ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPWI039

ENGINEERING STUDY OF CRAB CAVITY HOM COUPLERS FOR LHC HIGH LUMINOSITY UPGRADE*

HyeKyoung Park#, S.U. De Silva, R.G. Olave, J.R. Delayen
Center for Accelerator Science, ODU, Norfolk, VA 23529, USA
Z. Li, SLAC, Menlo Park, CA 94025, USA
T.H. Nicol, Fermilab, Batavia, IL 60510, USA
T. Capelli, CERN, Geneva, Switzerland
N.J. Templeton, STFC, Daresbury, UK

Abstract

The LHC is planning to employ crab cavities for the high luminosity upgrade. Old Dominion University and SLAC National Laboratory are developing a crab cavity completed with the HOM damping couplers [1]. The HOM couplers are coaxial type and perform over broadband up to 2 GHz. The amount of extracted power requires active cooling using liquid helium. The electromagnetic study has provided expected power dissipation on the coupler. Correlations between the fabrication tolerance and its damping performance have been studied and the results are providing guidelines on how to manufacture the HOM couplers. This paper summarizes the engineering studies; mechanical strength as a part of pressure system, thermal stability, and fabrication method to ensure the required tolerance.

HOM COUPLER DESIGN

The cavity is designed [2] to have the waveguide leading to the HOM coupler, of which cut off frequency is 945.8 MHz. Fig.1 is showing the overall cavity and the H-HOM coupler details inside.

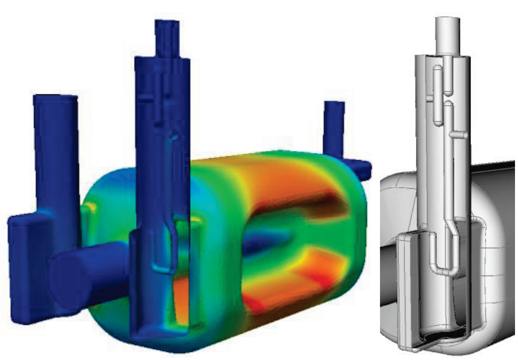

Figure 1: Cavity showing surface magnetic field distribution and H-HOM coupler internal structure.

There are two HOM couplers, one damping the horizontal HOM modes and the other damping the vertical HOM modes. The vertical HOM coupler is a simple coaxial probe type in the waveguide and the horizontal HOM (H-HOM) coupler is a high pass filter type comprised a hook and probes. This paper focuses on the horizontal HOM coupler.

*Research supported by DOE via the US-LARP program and by the High Luminosity LHC project. Also supported by DOE Contract No. DE-AC02-76SF00515.
#hkpark@jlab.org

THERMAL STUDY

The H-HOM coupler is designed with the niobium hook and probe. The dynamic and static heat loads must be dissipated by the liquid helium to ensure the niobium parts remain superconducting. To avoid a quench very conservative assumptions were used.

Thermal Properties of Material

The main property needed for the thermal study is the thermal conductivity of each material. Since the thermal conductivity is a temperature dependent property, a nonlinear thermal study was performed. The property curve of niobium is shown in Fig. 2 for example. Same type of nonlinear thermal conductivity was used for ceramic, stainless steel, and copper.

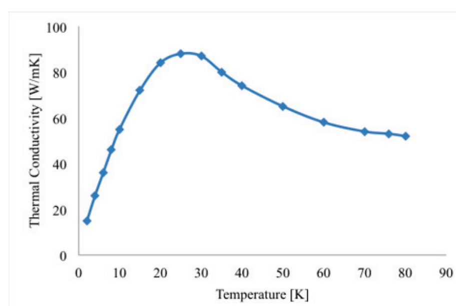

Figure 2: Temperature dependent thermal conductivity of niobium.

Dynamic Heat Load

The surface field is calculated from the finite element RF simulation, ACE3P developed at SLAC [2,3]. The heat load is Joule heating by this field and the surface resistance and it was numerically integrated as follows.

$$P = \frac{1}{2} R_s \int \left|\vec{H}\right|^2 da$$

where P is the power in Watt, Rs surface resistance in Ohm, H time averaged surface magnetic field in T. The power loss is scaled based on 1 kW of power extraction each mode. The surface resistance is assumed 10 nOhm, which is higher than typical niobium test results. For copper probe, the surface resistance was scaled to each frequency accounting for the anomalous limit of a normal conductor at the room temperature. Therefore, the

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPWI039

assumed surface resistance at 400 MHz is 5 mOhm and it increases to 8 mOhm at 1 GHz. The loss at the RF copper gasket is calculated as well assuming the surface resistance of 1 mOhm at 2K. The values are summarized in Table 1.

Table 1: Power Loss at Each Mode at 3.4 MV of Deflecting Voltage [unit in W]

f [MHz]	Nb hook	Nb tee	Cu probe	Cu gasket
400	5.99E-04	1.44E-06	4.90E-02	1.07E-01
627.5	6.85E-06	5.42E-06	3.00E-01	6.15E-04
633.8	6.24E-06	5.32E-06	3.09E-01	5.76E-04
690.2	3.36E-06	2.85E-06	3.35E-01	6.44E-04
716	3.87E-06	2.20E-06	3.48E-01	7.54E-04
735.5	3.10E-06	1.60E-06	3.49E-01	6.06E-04
761	3.90E-06	1.37E-06	3.31E-01	7.23E-04
783.1	3.22E-08	9.55E-09	2.71E-03	5.80E-06
800.5	1.37E-07	2.55E-07	3.18E-01	1.40E-05
875.5	2.68E-07	5.41E-08	2.55E-02	4.95E-05
909.5	2.46E-08	4.43E-09	2.29E-03	4.56E-06
946.5	5.14E-06	8.66E-07	4.81E-01	9.60E-04
1004.4	1.59E-07	2.62E-08	1.73E-02	2.83E-05

The RF heat load used in the thermal study is a sum of loss at the fundamental mode and that of a HOM which exhibits the largest loss. Also, the applied heat flow to the copper gasket was increased to 2 mOhm value to account roughness and strain effect.

Static Heat Load

The static heat load through the rigid line connection (see Fig. 3) was estimated 2W by CERN.

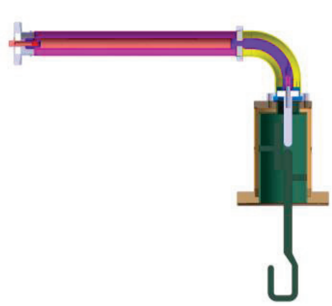

Figure 3: Rigid coaxial line of HOM coupler, showing a section of the connection.

The half of static heat load was applied to the inner conductor and the rest to outer conductor at the thermal study.

Results

The thermal study model included the feed through which has the ceramic window and copper probe. The dynamic heat loads are applied to the corresponding location and the static heat load is applied to the inner and outer conductor of the feed through. The surface of the coupler which contacts liquid helium was set to 2K. The resulting temperature profile is shown in Fig. 4.

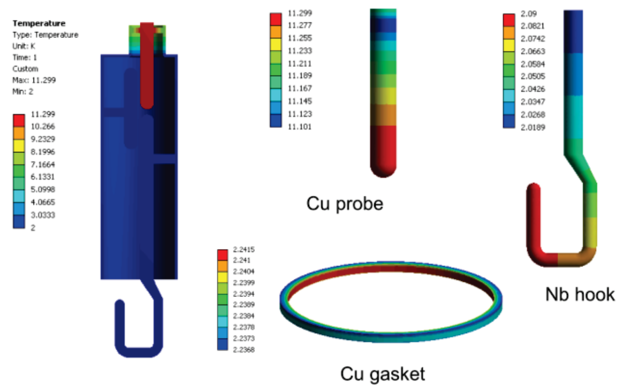

Figure 4: Temperature profile [unit in K].

The finite element analysis shows the temperature increase about 0.1 K at the niobium hook extremity, 0.24 K at the copper gasket. The temperature profile was checked against the initial assumption of the temperature dependent surface resistance. The results assure the temperature is converging to a stable point.

THERMAL DEFLECTION

The H-HOM coupler requires the hook and probe geometry stays to the design to maintain the specified impedance at each higher order mode. When the HOM coupler is cooled down it is expected to have a distortion due to the different thermal expansion coefficients of niobium and stainless steel. Therefore, the thermal deflection was analysed.

The results show that the hook is rotating 0.01 degree pivoting from the welded point. The amount is well within the tolerance [4].

STRUCTURAL STUDY

The HOM coupler tee and hook are both niobium pieces e-beam welded to a niobium shell and must remain superconducting during operation. To ensure adequate cooling, the annular space between the inner niobium shell and outer stainless steel jacket is connected to the same cryogenic system feeding the RF cavity and operates nominally at 2 K.

During operation, the pressure in this space is sub-atmospheric, but during initial testing will be subject to the same 1.8 bar test pressure as the rest of the cryogenic system, including the RF cavity. The pressure test occurs at room temperature where the allowable stress in the niobium is limited to 50 MPa. The allowable stress for stainless steel is over 120 MPa.

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPWI039

A structural analysis was performed to ensure the coupler satisfies the pressure vessel requirements. Aside from the applied annular pressure there are no other significant mechanical loads. Figure 5 shows a cross section through the coupler with the applied pressure of 1.8 bar external to the inner niobium shell and internal to the outer stainless steel shell. The bottom flange is fixed.

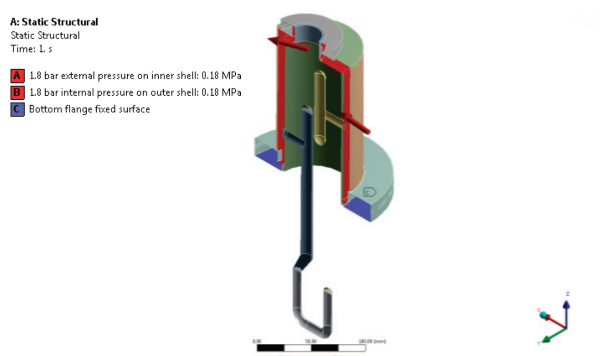

Figure 5: HOM coupler assembly – boundary conditions.

The resulting stresses are shown in Fig. 6. The maximum stress of 13 MPa occurs in the stainless steel shell so the stresses everywhere are below those allowed for both shell materials. The maximum deformation occurs at the top coupler flange and is less than 3 microns.

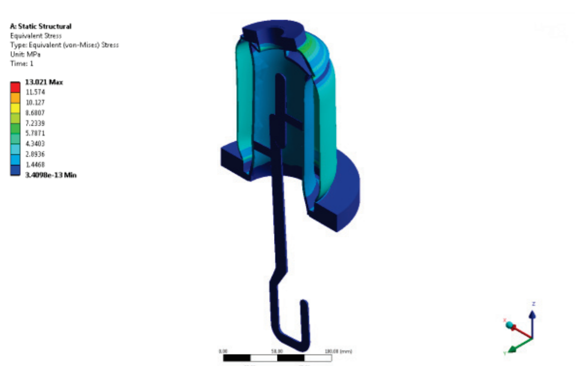

Figure 6: HOM coupler assembly – stresses.

FABRICATION

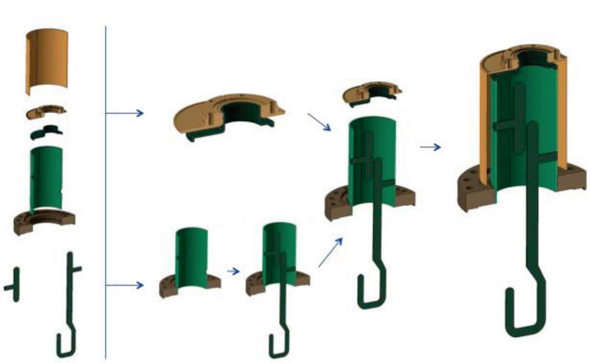

Figure 7: Assembly sequence.

The proposed fabrication step is straight forward for this HOM coupler. There are two types of material only for the main body shown in Fig. 7. The joint between niobium will be e-beam welded. The stainless steel flanges will be copper brazed to the niobium surface.

The feed through (not shown in Fig. 7) requires multiple brazing joints to assemble a copper inner conductor, a ceramic window, a copper outer conductor, and a stainless steel flange. Even though more material is involved, the design of the feed through is simple.

Tolerances are specified so that the HOM damping capability is not degraded. Dimensional and RF measurements are incorporated as important steps of the assembly procedure.

CONCLUSION

The high pass filter type HOM coupler was designed for the RF dipole crab cavity. The engineering studies were performed to investigate the adequacy in thermal and structural aspects. The fabrication procedure was considered as well with an extensive tolerance study [4].

The engineering study results manifest the robust design in terms of damping capability, thermal and mechanical stability. The design and fabrication plan were successfully reviewed by a third party.

ACKNOWLEDGMENT

Authors would like to thank Rama Calaga and Ofelia Capatina at CERN, Graeme Burt at Lancaster University, UK, and Alessandro Ratti at LBNL for their leadership and support.

Frank Marhauser and Ed Daly at Jlab, Slava Yakovlev at Fermilab also provided invaluable advices by conducting technical review.

REFERENCES

[1] S.U. De Silva et al., "Design and Prototyping of a 400 MHz RF-dipole Crabbing Cavity for the LHC High-Luminosity Upgrade," WEPWI036, these proceedings, IPAC'15, Richmond, USA (2015).

[2] Zenghai Li et al., "FPC and Hi-Pass Filter HOM Coupler Design for the RF Dipole Crab Cavity for the LHC Hilumi Upgrade," WEPWI004, these proceedings, IPAC'15, Richmond, USA (2015).

[3] K. Ko, et al., "Advances in Parallel Computing Codes for Accelerator Science and Development," Proc. LINAC2010, Tsukuba, Japan, 2010.

[4] S.U. De Silva et al., "Imperfection and Tolerance Analysis of HOM Couplers for ODU/SLAC Crab Cavity for LHC High Luminosity Upgrade," WEPWI037, these proceedings, IPAC'15, Richmond, USA (2015).