Lessons learned from RF-Dipole Prototype Cavities for LHC High Luminosity Upgrade

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**Original Publication Citation**
[https://doi.org/10.18429/JACoW-SRF2017-TUPB053](https://doi.org/10.18429/JACoW-SRF2017-TUPB053)

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Abstract

The rf-dipole cavity has successfully demonstrated the principles of using a compact cavity operating in TE_{11}-like mode in generating a transverse kick. Several proof-of-principle rf-dipole cavities have been fabricated and the rf tests have demonstrated high transverse gradients. The rf-dipole geometry has been adapted into a square-shaped geometry designed to meet the dimensional constraints for the LHC also maintaining crabbing in both horizontal and vertical planes. Recently, two prototype rf-dipole cavities intended for the test at SPS for have been completed that is designed to accommodate the FPC and HOM dampers. The performance during the rf tests have shown excellent results on achieving the design requirements of operation for the crab cavities for SPS. This paper presents the experiences and lessons learned during the cavity preparation and testing, including process validation, frequency tracking.

INTRODUCTION

A prototype rf-dipole cavity have been designed for the LHC High Luminosity Upgrade [1] to crab the proton beam in horizontal plane. Set of two crabbing cavities will be installed in a single cryomodule to be tested in SPS prior to installation in LHC. Two prototype cavities of SPS-style have been completed successfully with the performance of the bare cavity cryogenic tests exceeding design specifications [2]. The fully fabricated cavity is shown in Fig. 1. The rf tests of both the cavities have achieved transverse kicks of 4.4 MV and 5.8 MV well above the design requirement of 3.4 MV. The corresponding intrinsic quality factors at nominal voltage of 3.4 MV are $8.5 \times 10^9$ and $1.2 \times 10^{10}$ that corresponds to power dissipations of 3.2 W and 2.3 W respectively.

CAVITY FABRICATION

The two cavities were fabricated by Niowave Inc. under DOE SBIR/STTR program and completed at Jefferson Lab under US LARP. The cavity center body and end plates were formed with 4 mm high RRR Nb sheets. The FPC, HHOM, VHOM and beam pipes were formed with 3 mm Nb sheets. The stamped parts are shown in Fig. 2. The formed parts are welded in to 3 sub-assemblies consisting of center body, end group with FPC and HOM dampers and end group with VHOM coupler and pick up port as shown in Fig. 3.

*Work supported by DOE via US LARP Program and by the High Luminosity LHC Project. Work was also supported by DOE Contract No. DE-AC02-76SF00515 sdesilva@jlab.org

18th International Conference on RF Superconductivity 2017, Lanzhou, China
doi: 10.18429/JACoW-SRF2017-TUPB053

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Cavity Welding

The final two welds of the rf-dipole cavities were completed at Jefferson Lab electron beam welding machine. The machine issues during the welding resulted with poor welds in both the cavities. The RFD-002 cavity had incomplete welds and was rewelded. Both cavities showed heavy under bead and weld splatter as shown in Fig. 5. Measures were taken to remove the weld splatter as best as possible. However, the process was challenging due to the limited access to the inner surface through the beam pipes.

Figure 5: Weld under bead (top), incomplete welds (bottom left), and weld splatter (bottom right) of the final welds in the rf-dipole cavities.

CAVITY PROCESSING

The rf-dipole prototype cavity processing sequence is shown in Fig. 6 [3].

In RFD-001 cavity a light BCP of 30 µm was done after the cavity welding and heat treatment was completed. Additional reprocessing was performed as shown in Fig. 6, due to poor welds including an 80 µm bulk BCP and 20 µm light BCP. Similarly, the RFD-002 was reprocessed with a 100 µm bulk BCP and 20 µm light BCP after the final welding. The cavities was flipped at the half point of removal during the bulk BCP of the fully welded cavity. The cavities was oriented with VHOM coupler at the bottom in order to minimize the collection of rinsing water and easy drainage.

Figure 6: Cavity processing sequence followed for both rf-dipole cavities.

The removal was measured after each step on 39 locations on the cavity body using an ultrasonic thickness gauge as shown in Fig. 8. The measured removal for RFD-001 and RFD-002 are shown in Fig. 9. The average removal of RFD-001 cavity after the first bulk and light BCP is 145 µm, and the finale average removal is 225 µm.
Table 1: Simulated and Measured Frequencies of RFD-001 Cavity

<table>
<thead>
<tr>
<th>Step</th>
<th>Simulated</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta f$</td>
<td>$f_n$</td>
</tr>
<tr>
<td>Cavity after trimming and thinning</td>
<td>399.840296</td>
<td>399.846841</td>
</tr>
<tr>
<td>Shift due to bulk BCP</td>
<td>-39.441</td>
<td>-21.924</td>
</tr>
<tr>
<td>Cavity after bulk BCP</td>
<td>399.800855</td>
<td>399.824917</td>
</tr>
<tr>
<td>Shift due to frame</td>
<td>-765.648</td>
<td></td>
</tr>
<tr>
<td>Cavity after removing fixture</td>
<td>399.800855</td>
<td>399.059269</td>
</tr>
<tr>
<td>Weld shrinkage and weld bead</td>
<td>120.645</td>
<td>114.686</td>
</tr>
<tr>
<td>Cavity after final weld</td>
<td>399.921500</td>
<td>399.173955</td>
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<tr>
<td>Shift due to heat treatment</td>
<td>-10.743</td>
<td></td>
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<tr>
<td>Cavity after heat treatment</td>
<td>399.915738</td>
<td>399.146739</td>
</tr>
<tr>
<td>Shift due to light BCP</td>
<td>-5.762</td>
<td>-16.473</td>
</tr>
<tr>
<td>Pressure effect (23 torr)</td>
<td>-1.84</td>
<td></td>
</tr>
<tr>
<td>Dielectric effect air to vacuum</td>
<td>130.341</td>
<td></td>
</tr>
<tr>
<td>Thermal shrinkage</td>
<td>572.877</td>
<td></td>
</tr>
<tr>
<td>Shift due to change in skin depth</td>
<td>28.000</td>
<td></td>
</tr>
<tr>
<td>Cooled down cavity at 2.0 K</td>
<td>729.378</td>
<td>755.615</td>
</tr>
</tbody>
</table>

FREQUENCY TRACKING

The comparison of the simulated frequency recipe with the measurements are shown in Table 1 for the RFD-001 cavity. The frequencies are normalized to 20 C and 1 atm at 50% humidity. The frequency shifts during the cavity processing are in agreement with the simulation within ±30 kHz. A frame was used during cavity trimming and weld thinning process to match the profiles of the end groups to the center body. The measured final frequency shift of 743 kHz at 2.0 K is due to the use of the frame that was unaccounted during the fabrication process.

CONCLUSION

The rf-dipole cavity fabrication and processing procedure is well understood in achieving the design specifications including rf performance of bare cavities and target cavity frequency after trimming. The followed process demonstrates the processing of complex rf-dipole prototype cavities. Further processing is planned in using a rotating tool (at ANL) to BCP the cavities. Following the completion of bare cavity test, next the cavities will be tested with HOM couplers.

REFERENCES