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Superconducting Accelerating Cavity for KEK B-Factory

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1 Introduction

KEK-B is an asymmetric collider of 3.5GeV x 8GeV with the circulating beams of 2.6A(e^-) and 1.1A(e^+)[1]. These high currents require the RF cavities which have sufficiently damped higher order modes(HOMs), because RF cavities are the main source of the ring impedance that can cause the single bunch and coupled bunch instabilities. Another problem is a multibunch instability due to the accelerating mode. To avoid this instability, the amount of frequency detuning of the accelerating mode for minimizing the generator power is limited by the revolution frequency of 100kHz. For these requirements, two types of accelerating cavities are under development for the RF system of KEKB: a new normal conducting cavity(ARES)[2] and a superconducting(SC) cavity.

The development of SC cavities for KEKB has started since 1991[3] on the basis of the useful experiences in the construction and the operation of the TRISTAN SC cavities. A single cell cavity with a large aperture size has been designed to propagate HOMs toward the beam axis and damp them by ferrite absorbers bonded on the inner surface of beam pipes[4]. The study of full size HOM dampers made by HIP(Hot Isostatic Press) is in progress. Coaxial input couplers which were developed for TRISTAN cavities could pass 508MHz traveling RF power of 850kW. A prototype module using these components has been completed and will be installed in TRISTAN Accumulation Ring(AR) in 1996 for the beam test of 0.5A. In this paper, recent activity of an SC accelerating cavity for KEKB will be reported.

2 RF Parameters

The layout and RF parameters of KEKB are shown in Fig.1 and Table1. The interaction point(IR) is in the Tsukuba experimental hall. The Fuji straight section is used for injecting beams and installing RF cavities for LER. The other straight sections of Nikko and Oho will be used for RF cavities of HER and wiggler magnets of LER. In Nikko area, we have the 6.5kW LHe refrigerator that was used for TRISTAN SC cavities.

In the latest design of KEKB, the total RF voltages for LER and HER are designed as 4.9 - 9.4MV and 8.7 - 16.2MV, respectively[2]. They are determined by the requirement of a bunch length and the synchrotron tune which should be variable between 0.01 to 0.02 to find the optimum operation tune. Radiation losses of the beams are 2.7MW(LER) and 4.0MW(HER), but an additional loss of 1.8MW due to wiggler magnets can be concerned in LER to reduce the damping time. Because of such a heavy beam loading, the number of SC cavities depends strongly on the achievable input coupler power rather than the field strength of cavities. The RF parameters for the SC case are summarized in Table1, although the type of cavities, SC and/or NC, is not yet definite.

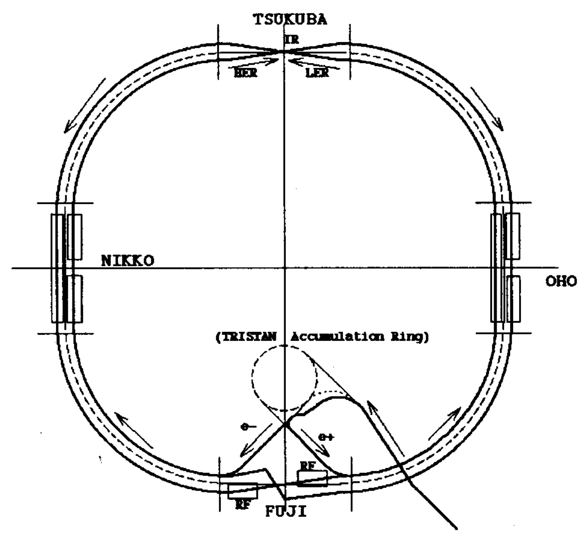

Fig.1: The layout of KEKB.

For the RF voltage of 0.9 - 1.6MV in HER, ten SC cavities with the Q of 5 x 10^4 require the coupler power of 400 - 500kW to maintain a larger growth time than the ring damping. The gap voltage of 0.9 - 1.6MV per cavity, which corresponds to 3.7 - 6.6 MV/m, is acceptable for SC cavities.

In LER, low RF voltage of 4.9 - 9.4MV requires less number of cavities with larger coupler power than that in HER. If the coupler power of 450kW is available, the number of cavities for LER is between 6 and 10, which depends on the beam power of 2.7 -4.5MW. Optimum coupling of input couplers relates to the gap voltage and beam loading power, so it is necessary to match the external Q of the input coupler to minimize the handling power as shown in Table 1. But the low growth time in LER will need the use of an RF feedback system to suppress the multibunch instability caused by the accelerating mode.

Table 1: RF parameters of KEKB (for superconducting cavity).

	LER		HER	
Beam energy	3.5		8.0	GeV
Beam current	2.6		1.1	A
Bunch length	0.4		0.4	cm
Synchrotron tune	0.01 - 0.02		0.01 - 0.02	
RF frequency	508.887		508.887	MHz
Harmonic number	5120		5120	
Total RF voltage	4.9 - 9.4		8.7 - 16.2	MV/turn
	no wiggler	with wiggler		
Beam power	2.7	4.5	4.0	MW
Number of cavities	6	10	10	
R/Q	93		93	Ω
Unloaded Q	1×10^9		1×10^9	
Gap voltage	0.8 - 1.6	0.5 - 0.9	0.9 - 1.6	MV/cavity
Coupler power	450		500 - 400	kW/cavity
External Q	$1.6 - 6 \times 10^4$	$0.6 - 2 \times 10^4$	5×10^4	
Growth time	1.2 - 1.4	0.3 - 0.5	23 - 54	msec

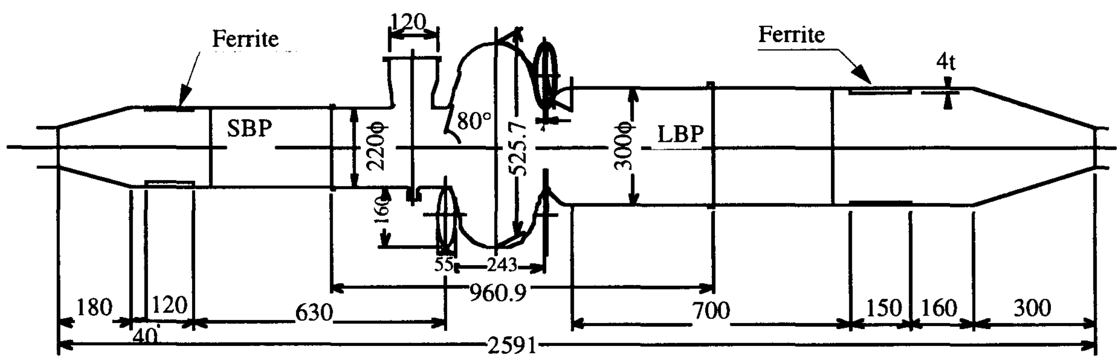

Fig.2: Optimized cell shape and ferrite absorbers.

3 R & D Status

Cavity Shape

A sketch of the cavity is shown in Fig.2 with ferrite dampers. A prototype module for the AR beam test is drawn in Fig.3. A single cell cavity has been chosen, so as to reduce the number of HOMs as well as to minimize the coupler power. The diameter of the aperture(220mm) was chosen to keep the desired coupling of the lowest monopole modes of TM-011 and TM-020. A large cylindrical beam pipe(LBP) of 300mm diameter was connected on one side to obtain a sufficient coupling of the lowest dipole modes, TE-111 and TM-110. The external Q of each HOM was estimated using the tuning curve method by J.Slater[5]. The cavity parameters of the accelerating mode are summarized in Table 2.

The optimization of HOM dampers has been made on IB-004 ferrite because of its superior RF properties around 1GHz. The damping characteristic of absorbers strongly depends on the geometrical parameters, such as the distance from a cell, the length and the thickness of ferrite and tapers between dampers and a beam duct[6]. These parameters are optimized by the SEAFISH code, which can calculate the Q of monopole modes for the cavity including resistive materials, and by the experiments using Al model. The experimental results using full size ferrite dampers have demonstrated the validity of the calculations. It has been shown that both monopole and dipole modes have the Q value of around 100. The HOM spectra of an aluminum model cavity with dampers are shown in Fig.4. The measured frequency and the Q value of HOMs are listed in Table 3.

Table 2: Cavity parameters of the accelerating mode (by SUPERFISH).

Frequency	508.6	MHz
Gap length	243	mm
Dia. of aperture	220	mm
R/Q	93	Ω
Loss factor	0.074	V/pC
Geometrical factor	251	Ω
Esp/Eacc	1.84	
Hsp/Eacc	40.3	Gauss/(MV/m)

Because of the short bunch length of 4 mm, the frequency of HOMs up to 20GHz should be concerned. The study using the ABCI code shows the loss factor of 2.3 V/pC per cavity, while the low loss factor of 0.66 V/pC for the cell without tapers. This increase in loss factor is caused by a pair of tapers that connect the cavity to beam ducts with a diameter of 100mm. In the case of a duct with 145mm, the loss factor can be reduced to 1.5 V/pC. Further, the loss factor becomes 1V/pC using long tapers of 1m(Fig.5). A preliminary experiment on the loss factor of the ferrite pipe measured by the synthetic pulse method shows the additional loss of 0.3V/pC per damper[7]. These results give the total loss factor of 1.6V/pC, which causes the absorbed power of 3.9kW and 22kW for a pair of ferrite dampers in HER and LER, respectively. Further, the HOM induced power of 1kW and 6kW due to mono-pole modes should be concerned.

Table 3: HOMs of Al model.

mono-pole

frequency MHz	mode	R/Q URMEL	Q meas.
783	LBP-TM01	0.1	132
834	LBP-TM01	0.3	72
1018	TM011	6.6	106
1027	TM020	6.4	95
1065	SBP-TM01	1.6	76
1076	LBP-TM01	3.2	65
1134	LBP-TM01	1.7	54

$R=V^2/P$

di-pole

frequency MHz	mode	R/Q' URMEL	Q meas.
609	LBP-TE11	1.9	92
648	LBP-TE11	40.2	120
688	LBP-TE11	170	145
705	TM110	227	94
825	SBP-TE11	6.2	60
888	SBP-TE11	3.5	97

$R/Q'=(R/Q)_r/kr^2$ (r=5cm)

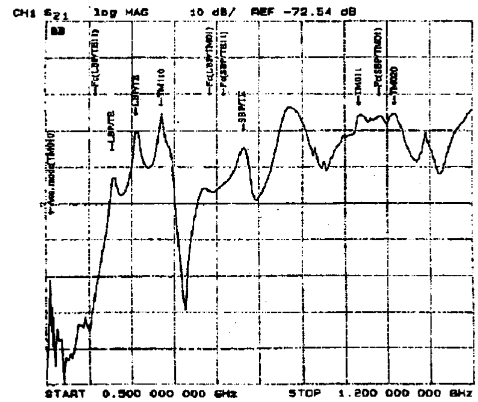

Fig.4: HOMs of an Al model cavity with ferrite dampers.

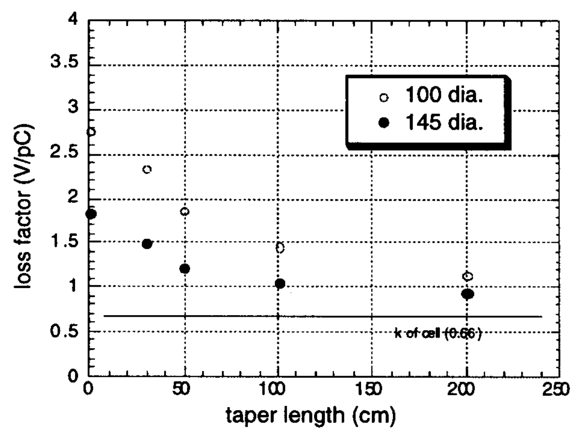

Fig.5: Loss parameter of a cavity connected to a beam duct of 100mm/145mm in diameter using tapers with various length(calculated by ABCI).

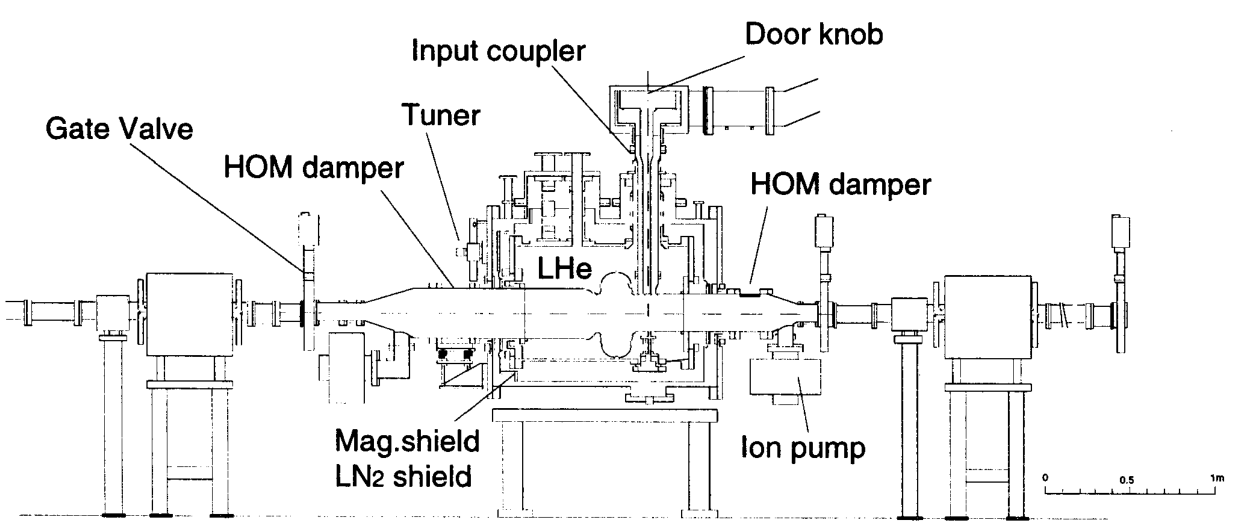

Fig.3: A sketch of the prototype cryo-module in TRISTAN Accumulation Ring(AR).

Cavity Performance

Up to now, we have fabricated two test cavities and one(CAVITYIII) for the beam test module. The surface treatment process is almost same as that for TRISTAN cavities, except for the final rinsing using ozonized pure water[8]. Maximum accelerating fields are 13.6 MV/m, 14.4MV/m and 13.1MV/m, respectively (Fig.6). The rather low Q of Cavity III may be caused by a heavy electropolishing that had to be given to remove the heating spots on the EBW seam[9].

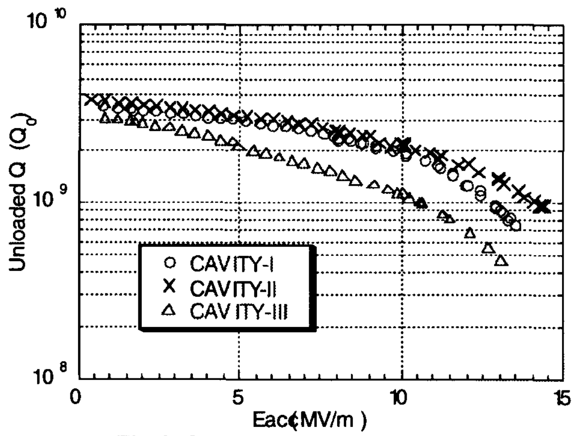

Fig.6: Q vs Eacc at vertical cold tests.

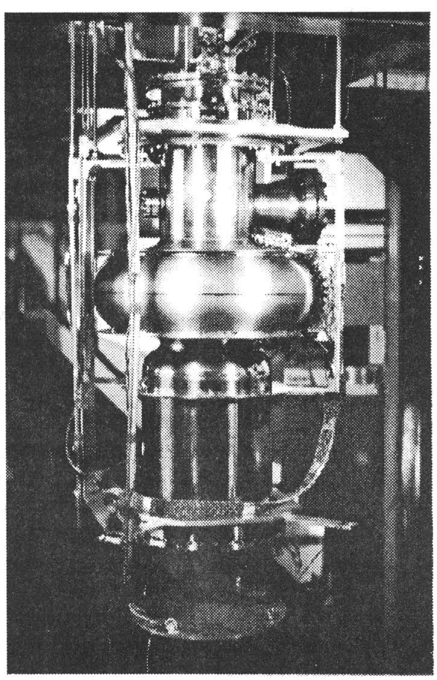

Fig.7: A Nb cavity with a mapping system using 25 carbon resisters and 19 PIN photo diodes.

HOM Damper

HOM dampers made of ferrite are located on both sides of the cavity: 4t x 220ϕ x 120mm and 4t x 300ϕ x 150mm. Up to now, our efforts on ferrite absorbers have been given to the establishment of the fabrication procedure. Three bonding methods have been investigated to fix IB-004 ferrite on copper beam pipes; ultrasonic soldering, vacuum brazing and HIP(Hot Isostatic Press). Among these methods HIP seems the most promising way, where the powder of IB-004 is packed in an iron vessel together with a copper cylinder and heated to 900°C in a furnace under 1500bar after vacuum pumping inside the vessel. In this process a cylindrical ferrite is sintered and bonded on the copper wall simultaneously under the vacuum circumstance[3].

To study the RF power capacity, reduced scale models with a HIPped ferrite cylinder, 4t x 100 x 150mm, have been fabricated. A TM_{01}-traveling RF of 5kW in 2.45GHz has been supplied and the absorbed RF of 4.0kW, that corresponds to 29W/cm^2 at the front edge of the ferrite, caused the temperature rise up to 200°C. No cracking has happened. The effective area of the power absorption estimated from the temperature distribution gave the average power density of 14W/cm^2. The power test of full size models was also performed using a coaxial line with 508MHz Klystron. The absorbed power of 11.7kW was given to a 220ϕ damper and 14.8kW to a 300ϕ damper. The average power density was 14.6W/cm^2 and 10.8W/cm^2, respectively. Both test were made under the atmospheric circumstance and no damage was observed on the ferrite[7].

A 300ϕ damper was installed in TRISTAN Main Ring and tested using TRISTAN beam. The maximum bunch current was 4 x 10^{-8}C/bunch, which was 20 times higher than the design value of KEKB-HER. No discharging and cracking was found on the ferrite surface. Because of the small total current of 12mA and the bunch shape, the maximum power absorbed by the ferrite was 273W. Fig.8 shows a full size model. Out gas rate of a full size model was 1 x 10^{-10} Torrl/sec.cm^2 at room temperature and 1 x 10^{-9} Torrl/sec.cm^2 at 90°C after baking of 120°C x 5days.

Input Coupler

A coaxial antenna coupler will be used as an input coupler, which has the same design as what has been developed for the TRISTAN SC cavities. The penetration of the inner conductor into the beam pipe is 7mm to obtain the Qext of 1 x 10^5. The ceramic window has also been used as the output window of 1MW Klystrons for TRISTAN. Three monitoring ports are added beside the ceramic for the monitoring of the vacuum pressure, emitted electrons and arcing.

The CW-traveling RF of 850kW could be supplied to two pairs of couplers at a test stand(Fig.9). This power level was achieved by the RF processing of 9 hours. The tests were limited both by the output power of the Klystron. The RF processing was mainly given to overcome the multipactoring levels of 50kW and 160 kW, where the interlocks of arcing and vacuum pressure have worked frequently. At higher power level, less processing was required. The power of 850kW was supplied to a pair of the couplers for 5 minutes and no cracking happened on the ceramics. The RF of 150kW under perfect reflecting could be supplied to a pair of couplers.

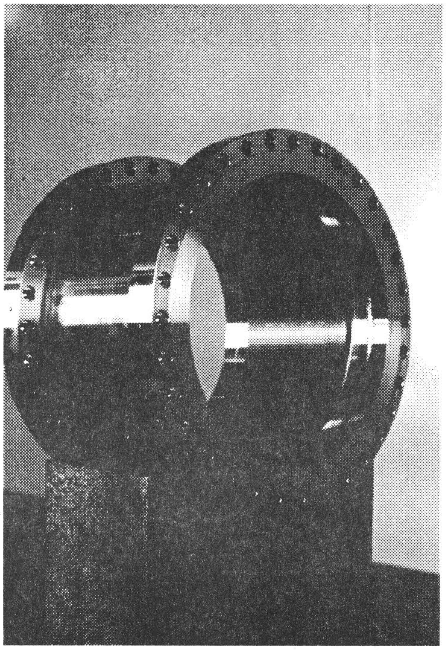

Fig.8: Full size model of ferrite damper. The powder of IB-004 ferrite was sintered and bonded on a Cu pipe by HIPping.

The loss of inner copper conductor is estimated as 360W for 500kW, which can be water cooled within the temperature rise of 10 degree. On the other hand, the loss of outer conductor, which is made of copper plated stainless steel, is 160W/m on the room temperature side and 30W/m on the 4.2K side. This power will introduce the heat loss of about 50W to LHe. To compensate this heat loss, an automatic control system of He gas flow for cooling the outer conductor will be required.

4 Summary

The development of the main components for an SC damped cavity for KEKB is in progress. A spherical single cell cavity with large beam pipes showed sufficiently damped HOMs using IB-004 ferrite absorbers bonded on the beam pipe surface. The RF power of $29W/cm^2$ in peak and $14W/cm^2$ in average was given to the 2.45GHz reduced model absorbers. A pair of the full size models could absorb the RF power of 11.7kW and 14.5kW. No cracking on the ferrite surface has been occurred during these power test and the beam test in TRISTAN. The gap voltage of 3MV could be obtained by Nb test cavities at vertical cold tests. The coaxial antenna couplers could transfer the traveling wave of 850kW and the standing wave of 150kW at a test stand.

The RF parameters of HER are acceptable, where 10 single cell cavities will be used to store the beam of 1.1A. The field gradient of each cavity is 3.7 - 6.6MV/m, and 400 - 500kW couplers with the Qext of 5×10^4 will be required. On the other hand, the use in LER will involve many difficulties. High power couplers with a low external Q will be required. The absorption of HOM power of 30kW will cause the temperature rise of ferrites and will become a gas source. A prototype module which includes these components has been completed and will be install in TRISTAN Accumulation Ring for the beam test of 0.5A that is scheduled for 1996.

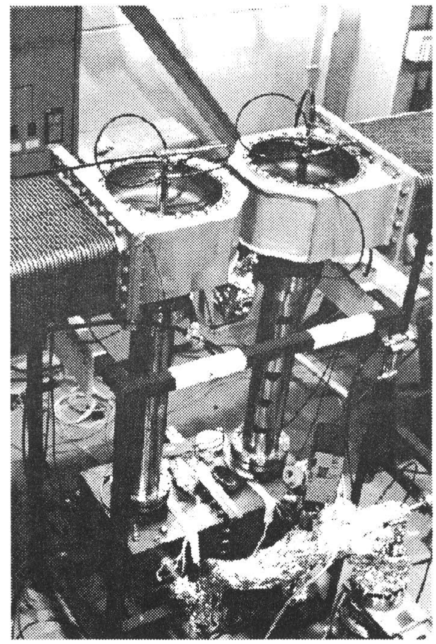

Fig.9: High power test bed for input couplers; traveling RF of 850kW was supplied to a pair of couplers.

5 Aknowledgements

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