2018

Room Temperature Measurements of Higher Order Modes for the SPS Prototype RF Dipole Crabbing Cavity

Subashini De Silva
Old Dominion University, pdesilva@odu.edu

P. Berrutti

Jean R. Delayen
Old Dominion University, jdelayen@odu.edu

N. A. Huque

Hyekyoung Park
Old Dominion University, hpark@odu.edu

Original Publication Citation
De Silva, S. U., Berrutti, P., Delayen, J. R., Huque, N. A., & Park, H. (2018). Room temperature measurements of higher order modes for the SPS prototype RF dipole crabbing cavity. In S. Koscielniak, T. Satogata, V.R.W. Shaa, & J. Thomson (Eds.), *Proceedings of the 9th International Particle Accelerator Conference* (pp. 3805-3807). Joint Accelerator Conferences Website. https://doi.org/10.18429/JACoW-IPAC2018-THPAL067

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAL067

ROOM TEMPERATURE MEASUREMENTS OF HIGHER ORDER MODES FOR THE SPS PROTOTYPE RF-DIPOLE CRABBING CAVITY*

S. U. De Silva[1, †], H. Park[2,1], J. R. Delayen[1], P. Berrutti[3], N. Huque[2]
[1]Old Dominion University, Norfolk, VA 23529, USA
[2]Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
[3]Fermi National Accelerator Facility, Batavia, IL 60510, USA

Abstract

LHC High Luminosity Upgrade will be developing two local crabbing systems to increase the luminosity of the colliding bunches at the ATLAS and CMS experiments. One of the crabbing systems uses the rf-dipole cavity design that will be crabbing the beam in the horizontal plane. The fully integrated crabbing cavity has two higher order mode couplers in damping those excited modes. Currently two sets of HOM couplers have been fabricated at Jefferson Lab for prototyping and testing with the LARP crabbing cavities. This paper presents the measurements of the higher order modes with the prototype HOM couplers carried out at room temperature.

INTRODUCTION

The crabbing systems for the LHC High Luminosity Upgrade (HL-LHC) will crab the proton beams with 7 TeV energy per beam; in order to increase the luminosity by allowing head-on collision of the bunches at the interaction point [1]. The crabbing cavities are expected to increase the luminosity up to 5×10^{34} $cm^{-2}s^{-1}$ with an integrated luminosity of 250 fb^{-1} per year. The crabbing system is expected to deliver a total transverse kick of 3.34 MV per cavity. The crabbing system will include two cryomodules per beam per side with two crabbing cavities in each cryomodule.

Fundamental power coupler design and higher order mode couplers are critical cavity components in the rf-dipole crabbing cavity design due to the high energy and high current of the proton beams in the LHC. The large beam current and the higher bunch population of the HL-LHC beam sets limitations on the longitudinal and transverse impedance thresholds for the cabbing cavities. The transverse impedances of modes up to 2 GHz are required to be below 1 MΩ/m and the total HOM power is required to be below 1 kW [2].

HOM COUPLERS FOR THE SPS PROTOTYPE RF-DIPOLE CAVITY

The rf-dipole crabbing cavity is one of the two crabbing cavities that will be installed in the LHC machine. The cavity is designed with all ancillary components including the fundamental power coupler, HOM couplers, adapters for the tuner etc. The rf-dipole cavity is designed with two HOM couplers named Horizontal-HOM (HHOM) coupler and Vertical-HOM (VHOM) coupler as shown in Fig. 1 [3].

*Work supported by DOE via US LARP Program and by the High Luminosity LHC Project. Work was also supported by DOE Contracts No. DE-AC02-76SF00515 and DE-AC05-06OR23177.
†sdesilva@jlab.org

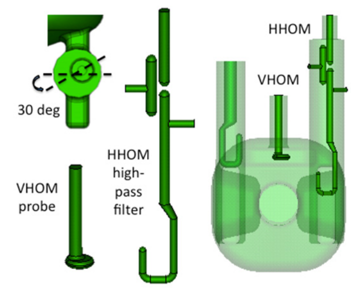

Figure 1: HHOM and VHOM couplers for the 400 MHz rf-dipole crabbing cavity.

The HHOM coupler is a high pass filter that damps the horizontal dipole modes and some of the accelerating modes and the VHOM coupler damps the vertical dipole modes and the other accelerating modes. Figure 2 shows the corresponding impedance of the HOMs up to 2 GHz.

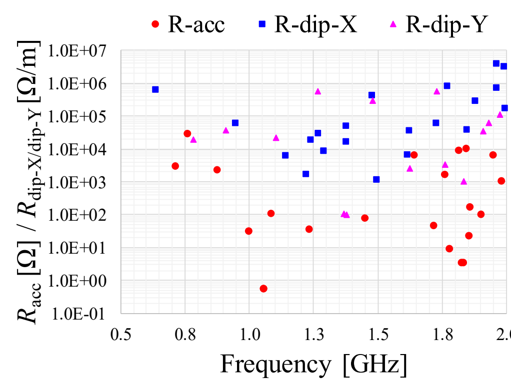

Figure 2: Longitudinal and transverse impedance of HOMs up to 2 GHz [3].

DETERMINATION OF Q_{EXT}

The accurate estimation of coupling between the cavity and ports in the cavity is important in estimating the higher order mode damping. The coupling of each mode can be described by the external quality factor (Q_{ext}) and coupling coefficient (β) in relationship to the intrinsic quality factor (Q_0) given by

$$\beta = \frac{Q_0}{Q_{ext}} . \quad (1)$$

The intrinsic and external quality factors of a resonant cavity are defined as

$$Q_0 = \frac{\omega U}{P_{diss}} \text{ and } Q_{ext} = \frac{\omega U}{P_{ext}} , \quad (2)$$

where ω is the resonant frequency, U is the stored energy, and P_{diss} is dissipated power of each mode. P_{ext} is power

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAL067

coupled out of the port. The loaded quality factor is then defined as

$$\frac{1}{Q_L} = \frac{1}{Q_0} + \frac{1}{Q_{ext}}, \tag{3}$$

hence Q_{ext} of each mode can be determined by

$$Q_{ext} = Q_L \left(1 + \frac{1}{\beta}\right). \tag{4}$$

The loaded quality factor can be determined by the magnitude of the forward transmission gain S_{21} using resonance frequency (f_0) and the frequency difference between the 3 dB down frequencies (f_1 and f_2) at each side of f_0 given by

$$Q_L = \frac{f_0}{f_2 - f_1}. \tag{5}$$

The coupling coefficient can be determined by the reflection coefficients (S_{11}) defined as

$$\beta = \frac{1 - S_{11}}{1 + S_{11}} \text{ (for under coupled)}, \tag{6}$$

$$\beta = \frac{1 + S_{11}}{1 - S_{11}} \text{ (for over coupled)}. \tag{7}$$

HOM MEASUREMENTS OF RF-DIPOLE CAVITY

Two prototype cavities of each type have been fabricated by Niowave Inc. and completed at Jefferson Lab under US-LARP. The final welding, chemical processing, and rf testing cavities were completed at Jefferson Lab with successful demonstration of transverse kicks of 4.5 MV and 5.8 MV respectively [4]. Two sets of HOM couplers for the rf-dipole cavity have been fabricated at Jefferson Lab as shown in Fig. 3.

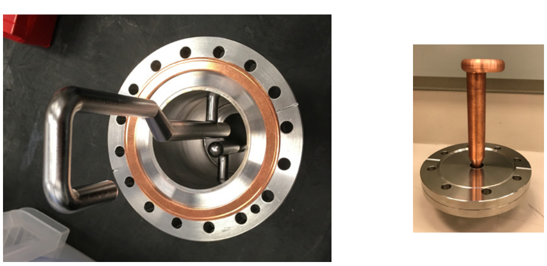

Figure 3: HHOM high pass filter (left) and VHOM coupler (right).

The measurements were carried out in room temperature to determine the combined Q_{ext} through the HHOM and VHOM couplers. Figure 4 shows the rf-dipole cavity with HOM couplers mounted on the cavity.

Figure 4: 400 MHz rf-dipole cavity with mounted HHOM and VHOM couplers.

A test probe with a coupling of 1.7×10^7 was used as the field probe with a pick up probe of 10^{11} coupling for the measurements. A series of measurements were carried to measure the S_{21} and S_{11} as listed below for the HHOM and VHOM couplers separately up to 2 GHz.

- S_{11}: from HHOM/VHOM with FPC open
- S_{21}: FPC to HHOM/VHOM with VHOM/HHOM unterminated
- S_{21}: HHOM to VHOM with FPC/Pick Up open

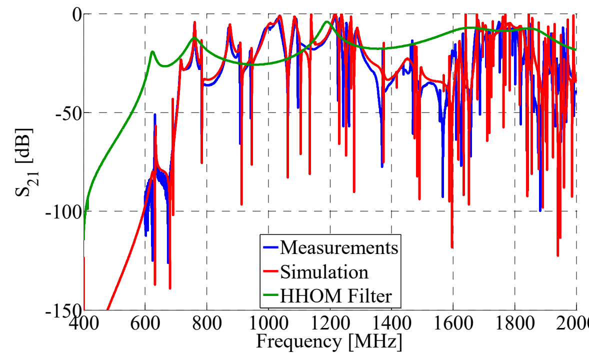

Figure 5: S_{21} transmission of HHOM to VHOM coupler.

Figure 5 shows the S_{21} transmission of HHOM to VHOM. The measurements are in good agreement with the simulations. In comparison with the S_{21} for high pass filter the fundamental mode has rejection of less than -100 dB.

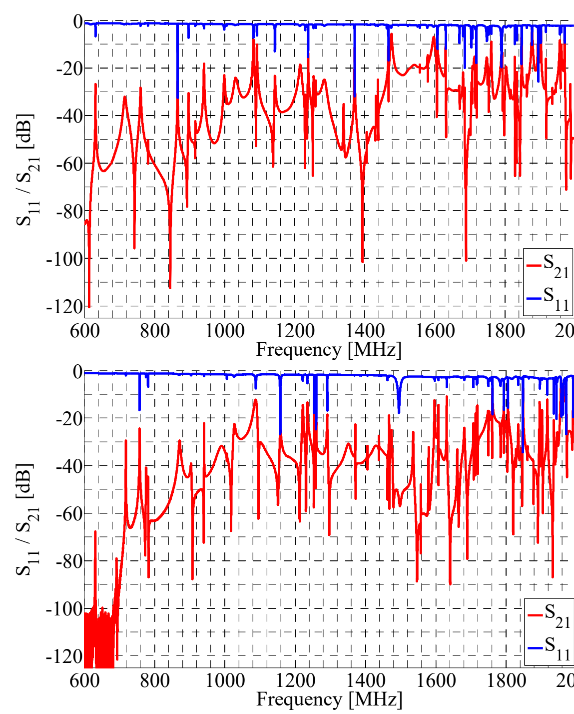

Figure 6: S_{11} and S_{21} measurements on HHOM (top) and VHOM (bottom) couplers.

The measurements of S_{21} and S_{11} up to 2 GHz shown in Fig 6. The Q_{ext} values for both HHOM and VHOM ($Q_{ext,HHOM}$ and $Q_{ext,VHOM}$) are determined separately up to 2 GHz following the method described in Eqs. 4,5,6, and 7. Some of dipole modes and accelerating modes are coupled through both of the HHOM and VHOM couplers. The combined Q_{ext} for each mode is then calculated as

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAL067

$$\frac{1}{Q_{ext}} = \frac{1}{Q_{ext,HHOm}} + \frac{1}{Q_{ext,VHOM}}. \quad (8)$$

Frequencies of some of modes were shifted that from the simulation, possibly due to deviations in the fabricated cavity, deviations in couplers, or frequency shift due to thermal shrinkage. Measured Q_{ext} matches with the simulation up to ~1.6 GHz (Fig. 7). However, at higher frequencies Q_{ext} could not be measured accurately, especially for modes with higher Q_{ext}.

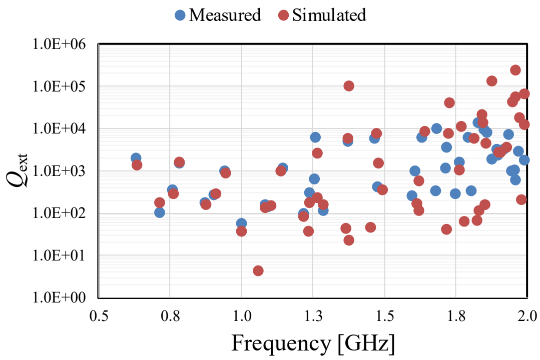

Figure 7: Comparison of Q_{ext} between simulation and measurements.

Tuning Sensitivity Measurements of HOMs

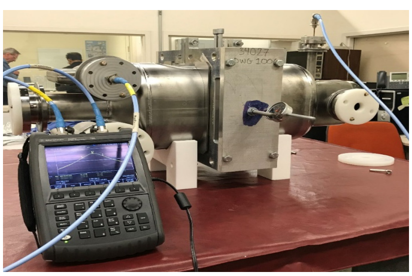

Figure 8: Setup for measuring tuner sensitivity for rf-dipole cavity.

The rf-dipole cavity was compressed and pulled at top and bottom surface as shown in Fig. 8, to replicate the tuner motion. The measured tuner stroke for the fundamental mode is 394 kHz/mm and matches with the simulation results of 345 kHz/mm [5]. The 760 MHz is one of the critical HOMs which falls closer to a beam spectrum line [6]. The tuner stroke of the 760 MHz mode is 33 kHz/mm, which is very small compared to that of the 400 MHz operating mode.

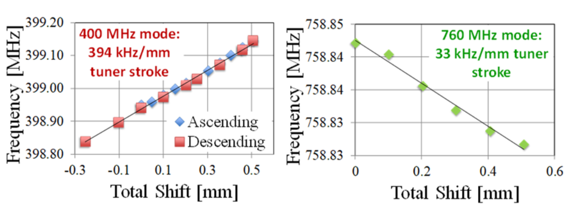

Figure 9: Tuner sensitivity for 400 MHz and 760 MHz modes.

The rf-dipole cavity was pushed and pulled at the top surface with frequency shifts of +450 kHz and –150 kHz on the fundamental mode. Figure 9 shows S_{21} transmission up to 2 GHz in comparison with the simulation. The frequencies of the HOMs are in good agreement with the simulation and the frequency shifts due to tuner shifts are insignificant. Therefore, the HOMs are insensitive to the pushing and pulling of the tuner and gives more control on the HOMs.

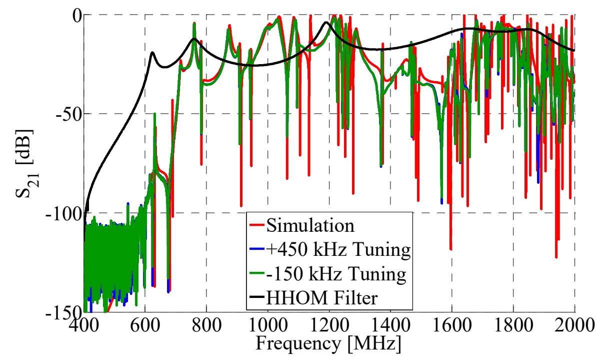

Figure 9: S_{21} transmission of HOMs with tuning of +450 kHz and –150 kHz compared with simulation.

CONCLUSION

Jefferson Lab has fabricated two sets of HOM couplers including two HHOM high pass filters and two VHOM couplers. RF-Dipole crabbing cavity completed at Jefferson Lab under US-LARP was used to measure the coupling of the HOM couplers, under technical leadership of ODU/SLAC. Following a series of measurements of S_{11} and S_{21}, Q_{ext} of HOMs are estimated up to 2 GHz. The Q_{ext} measurements are in agreement up to ~1.6 GHz and at higher frequencies the frequency shift of the HOMs is significant. Also, Q_{ext} cannot be estimated accurately at higher frequencies. More HOM measurements are planned for the rf-dipole cavity at cryogenic temperatures. The HOM measurements with the tuner in motion shows that HOM frequencies show negligible shift, compared to shift in the fundamental operating mode.

REFERENCES

[1] B. Schmidt, "The High-Luminosity Upgrade of the LHC: Physics and Technology Challenges for the Accelerator and the Experiments", *Journal of Physics: Conference Series*, vol. 706 (2016), 022002.

[2] E. Métral, "Impedance Update", Joint LARP CM26/HiLumi Meeting, SLAC, May 2016.

[3] Z. Li, J. R. Delayen, S. U. De Silva, H. Park, R, Olave, "FPC and High-Pass Filter HOM Coupler Design for the RF Dipole Crab Cavity for the LHC HiLumi Upgrade", in *Proc. of IPAC'15*, Richmond, VA, USA (2015), p. 3492.

[4] S. De Silva, H. Park, J. R. Delayen, Z. Li, "RF Tests of RF-Dipole Prototype Crabbing Cavities for LHC High Luminosity Upgrade", in *Proc. of SRF'17*, Lanzhou, China (2017), p. 509.

[5] H. Park, "RF-Dipole Cavity SPS Prototype Engineering", Crab Cavity System External Review, BNL, May 2014.

[6] S. Antipov, "Machine Impedance and HOM Power Update", 7th HL–LHC Collaboration Meeting, Madrid, Spain, November, 2017.