LHC Project Note 167

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Beam Position Monitor Alignment

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Summary

This document reviews 3 methods of aligning the BPM and the drift tube for the Short Straight Section of the LHC. It is intended solely as a reference and the final results/conclusions will figure in the following specification: LHC-ES-BPMST0001.

This is also a duplicate of an internal SL note: SL-Note-98-048 BI

1. Introduction

The latest requirement in the matter of BPM alignment precision is 0.5 mm rms for the button electrodes (PLC 34th meeting). Up until now, 1 mm has been considered just about acceptable for the drift tube excursion at the interconnection Rep. F. This last parameter determines the machine aperture.

Three methods have been investigated to determine the quality - cost ratio for the BPM and drift tube alignment.

i) method in relation with external references,
ii) method in relation with the warm magnetic axis
iii) method in relation with the cold magnetic axis. This last one requires a significant change in the present design.

The rms values have been calculated with a rectangular statistic distribution much more realistic then a delta function. Cf. B. Jeanneret.

$$Tol = t \qquad \sigma^2 = \int_0^t x^2 * dx / \int_0^t dx = t^2/3 \qquad \text{standard deviation } (rms) = tol/\sqrt{3}$$

Please see the drawing LHC-BPM-0002.0 and also the annexed figures 3 and 4.

i) Method with external references

The tolerance between the magnetic axis and the external references located on the inertia tube are 0.18 mm in both x and z axes. Cf. P. Vedrine CEA.
The inertial tube references are the pins inserted into the holes of the cold mass. The angular tolerance of the holes gives an additional error of 0.05mm leading to a tilt of 0.05/245 = 0.2 mrad. The translation due to this tilt at the optical level could be 0.1 mm. This tolerance could be reduced or cancelled.
The magnetic axis is not yet known but we assume it is inside this tolerance. The errors of the alignment device in the x, z axes are not included in this tolerance (± 0.05 mm).

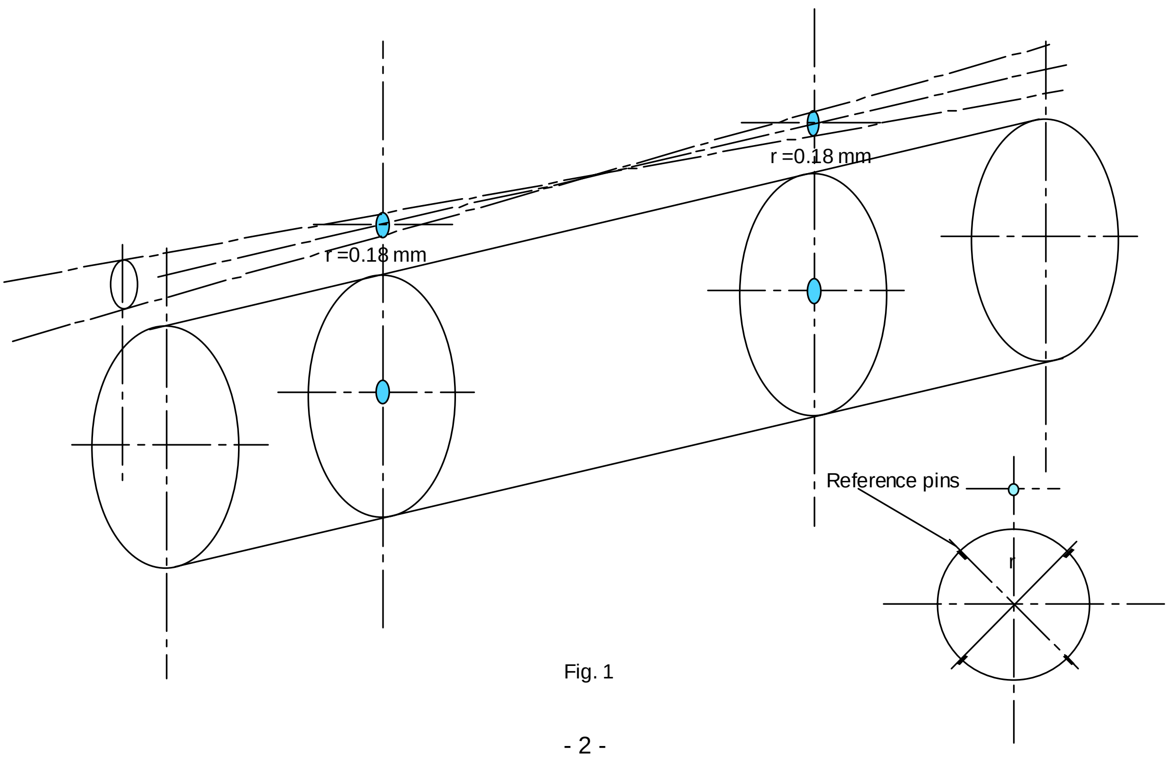


Fig. 1

TABLE 1a. (REFERRED TO D)

The alignment method consists of shimming the BPM support so that the y axis comes parallel to the optical axis. Then the support is aligned in relation to the optical axis with two spheres T&O. It is not necessarily orthogonal to the cold flange. So the effects of the inertia tube sagitta, the cold flange errors as well as the mechanical tolerances, tilts and concentricity of support with relation to the reference D will be cancelled too. A residual tilt due to the shim definition will remain.

* The optical line tilt gives:
2* 0.18 /2570 (distance between gauge references) = 0.14 mrad
Translation of Rep.D on the BPM support due to this tilt: 0.14 mrad * 2765 = 0.39 mm

Tolerances from MQ mechanical centre to Rep. D after alignment of the BPM support (dimensions in millimetres)				1a
	Individ. Tol. X	$Sigma^2$ axis X	Individ. Tol. Z	$Sigma^2$ axis Z
Translation of the BPM due to the tilt *	0.39	0.050	0.42	0.059
Alignment gauge accuracy	0.05	0.001	0.05	0.001
Alignment error of the BPM support on Rep. D (Survey)	0.10	0.003	0.10	0.003
• Tol. Max and σ on Rep. D	**0.54**	**0.23** ^{2}	**0.54**	**0.23** ^{2}

TABLE 2a (REFERRED TO THE BUTTON AXIS E)

Cold mass

The cold mass sagitta z=0.063 gives a tilt 0.02 mrad. This tilt has no effect on the BPM alignment if we shim the support.

Support

The auto collimation method has an angular definition of ± 0.01mrad but the support tilt will be only determined by the shim tolerances (± 0.02).
This difference gives a vertical tilt of 0.133 mrad and a horizontal tilt of 0.19 mrad.

BPM Buttons Rep. E

- At Rep. E, the lever arm is 120 mm.
  The vertical error will be: 0.133 mrad * 120 = 0.016 mm and
  the horizontal error will be 0.19 mrad * 120 = 0.023 mm.

- From Rep.D, an additional tilt of 0.2 mrad is due to the weld of the BPM.
  The translation error will be 0.02 mm on Rep. E (buttons)

- The translation error due to the optical axis tilt will give :
  0.14 mrad*120 = 0.017 mm.

Tolerances from MQ mechanical centre to button axis, Rep. E (dimensions in millimetres)				2a
	Individ. Tol. X	Sigma² axis X	Individ. Tol. Z	Sigma² axis Z
• of tol. on Rep. D [report from table 1a]	0.54	0.054	0.54	0.054
Tol. perpendicularity due to the shims	0.023	0.001	0.016	0.000
Tol. on H7g6	0.06	0.001	0.06	0.001
Tol. 3 symmetry of buttons	0.02	0.000	0.02	0.000
Tol. Due to optical axis tilt	0.017	0.000	0.017	0.000
Tol. due to the weld of BPM	0.02	0.000	0.02	0.000
• Tol. Max on Rep. E	**0.68**	**0.24²**	**0.67**	**0.23²**

It must be noted that the tolerance of 500 microns rms for the BPM position is the quadratic sum of the following errors:

- the sum of mechanical tolerances (see tables)
- the SSS alignment error in the tunnel (± 0.2 mm)
- the electronic error (± 0.1 mm)

TABLE 3a (REFERED TO THE DRIFT CHAMBER EXTREMITY, REP F)

The offset at this point is critical for the machine aperture. The tilt of the optical axis, the tolerances of the BPM and the deformation caused by the weld have repercussions at this point.

- Supposing that the BPM is perfectly aligned on the optical axis, it will have a 0.14 mrad tilt, adding a translation error of 0.14 * 560 = 0.08 mm
- The remarks about shim tolerances in the table 2 are also valid for the Rep. F
  now the lever arm is 560 mm.
  The vertical error will be .133 mrad * 560 = 0.08 mm and
  The horizontal error will be 0.19 mrad * 560 = 0.11 mm
- Tolerance on Rep. F due to the weld of BPM subassembly on the support : 0.1 mm

Tolerances from MQ mechanical centre to Rep. F at the extremity of the Drift Tube (dimensions in millimetres)				3a
	Individ. Tol. X	Sigma² axis X	Individ. Tol. Z	Sigma² axis Z
• of tol. on Rep. D [report from table 1a]	0.54	0.054	0.54	0.054
Tol. on H7/g6	0.06	0.002	0.06	0.002
Tol. due to the optical axis 0.14 mrad	0.08	0.002	0.08	0.002
Tol. tilt due to the shim tolerances	0.11	0.004	0.08	0.002
Tol. on drift tube flange due to the weld of BPM on the support	0.1	0.003	0.1	0.003
Tol. 2 Concentricity between D and F	0.2	0.013	0.2	0.013
• Tol. Max on Rep. F	**1.09**	**0.26²**	**1.06**	**0.26 ²**

ii) Method with alignment on the warm magnetic axis

It has been shown above that the optical axis tilt is the major source of error. Another method has been considered in order to reduce the number of added tolerances. Indeed it is not possible to tighten the tolerances anymore.

TABLE 1b. (REFERRED TO D)

DESCRIPTION OF THE MOUNTING SEQUENCE.

1- We assume that the measurement of the magnetic axis at 290K determines the coordinates x1, z1 of the H7 BPM support with a global precision of ±0.1 mm (survey + magnetic measure).
2- The perpendicularity and position of the reference face and diameter H7 (Rep. D) are adjusted in x, z axes by auto collimation.

Tolerances from MQ warm magnetic axis to Rep. D after alignment of the BPM support (dimensions in millimetres)				1b
	Individ. Tol. X	Sigma^2 axis X	Individ. Tol. Z	Sigma^2 axis Z
Magnetic warm axis measurement error (to be confirmed by J. Billan)	0.10	0.003	0.10	0.003
Alignment error of the BPM support on diameter H7 Rep. D (Survey)	0.10	0.003	0.10	0.003
• Tol. Max on Rep. D	**0.2**	**0.08** ^{2}	**0.20**	**0.08** ^{2}

TABLE 2b (REFERRED TO THE BUTTON AXIS E)

- The auto collimation method has an angular definition is ± 0.01mrad but there also, the support tilt will be determined by the shim tolerances (±0.02 mm).

  Tilts in z = 0.133 mrad and x= 0.19 mrad. Cf. remarks in table 2
- Additional tilt due to the weld of the BPM =0.02 mm

Tolerances from MQ warm magnetic axis to the position of the button Rep. E (dimensions in millimetres)				2b
	Individ. Tol. X	Sigma^2 axis X	Individ. Tol. Z	Sigma^2 axis Z
• of tol on Rep. D [report from table 1b] Tol. on H7/g6	0.2 0.06	0.006 0.001	0.20 0.06	0.006 0.001
Tol. perpendicularity due to the shims	0.023	0.000	0.016	0.000
Tol. symmetry of buttons	0.02	0.000	0.02	0.000
Tol. on drift tube flange due to the weld of BPM on the support	0.02	0.000	0.02	0.000
• Tol. Max on Rep. E	**0.32**	**0.08** ^{2}	**0.32**	**0.08** ^{2}

TABLE 3b (REFERED TO THE DRIFT CHAMBER EXTREMITY, REP F)

The vertical aperture will never be limited by the drift tube since the beam screen is only 36 mm.
The error due to the tilt of the support gives: 0.133 mrad * 560 = 0.075 mm vertical and 0.19 mrad * 560 = 0.11 mm horizontal.

Tolerances from MQ warm magnetic axis to Rep. F at the extremity of the Drift Tube (dimensions in millimetres)				3b
	Individ. Tol. X	Sigma^2 axis X	Individ. Tol. Z	Sigma^2 axis Z
• of tol. on Rep. D [report from table 1b]	0.20	0.006	0.20	0.006
Tol. on Rep. D, H7/g6	0.06	0.001	0.06	0.001
Tol. perpendicularity due to the shims	0.11	0.004	0.075	0.002
Tol. due to the weld of BPM on the support	0.10	0.003	0.10	0.003
Tol.2 Concentricity between D and F	0.20	0.013	0.20	0.013
• Tol. Max on Rep. F	**0.67**	**0.16** ^{2}	**0.64**	**0.16** ^{2}

After the cryostating, the alignment device used to fix the BPM support is re-installed. The x, z coordinates of the H7 support Rep. D can be found again as well as the angle by auto collimation. So it could be possible to check the position of the drift tube after the tack welding of the BPM with a simple device installed on Rep. F.

iii) Method with alignment on the cold magnetic axis

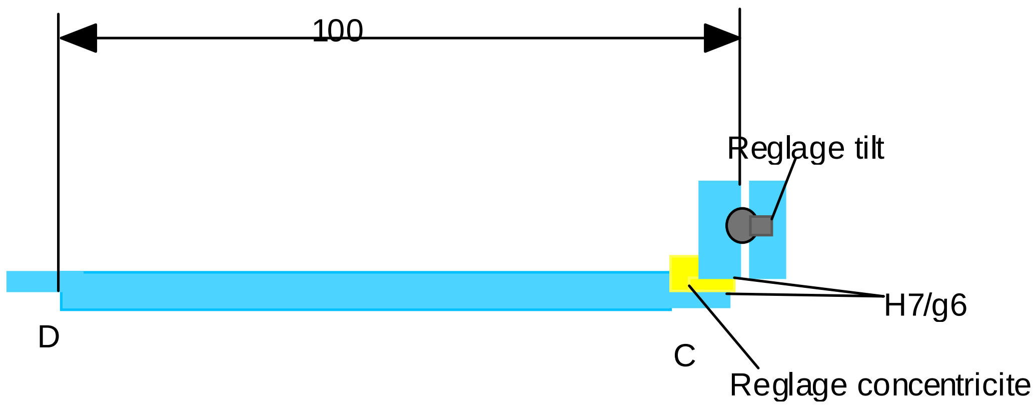


Fig.2

Support tilt effect on Rep. D due to the tolerance of the support posts
0.02*100/120 =0.02 mm

Tolerances from MQ cold magnetic axis to Rep. D after alignment of the BPM support. (dimensions in millimetres)				1c
	Individ. Tol. X	$Sigma^2$ axis X	Individ. Tol. Z	$Sigma^2$ axis Z
Offset axis precision between 1.9 K and 290 K. (to be confirmed by P. Sievers).	0.20	0.013	0.20	0.013
Tol. tilt support adjustment on Rep.D	0.02	0.000	0.02	0.000
Tol. concentricity collar on Rep. C	0.02	0.000	0.02	0.000
Tol. 2 X H7/g6 on Rep. C	0.12	0.004	0.12	0.004
Tol. concentricity between C and D	0.05	0.001	0.05	0.001
• Tol. Max on Rep. D	**0.41**	**0.13^2**	**0.41**	**0.13^2**

Tolerances from MQ cold magnetic axis to the button axis on Rep. E (dimensions in millimetres)				2c
	Individ. Tol. X	$Sigma^2$ axis X	Individ. Tol. Z	$Sigma^2$ axis Z
Σ of tol. on Rep D (report from table 1c)	0.41	0.018	0.41	0.018
Tol Rep. E due to the perpendicularity of the support 0.02*220/100 =0.04	0.04	0.001	0.04	0.001
Tol. H7/g6 on Rep. D	0.06	0.001	0.06	0.001
Tol. on drift tube flange due to the weld of BPM on the support	0.04	0.001	0.04	0.001
• Tol. Max on Rep. E	**0.55**	**0.15^2**	**0.55**	**0.15^2**

Tolerances from MQ cold magnetic axis to Rep F on the drift tube (dimensions in millimetres)				3c
	Individ. Tol. X	$Sigma^2$ axis X	Individ. Tol. Z	$Sigma^2$ axis Z
Σ of tol. on Rep D (report from table 1c)	0.41	0.018	0.41	0.018
Tol. Rep. F due to the perpendicularity of the support 0.02*560/100 =0.11	0.11	0.004	0.11	0.004
Tol. H7/g6 on Rep. D	0.06	0.001	0.06	0.001
Tol. due to the weld of BPM on the support	0.10	0.003	0.10	0.03
Tol. concentricity between Rep. D and F	0.20	0.013	0.20	0.013
• Tol. Max on Rep. F	**0.88**	**0.20^2**	**0.88**	**0.20^2**

CONCLUSIONS

The first method remains the favourite because it does not add costly measurements in the SSS assembly process and provides enough accuracy.

However, if the results of the practical tests do not fill the expected accuracy, the second method will provide a substantial gain of precision.

The method 3 will complicate the design without the anticipated benefits.

We should also take into consideration a possible verification of the Rep. F in relation with the cryostat references and consequently to the cold magnetic axis. This position could be corrected by the tunnel alignment method. The advantages have to be compared with the displacement of other correctors. (Cf. private discussion with B. Jeanneret).

TOLERANCE SUMMARY VERSUS REFERENCES (mm)						4
	External references		Warm magnetic axis		Cold Magnetic axis	
Worst case , arithmetic sum of tol.	Tol. X	Tol. Z	Tol. X	Tol. Z	Tol. X	Tol. Z
Tol. BPM on Rep. E (buttons)	0.68	0.67	0.32	0.32	0.55	0.55
Tol. Drift tube on Rep. F	1.09	1.06	0.67	0.64	0.88	0.88
σ of the tolerances (mm rms), (rectangular distribution)	Sigma X	Sigma Z	Sigma X	Sigma Z	Sigma X	Sigma Z
Tol. BPM on Rep. E (buttons)	0.24	0.23	0.08	0.08	0.15	0.15
Tol. Drift tube on Rep. F	0.26	0.26	0.16	0.16	0.20	0.20

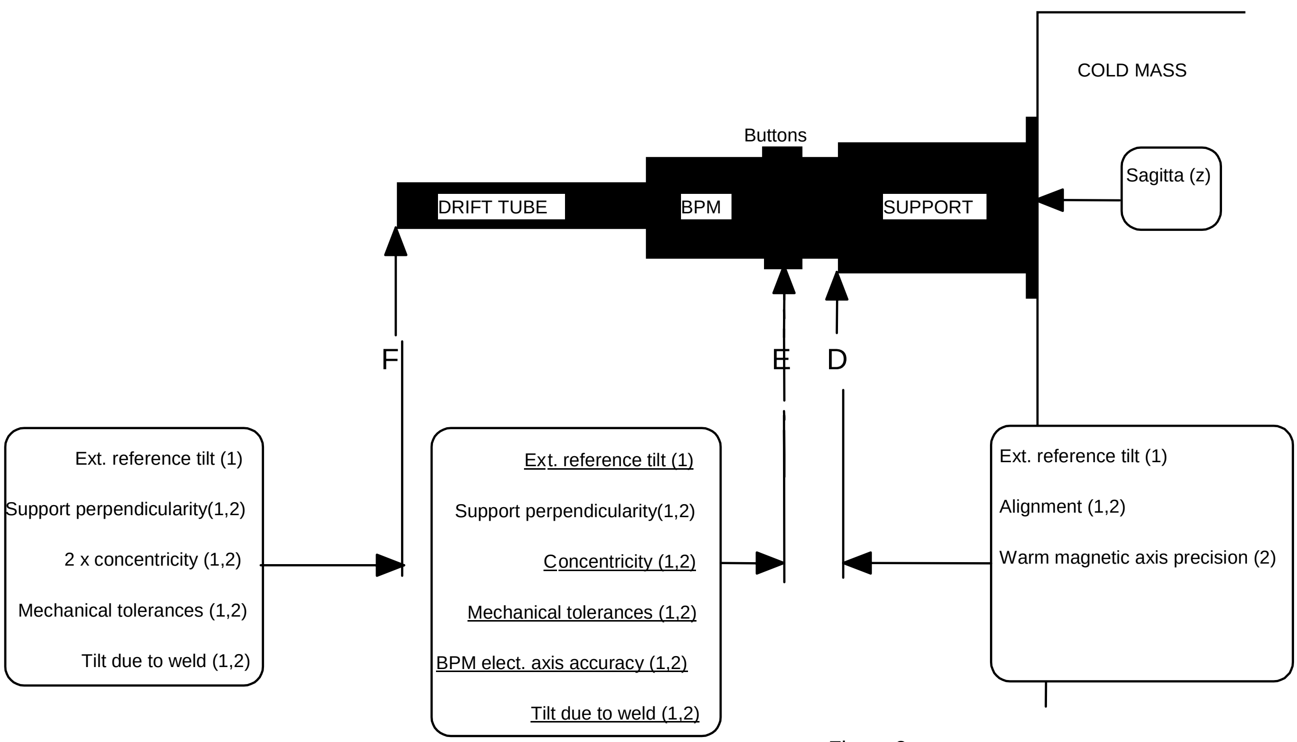
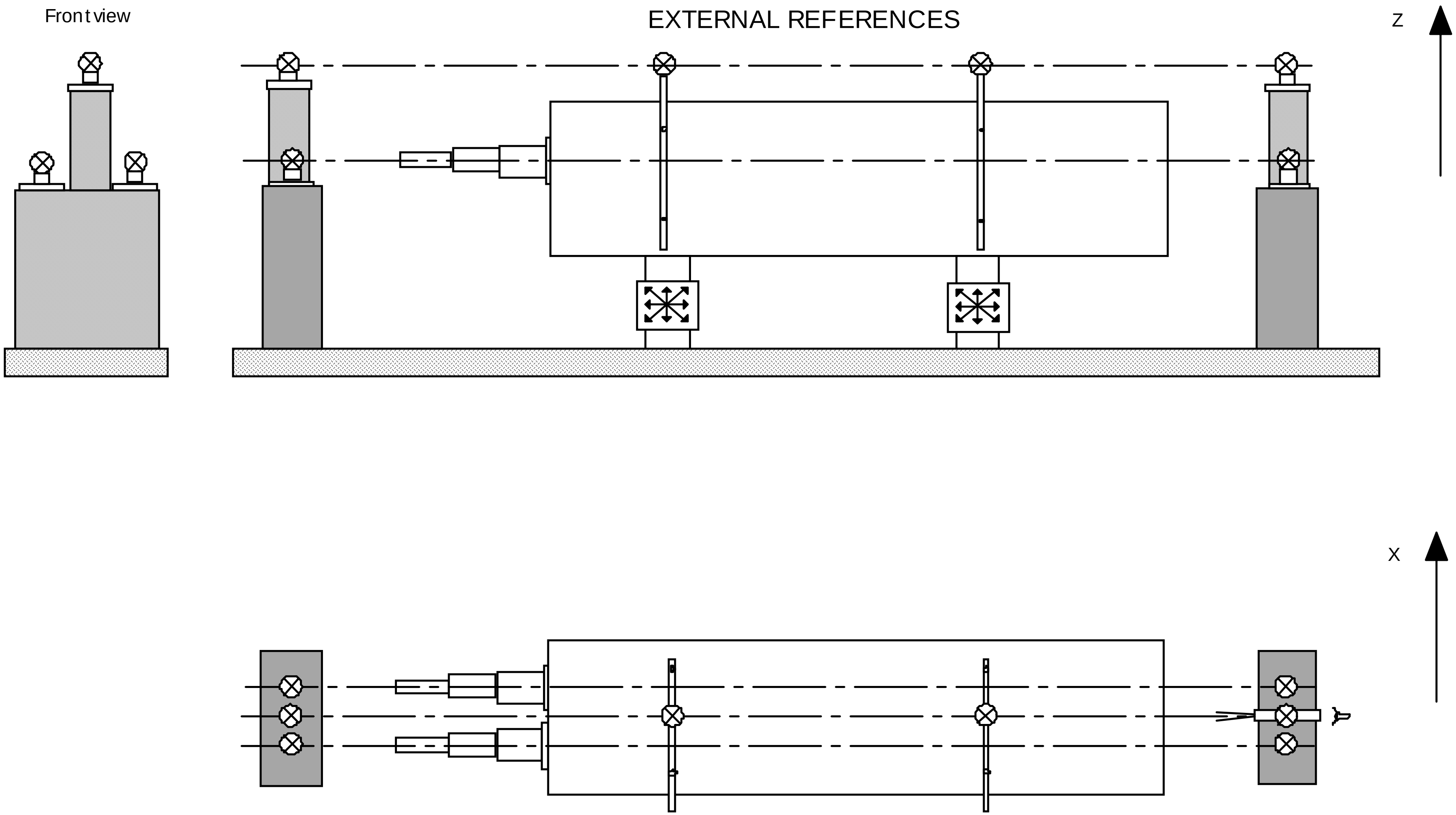
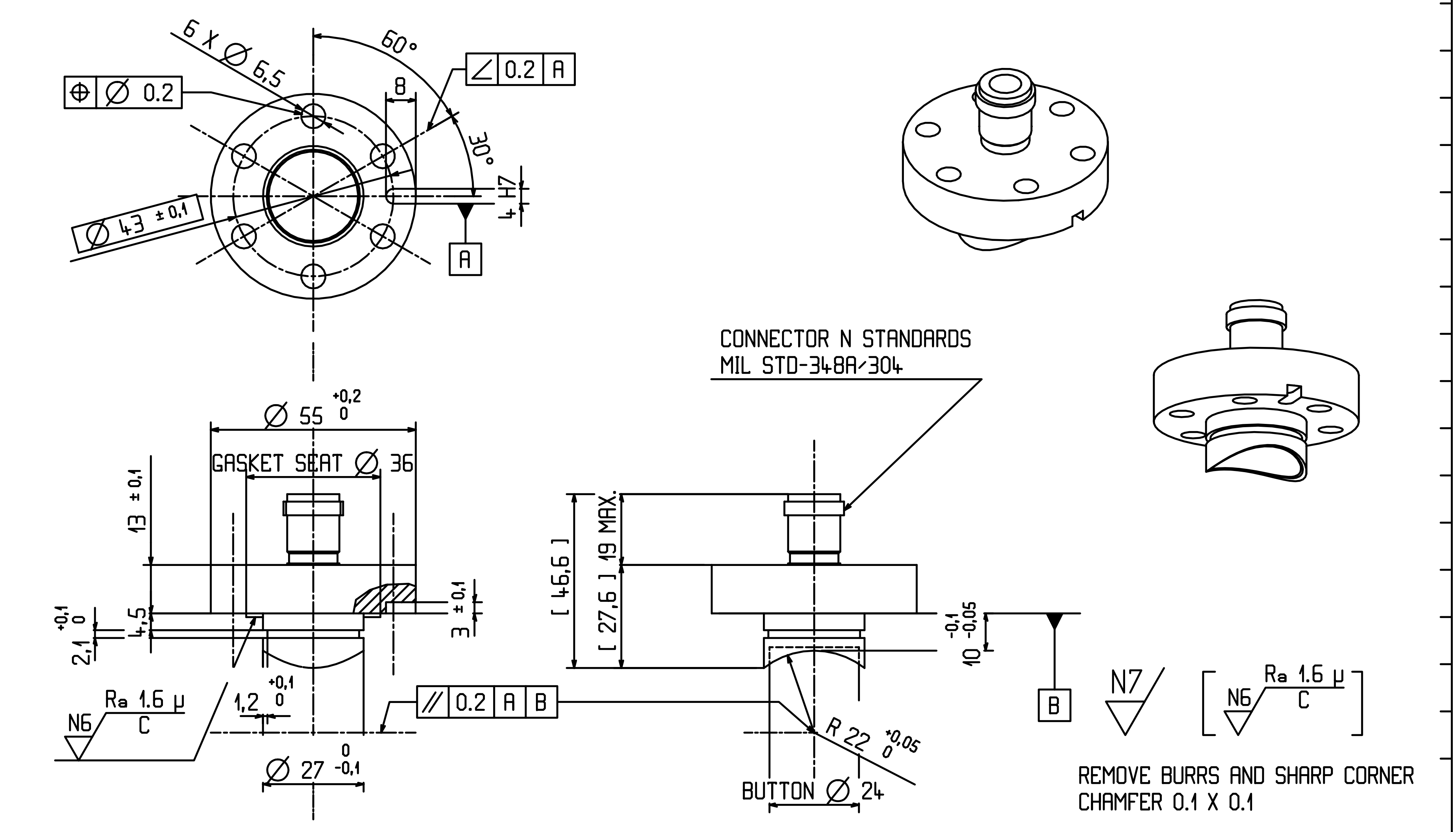


Figure 3



ALIGNMENT BENCH Figure 4



REMOVE BURRS AND SHARP CORNER
CHAMFER 0.1 X 0.1

GENERAL TOLERANCES GENERALES	DIMENSION	<=6	> 6	> 30	> 120	> 315	> 1000	> 2000
	USINAGE MOYEN/MEDIUM MACHINING	± 0.1	± 0.2	± 0.3	± 0.5	± 0.8	± 1.2	± 2
	MECANOSOUDE/WELDED STRUCTURE	± 0.5	± 1	± 2	± 3	± 5	± 7	± 10

DESSIN, RUGOSITE, TOLERANCES SELON NORME ISO
DRAWING, RUGOSITY, TOLERANCES ACCORDING TO ISO STANDARD

PROJECTION

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
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GENEVE

IND.	DATE	NOM/NAME	ZONE	MODIFICATION

Horizontal & vertical beam position monitor Standard

BEAM POSITION MONITOR BUTTON FEEDTHROUGH
MONITEUR DE POSITION TRAVERSEE A BOUTON

ECHELLE / SCALE: 1/1

DES/DRA.	C.REYMERMIER	1998-03-23
CONTROLLED	T.RENAGLIA	1998-05-04
RELEASED	J.PAPIS	1998-05-04
APPROVED		

LHCB,BPMXX_BEPROFM000,B001,B0011101PL

REMPLACE/REPLACES

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