# STATUS OF KEKB SUPERCONDUCTING CAVITIES AND STUDY FOR FUTURE SKEKB

Y. Morita#, K. Akai, T. Furuya, A. Kabe, S. Mitsunobu, M. Nishiwaki, S. Takano,
KEK, Tsukuba, Ibaraki, Japan

*Abstract*

With superconducting crab cavity, 8 superconducting accelerating cavities were stably operated last two years and KEKB luminosity reached the world record of $2.1\text{x}10^{34}$/nb/s. For future Super KEK B-Factory (SKEKB) we are developing a high power input coupler for 600kW, a HOM damper for high power absorption more than 30 kW and a cavity operation with reversed phase position for high power loading. The reversed phase experiment at 150 mA of a beam current in KEKB showed potential for the low voltage and high power application.

## INTRODUCTION

KEKB, an energy-asymmetric electron-positron double ring collider for B-factory, was commissioned in December 1998. Four heavily-damped superconducting (SC) accelerating cavities were installed in the high energy electron ring (HER) and commissioned. Another four cavities were installed in 2000[1]. A hybrid RF system of eight superconducting cavities together with twelve normal conducting accelerating cavities (ARES) provided the total RF voltage of 14 MV in the HER ring. The maximum current stored in the HER is 1.4 A[2].

Two crab cavities ware installed and started crab crossing operation in 2007[3]. The HER currents gradually increased up to 1.2 A with crab cavities. KEKB recently achieved the world luminosity record with crab crossing. SC cavities were operated stably during the crab crossing operation and contributed stable operation for the crab crossing.

R&D for the SKEKB is under way. One is a high power HOM damper [4]. The HOM power in each cavity is expected to be more than 30 kW. We are developing a new HOM damper with a ferrite thickness of 3 mm. Another is a high power input coupler [5]. Finally, we proposed new operation mode of the SC cavities for SKEKB. Synchronous beam phase of several SC cavities are reversed to maintain high accelerating RF voltage.

This paper presents present status of the SC cavities at KEKB and R&D status for the super-KEKB.

## KEKB SUPERCONDUCTING ACCELERATING CAVITY

A cross sectional view of a KEKB SC cavity is shown in Figure 1. In the HER ring, eight SC cavities and twelve ARES cavities provides the total RF voltage of 14 MV. Each SC cavity provides an RF voltage 1.4MV and delivers an RF power of 350-400 kW to the electron beam of 1.4 A. Typical forward and reflected RF powers are plotted in Figure 2. Achieved parameters during the KEKB commissioning are listed in Table 1.

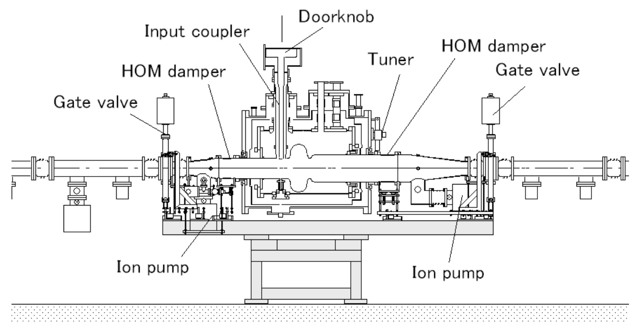


Figure 1: A cross sectional view of the KEKB superconducting accelerating cavity. A 509 MHz single cell cavity with a large iris diameter of 220 mm has ferrite HOM absorbers on both sides and a coaxial-type input coupler. The cryomodules of 3700 mm in length are connected to the beam ducts of 150 mm in diameter.

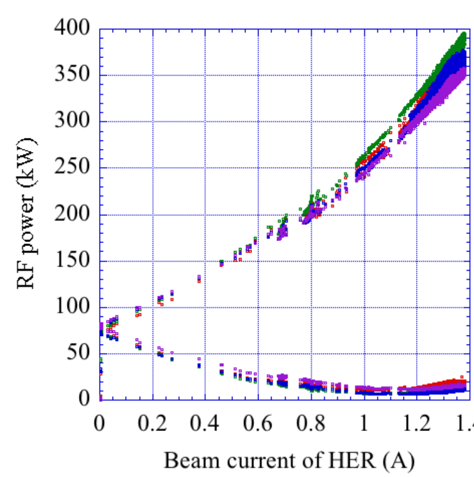


Figure 2: Input and reflected powers of each SC cavities for the external Q of $5\times10^4$ at 1.4 MV.

### *Trip Rate*

High currents and short bunch length produce large HOM powers, which have to be absorbed in the HOM dampers located on the beam pipes at room temperature (Fig. 1). The HOM powers in case of the beam current at 1.4 A and 1400 bunches with a bunch length of 6 mm are 16 kW in each SC cavity. The HOM power heats ferrite absorbers up to $90^0$C and causes outgas. Those outgases condenses on the cold cavity surface and triggers the discharge in the cavity. Statistics of RF trips in HER are

#yoshiyuki.morita@kek.jp

summarized in Figure 3. In the crab crossing operation, the HER currents were from 800 mA to 1.2 A depending on the beam optics. RF trip rates of the SC cavities improved from 0.5 to 0.1 trips per day. A half of the RF trip is caused by the discharge in the cavities or in the input power couplers and a half is caused by the system failures by RF power sources or by the helium refrigerator.

Table 1: Achieved parameters of the KEKB SC cavities

| Parameter | design | achieved | unit |
|---|---|---|---|
| Beam Current | 1.1 | 1.4 | A |
| Bunch charge | 2 | 10 | nC |
| RF voltage | 1.5 | 1.2-2 | MV/cav. |
| Beam loading | 250 | 350-400 | kW/cav. |
| HOM power | 5 | 16 | kW/cav. |

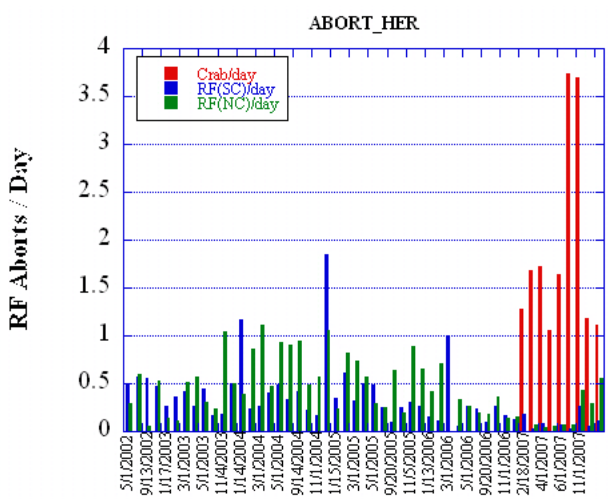


Figure 3: Statistics of RF trips caused by Crab, SC and ARES cavities.

## *RF Conditionings*

For stable operations of the SC cavities, conditioning of input couplers before cool-down and regular conditioning of the cavity during beam operation are necessary. The input couplers are conditioned at room temperature up to 300 kW under full reflection. DC bias voltages less than $\pm 2$ KV are applied between inner and outer conductors. Voltage biasing enhances the multipacting, and helps to release condensed gases on the coupler surface. RF conditionings for about 2 hours are given after cool-down every two or three weeks on the maintenance day. The pulse conditionings are frequently applied to some cavities to recover RF performances. This conditioning can relieve gas condensation on the cavity surface.

# R&D FOR SKEKB

R&D on the SC cavity for SKEKB is under way. We are developing a high power input coupler above 600 kW, a HOM damper for high power application more than 30 kW, and a reversed phase mode operation of the SC cavities.

## *Reversed Phase Mode*

Design parameters of the super-KEKB require high beam current, while the RF voltage is much lower than the present KEKB. The loaded Q factor of the SC cavities should be sufficiently reduced. Exchange of input couplers for low Q factor may cause two problems. One is a risk of particle contamination into the cavity, and the other is possible heating at the tip of the input coupler. A new operation scheme, reversed phase mode, was proposed. In this mode, the synchronous beam phase of some SC cavities is reversed so as to obtain lower total RF voltage. Figure 4 shows a phasor presentation of the RF voltage. Two cavities have reversed synchronous phase. Each cavity maintains high RF voltage, while the total RF voltage maintains as low as required voltage. The merit of this operation is equal beam loading for each EC cavity. A feasibility study was successfully conducted in KEKB, where one SC cavity phase was reversed with a low current beam. High current beam studies and application to the colliding beam operation is planned in the next machine time period in autumn 2009.

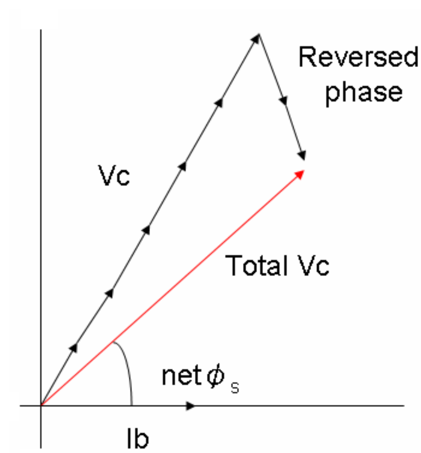


Figure 4: Phasor representation of the reversed phase mode operation. The synchronous phases of two cavities are reversed. The total voltage is lowered to meet the design value, while the high voltage for each cavity is maintained.

## *HOM Damper*

The design bunch length of the super-KEKB is 5 mm with a designed beam current of 2.2A. The HOM power generated in one SC cavity is estimated to be more than 30 kW. The SC cavity has two ferrite dampers on the beam pipe. The most serious issue is temperature rise of the ferrite surface and consequent outgas from the ferrite material. In order to suppress surface temperature rise we have been developing new dampers. The thickness of the ferrite material is reduced from 4 to 3 mm. In addition, a doubled cooling channel structure for efficient cooling is adopted. A prototype of the 3 mm thickness new dampers was fabricated and tested. Figure 5 shows a high power test stand for the prototype damper. Figure 6 shows surface temperatures of the ferrite material as a function of absorbed RF power. Surface temperature was 110$^0$C at an absorbed power of 18 kW.

Dampers with a double cooling channel structure are expected to reduce surface temperature. This type of damper is being fabricated and will be tested soon.

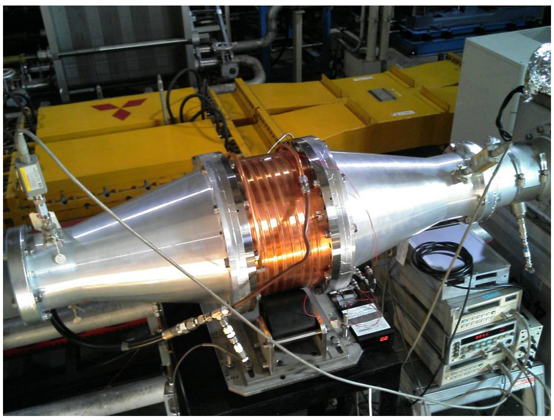

Figure 5: High power test stand for a large beam pipe (LBP) ferrite damper. A cylindrical ferrite of a thickness of 3 mm is sintered on the inside surface of a copper pipe by the hot isostatic press (HIP) method. A cooling water channel is wound on the outer surface of the copper pipe.

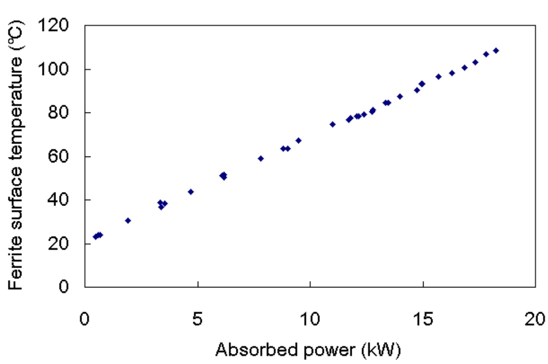


Figure 6: Temperatures at the surface of the 3 mm thickness ferrite damper as a function of the absorbed RF power. The cooling flow rate is 8.5 l/min.

### *Input Coupler*

To increase cooling capacity and reduce construction costs, a new input coupler was designed to have a single water cooling path and was recently fabricated [5]. This coupler was high power tested up to 750 kW with the travelling wave. The power limit was not due to the coupler performance but due to the power limit of the test klystron. A vacuum pressure gauge, an arc sensor and an electron collector sensor were set near a ceramic RF window and provided interlock signals and RF trips. Figure 7 shows an RF processing history. After about 50 RF trips coupler was processed up to 120 kW. Above 150 kW, hard multipacting levels disappear. RF powers were gradually increased without RF trips. Above 500 kW, the coupler frequently trips and finally reached to 750 kW.

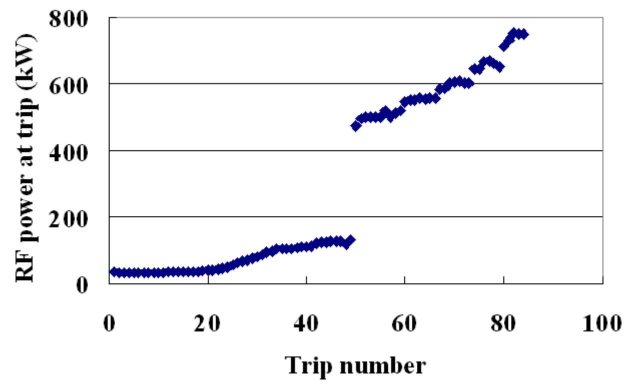


Figure 7: KEKB coupler RF processing history. Tested coupler was processed up to 750 kW.

## SUMMARY

Eight superconducting accelerating cavities in KEKB have been operated stably. The cavities provides a total RF power of 10MV and deliver 2.8 MW to the electron beams up to 1.4 A. Recently KEKB achieved the world luminosity records with crab cavities. Stable SC operation contributes to increase luminosity with crab crossing.

R&D for SKEKB is under way. A feasibility study for a new SC operation mode, a reversed phase mode, was successfully conducted with low beam current, and showed strong potentiality applicable for SKEKB.

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