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TRACTION TESTS FOR THE QUALIFICATION OF THE TTF/ILC COMPOSITE SUPPORT POSTS

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Abstract

Between January and June 2007 a new set of 6 low thermal conduction structural supports for the TTF cold mass has been produced at INFN Milano LASA. The support posts will be used for the cryomodule that will be delivered by INFN for the ILCTA at FNAL. This document resumes the characteristics of the pieces produced and describes the tests and measurements performed to characterize and qualify these devices.

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INTRODUCTION

The posts are the low thermal conduction structural supports for the cryomodule cold mass successfully used at the Tesla Test Facility (TTF, now FLASH [1]) and chosen as the cold mass supports for the XFEL and ILC projects. In the TTF modules[3,4] the 12 m cold mass (weighting less than 3000 kg) is supported by three tension-loaded posts[2] to the vacuum vessel. Each post is an assembly of a low thermal conduction composite material pipe (fiberglass pipe) and four stages of shrink-fit aluminum and steel discs and rings. The two stainless steel disc/ring sets are connected respectively to the room temperature and to the 2 K cold mass environments at the two pipe extremities. The two aluminum disc/ring sets between the pipe ends provide both structural support and pipe thermalization for the two thermal shielding levels, at 40-80 K and 5-8 K. Stainless steel and aluminum flanges are shrink-fit for good mechanical connection: the strict tolerances in pipe, discs and rings dimensions ensure a mechanical interference in the range of a few percent of the pipe thickness that supports up to 5000 kg of weight.

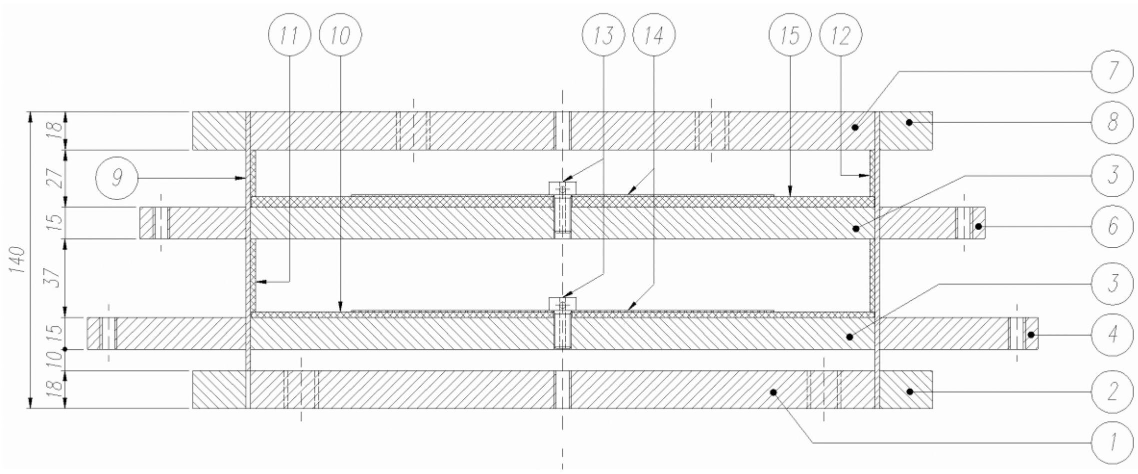
Between January and June 2007 a new set of 6 support posts has been produced at INFN Milano LASA, for the cold mass under procurement by INFN to the ILCTA at FNAL. This document resumes the characteristics of the pieces produced and describes the traction tests performed to validate the maximum load for these devices.

1 POST DESIGN

The reference design for the support post is a set of specifications and drawings produced at the Fermi National Accelerator Laboratory by T. Nicol in November 1993.

After the successful production at Fermilab of a few prototypes, INFN-LASA received from Fermilab the documentation for the production of the posts required for the fabrication of the cryomodules of the TTF facility at DESY. From the new set of reviewed drawing and specifications performed by INFN all the posts have been produced so far.

The overall design of a post is the following one:



Part name	*Part number*
1.8 K steel disk	1
1.8 K steel ring	2
4.5 K – 70 K aluminum disks	3
4.5 K aluminum ring	4

Part name	*Part number*
70K aluminum ring	6
300 K steel disk	7
300 K steel ring	8
Epoxy glass support tube	9

Here we resume the most important parameters and tolerance specifications of the parts composing a post:

Epoxy glass tube:

Dimension	*Nominal value (mm)*	*Tolerance Range (mm)*
External diameter	300.00	299.95 - 300.05
Internal diameter	295.58	295.53 - 295.63
Thickness	2.21	2.16 - 2.26

Aluminum and steel disks:

Dimension	Nominal value (mm)	Tolerance Range (mm)
External diameter	296.00	296.01 - 296.06

Aluminum and steel rings:

Dimension	Nominal value (mm)	Tolerance Range (mm)
Internal diameter	300.00	299.97 - 300.03

This set of tolerances guarantees a mechanical interference range between the epoxy glass tube and the ring+disk set of 0.15 – 0.30 mm. This range of values, corresponding to a few percent of the pipe thickness, assures that a set of three posts supports the whole cold mass of a cryomodule (weight ~ 3000 kg) with wide safety margins.

To characterize the posts, we performed for each post a set of measurements of all parts before assembly and of the entire assembled post, and a traction test for qualification. All the posts (the set produced at LASA in 1999 and the new one produced in 2006) were tested up to 5000 kg (load design value). One of the posts produced in 1999 has been tested up to mechanical failure (one of the disk started sliding over the tube), corresponding to a force of ~13000 kg.

Considering a high security coefficient (~ 5) the traction test allows to certify that each post supports an operational value of 1000 kg.

2 MATERIALS

The epoxy glass tubes have been produced by the US Company “Advanced Composite Products and Technology, Inc”. We ordered 24 tubes. The set of tubes we received has a certificate of conformance with the required specifications.

The aluminum (Al 6061-T6) parts, the steel (AISI 304) parts and the assembly tool have been produced by the Italian company “O.M.C.M. Lavorazioni Meccaniche di Precisione – CNC”. We ordered 6 complete sets of rings and disks and an assembly tool.

Dimensional measurements on all fiberglass and mechanical components have been performed upon acceptance for verification of the required tolerances and the results are discussed later.

3 POST THERMAL DESIGN AND CALCULATIONS

Thermal analysis has been performed to evaluate the heat loads during operational conditions. Both analytical calculations and FEM simulations have been done to estimate the heat loads due to the conduction through the epoxy glass tube and the radiation of the disks surfaces. We performed separate analytical calculations for the radiation and conduction contribution and FEM thermal analysis with and without radiation contribution.

3.1 Analytical calculations

Conduction

We wanted to assess the static heat inleak due to conduction through the epoxy glass tube at the temperature of 2 K (cold mass) and 5 K and 70 K (thermal shields). The post tube has an area $A_p = 2.068\ 10^{-3}\ m^2$.

We considered the conduction integral of epoxy glass (The data have been extracted from the CRYOCOMP library):

- from 2 K to 5 K: 0.141 W/m
- from 5 K to 70 K: 16.7 W/m
- from 70 K to 300 K: 150 W/m

The total heat flux results:

- at 2 K: $\dot{Q} = 0.029\,W$
- at 5 K: $\dot{Q} = 0.904\,W$
- at 70 K: $\dot{Q} = 10.553\,W$

These values are in good agreement with the one obtained in the ANSYS simulation without radiation contribution described in the following paragraph (within an error of few percents).

Radiation

We wanted to assess the static heat inleak due to radiation between the following couples of disks:

- 300 K steel disk and 70 K aluminum disk (separate by 27 mm)
- 70 K aluminum disk and 5 K aluminum disk (separate by 37 mm)
- 5 K aluminum disk and 2 K steel disk (separate by 10 mm)

To overestimate the contribution to the heat load due to radiation, we considered an emissivity of 1 for all the materials, and we did not consider the multi layer insulation.

The radiation configuration factor F of two disks with same radius for the couple of disks considered before is[5]:

- 300 K to 70 K: $F_{300\text{-}70} = 0.833$
- 70 K to 5 K: $F_{70\_5} = 0.779$
- 5 K to 2 K: $F_{5\_2} = 0.935$

Here we report the calculated radiation heat loads:

- between 2 K and 5 K: $\dot{Q} = 2.221 \times 10^{-6}\, W$
- between 5 K and 70 K: $\dot{Q} = 0.073\, W$
- between at 70 K and 300 K: $\dot{Q} = 26.262\, W$

Conduction and radiation

The total heat load at the post parts results:

- at 2 K: $\dot{Q} = 0.029 + 2.221 \times 10^{-6} = 0.029\, W$
- at 5 K: $\dot{Q} = 0.904 - 2.21 \times 10^{-6} + 0.073 = 0.977\, W$
- at 70 K: $\dot{Q} = 10.553 - 0.073 + 26.262 = 36.742\, W$

These values are in quite good agreement with the one obtained in the ANSYS simulation with radiation contribution described in the following paragraph. Better agreement of the total heat flux at 70 K can be obtained considering the mean surface temperature of the two facing disks obtained with the FEM analysis (around 290 K for the steel upper disk and around 80 K for the upper aluminum disk; both are due to the temperature drop induced by the conduction of the disks) and performing a new calculation of the radiation contribution with these temperatures. With this new calculation we obtained a better agreement of the calculated value with the FEM analysis:

- The total heat flux at 70 K: $\dot{Q} = 10.553 + 22.867 = 33.420\, W$

Clearly, the three-fold increase of the heat load due to the unshielded thermal radiation is not acceptable, and need to be dealt with, in order not to increase the static heat inleak at cold temperatures. In order to do that, a few layers of Multi Layer Insulation (MLI) blankets have been placed to protect the 70 K and 5 K circuits from the radiative heat inleak from the hotter facing surfaces.

Estimate of residual heat inleak with MLI

We estimated the residual radiative inleak with the multilayer insulation using the following data:

$\dot{Q} = 1.0 \dfrac{W}{m^2}$ considering 10 MLI layers at 300 K[6]

$\dot{Q} = 0.5 \dfrac{W}{m^2}$ considering 10 MLI layers at 70 K[7]

This results in the following residual radiative heat fluxes:

- at 70 K: $\dot{Q} = 0.069\, W$
- at 5 K: $\dot{Q} = 3.441 * 10^{-3}\, W$

3.2 FEM simulations

We performed a thermal calculation considering the post geometry without multi layer insulation and the following materials: stainless steel AISI 304, Aluminum 6061 T6 and epoxy glass G10. For each material, nonlinear temperature dependent thermal properties up to cryogenic temperatures have been inserted in the engineering data. The data have been extracted from the CRYOCOMP library. The MLI heat inleak estimations rely on experimental measurements reported in the literature and are not easily reproduced with FEM modeling.

Conduction

These loads have been considered in the simulation:

- Uniform temperature T = 2 K at the external surface of the 2 K steel ring
- Uniform temperature T = 5 K at the external surface of the 5 K aluminum ring
- Uniform temperature T = 70 K at the external surface of the 70 K aluminum ring
- Uniform temperature T = 300 K at the external surface of the 300 K steel ring

Here we resume the results:

- The total heat flux at 2 K is: $\dot{Q} = 0.041\,W$
- The total heat flux at 5 K is: $\dot{Q} = 0.865\,W$
- The total heat flux at 70 K is: $\dot{Q} = 9.906\,W$

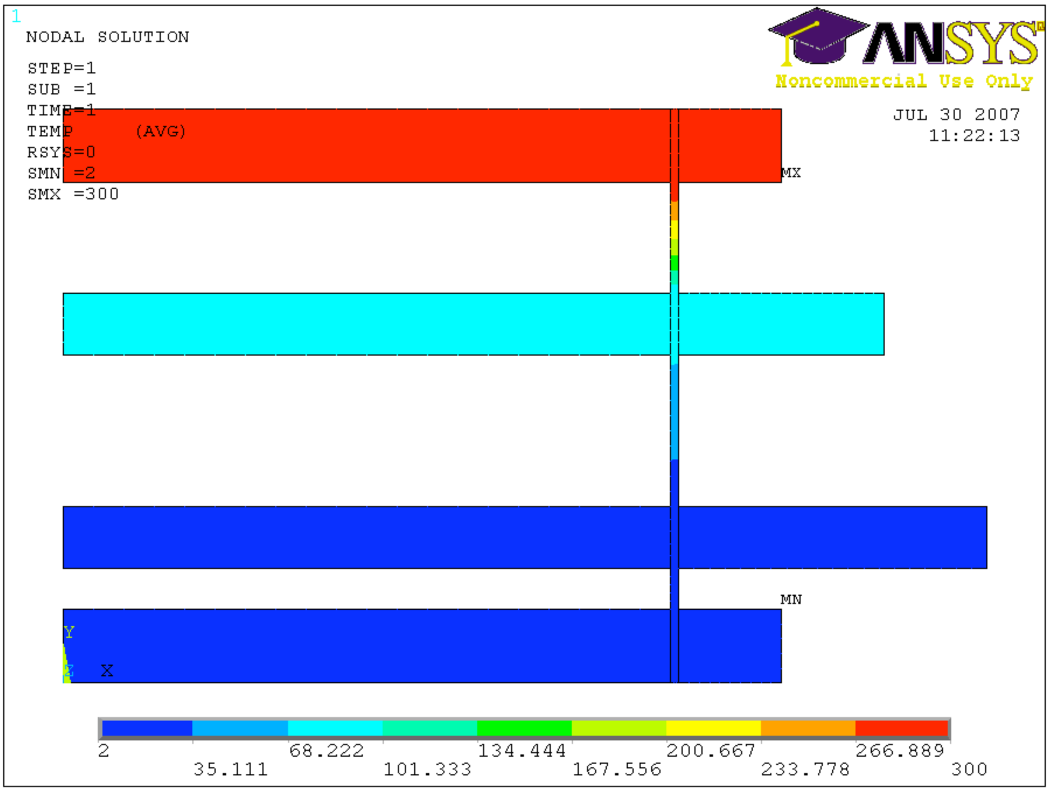


Figure 1: FEM thermal analysis results (case without radiation)

Conduction and radiation

We performed a second calculation, considering the radiation contribution of the metallic disks without multilayer insulations. The total heat load at the post parts results:

- The total heat flux at 2 K is: $\dot{Q} = 0.040\,W$
- The total heat flux at 5 K is: $\dot{Q} = 1.011\,W$
- The total heat flux at 70 K is: $\dot{Q} = 30.808\,W$

4 TRACTION TEST

For each post we performed a vertical test with a traction test machine (Instron 5500). In the machine we have to choose:

- the velocity of the movement between 0.002 mm/min and 500 mm/min;
- the maximum load or maximum displacement of the machine arm.

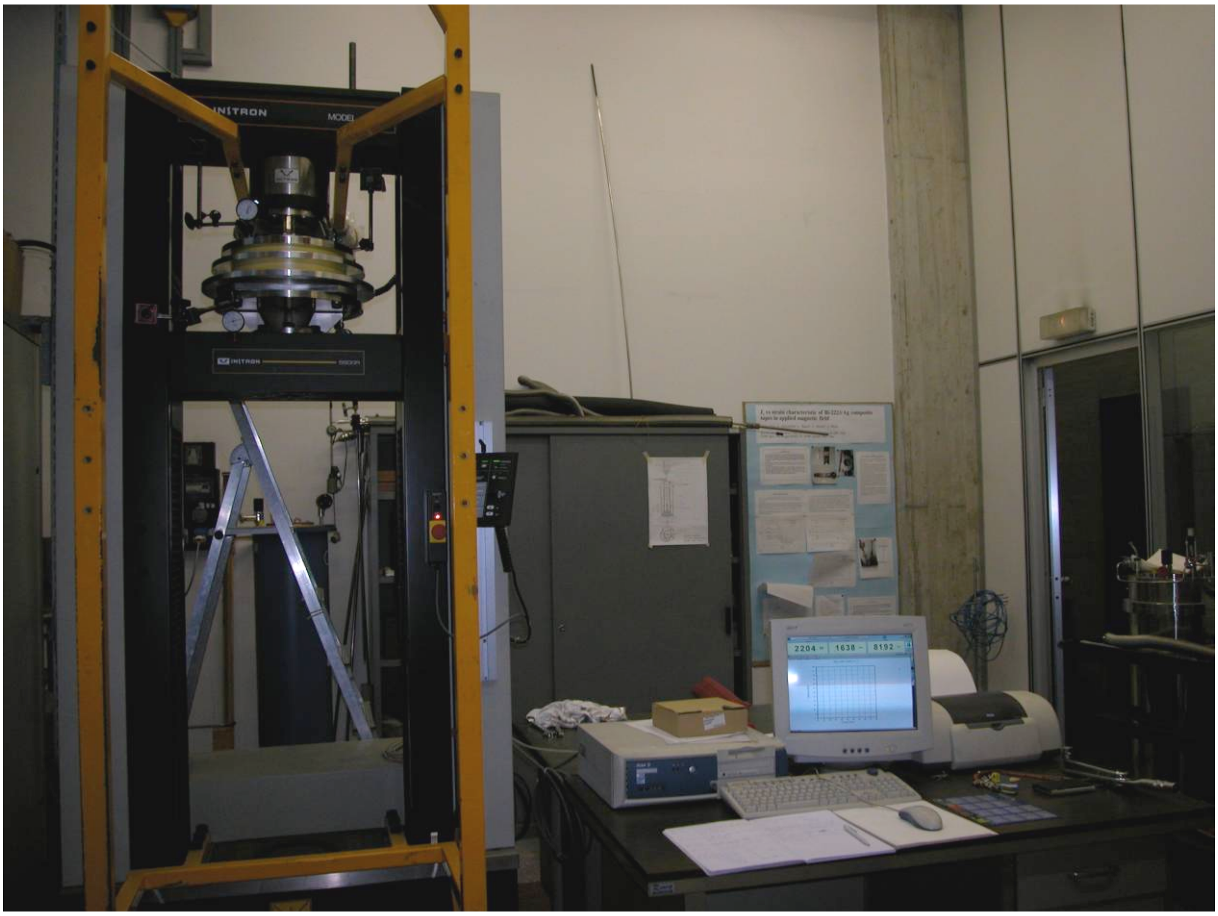


Figure 2: The post mounted on the test machine

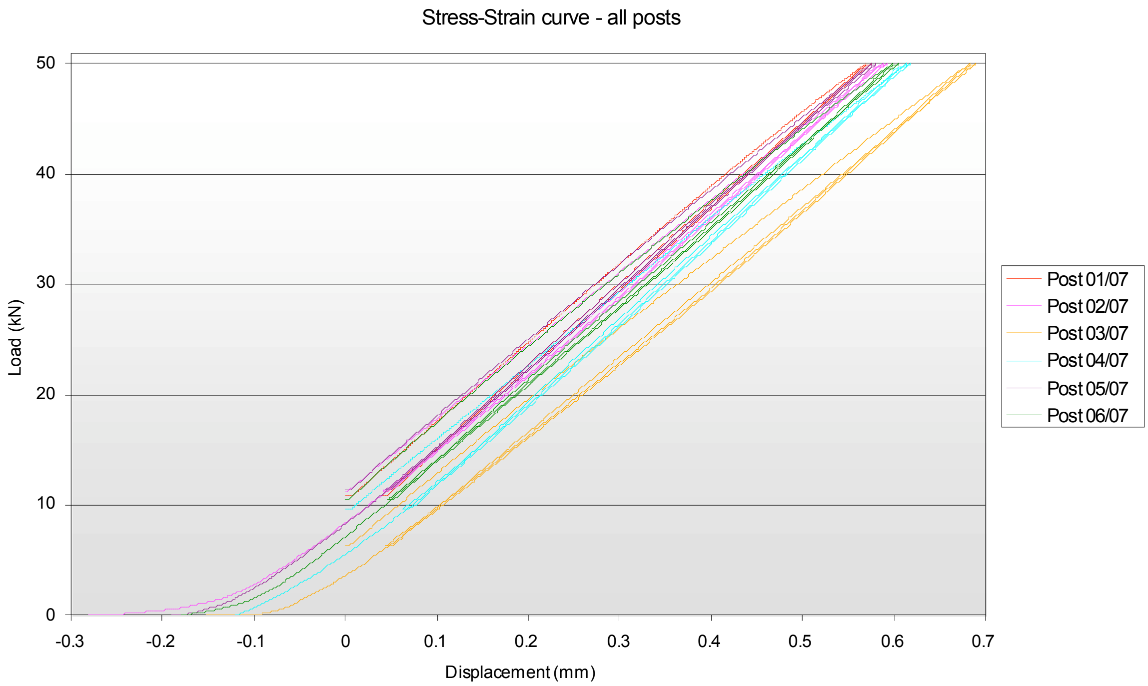
The test procedure for each post has been the following:

1. the post is mounted and fixed to the machine without tightening the bolts connecting the bottom side of the post (2K ring) to the machine;
2. these bolts are tightened with a torque wrench at 10 Nm (corresponding to a preload value of around 9 kN),;
3. the machine stretches the post up to a load of 50 kN (conditioning);

4. the post is relaxed reaching a load value equal to the preload;
5. the post is stretched again up to 50 kN;
6. the machine unloads the post.

During the test we positioned 4 dial gauges at the bottom and top flanges of the post, to keep under control the movement of the post flanges during the test. The dial gauges indications were consistent with the one provided by the machine itself, the main difference being the small sagging of the machine arm during operation. A purely elastic computation taking into account only the fiberglass pipe elasticity (E=27.6 MPa and nominal dimensions) yields an elastic elongation of 122 μm at 50 kN. The higher value measured in the tests by the instrumentation (>500 μm) accounts for all other elastic elements in the setup (machine arm, connecting flanges, flexure of the bolted flanges, etc.).

The results of the tests are shown in the following chart: all the posts succeeded in the test and showed an elastic reproducible behavior (after the initial conditioning). The horizontal axis shows the displacement indicated by the machine (the dial gauges showed approximately 60 % of the machine value). The vertical axis shows the load cell reading during the test.



5 POST DIMENSIONAL MEASUREMENTS

5.1 Epoxy glass tubes

The company OMCM measured the mean internal diameter (Di) and the mean external diameter (De) of the 24 US fiberglass tubes with a 3D machine in a thermally controlled environment. We derived the thickness of the tubes from these measurements.

The results of the measures show that nearly all the internal diameters of the tubes are out of the tolerance range. The hypothesis is that the production and measurement of the tubes in US has been done at a different temperature with respect to the measurements done in Italy. A temperature difference of -4°C with respect to the measurement performed in Italy is enough to bring 50% of the tubes results in the tolerance range.

5.2 Aluminum and steel disks and rings

The company OMCM measured the mean internal diameter (Di) of the rings and the mean external diameter (De) of the disks.

The measures show that on average a half of the parts is out of range for around 0.01 – 0.02 mm (except for the aluminum rings at 4K that result consistently out of range of around 0.02 mm).

5.3 Post assembly

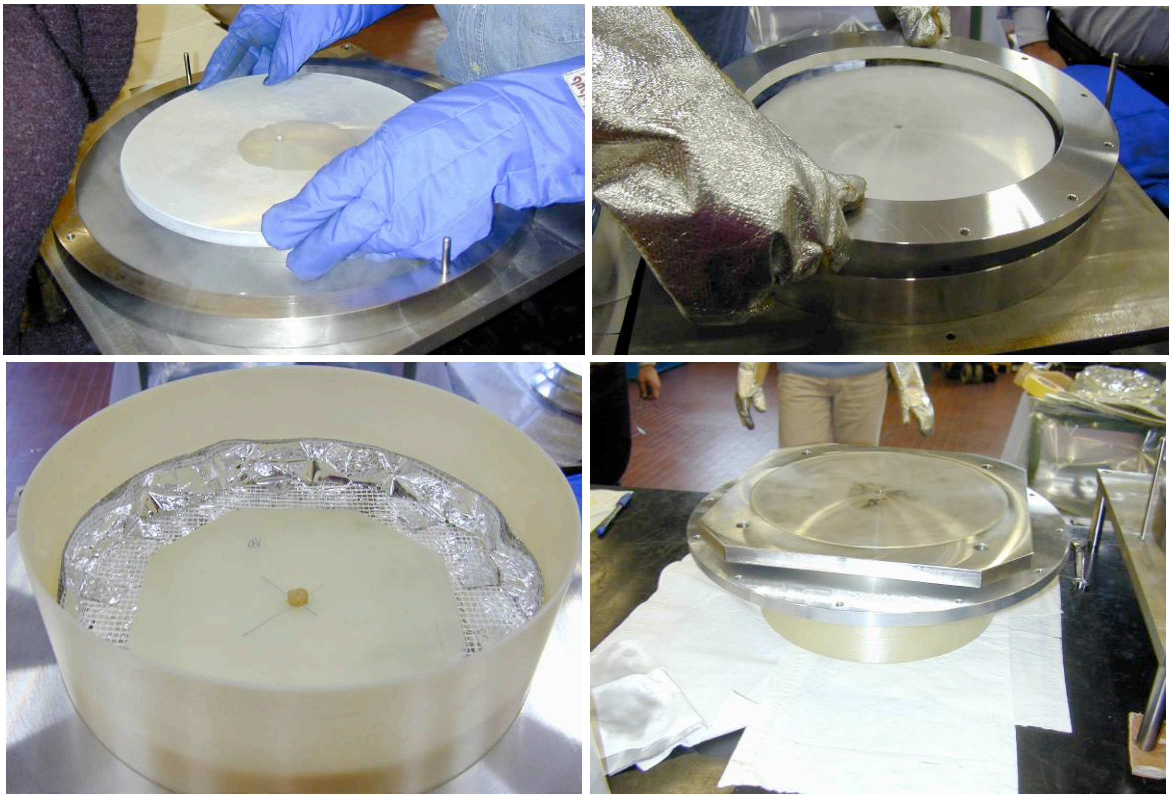
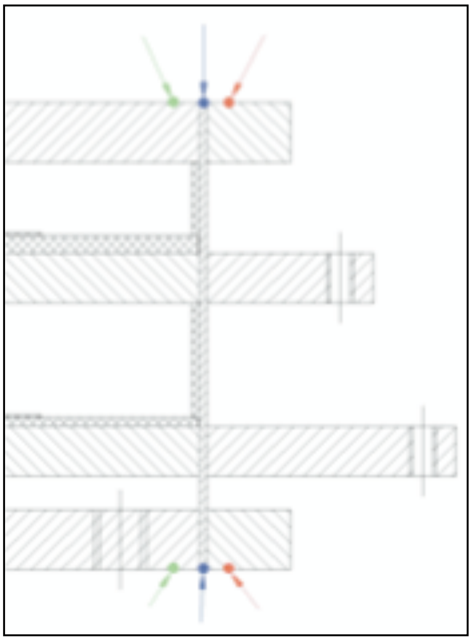


Figure 3: some steps of the post assembly

In spite of the small non conformity of many components with respect to the specifications, the components were sorted and matched in order to create sets in which the nominal mechanical interference of 0.15-0.3 mm was guaranteed for each of the six post assemblies.

We performed a set of measurement with a feeler pin: Mitutoyo 0.600 mm N. 192-653. We performed on a reference table (precision: cents of mm) 24 measurements for each post. We measured the vertical length of the 2K disk and ring, the room temperature disk and ring and the epoxy glass tube at 4 different angular positions corresponding to the 6 positions highlighted in the following drawing.

The measurements were performed before and after the traction test and we found a good agreement of the two sets of measurements: we measured a maximum difference of a few 10^{-2} mm that we think is due to different positioning on the reference table during the measures (the value is nearly constant for a whole set of measures of a single post).



The measurements reveal that on the room temperature side the steel disk (the part that in the cryomodule assembly is bolted to the supporting bracket) is the part in contact with the table, while on the 2K side the part in contact with the reference table is the epoxy glass support (instead of the ring that is the part bolted to the helium gas return pipe). We also calculated the mean distance between the 2K ring and the room temperature disk: the results show that all the mean values fulfill the tolerance (height of the tube 140.00±0.20) but one half of the values do not fulfill the parallelism tolerance between room temperature disk and 2K ring (//0.10).

6 CONCLUSIONS

We produced, measured and verified a set of 6 posts. They all were certified with a vertical traction test up to a load of 50kN, with no indication of non-linear behavior.

Concerning the post production, there are still some open questions that need improvements:

- **Tolerances of sub-components**: not all the mechanical measurements on the parts and on the final assembly achieved the tolerances required. This lack of conformity complicated the procedure of coupling disks and rings with tubes, because we had to match the components in order to meet the required interference.
- **Tolerances of the assembling tools:** presently, the assembly procedure does not guarantee the planarity tolerances that were specified. The origin of this small discrepancy, which does not effect the required performances, has been recognized as determined by the assembling tool and procedure. Marginal modifications will solve the problem.

As a conclusion of the detailed analysis outlined in this document, the tolerances in the fabrication drawings will be reviewed and the assembling tools improved in view of the foreseen mass production required for the European XFEL project.

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