WELDING A HELIUM VESSEL TO A 1.3 GHz 9-CELL NITROGEN DOPED CAVITY AT FERMILAB FOR LCLS-II*

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Abstract

Fermilab has developed a TIG welding procedure that is used attach a nitrogen doped 1.3 GHz 9-cell niobium (Nb) cavity to a titanium (Ti) helium vessel. These cavities will be used in the two prototype cryomodules for the Linac Coherent Light Source upgrade (LCLS-II) at SLAC National Accelerator Laboratory. Discussion in further detail will include setting up TIG welding parameters and tooling requirements for assembly and alignment of the cavity to the helium vessel. The weld designs and glovebox environment produce the best quality TIG welds that meet ASME Boiler and Pressure Vessel Code. The cavity temperature was monitored to assure the nitrogen doping is preserved, and RF measurements are taken throughout the process to monitor the cavity for excessive cell deformation due to heat loads from welding.

INTRODUCTION

The procedure for dressing a 1.3GHz cavity with a Ti helium vessel entails five steps with three welds in the following sequence: (1) Alignment of cavity and helium vessel on the assembly fixture, (2) Tack weld assembly in fixture and load into the welding glovebox, (3) circumferential TIG weld of the cavity to the helium vessel at the fundamental power coupler (FPC) end of the cavity, (4) circumferential TIG weld of the bellow cuff to the helium vessel at the tuner/field pick-up end of the cavity, (5) circumferential TIG weld of the bellow cuff to the Nb55Ti conical disk at the field pick-up/tuner end of the cavity. The welding procedure is followed by a vacuum leak check of the helium circuit, a pressure test to slightly above the maximum allowable working pressure (MAWP), and a follow-up vacuum leak check. The weld joint geometry is shown in Figure 1. Backing rings/ledges were incorporated on all TIG welds to avoid weld vapor deposition on the exterior surfaces of the cavity cells that could potentially degrade cavity performance.

TIG WELD QUALIFICATION

In order to qualify our TIG welding process, welders, and weld joints for ASME conformity, exact weld samples of each joint were fabricated. These samples were welded using the same process and environment as the real cavity/helium vessel. Upon completion, the samples were sent to an independent company for radiograph inspection and were processed in accordance with ASME Section VIII. Once the “Golden Sample” of each joint was achieved the next step in the assembly process was approved.

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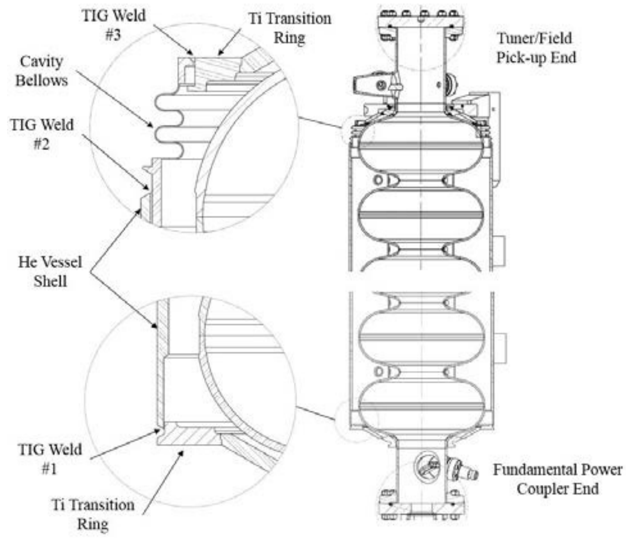

Figure 1: Section view of dressed cavity showing the weld joint geometry.

CAVITY TO HELIUM VESSEL ALIGNMENT

After all of the components are properly cleaned the cavity, helium vessel, and bellows are mounted in the assembly fixture shown in Figure 2. The assembly fixture function is similar to the design used to insert a coldmass into a vacuum vessel. The cavity is positioned on a long arm and is attached to the survey rings on the end groups.

The fundamental power coupler port on the cavity is aligned in the horizontal position and parallel to the moving cart using a bracket that engages the coupler flange. The helium vessel is mounted to the cart supported by the bearing lugs and travels along the rail track with bearing rollers. This design enables us to achieve the perpendicularity requirement of the coupler flange to the helium vessel bearing support lugs.

The helium vessel is rolled over the cavity until there is engagement of the vessel to the titanium transition ring on the FPC end of the cavity. The bellows at the tuner/field pick-up end (installed over arm prior to mounting the helium vessel) is then slid into place. Once the weld roots are established the fixture is locked to prevent the parts from shifting.

TIG WELDING

Before the aligned cavity and helium vessel can be moved into the glovebox, tack welds are added at the helium vessel joints to further lock the alignment. The "open-air" tacks are performed using a shielded cup on the TIG torch with an argon gas flow set to a 30 second post purge at a rate of 20 cfm. The argon is supplied from the boil-off gas from a 180L ultra-pure liquid argon dewar. Approximately 6-8 tacks are evenly spaced on the two circumferential weld joints discussed earlier.

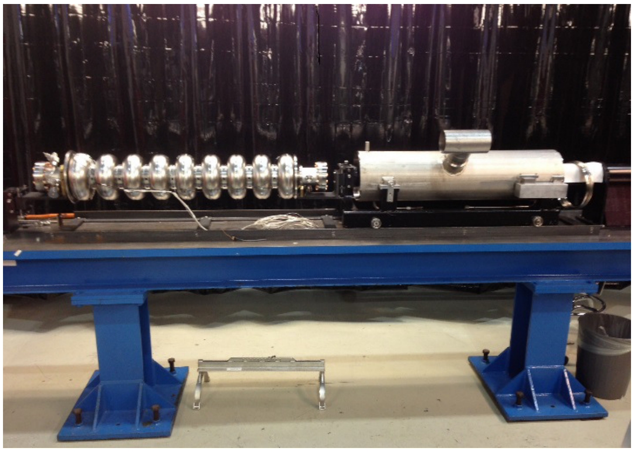

Figure 2: Assembly and alignment fixture.

After the tack welding has been completed, the assembly is ready to be moved into the glove box. Using a crane and a special lifting fixture clamped around the helium vessel, the jacketed cavity is carefully inserted into a 360 degree rotation cage inside the glove box. The vessel is attached to the cage by the four bearing lug mounts on the helium vessel and secured with clamps. Figure 3 shows the glove box configuration.

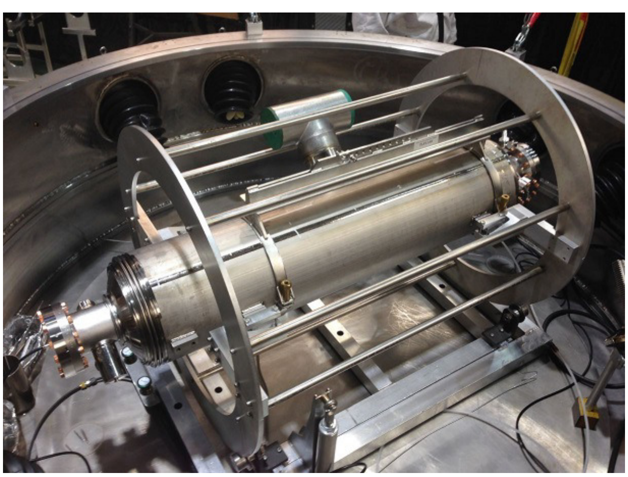

Figure 3: Cavity installed in rotation fixture.

The TIG welding done inside the glove box is operating on three separate and individually controlled argon purges. One line is dedicated for the main dome purge; a second line provides gas flow internal to the helium vessel. This helps expel oxygen molecules trapped inside the helium volume during backfilling process as well as providing a cool gas flow across the exterior surface of the cavity during welding. The third line provides gas for torch cooling. The cables for monitoring the frequency spectrum of the cavity are also attached and connect to feedthrough ports inside the glovebox. The glove box is equipped with a vacuum pump. Once all connections are made, the dome is installed and two pump downs and argon backfills are initiated to achieve the desired atmosphere inside the glove box. Figure 4 show the cavity installation prior to the start of welding.

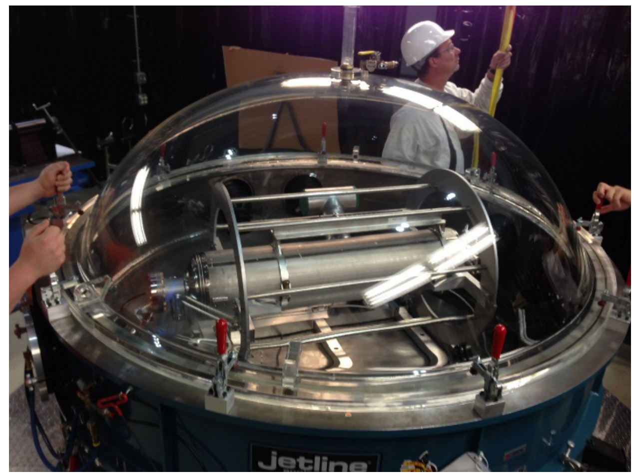

Figure 4: Cavity installed in glove box.

An oxygen monitor is attached to the glove box sampling the atmosphere, once the monitored level reaches 10ppm or less, the O2 level is safe and ready for welding; Figure 5 displays a typical O2 reading during welding. Another consideration prior to the start of welding is the humidity level. Previous cavity dressing's revealed slight discoloration in the welds even when the O2 monitor displayed levels below 10ppm, a hygrometer was placed inside the glove box and revealed that over 20% relative humidity in the glove box can cause problems from water molecules, for this we recommend 15%-20% or less suitable for welding.

Figure 5: Glove box O2 reading.

TIG welding progresses in 1" segments spaced 180 degrees apart to avoid overheating and plastically

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deforming the cavity or degrading the nitrogen doped surface of the cavity. A cool-down period of about 20 minutes is allowed after 3-4 segments have been completed at any given time, the continuous flow of argon gas inside the helium vessel helps facilitate cooling. Figure 6 shows a typical weld being applied in the glovebox.

Figure 6: Welding in the glove box.

The frequency spectrum is monitored during the entire welding process to insure the elastic limit of the cavity is not exceeded. Figure 7 represents a plot of the frequency response during TIG welding of the helium vessel to the cavity. In this figure the frequency measurement at the start of welding is a room temperature measurement and the final measurement is done the following day when all welding has been completes to allow for the cavity to cool back to room temperature. The plot for this cavity reveals about a 12 kHz shift in cavity frequency from start to finish of the dressing operation, which is about average for cavities FNAL has welded.

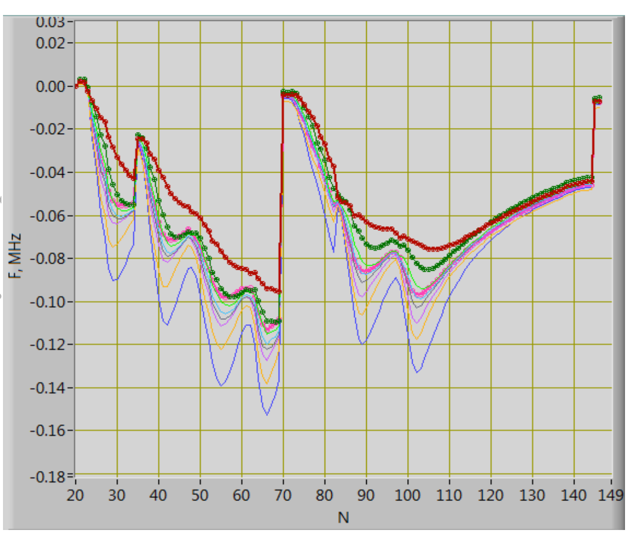

Figure 7: Frequency spectrum of cavity recorded during TIG welding. The vertical axis is F shift in MHz.

Once the first two circumferential welds are fully completed and the cooling period achieved, preparations begin for the final weld shown as weld #3 in Figure 1. For the final weld serious consideration for weld shrinkage was examined. The final circumferential weld of the bellow cuff to the Nb55Ti conical disk was not tacked in the initial steps; this was to allow for weld shrinkage from circumferential welds #1 and #2. This eliminated stresses on the cavity and possible de-tuning effects, it was determined that the bellows at the end of the cavity was the appropriate mechanical device to take the weld shrinkage on weld #3. Shims placed inside the glove box are used to center the cavity in the bellow cuff, they are placed at 12, 3, 6, and 9 o'clock positions with the minimum shim thickness of .003". Once the shims are in position, tack welds are added next to each location, then removed for the final TIG weld operation. Figure 8 are close-up views of the three finished circumferential welds.

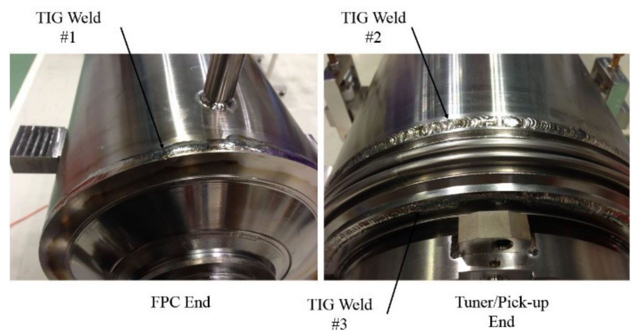

Figure 8: Close-up view of finished TIG welds.

CAVITY "Q" PRESERVATION

Another consideration for the welding process was to preserve the "Q0" of the cavity. LCLS-II requires high Q0 values on the cavities for the performance of the accelerator, the bare cavities are nitrogen doped to help achieve the specification. In order to not degrade the doped surface care was taken to not overheat the cell surfaces. Temperature measurements were taken with a hand held infrared thermometer placed inside the glove box, the measurements were taken at the base of the Nb55Ti conical disk after each weld and recorded for future reference. Figure 9 displays the area of the temperature measurements. This location was chosen because of the proximity of the end half-cell stiffening rings which is the thermal path to the end call from the heat generated by the welds. The highest temperature measurement taken was towards the final welds near TIG weld #3 at 122°F (50°C).

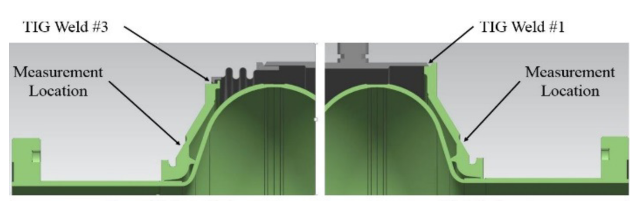

Figure 9: Temperature measurement locations.

Each LCLS-II cavity prior to dressing was tested in the vertical test stand (VTS) to get a baseline of the cavity performance including Q0. Upon competition of the cavity dressing with the helium vessel, it is prepared again for another round of testing in VTS as a dressed unit. The second test will verify the cavity performance which includes comparison of Q0 between the dressed and bare cavity. Figure 10 is an example of the LCLS-II cavities as tested in VTS showing the Q0 vs. Eacc curves before and after dressing.

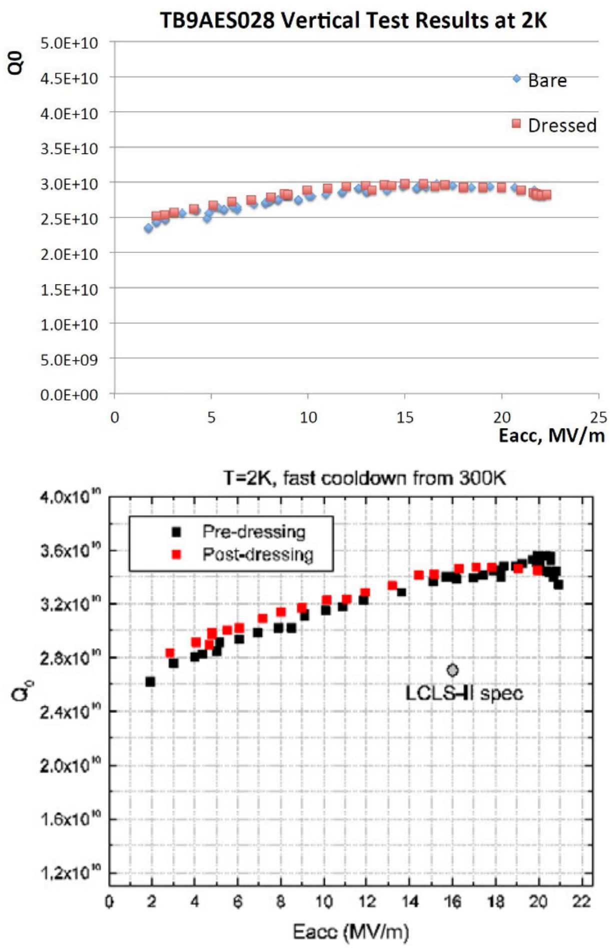

Figure 10: Q vs. E plots for a bare and dressed cavity.

CONCLUSION

Fermilab has dressed 19 high Q cavities for LCLS-II to date; all were VTS tested before and after the TIG welding process. The process described in this paper showed no significant effect on the Q0 or the tune of the cavity.

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