SS HELIUM VESSEL DEVELOPMENT FOR 1.3 GHZ SRF CAVITIES AT FERMILAB*

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Abstract

As part of its SRF Cavity Development efforts, Fermilab is developing a stainless steel helium vessel as an alternative to the current titanium vessel. Stainless steel (SS) components will be less expensive, easier to manufacture, and not require controlled atmosphere welding. Several obstacles exist which Fermilab engineers believe can be overcome in a way that does not require active tuning of the cavity during the cool down process. The major obstacles and solutions are presented here.

INTRODUCTION

Traditionally, titanium helium vessels have been used for Superconducting Radio Frequency (SRF) cavities due to its compatible thermal expansion coefficient with niobium cavities.

Stainless steel introduces two main problems in the design: it shrinks twice as much as niobium, and it cannot be easily welded to niobium.

An R&D program is ongoing at Fermilab to design, produce and test a stainless steel vessel for an ILC-type nine-cell elliptical cavity. The proposed design includes a braze joint between the end cell of the cavity and the stainless steel vessel, a modified end iris configuration, a new transition joint between the cavity end ring and the vessel, and a dedicated warm tuning procedure to avoid cavity plastic deformation.

STAINLESS STEEL VESSEL DESIGN

The design of the stainless steel vessel is based on the latest design of the titanium helium vessel developed at Fermilab for the ILC-type nine-cell cavities, with its coaxial blade tuner. The vessel and the tuner material have been changed from titanium to stainless steel.

Titanium helium vessels have been specified because the coefficient of thermal contraction of titanium is close to niobium. Thermal calculations show that from 293 K to 4 K the titanium shell undergoes a 1.5 mm length contraction, while a 316L SS shell undergoes a 3.0 mm length contraction [1].

The 1.5 mm difference between the niobium and the stainless steel has the potential to permanently deform the cavity and prevent it from returning to the nominal tuned position. Different designs have been proposed to compensate for this differential contraction, including active compensation during the cool down of the cavity using the tuner.

Active tuning requires a sophisticated control and instrumentation system that functions over a wide temperature range. An even more sophisticated system would be required to safely compensate for all the cavities in a cryomodule cooling at different rates and times. A number of additional feed-throughs would be required into both the vacuum and helium volumes.

In the Fermilab design, active tuning is eliminated by the mechanical process of stretching the cavity 1.5 mm at room temperature during helium vessel and tuner assembly. The two-piece helium vessel shell is welded at each end to the stainless steel cavity end plates. The tuner is assembled across the helium vessel shell gap and threaded rods are adjusted to widen the gap and stretch the cavity. When cold, the stainless steel shell contracts 3.0 mm, bringing the cavity back to its nominal tuned position.

CAVITY TUNING PROCEDURE

SRF cavities as supplied by the vendors need to be tuned. This tuning is accomplished by systematic stretching and compressing the individual cells until the desired tuned length is achieved. This process is required to deform the cavity shape and bring it close to the ideal frequency and field flatness, and shows that cavities are routinely stretched in their elastic range by even more than the 1.5 mm proposed by the SS helium vessel design.

A test was done on cavity AES-002 [2] where it was tuned, stretched, released, and re-measured. It was found that this cavity was able to be stretched 2.50 mm while remaining in the elastic range and returning to the nominal field flatness. Stretching again to 2.83 mm produced the first deviation in return measurement, yet still within the normal range for fully functional cavities. Actual testing of a cavity in a SS helium vessel is scheduled to follow in Fermilab's horizontal test cryostat.

A finite element simulation was also performed to simulate the tuning procedure in which the cavity (without the final weld to the vessel) was stretched 5.0 mm and released. This step evaluates the plastic strain and permanent elongation expected during this phase of tuning.

BRAZE JOINT DESIGN

In the titanium design, the niobium cavity is e-beam welded to a niobium-titanium transition piece, and then e-beam welded to a titanium ring which in turn must be controlled-atmosphere welded to the titanium shell (Figure 1). In the SS design, the niobium cavity will be brazed to a SS plate which can be welded in air to the SS shell.

The Fermilab niobium to SS braze transition is modelled after a similar Jefferson Laboratory joint [3]. In the Fermilab design, the last end cell is modified to move the e-beam weld from the iris to the point where the

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stiffening ring would have attached. This allows a flat SS plate positioned to avoid interference with the main coupler, and allows a single e-beam weld to the half cell from one side (Figure 2). A thermal analysis (see Figure 3) shows that even at an accelerating gradient of 35 MV/m, this change is acceptable [4]. An electrical field analysis shows that this weld location is preferable to an iris weld [5].

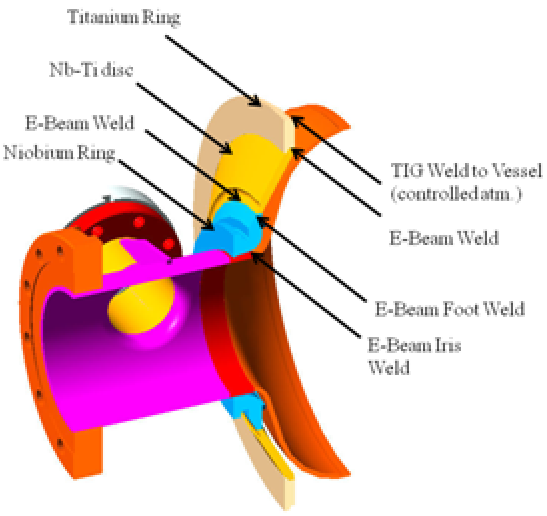

Figure 1: Section of titanium vessel end group.

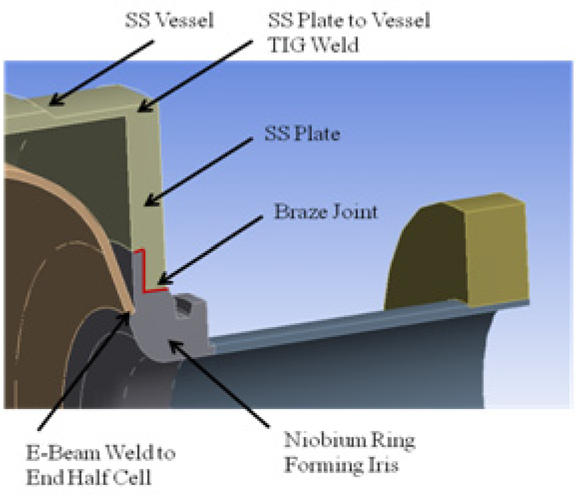

Figure 2: Section of SS vessel showing the braze joint at the main coupler end.

Design Specifics

The Fermilab braze design substitutes a flat SS plate for the conical niobium-titanium transition piece. Analysis shows that this plate is stiff enough to transmit the tuning forces to the cavity even more efficiently than the conical piece did. Fermilab has designed and built twelve test-braze components (Figure 4), and procured brazing materials of three different alloys: 35Au-65Cu, 50Au-50Cu, and Cu-OFHC. Braze testing is underway and mechanical analysis of the resulting braze joint is in process. The qualification of braze joint is to be done according to ASME Section IX, part QB brazing. A fully brazed assembly will be visually examined for any defects, and then subjected to a helium leak test. The assembly will also be subjected to a series of cold shock tests in liquid nitrogen followed by a leak test to ensure that there are no voids and that the cold shock did not open new leak paths.

In combination with these tests, test specimens are to be sectioned from the brazed assembly for micrographic examinations and tensile tests to measure the strength of the joint. Furthermore, radiographic examination of the full brazed joint is planned to ensure the absence of voids that can undermine the strength of the joint. The qualification process will include a combination of these tests in specimens as required by the code.

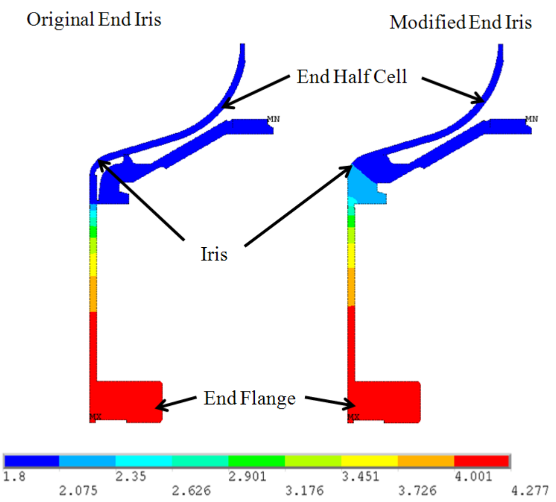

Figure 3: Comparison of thermal analysis results.

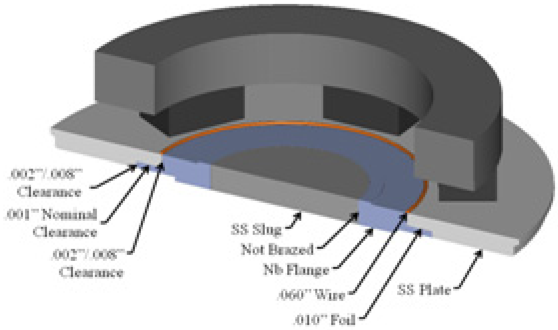

Figure 4: Section of the braze assembly setup.

Proximity of Subsequent Welds

Another concern with the redesigned end cell attachment was the proximity of the e-beam weld to the root of the braze joint. A test fixture was designed, built, and used to verify that the e-beam weld will not cause the braze material to melt. The solidus temperature of the braze metal is as low as 955 C. The fixture was tested at Sciaky with thermocouple and brazing powder monitoring. Even with high beam power and multiple passes, no brazing powder melting occurred and the thermocouple reading at the root of the braze joint never exceeded 233 C.

SS VESSEL STRESS ANALYSIS

The preliminary results shown below are based on operational loads, and are intended to illustrate actual behavior; the final analysis with ASME Code, Section VIII, Div. 2, Part 5 procedures will use an LFRD approach with factored loads, and address several possible failure scenarios in detail.

A 3-D elastic-plastic model has been created and includes the cavity, vessel, and simplified implementations of both the slow blade tuner and fast piezo tuner (Figure 5). For this analysis, detailed simulation of the blade tuner is not required; instead, it is represented by a cylindrical shell with the same material properties and overall mass as the real tuner. The fast tuner system, composed of two piezo actuators positioned on the neutral axis of the cavity, has been modeled as simple stainless rods.

The analysis includes the following steps:

- At 293K, extend the tuner 1.5 mm to stretch the cavity to simulate the pre-cooling procedure;
- Cool down the cavity to 2 K;
- Extend the tuner 1.5 mm, to simulate the maximum available tuning range during operation (Figure 6);
- Pressurize the vessel to 0.35 MPa.

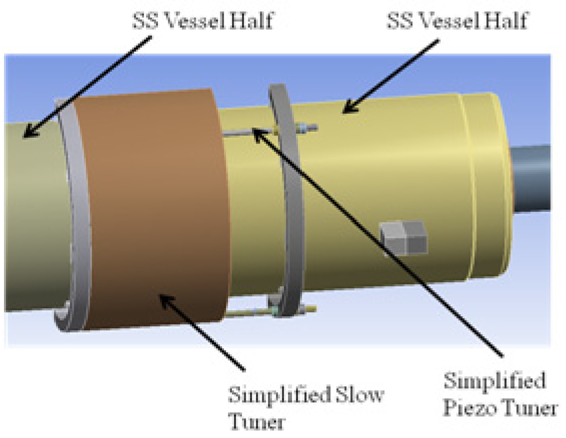

Figure 5: Section showing simplified tuner model.

The results indicate that no permanent deformation occurs in the cavity during operation, and that safe operation at 2 K and 0.35 MPa can be expected. The maximum elastic stress in the niobium cavity occurs in the iris of the end cells, and is less than 60% of the allowable stress. The maximum elastic stress in the stainless steel occurs in the bellows between the SS vessel halves, and is less than 90% of the allowable stress.

The maximum force on each piezo actuator is 6 kN, 50% of the allowable piezo load limit.

The simulation also addresses the behavior of the braze joint, and shows that the maximum shear stress and normal stress in the braze joint are within allowable limits (Figure 7).

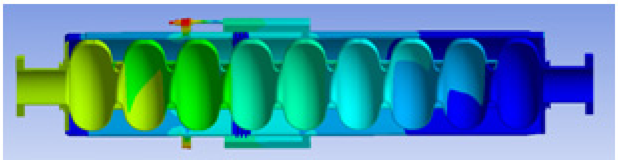

Figure 6: Cavity deformation after cool down and tuner extension.

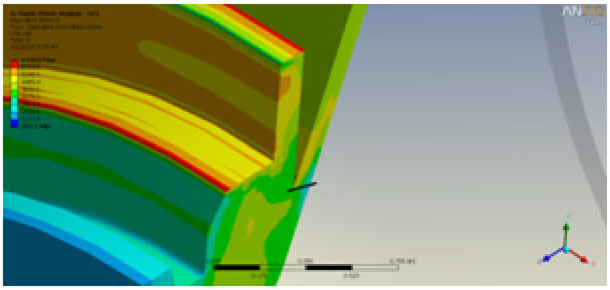

Figure 7: Stress in braze joint surfaces.

SUMMARY

Initial investigation and analysis have shown that the SS vessel is feasible for ILC-type nine-cell elliptical cavities. Currently, braze testing is underway and after a successful qualification, a pressure test will follow. Subsequently a cavity with modified end group design will be built, dressed with a SS vessel and tested under actual operating conditions. The finite element studies combined with mechanical tests have thus far shown that the cavity, tuner, and braze joint fall within safe margins of operation.

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