NEW DESIGN OF CRAB CAVITY FOR SUPERKEKB

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Abstract

For the design of crab cavities for SuperKEKB, a very high beam current with a short bunch length should be taken into account. We propose new damped-structure of crab cavities for SuperKEKB. It has a high kick voltage, sufficiently low coupling impedance to any parasitic modes including the lower-frequency mode, and a considerably low loss factor.

INTRODUCTION

The crab-crossing [1] [2] eliminates harmful beam-beam effects caused by finite-angle crossing, since the beams collide head-on in the center-of-mass frame, while keeping the advantages of the finite-angle crossing. According to a recent beam-beam simulation, it allows for a large beam-beam tune shift limit, increasing the luminosity by several times than the case of non-crab crossing [3]. Consequently, the crab-crossing scheme has been adopted for SuperKEKB, which is planned as an upgrade of KEKB.

Crab cavities will be used to generate a time-dependent transverse kick to tilt the beam. In accelerators where the beam current is not very high, a simple structure could be used as a crab cavity. In high-current accelerators such as KEKB or SuperKEKB, on the other hand, a heavily-damped structure is required to avoid coupled-bunch instability caused by parasitic modes. Since the operating mode (crabbing mode) is not the lowest-frequency mode, a special measure is needed for the damping scheme.

In 1992 we proposed an innovative crab cavity, which has a squashed cell and a coaxial beam pipe [4]. The damping property was confirmed by calculation and measurements. Sufficiently high kick voltage has been obtained at high-field tests with prototype superconducting cavities [5] [6]. Thus, it has satisfactory properties required for the B-factories with a beam current of 1∼2 A. This type of crab cavities will be installed in KEKB rings in 2006 to conduct the crab-crossing experiment for the first time.

For the crab cavity in SuperKEKB, due to much higher beam current of 10 A and a short bunch length of 3 mm, much heavier damping of parasitic modes as well as a lower loss factor is required. In this paper, we propose new crab cavities which meet the severer requirements for SuperKEKB.

DAMPING SCHEME

Crab cavity has a Lower-Frequency parasitic Mode (LFM) corresponding to the accelerating mode of accelerating cavities. In addition, frequencies of the Unwanted-Polarization of the Crabbing mode (UPC) and some of TE-like modes can be close to the crabbing mode. To damp all parasitic modes including these modes specific to the crab cavity, we have designed two types of new heavily-damped structure. The difference is the method for damping the LFM: using coaxial couplers or waveguide dampers. Schematic views are shown in Fig. 1 and Fig. 2, respectively.

Optimization of the cell and dampers has been carried out using MAFIA. The crabbing mode frequency was adjusted to 508.9 MHz. Details are described in the following.

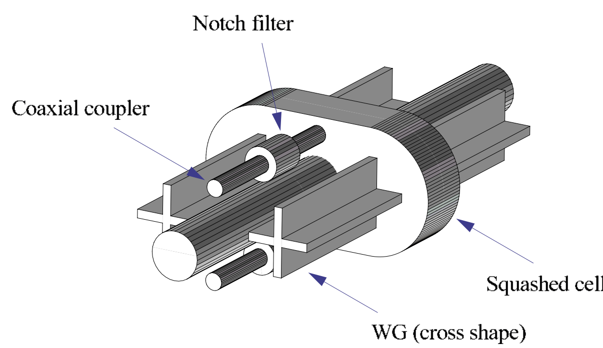

Figure 1: New crab cavity for SuperKEKB (1). Coaxial couplers are used for damping the LFM.

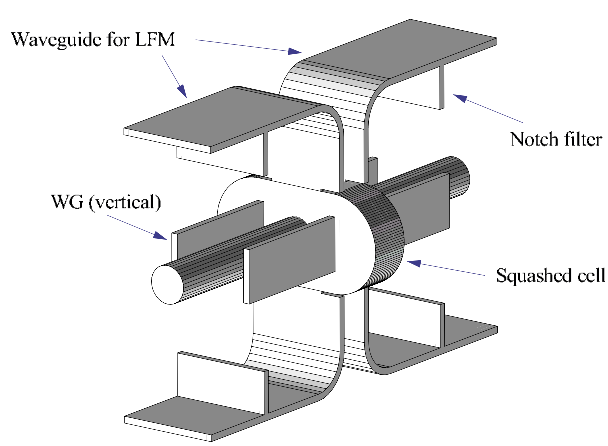

Figure 2: New crab cavity for SuperKEKB (2). Waveguide dampers are used for damping the LFM.

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Squashed cell

An extremely polarized single cell, called a squashed cell, where the horizontal size is about twice the vertical size, is used. A relatively short cell length is also chosen. Then, the frequencies of the UPC and any TE-like modes become sufficiently higher than the crabbing mode.

Fig. 3 shows the dependence of the loss factor for σ_z=3 mm and the R/Q value of the crabbing mode on the beam pipe radius. The radius of 75∼100 mm seems a good choice to make a compromise between the low loss factor and high R/Q value, and 85 mm is adopted.

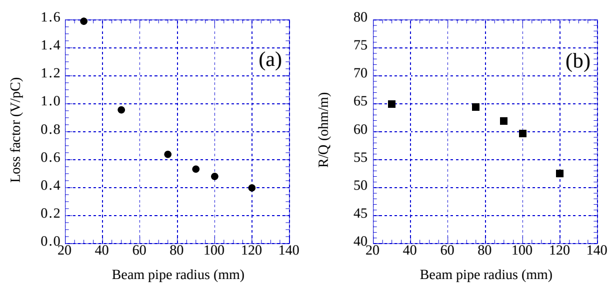

Figure 3: Dependence on the beam pipe radius: (a) the loss factor for σ_z=3 mm, and (b) the R/Q value of the crabbing mode.

Coaxial coupler for damping the LFM

Two coaxial couplers are located at positions where it has monopole coupling to the LFM and dipole coupling to the crabbing mode (Fig. 1). The cut-off frequency for the TE11 propagation mode in the coaxial line is made higher than the crabbing mode. For a strong coupling to the LFM, the inner conductor of the coaxial coupler is extended to the other side of the cell, as shown in Fig. 4. The Q_{ext} for the LFM was calculated by varying the vertical position y_0 and the outer radius r_o of the coaxial coupler. A sufficiently low Q_{ext} value of 25 is obtained. The effect of the coaxial damper on the crabbing mode is negligibly small; the R/Q value is decreased by only 1%.

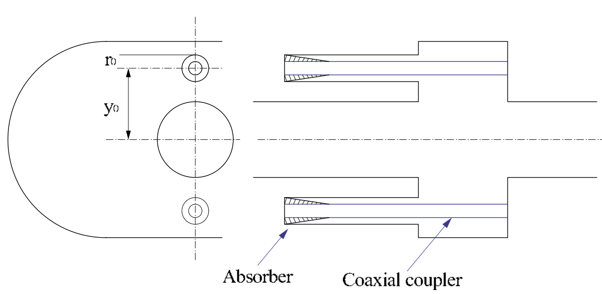

Figure 4: Two coaxial dampers are attached to the squashed cell.

Waveguide damper for the LFM

The other scheme employs four waveguide dampers for the LFM attached to the same squashed cell (Fig. 2) instead of the coaxial couplers. They are located at positions where the coupling of the dominant propagation mode (TE_{10}) to the crabbing mode is cancelled out by symmetry. The cut-off frequency for the TE_{10} mode is made lower than the LFM and the cut-off frequency for the second-lowest propagation mode (TE_{20}) higher than the crabbing mode. The width of waveguide is reduced at the connection to the cell to prevent the LFM frequency from becoming lower than the TE_{10} cut-off. The coupling impedance was calculated and it was confirmed that the Q value of the LFM is sufficiently damped to below 100.

Notch filter

Without any error, the crabbing mode power would not leak out to these dampers. A possible asymmetry of the cell shape, or a misalignment of the dampers, however, can give rise to finite coupling to the crabbing mode as the TEM mode in the coaxial line or the dominant propagation mode of the waveguide. This effect was quantitatively evaluated. For example, misalignment by 3 mm in the x-direction reduces the external Q value to about 2×10^5, and a large amount of power goes to the dampers. In order to avoid this problem, a notch filter is attached to reject the crabbing mode power back to the cavity. We designed notch filters for each of the coaxial line and waveguide.

It should be noted that the notch filter and the cavity cell can resonantly couple to each other. The coupling between the cell and damper largely changes depending on the distance between the filter and the cell. The distance was optimized to have a high external Q value for the crabbing mode and a low external Q value for the LFM at the same time.

Additional waveguides

Although these dampers for the LFM are also effective against most of higher-order parasitic modes, some other modes may not be sufficiently damped. Longitudinal and transverse coupling impedances were calculated by Fourier-transforming the wake functions obtained from the time-domain method of MAFIA. In order to damp those modes that are not sufficiently damped only with the waveguide dampers for the LFM, additional vertical waveguides are attached, as shown in Fig. 2. For the coaxial coupler case, in addition to the vertical waveguides, horizontal waveguides are also needed to damp the UPC. They form like cross-shaped waveguides, as shown in Fig. 1. In either case, the coupling slots are located at places where they do not cut the surface current of the crabbing mode. Then degradation of the Q-value of the crabbing mode due to the coupling slots is negligibly small.

RESULTS

RF property

Damping and loss factor Fig. 5 shows the longitudinal ($Z_{//}$) and transverse coupling impedance in the horizontal polarization (Z_x), respectively, for the new crab cavity with the coaxial damping scheme. Similar results were obtained for the waveguide damping scheme. Table 1 summarizes the highest values of the transverse impedance and the product of $Z_{//}$ and frequency that determine the growth rate, as well as the loss factor for σ_z=3 mm.

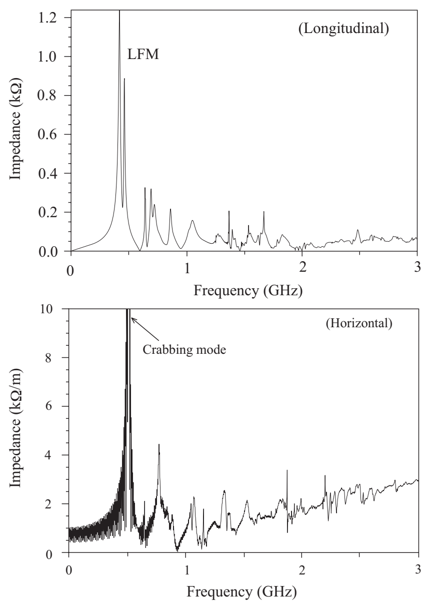

Figure 5: Coupling impedance of the new crab cavity: (upper) longitudinal, and (lower) horizontal.

Table 1: Highest values of coupling impedance as well as the loss factor for σ_z=3 mm.

	Original (KEKB)	New (Coax)	New (WG)
Z_x (kΩ/m)	25	4.7	5.7
Z_y (kΩ/m)	15	11.9	9.2
$Z_{//}$ × freq. (Ω · GHz)	2070	530	500
k_{loss} (V/pC)	1.58	0.56	0.56

Crabbing mode The R/Q value is about 60 Ω/m and the Q value for copper is 3.6×10^4. If it is made as a copper cavity, a kick voltage of 0.45 MV per cavity is obtained at a wall dissipation power of 90 kW. If it is made as a superconducting cavity, 1.5 MV kick can be obtained, based on the performance of existing SC accelerating cavities.

Comparison with KEKB crab cavity As seen in Table 1, the loss factor and the parasitic mode impedances of new crab cavities are greatly reduced compared with the KEKB cavity. In the case of KEKB crab cavity, a coaxial coupler is used as a coaxial beam pipe, rather than a mere coupler [4]. The inner conductor of the coaxial beam pipe has a relatively small radius due to the requirement for the TE_{11} cut-off. The other beam pipe is widely opened to extract higher frequency modes. The small radius as well as the different radius between both sides of the cell increases the loss factor, particularly for a short bunch length.

Feasibility for SuperKEKB

We evaluated the feasibility of using the new crab cavity in SuperKEKB. Table 2 shows tentative parameters for the crab crossing in SuperKEKB. The large $\beta_{x,crab}$ chosen to reduce the kick voltage significantly increases the growth rate of horizontal polarization of transverse coupled-bunch instability due to the crab cavities, despite that the number of crab cavities is much less than that of accelerating cavities. Nevertheless, the low coupling impedance makes the growth rate sufficiently low: the instability can be cured with the present bunch-by-bunch feedback system. The longitudinal growth rate is only 12 s^{-1} per cavity in LER. The parasitic mode power for the LER case is about 100 kW, which is comparable to that of accelerating cavities. In HER, both the growth rate and parasitic mode power are much less severe.

Table 2: Parameters for the crab crossing in Super-KEKB.

	LER	HER
Beam energy (GeV)	3.5	8.0
Beam current (A)	9.4	4.1
Bunch length (mm)	3	3
Circumference (m)	3016	
RF frequency (MHz)	508.9	
Crossing angle (mrad)	± 15	
β_x^* (m)	0.2	0.2
$\beta_{x,crab}$ (m)	100∼200	300∼400
Required kick (MV)	1.10∼0.78	1.45∼1.26

CONCLUSION

We have designed two types of new heavily-damped crab cavities. Each of them has excellent damping property and a low loss factor. The new crab cavity meets the requirements for SuperKEKB with a beam current of 10 A and a short bunch length of 3 mm.

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