Crab Cavity Development for the Cornell B-Factory, CESR-B*

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ABSTRACT

The present approach to a CESR B-factory is to divide the desired beam current of 1-2 amps into a large number of low current bunches, which helps reduce detector backgrounds. To fit 230 bunches into the CESR size ring, they need to be very closely spaced, eliminating room for any conventional separators. Instead, a small (12 mr) crossing angle is considered, which may cause harmful coupling between synchrotron and betatron motion [1]. By rotating the bunches before collision ("crabbing") so they collide head-on, and then rotating them back, so they pass through the arcs normally, this dangerous coupling can be eliminated [2]. We show that the needed transverse kick of ~ 2 MV can be achieved with one single cell superconducting cavity, operating in the TM110 mode at 500 MHz, while keeping the surface electric field below 25 MV/m to avoid excessive field emission. The cell design allows all modes higher in frequency than the crab mode to propagate out the beam pipe and be damped outside the cryostat with ferrite beam pipe absorbers. 1.5 GHz niobium cavities have been tested to study the multipacting behavior of the TM110 mode.

INTRODUCTION

A complete discussion of the CESR-B factory proposal and parameter list is given in another paper at this conference[3]. The accelerating system is based on superconducting cavities which are described in another paper of this conference[4]. One approach to crabbing is to use the transverse fields of an RF cavity in a deflecting mode. The TM110 is the most suitable as it has the highest transverse shunt impedance, R'/Q. For the same reasons of impedance and power economy as for accelerating cavities[4], it is desirable to minimize the number of crabbing cells. As we see below, it is possible to provide the entire deflecting voltage needed with one superconducting cell. A simple cavity model is the TM110 mode in a cylindrical pill-box cavity, for which only the magnetic field component B_φ is responsible for deflection, $F_\perp$, through the transverse force v x B.

In a real cavity both Er and $B\varphi$ contribute, as shown in Fig. 1, so that numerical programs such as URMEL must be used to calculate the net deflection $V_\perp$ from the force , $F_\perp$,[5].

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$$F_\perp = q\,(E_\perp + v \times B)$$

$$V_\perp = \sqrt{(R'/Q\ \omega\ U)}$$

$$R'/Q = \frac{\left| E_z(r=r_0)\, e^{jkz} dz \right|^2}{(kr_0)^2\ \omega\ U} \qquad k = \omega/c$$

Here r_0 is the displacement off beam axis.

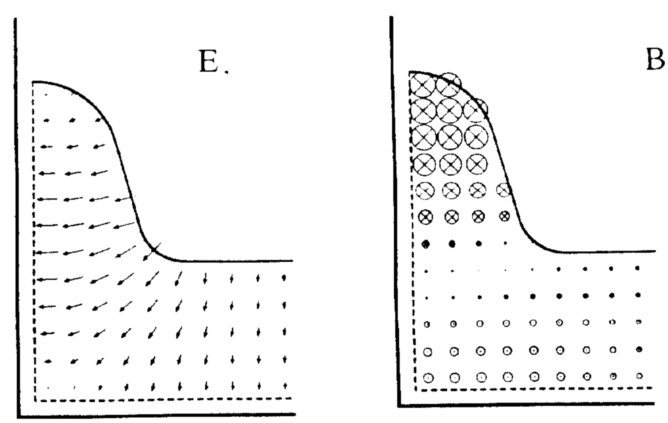

Fig. 1 Field Patterns for the TM110 mode

The crab cavity is located at an odd multiple of quarter betatron wavelengths from the interaction point. For deflection, the bunch is synchronized to pass through the center of the cavity at the zero crossing of the magnetic field. Thus the head and tail of the bunch are deflected in opposite directions. They then oscillate in the magnetic field of the insertion quadrupoles and reach their peak amplitude at an odd multiple of quarter betatron wavelengths, corresponding to the distance from the cavity to the interaction point. The maximum in the deflecting voltage reached in the TM110 mode is determined by the accelerator design parameters as [6] :

$$V_\perp = \lambda\, E\ \ \theta / 2\pi \sqrt{(\beta^* \beta c)}$$

where β^* is the horizontal beta-function at the IR, βc is the beta function at the cavity, E is the beam energy and θ is the half crossing angle. Here $V_\perp$ is the maximum in the sine wave.

CELL SHAPE

Computational studies for choosing the best cell shape for a superconducting crab cavity were carried out. Cell shape parameters varied were the beam pipe diameter, the cell length, the iris radius and the outer diameter. In each case the surface electric field was set at 25 MV/m, the maximum we feel is achievable in a superconducting cavity with standard chemical treatment. Fig. 2 shows the cell shape selected.

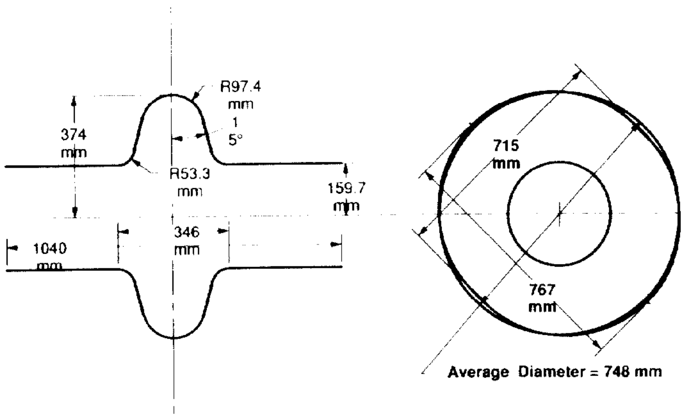

Fig. 2 Crab cavity cell shape

Table 1 lists the properties of the TM110 crabbing mode for the geometry selected. The parasitic mode properties and the loss factor are given in Table 2.

Table 1 : Properties of the crabbing mode

Frequency	500	Mhz
R'/Q	25	Ω/cell
V⊥ (Transverse Kick)	2	MV
Emax	25	MV/m
Hmax (iris)	720	Oe
Hmax (equator)	520	Oe
U	42.3	Joules
Pdiss	132	Watts/cell
@ Q $= 10^9$		
Geometry Factor(QRs)	218	Ω

Table 2 : Parasitic Mode Properties of the Crabbing Cavity

TM010	367	MHz	R/Q = 87 Ω/cell
TE111	485	Mhz	R'/Q = 5.5 Ω/cell
k (10 mm)	0.134	V/pC	

Splitting the degeneracy of the two polarizations of the TM110 mode is accomplished by cell deformation shown in Fig 2. The deformation is built into the cell forming die. Based on measurements with a factor of 3 smaller scale copper model, a separation of 14 MHz is expected for the TM110 mode and 1 MHz for the TE111 mode.

MULTIPACTING STUDIES IN THE CRABBING MODE

To use a superconducting cavity it is crucial that here be no strong multipacting. Superconducting separator cavities developed for the CERN separator were operated in the same mode and did show multipacting [7]. The shape selected here differs substantially from the CERN separator. Although theoretical understanding of multipacting in accelerator cavities has advanced considerably over the last decade, calculations for the TM110 mode are more difficult because of the absence of cylindrical symmetry of the mode. The only sure way to settle the question is to test a superconducting cavity in the crabbing mode at 500 MHz.

The first tests were carried out on a single cell 1500 MHz Nb accelerator cavities, but in the TM110 mode (2000 MHz). In the best test, we reached in one of the TM110 modes: E max = 31 MV/m, Hmax (iris) = 1000 Oe, and H max (equator) = 820 Oe at a Q = 1.5 $\times 10^9$. These values exceed the design values of Table 1. The important finding in all the cold tests was that we never encountered any multipacting at all. Field emission was observed during the tests which reached the highest fields. Although the absence of multipacting in the TM110 mode is encouraging, the shape of cavities tested is somewhat different from the shape selected for the B-factory crab cavity.

An exact shape Nb crab cavity with the TM110 mode at 1500 MHz was then constructed. Steps had to introduced into the beam pipe to match the pipe in the test set-up. (Fig 3.) These steps will not be present in the final crab cavity. After overcoming one low field multipacting barrier we were able to reach Epk = 30 MV/m @ Q = 1.2×10^9 in one polarization, and Epk = 27.5 MV/m @ Q = 2.3×10^9 in the other polarization of the TM110 mode. Both maximum fields were limited by field emission. It is possible that the multipacting may have been due to the step in the beam pipe.

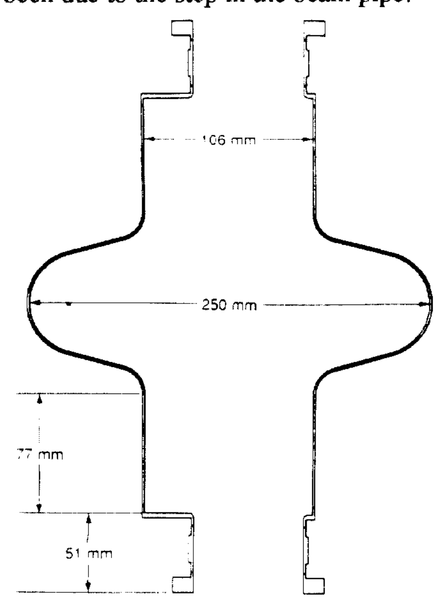

Fig. 3: 1500 MHz Nb crab cavity tested

PARASITIC MODES

As in the accelerating cavity, the crab cell design allows all modes (monopoles and dipoles) higher in frequency than the crabbing mode to propagate out the beam pipe and be damped outside the cryostat with Ferrite-50 beam pipe absorbers [8]. Q values of 100 or less are expected. 5 unwanted modes remain trapped in the cell region: the fundamental (TM010), 2 polarizations of the TE111 mode and one polarization of the TM110 mode. To avoid multi-bunch instabilities and resonant power deposition, one approach under investigation is to provide tuners that can allow modes to be parked at safe frequencies [9]. The tuning scheme has a chance to work since only two cavities per ring are contemplated. As there is a large spacing between the main revolution harmonics of 166.8 MHz, positioning the TM010 mode half way should avoid any problems. However there may be missing bunches, as during injection, or unequal charges in the bunches which could produce strong lines in between. In the worst case, the spacing could become as narrow as 390 Khz. Even then the positioning of the TM010 mode to a safe place could be accomplished without an active tuner. However the desire to avoid synchrotron and betatron side bands which may change with the running conditions would require an active tuner. A 50 KHz range would be sufficient. Similar considerations are under exploration for the dipole modes.

In tuners for the fundamental mode of sc cavities, the cavity is stretched or squeezed like an accordian. Such a tuner works to first order on the relative iris spacing. This method avoids a penetration into the cell, as in the case of a plunger tuner, which could have ill effects on the sc performance. Another tuning parameter is to vary the outer radius of the cavity. By choosing the azimuth such that the magnetic field in one polarization of the TM110 modes is strongest, it is possible to have different tuning coefficients for each polarization of the dipole modes. We have measured these coefficients for the dangerous modes from both equator iris tuning, and are continuing to explore the tuning approach[10].

INPUT POWER REQUIREMENT

If the beam goes through the cavity exactly on axis, only the power to sustain the fields in the crabbing mode will bIe required. However, there will always be some orbit errors. For a particle passing through off axis at a phase corresponding to the zero crossing of $B\varphi$, as is necessary for crabbing, the electric field Ez off axis is at a maximum. The cavity will behave as an accelerating cavity albeit with a small accelerating field. For a 1 mm displacement and a transverse voltage maximum of 2 MV, the effective accelerating voltage is 2×10^4 Volts. A 1 amp beam current extracts or gives back about 20 (x) kWatts for x mm displacement. The required coupling of $Q_{ext} = 6.4 \times 10^6/x$ (mm) can be accomplished by a coaxial coupler similar to input couplers presently used for storage ring sc cavities.

CONCLUSIONS

Realization of a crab crossing could open up higher luminosity with less background problems for a future B-factory. It appears possible to achieve the desired kick with a single cell sc cavity which reduces the need for space near the interaction region and at the same time provides a low impdedance solution. Dealing with the lower frequency parasitic modes is, however, a remaining important problem which may be approached by selective tuning.

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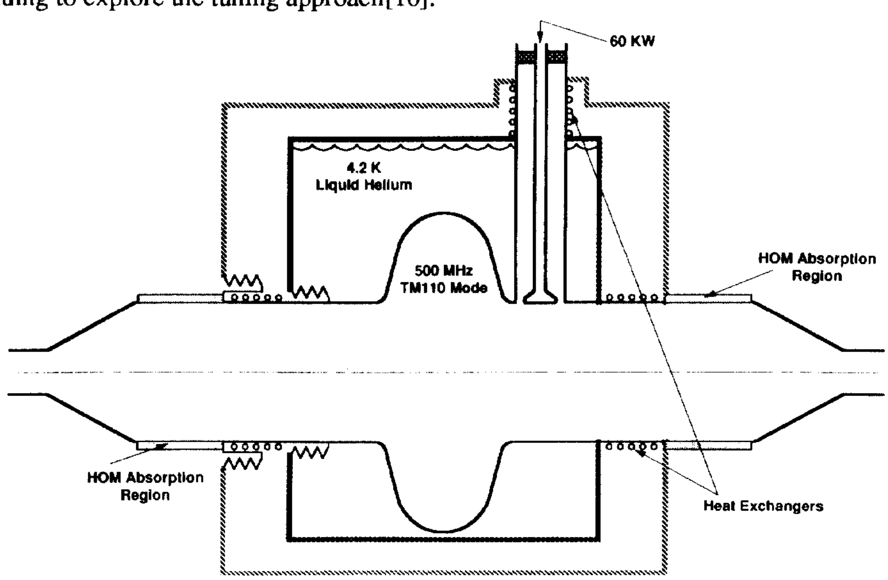

Fig. 4: Conceptual sketch of crab cavity, coupler and cryostat