DEVELOPMENTS OF SiC DAMPER FOR SuperKEKB SUPERCONDUCTING CAVITY*

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Abstract

Upgrade works for SuperKEKB is in the final stage and the commissioning operation will start in this JFY. Eight superconducting accelerating cavities were operated for more than ten years at KEKB electron ring and are to be used at SuperKEKB. The cavity operation at those high current accelerators requires sufficient absorption of the beam-induced HOM power. In KEKB, the absorbed HOM power of 16 kW in two ferrite dampers attached to each cavity was achieved at the beam current of 1.4 A. On the other hand, the expected HOM power at SuperKEKB is calculated to be 37 kW in the beam current of 2.6 A. To cope with the HOM power issue, we developed additional HOM dampers made of SiC to be installed to the downstream of the cavity module. From precise calculations, it was found that the additional dampers reduce the HOM power loads of the ferrite dampers more effectively than the large beam pipe model of cavity module, which is another option to reduce the HOM loads. New SiC dampers were fabricated and high power-tested. Those SiC dampers successfully absorbed the expected HOM power. In this report, we will describe the results of calculations and high-power RF tests of new SiC dampers.

INTRODUCTION

SuperKEKB is an upgrade machine from KEKB accelerator that is an asymmetric energy electron-positron double-ring collider. The construction processes of SuperKEKB have reached the final stage and the commissioning operation will start in early 2016. The design luminosity is 8×10^{35} /cm^2/s, which is 40 times higher than that of KEKB [1]. In order to achieve this luminosity, stored beam currents have to be increased twice higher than those of KEKB, that is, 2.6 A for an electron ring (high energy ring, HER) and 3.6 A for a positron ring (low energy ring, LER), respectively.

A hybrid RF system of superconducting accelerating cavity (SCC) [2,3] and normal conducting (ARES) cavities was adopted as the RF of HER in KEKB [4]. This SCC system of eight SCC modules is to be re-used again in HER of SuperKEKB. The SCC-related parameters are listed in Table 1. The main issues are the higher beam current, the shorter bunch length and the large beam power for SCC in both KEKB and SuperKEKB. The SCC shares the beam power with ARES cavities as in the case of KEKB. Therefore, the beam power delivered by SCC can keep the same level giving the phase offset between SCC and ARES system.

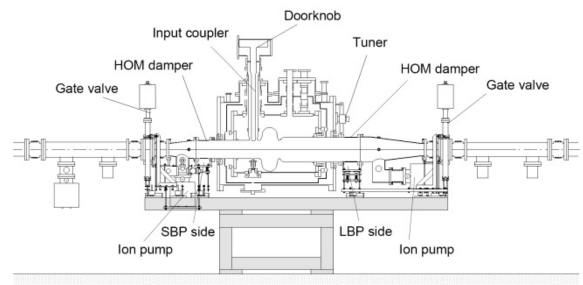

Figure 1: Cross-section drawing of the superconducting cavity module of KEKB.

Table 1: SCC-related Parameters in HER

Parameters	KEKB (operation)	SuperKEKB (design)
Energy [GeV]	8.0	7.0
Beam current [A]	1.4	2.6
Number of bunches	1585	2500
Bunch length [mm]	6	5
Number of cavities	8	8
Total beam power [MW]	~5	8.0
Beam power [kW/cavity]	400	400
Total RF voltage [MV]	15.0	15.8
RF voltage [MV/cavity]	1.5	1.5
HOM power [kW/cavity]	16	37

On the other hand, the higher-order-mode (HOM) power becomes large due to the higher beam current and shorter bunch length. To absorb HOM power, ferrite dampers are attached at the both sides of the cavity beam pipes, called small beam pipe (SBP) and large beam pipe (LBP) as shown in Fig. 1. The ferrite was sintered on copper base pipe by the hot isostatic press (HIP) method. The thickness of the ferrite is 4 mm to achieve sufficiently low Q values of higher order modes and thermal conductivity of ferrite material [5]. In KEKB, the HOM power of 16 kW at the beam current of 1.4 A was successfully absorbed with by a pair of ferrite dampers

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without any problems [6]. In SuperKEKB, however, simulation predicts the HOM power of 37 kW. The power capacity of existing ferrite dampers must be a serious problem. To cope with the large HOM power, we have simulated the possibility of additional silicon carbide (SiC) damper in order to reduce each damper's load by using a new calculation method [7,8]. In this report, we will present a summary of calculation results and a high power test result of a prototype of the SiC damper.

CALCULATION RESULTS

To estimate the HOM power in the high beam current operation, we developed a new calculation method with power flow monitor of wake-filed simulation using CST-Particle Studio: wakefield solver [7,8]. Figure 2 shows a model of SCC module in the calculations. Wake field power flow monitors are set at the surface of dampers and the end of beam pipes. The time integrals of the power flow signals over the surface give emitted and absorbed energies through the beam pipe or in the dampers. The total energy including stored energy in the cavity structure is consistent with the energy deposit independently calculated from the loss factor. Using the ratio of the energy, we can get the equivalent loss factors and HOM loads of each component as shown in Table 2.

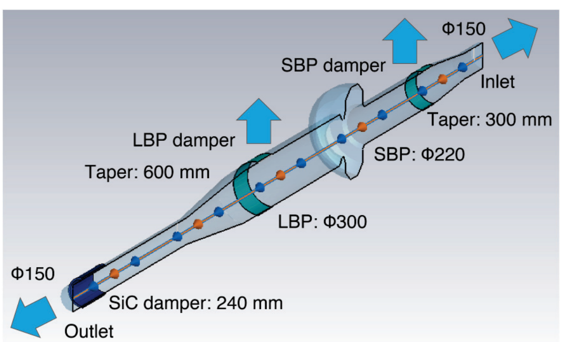

Figure 2: Calculation model of the SCC module. Bunched beam comes from inlet side. Monitors are set at SBP and LBP ferrite dampers, additional SiC damper and both ends of beam pipes (inlet and outlet)

From the calculation results, the existing SBP and LBP ferrite damper loads are not large. However, the emitted out power through the outlet beam pipe toward the downstream cavity becomes large. Therefore, the large emission power must be reduced because it becomes another load to the next cavity module.

Evaluation of Additional SiC Damper

We studied an additional SiC damper using the same calculation method. The material of SiC as the HOM damper has been already established in KEK, for instance KEKB-ARES [4], KEKB-Crab cavity [4] and so on. There are several types of SiC damper depending on the uses. In this calculation, a cylindrical type, that is similar to the existing ferrite dampers, was chosen. The SiC damper was located at downstream of outlet beam pipe in the calculations (Fig. 2). The equivalent loss factor of SiC damper and the emission power as a function of length of SiC were calculated. Those results are plotted in Fig. 3. The results show that the additional SiC damper can absorb more emission power as increase the length of SiC. The results are nearly independent of varying parameters of SiC material in possible range. In consideration of our practical conditions, the load of SiC damper has to be less than 30 kW, i.e. the loss factor of 1.1 V/pC. Therefore, 240 mm is a suitable length for our SCC modules. The emission power can be more than 70% reduced by 240-mm SiC damper as shown in Table 2. On the other hand, the load of the existing ferrite dampers dose not increase significantly and is acceptable.

This scheme has the advantage that the additional SiC damper is enough on the beam pipe outside the gate valve of the module. As a result, we can avoid the risk of performance degradation caused by the air exposure of cavity surface.

Table 2: Summary of Equivalent Loss Factors (Eq.LF) and HOM Loads at 2.6-A Beam Operation

Part	SCC module		With 240-mm SiC	
	Eq.LF [V/pC]	HOM Load [kW]	Eq.LF [V/pC]	HOM Load [kW]
Inlet	0.05	1.3	0.05	1.4
Outlet	0.58	15.7	0.15	4.0
SBP damper	0.32	8.6	0.35	9.5
LBP damper	0.43	11.7	0.47	12.8
SiC damper	-	-	0.97	26.1
Total	1.38	37.4	1.99	53.8

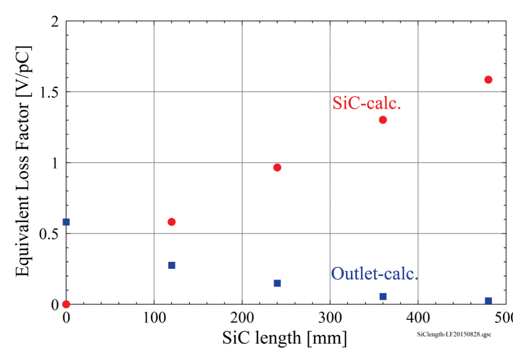

Figure 3: Equivalent loss factors of SiC damper (red) and the emitted out to the next cavity (blue). The length of 240 mm is suitable for the practical condition.

Evaluation of Large Beam Pipe Model

We have another option to reduce the HOM load of the SCC module that is to replace the present beam pipes of 150 mm in diameter with beam pipes of larger diameter.

A model with large beam pipes of 200 mm in diameter and gentle slope-taper pipes was simulated to calculate the loss factor and damper loads using the same calculation method as shown in Fig. 4. Table 3 shows the calculation results. The total loss factor is reduced to 1.14 V/pC due to the large beam pipes. Thus, total HOM load and the emission power from the outlet beam pipe are also reduced. However, the loads of ferrite dampers are slightly higher than that of the original SCC model (see Table 2). Furthermore, the emission power and each damper load are nearly equal to those of the SCC model with 240-mm SiC.

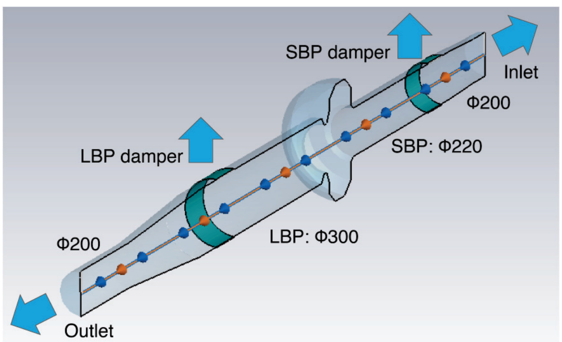

Figure 4: Calculation model of the SCC module with large beam pipes. The size of inlet and outlet beam pipes changed from 150 mm to 200 mm in diameter.

Table 3: Summary of Eq.LF and HOM Loads at 2.6-A Beam Operation in Large Beam Pipe Model

Part	Beam pipe of 200 mm dia.	
	Eq.LF [V/pC]	**HOM Load [kW]**
Inlet	0.06	1.7
Outlet	0.25	6.7
SBP damper	0.37	9.9
LBP damper	0.46	12.3
Total	1.14	30.7

When the beam pipes are replaced with large size pipes, there must be a risk of particle contamination that the cavity performance will degrade. In addition, the existing beam pipes and quadrupole magnet between the SCC modules have to be replaced with the 200-mm bore diameter types. On the other hand, the SCC module with the additional 240-mm SiC damper effectively reduce the emission power and its ferrite damper loads are nearly equal to those of 200-mm beam pipe model as mentioned above. This option has no risk of particle contamination because the SiC damper can be set in the connecting pipes between SCC modules without opening the cavity module.

To summarize above considerations, the adoption of the additional SiC damper scheme is the optimum measure against the HOM power.

HIGH POWER TEST OF SiC DAMPER

Prototype of SiC Damper

In consideration of the practical condition of the cooling capacity, the length of SiC damper is designed to be 120 mm to divide the heat load. Thus, a pair of dampers will be installed to one SCC module. At the beginning, material test of SiC was performed. The absorption power of 12 kW was given to a sample SiC cylinder of 120 mm in order to confirm the power capacity expected in SuperKEKB. In the cycle test of high power RF as a simulation of the practical beam operation, the SiC absorbed safely 12-kW power without problems. From the results of the material tests, two prototype SiC dampers were fabricated as shown in Fig. 5. The dimensions of SiC are 120 mm in length, 150mm in bore diameter and 10 mm in thickness. The total length of damper duct is 220 mm.

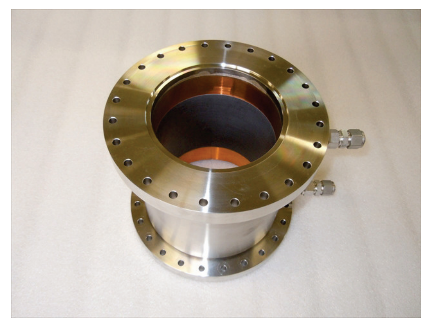

Figure 5: Prototype of SiC damper. The length of SiC is 120 mm. Two dampers will be installed to one SCC module.

High Power Test Stand

Figure 6 shows a picture of the high power test stand of the damper. The test station is 509 MHz-coaxial line with a klystron, a circulator and two dummy loads. The damper was cooled by water flow with a chiller. The water flow rate was measured by calibrated flow meters. The temperatures of inlet and outlet water were measured by metal-sheathed resistance thermometers. The absorbed power was measured by the temperature increase of cooling water. The input, reflection and transmit RF power to/from the damper were measured by power meters. The absorbed power was also obtained as a subtraction of the transmit power from the input power. The surface temperature of SiC was observed by a radiation thermometer via a small hole at the outer conductor of downstream of the damper. The temperature of the outside surface of the damper duct and flanges were measured. To detect a sound of cracking the SiC, three acoustic emission (AE) sensors were set on the damper duct surface.

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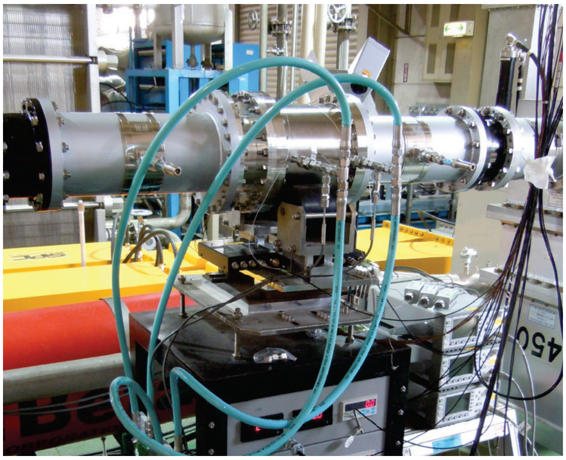

Figure 6: High power RF test stand with 509 MHz coaxial line for HOM damper of SCC module. The test stand consists of a klystron, a circulator, two dummy loads, a water cooling system for damper, thermometers and RF power meters.

Test Results

The high power tests of the prototype SiC dampers were performed. The tests were done with 10 – 15 L/min of the water flow rate. The absorbed power of 18 kW was achieved by each SiC damper under the water flow rate of 15 L/min as plotted in Fig. 7. It means that a pair of dampers can absorb the power with a margin of 1.3 times of the calculated HOM load. The maximum temperature of the SiC surface was 80 degrees C at the absorption power of 18 kW. According to the surface survey by a microscope camera after the test, there is no crack on the SiC surface.

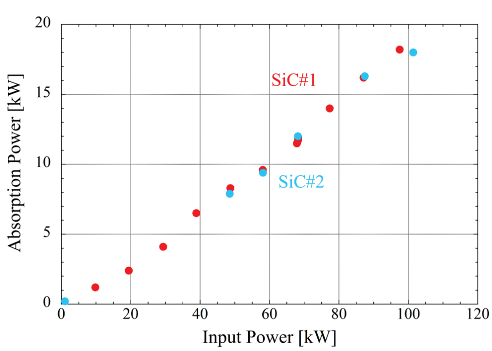

Figure 7: High power RF test results of the prototype of SiC dampers. The absorption powers of 18 kW were achieved by both dampers under the water flow rate of 15 L/min.

We have established the SiC damper. We are planning to install the prototype SiC dampers in the SuperKEKB ring in order to demonstrate the absorption of the HOM power by the beam test. After the beam test, all of the SiC damper will be prepared and install for our SCC modules.

SUMMARY

To cope with expected large HOM power in the SuperKEKB operation, we developed a new calculation method with CST particle studio. The distribution of HOM load in the SCC module was calculated. Calculation results showed the loads of existing SBP and LBP ferrite dampers are acceptable. However, the large HOM power is emitted out toward the next cavity module. To reduce the emission power, the additional SiC damper is needed. According to the calculations, the SiC damper of 240 mm in length is suitable for our SCC module. The prototype SiC dampers were fabricated and high powered at the test stand. Those dampers successfully absorbed 1.3 times power of the required in SuperKEKB. Furthermore, these prototype SiC dampers will be mounted to one of the SCC module to confirm the simulated scheme and performance in SuperKEKB.

ACKNOWLEDGMENT

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