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IMPERFECTION AND TOLERANCE ANALYSIS OF HOM COUPLERS FOR ODU/SLAC 400 MHz CRABBING CAVITY*

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Abstract

In preparation for the LHC High Luminosity upgrade, a 400 MHz crab cavity has been developed jointly at ODU/SLAC, including two higher order mode couplers designed to damp the wakefields in order to comply with the impedance budget specified for the LHC system. During fabrication, assembly, and processing of the couplers, a number of imperfections may arise that could modify the higher order mode spectrum and the associated impedance for each mode. We present here a detailed study of the imperfections of the horizontal- and vertical- HOM couplers, and the associated allowed tolerances for manufacture, assembly and processing.

INTRODUCTION

A crabbing cavity system for the LHC High Luminosity Upgrade has been designed including the ancillary components such as the fundamental power coupler (FPC), higher order mode (HOM) couplers [1]. The corresponding high current operation demands extraction of 1 kW of HOM power and also impose a strict impedance budget. The full impedance study for the 7 TeV per beam LHC operation is ongoing.

The rf-dipole crabbing cavity is designed with a horizontal (H-HOM) and a vertical (V-HOM) HOM coupler set to meet the design specifications and dimensional requirements for LHC operation [2, 3]. The cavity design with the FPC and HOM couplers are shown in Fig. 1.

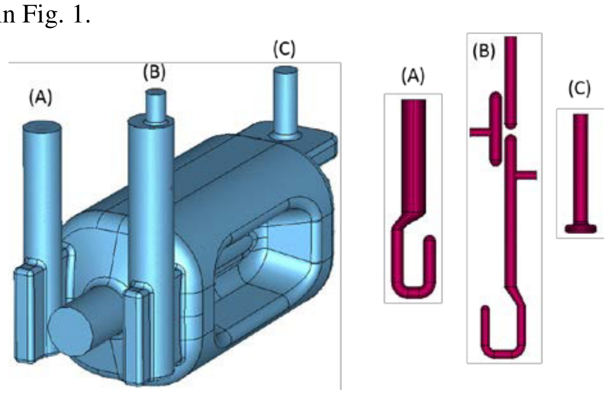

Figure 1: Complete rf-dipole cavity with (A) FPC, (B) HHOM filter, and (C) VHOM probe.

The rf-dipole geometry does not have any lower order modes or similar order modes. The H-HOM coupler is a high pass filter that cuts off the fundamental operating mode, and damps the horizontal dipole modes and accelerating modes. The high pass filter has excellent broad band transmission above 630 MHz up to 2 GHz [3]. The V-HOM coupler damps the vertical dipole modes and some of the accelerating modes. One attractive feature of the HOM couplers of the rf-dipole cavity is that all the couplers are at the end plates in the low field region. This reduces the rf heating at the HOM couplers.

HOM TOLERANCES

The fabrication procedure for the high pass filter is outlined in Ref. [4]. The H-HOM filter consists of three parts as shown in Fig. 1 with a hook, probe and T. The gap between T with the probe and hook is 2.8 mm, which needs to be controlled for precision during fabrication to minimize fundamental mode leakage through the filter.

The manufacturing, assembly, and processing may introduce deviations from the ideal filter shape. This may further have an impact to the effectiveness in HOM damping. Figure 2 shows the important tolerance parameters that have been investigated for the H-HOM high pass filter. HOM tolerances include translational in both vertical (gap probe, gap top, y tip) and transverse (gap bar P, gap bar H, gap T) directions and rotations around x and z axes.

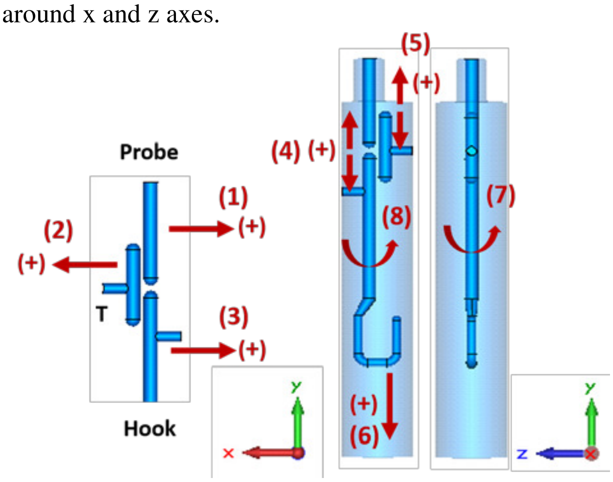

Figure 2: H-HOM tolerances: (1) gap bar P (2) gap bar T (3) gap bar H (4) gap probe (5) gap top (6) y tip (7) rotation about x axis (7) rotation about z axis.

Any variations on gap bar thickness in the T, probe and hook may be caused during fabrication of parts and chemical processing, which are the most crucial parameters for performance. The vertical and rotational deviations may be introduced during assembly of the components and electron beam welding (EBW) process. Extra measures are taken in using a collapsible fixture to hold parts during EBW. The welded parts will be measured to ensure the tolerances are met.

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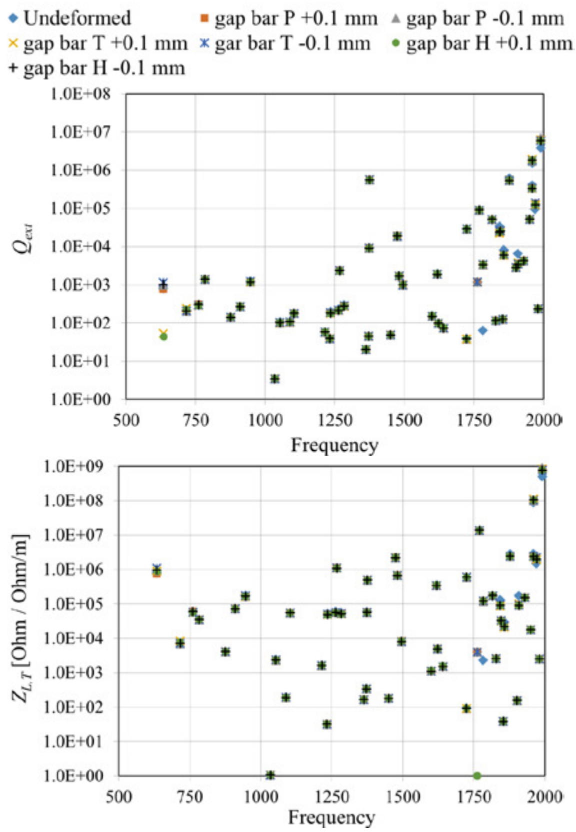

Figure 3: Q_{ext} and impedance change due to HOM tolerances of gap bar P, gap bar T, and gap bar H.

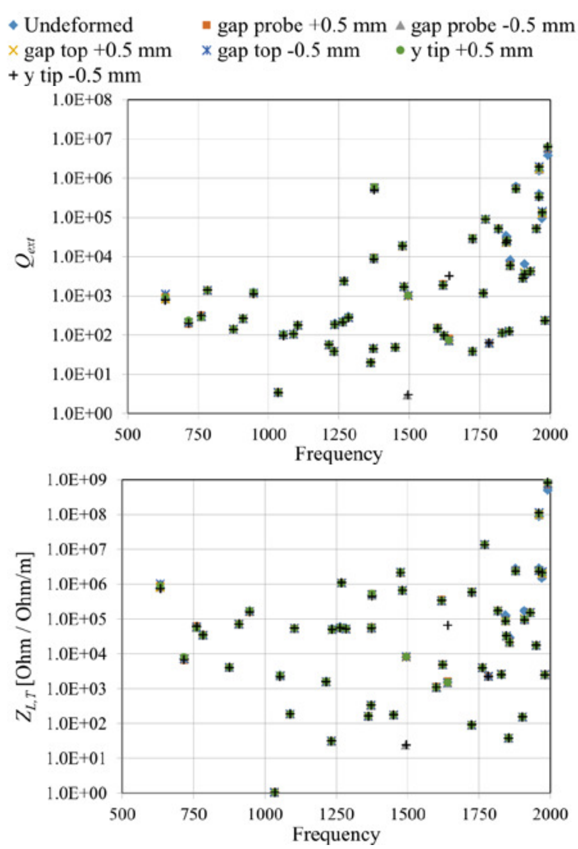

Figure 4: Q_{ext} and impedance change due to HOM tolerances of gap probe, gap top, and y tip.

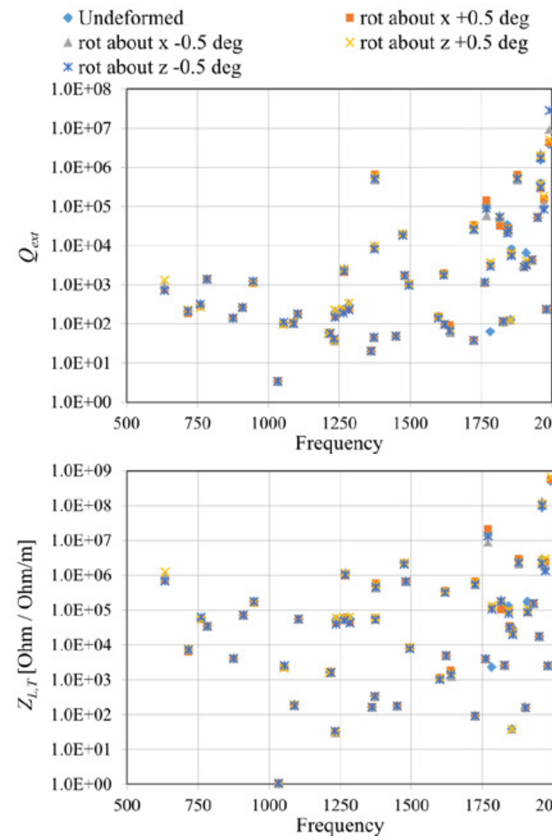

Figure 5: Q_{ext} and impedance change due to HOM tolerances of rotation about x and y axes.

Tolerances considered for gap bar H, P and T are ±0.1 mm assuming the resultant changes during chemical processing. Larger tolerances of ±0.5 mm were evaluated for vertical deviations for vertical gap (gap probe), gap top and hook offset from beam axis center (y tip). The rotational tolerances used for the hook is ±0.5 deg in both x and z axes, which is well controllable during fabrication. Figures 3, 4, and 5 shows the Q_{ext} and corresponding longitudinal and transverse impedances ($Z_{L,T}$) for each tolerance. There is no significant impact on impedance due to HOM tolerances compared with the nominal cavity design.

CAVITY TOLERANCES

Additional tolerances were studied related to the cavity. In the rf-dipole cavity any asymmetries in the poles leads frequency deviations and field non-uniformity across the beam aperture.

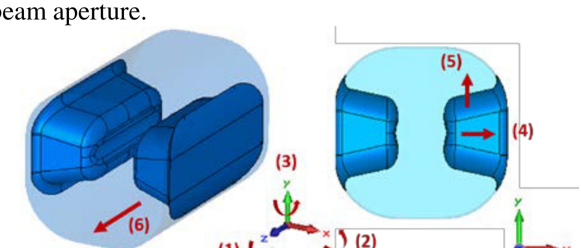

Figure 6: Cavity tolerances: (1) roll (2) pitch (3) yaw (4) x offset (5) y offset (6) z offset.

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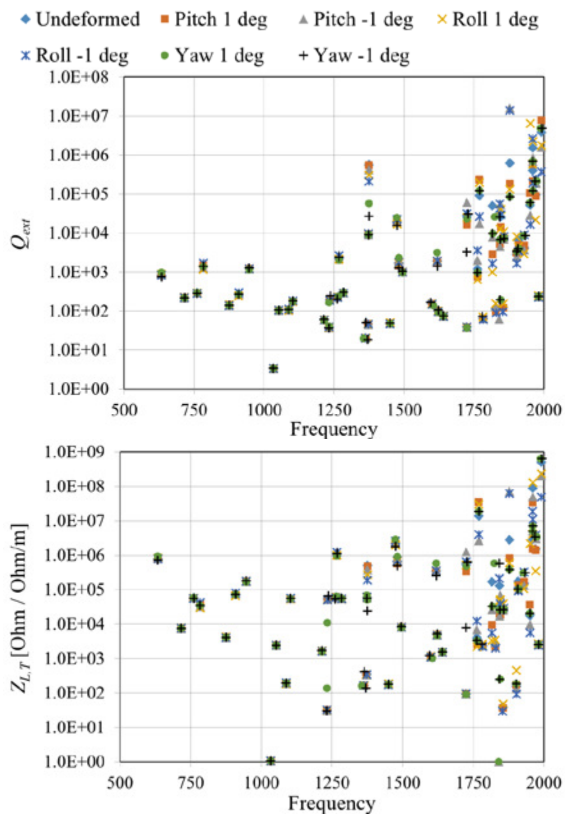

Figure 7: Q_{ext} and impedance change due to cavity tolerances of pitch, roll, and yaw.

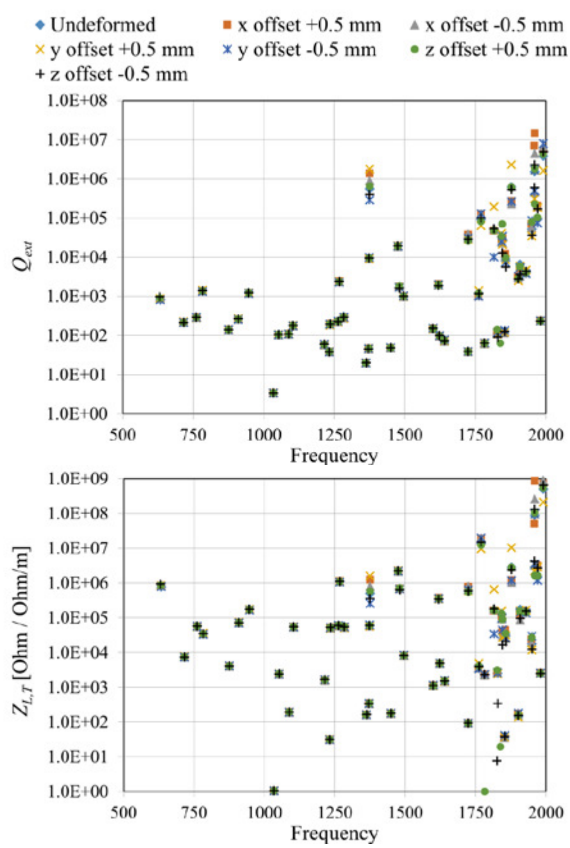

Figure 8: Q_{ext} and impedance change due to HOM tolerances of x, y, and z offsets.

As shown in Fig. 6 effects on HOM damping were evaluated for rotational deviations (pitch, roll and yaw) and translational offsets (x, y and z offsets) for a single pole along each axis. Figures 7 and 8 shows the Q_{ext} and corresponding impedance for the HOMs up to 2 GHz. Considerable deviations are noticed as the frequency increases in similar modes. However the deviations in the $Z_{L,T}$ does not drastically increase from that of the nominal cavity design. The considered deviations of ±1 deg and ±0.5 mm exceed the manufacturing tolerances, therefore the performance of the HOM couplers is not affected by the expected cavity tolerances.

The Q_{ext} deviations in the fundamental mode due to HOM and cavity tolerances increase the power to be extracted by the HOM couplers. The current HOM couplers are designed to extract 1 kW of power from each coupler. The calculated deviations shift the nominal cavity design Q_{ext} of 10^{12} to 10^{9} for the fundamental operating mode, which corresponds to about 25 W. Compared to the designed HOM power extraction this increase is negligible. At the actual expected deviations these power levels are lower than the above calculated. During the rf tests the change in Q_{ext} needs to be taken into account in calculating Q_0.

CONCLUSION

A detailed analysis of the effects on HOM damping due to H-HOM filter and cavity tolerances was performed. The critical HOM tolerances expected during fabrication, assembly and processing do not show significant impact on the HOM damping. Furthermore, the cavity tolerances considered here exceed the tolerable machining errors. Therefore changes seen in impedance do not have an impact on HOM damping. Extra measures will be taken during the HOM coupler fabrication to measure and minimize any deviation in the high pass filter.

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