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TESLA TEST FACILITY ALTERNATE CRYOSTAT DESIGN

T.H. Nicol

Fermi National Accelerator Laboratory
Batavia, IL, 60510, USA

ABSTRACT

Collaborators on the design of a Tevatron Superconducting Linear Accelerator (TESLA) are working toward construction of a test cell consisting of four full length cryostats, 12 meters long, each consisting of eight, 9-cell superconducting RF cavities. The purpose of this facility is to test all aspects of the accelerator system design; vacuum, cryogenics, RF, and electron source, prior to initiating construction of the full linac. The design for these cryostats pose many interesting challenges to cryostat designers. The systems must be capable of supporting all eight cavity structures within tight alignment tolerances, impose very low thermal heat loads on the 1.8K cryogenic system, provide strength and stiffness to resist structural loads during fabrication, shipping, and installation, and be manufactured at low cost. Several design options are being explored, each of which attempt to address requirements imposed by the reference design guidelines. This paper describes the design and analysis of one design alternative.

INTRODUCTION

During the course of early work by the TESLA collaboration, two working groups formed charged with the design of cryostats for use in the TESLA Test Facility (TTF). One group worked toward final development of ideas originating at DESY prior to the formation of the full collaboration. A second group worked on ideas based on the collective experiences gained during development of various cryostats at Fermilab, CEN-Saclay, DESY, INFN-Frascati, and E. Zanon SPA. The latter is an Italian industrial company which fabricated cryostats for HERA at DESY. This paper describes the baseline

Table 1. Cryostat Miscellaneous Design Parameters	
Heat load to 1.8K	3 W
Heat load to 4.5K	14 W
Heat load to 70K	80 W
Vertical dynamic load	1 g
Lateral dynamic load	1 g
Axial dynamic load	1.8 g
Primary structural resonance	25 Hz
Cavity alignment tolerance	± 0.5 mm

design, now fully developed and being fabricated for use in TTF as well as alternatives to various elements of that design in various stages of completion which are available for use if full testing of the baseline indicates any need for further development. Some of the more critical design specifications applicable to any cryostat design effort are outlined in Table 1.

OVERVIEW OF THE BASELINE DESIGN

The baseline design is described in the literature, but is briefly outlined here for reference.^{1,2} Figure 1 illustrates a typical cross section through the

Figure 1. Baseline cryostat cross section

Figure 2 Baseline cryostat design longitudinal view

baseline cryostat. Figure 2 illustrates a longitudinal view of the same design. These figures are similar to, but not necessarily identical to the final design and do not include a depiction of the quadrupole due to lack of detail by this author.

Each cryostat contains eight superconducting RF cavities, their respective helium containment vessels, RF tuning systems, and input couplers, a gas helium (GHe) return header, two thermal radiation shields, cryogenic service pipes and connections, a structural support system, a single superconducting quadrupole, and vacuum vessel. The GHe return tube is attached to the vacuum vessel by means of three support posts similar to those developed for use in the Superconducting Super Collider (SSC) dipole magnets. The posts also serve to support the 4.5K and 70K thermal radiation shields, multilayer insulation, and cryogenic pipes. The cavities, helium vessels, and quadrupole are all hung from the GHe return tube. Input couplers which serve as coaxial connections between the RF system and the cavities are attached to one end of each cavity at each of the eight internal cavity interconnections. By virtue of there being three external supports and the use of the GHe return as a structural girder, the design of the input couplers must accommodate up to 15 mm of axial contraction during cooldown of the cryostat assembly.

GOALS OF THE ALTERNATE DESIGN

Alternatives to the baseline design have been encouraged throughout the collaborative effort as a means of ensuring that options exist should they become necessary at some point in the project. The following represent the main goals of the alternate cryostat design effort as well as a brief rationale for each. The content of the goals do not represent areas of concern with the baseline design, but rather are areas in which different design philosophies can be exercised without making significant perturbations to the general cryostat cross section.

- The design should accommodate a rigid or nearly rigid input coupler. This requires a minimum of four and possibly five supports and most likely implies "back-to-back" mounting of the input couplers, that is, two couplers at every other internal interconnect as opposed to one coupler at each internal interconnect as in the baseline design. The hope is that by minimizing the axial contraction during cooldown at the input coupler locations one can simplify the design of the coupler itself. These devices are very sophisticated and are prone to sparking and multipacting, some of

which may be due to bellows required to accommodate axial movement. No design may be truly rigid due to radial shrinkage and required allowances for assembly tolerances, however, flexibility requirements for these allowances are small.

- The design should attempt to structurally decouple the GHe return tube and the cavity vessels. Some concern exists that thermal distortions during cooldown will affect assembly alignment of the cavities.³ It seems plausible to connect the cavity and helium vessel assembly directly to the supports as a means of minimizing changes in cavity alignment during cooldown.
- An attempt should be made to minimize the liquid helium inventory. Early helium vessel designs were substantially larger in design than the cavity to allow for two-phase flow over the top of the cavity. This resulted in a helium inventory significantly higher than that necessary to maintain the cavity temperature at 1.8K. Very early in the process of developing alternate designs, the helium vessel diameter was reduced significantly and a small connecting tube added above the vessel to allow for the same two-phase flow.⁴ Since that time a very similar configuration was adopted for the baseline design. The revised vessel is shown in Figure 1. The large annular space around the helium vessel was necessary for the earlier design and has been retained in the TTF modules to minimize required design changes in other system components.
- The overall cryostat (vacuum vessel) diameter should be reduced as much as possible out of consideration for reducing overall cost and facilitating tunnel accessibility.
- Every effort should be made to minimize cost. It is safe to say this has also been a goal of the baseline design. Cost minimization in the alternate design is simply a continuation of that same philosophy.
- The axial and lateral suspension stiffnesses should be made as high as possible, while maintaining heat loads to the thermal intercepts at or below design limits. Although difficult to quantify specific goals, recent design studies and field tests on SSC dipoles at Fermilab indicate that high suspension system stiffness simplifies alignment and minimizes perturbations to system components during shipping and handling. Flexure of the GHe return defines the lowest frequency dynamic modes of the internal cryostat structure.⁵ If the number of supports are increased and the GHe return is structurally decoupled from the cavity helium vessels it is possible to drive up the lowest modal frequencies.

CONSTRAINTS ON ALTERNATE DESIGNS

The goals in any design project must be consistent with a set of design constraints. The alternate cryostat design is no different. The constraints listed below represent a starting point for any responsible cryostat design effort which is aimed at providing alternatives to the TTF baseline.

- Any new design must be compatible with cavities being procured by DESY and INFN.
- The helium vessel should be modeled after that currently being designed at DESY, i.e. it should be of the same material, be nearly the same diameter, and interface to the cavity in the same way.
- The helium vessel and cryostat layout should be compatible with the cold tuning system being developed at CEN-Saclay.
- The piping system in any new design must be compatible with the TTF cryogenic system. It is too severe to dictate that any new design have exactly the same interconnect. However, it should have the ability to connect to a baseline cryostat with an adapter assembly.
- The design must include consideration of the quadrupole being designed at DESY.
- Cryomodule-specific design requirements must be met. For example, shipping and handling requirements must be met, heat loads should be consistent with those outlined in the design criteria, pipe sizes should be consistent with required flow rates, etc.

OVERVIEW OF THE ALTERNATE DESIGN

Figures 3 and 4 illustrate a cross section and longitudinal view of the alternate cryostat design for TTF. Clearly they are similar to their baseline counterparts in Figures 1 and 2, but there are some important differences. A detailed comparison of the baseline and any alternate cryostat design is not possible due to the fact that few detailed alternate designs exist. However, it is possible to describe design differences in general terms. The primary departures in design originate in the orientation and location of suspension system components. This departure is key because it gives rise to the ability to control cooldown contractions, the ability to decouple the GHe return from the balance of the internal components, and the ability to control the dynamic response.

As described above and shown in Figures 1 and 2, the baseline uses three supports located on the top of the vacuum vessel and connected to the GHe return at three points. The center attachment serves as the axial anchor point. The outboard two attachments are fixed vertically and laterally, but are free to slide axially to accommodate cooldown contraction. The cavity helium vessels are suspended from the GHe return by hangers.

In contrast, the alternate design uses five supports fixed rigidly to the bottom of the vacuum vessel. As shown in Figure 4, this allows rigid connections at one end of each cavity helium vessel which, in turn, enables one to contemplate couplers which need be flexible at levels significantly less than the 15 mm required by the baseline design. The GHe return is attached to a mounting bracket attached to the top of each support and allowed to "float",

Figure 3. Alternate cryostat design end view

decoupled structurally from the cavity helium vessels. As a direct result of the bottom mounted supports, the effective stiffness of the suspension is increased from the point of view of the cavity vessels due to the reduced lever arm between the base of the support and the centerline of the cavity. The individual supports for each design are identical with the exception of the composite tube thickness. The thickness is scaled by the number of supports so that the conduction heat loads for each case are identical.⁶

There are of course potential problems with the alternate design. Support for the free ends of the cavity helium vessels and allowance for cooldown contraction are not as straightforward as in the baseline due to the alternate design not relying on the GHe return for structural support. The ends of the cavity helium vessels between supports must be connected to each other by a bridge to effect a rigid interconnection. In addition, the increased number of supports implies more penetrations through the thermal radiation shields, more supports, and more penetrations in the vacuum vessel. The advantages

Figure 4. Alternate cryostat design longitudinal view

in terms of simplified input couplers and greater suspension system stiffness may prove worth the added complications. A responsible determination can only be made after a detailed design, analysis, and cost estimate is done.

SUMMARY

Fabrication of baseline design cryostats for TTF is well under way. The first completed cryomodule is scheduled to be shipped to DESY from Zanon in Schio, Italy in the fall of 1995. Every expectation exists that the baseline design will perform its intended function well and will meet the design specifications. As with any design and production process, the possibility exists that changes will be indicated for either the balance of the TTF cryomodules or for production modules for the remainder of the linac. In the event that either of those things happen, it is hoped that the body of work done on alternate designs can serve as a basis for implementing any required changes or incorporating added functionality.

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