800MHZ CRAB CAVITY CONCEPTUAL DESIGN FOR THE LHC UPGRADE*

Liling Xiao[1], Zenghai Li, Cho-Kuen Ng, Andrei Seryi, SLAC, Menlo Park, CA, US

Abstract

In this paper, we present an 800 MHz crab cavity conceptual design for the LHC upgrade. The cell shape is optimized for lower maximum peak surface fields as well as higher transverse R/Q. A compact coax-to-coax coupler scheme is proposed to damp the LOM/SOM modes. A two-stub antenna with a notch filter is used as the HOM coupler to damp the HOM modes in the horizontal plane and rejects the operating mode at 800MHz. Multipacting (MP) simulations show that there are strong MP particles at the disks. Adding grooves along the short axis without changing the operating mode's RF characteristics can suppress the MP activities. Possible input coupler configurations are discussed.

INTRODUCTION

It has been proposed to use crab cavities to improve luminosity for the LHC Phase II upgrade. A first crab cavity prototype is anticipated to be tested during the early stages of the LHC phase I upgrade and commissioned in a special global scheme. Due to space constraints and technical ease, the prototype test will utilize two 2-cell 800MHz superconducting crab cavities for each beam to provide a 5MV deflecting voltage required for the crabbing [1].

In this paper, we will describe the LHC crab cavity conceptual design, including the cell shape optimization and LOM/SOM/HOM couplers. With an optimized elliptical cell shape, a 2-cell cavity design can achieve high transverse shunt impedance and low peak surface magnetic and electric fields. A baseline design is then obtained in which one LOM/SOM and the HOM couplers are located at upstream of the cavity and another SOM/LOM coupler and the input coupler at downstream. It is found that there is cross coupling between the input coupler and LOM/SOM coupler in the baseline design, so other input coupler configurations have been considered to solve this problem. Furthermore, MP is observed at the disks from simulations and the design is modified in order to suppress the MP activities.

CELL SHAPE OPTIMIZATION

The crab cavity cell design aims to achieve high transverse R/Q for a TM_{110} operating mode that provides the required deflecting voltage for the beam with less input power while meeting the LHC aperture requirements. The maximum deflecting voltage is determined by the critical magnetic field for quenching as well as the electric field for electron emission on the cell surface. The cell shape profile can be described by a few of parameters as shown in Fig. 1.

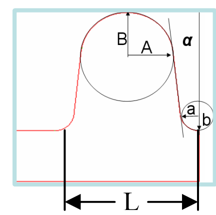

Figure 1: Cell shape parameters

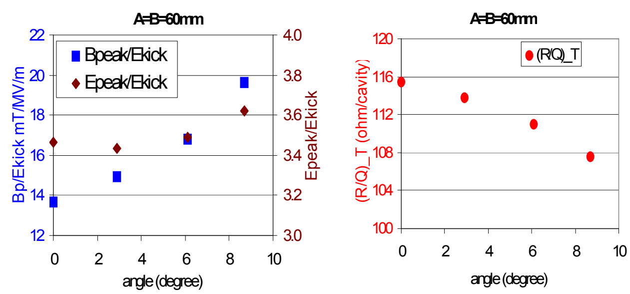

Figure 2: Peak surface fields (left) and R/Q (right) as a function of the wall angle for 60mm of the equator radius.

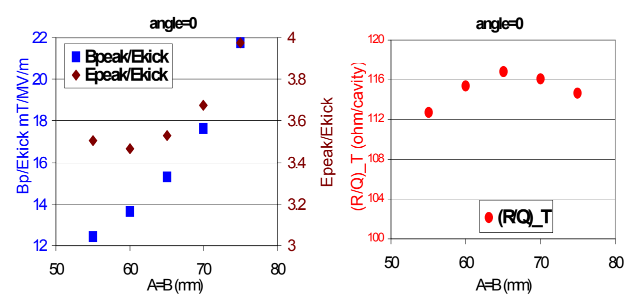

Figure 3: Peak surface fields (left) and R/Q (right) as a function of the equator radius A=B for 0 degree of the cavity wall angle.

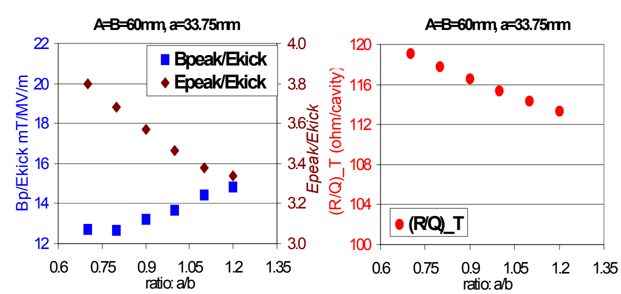

Figure 4: Peak surface fields (left) and R/Q (right) as a function of the iris ellipse aspect ratio a/b. The wall angle is 0 degree and the equator radius is 60mm.

* Work supported by US Department of Energy under contract DE-AC02-76SF00515

[1] liling@slac.stanford.edu

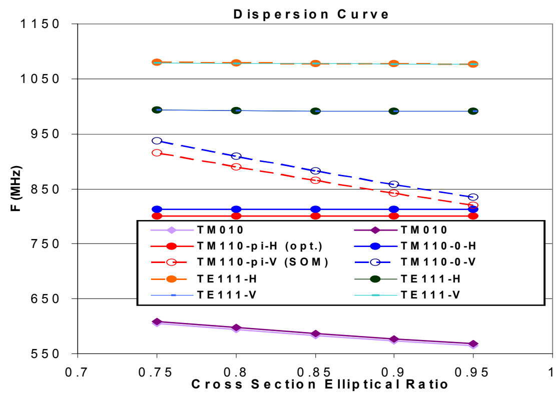

Figure 5: Dispersion curve for the 2-cell crab cavity as a function of the cell squash ratio. The beampipe cutoff frequency is 1.2GHz.

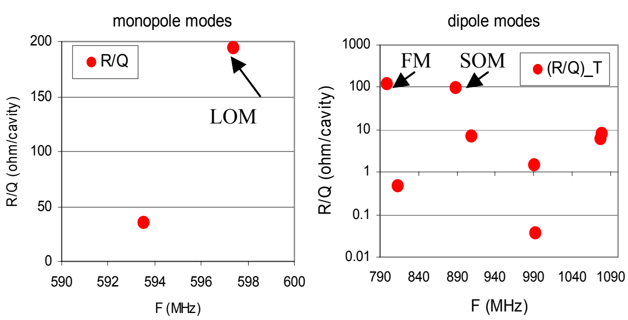

Figure 6: Calculated R/Q of the first monopole band TM010 modes (left), and the first two dipole band TM110/TE111 modes (right).

The cell length is fixed at 187.5mm for beta=1. The iris radius is chosen to be 70mm for the cell shape optimization. A circular equator (A=B) is preferred because of its better cavity mechanical performance. Only four parameters (A, a, b and α) are to be optimized with the constraint that the cell frequency is maintained at 800MHz by adjusting the cell radius. Simulation results obtained by the parallel eigensolver Omega2/Omega3P [2] are shown in Figs. 2 to 6. The RF parameters of an optimum 2-cell crab cavity are listed in Table 1.

Table 1: RF parameters for an optimum geometry.

Operating mode frequency	800MHz
SOM mode frequency	891MHz
Cell transverse dimensions	195.938mm*244.922mm
Cell equator radius (A=B)	60mm
Cavity wall angle (α)	0
Cell iris dimensions (a, b)	33.75mm*27mm
(R/Q)_T	117ohm/cavity
Deflecting voltage VT	2.5MV
Deflecting gradient	6.67MV/m
Epeak	25MV/m
Bpeak	83mT

The LOM with higher R/Q and the SOM have frequencies below the beampipe cutoff frequency, and have to be strongly damped with Qext below 200 which is very critical for beam dynamics [1]. In the following two sections, we will present the LOM/SOM and HOM coupler designs that satisfy the damping requirements.

LOM AND SOM COUPLER DESIGN

A coax-to-coax coupler scheme in the vertical plane (orthogonal to the operating mode) located on each side of the cavity is proposed to damp the LOM and SOM, as shown in Fig. 7. The centre conductors of the couplers are at the electric node of the operating dipole mode, so the couplers naturally reject the coupling to this mode and no notch filters are needed. In addition, the coupler without a notch has the advantage of handling potentially high power generated by beam loading. Because the high R/Q modes are below the beampipe cutoff, it is difficult to obtain the required damping using the coaxial coupler alone without excessive intrusion of the centre conductor into the beampipe. To achieve a strong damping, a coaxial beampipe is inserted into the coupler region to enhance the coupling. The end-tubes are enlarged from 70mm to 80mm allowing the insertion of the small beampipe with required minimum aperture ~60mm. The iris disk is still kept at 70mm. While the resulting RF characteristics are maintained similar to those listed in Table 1, the compact coax-to-coax couplers damp the LOM and SOM to Qext less than 100.

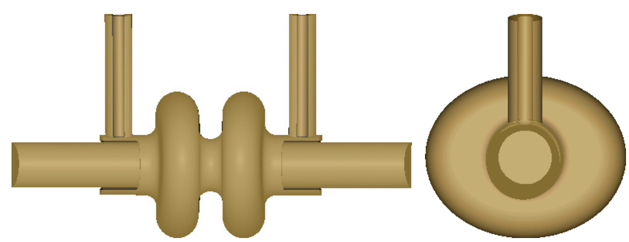

Figure 7: Crab cavity with coax-to-coax LOM/SOM couplers: left) cavity y-z cross section; right) cavity x-y cross section.

HOM COUPLER DESIGN

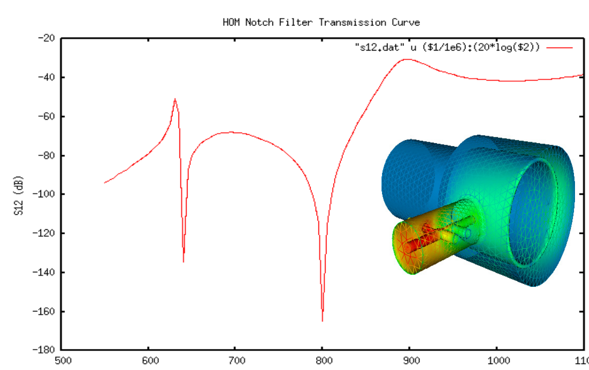

Figure 8: HOM filter transmission curve; inset is the HOM coupler structure.

The HOMs in the horizontal plane are damped through a HOM coupler. A notch filter is needed in the HOM coupler to reject the operating mode at 800MHz. The HOM coupler consists of a two-stub antenna and a pickup probe as shown in Fig. 8. This simplified HOM coupler geometry can reduce the chance of MP. The stub positions and the notch gap are optimized to provide operating mode rejection with a reasonable notch tuning sensitivity. The HOM notch filter tuning curve obtained by the scattering parameter solver S3P [2] is shown in figure 8. Besides the stop-band at 800 MHz, another one appears around 640MHz where no passband modes are in this range. The damping of the horizontal dipole modes are found to be about a few thousands.

MULTIPACTING STUDIES

MP may cause lengthening of the rf conditioning process and damage of the structure. The particle track code Track3P [2] is used to simulate MP in the cavity cell and the LOM/SOM/HOM couplers. Figure 9 shows the resonant particles which can contribute to MP. It is found that MP exists on the disks in the short axis of the cavity where the magnetic field is strong and the electric field is weak. Unfortunately, one of the MP bands covers the cavity operating field gradient. The types of MP events are two-point, low-order which are similar to those in KEKB 509MHz crab cavity [3].

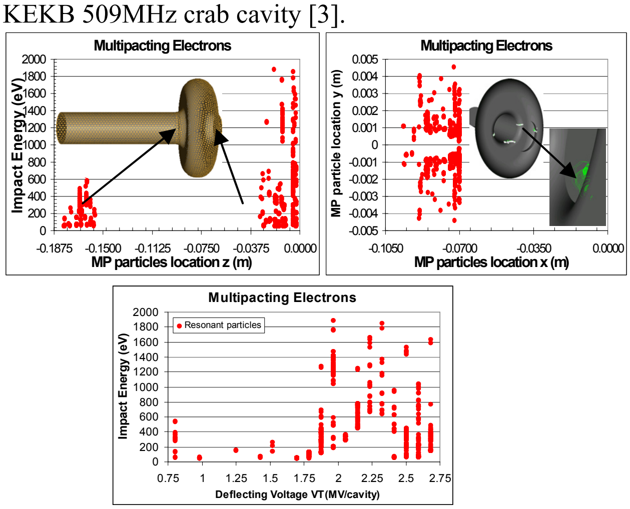

Figure 9: Multipacting in the crab cavity cell. (Up left) MP as a function of the longitudinal position, (Up right) MP at the cavity x-y cross section and (Down) MP bands.

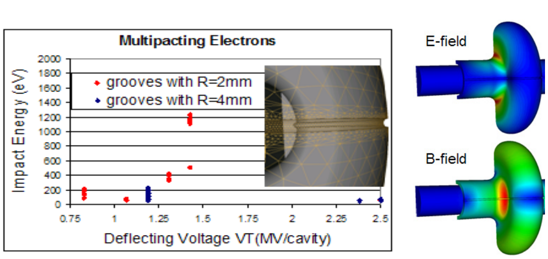

Figure 10: Multipacting in the grooved crab cavity cell (left) and the operating mode's field patterns (right).

MP in the LOM/SOM/HOM couplers is also analyzed. If the tip of the centre conductor is fully rounded, no MP activities are found in the LOM/SOM coupler and coaxial beampipe regions. MP in HOM coupler is found in the notch gap. Further HOM optimization is underway in order to meet the requirements of maintaining low peak surface fields and better performance in suppressing MP.

INPUT COUPLER CONFIGURATION

A small coax coupler has been adopted as the input coupler to reach the required coupling of 10^6. Incorporating the LOM/SOM/HOM coupler designs discussed in previous sections, a baseline design for the LHC crab cavity is shown in figure 11.

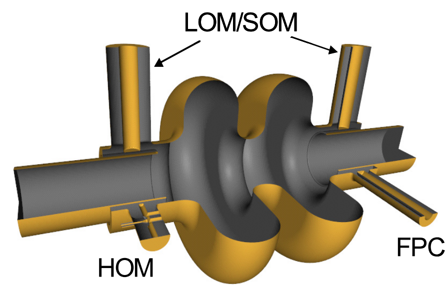

Figure 11: 800MHz crab cavity baseline design.

Since there is no notch filter, the rejection of the operating mode for the LOM/SOM coupler relies on the field symmetry in the coupler region. In the present coupler configuration, the FPC and HOM coupler induce field asymmetry in the end-groups. At the upstream, the centre conductor of the LOM/SOM coupler will be slightly bent so that the rotating flange can adjust the tip of the centre conductor to lie exactly along the electric field node of the operating mode. At the downstream, cross coupling of input power to the LOM/SOM coupler exists. New arrangements of the coupler positions are in progress to solve this problem, including separating the two cells by half wavelength and putting the input coupler in between them, or using a waveguide input coupler in the vertical plane along the beam axis to eliminate cross coupling.

Further studies are planed to investigate the sensitivity in field balance, and to analyze thermal and mechanical effects.

ACKNOWLEDGEMENTS

We thank all members of LHC crab cavity collaboration for valuable discussions, and Joachim Tuckmantal for his useful suggestions and comments.

REFERENCES

[1] R. Calaga, *et al*, "Status of LHC Crab Cavity Simulation and Beam Studies," in these proceedings
[2] Z. Li, *et al*, "Towards Simulation of Electromagnetics and Beam Physics at the Petascale," PAC07.
[3] Y. Morita, *et al*, "Multipacting in the Crab Cavity," SRF 2003.