SLIM ELIPTICAL CAVITY AT 800 MHz FOR LOCAL CRAB CROSSING

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Abstract

A slim highly eccentric elliptical Crab cavity with vertical deflection at 800 MHz, compatible to beam line distances everywhere in the LHC ring, was designed. It is a good fall-back solution in case of problems with new compact 400 MHz designs. Simulated RF characteristics of the deflecting mode, HOM spectra and damping, tuning and multipacting effects are presented. First the most simple HOM coupling system was investigated. The rejection of the working mode was not sufficient and a notch filter was added. Results of both cases will be presented.

SLIM CRAB CAVITY PARAMETERS

A 3D sketch of the slim elliptical crab cavity (CC) design is shown in Fig. 1.

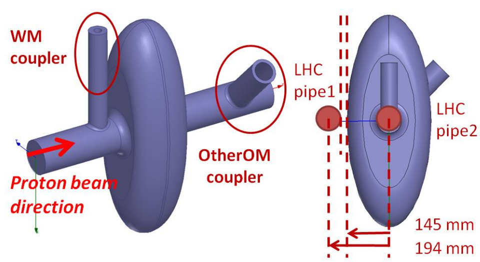

Figure 1: Perspective view of the cavity with couplers encircled (left); View in beam direction of the cavity with spatial constraints highlighted (right). Maximum extension 292x729 mm.

The final cavity design includes the working mode (WM) feed power coupler and the unique damping coupler optimized to attenuate all the other order modes (OOM) as required.However, the coupling to the WM remained too strong, requiring an additional coaxial stub filter.

Table 1: Slim crab cavity WM parameters

	HFSS	CST-MWS
$(R/Q)_\perp$ [Ω]	17.5	17.5
E_{peak}@$2.5MV_\perp$[MV/m]	32	33
B_{peak}@$2.5MV_\perp$[mT]	115	107

Table 1 shows the principal parameter as calculated in good agreement with both MicroWave Studio and HFSS.

OTHER ORDER MODE DAMPING

The lowest (accelerating) mode (LOM) resonates 150 MHz below the WM, the next highest 50 MHz above the WM. All these other order modes (OOM) have to be damped correspondingly to avoid beam instabilities, i.e. in total $Z_{\parallel,n} < 2.4\ M\Omega$ and $Z_{\perp,n} < 1.5\ M\Omega/m$[1]. Assuming that there are four cavities per ring, one before and one after each of the two main interaction points, each cavity can account for up to 1/4 of these values. Since couplers break the symmetry the OOMs were grouped by their main field orientation as defined in Fig. 2.

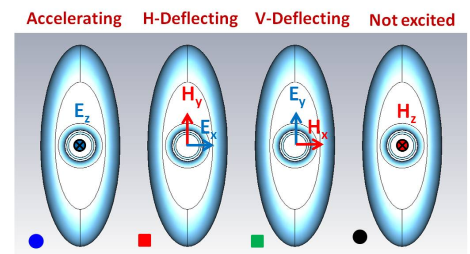

Figure 2: (From left to right) pure accelerating, horizontal and vertical deflecting and not excited modes. Trapped mode will be represented by black stars.

Fig. 3 shows the configuration of the damping coupler for both the investigated solutions. It was possible to damp all longitudinal OOMs using a simple coaxial to coaxial coupler as shown in Fig. 3 (left). All monopole modes are propagating along the coaxial to coaxial coupler but with different coupling factors. In the notch filter case (Fig. 3, right) the OOM power is not taken out by a lateral antenna but by resistive absorbers down the main coaxial line. Calculations were done in assuming that the wave at the end of the represented section is fully absorbed.

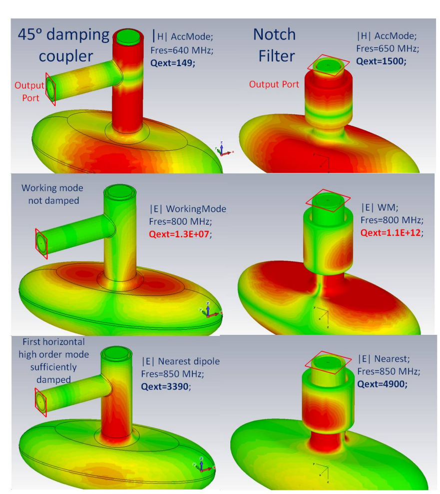

Figure 3: (Top) damping schemes for the fundamental mode and (center/bottom) for the first two dipole modes.

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Coupling to the horizontal and vertical HOMs

In Fig. 3 we compare the coupling to the WM with a high Q_{ext} (rejection) and to the first dangerous higher order dipole mode with a low Q_{ext} (good coupling) for the antenna scheme. Fig. 3 (bottom, center right) shows the same for the notch filter scheme.

Without using the notch filter the maximum rejection of the WM in terms of Q_{ext} is only 10^7, at least two orders of magnitude too low. One way would be to displace the inner conductor of the main coaxial line as studied in [2].

Another possibility is to introduce the notch filter as shown in Fig. 3 (right). The designed notch filter is tuned to be $\lambda_g/4$ long at 800 MHz but acts also on the other modes of the coaxial pipe. This notch filter — well tuned — increases the Q_{ext} of the WM to $4 \cdot 10^{12}$; the parallel increase of Q_{ext} for the most critical higher order dipole mode by about 30% presents no real problem.

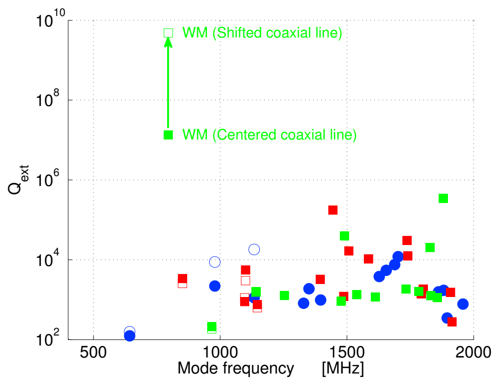

Figure 4: Q_{ext} of the 45° antenna design.

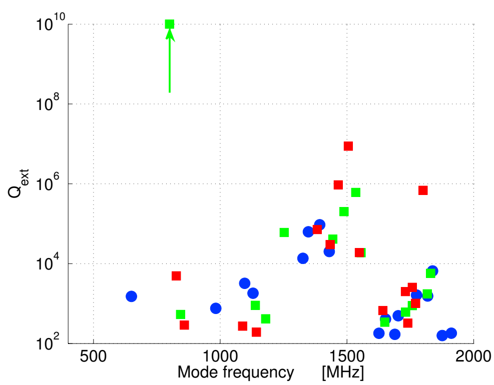

Figure 5: Q_{ext} of the notch filter design with very high rejection of the WM, larger than 10^{12} (out of scale).

The achieved damping

The final Q_{ext} are shown in Fig. 4 for the antenna coupler without notch filter. The working mode shows a $Q_{ext,OOM}$ slightly larger than 10^7. This rejection should be increased to at least 10^9 which is possible with a slight shift of the inner conductor transverse position as the unfilled green marker show (details in [2]).

In Fig. 5 there are the equivalent values including the notch filter. The very high Q_{ext} of the WM is out of scale, the other data show that the notch intruduction does not seriously degrade the coupling to the other dangerous modes.

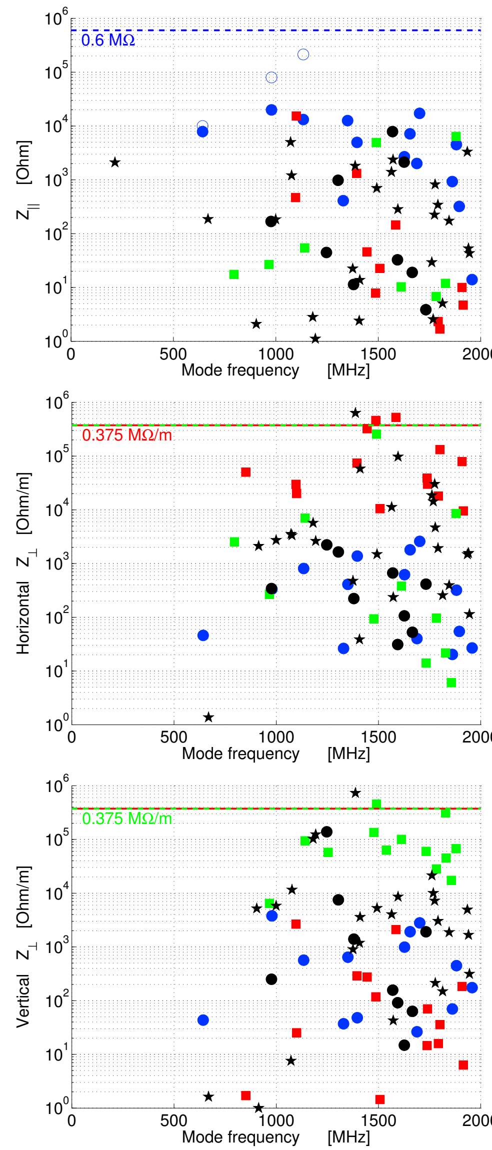

Figure 6: Lateral antenna coupler: (top) longitudinal, (center) horizontal, (bottom) vertical beam impedances.

With this we obtained the results for the beam impedance as shown in Fig. 6 for the antenna coupler without notch filter. The dashed lines are the impedance limit for the LHC crab cavities for the worst case of beam energy. With the proposed coupling scheme all the unwanted modes are damped below this limit.

Finally in Fig. 7 the equivalent results for the coaxial coupler with the notch filter are shown. As the plot shows some HOMs (especially for those above 1.3 GHz) are affected by the presence of the notch filter. However,we have to consider that the threshold of acceptable impedance increases exponentially with frequency above its minimum, represented by the dashed line.

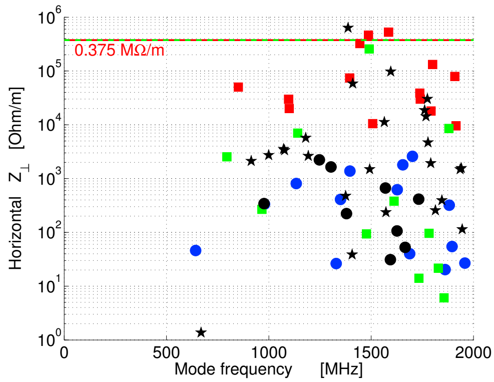

Figure 7: Notch filter coupler: longitudinal and transverse beam impedances.

MULTIPACTING STUDIES

Run-away resonant trajectories were found at several locations in the cavity and within the low field band as shown in four time instances in Fig. 8.

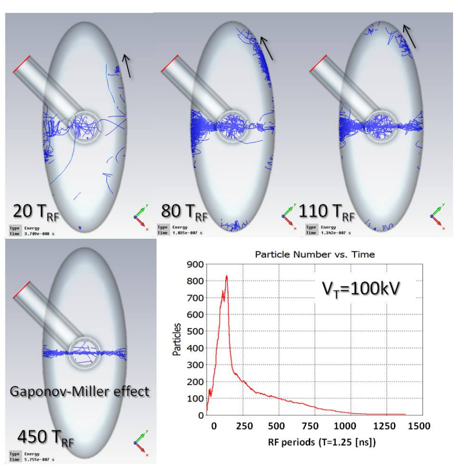

Figure 8: Electron trajectories and population at 4 different time and at low deflecting voltage (100 kV).

In the range $V_\perp = 50 - 400$ kV three different effects were found. Run-away resonant trajectories start in the equatorial area moving in the direction of the small radius equatorial area; they were extinguished in less than 400 RF periods, or could produce longer trajectories having a more stable position around the large radius equatorial area; but also this resonance disappears after 1 μs as shown in Fig. 8. The third effect is the Gaponov-Miller effect [3], which tends to push charged particles towards regions of low field amplitude. Stable resonant trajectories were found around the large radius equatorial area within the high field band, for example in Fig. 9 (top). As the trajectories show, after the first ten periods an electron avalanche is established. Trajectories also show a predominance of 1/2 order multipacting with two stable points crossing the cavity equator; these could be processed away easily in the LHC and LEP cavities.

Stable resonant trajectories were found at the end of the inner coaxial pipe at low field level (Fig. 9 (bottom)). No resonant trajectories were identified in the OOM coupler area at high deflecting voltage.

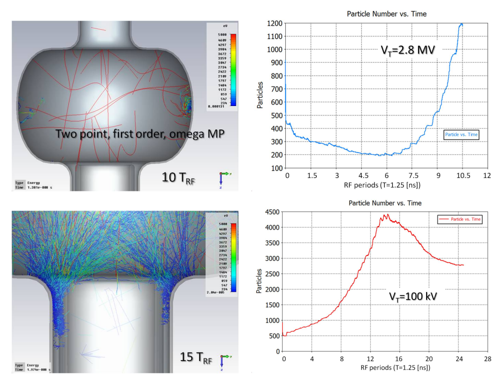

Figure 9: (Top) electron trajectories and population after 10 RF periods at high deflecting voltage (2.8 MV) and (bottom) after 15 RF periods at low deflecting voltage (100 kV).

CONCLUSIONS

The RF design of an 800 MHz CC sufficiently compact to fit *anywhere* in the LHC ring has been realized for the LHC High Luminosity upgrade (HL-LHC) with the local crab option, providing a voltage of $V_\perp = 2.5$ MV. The geometry has been optimized for the lowest peak surface fields preserving $(R/Q)_\perp$.

This CC is an oblong classical cell exited on the vertical TM_{110}-like mode. It is loaded by a special coaxial damper integrated onto one of the beam tubes. Two different damping system were investigated: A lateral antenna coupler placed at 45° and the introduction of a dedicated notch filter between the cavity body and the OOM power output. The latter has provided the expected preliminary results by increasing the Q_{ext} of the WM to acceptable values. Tracking was done to predict any signs of multipacting in a range of $V_\perp = 0.01 - 3MV$.

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