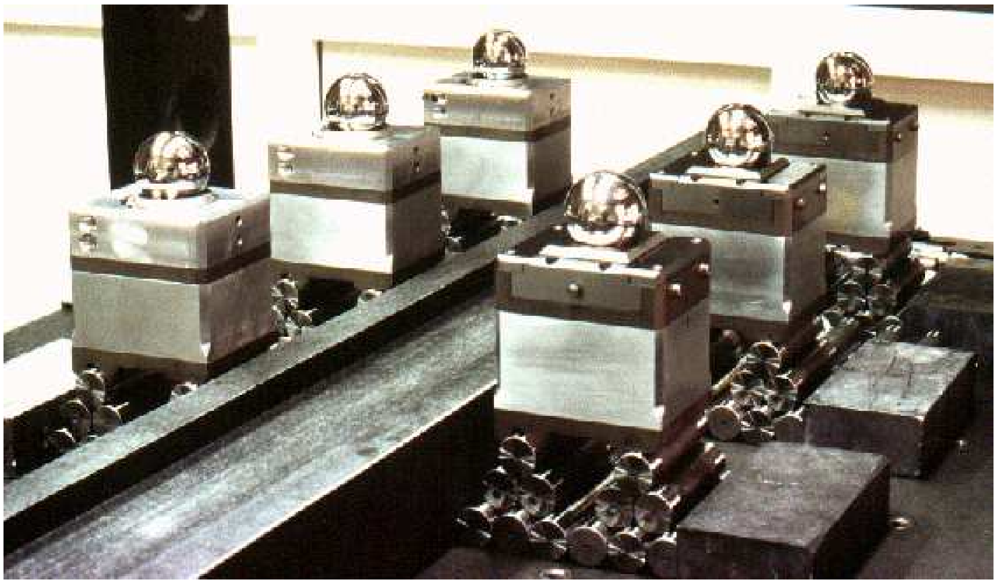

Figure 6: Picture of the precision blocks on the 3-D machine table.

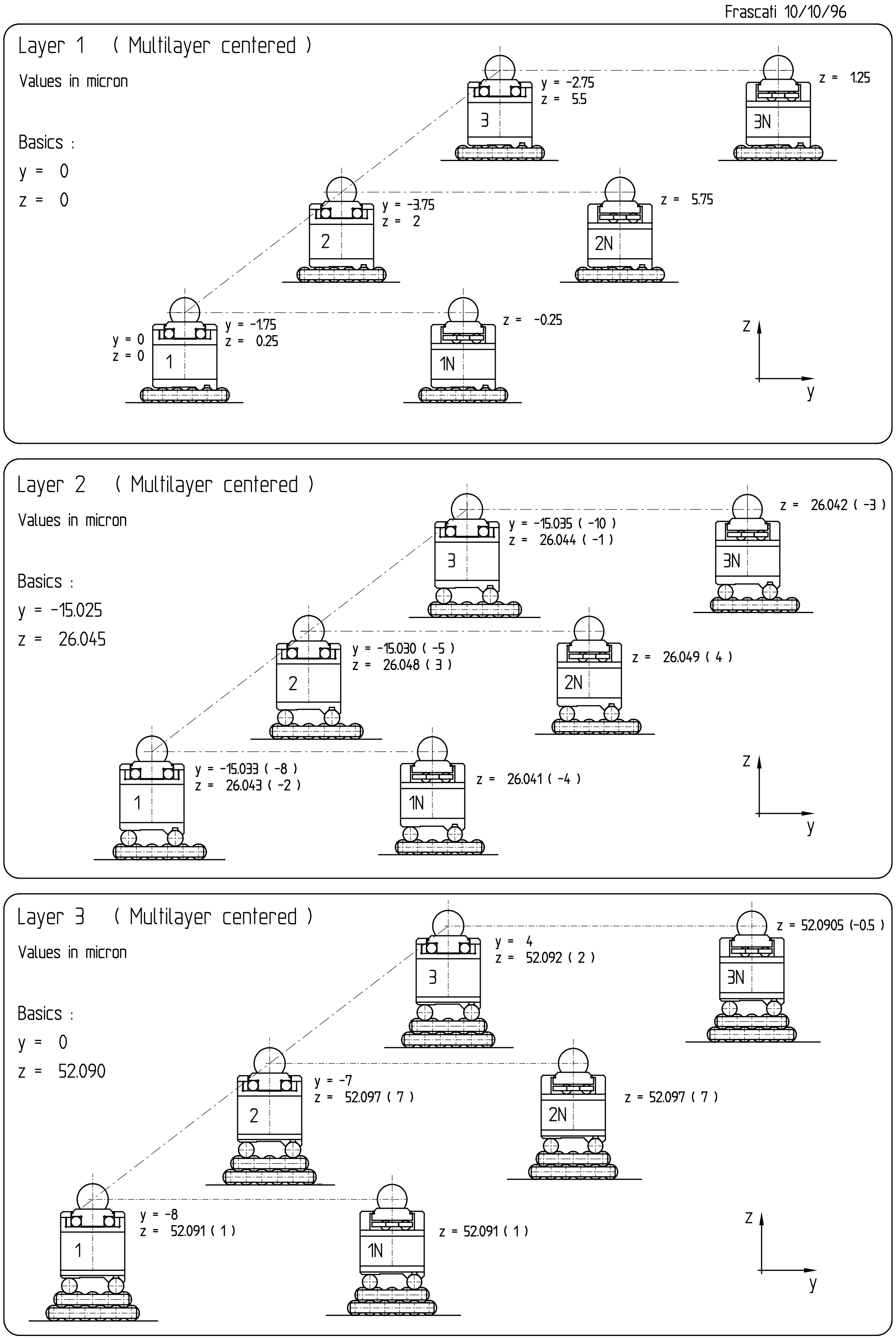

Figure 7: Results of the simulated sequence of operations needed for mounting the first BML multilayer (layers 1,2,3).

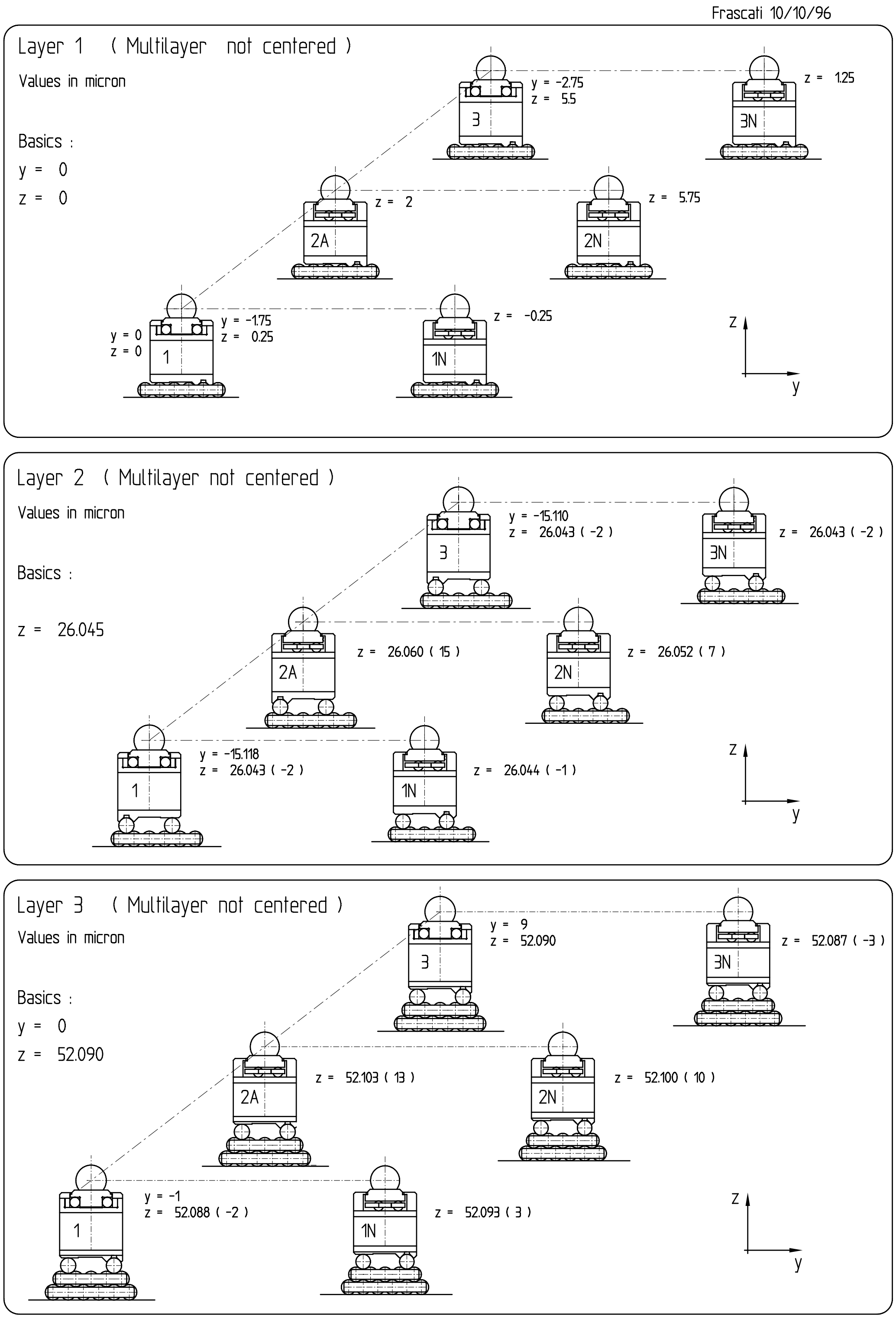

Figure 8: Results of the simulated sequence of operations needed for mounting the second BML multilayer (layers 4,5,6).

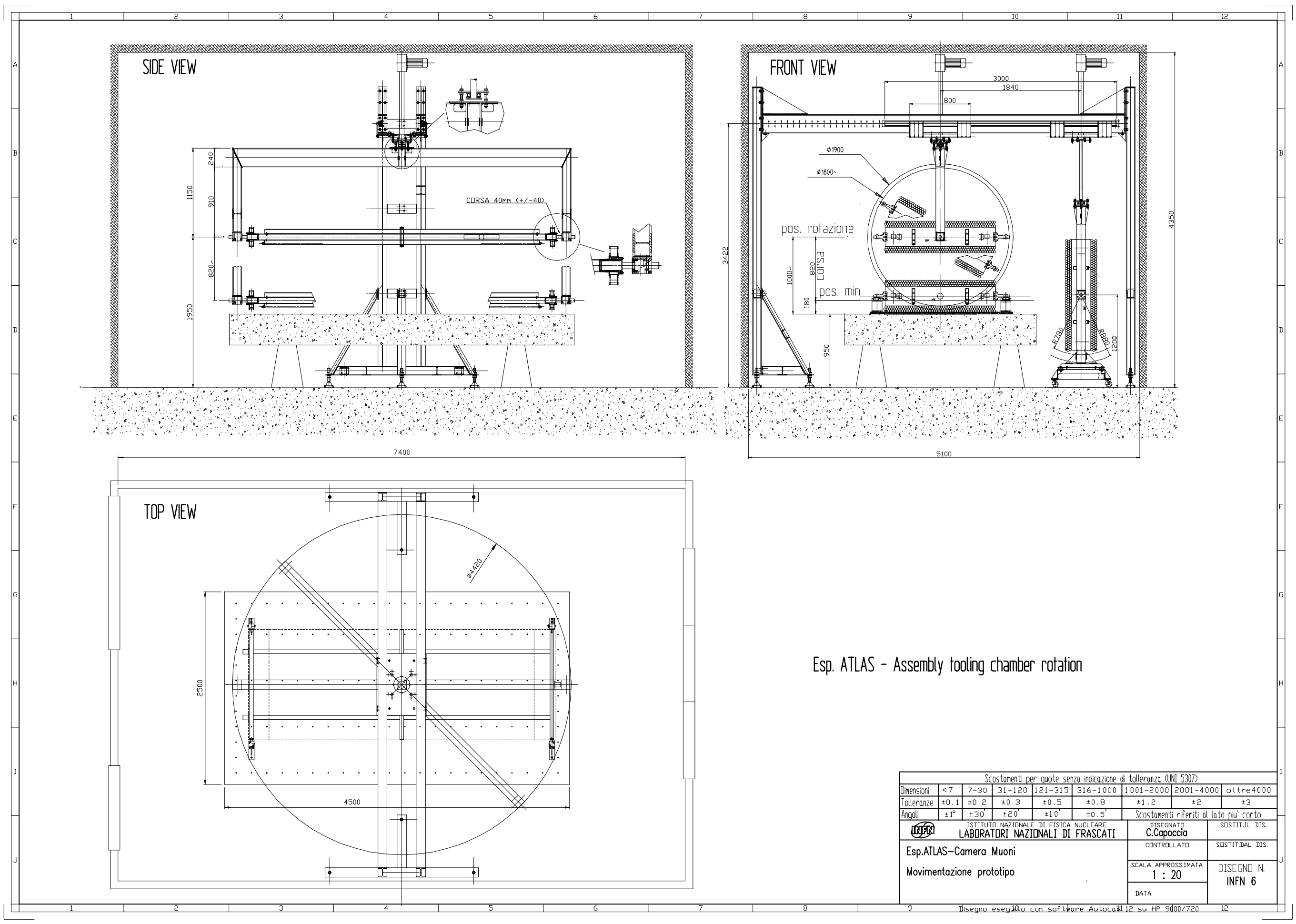

Figure 9: fig The lifting/rotating system for the BML chamber.

4.3 *Chamber lifting/rotating system*

The chamber is lifted and rotated with the help of the system shown in figure 9.

This system holds the weight of the chamber and allows for lifting, lowering and rotating the chamber.

The positioning of the chamber is only determined by the spheres finding their position in the centering holes in the support blocks.

4.4 *Glue distributor*

The glue is distributed on the layer positioned on the jig, in 3 lines along the whole length of the tubes: the line between two neighbouring tubes and the two lines of the closest approach with the next layer. The distributor is shown in figure 10.

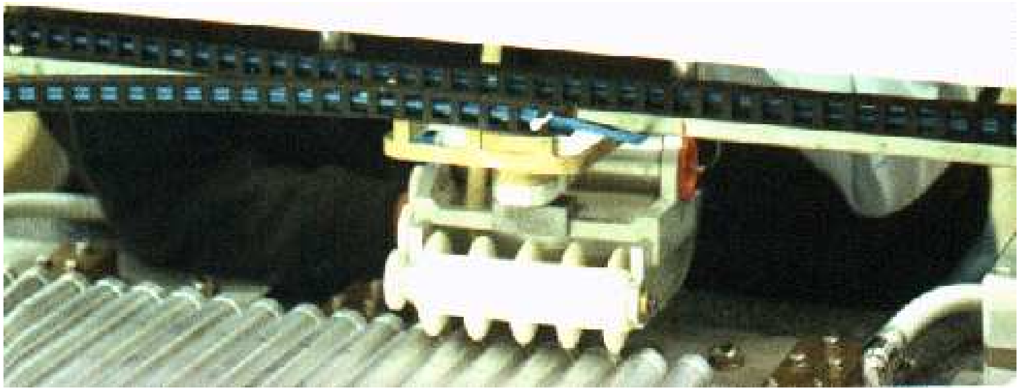

Figure 10: The glue distribution system.

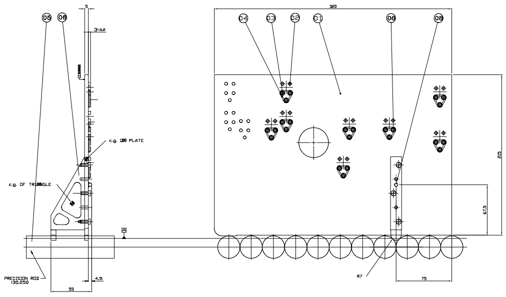

Figure 11: Dowelpin mounting template.

5 Assembly procedure

5.1 Assembly of spacer

The spacer was assembled first, by gluing the long beams to the cross-plates.

This operation was done on the chamber assembly table, holding the cross-plates by the spheres on their supports, and controlling the relative position and orientation of cross-plates by an additional frame.

5.2 Mounting of dowel pins for alignment sensors

The dowel-pins for the alignment sensors were mounted on the cross-plates by means of a jig (see figure 11), which refers the positions of the dowel pins to the combs, and were glued in position. This jig was designed and built by the Nikhef group.

5.3 Assembly of tube layers

Individual tubes were positioned on the jig. When the layer was completed, weight was put on the tubes in correspondence of each line of suckers at a time and the vacuum was turned on for that line and the weight was removed. When all the lines of suckers were activated, the layer was ready for the distribution of the glue.

Before distributing the glue an inspection on the layer was made to check the spacing between adjacent tubes.

The glue was distributed on the layer. A visual inspection of the lines of glues was made.

The spacer was lowered in position on the layer.

The overall operation was smooth and fast (typically it took a couple of hours). The glue was let to cure.

For the successive layers the operation was repeated in the same way, having inserted the appropriate rods below the spacing blocks, to prepare for the following position of the spacer.

Once completed three layers of one multilayer the chamber was turned, and the operation repeated.

Finally the chamber was dismounted from the jigging, with the aid of the same chamber lifting/rotating system.

A drawing of the chamber is shown in figure 12. A picture is shown in figure 13

6 Shifted layer

The method applied can control the position of each layer individually. It allows for flexibility in the design of the chamber, according to special requirements motivated by autocalibration, pattern recognition, or stereo reconstruction needs.

These aspects need further consideration. In particular it has been suggested [7] that if the middle layer is shifted from the centered position with respect to the first and third layer, the drift velocity in the tubes as a function of the drift time can be measured.

Using this method for the autocalibration of the chambers, a space-time relation, free of systematic biases, can be determined.

To test the feasibility of the shift and in order to study experimentally the performance of that method of autocalibration, one of the multilayers of the BML was built with the middle layer shifted by 80 μm.

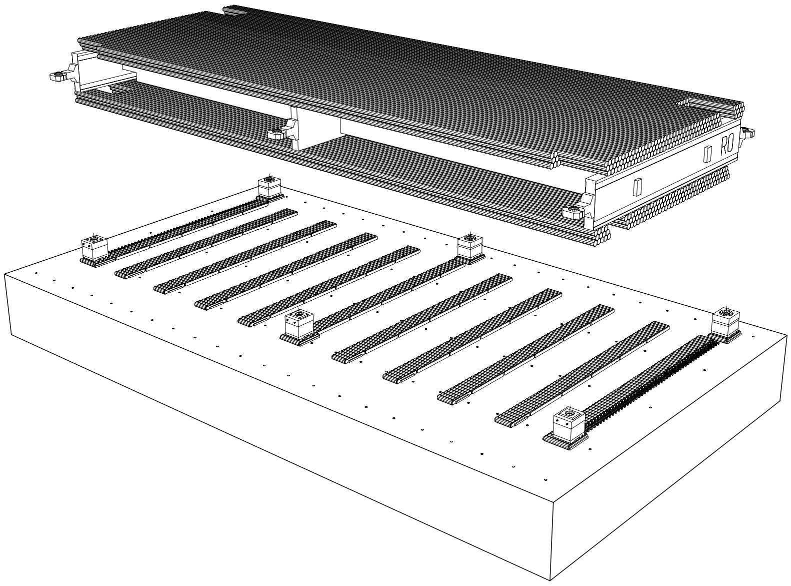

Figure 12: Drawing of BML chamber and jig.

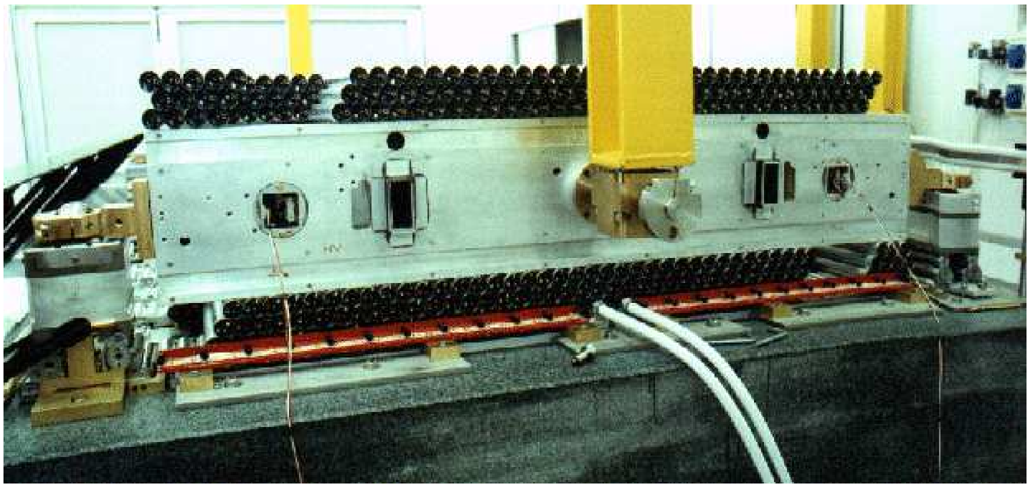

Figure 13: The BML chamber on the granite assembly table.

7 Cut-outs

For the alignment path, cut-outs may be needed in some of the chambers.

The implication of cut-outs for the assembly method described here is the use of additional combs in correspondence of the ends of the cut-out tubes.

This BML, which has to be installed in the DATCHA alignment test stand at CERN, was built with the required cut-outs, visible in figure 13.

8 Mechanical precision

The chamber was sent to CERN, where it has been measured with X-ray tomography .

The preliminary result of one-dimensional scanning show a wire positioning of about 15 μm precision in the centre of the tubes.

This includes the precision on the positioning of the wire in the tubes through wire-locator, and the measurement resolution.

A factor 2 worse result ($\simeq$ 30 μm) is seen at the two ends of the tubes.

It had been seen by X-ray measurements of single tubes, that the 'Italian' wire-locator used at the ends of the tubes had a two-fold assembling ambiguity and this caused a systematic shift of the wire position depending on the way the two parts, constituting the wire-locator, were assembled together.

This effect was discovered when most of the BML tubes were already made.

In the middle of the tubes the 'German' wire-locator was used, and it did not have such an effect.

Therefore the results in the centre of the tubes, achieved in all the layers, give a more reliable information on the mechanical precision achieved in the assembly of the tubes, which is below the specification.

Results for the 2-D analysis of the X-ray measurements will give more complete information on the chamber precision.

9 Conclusions

The assembly jigging and assembly procedure used to build a full size BML has been described here.

The assembly operation went smooth and fast, and the results appear to be very good.

Further analysis of the scheme presented here and further design work, in collaboration with other groups, is going on to finalise the design, based on the experience with the BML construction, which many colleagues have shared directly in Frascati during the construction.

The scheme allows for a detailed quality control of the assembly steps during the assembly to guarantee the quality of the production. Appropriate monitoring systems are being studied and will be implemented when the next prototypes will be built at MPI and Frascati.

Aknowledgements

We would like to thank G.Bisogni, head of the Frascati workshop, and A.De Paolis, G.Ferretti, E.Iacuessa, U.Martini, A.Olivieri, from the staff of the workshop, for the excellent work done in the construction of the jig components.
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Finally, we would like to thank C.Federici and G.Di Giovanni, of the 'Servizio Informazioni Scientifiche' of the Frascati Laboratory, for the realization of an excellent photographic and video documentation of the BML assembly.

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