Development of Crab Cavity for CESR-B*

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Abstract

In order to realize the crab crossing scheme desired for B-factories, we designed single cell superconducting crab cavities operating in TM110 mode. A coaxial beam pipe was attached to damp dangerous monopole and dipole parasitic modes. We designed two kinds of cell shape depending on the method to cure unwanted polarization of TM110 mode; one is a round cell which will be slightly polarized and the other is an extremely polarized (squashed) cell. We made one-third scale copper/aluminum model cavities to check damping property. Q values of all dangerous monopole and dipole modes are damped to less than the order of 100, as was expected by calculations. We also measured one-third scale niobium model cavity in liquid helium. Design goals of field and Q value to provide necessary kick voltage for CESR-B were achieved successfully. These results show that our design of the crab cavity is promising to realize the crab crossing.

I. INTRODUCTION

In order to attain the luminosity of 3×10^{33} - 10^{34} $cm^{-2}s^{-1}$ required for B-factories, a finite angle crossing scheme is the most desirable method to avoid parasitic collisions and to minimize synchrotron radiation generated near interaction point (IP). Experiences concerning storage rings with a finite angle crossing have shown, however, lower beam-beam limits due to synchrotron-betatron coupling resonances [1,2]. In order to overcome this problem, the crab crossing scheme has been invented by Palmer [3] for linear colliders and by Oide and Yokoya [4] for storage rings. In the crab crossing scheme, bunches are tilted by a time dependent transverse kick in RF deflectors located before the IP in each ring and thereby collide essentially head-on. This tilt is kicked back to the original orientation in another deflector after the IP.

Necessary deflecting voltages for the 8 GeV (HER) and 3.5 GeV (LER) rings of CESR-B are 1.8 MV and 0.8 MV, respectively [5]. Multibunch instabilities should be taken care of also in the crab cavities, as well as in accelerating cavities for B-factories. Q values of dangerous parasitic modes should be sufficiently lowered to typically the order of 100. Since the deflecting mode used for the crabbing is not the lowest frequency mode, special attention is required for damping parasitic modes, as will be described in a later section.

We designed single cell superconducting crab cavities to realize the crab crossing for CESR-B. Since we previously reported our design of crab cavity in detail in ref. [6], here we will give a brief summary of the design in section II. Results of measurements of model cavities are described in section III.

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II. DESIGN OF THE CRAB CAVITY

Our design is to operate the cavity in TM110 mode since this mode has high transverse shunt impedance, R*/Q. As for the damping of higher order modes, we adopted the beam pipe coupling scheme. In this scheme, higher order modes propagate in the beam pipe and are absorbed by some absorbing material attached on the beam pipe. However, since the TM110 is not the lowest frequency mode, there are some modes whose frequency is lower than or about the same as this mode. Four unwanted parasitic modes remain trapped in the cavity region with high Q even if a beam pipe with a large radius is attached. Those are TM010 monopole mode, two polarizations of TE111 dipole mode and unwanted polarization of TM110 mode.

In order to solve this problem we attached a coaxial beam pipe at one side of the cavity cell (Figure 1). In a coaxial transmission line there is no cut-off frequency for TEM mode waves, but there is a cut-off frequency for dipole modes. By attaching a coaxial beam pipe to the crab cavity, all monopole modes in the cavity can couple to the coaxial beam pipe as a TEM mode wave and propagate. In addition, all dipole modes in the cavity can couple to the coaxial beam pipe as a dipole mode wave and propagate if the frequency is higher than the cut-off. By designing a cell shape such that f(TE111)>f(cut off)>f(TM110), it is possible to make all monopole and dipole modes except the TM110 mode in the cavity to propagate down the coaxial beam pipe. We chose the outer and inner radii so that it has a cut-off frequency of 600 MHz, which makes the attenuation for the crabbing mode 60 dB/m.

One dipole parasitic mode still left trapped in the cavity is the unwanted polarization of TM110 mode. Since this mode has high transverse shunt impedance, it has to be cured. We designed two types of cell shape depending on the method to cure this mode; one is a round cell that will be slightly polarized and the other is an extremely polarized cell ("squashed cell"). In the squashed cell by having a cross section of the cavity cell to be an ellipse or race-track shape with a large eccentricity, we can make the frequency of the unwanted TM110 mode to be above the cut-off of the dipole mode wave in the coaxial beam pipe. Computational studies to optimize the cell shape of the round cell and the squashed cell have been carried out. Finally selected design of the squashed cell is shown in Figure 2.

Asymmetry due to machining inaccuracies or misalignment of the coaxial beam pipe may cause a part of energy of the crabbing mode to couple to the coaxial beam pipe as a TEM mode wave, which propagates down the coaxial beam pipe without attenuation and increases the power dissipation at the absorber. In order to avoid this, a notch filter is attached on the coaxial beam pipe to reject the TEM-coupled crabbing mode back to the cavity.

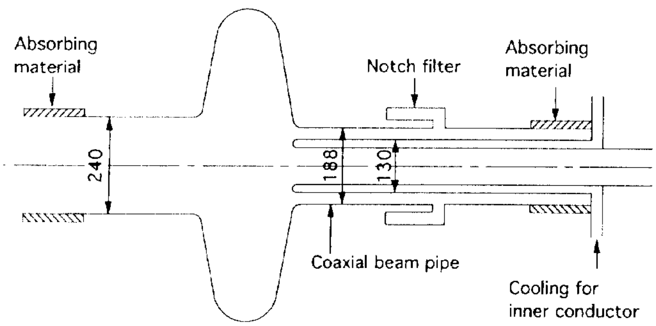

Figure 1. The crab cavity with a coaxial beam pipe.

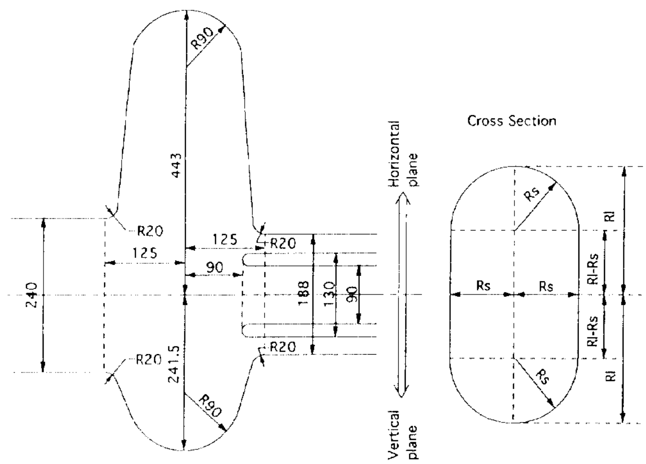

Figure 2. Squashed cell design of the crab cavity.

III. MODEL MEASUREMENTS

A. Damping property

In order to confirm damping property and to study effects of a coaxial beam pipe on the crabbing mode, we made one-third scale (L band) model cavities of round cell of copper and squashed cell of alminum with a coaxial beam pipe and ferrite absorbers attached.

First of all, we attached the coaxial beam pipe and ferrite absorbers to the round cell cavity, changing the penetration length of the inner conductor of the coaxial beam pipe into the cell. Figure 3 shows the loaded Q of the most dangerous parasitic mode, TM010, as a function of the penetration length. Q value is damped to below 100 when the penetration is 0 mm. With this penetration length calculated surface peak field at the tip of the inner conductor of the coaxial beam pipe is less than half of the surface peak field on the cell. Thus TM010 is damped to below 100 with a moderate penetration of the inner conductor.

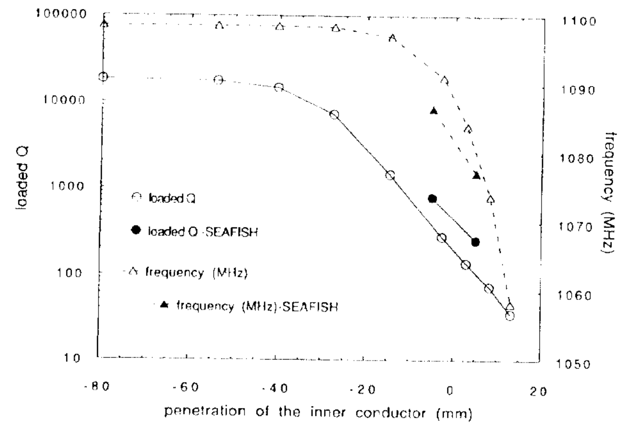

Figure 3. Damping of TM010 mode in the crab cavity with the coaxial beam pipe.

Then we fixed the penetration there and measured all parasitic modes up to 4 GHz. Measurement was done with both of the round cell and the squashed cell. Figure 4 shows frequency spectrum of the squashed cell without the coaxial beam pipe and ferrite absorbers (4a) and with them attached (4b). As was expected with MAFIA calculations, all the dangerous monopole and dipole modes including the unwanted polarization of the crabbing mode are damped to less than the order of 100. One mode observed at 2.6 GHz with high Q is a quadrupole-like TE1-1-1 mode. (For the squashed cell we use rectanguler coordinate notation as TE or TM x-y-z rather than cylindrical notation as TE or TM ϕrz.) Since the beam-cavity coupling of a quadrupole mode is quite small, it is probably not necessary to damp this mode significantly. Using a conventional higher order mode coupler at the same time, this mode can be damped to 10^3 or 10^4, which is probably safe. Frequency spectrum of the round cell was found to be essentially the same as that of the squashed cell except the unwanted polarization of the crabbing mode.

Next we studied effects of the inner conductor on the crabbing mode. It can be seen in Figure 4b that the crabbing mode has high Q in the presence of the coaxial beam pipe. The effect of misalignment of the inner conductor with respect to the outer conductor on the crabbing mode was measured with the copper model. Loaded Q is almost the same as without the coaxial beam pipe when the inner conductor is aligned with the accuracy of 1 mm. This means that the external Q for the coaxial beam pipe is at least the order of 10^5 with such an alignment because the intrinsic Q is 23000 for this copper cavity. The notch filter assures an additional 50 dB more reduction that makes the external Q more than 10^{10}. Since this is a result of one-third scale model, we can expect the alignment tolerance of about 3 mm for the full scale cavity, which can be achieved easily.

(a)

(b)

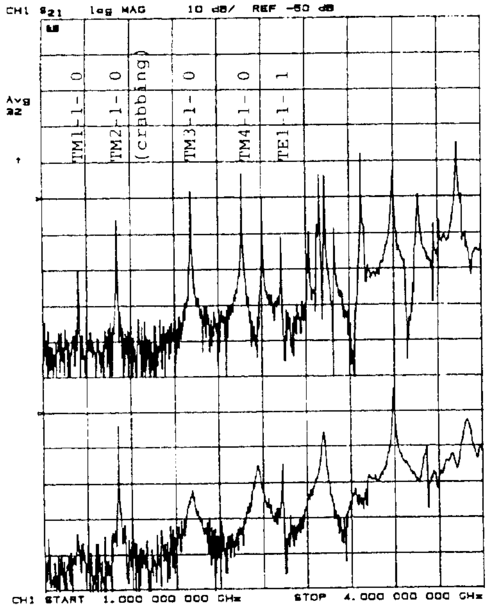

Figure 4. Frequency spectrum from 1 to 4 GHz measured in the squashed crab cavity, (a) without the inner conductor of the coaxial beam pipe and ferrite absorbers and (b) with them attached. Some of the peaks are identified as corresponding resonances in a rectanguler cavity.

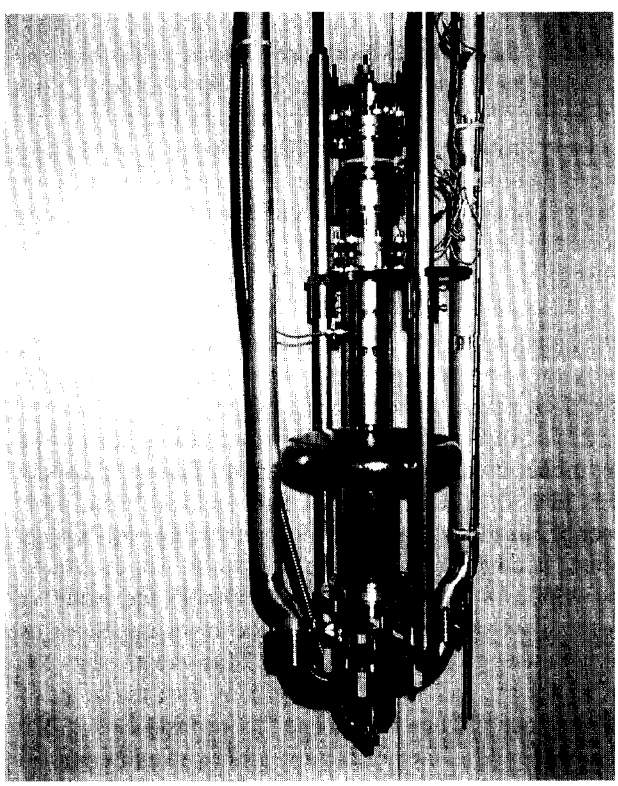

Figure 5. One-third scale niobium crab cavity with a notch filter and a coaxial beam pipe mounted on a test stand.

B. High Field Performance

Necessary kick voltage for the crabbing is 1.8 MV corresponding to the surface peak field of 20 MV/m. Present technology of superconducting accelerating cavities has shown that the surface peak field of 20 MV/m corresponding to the accelerating gradient of about 10 MV/m can be obtained without serious difficulties. For the crab cavity it is still crucial to check high field performances because our design of the crab cavity has several new features such as the coaxial beam pipe and the notch filter on the beam pipe which are not present in accelerating cavities and might cause some limitation to the field due to multipacting.

We made an one-third scale niobium model of round cell cavity, coaxial beam pipe and notch filter. Figure 5 shows the system mounted on a test stand. It was cooled down to 1.5 K in liquid helium and measured in TM110 mode at 1.5 GHz. At surface peak field of 1 MV/m multipacting was encountered which is considered to occur at the coaxial beam pipe. This was processed away in an hour with RF processing. Figure 6 shows Q value versus peak field curve of this measurement. The maximum surface peak field we reached was 25 MV/m, where field emission occured. We achieved the design goals of field and Q value to provide necessary kick voltage for CESR-B (1.8 MV/m for HER and 0.8 MV/m for LER).

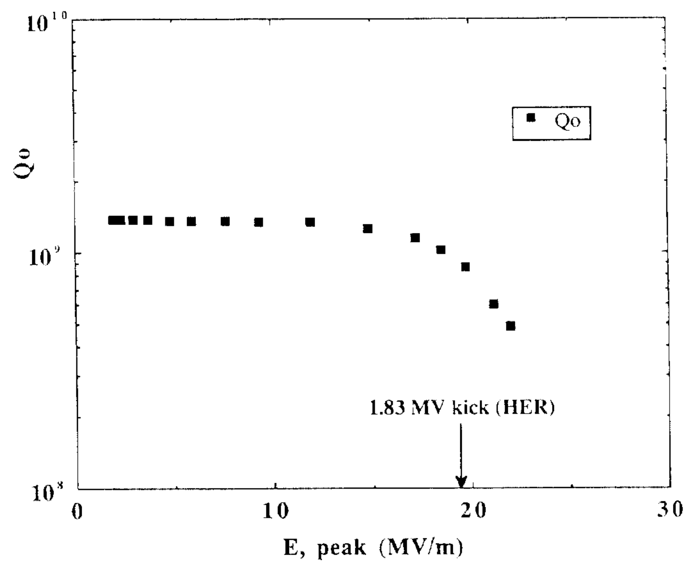

Figure 6. Surface peak field versus Q curve.

IV. REFERENCES

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