FABRICATION, PROCESSING AND RF TEST OF RF-DIPOLE PROTOTYPE CRABBING CAVITY FOR LHC HIGH LUMINOSITY UPGRADE*

S. U. De Silva[1#], H. Park[2], J. R. Delayen[1]
[1]Old Dominion University, Norfolk, VA, USA
[2]Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

Abstract

The superconducting rf-dipole crabbing cavity is one of two crabbing cavity designs proposed for the LHC high luminosity upgrade. The proof-of-principle rf-dipole cavity operating at 400 MHz has demonstrated excellent performance exceeding the design specifications. The prototype cavity for SPS beam test has been designed to include the fundamental power coupler, HOM couplers, and all the ancillary components intended to meet the design requirements. A crabbing cavity system is expected to be installed in the SPS beam line and tested prior to the installation in LHC; this will be the first crabbing cavity operation on a proton beam. The fabrication of two prototype rf-dipole cavities is currently being completed at Jefferson Lab. This paper presents the details on cavity processing and cryogenic test results of the rf-dipole cavities.

INTRODUCTION

The High Luminosity Upgrade of LHC will be implementing crabbing systems at the ATLAS and CMS experiments in increasing the luminosity of the colliding proton bunches. These crabbing systems will also reduce the pile up at the interaction points. The rf-dipole cavity will be crabbing the beam in horizontal plane for the CMS experiment.

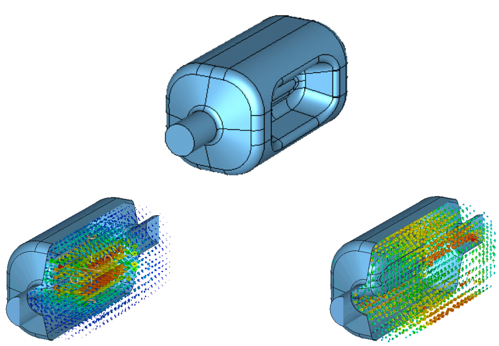

Figure 1: 400 MHz rf-dipole cavity (top) and electric (bottom left) and magnetic (bottom right) field profiles of the cavity.

The two parallel beam lines of the LHC ring set a very tight dimensional constraint in designing a crabbing cavity operating at 400 MHz [1]. The rf-dipole cavity operating in TE_{11}-like mode shown in Fig. 1 is adapted in to a square shaped design to meet the dimensional constraints of LHC. A proof-of-principle cavity has been fabricated and tested [2]. The prototype rf-dipole cavity has improved rf properties compered to proof-of-principle (PoP) cavity shown in Fig. 2. The rf properties of the PoP and prototype cavities are listed in Table 1.

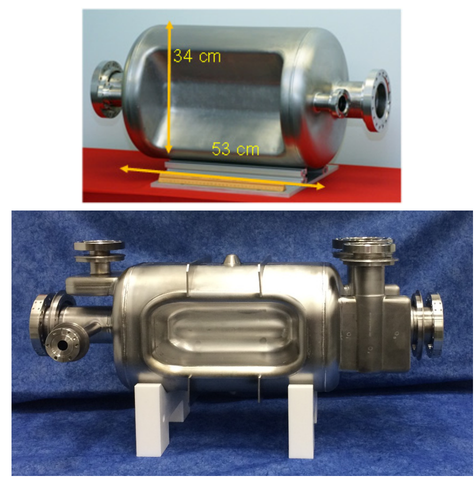

Figure 2: 400 MHz proof-of-principle (top) and prototype (bottom) rf-dipole cavities.

Table 1: RF properties of cylindrical shaped P-o-P and square shaped prototype rf-dipole cavities

Parameter	P-o-P Cavity	Prototype Cavity	Units
Nearest HOM	590	633.5	MHz
Peak electric field (E_p*)	4.02	3.6	MV/m
Peak magnetic field (B_p*)	7.06	6.2	mT
Geometrical factor	120	107	Ω
$[R/Q]_t$	287	430	Ω
$R_t R_s$	3.4×10^4	4.6×10^4	Ω^2
At E_t* = 1 MV/m			
V_t	3.4		MV
E_p	36.5	33	MV/m
B_p	64	56	mT

The prototype cavity will operate at peak fields of 33 MV/m and 56 mT at nominal operating voltage of 3.4 MV. This cavity also has wider frequency separation of ~230 MHz between fundamental mode and the nearest HOM. The prototype cavity is designed with all the

*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

ancillary including fundamental power coupler and HOM couplers. The rf-dipole cavity has two HOM couplers named HHOM and VHOM as shown in Fig. 3. The HOM coupler is a high pass filter for damping horizontal dipole modes, and VHOM is coaxial that couples to vertical dipole modes.

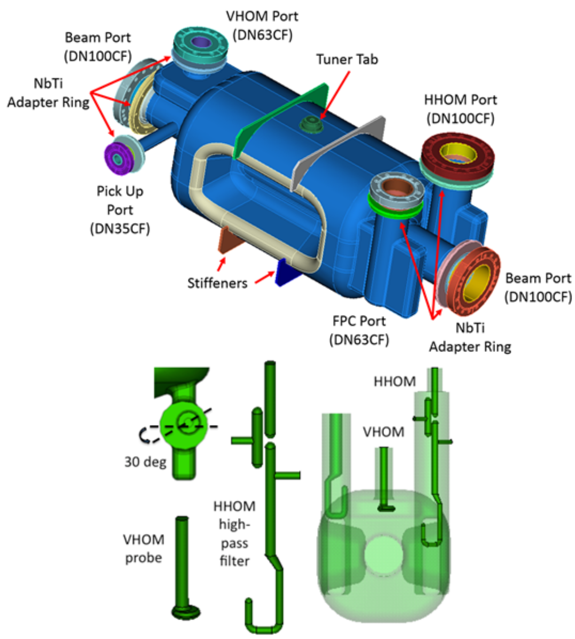

Figure 3: Bare prototype cavity for SPS (top) and FPC and HOM couplers (bottom) of the rf-dipole cavity.

CAVITY PROCESSING AND PREPARATION FOR RF TEST

The rf-dipole prototype cavity was fabricated in three sub-assemblies as shown in Fig. 4. Two sets of sub-assemblies were fabricated by Niowave Inc. and delivered to Jefferson Lab. The final welding, cavity processing and rf testing was carried out at Jefferson Lab [3, 4]. Both cavities have completed the cavity processing and one cavity has been successfully rf tested.

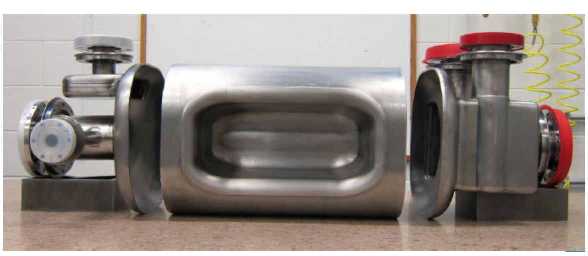

Figure 4: Sub-assemblies of rf-dipole prototype cavity.

Frequency measurements performed on vertically stacked sub-assemblies indicated that one cavity had a frequency shift of about 1 MHz at room temperature due to deformation of the center body. The center body was fixed as shown in Fig. 5 by plastically deforming the top and bottom surface outward to meet the desired frequency before cavity processing.

Figure 6 shows the sequence of the cavity processing plan followed by the two prototype cavities. The sub-assemblies of both the cavities underwent rigorous surface polishing at welds and on the internal surface to remove any protrusions and pits that would limit the cavity performance. The surface polishing on the sub-assemblies gave access to most of the critical welds in the high electric and magnetic field regions with limited access to the welds in the waveguide stubs.

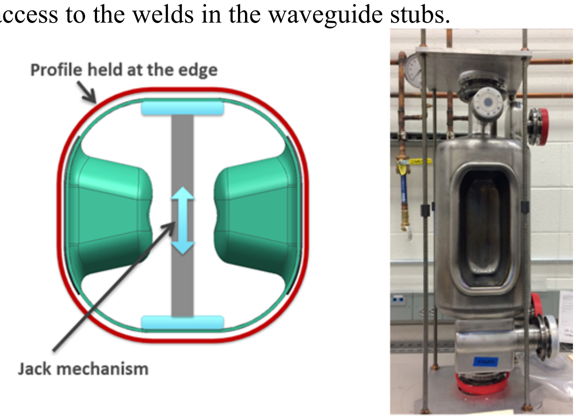

Figure 5: Set up for fixing of the center body (left) and vertical stacked assembly for frequency measurements (right).

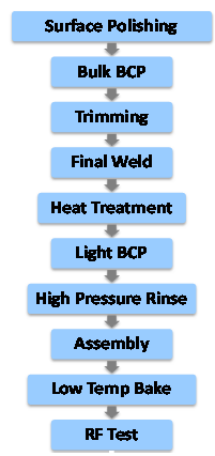

Figure 6: Sequence of cavity processing.

The bulk BCP of the rf-dipole prototype cavities was performed on the individual sub-assemblies as shown in Fig. 7. Bulk BCP was carried out in a closed cabinet to remove an average of 140 microns.

Figure 7: Bulk BCP of sub-assemblies.

The cavity trimming was performed on the sub-assemblies after bulk BCP. The edges of center body were trimmed and all the edges of the three sub-assemblies were thinned to 3 mm from 4 mm for preparation of final

ISBN 978-3-95450-182-3

welding. Both the cavities achieved the target frequency as shown in Fig. 8.

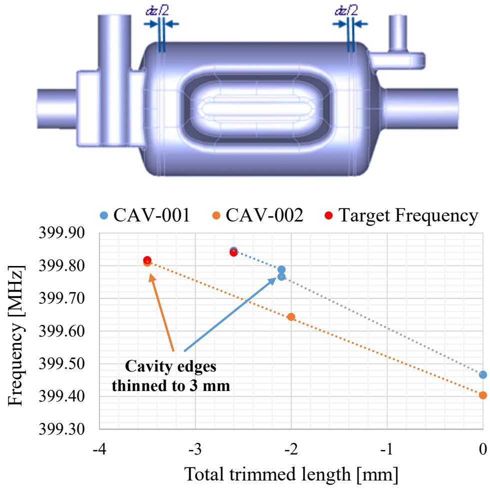

Figure 8: Trimming of Bulk BCP of sub-assemblies.

The cavity final welding was performed after the bulk BCP of sub-assemblies. The unexpected behaviour of the electron beam welding machine during the welding resulted in incomplete welds in one of the cavities. The cavities were rewelded, which resulted in a heavy under bead and weld splatter. The cavities were then reprocessed with bulk BCP, followed by heat treatment and light BCP.

The cavities were heat treated at 600 C for 10 hours followed by light BCP to remove a layer of 20-30 microns. Then the cavities were high pressure rinsed prior to assembly. The assembled cavity set up is shown in Fig. 9. The input probe and field probe were calibrated at 5×10^9 and 2×10^{11}.

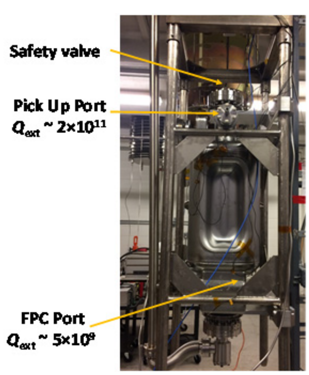

Figure 9: Cavity rf test assembly.

CRYOGENIC RF TEST RESUTLS

The CAV-001 has been successfully tested and CAV-002 is in preparation for the first cold test. The cryogenic test results of the CAV-001 are shown in Fig. 10 [4]. The cavity achieved a transverse voltage of 4 MV during Test 1 with peak fields of 38 MV/m and 66 mT. The cavity experienced high field emission levels that resulted in cavity quench at 4.0 MV. The Q_0 at nominal voltage during Test 1 was 5×10^9. Multipacting was processed easily and didn't reoccur in the following tests.

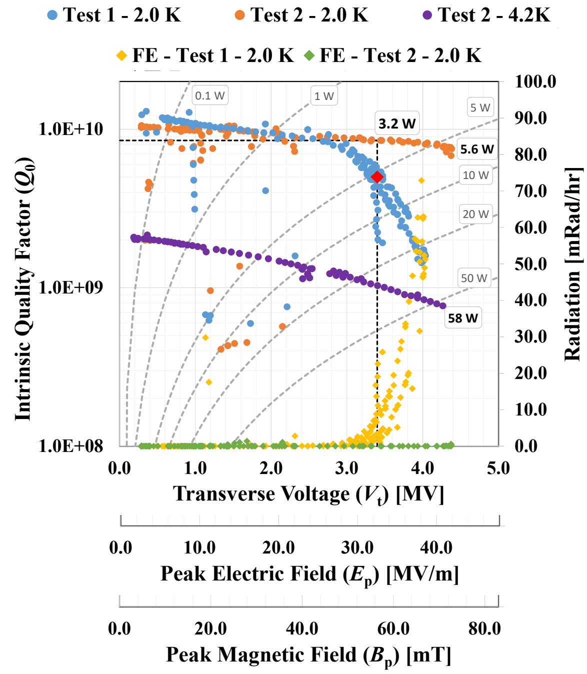

Figure 10: Quality factor at 4.2 K and 2.0 K of the 400 MHz rf-dipole cavity.

The cavity was reprocessed at retested at both 2.0 K and 4.2 K. During Test 2 the cavity achieved a transverse voltage of 4.4 MV that exceeds the operating voltage of 3.4 MV with a Q_0 of 8.5×10^9 that corresponds to a power dissipation of 3.2 W. At low fields the Q_0 was greater than 10^{10}. The cavity achieved peak surface fields of 42 MV/m and 73 mT. The cavity performance was limited by thermal quench possibly due to a defect near the high magnetic field region.

CONCLUSION

Fabrication of two prototype rf-dipole cavities has been completed. One cavity has been successfully tested and achieved a V_t of 4.4 MV at 3.2 W with no field emission present. The second cavity is in preparation for cold test. Following the experiences of prototype cavity processing no major change will be done to the cavity design for LHC.

ACKNOWLEDGEMENT

We would like to thank for the technical support by the srf production team at Jefferson Lab.

REFERENCES

[1] P. Baudrenghien, et al., Functional Specifications of the LHC Prototype Crab Cavity System, Tech. Rep. CERN-ACC-NOTE-2013-003 (CERN, 2013).
[2] S. U. De Silva and J. R. Delayen, Phys. Rev. ST Accel. Beams 16, 082001 (2013).
[3] H. Park, International Review of the Crab Cavity Performance for HiLumi, CERN, April 2017.
[4] S. De Silva, International Review of the Crab Cavity Performance for HiLumi, CERN, April 2017.