RECENT STATUS OF THE SUPERCONDUCTING CAVITIES FOR KEKB

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Abstract

The commissioning of the KEK B-factory storage rings started on December 1, 1998. Four superconducting damped cavities have been installed in High Energy Ring (HER) and operated since the beginning of the commissioning. During the commissioning, the beam current of HER reached 514mA and the SC cavities supplied the rf voltage of 4.8-8MV smoothly as occasion demands. The maximum rf power transferred to the beam reached 1.4MW, well above the planned value of 1MW. The maximum HOM power absorbed by the ferrite dampers was 2.5kW per module that was in agreement with the calculated one. The next four cavities are under fabrication and will be installed in the summer of 2000. Furthermore, the development of a superconducting crab cavity has been continued in order to suppress the beam-beam interaction due to a finite crossing angle at the colliding point. A full size model cavity showed the sufficient surface field of 32MV/m. The superconducting crab cavities will be installed in KEKB in the future.

1 INTRODUCTION

A B-meson factory, KEKB, has been completed and been commissioned since December, 1998. KEKB is an asymmetric electron-positron collider using 8GeV(HER) and 3.5GeV(LER) storage rings. To achieve the goal luminosity of $10^{34}cm^{-2}s^{-1}$, the beams of 1.1A and 2.6A in 5000 bunches have to be stored in HER and LER, respectively[1]. In such a high beam intensity and multi-bunch operation, an rf system with sufficiently damped higher order modes(HOMs) is required to avoid coupled bunch instabilities. Furthermore, the amount of frequency detuning of the accelerating mode required to minimize the generator power has to be kept within the revolution frequency of 100kHz. For these requirements, a single cell superconducting(SC) damped cavity has been developed, where the power capacity of components, such as input couplers and higher order mode(HOM) dampers, is important as well as the cavity performance[2-4]. Up to now, four SC cavities were built and installed in HER for the KEKB commissioning.

Another application of SC cavities to KEKB is a crab cavity. KEKB has a finite crossing angle of ±11mrad to obtain the minimum bunch spacing of 60cm, where a full-bunch operation is possible without any separation bend magnets. This crossing scheme, however, has a possibility of the luminosity reduction due to beam-beam interaction as well as the geometrical effect. For this reason, a crab crossing scheme is considering using a pair of SC-TM110 cavities in each ring, that is, crab cavities. The development of SC crab cavities is in progress[5].

In this paper the commissioning of the SC accelerating cavities and the R&D status of a crab cavity will be described.

2 SUPERCONDUCTING DAMPED CAVITIES

2.1 Layout of KEKB

The rf system of HER is a combination of SC and normal conducting cavities(ARES)[1]. The SC cavities are in the NIKKO straight section, because of the existing LHe

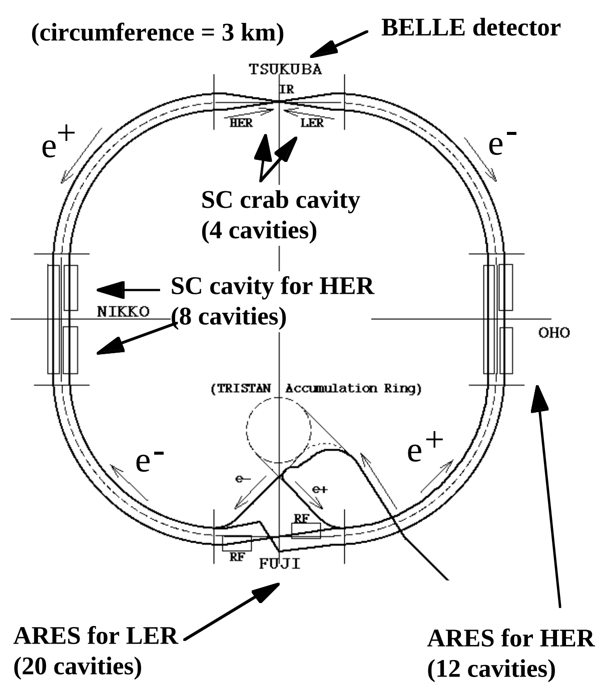

Figure 1: Layout of KEKB.

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refrigerator of 6.5kW that was used for the TRISTAN SC cavities. The SC crab cavities are to be installed on both sides of the interaction point in the TSUKUBA section. A schematic drawing of the KEKB rings is shown in Fig. 1.

The designed gap voltage per cavity is 1.5MV for SC and 0.5MV for ARES. The rf power delivered to the beam can be shared by giving an offset to the rf phase between SC and ARES cavities. The rf parameters are summarized in Table 1. At the beginning of the commissioning, almost half of the cavities were installed in both rings. The number of the cavities is to be increased as shown in Table 1.

Table 1: RF parameters of KEKB.

	LER	HER	
Beam energy (GeV)	3.5	8	
Beam current (A)	2.6	1.1	
Number of bunches	5000	5000	
Bunch charge (C)	5.1E-09	2.1E-09	
Bunch length (mm)	4	4	
Max. rf voltage (MV)	10	18	
Total beam power (MW)	4.5	4.0	
RF frequency (MHz)	508.887	508.887	
Harmonic number	5120	5120	
Total number of cavities	ARES	SC	ARES
At commissioning	12	4	6
Summer of 1999	16	4	10
Final (Summer of 2000)	20	8	12
Gap voltage (MV/cavity)	0.5	1.5	0.5
Beam power (kW/cavity)	220	250	170

2.2 SC Module

A sectional view of the SC module is in Fig. 2. The cavity cells were made of 2.5mm thick Nb sheets with RRR of 200. After grinding the welding seams on the inner surface, the cavities were treated as follows; 1) electropolished by 80µm, 2) degassed at 700˚C for 1.5hr, electropolished by 15µm and rinsed with 3ppm ozonized ultra pure water(OUR) [6].

The completed cavities were tested in a vertical cryostat before assembling. In spite of the operation voltage of 1.5MV(6MV/m), we set our target voltage as 2.5MV(10MV/m) to obtain the enough margin for stable operation. Two of the cavities achieved the maximum accelerating gradient of 11MV/m and 19MV/m at the first cold test. The limitation of 19MV/m, which corresponds to the surface peak field of 35MV/m and the magnetic field of 750Gauss, is not a breakdown but an available rf power. Another two cavities did not reach 10MV/m at the first cooldown. One of them was damaged by a discharging at 14MV/m during the first cold test, and the other was limited by a defect on the equator seam. They were recovered by grinding and additional polishing.

Table 2: Design parameters of the SC module.

Frequency	508.887	MHz
R/Q ($R=V^2/P$)	93	Ω/cavity
Gap length	0.243	m
Diameter of iris	220	mm
Geometrical factor	253	Ω
Eacc/Vc (L=0.243m) Esp/Vc Esp/Eacc Hsp/Eacc	4.11 7.65 1.84 40.3	m^{-1} m^{-1} G/(MV/m)
Total length	3701	mm
Volume of LHe	290	liter
Static loss	30	Watts
Qext of input coupler	5.3-7.7E+04	
HOM damper size SBP LBP	Ferrite(IB-004) 4t x 220_x 120 4t x 300_x 150	 mm mm
HOM Max. R(TM011) Max. R(TM110)	 2 37	 kΩ kΩ/m
Loss factor at 4mm Cavity with tapers Ferrite dampers total	 1.2 0.3 x 2 1.8	 V/pC V/pC V/pC

The inner conductor and ceramic window of the input coupler were conditioned up to 800kW in a traveling wave mode. Then, a set of the inner and outer conductors was conditioned to 300kW under a reflection of 130kW. These conditioning processes were given at a test stand before assembling. HOM dampers were tested up to 5kW and 7kW for SBP and LBP, respectively, then baked at 150˚C for about one month to reduce outgassing rate.

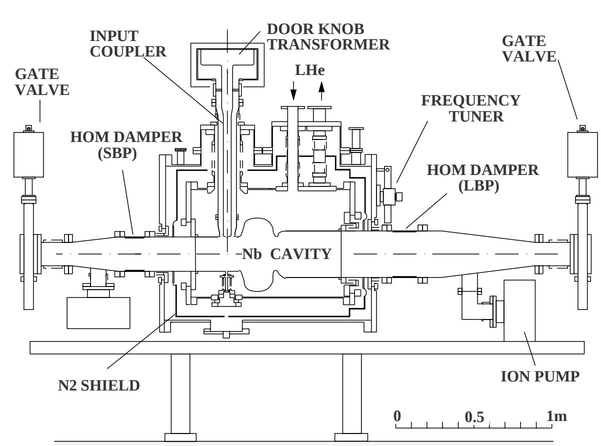

Figure 2: A sectional view of the SC damped cavity.

Our cryostat has an iron vacuum vessel of 12mm in thickness to shield geomagnetism, and has no other shielding. The measured residual magnetic flux at the center of the He vessel is 50mG, which is mainly due to the penetration from the openings for beam pipes on both ends.

After assembling, modules were tested one by one at a horizontal cold test stand, and moved to the tunnel. Each module was connected to a 1MW klystron, being isolated with a 1MW circulator. The geometrical parameters of the cavity are shown in Table 2.

3 COMMISSIONING

The commissioning of the KEKB rings started on December 1, 1998. The current growth of both rings is shown in Fig. 3. The period from the beginning through April was spent for the basic research of the rings and a high current operation without the BELLE detector. The current of more than 0.5A was achieved in both rings at this period. The maximum current of 0.51A at HER was limited by the available rf power due to the less number of cavities, while the beam blow up due to a multi bunch instability limited the current of LER to 0.54A. After a five-week shutdown in May for the installation of BELLE, the collision study was continued till the beginning of August. In most of this period, the current of HER was restricted to 100mA because of the background radiation near the detector. The maximum luminosity of this period achieved 2.9 x $10^{32}cm^{-2}s^{-1}$.

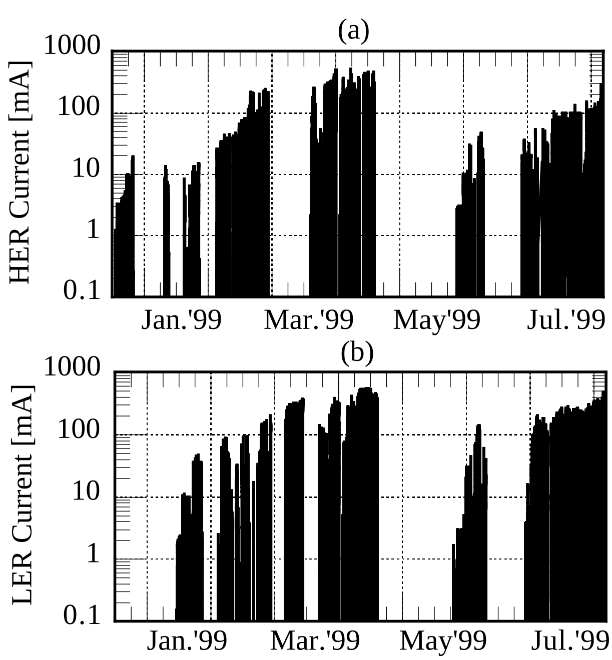

Figure 3: The current growth of HER(a) and LER(b) during the commissioning.

3.1 Cavity Performances

Because of the scheduled and unexpected shutdown of the rings, four times of warming were repeated on the SC cavities. At every cooling down, the same procedure of the cavity conditioning is adopted.

- Conditioning of the input coupler before cooling. The rf power to 300kW is given to the coupler for the various bias voltages up to ±2kV between the inner and outer conductor, as shown later.
- Cooling down the cavity within 3 days.
- Conditioning of the cooled cavity.
- Measurement of the Q at 2.0 and 2.5MV with the LHe consumption rate.

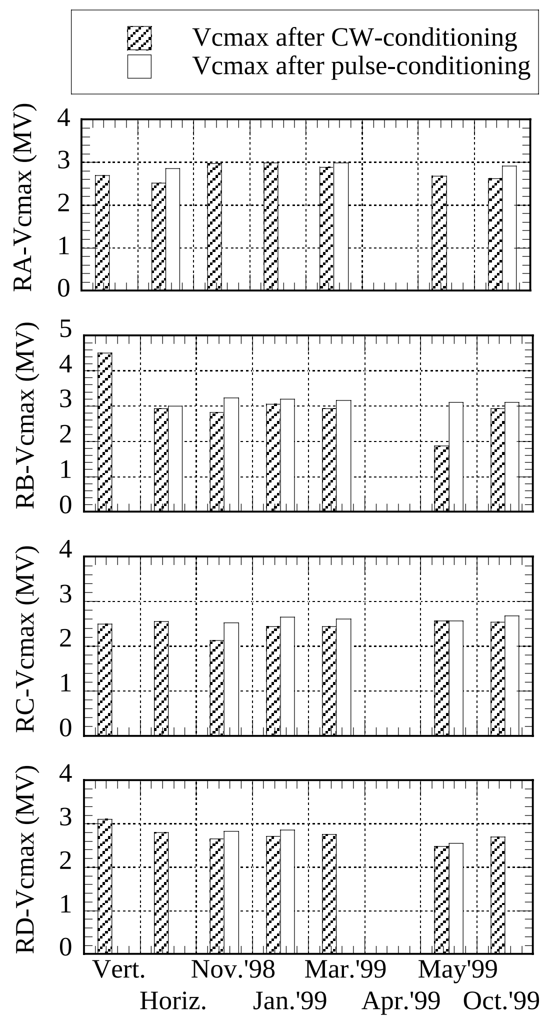

Figure 4: Vcmax of cavities, RA, RB, RC and RD, achieved at every cooling. The cavity RB was opened in April for repairing the insulation vacuum leakage. The initial Vcmax of RB was recovered by the pulse conditioning process.

These conditioning processes are made under full reflection condition. For the conditioning of cooled cavities, a conditioning with a CW power is given first. A pulse conditioning process is followed to the cavity with the voltage less than 2.5MV, where a small rf pulse with a repetition rate of 100Hz (duty cycle < 10%) is added to the CW so that the peak rf voltage reaches >3MV. This pulse conditioning can keep the discharging not to grow up to an avalanche, so that we can continue the conditioning without breaks due to breakdown. This method is quite effective to enhance the outgassing rate. Finally, resonance phase is scanned by ±30˚ so as to move the standing wave in the coupler for an additional conditioning. The maximum cavity voltages achieved after these conditions are summarized in Fig. 4, and the Q of each cavity is shown in Fig.5. So far, no degradation of the cavity performances has been observed as shown in Fig.4 and Fig. 5.

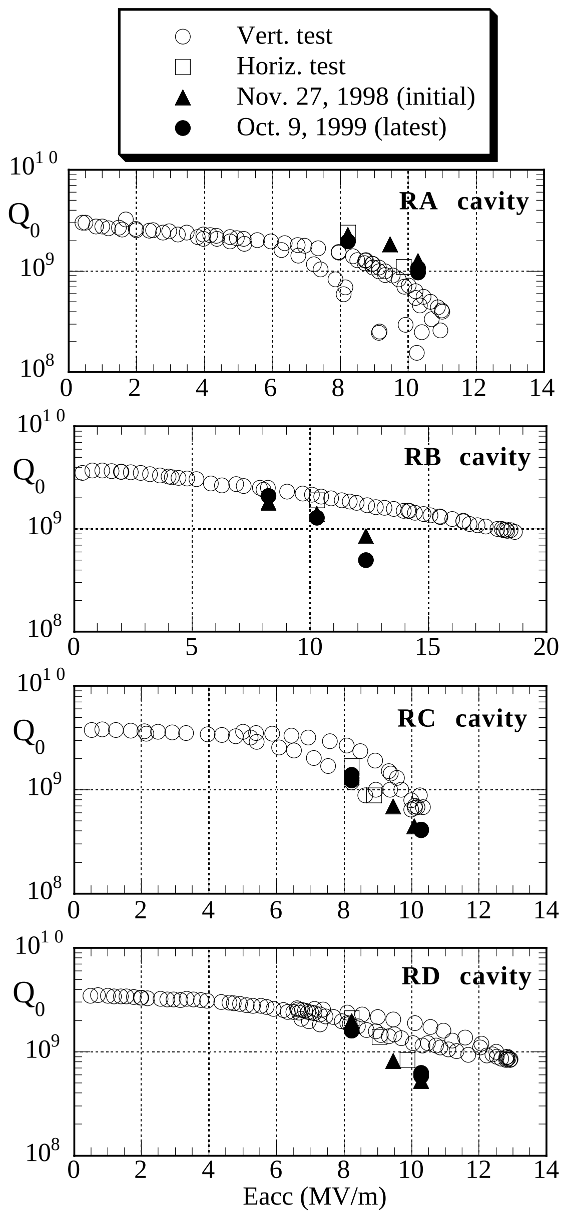

Figure 5: The Q-E of the cavities at various stages; vertical cold test, horizontal cold test and in the tunnel.

3.2 Operation

In most of the operation period, the total rf voltage of HER was kept at 8MV, where the SC cavities supplied the voltage of 6MV. Sometimes the SC voltage was scanned between 4.8MV and 8MV as occasion demand. No major problem has been observed on the cavities up to a current of 0.5A so far.

Fig. 6 shows the beam power of RA cavity during the high current operation. Our input couplers supplied the rf power of 400kW to the cavity, and the maximum power delivered to the beam reached 1.4MW in total, which was 140% of the design value. Even in such a high current operation, the cavities did not trip and no additional conditioning was required.

The HOM power absorbed by the dampers are obtained from the temperature rise and the flow rate of the cooling water. The maximum power was 10.6kW in total as

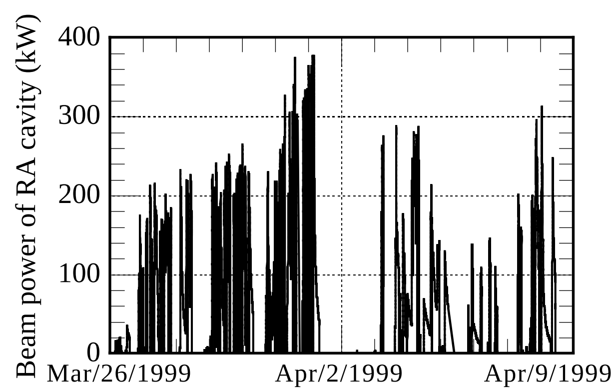

Figure 6: The beam power of RA cavity during the high current operation.

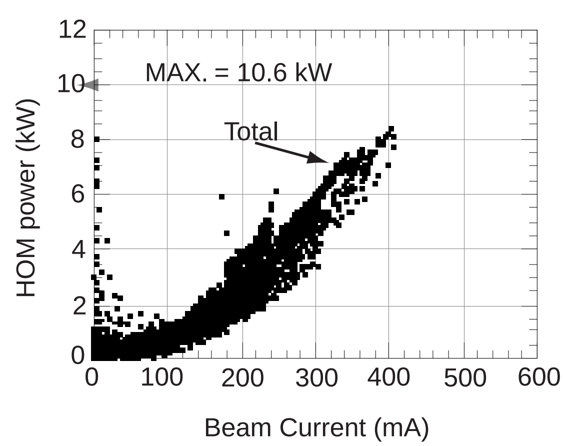

Figure 7: The HOM power absorbed by the dampers.

shown in Fig. 7. In Fig. 7, one can also see that the measured power for each cavity is the same. This indicates no difference of the HOM damping characteristic among all modules. The results related to the beam are summarized in Table 3 as well as the design values.

Table 3: Summary of the results achieved with beams.

	design	Achieved
Number of SC cavities	8	4
Beam current (A)	1.1	0.514
Number of bunch	5000	800
Bunch length	4	6-7
RF voltage (MV/cavity)	1.5	1.2-2.0 1.5 at 0.514A
Max. of Pin/Pref		Total:1.5MW / 70kW RA:410kW / 40kW RB:410kW / 30kW RC:390kW / 5kW RD:390kW / 20kW
Beam power (kW/cavity)	>250	Total: 1.4MW RA:370kW RB:380kW RA:380kW RA:370kW
HOM power (kW/cavity)	5 at 1.1A	2.6 at 0.44A

3.3 RF Trips

At the beam test of a prototype module in 1996, we have experienced the frequent rf trips caused by the discharging in the cavity and input coupler[7]. The trips were due to the condensed gasses penetrating from the neighboring section of the SC cavity with a poor vacuum pressure (100 nTorr). From this experience, we considered the following items; 1) pressure below 1 nTorr, 2) reduction of synchrotron radiation(SR) from bending magnets and 3) coupler conditioning.

The beam ducts between the SC cavities are equipped with NEG pumps every 60cm. Further, the SC cavity section in NIKKO is guarded against the gas from the ring by using the beam ducts of 20m, which have also NEG pumps every meter. Because of this evacuation system, the pressure around the SC cavities was kept below 10 nTorr for a beam of 0.5A.

For the reduction of the SR to the cavities, the bending radius of the magnets at the end of every arc sections is designed as five times larger than that of normal bending magnets. Furthermore, the distance of 140m from the magnet to SC cavities reduces the radiation power to 0.4 W/m. In addition, each SC cavity has a shielding mask of copper.

As already described, the input couplers are conditioned before cooling. The input power can reach 300kW within 30 minutes, showing no vacuum burst. However, supplying a bias voltage between the inner and outer conductors, we can find many outgassing levels on both positive and negative bias voltages, as shown in Fig. 8(a). In the figure the vacuum pressure against the input power is described for the various bias voltages up to ±1.8kV on the coupler before(a) and after(b) the biased conditioning process. One can see the traces of outgassing power levels increasing as the square of bias voltage. Although the traces can be suppressed as shown in 8(b), they still remain after cooling and appears again at the same power level after warming up to the room temperature. The same traces are observed for all our couplers.

Up to now, only fourteen times of trips have happened due to the cavity breakdown. These trips seem to have no relation to the beam intensity. Other trips are due to the interlocks from components, such as klystrons, refrigerator, vacuum protection and so on.

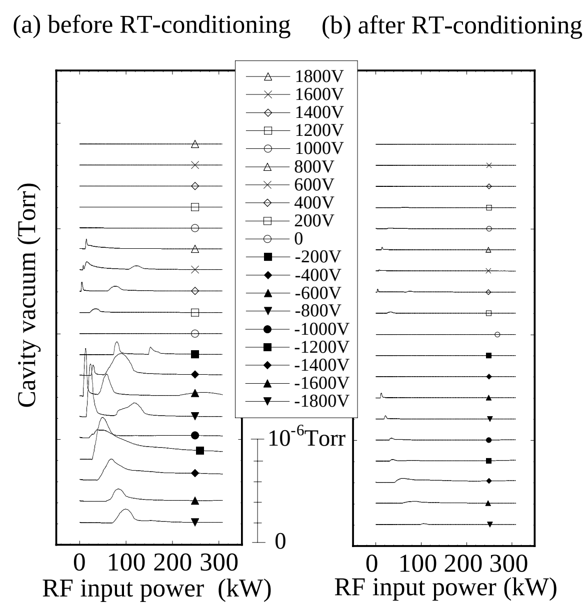

Figure 8: Mapping of vacuum pressure versus input power, scanning the power for the various bias voltages up to ±1.8kV.

4 SUPERCONDUCTING CRAB CAVITY

To relieve the disadvantages caused by a finite crossing angle at the interaction point(IP), a crab crossing scheme has been considering for KEKB, where the beam bunches of both LER and HER are tilted horizontally by 11 mrad at the IP in order to keep the head-on collision condition.

A pair of rf cavities is located in each ring on both sides of the IP to kick and kick back the bunches. The required transverse kick voltage is as high as 1.4MV, on the other hand no beam power is essentially required. Therefore, the superconducting TM110 mode cavity is the best choice for this purpose. For this reason, the R&D of SC crab cavities is in progress.

A squashed-cell cavity is used for the KEKB crab cavities, because of a large separation of two TM110 modes, that is, vertical and horizontal ones[8]. A full size Nb cavity, which has an oval-like cross section of 866 x 483 mm, has been fabricated and devoted to the fundamental study. The Q-E of the model cavity was measured at 4.2K and 2.8K. The surface peak field(Esp) reached 32MV/m and 40MV/m by HPR, exceeding the design value of 21MV/m, as shown in Fig. 9. Because of the deflecting mode of TM110, the cavity has not only higher order modes but also lower frequency modes such as TM010. To damp these modes, a co-axial coupler is deeply inserted into a beam pipe along the beam axis to couple them out toward an absorber located on a room temperature side. Therefore, the study on the effect of this coupler to the cavity performance is also under way[9].

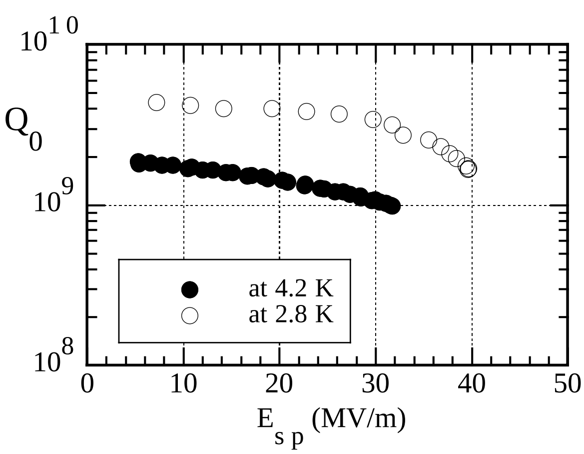

Figure 9: Q-E of the full size model cavity.

5 SUMMARY

In KEKB, two types of superconducting cavities are used for accelerating and deflecting the beam. Four accelerating cavities have already been commissioned in HER(Fig. 10), and deflecting cavities are under R&D phase. During the first commissioning period of KEKB, the beam current of HER reached 0.51A, which was limited by an available rf power from the existing cavities. The SC cavities supplied the total rf voltage of 4.8-8MV smoothly during the period. The rf power transferred to the beam also increased smoothly as the beam intensity went up, and achieved 1.4MW that is 40% higher than the design value. The maximum HOM power absorbed by the ferrite dampers reached 2.5kW for each cavity. During the whole commissioning period, the SC cavities worked quite well and no serious problem was observed for a beam up to 0.5A. The next four cavities are under fabrication and will be installed in the summer of 2000. The development of a superconducting crab cavity has been continued successfully. A prototype module will be designed in the near future.

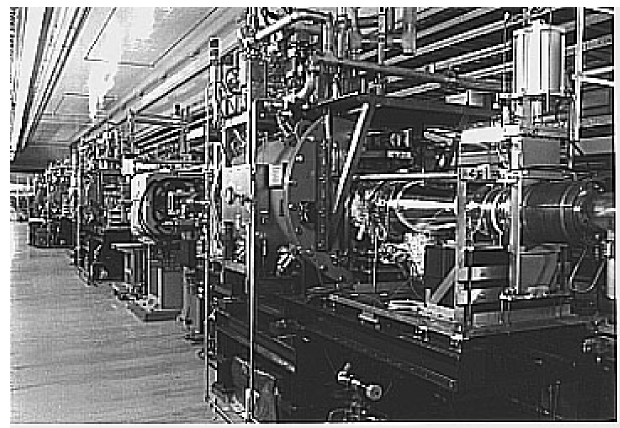
Figure 10: Four SC damped cavities installed in HER.

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