Crab Cavity for KEKB

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Introduction

The construction of KEK B-Factory (KEKB)[1], a high luminosity 8 x 3.5 GeV asymmetric electron-positron collider, began in 1994 as a five year project at KEK. The design of the KEKB has chosen to have a finite angle crossing of 2 x 11 mrad at the interaction point to reduce the background rates and to simplify beam optics at interaction region. The consequences of this finite crossing angle are luminosity reduction due to geometrical effect and the possibility of beam-beam instability by synchrotron-betatron coupling resonances. Both of these effects can be eliminated by the crab crossing scheme[2,3] shown in Fig.1. In this scheme bunches to the interaction point are tilted by time-dependent transverse kick in RF deflectors (crab cavities) and head-on collide. After the collision these bunches are kicked back to the original orientation in another deflectors.

The R&D program for the KEKB superconducting crab cavity was started at KEK in 1994. For the base line design of the KEKB superconducting crab cavity, we have adopted the squashed cell cavity which was designed and studied extensively at Cornell[4] in 1991 and 1992 for CESR-B under KEK-Cornell collaboration.

Design concept of crab cavity for KEKB

We want to discuss about concept of crab cavity briefly. The detailed discussion about design of crab cavity was carried out in reference 4. Figure 2 shows conceptual design of a crab cavity with damping scheme for all lower and higher frequency modes. The TM110 mode is used to get time-dependent transverse kick for the crab crossing. Unwanted modes are extracted from the cavity through a large aperture beam pipe and a coaxial beam pipe on both ends and absorbed by RF absorbers attached on the beam pipes at room temperature. Figure 3 shows dimension of crab cavity for KEKB. Figures 4 (a) and (b) show schematic pictures of electric and magnetic fields patterns and resonant frequencies for crabbing and unwanted modes in round cell cavity and squashed cell cavity[4], respectively. (In Fig. 4 (b), the modes in the squashed cell cavity are assigned by subscript x-y-z of Cartesian coordinates.) These unwanted parasitic modes remained trapped in the cavity region with high Q-values even if a beam pipe with a large aperture is attached. All monopole modes in the cavity can coupled to the coaxial beam pipe as TEM mode wave and propagate to RF absorber attached at end of the beam pipe. In addition, all dipole

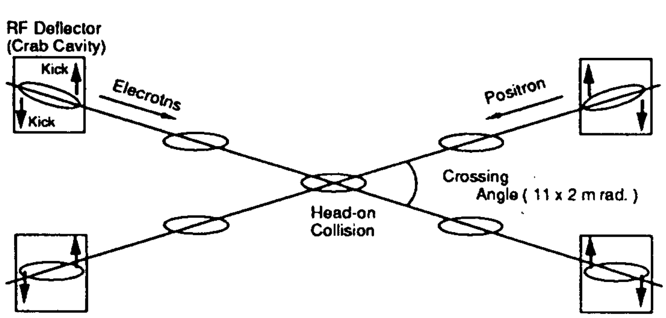


Fig. 1 Crab crossing scheme for KEKB

Table 1. Selected parameters for crab cavity for KEKB

	LER	HER	
Beam Energy	3.5	8.0	GeV
RF Frequency	508.887		MHz
Crossing Angle	± 11		mrad
βx	0.33	0.33	m
βcrab	20	100	m
Required kick	1.41	1.44	MV

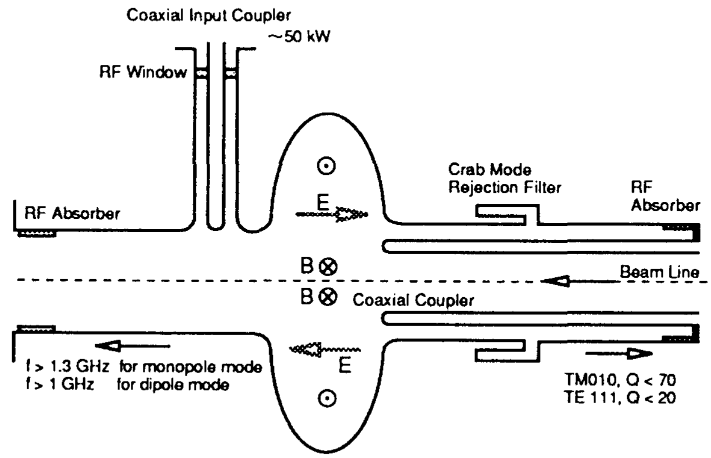


Fig. 2 Conceptual design of a crab cavity with damping for all lower and higher frequency modes.

modes in the cavity can couple to the coaxial beam pipe as a dipole wave and propagate if the frequencies are higher than the cut-off frequency of the coaxial beam pipe. If we design the cavity cell structure such that f(TE110) < f(cut-off) < f(TE111), it is possible to make all monopole and dipole modes except the TM110 in the cavity to extract out through coaxial beam pipe. In case of the round cell cavity design, unwanted TM110 mode with almost same frequency as crabbing mode is remained trapped in the cavity. Of course there is a possibility to tune the frequency of this unwanted mode carefully so that the mode is not excited by the beam. However this require the proper tuning for the unwanted mode and the crabbing mode independently. It is not clear that we can achieve this kind of complicated tuning accurately enough for the beam operation. On the other hand by making the cross section of the cavity cell an ellipse or race-track shape with large eccentricity, so called "squashed" cell shape, the polarization is sufficient enough so that the frequency of unwanted TM110 mode is increased above the cut-off frequency of the coaxial beam pipe.

Required deflecting voltage of crab cavities for KEKB

Selected parameters for crab cavity for KEKB are listed in Table1. Required deflecting voltages for the 3.5 GeV low energy positron ring LER and 8 GeV high energy electron ring

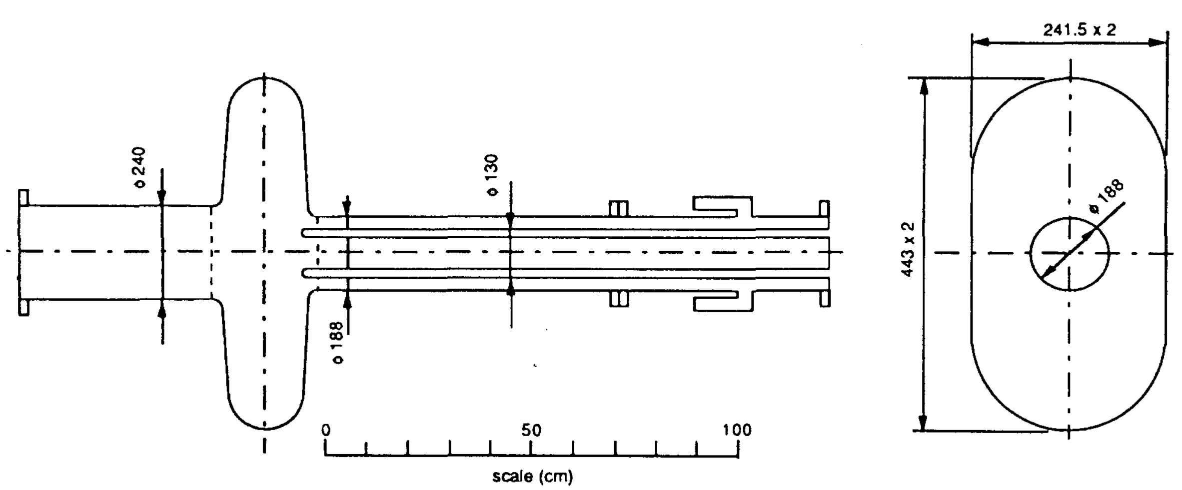


Fig. 3 Dimension of crab cavity for KEKB

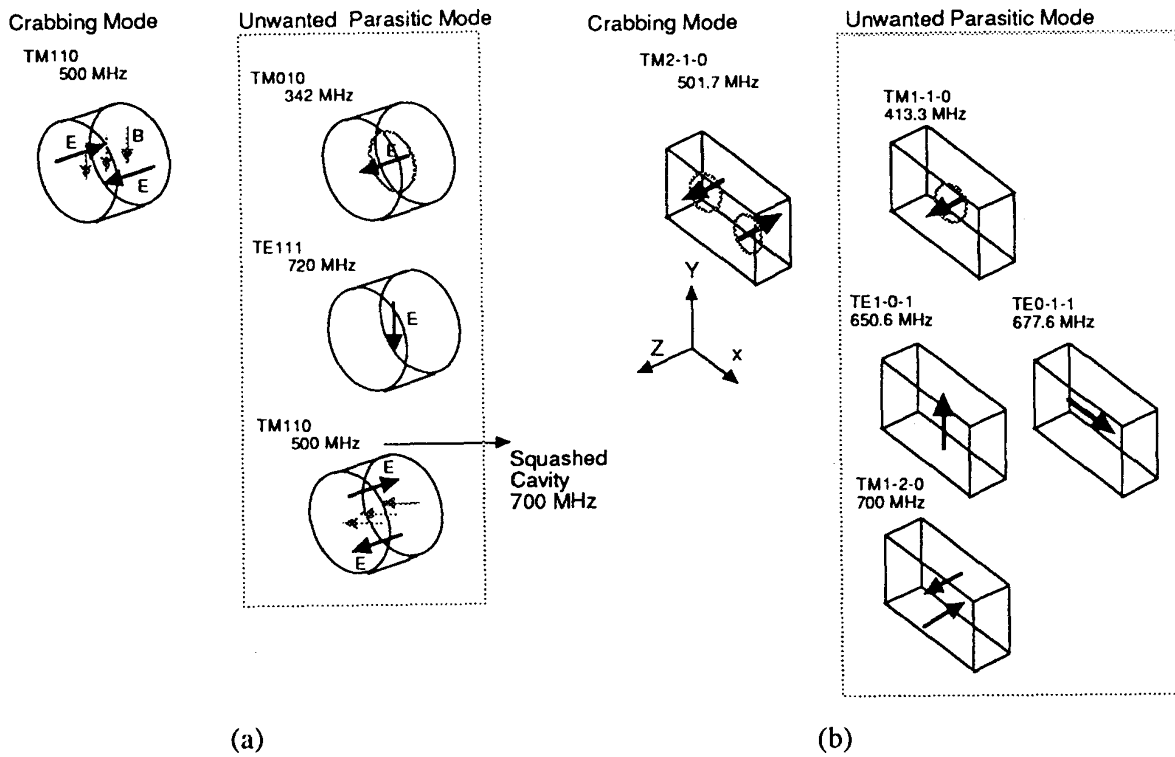


Fig. 4 Schematic pictures of electric and magnetic fields patterns and frequencies for crabbing and unwanted modes in (a) a round cell cavity, (b) a squashed cell cavity.

HER are 1.41 and 1.44 MV, respectively. Because the ratio of maximum surface electric field to deflecting voltage Esp/Vkick for the squashed cell cavity design is 14.4 (MV/m)/MV, the maximum surface electric field for the KEKB crab cavity is about 21 MV/m.

Stress analysis of squashed cell cavity

The squashed cell cavity must behave elastically under the external pressure of 0.13 MPa in the helium vessel, especially initial stage of cooldown, i.e. at room temperature, so that it resonant frequency is reproducible. Deformation and stress analysis of the squashed cell cavity is carried out using finite element softwares ANSYS and MARC under the following conditions; external presser 0.13 MPa, at room temperature, both ends of the cavity free and constraint. Figure 5 shows the results of the calculations with different thickness (4 mm and 7 mm) of cavity wall and ribs for reinforcements. The stress on the cavity is concentrated on iris part due to non-axially symmetric structure of squashed cell cavity. In the cavity with 4 mm wall thickness and without ribs (case 1), the maximum stress is 17.5 kg/mm^2. This value exceeds allowable stress value of 8.1 kg/mm^2 for niobium sheet at room temperature. If we choose 7 mm for the wall thickness, we can reduce the maximum stress value to 7.2 kg/mm^2 lower than the allowable stress value (case 2). Though this extremely localized stress concentration due to non-axially symmetric shape could not be improved by constraint of both cavity end, this can be cured by adding the ribs (10 mm width x 20 mm height) for reinforcement to cavity outer surface as shown in Fig. 4 case 3 and 4. By the ribs we can reduce the maximum stress values to 7.4 kg/mm^2 and 6.9 kg/mm^2 for 4 ribs (case 3) and 8 ribs (case 4), respectively. As for KEKB full scale model crab cavity we want to adopt the case 3, i.e. 4 mm wall thickness with 4 ribs. For the 1/3 scale squashed cell model cavity with 2.5 mm wall thickness and without ribs, the maximum stress values are 4.9 kg/mm^2 and 8.2 kg/mm^2 under the both end constraint and free conditions, respectively. For this cavity we use supporting structure to constraint both cavity end to lower the maximum stress values to 4.9 kg/mm^2.

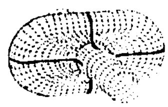
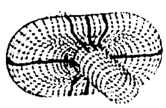
	Structure	Thickness	Maximum Stress
Case 1		thickness t = 4 mm	σ max 17.6 kg / mm2
Case 2		thickness t = 7 mm	σ max 7.2 kg / mm2
Case 3		thickness t = 4 mm 4 ribs (10mmx 20mm)	σ max 7.4 kg / mm2
Case 4		thickness t = 4 mm 8 ribs (10mmx 20mm)	σ max 6.9 kg / mm2

Fig. 5 Maximum stress of Nb squashed cell cavities. Case 1 and 2 show the maximum stress of the cavity with wall thickness of 4 mm and 7 mm respectively. Case 3 and 4 shows the results with 4 and 8 Nb ribs (10 mm width and 20 mm high) as shown in bold lines in the picture.

Fabrication of niobium 1/3 scale squashed cell model

The R&D work on the crab cavity for KEKB will take advantage of the fabrication techniques of niobium superconducting RF cavities that have been established at KEK through constructing the TRISTAN SCRF system. Three 1/3 scale squashed cell model cavities with 2.5 mm niobium are fabricated using hydro-forming process, with a hydraulic female and a male die, to establish the fabrication techniques for non-axially symmetric structure. Figure 6 shows the pictures of the hydro-forming for a cell part of 1/3 scale squashed cell model cavity. Figure 7 shows a completed 1/3 scale squashed cell cavity just before electropolishing and annealing. The RF test of these cavities in 1.8 K vertical cryostat will be performed by the end of FY1995.

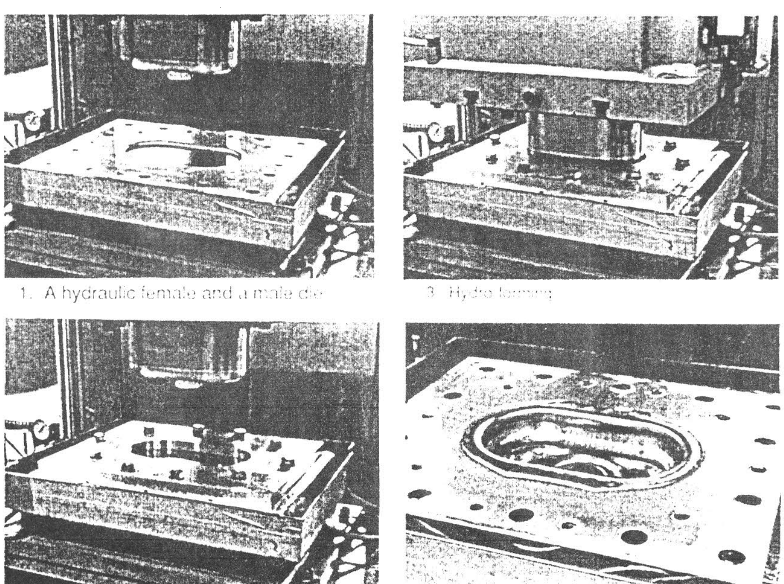


Fig. 6 Hydro-forming of a 1/3 scale 1.5 GHz squashed cell model cavity

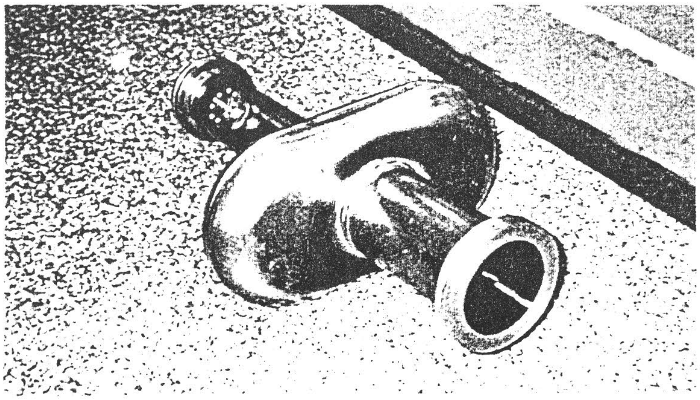


Fig. 7 A Nb 1/3 scale 1.5 GHz squashed cell model cavity

R&D schedule of crab cavity for KEKB

In the R&D program of the crab cavity for KEKB, we are planning to fabricate a full-scale superconducting cavity in horizontal cryostat to confirm the availability of the superconducting crab cavity system for KEKB in three years. Figure 8 shows the R&D schedule of the crab cavity for KEKB. Three 1/3 scale squashed cell niobium model cavities are designed and made to establish the fabrication techniques for non-axially symmetric structure by the end of FY1995. At the final stage of the R&D, full-scale squashed cell shape prototype cavities, equipped with coaxial beam pipe and notch filter, will be designed and fabricated. After an RF test at vertical cryostat, one of these cavities will be installed in horizontal cryostat. The prototype cavity in horizontal cryostat will be cooled by a helium refrigerator, and high power RF test will be conducted to confirm the performances that are required of KEKB.

Acknowledgments

The authors wish to express their gratitude to Professors S.Kurokawa, E.Ezura, Y.Yamazaki and K.Takata for their continuous support and many discussions.

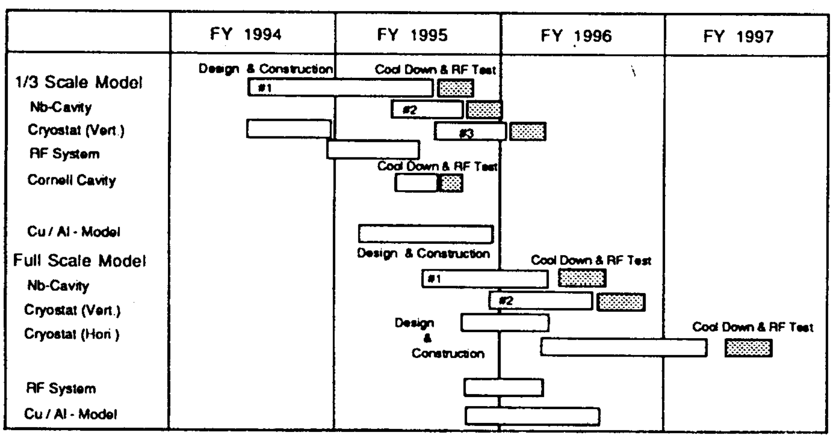


Fig. 8 R&D schedule of the crab cavity for KEKB

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