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Cross-plate sag compensation in the assembly of the MDT chambers

C.Capoccia, S.Cerioni, M.Curatolo, B.Esposito, M.L.Ferrer, G.Maccarrone

Laboratori Nazionali di Frascati dell'I.N.F.N., Frascati, Italy

F.Linde, P.Werneke

Nikhef, Amsterdam, The Netherlands

K.Ackermann, A.Manz

MPI, Munich, Germany

Contents

1 Introduction

The construction of the MDT chambers, with the specification of $20\mu m$ rms on the wire positioning, requires a high level of mechanical precision in the assembly procedure.

During the gluing operation, the relative position of the layers of tubes to be glued with respect to the layers previously glued, can be influenced by undesired sagging of the cross-plates, to which the glued tubes are attached. Such an effect would affect the achievable precision in any assembly scheme.

In this note the issue of cross-plate sag is addressed and the methods to solve the problem are discussed for the barrel chambers and the end-cap chambers.

2 Design features of cross-plates

The spacer, to which the tubes (3 or 4 layers) are glued on the two sides, is represented in fig. 1.

It consists of 3 cross-plates plus two longitudinal beams.

The barrel chambers will be supported in the detector at the ends of the long beams.

The design of the chambers requires the cross-plates to be stiff enough to not affect, with their sag, the tube positioning, while the long beams should sag following the sag of the wires.

To minimise the sag of the cross-plates, the two long beams support the cross-plates in points close to the "Bessel points", and by design, the cross-plates of the barrel chambers have a negligible sag in such a condition.

The case is different for the end-cap chambers, since they are mounted vertically in the apparatus. In this orientation, the layers of tubes themselves are quite stiff, and the requirements on the stiffness of the cross-plates are therefore looser than in the case of the barrel chambers.

3 Sagging of the cross-plates in the assembly

During the assembly, both barrel and end-cap chambers, are in the horizontal plane. In order to glue layers of tubes to the spacer with high precision, the cross-plates have to be precisely positioned with respect to the jig, which determines the position of the layers of tubes to be glued. This is achieved by holding in precise positions the ends of the cross-plates (see for ex. [1,2]). If nothing else is done, this will result in a not optimal support for the cross-plates, which would be supported at the ends. In this configuration, the cross-plates of the barrel chambers would sag more than when mounted in the detector, where

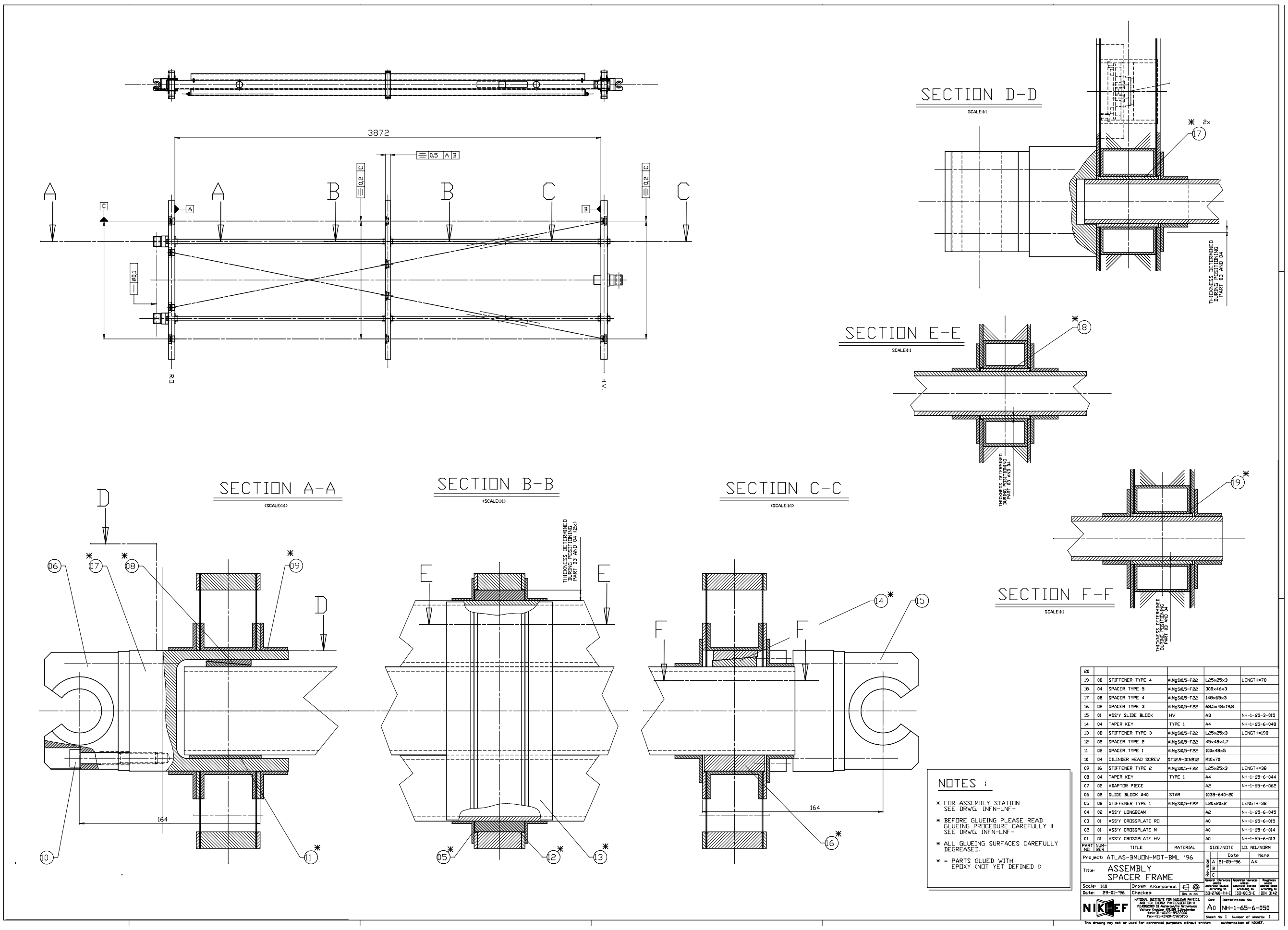

Figure 1: Drawings of the spacer

they are supported in the "Bessel points", by a factor 48, according to the simple beam calculations, reported in the appendix.

As a result, a cross-plate satisfying the sag specification of the design, could however have unacceptable sag during the assembly procedure.

The problem would be solved if we could, also during the assembly, support the chambers in the "Bessel points", gaining back the factor 48, so that cross-plate designed to support correctly the tube in the detector, would also meet the requirement during the assembly.

A scheme to provide a "Bessel support" for the cross-plates during the assembly by supporting them by the long beams, and not interfering with precise positioning of the cross-plates trough their ends, has been designed and will be described in the following. In this way, the problem for the barrel chamber assembly is solved.

The case of the end-cap chambers has to be treated separately. In this case, since by design the stiffness of the cross-plates is not required to be at the same level of the barrel ones, the gain of a factor 48 with respect to the end support might not be sufficient. However if the cross-plates are supported both at the ends and, by the long beams, in two internal points, the position of the two internal additional supports and their fraction of the load can be optimised to minimize the sag.

From simple beam calculations, reported in the appendix, in the case of uniform load, with the optimal support described above, a reduction in the sag of a factor 252 with respect to the case of a simple support at the ends is obtained. Such a large factor will allow to reduce even large sags to acceptable values of a few microns.

In the case of the end-cap chambers, part of the load is not uniform due to the different length of the tubes along the cross-plate. However it is not expected that the order of magnitude of the reduction factor will change. Therefore the same scheme applied to the barrel chambers can be applied to the end-cap chambers and properly optimised for that case.

The optimisation of the support can be done by optimising the position of the long beams, which are not bound by design to be in the "Bessel points", as it is the case of the barrel chambers. In that way, the problem with the end-cap chambers assembly is also solved.

4 Supporting the cross-plates in the assembly of barrel chambers

The scheme proposed is shown schematically in fig. 2.

Two forces are applied on the long beams, supporting the full weight of the cross-plates, plus long beam load, plus tube load. In this configuration the cross-plate shape will be exactly the same as when the chamber is mounted in the apparatus. At the two ends a high

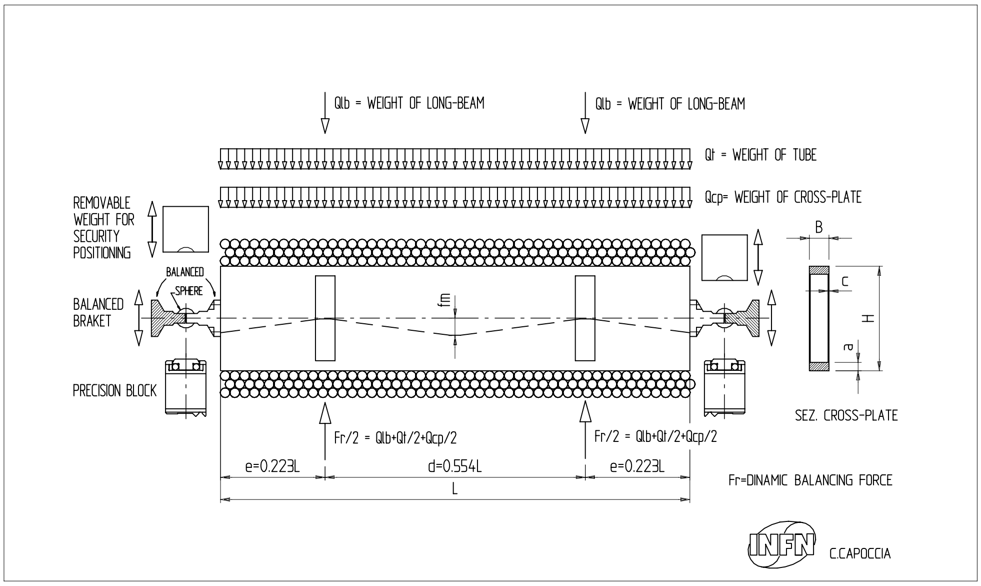

Figure 2: A schematic drawing of the cross-plate supporting scheme

precision sphere is attached to the cross-plate, by means of a symmetric braket. When the sphere is positioned in the precision hole in the jig support block, by which the positioning of the cross-plate is precisely controlled during the assembly, the reaction of the support will cancel any moment due to this braket on the cross-plate and no additional deflection on the cross-plate will be produced. The deflection of the cross-plate will be exactly the one produced by the "Bessel supports". This condition is adequate, by chamber design.

In order to save the precise position control by means of the sphere and their support precision blocks, the two additional forces must be applied in such a way that no constraints are introduced on the position of the cross-plate by the application of those forces.

This is achieved with the setup schematically illustrated in fig. 3.

A bar on one side of the end cross-plates and two bars at the two sides of the middle cross-plate are connected to the long beams and are supported at their ends on pneumatic pistons. The pressure inside the pneumatic pistons determines the forces, which trough the bars are transmitted to the long beams and trough the long beams to the cross-plates. The positions of the pistons and of the bars will adjust accordingly to the position of the cross-plate determined by the spheres. The deflection of the bar is irrelevant.

A more detailed design is shown in fig. 4 and 5.

5 Calculation of sags for barrel chambers

The sags resulting for the barrel chambers, when the method described above is applied during the assembly, are reported in table 6 and 7.

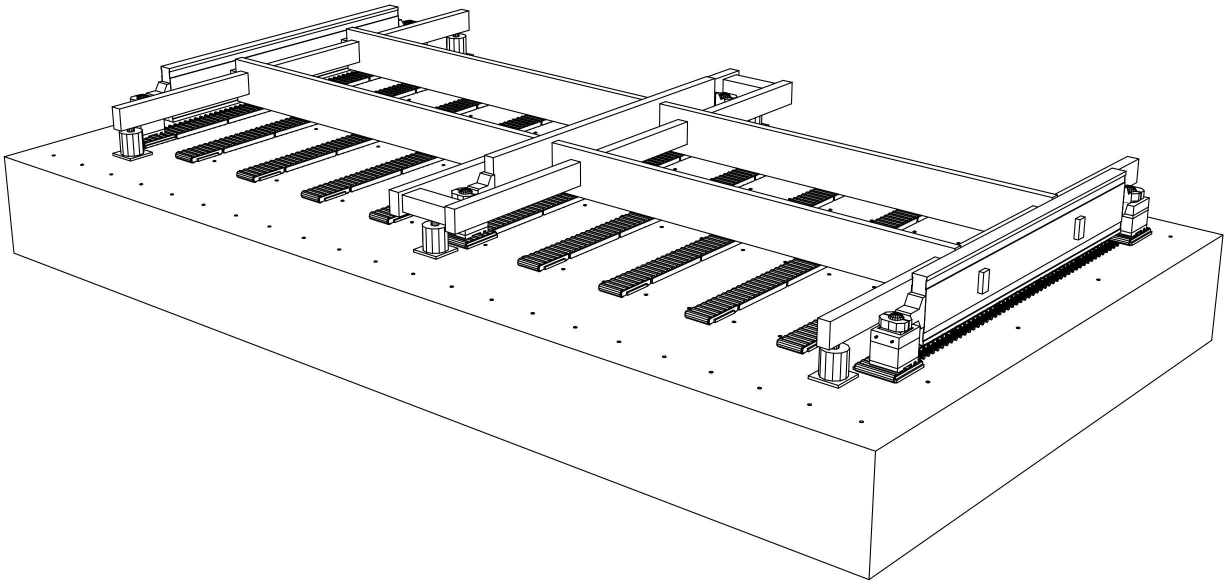

Figure 3: Schematic illustration of the setup with the additional forces applied

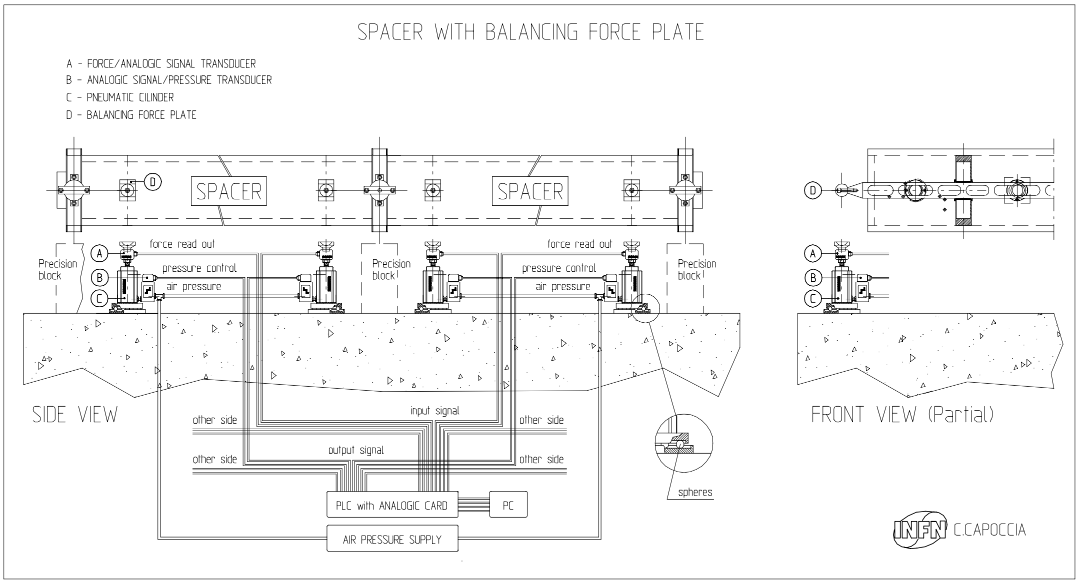

Figure 4: Illustration of the pneumatic supporting system for the cross-plates

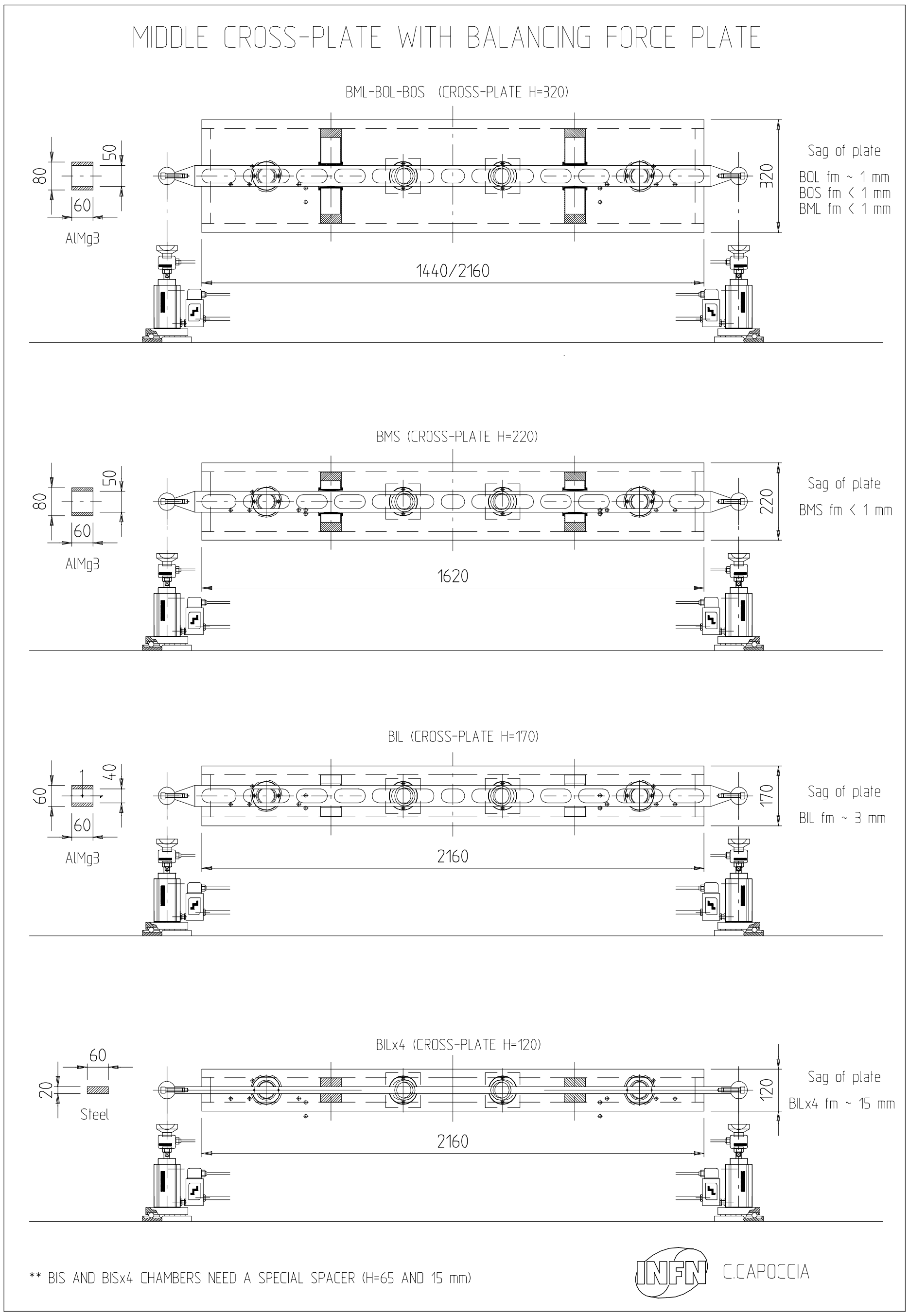

Figure 5: Middle cross-plate sags for variour barrel chambers, with the additional forces applied

The cross-plate design, which has been under consideration for those chambers, has been assumed.

The value of the sag obtained is so small that one can consider a simplification of the spacer. In table 8 and 9 the same calculations are reported for simplified cross-plates, to illustrate the point.

A final design of the spacers for the various chambers has to be made.

6 Supporting the cross-plates in the assembly of end-cap chambers

The scheme, illustrated for the barrel chambers, can be applied to the end-cap chambers too, with the provision of optimising the position of the long beams, and optimising the partition of the load.

To work out a detailed scheme, one has to take into account also the non uniform load on the cross-plate due to the trapezoidal shape of the chambers.

7 Calculation of sags for end-cap chambers

Calculations for the end-cap chambers have been performed by C. Daly.

Those calculations have been performed under the assumption of a support at the end of the cross-plate. The sag values obtained are quite high, up to 620μm.

The method of supporting the long beams during the assembly, discussed above, produces a reduction of the sag with respect to those values by a factor of the order of 250. Therefore it is expected that with this method the sag can be reduced to a few microns, so that it is below the limit at which we should worry for the precision of the assembly.

Aknowledgements

We would like to thank M.A.Franceschi and S.Moccia for the very useful discussions on the engineering aspects of the assembly and for suggestions and comments on the calculations performed.

MIDDLE CROSS-PLATE
WITH BALANCING FORCES IN THE BESSEL POINTS

			BIL	BIL/4	BML	BML/L	BOL	BOL/S
WIDHT OF PLATE	B	mm	60	60	60	60	60	60
DEPTH OF PLATE	H	mm	170	120	320	320	320	320
THIKNESS OF SIDE FRAME	c	mm	1	1	1	1	1	1
THIKNESS OF EXT. FRAME	a	mm	25	25	25	25	25	25
LENGHT OF PLATE	L	mm	2160	2160	1440	1680	2160	1680
LONG-BEAM POINTS DIST.	d	mm	1196,64	1196,64	797,76	930,72	1196,64	930,72
LONG-BEAM POINTS DIST.	e	mm	481,68	481,68	321,12	374,64	481,68	374,64
Wf MODUL	Wf	mm3	190741	116369	429409	429409	429409	429409
I MODUL	I	mm4	16213000	6982167	68705500	68705500	68705500	68705500
E MODUL	E	N/mm2	70000	70000	70000	70000	70000	70000
SQUARE MEASURE	S	mm2	3240	3140	3540	3540	3540	3540
VOLUME	V	mm3	6998400	6782400	5097600	5947200	7646400	5947200
WEIGHT OF CROSS-PLATE	Qcp	daN	18,9	18,3	13,8	16,1	20,6	16,1
WEIGHT OF LONG-BEAM	P3	daN	22,0	22,0	35,0	35,0	46,0	46,0
WEIGHT OF 5/8 LONG-BEAM	Qlb	daN	13,8	13,8	21,9	21,9	28,8	28,8
LENGHT OF TUBE	L2	mm	2700	2700	3580	3580	4990	4990
TUBE BY LAYER	n	pz	72	72	48	56	72	56
WEIGHT BY TUBE LAYER	P2	daN	23	23	20	23	40	31
WEIGHT OF 5/8 LAYER	Qt	daN	14,4	14,4	12,2	14,3	24,7	19,2
SAG OF CROSS-PLATE								
ONLY WEIGHT OF PLATE	fm	um	0,44	1,00	0,02	0,04	0,11	0,04
WITH 1 LAYER	fm	um	0,78	1,79	0,04	0,08	0,25	0,09
WITH 2 LAYER	fm	um	1,12	2,58	0,06	0,12	0,39	0,14
WITH 3 LAYER	fm	um	1,46	3,36	0,08	0,15	0,53	0,19
WITH 4 LAYER	fm	um	1,80	4,15	0,10	0,19	0,66	0,24
WITH 5 LAYER	fm	um	2,14	4,94	0,12	0,23	0,80	0,29
WITH 6 LAYER	fm	um	2,48	5,72	0,14	0,27	0,94	0,34
WITH 7 LAYER	fm	um		6,51				
WITH 8 LAYER	fm	um		7,30				
DINAMIC BALANCING								
Fr/2 FOR CROSS-PLATE	Fr/2	daN	9,4	9,2	6,9	8,0	10,3	8,0
Fr/2 FOR LONG-BEAM	Fr/2	daN	13,8	13,8	21,9	21,9	28,8	28,8
Fr/2 BY LAYER OF TUBES	Fr/2	daN	7,2	7,2	6,1	7,1	12,4	9,6

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Figure 6: Summary of results of calculations for various chambers

MIDDLE CROSS-PLATE
WITH BALANCING FORCES IN THE BESSEL POINTS

			BIS	BIS/4	BMS	BMS/N	BOS	BOS/N
WIDHT OF PLATE	B	mm	60	60	60	60	60	60
DEPTH OF PLATE	H	mm	65	15	220	220	320	320
THIKNESS OF SIDE FRAME	c	mm	1	1	1	1	1	1
THIKNESS OF EXT. FRAME	a	mm	25	7,5	25	25	25	25
LENGHT OF PLATE	L	mm	960	960	1620	1440	2160	1800
LONG-BEAM POINTS DIST.	d	mm	531,84	531,84	897,48	797,76	1196,64	997,20
LONG-BEAM POINTS DIST.	e	mm	214,08	214,08	361,26	321,12	481,68	401,4
Wf MODUL	Wf	mm3	41748	2250	268126	268126	429409	429409
I MODUL	I	mm4	1356813	16875	29493833	29493833	68705500	68705500
E MODUL	E	N/mm2	70000	70000	70000	70000	70000	70000
SQUARE MEASURE	S	mm2	3030	900	3340	3340	3540	3540
VOLUME	V	mm3	2908800	864000	5410800	4809600	7646400	6372000
WEIGHT OF CROSS-PLATE	Qcp	daN	7,9	2,3	14,6	13,0	20,6	17,2
WEIGHT OF LONG-BEAM	P3	daN	22,0	22,0	26,9	26,9	35,0	35,0
WEIGHT OF 5/8 LONG-BEAM	Qlb	daN	13,8	13,8	16,8	16,8	21,9	21,9
LENGHT OF TUBE	L2	mm	1600	1600	3100	3100	3800	3800
TUBES BY LAYER	n	pz	32	32	54	48	72	60
WEIGHT BY TUBE LAYER	P2	daN	7	7	19	17	31	26
WEIGHT OF 5/8 LAYER	Qt	daN	4,2	4,2	12,2	10,8	19,4	16,1
SAG OF CROSS-PLATE								
ONLY WEIGHT OF PLATE	fm	um	0,19	4,63	0,08	0,05	0,11	0,06
WITH 1 LAYER	fm	um	0,30	12,97	0,15	0,09	0,22	0,11
WITH 2 LAYER	fm	um	0,40	21,31	0,21	0,13	0,33	0,16
WITH 3 LAYER	fm	um	0,51	29,66	0,28	0,17	0,44	0,21
WITH 4 LAYER	fm	um	0,61	38,00	0,35	0,22	0,54	0,26
WITH 5 LAYER	fm	um	0,71	46,34	0,41	0,26	0,65	0,31
WITH 6 LAYER	fm	um	0,82	54,68	0,48	0,30	0,76	0,37
WITH 7 LAYER	fm	um		63,02				
WITH 8 LAYER	fm	um		71,36				
DINAMIC BALANCING								
Fr/2 FOR CROSS-PLATE	Fr/2	daN	3,9	1,2	7,3	6,5	10,3	8,6
Fr/2 FOR LONG-BEAM	Fr/2	daN	13,8	13,8	16,8	16,8	21,9	21,9
Fr/2 BY LAYER OF TUBES	Fr/2	daN	2,1	2,1	6,1	5,4	9,7	8,1

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Figure 7: Summary of results of calculations for various chambers

MIDDLE CROSS-PLATE -LIGHTER-

WITH BALANCING FORCES IN THE BESSEL POINTS

			BIL	BIL/4	BML	BML/L	BOL	BOL/S
WIDHT OF PLATE	B	mm	60	60	60	60	60	60
DEPTH OF PLATE	H	mm	170	120	320	320	320	320
THIKNESS OF SIDE FRAME	c	mm	1	1	1	1	1	1
THIKNESS OF EXT. FRAME	a	mm	10	25	1	1	3	1
LENGHT OF PLATE	L	mm	2160	2160	1440	1680	2160	1680
LONG-BEAM POINTS DIST.	d	mm	1196,64	1196,64	797,76	930,72	1196,64	930,72
LONG-BEAM POINTS DIST.	e	mm	481,68	481,68	321,12	374,64	481,68	374,64
Wf MODUL	Wf	mm3	97088	116369	52578	52578	88776	52578
I MODUL	I	mm4	8252500	6982167	8412412	8412412	14204137	8412412
E MODUL	E	N/mm2	70000	70000	70000	70000	70000	70000
SQUARE MEASURE	S	mm2	1500	3140	756	756	988	756
VOLUME	V	mm3	3240000	6782400	1088640	1270080	2134080	1270080
WEIGHT OF CROSS-PLATE	Qcp	daN	8,7	18,3	2,9	3,4	5,8	3,4
WEIGHT OF LONG-BEAM	P3	daN	22,0	22,0	35,0	35,0	46,0	46,0
WEIGHT OF 5/8 LONG-BEAM	Qlb	daN	13,8	13,8	21,9	21,9	28,8	28,8
LENGHT OF TUBE	L2	mm	2700	2700	3580	3580	4990	4990
TUBE BY LAYER	n	pz	72	72	48	56	72	56
WEIGHT BY TUBE LAYER	P2	daN	23	23	20	23	40	31
WEIGHT OF 5/8 LAYER	Qt	daN	14,4	14,4	12,2	14,3	24,7	19,2
SAG OF CROSS-PLATE								
ONLY WEIGHT OF PLATE	fm	um	0,40	1,00	0,04	0,07	0,15	0,07
WITH 1 LAYER	fm	um	1,07	1,79	0,20	0,38	0,82	0,48
WITH 2 LAYER	fm	um	1,74	2,58	0,37	0,68	1,48	0,89
WITH 3 LAYER	fm	um	2,40	3,36	0,53	0,99	2,15	1,30
WITH 4 LAYER	fm	um	3,07	4,15	0,70	1,29	2,81	1,71
WITH 5 LAYER	fm	um	3,74	4,94	0,86	1,60	3,47	2,12
WITH 6 LAYER	fm	um	4,40	5,72	1,03	1,90	4,14	2,53
WITH 7 LAYER	fm	um		6,51				
WITH 8 LAYER	fm	um		7,30				
DINAMIC BALANCING								
Fr/2 FOR CROSS-PLATE	Fr/2	daN	4,4	9,2	1,5	1,7	2,9	1,7
Fr/2 FOR LONG-BEAM	Fr/2	daN	13,8	13,8	21,9	21,9	28,8	28,8
Fr/2 BY LAYER OF TUBES	Fr/2	daN	7,2	7,2	6,1	7,1	12,4	9,6

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Figure 8: Summary of results of calculations for various chambers

MIDDLE CROSS-PLATE -LIGHTER-
WITH BALANCING FORCES IN THE BESSEL POINTS

			BIS	BIS/4	BMS	BMS/N	BOS	BOS/N
WIDHT OF PLATE	B	mm	60	60	60	60	60	60
DEPTH OF PLATE	H	mm	65	15	220	220	320	320
THIKNESS OF SIDE FRAME	c	mm	1	1	1	1	1	1
THIKNESS OF EXT. FRAME	a	mm	2	7,5	1	1	2	1
LENGHT OF PLATE	L	mm	960	960	1620	1440	2160	1800
LONG-BEAM POINTS DIST.	d	mm	531,84	531,84	897,48	797,76	1196,64	997,20
LONG-BEAM POINTS DIST.	e	mm	214,08	214,08	361,26	321,12	481,68	401,4
Wf MODUL	Wf	mm3	8494	2250	28778	28778	70791	52578
I MODUL	I	mm4	276050	16875	3165545	3165545	11326603	8412412
E MODUL	E	N/mm2	70000	70000	70000	70000	70000	70000
SQUARE MEASURE	S	mm2	362	900	556	556	872	756
VOLUME	V	mm3	347520	864000	900720	800640	1883520	1360800
WEIGHT OF CROSS-PLATE	Qcp	daN	0,9	2,3	2,4	2,2	5,1	3,7
WEIGHT OF LONG-BEAM	P3	daN	22,0	22,0	26,9	26,9	35,0	35,0
WEIGHT OF 5/8 LONG-BEAM	Qlb	daN	13,8	13,8	16,8	16,8	21,9	21,9
LENGHT OF TUBE	L2	mm	1600	1600	3100	3100	3800	3800
TUBES BY LAYER	n	pz	32	32	54	48	72	60
WEIGHT BY TUBE LAYER	P2	daN	7	7	19	17	31	26
WEIGHT OF 5/8 LAYER	Qt	daN	4,2	4,2	12,2	10,8	19,4	16,1
SAG OF CROSS-PLATE								
ONLY WEIGHT OF PLATE	fm	um	0,11	4,63	0,12	0,08	0,17	0,10
WITH 1 LAYER	fm	um	0,62	12,97	0,74	0,46	0,82	0,52
WITH 2 LAYER	fm	um	1,13	21,31	1,36	0,85	1,48	0,94
WITH 3 LAYER	fm	um	1,64	29,66	1,98	1,23	2,13	1,37
WITH 4 LAYER	fm	um	2,15	38,00	2,60	1,62	2,78	1,79
WITH 5 LAYER	fm	um	2,66	46,34	3,21	2,01	3,43	2,21
WITH 6 LAYER	fm	um	3,17	54,68	3,83	2,39	4,08	2,64
WITH 7 LAYER	fm	um		63,02				
WITH 8 LAYER	fm	um		71,36				
DINAMIC BALANCING								
Fr/2 FOR CROSS-PLATE	Fr/2	daN	0,5	1,2	1,2	1,1	2,5	1,8
Fr/2 FOR LONG-BEAM	Fr/2	daN	13,8	13,8	16,8	16,8	21,9	21,9
Fr/2 BY LAYER OF TUBES	Fr/2	daN	2,1	2,1	6,1	5,4	9,7	8,1

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Figure 9: Summary of results of calculations for various chambers

Appendix - Beam calculations

Let's consider a beam, as shown in fig. 10.

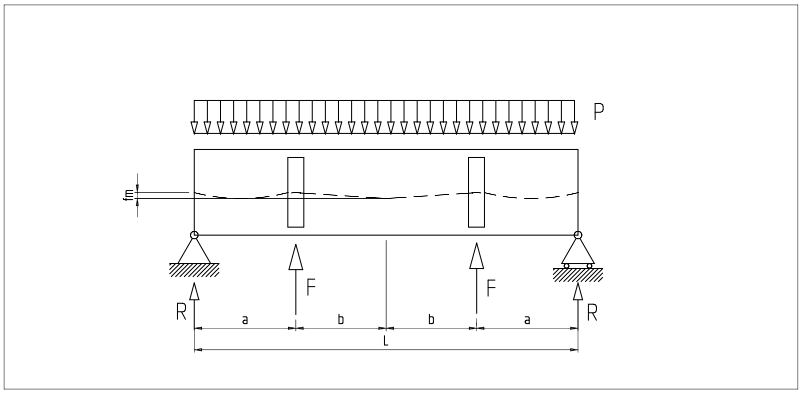

Figure 10: The scheme and the symbols used in the beam calculations

The equation for the profile of the beam $\nu(z)$ is:

$$EJ\nu'' = \frac{pz^2}{2} - Rz - F(z-a) \tag{1}$$

After integration we get

$$EJ\nu' = \frac{pz^3}{6} - \frac{Rz^2}{2} - \frac{F(z-a)^2}{2} + C_1 \tag{2}$$

$$EJ\nu = \frac{pz^4}{24} - \frac{Rz^3}{6} - \frac{F(z-a)^3}{6} + C_1 z + C_2 \tag{3}$$

were the term $\frac{F(z-a)^3}{6}$ has been considered only for $z > a$.

The symbols are explained in fig. 10

and

E modulus of elasticity
J momentum of inertia
C_1 and C_2 constant of integration.

C_1 and C_2 can be determined by imposing

- symmetry $\Rightarrow \nu' = 0$ (at the center)

- support $\Rightarrow \nu(0) = 0$

This gives

$$C_1 = -\{\frac{p(a+b)^3}{6} - \frac{R(a+b)^2}{2} - \frac{Fb^2}{2}\} \tag{4}$$

$$C_2 = 0 \tag{5}$$

We can introduce an adimensional coordinate

$$\xi = \frac{z}{\frac{L}{2}} \tag{6}$$

and adimensional parameters

$$x = \frac{a}{\frac{L}{2}} \tag{7}$$

$$y = \frac{F}{p\frac{L}{2}} \tag{8}$$

Substituting in (3), the beam profile is given by

$$\nu(\xi) = \frac{5pL^4}{384}\{\frac{1}{5}[\xi^4 - 4(1-y)\xi^3 + 8\xi + 12y(-2x + x^2)\xi] - \frac{4}{5}y(\xi - x)^3\} \tag{9}$$

where $0 < \xi < 1$, corresponding to the half lenght of the beam, and the term $\frac{4}{5}(\xi - x)^3$ has to be considered only for $\xi > x$.

The multiplying factor is the maximum sag for a beam only supported at the ends (i.e. for $x = 0$ and ν calculated at $\xi = 1$).

Therefore the function

$$f(\xi)) = \frac{1}{5}[\xi^4 - 4(1-y)\xi^3 + 8\xi + 12(-2x + x^2)\xi] - \frac{4}{5}y(\xi - x)^3 \tag{10}$$

represents the profile of the beam in units of the maximum sag when the beam is supported at the two ends and describe a beam of any lenght, subject to any uniform load, of any elasticity module, and any constant momentum of inertia.

$f(\xi)$ gives also the dependence of the deformation on the parameters x and y, describing where the force is applied and what fraction of the load it balances.

Notice that formally we are always considering the beam supported anyway at the end. But, if $y = 1$, the full load is taken by the force in x and there is no load on the supports at the ends.

Therefore everything is as if there was no support at the end, apart from the fact that the origin of the deformation axis is anyway put in $\xi = 0$, in the determination of the second constant of integration.

From (10) two cases can be studied:

1. $y = 1$ This corresponds to the case when only two supporting forces are applied to the beam in the points specified by x. In this case, by minimizing the difference between the maximum deformation $f_{max} - f_{min}$, th optimal value of x is found, which minimize the sag. This value is $x = 0.4463$. It corresponds to the *Bessel* point support. In such a condition the maximum deformation is $\frac{1}{48}\times$ (sag for *end-support* only).

2. $y < 1$ This corresponds to the case when 4 forces are applied to the beam at the two ends and in two internal points, specified by the parameter x. By minimizing the maximum deformation one can estimate the optimal values for x and y. They are $x = 0.62226$ and $y = 0.7658$. In such a condition the maximum deformation is $\frac{1}{252}\times$ (sag for *end-support* only).

The profile of the beam for the cases considered above is shown in fig. 11 and fig. 12. In those figures the full lenght of the beam is represented with an adimensional coordinate going from 0 to 1 (abscissa axis).

A summary of the result of this analysis is reported in fig. 13.

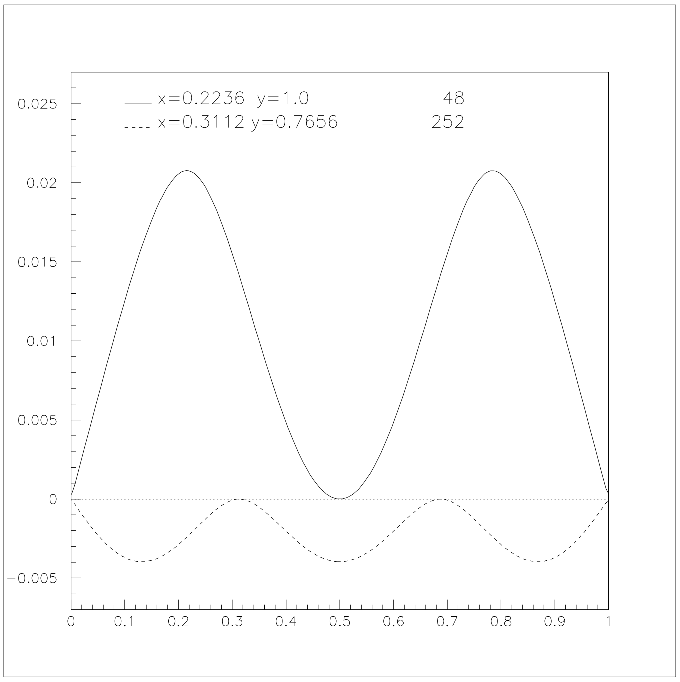

Figure 11: The profile of the beam supported at the Bessel points (full line) and at four points, two internal plus the two ends (dashed line)

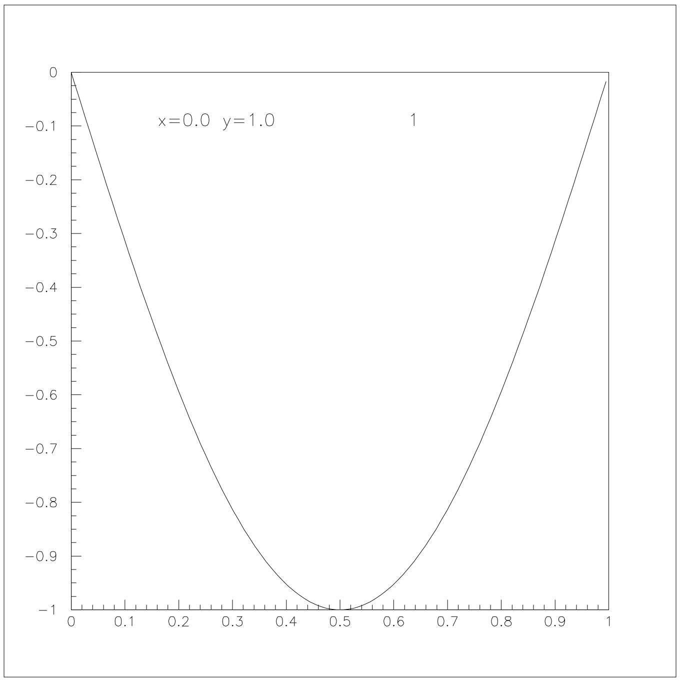

Figure 12: The profile of the beam supported at the two ends only

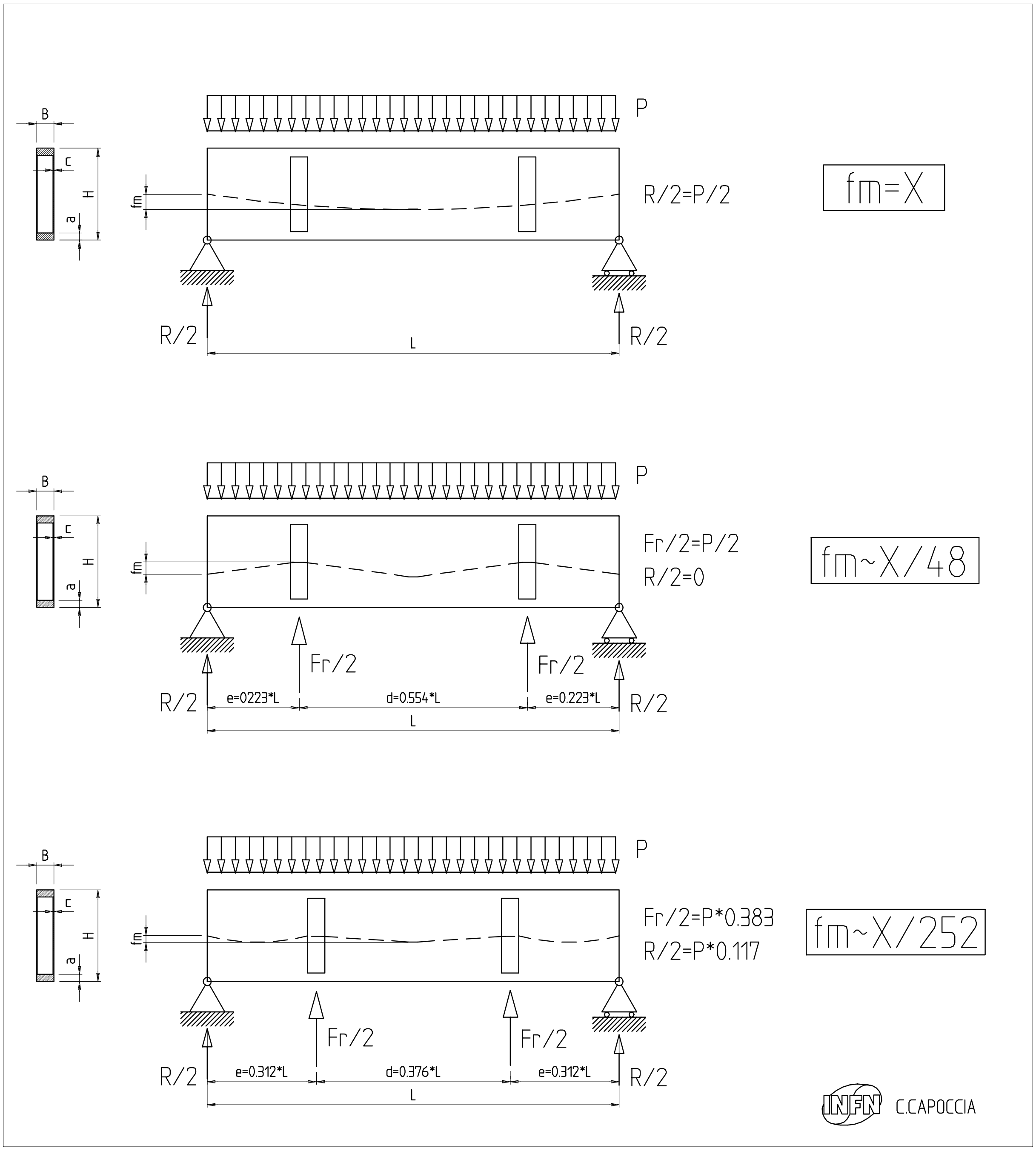

Figure 13: The profile of the beam when supported in the ends only, in the Bessel points and in four points (two internal plus the two ends)

References

[1] H.Bilokon et al.,
MDT chamber assembly procedure and construction of a full scale BML,
ATLAS-MUON Note N.152

[2] A.Biscossa et al.,
The First Full-Scale Prototype of a BIL MDT Chamber for the ATLAS Muon Spectrometer, ATLAS-MUON Note N.136