SC CRAB CAVITY WITH REDUCED TRANSVERSE SIZE FOR THE LHC UPGRADE*

N. Solyak, I. Gonin, T. Khabibouline, and V. Yakovlev, FNAL, Batavia, IL 60510, U.S.A.

Abstract

In the paper the Crab Cavity is described for local Crab schemes for LHC that demand reduced transverse cavity dimensions small enough to fit limited space necessary for the beams separation. The results of the configuration cavity optimization are presented that include (a) the surface field minimization; (b) parasitic monopole and dipole spectrum optimization and dumping, (c) the input and the parasitic mode damping couplers design. The results of multipacting simulations, which were performed in order to understand the possible gradient limitations, are discussed also.

INTRODUCTION

In order to increase the LHC luminosity by 15% for the nominal, and by 43-62% for Phase II upgrade, the crab cavity compensation scheme is suggested [1]. In the case of successful proof-of-principle experiments with a global scheme, the local scheme crab cavity scheme will be used in the Phase II of upgrade, as shown in Figure 1 taken from [1].

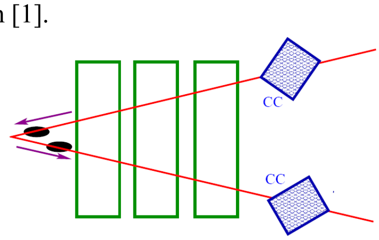

Figure 1: LHC crab crossing Phase II scenario. Two crab structures are shown on the side of interaction point to crab and anti-crab the beam in the IR region.

This scheme demands redesign of the optics in the interaction point region. A new approach to the existing IR upgrade optics by using additional D_{11} & D_{12} dipoles allows separate the two beam lines to ~27 cm for inserting crab cavities as shown in Figure 2. The crab cavity should provide the transverse kick of up to 5 MV [1]. The cavity aperture is limited by 120-140 mm. In order to prevent CBM instability, the Q-factor of lower monopole modes is to be lower than 200, and shunt impedance should not exceed 137 kOhm [1]. Transverse impedance is to be much lower than 2 MOhm/m [1].

However, the limitation of the transverse size by 27 cm makes impossible utilization of a conventional cavity even at 800 MHz, and a cavity with reduced horizontal size should be used, for example, “mushroom” cavity that was used for the beam deflecting in 180 MHz gyrocon built in Budker INP [2]. The version of 800 MHz mushroom cavity having elliptical transverse cross section was suggested for the crabbing in [3], see Figure 3. The 2-cell mushroom cavity has coaxial coupler similar to one of the KEK crab cavity [4], and provides required impedance for parasitic modes. However, this scheme is problematic in case of using side couplers.

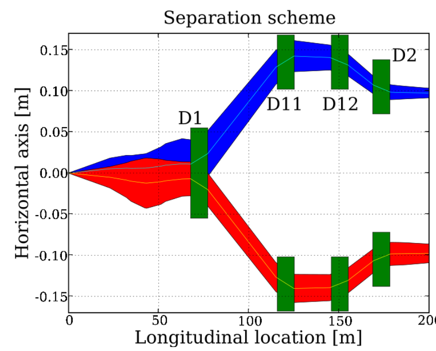

Figure 2: Schematic of the crab crossing scheme for the Phase II upgrade of the LHC.

In present paper, the modification of mushroom 2-cell mushroom cavity is discussed that is shown in Figure 4. The cavity has “mushroom” configuration in *xz*-plane only, and allows the coaxial coupling units, where both power and HOM damping couplers may be installed [5]. The operating mode is TM_{110} π-mode at 800 MHz with the polarization having vertical transverse magnetic field providing, therefore, horizontal kick.

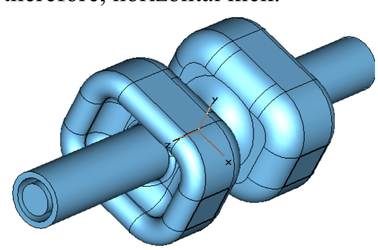

Figure 3: Initial version of the mushroom crab cavity with the coaxial couplers. Horizontal size is 350 mm. For the kick of 2.5 MV E_{peak}=36.6 MV/m and H_{peak}=135 mT.

GENERAL

Cavity Shape Optimization

On the first stage, the cavity shape was optimized in 2D simplification, see Figure 5. The goal was to reach minimal surface magnetic field H_{surf} at fixed value of the effective deflecting magnetic field H_{eff}, that is proportional to transverse kick $V_{\perp}$:

$$H_{eff} = \frac{2V_{\perp}}{Z_0 \lambda}.$$

One can see the optimal gap value is 12.5 mm. The cavity transverse size R_{cavity} was 175 mm, the cavity aperture R_{ap}=60 mm.

*Work supported by US DoE.
#solyak@fnal.gov

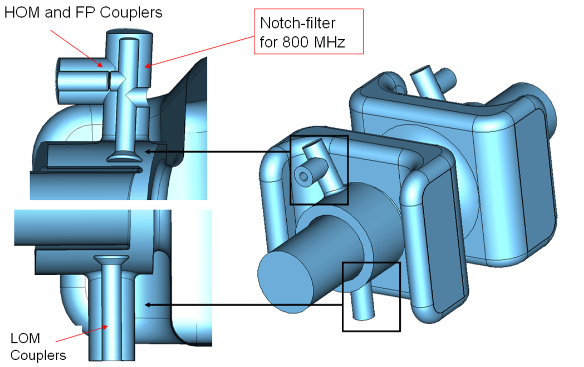

Figure 4: 2-cell mushroom crab cavity design with the coaxial coupler units at the cavity ends.

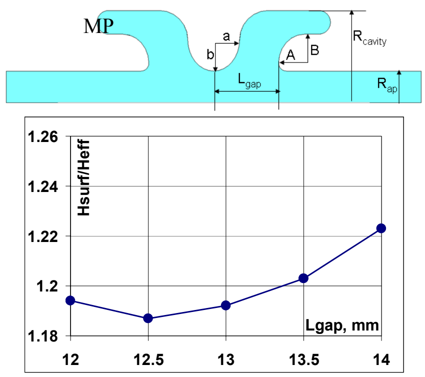

Figure 5: The cavity optimization in 2D approximation. The cavity cross section (top) and maximal surface magnetic field vs. gap length (bottom).

The results of optimization of the cavity transverse dimensions are shown in Figure.6. The optimal value for ratio of the vertical cavity size D_1 to horizontal size D_2 is 0.84. Horizontal size D_2 is fixed and equal to 350 mm. For the kick of 2.5 MV E_{peak}= 31.7 MV/m and H_{peak}= 77.4 mT.

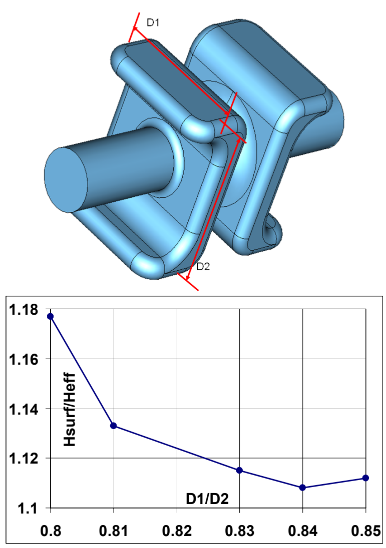

Figure 6: 3D cavity shape optimization.

Coupler Optimization

The cavity has the following parasitic modes that should be damped:

1. *Low Order Modes (LOM)* – the two (0 and π) monopole modes that have frequency lower then operating one, 650.5 and 651.3 MHz, respectively.
2. *Same-Order Mode (SOM)* - the dipole modes that have polarization other than the operating mode, it's frequencies are 1043.9 and 1064.8 MHz respectively.
3. *High-Order Modes (HOM)* – all other modes, monopole and multipole having the frequencies higher than the operating one.

Thus,the cavity needs (i) power coupler that provides the RF power in order to build up deflecting rf voltage and compensate the beam loading; loaded Q is to be 5×10^5; (ii) LOM coupler necessary to suppress LOM modes; the loaded Q is limited by the power that can be extracted to the external load. For KEK crab cavity this power is 10 kW [4]; (iii) SOM and HOM couplers that should provide required longitudinal and transverse impedance, see above.

An example of the coupler configuration optimized for SOM damping and operation mode insulation is shown in Figure 7. The coupler has notch filter that rejects operating one as one can see from Figure 8. However, damping of the operating 0-mode at 807.47 MHz is not optimized, and has shunt impedance of 20 MOhm/m, that is ~40 times smaller than the operating π-mode at 800 MHz. Anyway, further optimization of the SOM filter is required. It is possible to move the S_{12} maximum that has now the frequency of 840 MHz (Figure 8) to the resonance of 0-mode and keep the same insulation for the operating π-mode, using for example, two-stage filter.

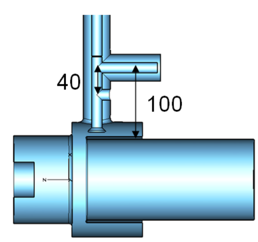

Figure 7: SOM coupler layout, dimensions are in mm

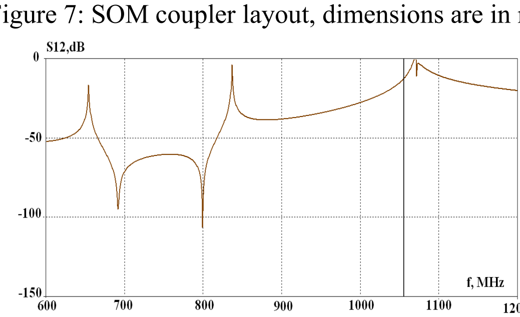

Figure 8: The SOM coupler: S_{12} versus frequency

Main coupler is rotated by 3° in order to achieve required coupling (Figure 4). The loaded Q-factor dependence on the angle is shown in Figure 9. Resulting mode parameters are shown in Table 1. One can see that the shunt impedances of the parasitic modes are well below requirement.

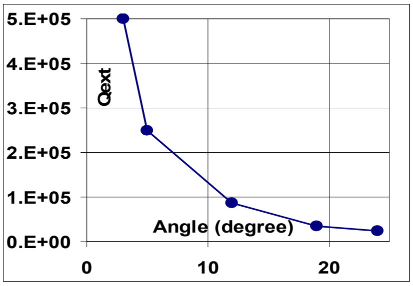

Figure 9: Loaded Q – factor for the operating mode versus the couler orientation angle.

Multipacting Simulations

Multipacting discharge can be an issue limiting the performance of crab cavity. Preliminary Analyst [7] simulations of MP show strong MP in wide range of kick value in area denoted as MP at Figure 5.

.

Growth rate is positive even in case of low value of maximum secondary emission yield (Figure 10). Additional investigations are necessary to understand whether MP is soft or hard

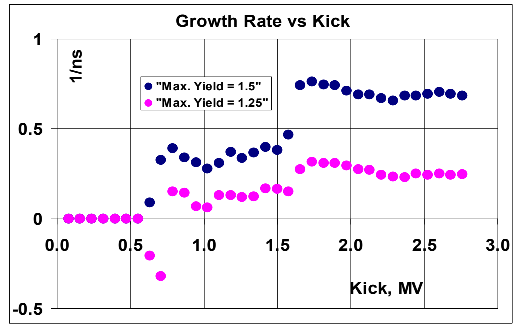

Figure 10: Growth rate of MP vs. kick for different secondary emission yield functions (Maximum 1.5 and 1.25 respectively.

Table 1: Resulting parameters of the crab cavity modes.

F, MHz	Q	Modes	R‖, kOhm	R‖/Q, Ohm	R⊥,MOhm/m	R⊥/Q, kOhm/m
Cavity Modes						
650.5	123	Monopole, LOM, 0	0.2	1.8	-	-
651.3	116	Monopole, LOM, π	19.2	165.9	-	-
800.0	5*105	Dipole, Operating, π	-	-	746	1.49
807.5	3.2*105	Dipole, Operating, 0	-	-	19	0.06
1043.9	82	Dipole, SOM. π	-	-	0.17	2.1
1057.6	34	Monopole, HOM, 0	0.7	20.5	-	-
1058.2	128	Monopole, HOM, π	0.6	4.5	-	-
1064.8	89	Dipole, SOM, 0	-	-	0.3	3.6
1072.6	81	Dipole, HOM, π	-	-	0.2	2.5
1203.4	360	Dipole, HOM, 0	-	-	0.07	0.2
Coupler Modes						
674.2	191	Monopole, 0	7.5	39.4	-	-
675.3	211	Monopole, π	5.9	28	-	-
1014.8	1260	Dipole, 0	-	-	0.2	0.16
1057.6	740	Dipole, π	-	-	0.4	0.5

SUMMARY

The crab cavity with reduced transverse sizes is suggested for the local crab scheme of the LHC upgrade. The quarter-wave coupler unit with the couplers and filters provides relevant Q-factors for LOM, SOM and HOM modes. All the couplers are oriented in vertical plane that satisfies the environment constrains. Analysis show possible presence of MP in the cavity periphery.

REFERENCES

[1] I. Ben-Zvi, R. Calaga, *et al,* "LHC Crab Cavities," Proceedings CARE-Conf-08-032-HHH
[2] M. Karliner, *et al*, "Circular electron beam deflection in a gyrocon," Budker INP Preprint, 82-147.
[3] I. Gonin, *et al*, "LHC Crab Cavity. FNAL Update", CM12 Webex meeting, Apr 2008.
[4] K.Hosoyama, *et al*, SRF2007, MO405.
[5] N. Solyak, *et al*, C11 Workshop, FNAL, Oct 2008.
[6] L. Xiao, Z. Li, C12 Workshop, SLAC, Apr. 2009.
[7] J.DeFord et al., Proc. of PAC 2003, Portland, OR, pp. 3554-3556.