CRYOMODULE DEVELOPMENT FOR SUPERCONDUCTING RF TEST FACILITY (STF) AT KEK

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Abstract

The Current status of cryomodule development for the superconducting RF test facility (STF) at KEK is described. An objective of this effort is to experience fabrication of 5-m long cryomodule and to perform high power testing of superconducting RF cavities towards ILC (International Linear Collider). The STF features two 5-m long cryomodules, each holding up to four 9-cell cavities. The cavities, about 1-m long each, will be cooled by saturated superfluid helium at 2.0 K

INTRODUCTION

To facilitate development of superconducting RF technologies for ILC, construction of the superconducting RF test facility (STF) is proceeding at KEK since 2005 [1]. Two units of 5-m long cryomodules (horizontal cryostats) are being prepared for the first phase of STF. Each cryomodule will house up to four 9-cell cavities. At present, two types of cavities are under development at KEK: one with a LL-type 9-cell design aiming at 45 MV/m, and the other with a modified TESLA-type design aiming at 35 MV/m. Since the details of the mechanical designs of these cavities, for instance, those of the input couplers, are somewhat different, the two cryomodules are built to accommodate such design variations. This paper describes the current state of the design and development for the STF cryostats.

CRYOSTAT

Development of the cryomodule for superconducting linear accelerators has been spearheaded by the TESLA group in the past decade. Since its design and performance are already in good maturity, except some needs for ILC-specific further improvement, we decided to build our STF cryomodules on the basis of TESLA design [2], and to start the development from there. Consequently, the structural design of the STF cryostat is very similar to that of TESLA, except for the revisions necessary for accommodating different mechanical designs of the STF cavities.

Figure 1 shows a cross section of the STF cryostat. The major components of the cryostat include: the vacuum vessel, support post, 80-90 K thermal shield, 5-10 K thermal shield, helium gas return pipe (GRP), cryogenic piping, helium vessel containing superconducting cavity and RF input coupler. Figure 2 shows a longitudinal view of the STF cryomodule consisting of two 5-m long cryostats connected together.

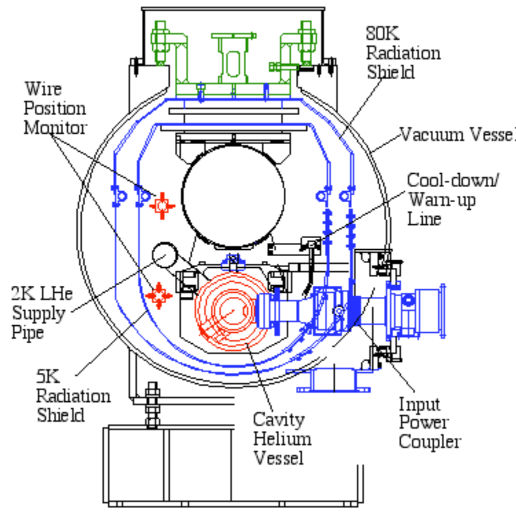

Figure 1: Cross-section of the cryostat.

Helium Vessel

For the first stage of STF, two types of cavities are in development at KEK: modified TESLA-type cavity (35 MV/m cavity) with a titanium helium vessel and LL-type cavity (45 MV/m cavity) with a stainless-steel helium vessel. The lengths of the 9-cell cavities of both types are slightly longer than that of TESLA design, because of attempts by the KEK group to improve either mechanical or electrical designs. The tuners and the RF input couplers for these cavities were also redesigned and fabricated. The details on the RF equipment will be presented elsewhere [3].

Vacuum Vessel

The outermost component of a cryomodule is the vacuum vessel, which contains the insulating vacuum. In case of failures of internal cryogenic lines, it also functions as the pressure containment vessel. It also serves as the central structural element to hold all other components, when installed on the floor of accelerator tunnels. The vessel is made of carbon steel tube with an outer diameter of 965.2 mm and a wall thickness of 12 mm. As shown in Fig. 2, two cryostats are connected by a sliding sleeve, which encloses the interconnect regions. At one end of each vessel, three flanged ports for monitoring the low temperature characteristics of the cryostat are distributed around the vessel circumference. During normal operation, the vessel is evacuated to a pressure of 10^{-4} Pa. Therefore, the inner surfaces of the vessel have no coating, so as to avoid troubles of out gassing. The design over pressure is 0.2 MPa.

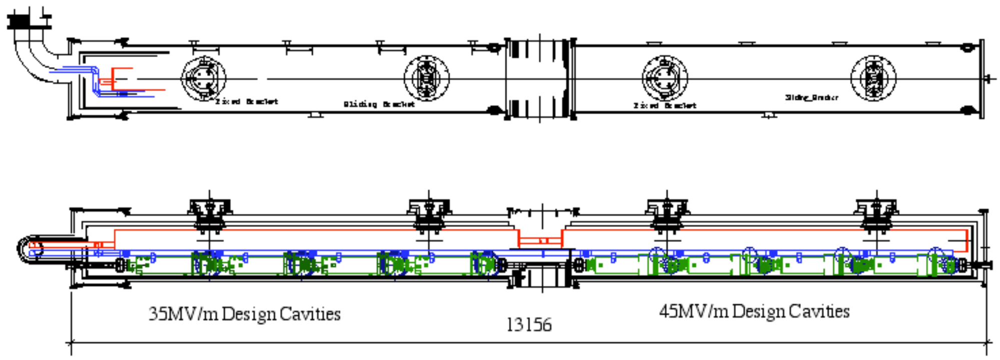

Figure 2: Longitudinal view of the STF cryomodule connecting two 5-m long cryostats.

Since this vessel has to accommodate rather fragile RF input couplers, a number of constraints have been put on the shape (tolerance of the coupler flange position < ±2 mm and tolerance of tilting < 2.5 mrad), and was built by using a milling machine.

Support Structure

The support structure of the cryostat is very similar to that of the TESLA cryomodule. The Gas Return Pipe (GRP), whose diameter is 318.5 mm, acts as the main support structure. All helium vessels containing the 9-cell cavities will hang from this GRP. The total weight of components hanging from the GRP is about 1000 kg for each cryostat. The GRP in a cryostat is suspended from the external vacuum vessel by two support post. One post is fixed. The other can slide longitudinally to accommodate the differential thermal shrinkage and expansion. The longitudinal positions of the two posts are arranged to minimize the gravitational sagging of the GRP. The cavity support system is, again, similar to that of TESLA, although some modifications were applied to match the STF cavities. The brackets are extending from the GRP. At the end of each bracket, there is a C-shaped stainless-steel block that clamps a pad, which is welded on the exterior of the cavity helium vessels. To ensure the required accuracy of the cavity alignment, the support post flange and the cavity support are finished on a milling machine after welding the ancillary components on the GRP.

Thermal Shield

The cryostat has two layers of aluminium thermal shields, which operate in the temperature ranges of 5-10 K and 80-90 K, respectively. The shields will surround the 2 K helium vessel, and absorb the radiation heat flux from outer regions within the cryostat and to provide heat sink stations for the support system and the RF input couplers. Each shield consists of stiff upper parts and semicircle lower parts, both divided into two halves to accommodate the thermal shrinkage of the shield. The upper sections, 5 mm thick, are supported by intermediate flanges of the support post. The lower sections, 3mm thick, have cooling pipes and are bolted to the upper shield sections.

The surfaces of the thermal shields are covered with multi-layer insulation (MLI). A 30 layer of MLI is used on the higher temperature shield, while a 10 layer MLI on the lower. In addition, the cavity helium vessels, GRP and 2-10 K pipes are wrapped with 5 layers of MLI. The expected heat fluxes are 1.5 W/m^2 and 0.1 W/m^2 for the 80-90 K and 5-10 K shields, respectively.

Deformation Analysis

Mechanical design of the cryostat has to ensure that the alignment of the components be maintained within a required range. To estimate the displacements of the cavities inside the cryostat during operation, a finite element analysis of the support structure (the vacuum vessel, support posts and GRP) was performed. It is predicted that the vertical positions of the GRP near the support posts will sink by about 0.6 mm, when fully loaded with the cavities under the vacuum. The maximum differential displacement along the GRP, as built, would reach up to about 0.1 mm. However, this deformation can be reduced to ~0.05mm by adjusting the levels of the two posts.

Heat Loads

The heat load at the thermal shield boundaries has been estimated by considering various heat transfer processes. Table 1 shows the results obtained under a nominal insulation vacuum of 10^{-4} Pa for the cryostat configuration, as shown in Fig. 2. It was found that the dominant heat load is the RF losses. A large heat input to 2 K level is mainly cause by the bundle of monitor cables, which are introduced for monitoring the temperature distributions around the input couplers and for measuring the cavity alignment. The thermal performance of the cryostat will be confirmed experimentally, when the cryostat is readied for a cool-down test.

Table 1: Heat load estimates for a 13 m long cryomodule.

	Static losses (W)	Total losses (W) (RF on)
2 K	10.1	24.1
5-10 K	15.2	16.7
80-90 K	123.2	140.2

TITANIUM AND STAINLESS-STEEL JOINT

The helium vessel of the modified TESLA cavity is made of titanium. This titanium cavity enclosure has to be connected to the stainless-steel cooling line. We are developing a technique for titanium and stainless-steel joint for that purpose. Two bonding methods are being examined: a friction welding and a hot isostatic pressing (HIP). In the friction welding method, optimization of the welding condition was mainly studied. In the HIP method the choice of insertion metal and the optimum HIP condition were surveyed. Tensile tests of many samples have been performed at 300 K and 80 K. Some samples were broken in the boundary of the joint, and some were broken in the base metal during the test. The tensile strengths of the joints are in the range of 380-490 MPa (at 300 K) and 500-730 MPa (at 80 K). No distinct differences of the tensile strengths have been found between the two bonding methods. Tests for leak tightness of pipe-shaped joints have been also performed at 2 K with very good results (no leaks).

Figure 3: Sample of friction welded Ti-stainless steel joint and the broken samples after a tensile test.

MAGNETIC SHIELD

A source of residual loss of a superconducting cavity is DC magnetic fields in the vicinity of the cavity. To obtain the highest Q_0 a cavity must be well shielded from the earth's field. Consequently, the magnetic shielding technology is an important aspect of the cavity cryostat design. As a first step of development in this area, we have performed permeability measurements of shield materials in low magnetic field conditions. Figure 4 shows the results that have been obtained at three different temperatures: room temperature, liquid nitrogen temperature and liquid helium temperature. The mu-metal is a commercially available standard shield material which is used at high energy physics experiments. The iron is a pure iron steel used for the yoke of electromagnets. The permalloy-PC is a standard shield material used for shield room fabrication and the permalloy-R is a special shield material for low temperature applications. The results indicate the following: 1) the permalloy-R has a largest permeability at low field and the next is the permalloy-PC; 2) the permeability of these materials decreases with the temperature; 3) iron is not useful for shielding the earth's field of ~50 μT. However, although the permalloy-R has better characteristics as the shield material of the cavity cryostat, it is not easily available commercially at present. Therefore, we have selected the permalloy-PC for the STF cryostats.

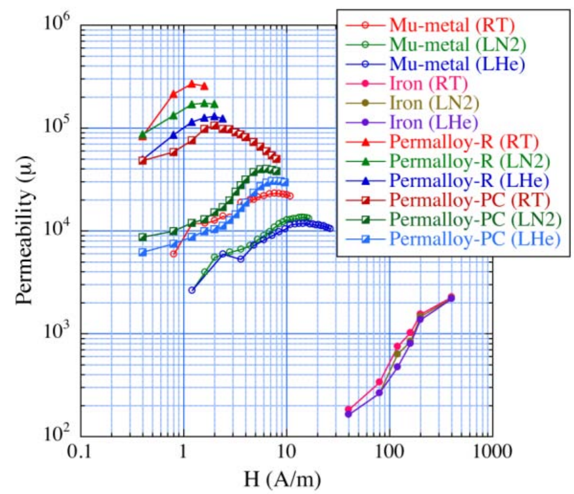

Figure 4: Permeability of shield materials.

SUMMARY

KEK has started the fabrication of a STF cryomodule, which consists of two 5-m long cryostats. Each cryostat accommodates four 9-cell cavities, aiming at 35 MV/m and 45 MV/m. We are planning to perform cool-down tests of the cryostats next year. Through fabrication and testing, we would like to make surveys on the issues to address in the next stage of STF and to develop a cryostat design better optimized for ILC.

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