OPTIMIZATION OF THE DOUBLE QUARTER WAVE CRAB CAVITY PROTOTYPE FOR TESTING AT SPS*

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Abstract

The crab cavity program for LHC luminosity upgrade envisages the testing of at least one of the three competing crab cavities in the Super Proton Synchrotron (SPS) of CERN by 2016. This paper presents the design optimization of a Double Quarter Wave Crab Cavity (DQWCC) prototype suited for testing in SPS.

INTRODUCTION

The LHC luminosity upgrade would significantly increase the potential to discover new physics from rare processes. Bunch crabbing is one of the technologies under development for increasing and levelling the luminosity of LHC and different crab cavity designs have been proposed for this purpose [1].

The crab cavity program envisages a first phase of cold tests for validation of the nominal deflecting voltage and its quench limit. In a second phase, at least one of the three competing cavities in a prototype cryomodule will be tested with proton beams in SPS by 2016.

A first prototype of the DQWCC, one of the cavity candidates for the LHC bunch crabbing system, was fabricated in niobium by Niowave. The prototype is currently being cold tested at BNL. This paper describes the design of a second DQWCC prototype suited for testing at SPS.

THE DOUBLE QUARTER WAVE CAVITY

The double quarter wave cavity is an evolution of the quarter wave cavity proposed as crab cavity, which was symmetrized along the beam axis to cancel the residual longitudinal acceleration along the cavity gap [2].

The DQWCC can be seen as a coaxial line, which central conductor has been transversally split into two halves. The beam would then pass through the two resultant capacitive plates, being a vertical electric field excited in between both plates at the fundamental mode. The deflecting voltage sustained in this type of cavity is then the combined effect of the electric and the magnetic fields (see Figure 1). The beam would experience no acceleration in the DQWCC, but the choice of the ports location may introduce some residual acceleration, which should be negligible (tenths of kV).

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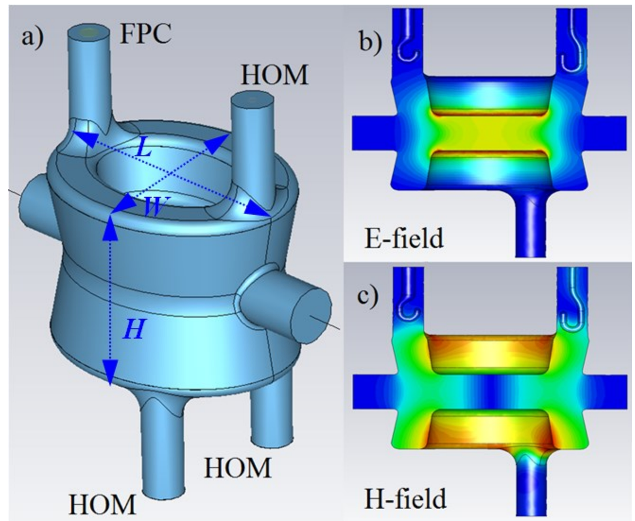

Figure 1: The DQWCC with input and HOM ports and beam pipes (a) and longitudinal section of the cavity showing the distribution of the electric (b) and magnetic (c) fields.

A DQWCC FOR TESTING AT SPS

The technical specifications for the crab cavity prototypes to be installed and tested in SPS are found in Ref. [3]. The present DQWCC optimization is based on the cavity geometry presented in Ref. [2]. The main changes with respect to the former model are the port design and the final cavity length.

Ports Configuration

The present SPS DQWCC design foresees 4 ports. There will be two ports on the top plate, in line with the beam axis, and the other two on the bottom plate, forming 45 degrees with respect to the beam axis to provide clearance for the adjacent beam pipe of LHC. One of the upper ports belongs to the Fundamental Power Coupler (FPC); the other three will house the Higher Order Modes (HOM) couplers, as shown in Figure 1. The former DQWCC model had 4 HOM couplers, but 3 are enough to damp the HOMs with the specifically designed high-pass filters [4], thence this solution was adopted to reduce cost.

The selected port configuration is symmetric, which reduces the multipolar components, and also provides the lowest external Q of HOMs for frequencies up to 2 GHz. The modes with frequencies above 2 GHz are expected to be Landau damped [3]. The ports are located in the high

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magnetic field region of the cavity and so all ports use hook-shaped antennas.

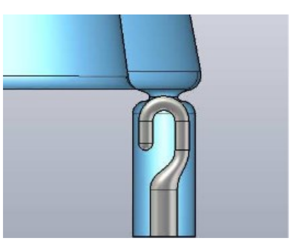
To maintain the symmetry of the cavity, the pick-up port will be located instead on the beam pipe, where fields are low but still high enough to extract about 1 W providing the requested external Q of about 10^{10} for the pick-up antenna.

Couplers Design

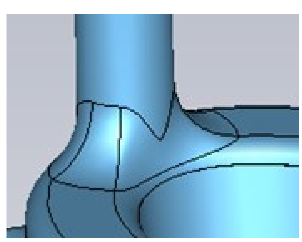
The port diameter for the FPC was fixed to 62 mm for all the crab cavity designs. The former HOM couplers were also designed to have the same diameter, but with a narrowing in the interface of the port to the cavity, as shown in Figure 2 (a). The electric center of the field – the location where the longitudinal acceleration is zero – is not the same as the geometric center of the cavity due to the asymmetry introduced by the 45 degree HOM ports. The different aperture of the FPC and HOM ports introduced a non-negligible center offset. By adopting the same port aperture for both the FPC and HOM couplers in the present cavity design, the center offset is of 0.04 mm, so small that falls into the position resolution of the Beam Position Monitors (BPM) of LHC.

The interface of the ports to the cavity is a critical region where high magnetic field is concentrated (see Figure 3). Three different port interfaces with the large aperture were designed to lower the high magnetic field at the opening. Figure 2 shows the port interfaces. Their electromagnetic performances were evaluated with Microwave Studio [6]. All three options showed a peak surface magnetic field of about 68 mT for a nominal deflecting voltage of 3.3 MV, so the simple-blended port interface was selected as it was easier to manufacture.

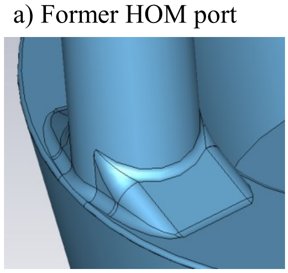
The present cavity design shows an R_t/Q for the fundamental mode of about 426 Ω. An external Q of about 10^6 is required for the FPC so that the power required to feed the cavity is within the 40-80 kW provided by the 400 MHz amplifiers that will be used for the crab cavity testing at SPS.



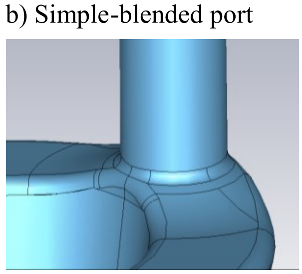
a) Former HOM port



b) Simple-blended port



c) Slope pedestal port



d) Cone pedestal port

Figure 2: Detail of the different port interfaces considered for the DQWCC. The slope pedestal port is based on the design implemented in Ref. [5].

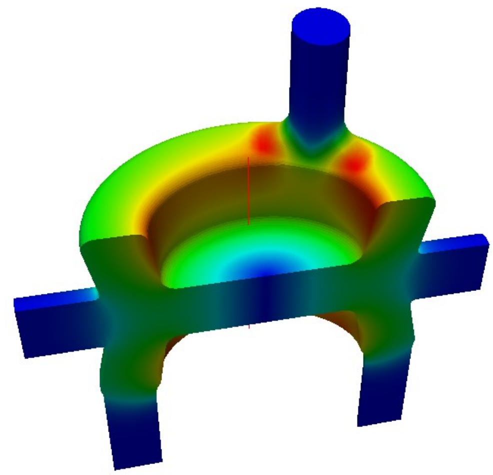


Figure 3: Distribution of magnetic field on the simple-blended model evaluated with ACE3P [7].

The FPC hook will be made of copper and the HOM ones of niobium. The antenna diameter of the FPC was fixed for all the crab cavity models to be 27 mm. Figure 4 shows the final geometry and dimensions of the FPC hook. The external Q of the FPC increases as the hook retracts out from the cavity, so the port length is determined by the necessary penetration depth dP for the hook to reach the required external Q. The current hook design leads to an external Q of 8.4×10^5 for the fundamental mode, so the required power to sustain a deflecting voltage of 3.3 MV in the cavity is about 30kW.

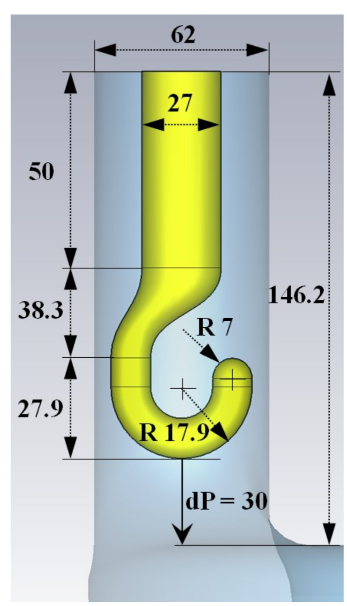


Figure 4: Details of the FPC hook in its port (all dimensions are in mm).

Cavity Dimensions

In principle the crab cavity should be designed for both vertical and horizontal kick configurations at LHC. Therefore, respectively the width and height of the crab cavity are constrained by the LHC beam pipe spacing of 194 mm.

This constraint results in longer cavity, which leads to higher peak surface magnetic fields. The final dimensions of the cavity and its main electromagnetic quantities are shown in Table 1.

Figure 5 illustrates the cavity and helium vessel walls in the space between the LHC beam pipes. The width and height of the cavity are such that there are 6 mm remaining between the adjacent beam pipe wall and the cavity wall. In this space one has to fit the Helium vessel wall, leave enough clearance between all the bodies and provide enough space for the liquid Helium to flow in between the cavity wall and the helium vessel.

Table 1: Properties of the SPS DQWCC

Geometrical parameter *(at 300K)*		**Unit**
Cavity length *L*	344	mm
Cavity half-width *W/2*	139	mm
Cavity half-height *H/2* (w/o ports)	139	mm
Cavity thickness	4	mm
Beam pipe diameter	84	mm
Port diameter *PD*	62	mm
Port length *PL*	146.2	mm
Electromagnetic quantity *(Microwave Studio simulations)*		**Unit**
Crab mode frequency f_0	400	MHz
Nearest mode frequency f_1	581	MHz
Deflecting voltage V_t (1)	3.3	MV
Accelerating voltage V_{acc} (2)	0.015	MV
Center offset	0.04	mm
Peak surface electric field E_{pk} (2)	37	MV/m
Peak surface magnetic field B_{pk} (2)	68	mT
Stored energy U (2)	10	J
R_t/Q	426	Ω

(1) Nominal deflecting voltage per cavity [3].

(2) For a nominal deflecting voltage Vt of 3.3 MV.

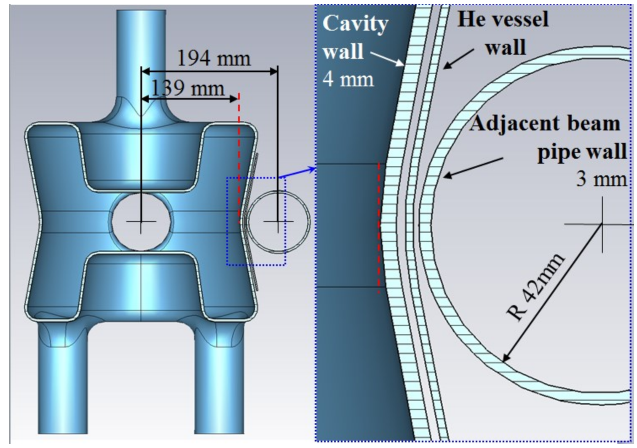


Figure 5: Clearance between the LHC beam pipes for the vertical kick configuration of the crabbing scheme.

FURTHER STEPS

The adaptation of the DQWCC design to the specifications for testing at SPS will continue with the study of the multipacting in the cavity, the evaluation of the multipolar components and the calculation of the expected frequency shifts from microphonics, beam loading and Lorentz force detuning.

The HOM filter design is in progress and it will be completed with the optimization of the HOM hooks for better fundamental mode rejection.

A helium vessel has to be designed yet for the cavity, together with the frequency tuning system. The design of the helium vessel will be performed in parallel with the integration of the cavity into the cryomodule. Thermo-mechanical studies of the vessel-cavity design will follow to guarantee that the safety requirements for cavity installation at SPS and operation are satisfied.

REFERENCES

[1] R. Calaga, "Crab Cavities for the LHC Upgrade", Proceedings of the Chamonix 2012 Workshop on the LHC Performance, Chamonix, February 2012.

[2] R. Calaga et al., "A Double Quarter Wave Deflecting Cavity for the LHC", IPAC'13, Shanghai, May 2012, WEPWO047, p. 2408 (2012).

[3] P. Baudreghien et al., "Functional Specifications of the LHC Prototype Crab Cavity", CERN-Acc-Note-2013-003 (April 2013).

[4] B. P. Xiao et al., "Compact Higher Order Mode Filter for Crab Cavities in the Large Hadron Collider", THP044, these proceedings.

[5] Q. Wu and I. Ben-Zvi, "Optimization for Higher Order Mode Dampers in the 56 MHz SRF Cavity for RHIC", IPAC'10, Kyoto, WEPEC086, p. 3081 (2010).

[6] CST Microwave Studio Suite 2013.

[7] ACE3P Omega3P.

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