WELDING HELIUM VESSELS TO THE 3.9 GHz SUPERCONDUCTING THIRD HARMONIC CAVITIES*

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Abstract

The 3.9 GHz 3rd harmonic cavities are designed to serve as compensation devices for improving the longitudinal emittance of the free-electron laser FLASH at DESY. These cavities operate in the TM010 mode, and will be located between the injector and the accelerating cavities. Fermilab is obligated to provide DESY with a cryomodule containing four 3rd harmonic cavities. In this paper we discuss the process of welding helium vessels to these cavities. Included will be a description of the joint designs and weld preparations, development of the weld parameters, and the procedure for monitoring the frequency spectrum during TIG welding to prevent the cavity from undergoing plastic deformation. Also discussed will be issues related to qualifying the dressed cavities as exceptional vessels (relative to the ASME Boiler and Pressure Vessel Code) for horizontal testing and eventual installation at DESY, due to the necessary use of non-ASME code materials and non-full penetration electron beam welds.

INTRODUCTION

The procedure for dressing a 3.9 GHz 3rd harmonic cavity with a helium vessel entails three welds in the following sequence: (1) Electron-beam (EB) weld of the helium vessel titanium shell to the large Nb55Ti conical disk, (2) EB weld of the titanium spacer ring to the small Nb55Ti conical disk, and (3) TIG fillet weld joining the titanium spacer ring to the titanium shell of the helium vessel. The weld joint geometry is shown in Figure 1. Full penetration EB welds are not allowed due to the possibility of vapor or weld debris deposition on the exterior surface of the cavity cells, thus potentially degrading the heat transfer rate from the cavity to the surrounding helium bath. The objective was to attain sufficient penetration to insure structural integrity and operational safety.

WELD PARAMETERS

Weld samples were developed to generate final welding parameters. Each sample was cut, polished and etched. Figure 2 shows a final sample of the EB weld joining the helium vessel shell to the large conical disk. Penetration depth achieved is approximately 3 mm. Figure 2 also shows a final sample of the EB weld joining the titanium spacer ring to the small conical disk. Penetration depth is approximately 2.25 mm. Before TIG welding, a titanium filler ring will be inserted to span the gap between the

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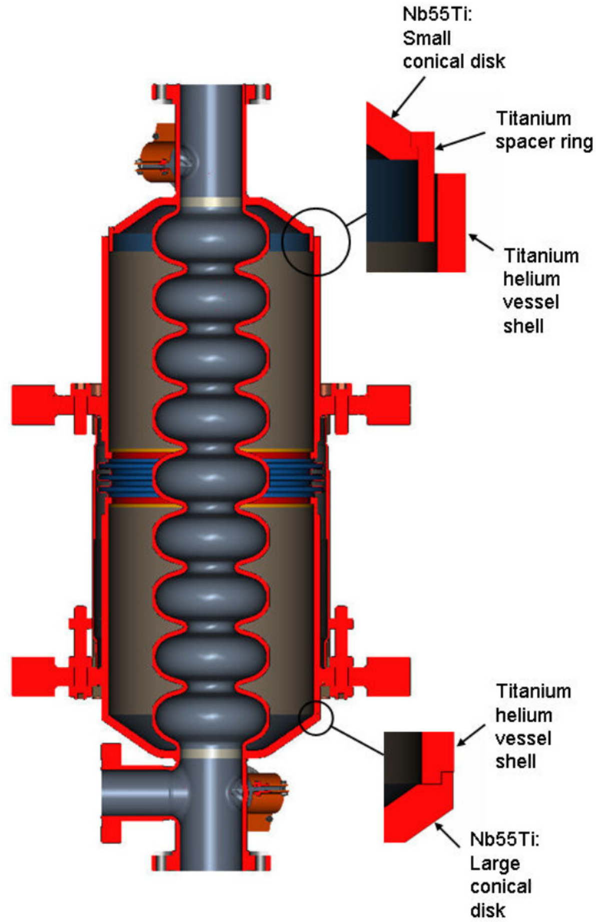

Figure 1: Breakaway view of dressed cavity showing the weld joint geometry.

spacer ring and the inner wall of the helium vessel shell. This is shown in Figure 3. The filler ring helps align the cavity and the helium vessel, and supplies material to augment the TIG fillet weld. The filler ring is fusion welded to the spacer ring on the cavity and the helium vessel shell, thus closing the entire circumferential gap between the helium vessel and the cavity. A TIG fillet weld will complete the process. Figure 3 shows the final sample for the TIG fillet weld.

WELDING PROCEDURE

After all components are properly cleaned and no more than twenty-four hours before EB welding, the cavity and helium vessel are assembled in a specially designed welding fixture in a clean room environment as shown in Figure 4. The entire assembly is enclosed in a polyethylene bag, sealed, and backfilled with nitrogen for transportation to the EB welding site.

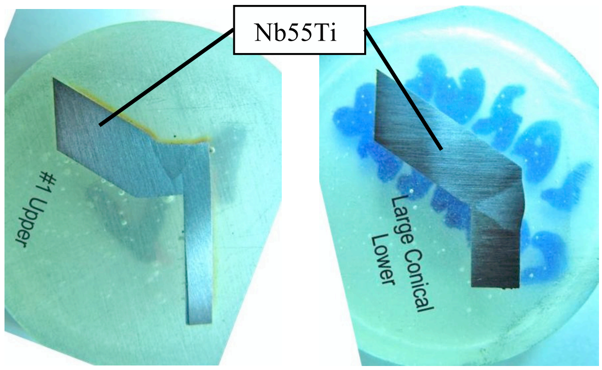

Figure 2: EB weld samples of helium vessel Ti shell to large conical disk (right), and Ti spacer ring to small conical disk (left).

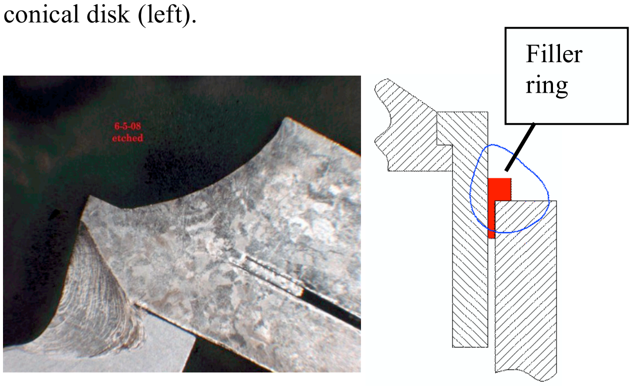

Figure 3: Drawing on the right shows titanium filler ring inserted in the gap between the spacer ring and the inner wall of the helium vessel shell. On the left is the TIG fillet weld sample generated using final weld parameters.

Following the completion of the EB welds the distance between the blade tuner flanges is measured at several locations to verify whether they are parallel. Nuts on the support rods connecting the blade tuner flanges (see Figure 4) can be adjusted for minor corrections. If the blade tuner flanges are significantly out-of-parallel, the cavity may have to be bent. At this point the titanium filler ring is inserted into the remaining gap between the cavity and the inner wall of the helium vessel shell.

TIG Welding

TIG welding is done in a glove box purged with argon. The oxygen level is required to be less than 20 ppm for welding to proceed. Figure 5 shows the glove box configuration. Feedthroughs and hose lines are installed to pass a flow of argon through both the cavity and the helium vessel while TIG welding is in progress. Argon to the cavity passes through a 0.01 micron ceramic filter to avoid contamination. Once the helium vessel is tack welded to the cavity, the support rods are removed from the blade tuner flanges so that the bellows can relieve limited thermal expansion.

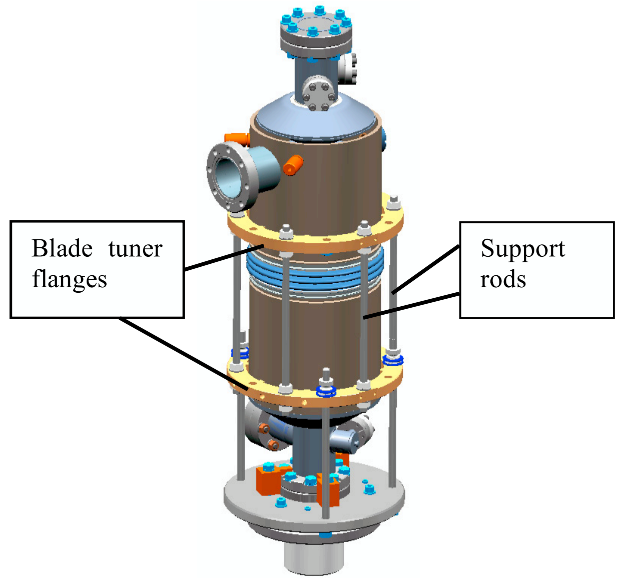

Figure 4: Cavity with helium vessel assembled in EB welding fixture.

TIG welding progresses in segments to avoid overheating and plastically deforming the cavity. A cool down period of ~ 15 minutes is allowed after each TIG weld segment. A continuous flow of argon gas is passed through both the cavity and the helium vessel during welding to facilitate cooling. The frequency spectrum of the cavity is monitored after every step of the welding process to insure the elastic limit of the cavity is not exceeded. Figure 6 shows a plot of the frequency response during TIG welding of cavity No. 7. A close-up view of a

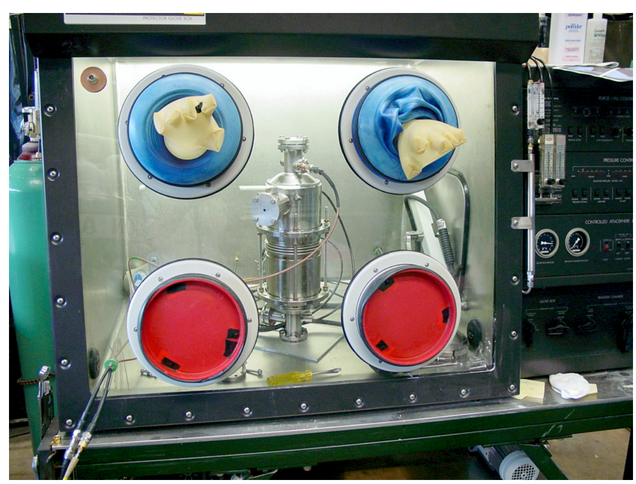

Figure 5: Glove box with cavity installed for TIG welding. Note the cables for monitoring the frequency spectrum of the cavity, and the lines for passing argon through the cavity and helium vessel during welding.

completed TIG weld on one of the cavities is shown in Figure 7.

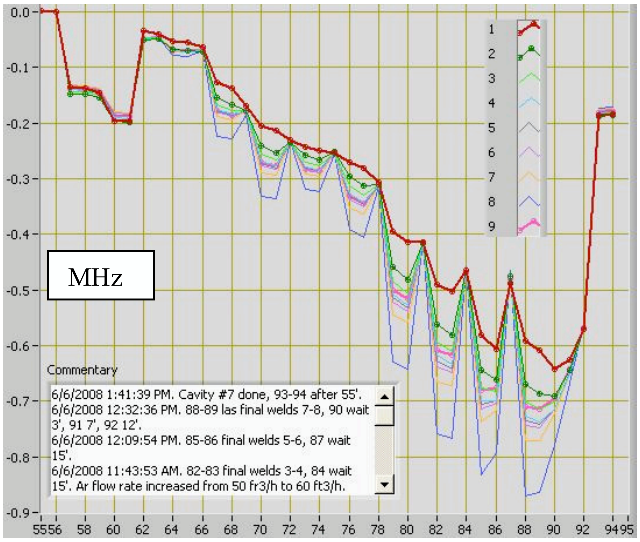

Figure 6: Frequency spectrum of cavity No. 7 recorded during TIG welding. The horizontal axis is time.

Figure 7: Close-up view of 3rd harmonic cavity with helium vessel after TIG welding is complete.

RESULTS

A total of eight 3rd harmonic cavities have been fabricated, including one prototype. Five have been dressed (including the prototype). The two EB welds have had no significant effect on the tune of any of the five dressed cavities. This was expected because the cavities were not restrained during EB welding. Figure 8 shows plots of the field distribution for cavity No. 7 before and after TIG welding. Note that the field flatness is basically unaltered. This result is typical for the cavities that were TIG welded following the procedure described in the preceding section.

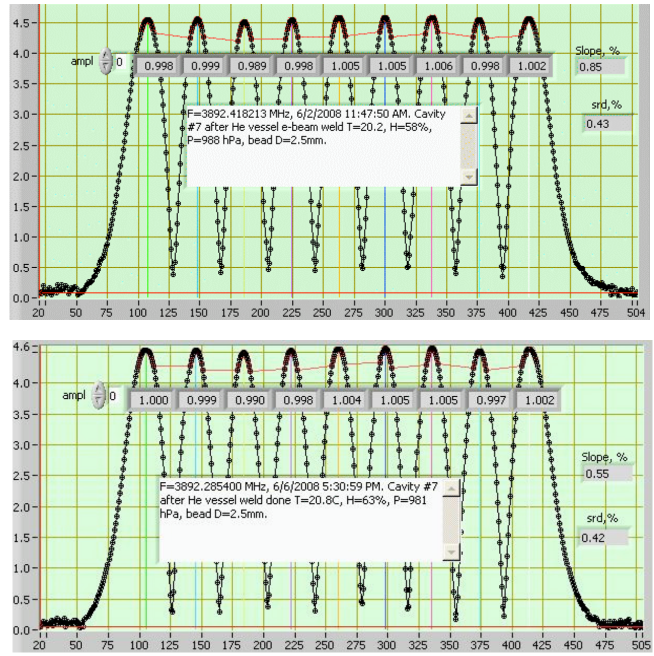

Figure 8: Field distribution of cavity No. 7 after EB welding and before TIG welding (top), and after TIG welding (bottom).

PRESSURE VESSEL ISSUES

Each dressed cavity is defined by Fermilab safety standards as a pressure vessel. By definition, a pressure vessel follows the guidelines of the ASME Boiler and Pressure Vessel Code. As part of the Fermilab safety standard, an engineering note must be generated and submitted for approval to an internal Fermilab review committee. Once the note is approved, the dressed cavity is qualified for horizontal testing and eventual shipment to DESY. Because of the design and welding procedure of parts of the dressed cavity, these vessels are defined as "Exceptional Vessels" relative to the Fermilab safety standards. The major issues are: (1) Niobium and Nb55Ti are not ASME code certified materials, and (2) EB welds joining the helium vessels to the cavities are not full penetration. Furthermore, the published data on the mechanical properties of niobium and Nb55Ti at cryogenic temperatures are not entirely consistent at present. The objective in the engineering note is to demonstrate the vessels are safe at a level equivalent to the ASME code. The ASME Boiler and Pressure Vessel Code, Section VIII, Divisions 1 and 2 were used for guidance. FEA was done using the most conservative material properties in the published literature. Each dressed cavity will be pressure tested to 2.3 bar; i.e., 1.15 times the MAWP of 2.0 bar. To address these issues in the future, Fermilab has established an internal task force to discuss aspects of pressure vessel safety relative to the design, documentation, and review of SRF accelerating components.