HOM DAMPING OF ARES CAVITY SYSTEM FOR SUPERKEKB

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Abstract

The ARES cavity system, developed to minimize the coupled-bunch instability due to the accelerating mode, is one of the decisive edges of KEKB. Its RF scheme is a coupled-cavity system where an accelerating cavity is coupled with a large energy storage cavity via a coupling cavity between. The accelerating cavity, itself, is a HOM-damped structure smoothly embedded into the whole coupled-cavity scheme. Currently, the total HOM power dissipated in the RF absorbers per cavity is 5.6 kW for the KEKB LER with beam current of 1.6 A. For SuperKEKB aiming at the luminosity frontiers far beyond 10^{35} cm^{-2}s^{-1}, the total HOM power per cavity is estimated about 95 kW for the LER with the design beam current of 9.4 A. This article reports the design of a HOM-damped structure for the SuperKEKB ARES cavity, together with related R&D activities.

INTRODUCTION

The ARES cavity system was developed as a means to minimize the coupled-bunch instability due to the accelerating mode, whose resonant frequency needs to be detuned downward with respect to the RF frequency (508.887 MHz) in order to compensate for the reactive component of the beam loading. Its RF scheme is a three-cavity system stabilized with a π/2-mode operation [1], where an accelerating cavity is coupled with a large cylindrical high-Q energy storage cavity via a coupling cavity between. The design of the ARES cavity for KEKB, shown in Fig. 1, is based on a high-power conceptual demonstrator ARES96 [2], where a HOM-damped accelerating cavity with four rectangular waveguides at the upper and lower sides and grooved beam pipes [3] at both ends, is coupled with a cylindrical energy storage cavity operated in the TE013 mode, via a coupling cavity equipped with an antenna-type coupler [4].

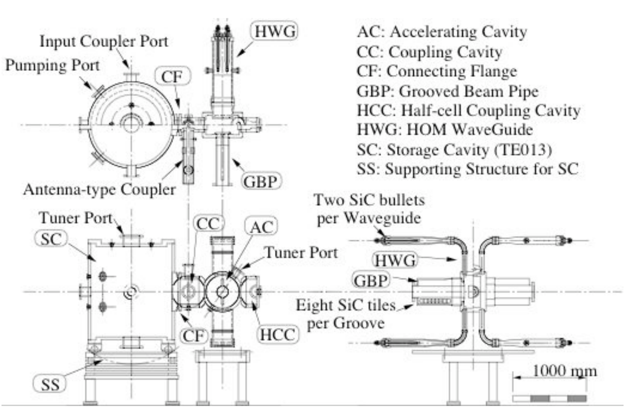

Figure 1: Top, front and side views of the ARES cavity for KEKB.

The accelerating mode is the π/2 resonant mode of the three-cavity system, where the ratio U_S/U_A of the stored energy U_S in the storage cavity to U_A in the accelerating cavity is set to 9 for KEKB. It should be noted that the energy ratio U_S/U_A for the π/2 mode can be kept almost constant in the presence of detuning for the accelerating cavity loaded with beam. In a figurative sense, the storage cavity functions as an electromagnetic flywheel to stabilize the accelerating mode subject to beam loading. Other parasitic 0 and π modes, brought by the coupled-cavity scheme, are damped with the antenna-type coupler attached to the coupling cavity, whereas the π/2 mode does not couple to the coupler.

SuperKEKB is a challenging project to boost the luminosity frontiers far beyond 10^{35} cm^{-2}s^{-1}. The design beam currents are 9.4 A and 4.1 A for the LER and HER, respectively. Judging from the operational performance so far, we will probably be able to manage with the current KEKB version of the ARES cavity for the HER with beam current of 4.1 A at maximum. On the other hand, for the LER to be operated at 9.4 A, we need to upgrade the ARES cavity system. For example, related to the fundamental mode issues, the stored energy ratio U_S/U_A needs to be increased from 9 to 15. The fundamental mode issues for the SuperKEKB ARES cavity system are discussed in detail in Ref. [4]. Needless to say, we also need to upgrade the HOM-damped structure, especially the power capacities of the HOM loads.

HOM POWER STATUS AND PROJECTION

Figure 2 shows the HOM-damped accelerating cavity part of the KEKB ARES cavity, together with close-up views of the HOM loads. The monopole and vertically polarized dipole HOMs are damped with use of four rectangular waveguides attached to the upper and lower sides of the accelerating cavity. The horizontally polarized dipole HOMs are damped with use of two grooved beam pipes [3] at both end plates. Each beam pipe is twofold with upper and lower grooves.

The waveguide load consists of two bullet-shaped SiC (silicon carbide) absorbers [4] made of HEXOLOY, a SiC material sintered under atmospheric pressure, which is available from Hitachi Chemical. Each absorber, 55 mm in diameter and 400 mm in effective length including the nosecone section, is cooled directly by water flowing in the channel bored inside. Its power capacity has been verified up to 3.3 kW per bullet (26.4 kW per cavity) at a test bench with an L-band CW klystron. However, this limit is only due to the maximum RF power stably supplied from the klystron.

The load of the grooved beam pipe consists of eight SiC tiles per groove, where each tile is brazed to a water-cooled copper plate with a copper-compliant layer between [4]. The adopted SiC material is CERASIC-B supplied by Toshiba Ceramics, another SiC material sintered under atmospheric pressure. The load was also tested up to 0.9 kW per groove (3.6 kW per cavity) at the test bench. The upper limit was due to the vacuum pressure rise, not easily conditioned. Although the power capacity has already been certified to be about 1.7 times larger than that required for the KEKB LER to be operated at 2.6 A, the cause of the pressure rise, not yet determined, needs to be further investigated.

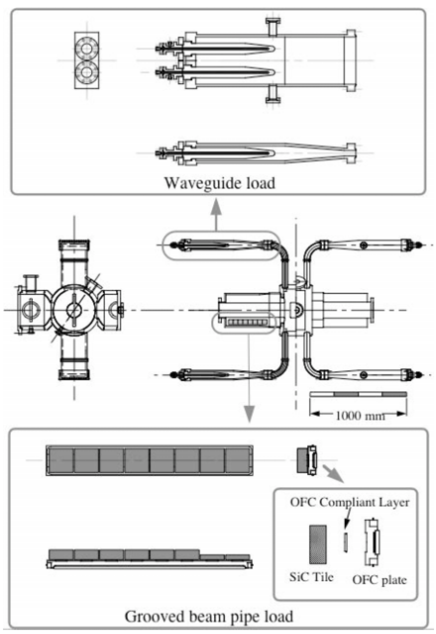

Figure 2: Front and side views of the HOM-damped accelerating cavity part of the KEKB ARES cavity, together with close-up views of the HOM loads.

The HOM powers were calorimetrically measured for the waveguide load unit with two SiC absorbers, and the grooved beam pipe load unit with eight SiC tiles, respectively, at the KEKB LER. The results are plotted as a function of beam current (1293 bunches with σ_z =7 mm) in Fig. 3. Owing to the fourfold symmetry of the HOM-damped structure (see the side view in Fig. 2), the total HOM power per cavity is four times the sum of those HOM powers, and estimated about 5.6 kW at 1.6 A.

In Fig. 4, the loss factors were computed with 3D-MAFIA for the following two cases: the whole damped structure and the two grooved beam pipes only. The results are plotted as a function of bunch length, together with those computed with 2D-ABCI for a simplified axially symmetric accelerating cavity with circular beam pipes attached to both end plates. Comparing the HOM power data in Fig. 3 with those predicted from the loss factors, we found that about 80 % of the power dissipation in the grooved beam pipe load might be attributed to the horizontally polarized HOMs, whose contributions are enhanced due to the mirror asymmetric accelerating cavity part (see the front view in Fig. 1). The half-cell coupling cavity (HCC in Fig. 1) can restore mirror symmetry for the fundamental mode only.

From the HOM power measurements and the loss factor computations, together with consideration of the effect due to the unavoidable mirror asymmetry as stated above, we have estimated the HOM powers for the SuperKEKB LER with the design beam current of 9.4 A (5000 bunches with σ_z = 3 mm). The results are as follows: 18 kW for the waveguide load, 5.7 kW per groove for the twofold grooved beam pipe. Then, the total HOM power per cavity becomes 95 kW.

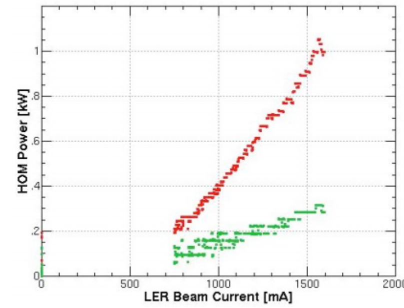

Figure 3: Results of HOM power measurements at the KEKB LER. The upper plot shows the power dissipation in the waveguide load consisting of two bullet-shaped SiC absorbers, and the lower shows the grooved beam pipe load consisting of eight SiC tiles.

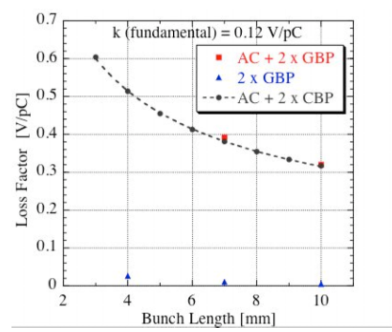

Figure 4: Computed loss factors are plotted as a function of bunch length: rectangles for the whole damped structure, triangles for the two grooved beam pipes only, and circles for a simplified axially symmetric cavity with circular beam pipes attached to both end plates.

HOM LOAD UPGRADE

For upgrading the waveguide load, we may need to increase the number of absorbers, depending on the results of high power testing over 3.3 kW, which will be carried out at a new test bench (see Fig. 5). The new HOM-load test bench has been constructed with reuse of a prototype of 1.2-MW CW klystron (Toshiba E3718, freq. = 1.25 GHz), developed for an old project of some other laboratory, and later stored in a warehouse at KEK. The operating conditions related to the high voltage power supply and the cooling system were adjusted to meet our requirement to deliver the RF power of several tens of kW, or 100 kW at maximum. The construction has been almost finished, and recently the RF power up to 30 kW

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has become available. A series of high power tests will be started soon, and the first mission is to determine the power capacity of the bullet-shaped absorber.

For the grooved beam pipe, the HOM load of eight SiC tiles brazed to the water-cooled copper plate needs to be replaced with a directly water-cooled SiC absorber like the waveguide load. Figure 6 shows a 3D conceptual model for the twofold grooved beam pipe with two bullet-shaped absorbers. The basic dimensions of the beam pipe and the absorber are assumed to be the same as those for KEKB. The absorbers are tilted with respect to the beam axis so as to avoid the interference with the beam pipe flange when inserting or removing them.

The reflection coefficient of the load shown in Fig. 6 was calculated with HFSS. The results are shown in Fig. 7, where the reflection coefficients are plotted as a function of frequency. It should be noted that the cutoff frequency for the TE11 mode is 1170 MHz inside the circular beam pipe part at the right side in Fig. 6, whereas 630 MHz inside the grooved beam pipe at the left side. Open circles in Fig. 7 are for the case, as a first step, with the absorbers made of HEXOLOY, the same as for KEKB. On the other hand, open rectangles are for a new case with the absorbers made of CERASIC-B, which has a larger dielectric constant compared with HEXOLOY. Judging from the response of the reflection coefficient to the frequency, especially below 800 MHz, CERASIC-B seems to be preferable to HEXOLOY, although the optimization of the dimensions has not yet been done.

Figure 5: New HOM-load test bench under tuning.

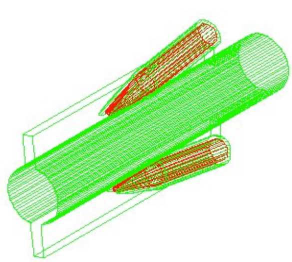

Figure 6: 3D model of a twofold grooved beam pipe loaded with two bullet-shaped SiC absorbers.

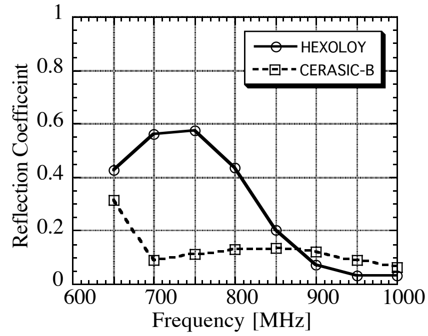

Figure 7: Reflection coefficients computed for the HOM load model in Fig. 6: open circles for HEXOLOY and open rectangles for CERASIC-B.

SUMMARY

The RF power dissipations in the HOM loads of the ARES cavity have been estimated for the design beam current of 9.4 A for the SuperKEKB LER. The results are as follows: 18 kW for the waveguide load (9 kW per bullet-shaped SiC absorber) and 5.7 kW per groove for the twofold grooved beam pipe. The total HOM power per cavity becomes 95 kW. Therefore, the power capacities of the HOM loads need to be upgraded by one order of magnitude. We have constructed a new HOM-load test bench with an L-band CW klystron supplying RF power of 30 kW or more. A series of high power tests of HOM loads for SuperKEKB are scheduled at the new test bench. The first mission is to determine the power capacity of the current bullet-shaped SiC absorber. A new grooved beam pipe structure loaded with directly water-cooled SiC absorbers has been proposed and its detailed design and optimization are under way.

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