PRODUCTION AND QUALIFICATION OF LOW THERMAL CONDUCTION SUSPENSION SUPPORTS FOR THE COLD MASS OF LONG SUPERCONDUCTING ACCELERATION MODULES

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Abstract

A post is an assembly of a low thermal conduction composite material pipe (fiberglass pipe) and some shrink-fit aluminium and steel discs and rings, designed to provide a mechanical support and a thermal insulation to the cold mass of the long cryomodules of the TTF, which are foreseen also for the XFEL and ILC. We review here the production, testing and qualification for the production of post supports, which have been successfully provided for the cryomodules of the TTF in DESY, the STF in KEK and ILCTA in FNAL.

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, the ILCTA and the STF 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 aluminium 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 aluminium 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 aluminium 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. A second set of posts has been produced at DESY and tested both at DESY and INFN.

This paper resumes the characteristics of the assemblies produced and describes the traction tests performed to validate the maximum load for these devices.

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.

Dimensions and tolerances have been designed to guarantees a mechanical interference range between the fiberglass 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.

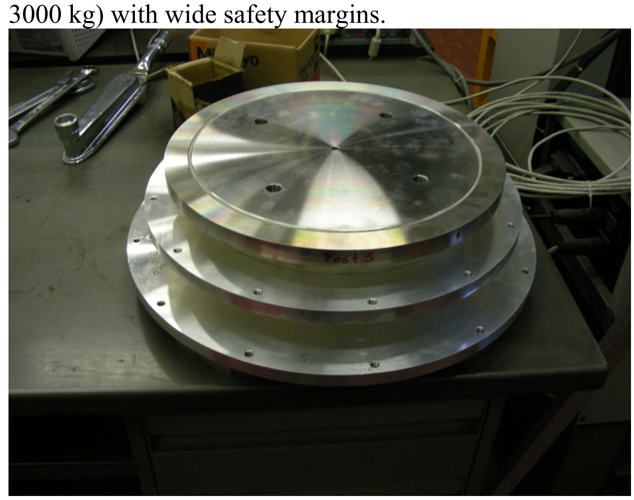

Figure 1: Post layout.

The fiberglass tube is the most critical component in the assembly. We found only two companies that guaranteed the strict required tolerances: a US company, which provided the tubes for the posts produced at FNAL and at INFN and a Danish company which provided the tubes for the Desy posts.

The set of posts produced at LASA in 1999 and the new one produced in 2007 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.

A set of 4 posts produced at DESY has been tested up to 10000 kg and one of them up to mechanical failure corresponding once more to a force of ~13000 kg.

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

POST DIMENSIONAL MEASUREMENTS

Concerning the INFN production of the posts, dimensional measurements of all fibreglass pipes and mechanical components have been performed upon acceptance for verification of the required tolerances.

The components were than 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 some length measurements of the whole post before and after the traction test (described below) and we found a good agreement of the two sets of measurements: we measured a maximum difference of a few 10^{-2} mm, within the positioning uncertainties on the reference table during the measurements.

THERMAL BEHAVIOR

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 fiberglass tube and the radiation between the disks surfaces. We performed separate analytical calculations for the radiation and conduction contribution and FEM thermal analysis with and without radiation contribution.

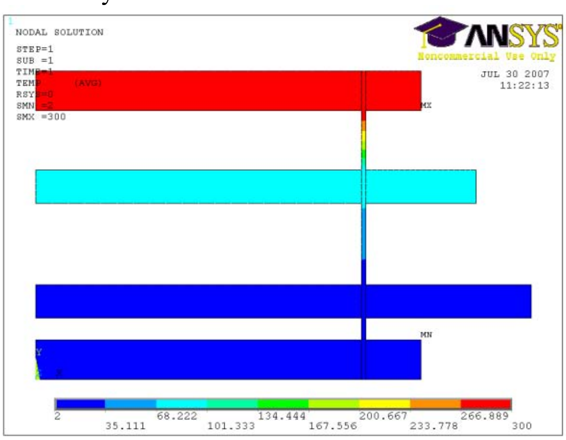

Figure 2: FEM thermal analysis results

We analytically evaluated the total heat inleak at the posts superimposing the radiative and conductive contribution and we obtained the following results:

The total heat flux at 2 K is: $\dot{Q} = 0.029\,W$

The total heat flux at 5 K is: $\dot{Q} = 0.9\,W$

The total heat flux at 70 K is: $\dot{Q} = 10.5\,W$

To verify the analytical calculations we performed a FEM simulation with the real geometry of the assembly. For the materials, nonlinear temperature dependent thermal properties extracted from the CRYOCOMP library up to cryogenic temperatures have been used. The FEM values differ from the analytical one for a few percents.

TRACTION TEST

All the posts produced have been tested with a traction test machine.

The first set of posts, assembled in 1999 at an external company, has been tested directly at the company site. All the posts showed an elastic behavior up to 5000 kg. One of the posts has been tested up to mechanical failure.

For each post assembled at INFN in 2007 we performed at INFN site a vertical test with a traction test machine (Instron 5500) up to a load of 5000 kg.

The Desy series of posts has been tested at Desy up to 5000 kg and 4 of them have been tested at INFN with the Instron machine up to 10000 kg. One of these posts has been than tested up to mechanical failure.

Figure 3: The post on the traction machine

The test procedure at INFN has been the following:

- the post is mounted and fixed to the machine with a preload value of around 1 kg
- the machine stretches the post up to a load of 5000 kg (or 10000 kg) (conditioning);
- the post is relaxed to the preload value;
- the post is stretched again up to 5000 kg (10000 kg) (verification test);
- the machine unloads the post.

During the test we positioned some 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 5000 kg. 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 figure 4: all the posts succeeded in the test and showed an elastic reproducible behavior (after the initial conditioning).

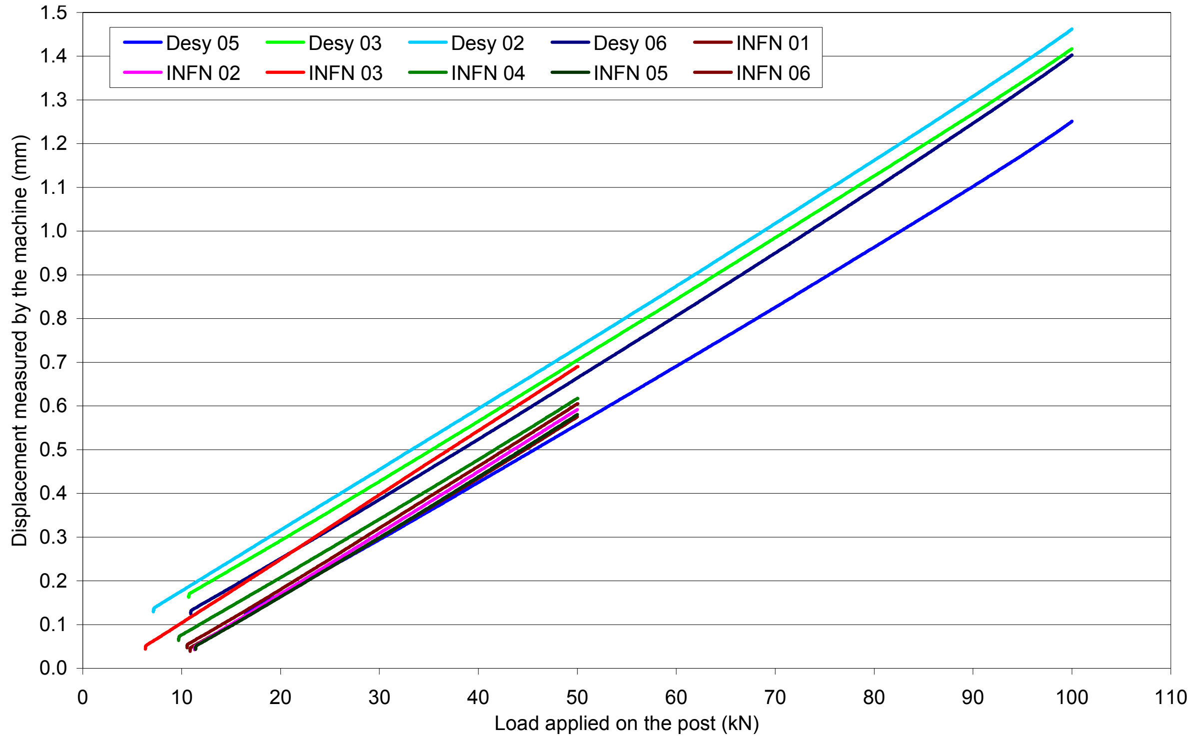

Figure 4: post behaviour during verification test

Failure tests

A first test up to mechanical failure has been performed in 1999. The post has been vertically pulled up to failure, corresponding to a load of 13000 kg. The failure consisted of the sliding of the upper steel disk of the post, with respect to the fibreglass pipe (see fig. 5). The pipe itself (provided by the US Company) did not break nor showed any damage.

A second failure test has been performed at INFN with one of the posts assembled at Desy, with a fibreglass pipe produced at the Danish company.

This test shows a very similar behaviour to the first one: the post failed at around 13000 kg and the failure corresponded to a sliding of the upper disk respect to the fibreglass pipe. This time too the pipe did not show any damage.

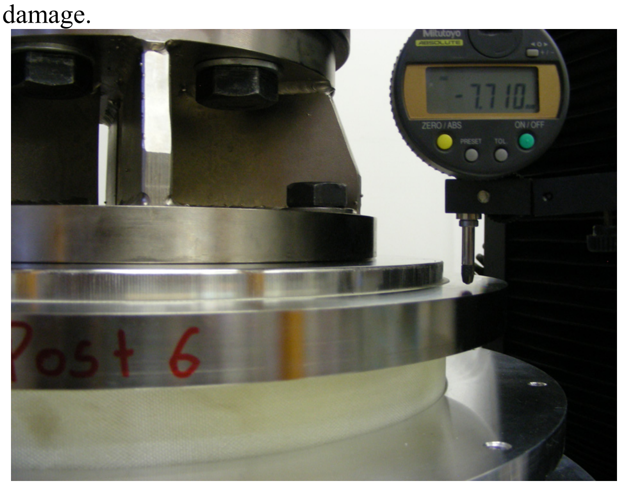

Figure 5: onset of failure: the upper disk is being dragged out of the fibreglass pipe.

CONCLUSIONS

A set of 6 posts has been recently produced, measured and verified at INFN. A second set of 6 posts has been produced at DESY and tested at INFN, to qualify an additional vendor for the fiberglass pipes.

All the posts have succeeded the vertical traction test up to a load of 5000 kg (10000 kg for the Desy posts) with no indication of non-linear behavior in this regime.

A rupture test has been performed on two posts, one from a previous INFN production (1999) having the same design and fiberglass vendor as the new series, the other from the Desy production. The two posts showed a similar behavior: both break at about 13000 kg with the same result. The upper disk started sliding over the fiberglass pipe. This allows us to accept the second vendor as a qualified supplier for further post production.

REFERENCES

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