RF ACCELERATING STRUCTURE FOR THE DAMPING RING OF THE SuperKEKB INJECTOR

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Abstract

A positron damping ring (DR) is under consideration to meet the requirement of the low-emittance beam injection to the main rings (MRs) of SuperKEKB based on the nano-beam scheme. We present design of an RF accelerating structure, including its higher-order-mode (HOM) dampers. This structure is based on the normal-conducting accelerating cavity system ARES, where 32 ARES cavities have been successfully operated so far in the KEKB MRs with extremely low trip rates. All the HOM absorbers on the cavity are made of silicon carbide (SiC) ceramics, bullet-shaped, and to be directly water cooled; the structure presented in this paper can be also a prototype for accelerating beams of the order of 10 A stored in the SuperKEKB MR in the high-current scheme.

INTRODUCTION

SuperKEKB is the upgrade project of KEKB with much higher luminosities, where a positron DR is needed at the injector linac due to the small dynamic aperture of the SuperKEKB optics. Some latest DR parameters are shown in Table 1. Since the RF frequency for acceleration (f_a) is the same as that of the KEKB MRs, 508.887 MHz, we develop an accelerating cavity based on the ARES cavity system [1]. In the KEKB MRs, 32 ARES cavities, 20 for LER and 12 for HER, have been successfully operated so far. In addition to the accelerating cavity with damped structures, we need taper sections to connect the $\phi 150$ beam duct on the cavity with the $\phi 40$ beam duct leading to the regular $\phi 34$ beam duct in the normal cells.

There are two major changes from the original ARES cavity; first, we do not use the storage and coupling cavities of the ARES three-cavity system because the detuning frequency from 508.887 MHz is 5 kHz, which is much lower than the revolution frequency of 2.2 MHz, so that we do not need to cure the -1 mode instability driven by the accelerating mode. Consequently, we need to change the cavity diameter to have $f_a = 508.887$ MHz. Secondly, we upgrade the HOM damper of the Grooved Beam-Pipe (GBP) [2], from SiC tiles [3] into SiC bullets to be set in a winged chamber (new HOM damper) [4], like [5], where we can use spares of the SiC bullets for the KEKB MRs. The SiC tiles in the ARES GBP are indirectly water cooled via a copper plate, and the power capability was estimated to be 1 kW/Groove in the test stand. Using SiC bullets, which are directly water cooled, increases the power capability up to 5 kW/Groove. In addition, the basic design elements are common with the ARES cavity system of the KEKB MRs. Therefore, this new HOM damper can be also a prototype for accelerating beams of the order of 10 A stored in the SuperKEKB MR in the high-current scheme.

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Table 1: Part of the DR Parameters as of May 14th, 2010

Energy	1.1	GeV
Number of bunches / ring	4	
Circumference	135.5	m
Maximum stored current	70.8	mA
Horizontal damping time	10.87	ms
Injected-beam emittance	1700	nm
Equilibrium emittance (h/v)	41.4 / 2.07	nm
Cavity voltage	0.5	MV
Equilibrium bunch length	11.01	mm
RF frequency	508.887	MHz
Chamber diameter (normal cell)	34	mm

Figure 1 shows an overview of the RF-related design, where the accelerating cavity has damped structures consisting of HOM waveguides and GBP with SiC bullets (HEXOLOY) to absorb HOMs generated in the cavity, and the SiC ducts (CERASIC-B) to absorb HOMs generated in the taper sections. Input RF power is fed into the cavity via a coaxial-line input coupler with a coupling loop.

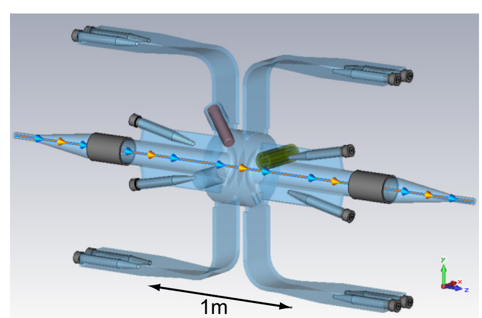

Figure 1: RF-related design with $f_a = 508.887$ MHz, $R_a/Q_0 = 150\,\Omega$, and $Q_0 = 29000$ for IACS90%, where R_a and Q_0 indicate the shunt impedance and unloaded quality factor of the accelerating mode, respectively.

PRECISE DETERMINATION OF THE CAVITY DIAMETER

The f_a can be tuned to 508.887 MHz by adjusting the cavity diameter. Since the accelerating mode, TM_{010}, travels in the input coupler with a non-negligible volume contributing to mode frequencies, we use the Slater's Tuning Curve Method [6] to calculate f_a precisely.

We ran the eigenmode solver of `CST MICROWAVE STUDIO` (MWS) [7], for a simplified model without HOM absorbers with increased number of mesh lines per wavelength, many times with different lengths of the input coupler port (d), and then fit the results with the following formula:

$$d - d_0 \;=\; \frac{\lambda}{2\pi}\,\tan^{-1}\left[Q_{\rm ext}^{-1}\left(\frac{f}{f_a}-\frac{f_a}{f}\right)^{-1}\right] + \frac{\lambda}{2}n\,, \quad (1)$$

where f indicates the mode frequency obtained in the eigenmode analysis, λ indicates the guide wavelength: $\lambda = c_0/f$ (c_0: speed of light in vacuum) in this case, $Q_{\rm ext}$ indicates the external quality factor, and n is an integer.

Before the determination of the cavity diameter, we made the coupling factor of the input coupler, $\beta = Q_0/Q_{\rm ext}$, to be about one by adjusting the angle of the coupling loop ($\theta_{\rm LoopAngle}$). In Fig. 2-(a), a fitting status is shown for $\theta_{\rm LoopAngle} = 50^\circ$ with the cavity diameter of the ARES cavities in the KEKB MRs, 438 mm, where the three parameters of d_0, f_a, and $Q_{\rm ext}$ in Eq. (1) are floated in fitting. In Fig. 2-(b), $Q_{\rm ext}$ values obtained from fitting with the tuning curves are shown. Since $Q_0 = 29000$ for IACS90% (during high power operations), we set $\theta_{\rm LoopAngle} = 75^\circ$ in the following simulations.

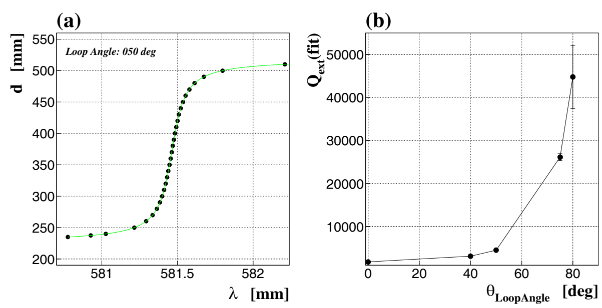

Figure 2: (a) An example of the tuning curves ($\theta_{\rm LoopAngle} = 50^\circ$), where the green curve is a result of the fit with Eq. (1). (b) $Q_{\rm ext}$ values obtained from the tuning curves as a function of the loop angle of the input coupler, where the error bars are calculated assuming $\chi^2/{\rm ndf} = 1$ (ndf: number of degrees of freedom).

Results on f_a as a function of the cavity diameter are shown in Fig. 3-(a); we have determined the cavity diameter for $f_a = 508.887$ MHz to be 443.9 mm. The accuracy on the obtained f_a is estimated to be about 150 kHz from Fig. 3-(b), which is small enough because the frequency change by the mechanical tuner of the cavity is about 40 kHz/mm, and the tuner has a stroke of 50 mm.

The above results are cross-checked by using another method based on the following formula:

$$\arg(S_{11}) \;=\; -2\,\tan^{-1}\left[Q_{\rm ext}\left(\frac{f}{f_a}-\frac{f_a}{f}\right)\right] + \phi_0\,, \quad (2)$$

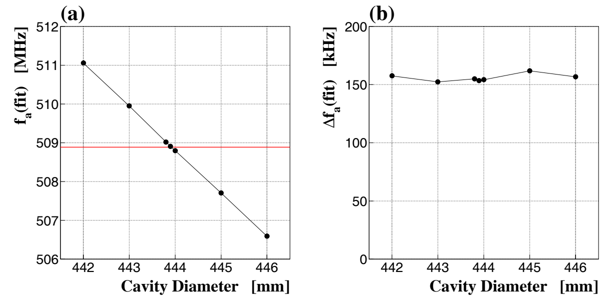

Figure 3: (a) Results on f_a as a function of the cavity diameter, where the horizontal red line indicates 508.887 MHz. (b) Fitting errors on f_a assuming $\chi^2/{\rm ndf} = 1$.

where S_{11} and ϕ_0 indicate the reflection coefficient and the phase offset, respectively. We ran the frequency domain (FD) solver of MWS around f_a with an input wave into the input coupler port, then fit the results on S_{11} with Eq. (2). Figure 4-(a) is an example to show how the phase of S_{11} changes around the mode frequency, or resonance. We performed the above procedure with different numbers of mesh lines per wavelength. In Fig. 4-(b), there can be seen a good agreement with the result from the eigenmode analyses (the horizontal red line).

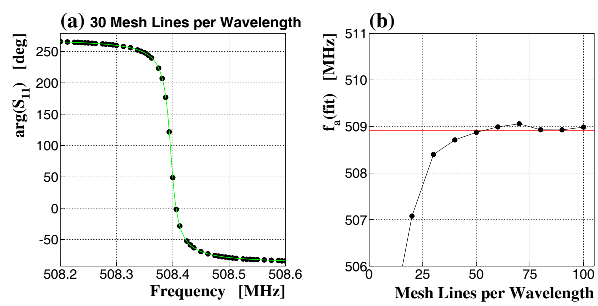

Figure 4: (a) An example in the FD analyses (30 mesh lines per wavelength), where the green curve indicates a result of the fit with Eq. (2). (b) Obtained f_a values as a function of the number of mesh lines per wavelength.

OPTIMIZATION OF THE NEW HOM DAMPER

As for the SiC bullet in the winged chamber, we have optimized its position and attitude, and the clearance distance between the bullet surface and chamber inner wall, regarding the chamber as a waveguide with a load as shown in Fig. 5-(a), and by minimizing the reflected power from the load in the frequency range above 650 MHz.

From the results obtained in the FD analyses by MWS, shown in Fig. 6, we have determined the attitude angle of the SiC bullets to be 12.12°, a minimum with no spatial conflict between the flanges for the SiC bullets and flange of the beam duct, keeping the tip position of the SiC bullets as in "ParaL". As for the clearance, we adopt the smaller one, 5 mm.

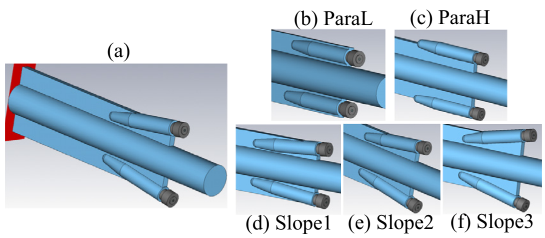

Figure 5: (a) A waveguide of the winged chamber loaded with SiC bullets, where input wave comes from the left. (b) and (c): SiC bullets set parallel to the beam axis. (d), (e), and (f): SiC bullets set with attitude angles of $4.52°$, $8.48°$, and $12.49°$, respectively.

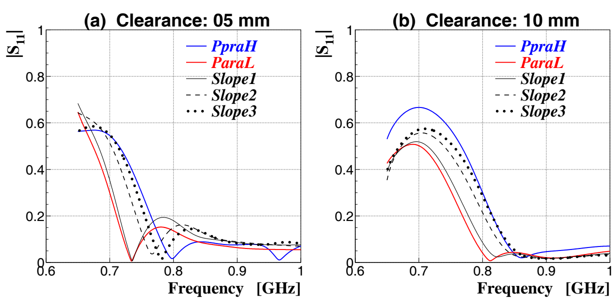

Figure 6: Reflection coefficients of the HOM-damper waveguide for the (a) 5 mm and (b) 10 mm clearances.

PROTOTYPE OF THE NEW HOM DAMPER

Based on the above design, we have fabricated a prototype of the new HOM damper, shown in Fig. 7. Two half parts of the winged chamber, separated by the vertical mid-plane, were machined with the inner surface exactly as designed in this study. Then, the two half parts were butt-welded, followed by welding of the ports. This prototype will be high-power tested soon in the test stand using a 1.25 GHz CW klystron.

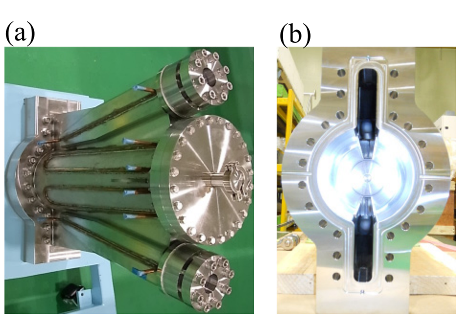

Figure 7: Prototype of the winged chamber loaded with SiC bullets: (a) side and (b) inside views.

LONGITUDINAL HOM IMPEDANCE

In order to confirm that there are no dangerous trapped modes potentially causing longitudinal coupled bunch instabilities (LCBIs), we have calculated long-range wakepotentials by the Finite Difference in Time Domain (FDTD) computation of `GdfidL` [8] with the full geometry shown in Fig. 1. In this computation, we used the same geometry converted from the `CST` simulation environment via the STL format. We have obtained the HOM impedance from the wakepotentials up to 100 m, as shown in Fig. 8-(a), and estimated the growth time of the LCBI driven by the HOM impedance of the RF section to be 56 msec, which is much longer than the longitudinal radiation damping time of 5.4 msec. From the Fig. 8-(b), we do not need to compute wakepotentials in a longer range than 100 m.

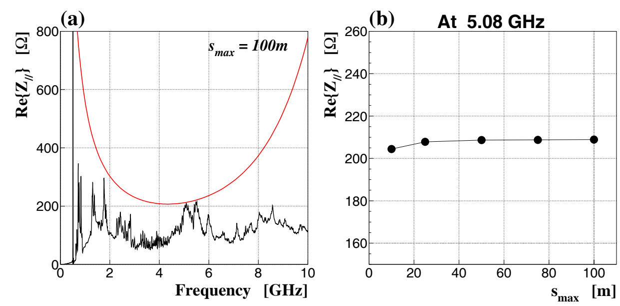

Figure 8: (a) Real part of the longitudinal HOM impedance with a LCBI line for 56 msec growth time (red curve). (b) Impedance at 5.08 GHz as a function of the wakepotential range ($s_{\max}$) included in this impedance calculation.

SUMMARY

We have designed the accelerating structure of the DR for the SuperKEKB injector based on the ARES cavity system of the KEKB MRs, where the HOM damper of the GBP is to be upgraded into the winged chamber loaded with SiC bullets with more power capability. Verification of the high power performance of this new HOM damper will be carried out soon in the test stand.

We have confirmed that there are no dangerous trapped modes potentially causing LCBIs by the FDTD computation with the full geometry of the RF section.

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