A DOUBLE QUARTER-WAVE DEFLECTING CAVITY FOR THE LHC *

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Abstract

An asymmetric quarter wave deflecting cavity at 400 MHz for crab crossing in the LHC was already proposed in 2011. Due to improved cancellation of on-axis longitudinal field and the higher order components of the deflecting field, a symmetric version is now considered as the baseline for the quarter wave geometry. Relevant RF properties of the symmetric cavity are compared to the original asymmetric cavity. Some aspects of input coupler design, higher order modes, multipacting and frequency tuning are also addressed.

INTRODUCTION

An asymmetric quarter-wave crabbing (deflecting) cavity was proposed and designed to meet the tight transverse space constraints of the LHC while providing an excellent surface field to kick voltage ratio [1, 5]. However, the non-zero accelerating voltage and presence of low order multipoles due to the asymmetry make it less attractive due to high beam currents in the LHC and the large β-functions at the location of the crab cavities. A symmetric version was

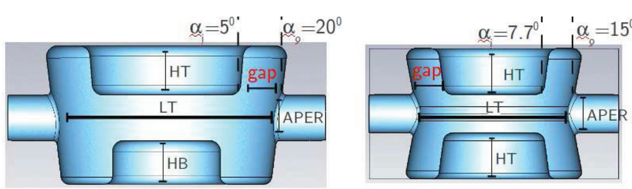

Figure 1: Longitudinal cross sections of the asymmetric and symmetric quarter wave geometries.

proposed as an optimum way to cancel the on-axis accelerating field and comply with the requirements on the multipole components of the deflecting field [4]. The symmetric cavity was resized to have equal dimensions in both transverse planes, thus making it suitable for alternate crossing angles used at the LHC interaction regions. It should be noted that these improved features come at a small loss of compactness and a smaller separation between the the operating mode and the first higher order mode (HOM). Fig. 1 shows the longitudinal cross section of the asymmetric and symmetric cavities.

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RF DESIGN

A detailed scan of the relevant geometrical parameters was already carried out for the asymmetric cavity and presented in Ref. [1]. The same principle was used for the symmetric cavity but with initial conditions derived from its predecessor. Therefore, only an incremental optimization was required to arrive at the final design. The geometrical parameters are listed in Table 1 and are compared to the asymmetric cavity.

Table 1: Geometrical parameters for the three geometries reaching fairly optimized RF performance.

	unit	Asymmetric	Symmetric
LT	[mm]	405	331.64
Gap	[mm]	60	60
$\alpha_{i,o}$	[deg]	4.7/20	7.7/15.0
HT	[mm]	90.2	100.5
HB	[mm]	80	-
r_{top}, r_b, r_c	[mm]	20, 15, 20	20, 15, 20
Ellipticity		1.42	1.16

The relevant RF parameters of both the symmetric and asymmetric cavities are listed in Table 2 optimized for the deflecting mode.

Table 2: RF parameters for the asymmetric and symmetric cavities reaching optimized RF performance.

	unit	Asymmetric	Symmetric
Frequency	[MHz]	400	
Next Mode	[MHz]	646	585
V_T	[MV]	3.3	
R/Q	[Ω]	345	395
E_{pk}	[MV/m]	47	36
B_{pk}	[mT]	67	63
V_a $(z = 0)$	[MV]	0.12	0.0

Due to the lack of axial symmetry along the beam, higher order multipoles of the deflecting field can be present. The large beam size at the location of the crab cavities in the LHC require that these multipoles be suppressed to tolerable limits to avoid a reduction in the lifetime. The symmetric quarter wave cavity significant advantage over its predecessor as certain multipoles are canceled by symmetry in the deflecting plane and the overall deviation of the deflecting voltage as a function of offset is significantly reduced as shown in Fig. 2. Table 3 lists the multipole components calculated numerically using the formalism developed in Ref. [3] and the RF-kick is equated to the magnetic kick of the same strength assuming an ultra-relativistic particle.

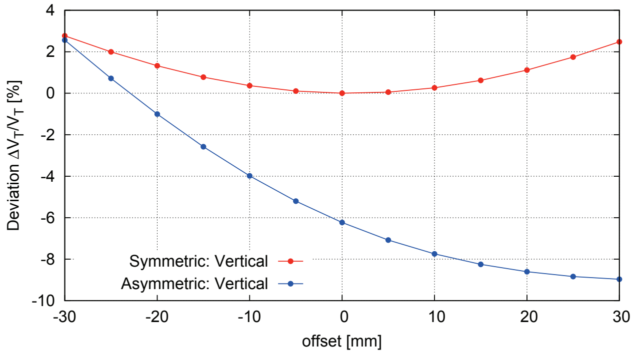

Figure 2: Deviation of the deflection voltage as a function of offset for the symmetric and asymmetric cavities.

Table 3: RF multipole components up to b_4 are numerically calculated for the asymmetric and symmetric cavities [3].

	Asymmetric	Symmetric
	$\Re(b^n) + \Im(b^n)$	$\Re(b^n) + \Im(b^n)$
b_2	111.3 + 0.0	0.36 + 0.06
b_3	1266.7 - 0.15	1076.8 + 0.01
b_4	1821 + 11.48	90.9 - 17.94

INPUT & HOM COUPLERS

The input coupling is specified to reach a $Q_{\text{ext}} = 1 \times 10^{5-6}$ ($Q_{ext} = Q_L$) to optimize the available RF power to compensate for beam loading and maintain reasonable cavity stability and tuning resolution [4]. Due to cavity geometry and field distribution, both electrical and magnetic fields near the aperture is small. In addition, the aperture is well below the cutoff frequency making it difficult to couple RF power from the beam pipes which is standard practice. Therefore, a port on bottom plate of the cavity with a hook-type antenna was chosen. A special interface between the cavity top or bottom plate and the 62 mm coaxial line was required to suppress field enhancement due to addition of ports in the high field region (see Fig. 3).

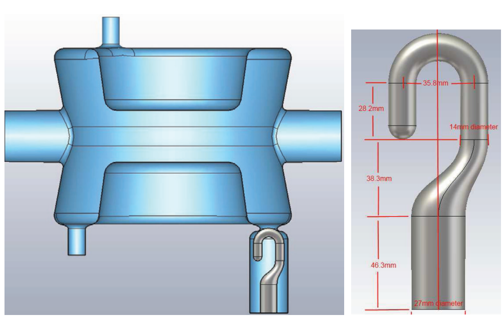

Figure 3: The input coupler interface to the cavity (left) and the hook-type antenna geometry (right).

The principle advantage of the quarter wave cavity is the large separation between the operating mode and the fundamental mode. This immediately allows for the use of a high pass filter which is significantly more reliable than the standard practice of notch filters, which rely on precise tuning at room temperature operated at cryogenic temperatures. The HOM spectrum is calculated up to 2 GHz and Fig. 4 shows the R/Q's as a function of frequency. The modes are classified according to the dominant field component either longitudinal or transverse.

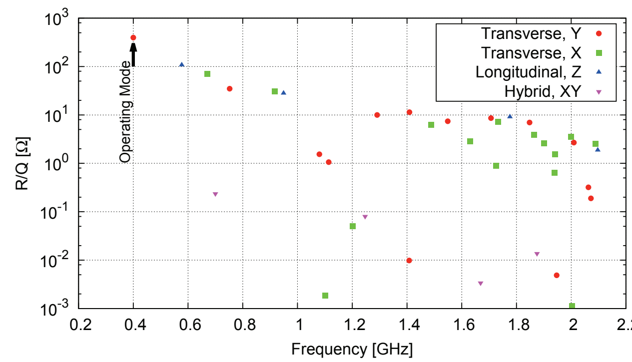

Figure 4: Higher order mode spectrum for longitudinal and transverse modes and their corresponding R/Q values up to 2 GHz.

To intercept all the HOMs, a similar strategy as the input coupler is employed with a total of 4 ports on the top and bottom plates. (see Fig. 5). The two other ports correspond to the input and pickup couplers. A magnetic loop at each of the 4 ports with a high-pass filter to the reject the operating mode is efficient in damping all modes the strongest modes to within a Q_{ext} to a few 1000 or below [5]. The asymmetric placement of the ports is required for the passage of the second beam pipe for horizontal kick configuration.

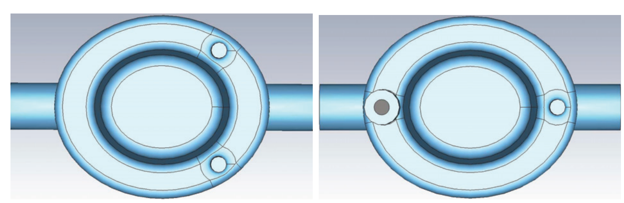

Figure 5: HOM coupler ports on the top and bottom plates using loop couplers.

MULTIPACTING

Due to ellipticity in the axis of symmetry, presence of the beam pipes and couplers, a 3D multipacting simulation is required to assess the true onset of multipacting as a function of operating field. However, a first study is carried out using a 2D Helsinki code [7] code assuming an ellipticity of 1 and without the presence of beam pipes to validate the general cavity shape. 3D simulations are underway for a full validation. Fig. 6 shows the total number of electrons after a given number of impacts normalized to the average secondary emission coefficient corresponding to the specific impact energy (enhanced counter function, ECF) as

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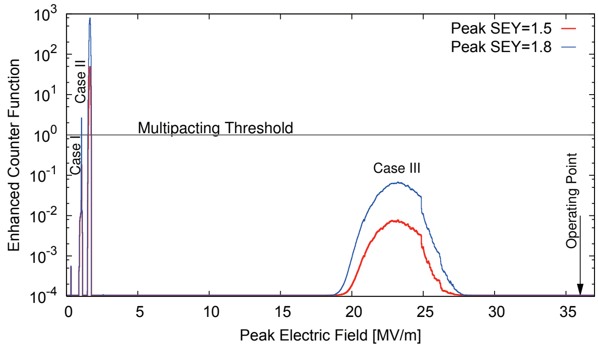

Figure 6: The number of secondary electrons after 40 impacts normalized to the SEY corresponding to the impact energies plotted as a function of surface electric field.

a function of surface electric field. Two different types of SEY curves were used to distinguish between a good surface (Peak SEY = 1.5) compared to that of an untreated one (Peak SEY = 1.8). There are a few bands in the extremely low field region (see Fig. 7, top) and a rather broad band at about 23 MV/m (see Fig. 7, bottom). The band with ECF greater than one is non-physical as a beam pipe is present in the real cavity for which other type of trajectories maybe supported. All of them appear benign.

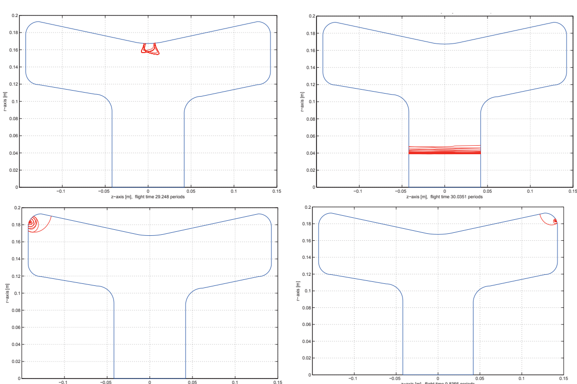

Figure 7: Trajectories of the two low field region bands (top) and the high field region band (bottom).

TUNING, STIFFENERS & PROTOTYPE

A change of the semi-major axis or a movement in vertical direction of the capacitive plate results in a frequency shift of approximately 1-2 MHz/mm. Therefore, a stable tuning system along with mechanical stiffeners on the flat part of the inner conductors will be needed to minimize frequency perturbations from external vibrations. During the cavity cool-down, external pressure can reach beyond 2 bar with a safety margin included. However, it was found that the cavity deformation at such high pressures can reach into the plastic limit. A detailed study was launched to investigate several stiffening solutions [6]. A solution using a rectangular frame to balance the forces between the two quarter wave plates was adopted for the prototype cavity as the simplest mechanism both for its role in stiffening and as a tuner. A further improvement of this concept with a compact coaxial tank acting as a stiffener, tuner and a He-vessel is adopted for the final design into a cryostat [6].

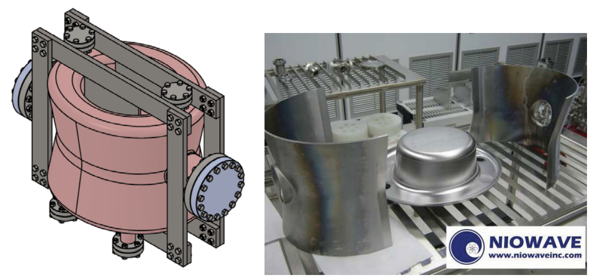

Figure 8: Stiffening and tuning structure for the first prototype (left). the first prototype in bulk Niobium for deflecting field validation up to nominal voltage and beyond (Courtesy Niowave Inc.).

The the first prototype of the baseline symmetric double quarter wave was built in industry as a first step for field validation of the cavity to the nominal voltage and it quench limit. Fig. 8 shows the various parts of the cavity ready for e-beam welded. The fabrication is now completed and is undergoing surface preparation before cold tests. The prototype will help also help determine some critical aspects such as minimum dynamics heat loads for cryogenics and cavity stability for machine protection.

CONCLUSION

A symmetric double-quarter wave cavity was designed and optimized towards the LHC crab crossing project. The symmetric cavity presents improved cancellation of the on-axis accelerating fields and higher order multipoles of the deflecting field compared to its predecessor. The HOMs frequencies and their R/Q values up to 2 GHz are presented. Frequency tuning concept adopted for the cavity also plays the role of cavity stiffening which has been validated in simulations. A prototype cavity in Niobium is built and presently being prepared for cold testing for field validation.

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