THERMAL LOSSES IN COUPLERS AND PORTS OF A SPS DOUBLE-QUARTER WAVE CRAB CAVITY*

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Abstract

The Double-Quarter Wave (DQW) crab cavity for beam tests at SPS will be equipped with a Fundamental Power Coupler (FPC), three HOM filters and one pickup. FPC and HOM couplers are located in the cavity high magnetic field region and have a hook shape. The FPC will be made in copper while HOM and pickup are in niobium. This paper explains the material choice for the FPC, HOM and pickup couplers given the calculated power dissipation for the fundamental mode. It also describes the envisaged cooling system and corresponding thermal distribution for each coupler.

INTRODUCTION

The HL-LHC Crab Cavity project aims at testing two DQW cavities with beam in SPS. The heat load budget for these tests is limited and efforts have been made during the design process of couplers and cavity interfaces among others to reduce the heat loads [1].

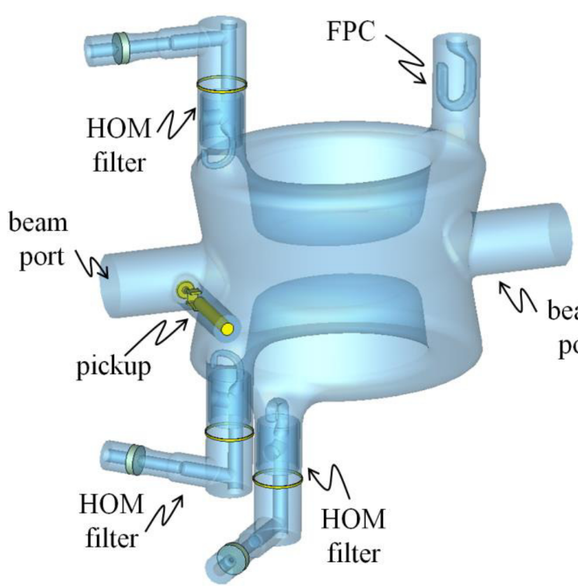

Figure 1: RF volume of SPS DQW cavity with all couplers.

The SPS DQW cavity is equipped with one FPC, three HOM filters and one pickup. The SPS DQW cavity body with all its couplers is shown in Fig. 1.

FUNDAMENTAL POWER COUPLER

The FPC port is opened in the inductive region of the SPS DQW cavity. Both FPC hook and antenna will be made of bulk OFE copper. The FPC has a hook shape for better coupling to the fundamental mode of the DQW cavity.

The hook shape and penetration were chosen to provide a large enough coupling while limiting the power dissipation. The final geometry of the FPC was provided in Ref. [2]. CST simulations [3] were used to determine the RF coupling and power dissipation for the fundamental mode, respectively, 5.3×10^5 and about 100 W for a nominal deflecting voltage of 3.34 MV. The maximum peak surface magnetic field of 8 mT is located at the hook bending for cavity operation at the nominal deflecting voltage. Posterior Omega3P [4] simulations validated these numbers.

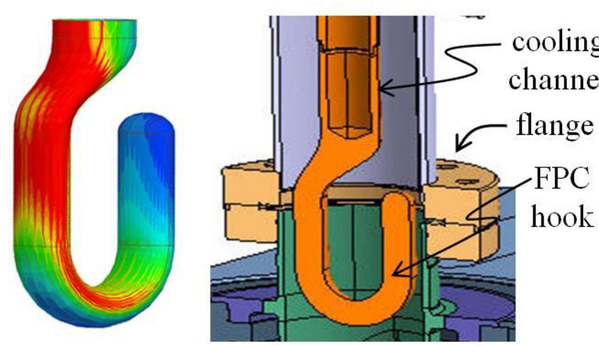

Figure 2: [Left] Surface current distribution on FPC hook provided by CST. The highest surface currents are close to the cooling channel; therefore, improving the extraction of power. [Right] CAD model of FPC hook with cooling channel.

Coupled HFSS/ANSYS simulations [5] were later used to evaluate the temperature distribution on the hook surface and calculate the corresponding radiation losses. The FPC antenna is equipped with a cooling channel for circulating water, as shown in Fig. 2. The cooling channel stops at the beginning of the hook bending. The hook has

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an elliptical cross section to improve the extraction of heat while providing large RF coupling. Iterative calculations considering the surface resistance dependence on temperature found a maximum temperature of about 98.6°C. This maximum temperature was found to be on the hook tip, the farthest end of the hook from the cooling channel (see Fig. 3). Calculations assumed a convective coefficient for water equal to 5000 W/m^2/K. The power loss in the hook resulted to be about 110 W for cavity operation at nominal deflecting voltage.

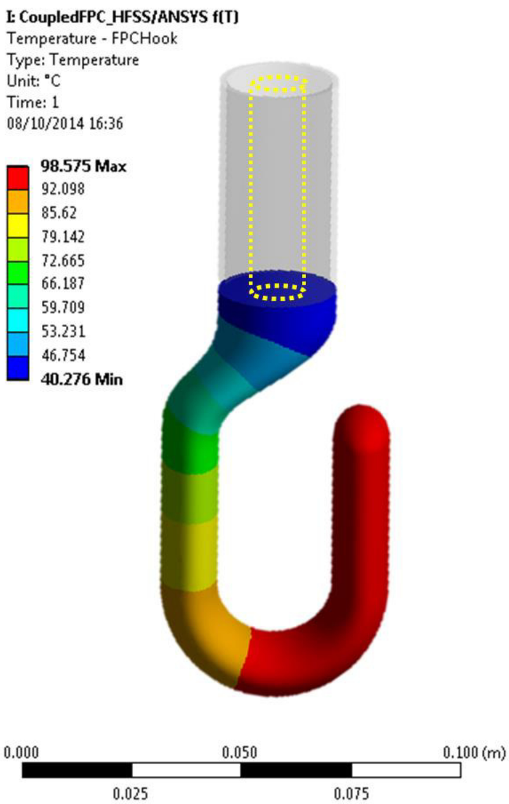

Figure 3: Temperature distribution in the FPC hook for nominal deflecting voltage from HFSS/ANSYS simulations. The dotted yellow lines represent the cooling channel opened in the coupler stem.

HOM FILTER

The RF design of the HOM filters was presented elsewhere [6]. The HOM ports are opened in the domes of the DQW cavity. The length of the main HOM filter section was chosen to reduce the maximum peak magnetic field on the hook. The maximum peak magnetic field is found on the hook bending and has a value of 61.3 mT for the fundamental mode at nominal deflecting voltage. This value is below the maximum peak magnetic field of 71.3 mT found in the cavity.

Each HOM filter consists of two main parts. One part is made of niobium and the other part (or pin) is made of copper. The power dissipated on the different HOM filter parts was evaluated with ACE3P. Calculations used a surface resistance of 5 mOhm for copper and 10 nOhm for niobium. The power dissipated in the niobium part is about 14 mW and the loss in the copper pin is about 0.3 mW. These quantities are evaluated for operation at fundamental mode at nominal deflecting voltage.

A 10mm-diameter cooling channel was opened in the main body of the HOM filter, as illustrated in Fig. 4. Active cooling will be applied to this section. CST was used to calculate the temperature distribution in the HOM filter. The HOM coupler heating will be quite sensitive to thermal conductivity (i.e. RRR) of niobium. The calculation assumed a surface resistance of 5 nOhm for RRR 20 niobium. A maximum temperature of 1.815 K is reached at the hook tip when assuming that the coolant temperature is 1.8 K for a deflecting voltage of 1 MV. The maximum temperature rise is about 0.06 K for nominal deflecting voltage. The temperature distribution in the HOM filter is shown in Fig. 5. The cooling channel is capable of extracting about 1.5 W.

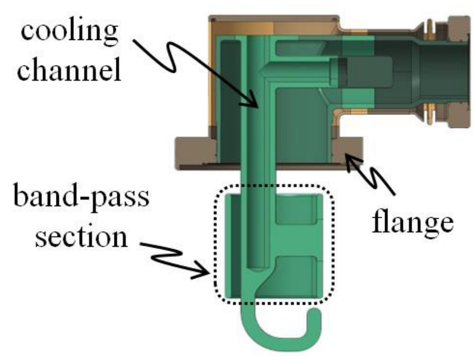

Figure 4: CAD model for the HOM filter showing the cooling channel.

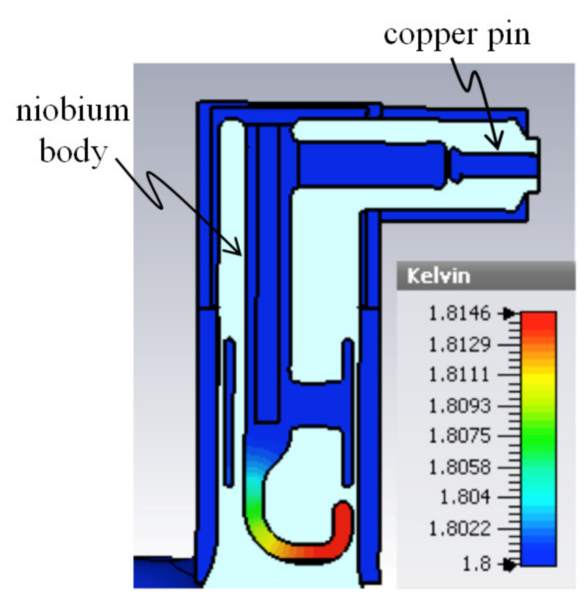

Figure 5: Temperature distribution in the HOM filter for fundamental mode and deflecting voltage of 1 MV (CST simulations).

PICK-UP COUPLER

The RF pick-up port is opened on one of the beam pipes, where field is pretty well damped, as only 1 W of fundamental mode power is required. The pick-up coupler consists of two main parts. At the very end of the coupler there is an umbrella-shaped section with good coupling to the 1.75 GHz HOM. Then there is another section with the shape of a hook that couples well to the fundamental mode. Fig. 6 shows the pick-up coupler. The umbrella-shaped section increases the power dissipation losses for the fundamental mode. Therefore, the pickup coupler will be made in niobium to limit the power dissipation losses for the fundamental mode.

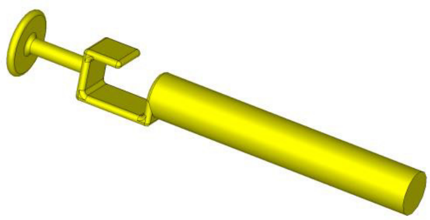

Figure 6: Pick-up coupler.

PORT FLANGES AND TUBES

The SPS DQW cavity ports will use OFE copper RF-seal gaskets. RF-seal gaskets, illustrated in Fig. 7, significantly reduce power losses in flanges interconnections. RF-seal gaskets are specifically designed to screen the stainless steel of the flanges off from the electromagnetic field excited in the cavity. Surface currents that lead to power dissipation by Joule effect are thus only generated in the copper of the gaskets.

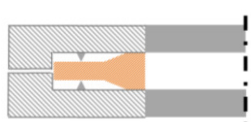

Figure 7: Profile section of an RF seal gasket (in orange) in a CF flange (in grey).

All calculations are done for 3mm-thick gaskets. The gasket size depends on the port type. FPC and HOM ports are made out of 62 mm inner diameter tubes and use stainless-steel DN63CF flanges with its corresponding size gasket. Beam ports have 84 mm inner diameter tubes and are equipped with stainless-steel DN100CF flanges.

A value of 1 mOhm has been used for the surface resistance for copper at 2 K. This value considers the anomalous skin effect of copper at 2K and 400 MHz with a 30% corrective factor to account for roughness effects on surface resistance.

Calculations assume that flanges are thermally intercepted at 2K and that there is ideal heat conduction from flanges to RF-seal gaskets, so that RF-seal gaskets will also be 2K despite being exposed to the electromagnetic field.

The position of the flange for the FPC port was chosen for reduced conductive losses on the FPC antenna tube. The power dissipated in the gasket and copper-coated tube is about 0.02 and 0.05 mW, respectively. The calculations account for a change in temperature along the copper-coated FPC antenna tube from 2 K (at gasket location) to 300 K (set at 450 mm from cavity center).

The flanges of the beam ports are at a considerable distance from the cavity center where the fields are pretty well damped. Stainless-steel tubes will be connected to these ports. Calculations show that about 50 mW per port will be dissipated on the tube walls. If the tubes are copper coated, the losses can be reduced down to 4 mW per port. The position of the flanges for each port of the SPS DQW cavity is shown in Fig. 8.

The capacitive cylinder and inductive rod section of the HOM filter constitute a stop-band structure specifically designed to reduce losses in the flange gasket. The HOM ports are cut immediately after this section. The losses in the gaskets are of 7.8 mW per HOM port as evaluated for fundamental mode for cavity operation at nominal deflecting voltage.

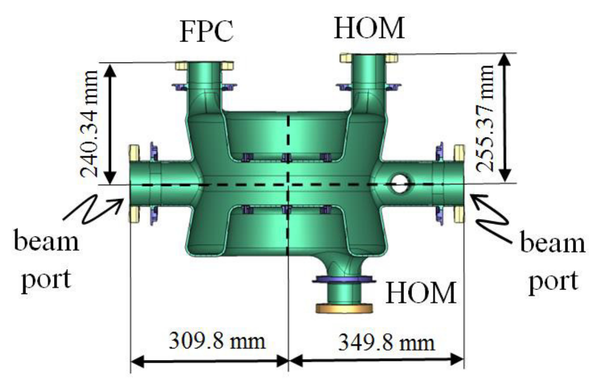

Figure 8: SPS DQW cavity with flange position.

CONCLUSIONS

The design of the couplers for the SPS DQW cavity has been optimized to reduce heat loads. The paper presented the evaluation of heat losses for couplers, port flanges and tubes.

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[1] F. Carra et al., “Crab Cavity and Cryomodule Development for HL-LHC”, these proceedings, SRF’15, Whistler, Canada (2015).
[2] S. Verdú-Andrés et al., “Design and Prototyping of HL-LHC Double Quarter Wave Crab Cavities for SPS Test”, IPAC’15, Richmond, May 2015, pp. 64-66 (2015); http://www.JACoW.org
[3] CST – Computer Simulation Technology.
[4] ACE3P – Advanced Computational Electromagnetic Simulation Suite.
[5] ANSYS Simulation Code.
[6] B. P. Xiao et al., “Overview of Recent HOM Coupler Development”, these proceedings, SRF’15, Whistler, Canada (2015).

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