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SIMULATION AND MEASUREMENTS OF HOM FILTER OF THE LARP PROTOTYPE RF-DIPOLE CRABBING CAVITY USING AN RF TEST BOX*

S. U. De Silva[1]†, J. R. Delayen[1], Old Dominion University, Norfolk, VA, USA
[1]also at Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
Z. Li, Stanford Linear Accelerator National Laboratory, Menlo Park, CA 94025, USA

Abstract

The RF-Dipole Crabbing Cavity designed for the LHC High Luminosity Upgrade includes two higher order mode (HOM) couplers. One of the HOM couplers is an rf filter, which is a high pass filter designed to couple to the horizontal dipole modes and accelerating modes up to 2 GHz, while rejecting the fundamental operating mode at 400 MHz. The coupler consists of a high pass filter circuit where the rejection of the operating mode and transmission of HOMs are sensitive to dimensional deviations. An rf test box has been designed to measure the transmission of the rf filter in order to qualify the fabricated HOM coupler and to tune the coupler. This paper presents the measurements of the HOM coupler with the rf test box.

INTRODUCTION

The high luminosity upgrade of LHC will be installing local crabbing systems at the two interaction points (IP) of IP_1 and IP_5, in order to increase the luminosity of the colliding bunches [1]. These crabbing systems will be the first crab cavities in a circular collider with proton beams. The transverse kick given by the crabbing cavities tilts each bunch, which allows head-on collision at the IP, increasing the number of interactions between the colliding bunches [2]. Two crabbing systems operating at 400.79 MHz will be installed in the LHC with Double Quarter Wave (DQW) cavities [3] for vertical crabbing at IP_1 and RF-Dipole (RFD) cavities [4] for horizontal crabbing at IP_5. The required total crabbing voltage per beam per side is 10 MV.

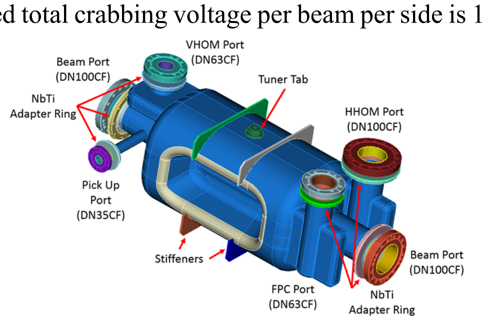

Figure 1: 400 MHz LARP prototype rf-dipole cavity.

The rf-dipole crabbing cavity operates in TE_{11}-like mode where the primary contribution to the transverse kick is given by the transverse electric field. A compact square-shaped cavity is designed as shown in Fig. 1 to fit in between the parallel beam pipes in the LHC ring. A fully integrated crabbing cavity including all the ancillary components was first designed under the US LHC Accelerator Research Program (US–LARP). Fabrication of the first two LARP prototypes were carried out by Niowave Inc. and the final welding, cavity processing and rf testing were completed at Jefferson Lab [5]. Currently, an improved design is being designed and developed to meet the latest requirements for LHC under Accelerator Upgrade Project (AUP) at Fermilab with collaborations from ODU, SLAC and BNL.

HOM Couplers of LARP RFD Cavity

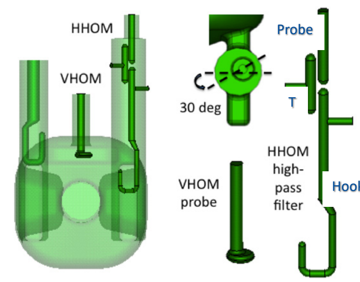

Figure 2: HHOM and VHOM couplers of the rf-dipole crabbing cavity.

The rf-dipole crabbing cavity is designed with two HOM couplers to damp HOMs up to 2 GHz as shown in Fig. 2 [6]. The HHOM coupler is a demountable rf filter designed to cut off the fundamental mode and damp horizontal dipole modes and some of the accelerating modes present in the cavity. The VHOM coupler damps the vertical dipole modes as well as the accelerating modes that doesn't couple through the HHOM coupler. Also, the VHOM coupler is designed as a coaxial style coupler since it doesn't couple to the fundamental mode. The HOM couplers are placed on the end plates of the cavity in the low field region, therefore has low rf losses. The rf filter consists of a Hook, T and a Probe (Fig. 2), where the T and Hook are made out of Nb and the Probe is designed as a removable rf feed through made with Cu. The notch at 400 MHz is very sensitive to the gap between the Hook and T. A shift in the notch increases the rf power leakage of the fundamental mode through the HHOM coupler.

RF TEST BOX DESIGN

The complex HOM couplers require a mechanism in fully characterizing the fabricated HOM couplers before installing them in the cavities. Measurements obtained from CMM machine aren't sufficient to provide detailed measurements of the couplers due to the limited access of its parts. In addition, cryogenic measurements of the cavity with HOM couplers in a vertical test assembly can't fully

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†sdesilva@jlab.org

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verify the damping of the HOMs. Therefore, an rf test box has been designed to qualify the fabricated HHOM couplers of the LARP prototype cavities.

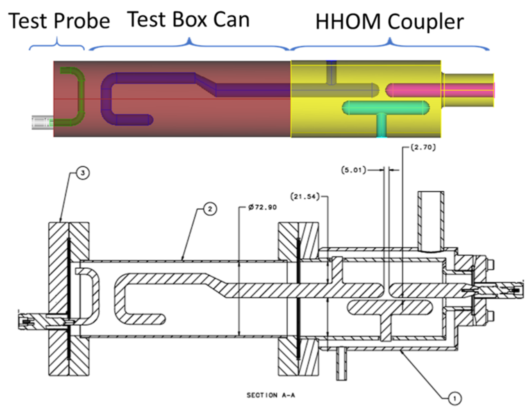

Figure 3: Schematic (top) and mechanical drawing (bottom) of the rf test box with HHOM coupler.

The rf test box consists of a test box can and a test probe as shown in Fig. 3. The first HOM of the rf-dipole cavity is at 633.5 MHz. The test probe is optimized with a hook shaped probe to achieve maximum transmission above 600 MHz which includes all the HOMs as shown in Fig. 4. The optimization of the probe does not affect frequency of the notch. The rf test box design cuts off the transmission of the fundamental mode with zero transmission at -140 dB. The functional requirements specify an HHOM coupler is acceptable with a 3 dB or lower deviation in S_{21} measured at room temperature [7].

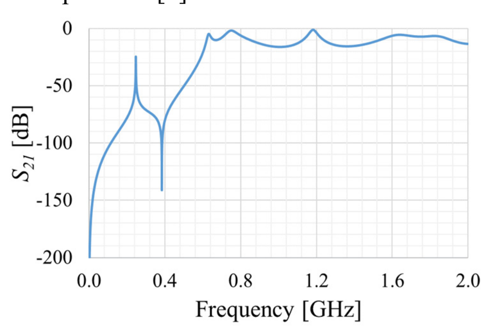

Figure 4: S_{21} transmission of the HHOM coupler in the rf test box.

Tolerance Study of the RF Test Box

A detailed analysis of the variations in each parameter in the rf test box was carried out to determine the tolerances in fabrication. Figure 5 shows the parameters studied and the tolerances with the corresponding change in the transmission are listed in Table 1. The tolerances are kept tight in order to minimize the deviations in the test box can or the test probe contributing to a shift in S_{21}. This allows the measurement of any deviations in S_{21} to be attribute to deviations in the HHOM coupler.

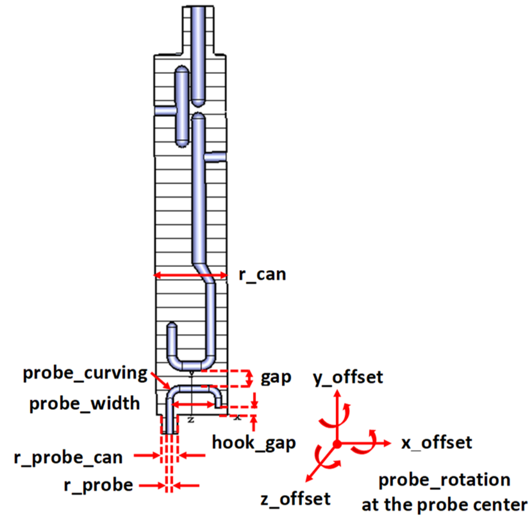

Figure 5: RF test box parameters evaluated for tolerances.

Table 1: Tolerances and Change in S_{21} for RF Test Box

Parameter	**Value**	**Change in S_{21} [dB]**
r_can	± 0.01"	0.15
can_height	± 0.005"	0.06
r_probe_can	± 0.01"	0.18
r_probe	± 0.005"	0.23
probe_concentricity	± 0.01"	0.12
probe_height	± 0.005"	0.07
probe_width	± 0.01"	0.15
probe_curving	± 0.01"	0.07
hook_gap	± 0.01"	0.17
probe_rotation (With respect to center of probe)		
x axis	± 1 deg	0.15
y axis	± 1 deg	0.02
z axis	± 1 deg	0.35

FABRICATION OF RF TEST BOX

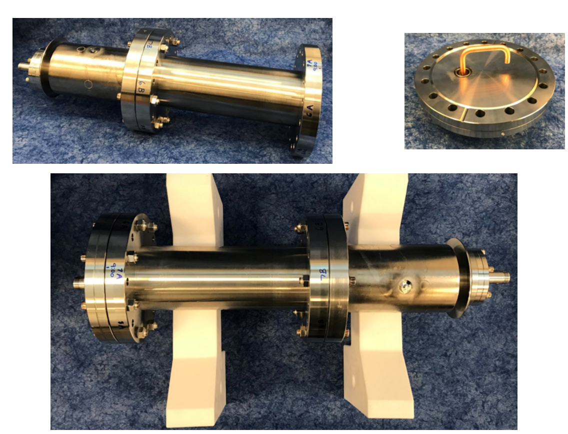

Figure 6: Test box can assembly with HHOM coupler (top left), test probe (top right), and fully assembled setup (bottom).

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The fabrication of the rf test box was completed at Jefferson Lab. The test box can was fabricated using SS tube with 6" CF flanges. The Cu probe in the test box probe was formed with a fixture and brazed in to an rf feed through that was welded to the 6" CF flange as shown in Fig. 6. One of the two HHOM couplers (Fig. 7) fabricated at Jefferson Lab has been used for the measurements with the rf test box.

Figure 7: Fabricated HHOM coupler. Demountable HHOM coupler (left) and Probe (right).

MEASUREMENTS ON RF TEST BOX

A detailed CMM measurements were carried out on both test box can and the test probe to determine the accuracy of the fabricated parts. Forming of the Cu probe and brazing it to the flange introduced deviations above specified tolerances. The rf test box model has been updated including the deviations measured in the fabricated test box can and test probe. Figure 8 shows the new reference S_{21} with an ideal HHOM coupler. Deviation in the S_{21} between the designed and fabricated rf test box is less than 0.5 dB with no change in the notch frequency.

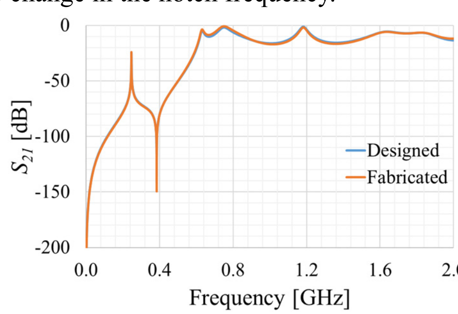

Figure 8: S_{21} transmission for the designed and fabricated rf test box.

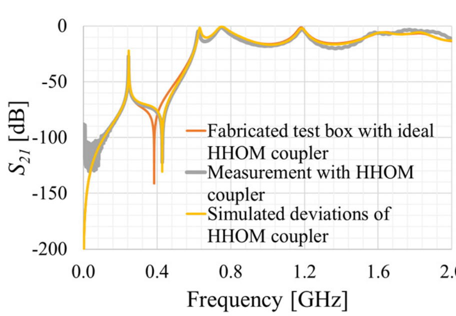

Figure 9: Measured S_{21} transmission of the HHOM coupler in the rf test box (red) compared with the ideal HHOM coupler (grey). Simulated deviations of the HHOM coupler (orange).

Figure 9 shows the measurement of the fabricated HHOM coupler in the rf test box. Measurement of the fabricated HHOM coupler with the rf test box shows deviations up to 5 dB at higher frequencies with a shift in the notch frequency. Deviation in the notch is accounted to be due to a shift of about 0.6 mm in T and Hook with respect to the Probe. The measurements obtained shows that the can be used in characterizing the fabricated HHOM couplers.

Tuning of HHOM Coupler

Measurements may indicate that some HHOM couplers would require tuning to adjust the notch frequency. A method is proposed in tuning the HHOM couplers by adjusting the diameter or the length of the Cu probe. Figure 10 shows dependence on S_{21} with varying probe length and diameter. The notch can be tuned by either method with negligible change in the transmission at higher frequencies.

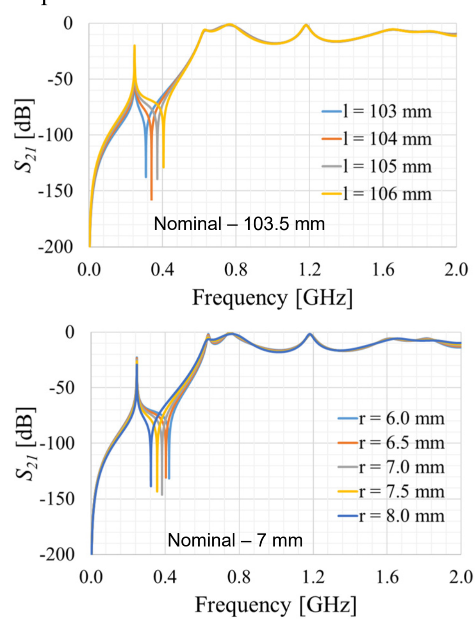

Figure 10: Dependence on S_{21} transmission with varying probe length (top) and diameter (bottom).

CONCLUSIONS

The LARP rf-dipole crabbing cavity designed for the LHC high luminosity upgrade has two HOM couplers. The rf filter (HHOM coupler) is designed to cut off the fundamental mode while damping the HOMs up to 2 GHz. An rf test box has been designed and fabricated to qualify the LARP HHOM couplers. The components of the fabricated rf test box have been carefully surveyed and compared with the designed model. The low power measurements were carried out in room temperature with the fabricated HHOM coupler. The S_{21} measurements show a deviation larger than 3 dB due to the shift in T and Hook with respect to the Probe. A solution is proposed to compensate for the S_{21} deviations by adjusting Probe length and diameter. Further measurements will be carried with varying Probe radius and length to establish a mechanism in tuning the HHOM couplers in the production series.

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