ACHIEVEMENTS OF THE SUPERCONDUCTING DAMPED CAVITIES IN KEKB ACCELERATOR

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Abstract

After the last workshop of 2001, drastic progress has been achieved in KEKB. The beam intensity of High Energy Ring (HER) reached the design value of 1.1 A, and the operation in reduced number of bunches achieved a peak luminosity of 1.06×10^{34} $cm^{-2}s^{-1}$. Eight superconducting (SC) damped cavities installed in HER have provided an accelerating voltage of 10 MV and delivered the RF power of 2.2 MW to the electron beam. The bunch charge of 8 nC which was four times higher than the designed one induced a HOM power of more than 10 kW in each SC cavity module. Ferrite dampers absorbed this HOM power sufficiently and no beam instability has been observed. Update of the operation performance will be given.

INTRODUCTION

KEKB was commissioned at the end of 1998[1]. Since then, beam intensity of both rings, HER (electron ring of 8 GeV) and LER (positron ring of 3.5 GeV), has been improved continuously[2,3,4] and reached 1.10 A in HER and 1.86 A in LER so far, which correspond to 100% and 70% of the design intensity, respectively. Precise control of these beams has brought the peak luminosity of 1.06×10^{34} $cm^{-2}s^{-1}$ to the BELLE detector and an integral luminosity of 579 pb^{-1}/day has been delivered.

Eight superconducting (SC) cavities and twelve normal conducting (NC) cavities installed in HER showed a stable operation performance under the beam of 1.1 A. These SC and NC cavities provide the stable accelerating voltage of 13 MV sharing the voltage of 10 MV and 3 MV, respectively. Each SC delivered the power of 300 kW to the beam. Analysis of SC-trips showed that the beam intensity of 1.1 A had no influence on a SC-trip rate and kept the rate at 0.5 times/day in total for eight cavities.

This paper will present the recent accelerating performance achieved by the SC damped cavities in KEKB-HER.

LUMINOSITY GROWTH OF KEKB

From the beginning of the commissioning, LER is always suffering from the beam blow up caused by electron-cloud instability. Vertical size of a positron beam in a multi-bunch operation is blown up by photo-electrons emitted from the chamber wall. To prevent the electrons moving toward the beam axis and to suppress this blow up, solenoid magnets have been installed in LER as well as increasing a bunch space to 2.4 m. The total length of the solenoid magnets is still increasing as described in Fig.1and covered 2275 m of the LER beam duct. These efforts have improved the threshold of beam blow up in LER and the maximum intensity reached 1.86 A which corresponds to 70% of the goal intensity of 2.6 A.

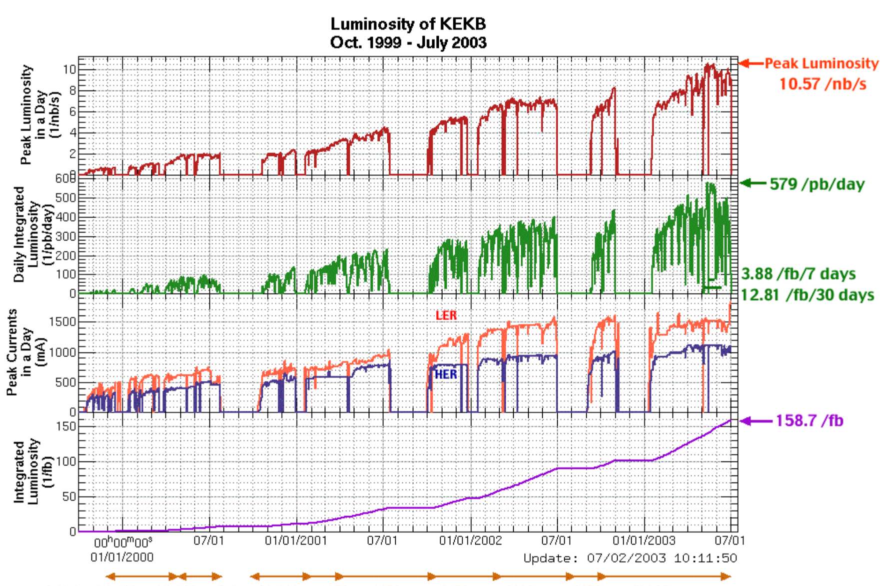

Figure 1: Performance growth of KEKB: peak luminosity, daily integrated luminosity, beam currents of LER (red) and HER (blue) and total integrated luminosity. Bottom arrows shows the total length of a LER beam duct covered by solenoid coils for suppressing the electron-cloud instability.

On the other hand, no serious beam-instability has been observed so far in HER, and the peak current has reached the design value of 1.1 A. However, the bunch configuration with a longer spacing of 2.4 m increases the bunch current by a factor of four. As a result, the peak luminosity of 1.06×10^{34} cm^{-2}s^{-1} can be achieved with rather small beam intensity of LER, as shown in Table 1. At the same time, this configuration causes a serious HOM power in HER.

Table 1: Machine parameters at the luminosity of 1.06×10^{34} cm^{-2}s^{-1}

Machine Parameters of the KEKB (May 13 2003)

	LER	HER	
Horizontal Emittance	18	24	nm
Beam current	1377	1050	mA
Number of bunches	1284		
Bunch current	1.07	0.818	mA
Bunch spacing	2.4		m
Bunch trains	1		
Total RF volatage Vc	8.0	13.0	MV
Synchrotron tune ν_s	-0.0249	-0.0207	
Betatron tune ν_x / ν_y	45.507/43.546	44.512/41.580	
beta's at IP β_x^* / β_y^*	59/0.58	58/0.7	cm
Estimated vertical beam size at IP σ_y^*	2.2	2.2	μm
beam-beam parameters ξ_x / ξ_y	0.096/0.069	0.065/0.052	
Beam lifetime	127@1377	256@ 1050	min.@mA
Luminosity (Belle CsI)	10.567		10^{33}/cm^2/sec
Luminosity records per day / 7days/ month	579/3876/12760		/pb

OPERATION OF SC CAVITIES

In these two years, the beam intensity of HER has increased from 870 mA to 1.1 A, where a beam power of 4 MW are required. RF voltage of LER and HER are 8 MV and 13 MV, respectively which are provided by twenty-three klystrons of 1MW. Fig. 2 shows the operation status of all klystrons of KEKB-RF. Each klystron of D07 and D08 supplies the power to a couple of NC cavities for LER that generates the accelerating voltage of 0.8 MV.

Five klystrons of D04 and D05 are connected with ten NC cavities of HER and generate the accelerating voltage of 3 MV. The other klystrons of D10 and D11 are connected with eight SC cavities and share the voltage of 10 MV in total. In this figure, D11-B provides the voltage of 2 MV with a RF incident power of 125 kW as a performance test of the D11B cavity.

In the summer of 2003, another klystron unit including a pair of NC cavities was installed in D4 as a final reinforcement of KEKB-RF. As a result, the beam intensity of HER will be upgraded to 1.2 A or more.

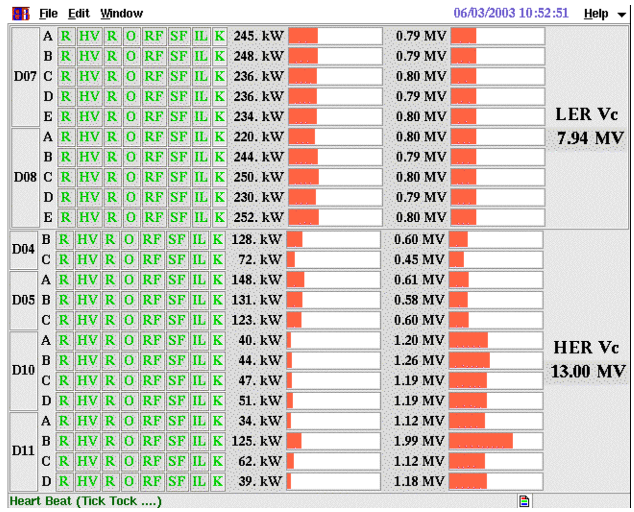

Figure 2: RF klystrons of KEKB. Eight klystrons of D10 and D11 sites provide the RF power to the SC cavities.

HOM POWER

Because of the operation with less number of bunches as described in Table 1, the bunch current of HER has been four times larger than the design value. Therefore, broadband HOM induced by the beam of 1.1 A has far exceeded the expected one induced in a 5000 bunch operation. Figure 3 shows the HOM power obtained from a temperature rise and a flow rate of the cooling water of HOM dampers. The peak HOM at 1.1 A has reached 10 kW per module, which is two times larger than the predicted power of 5 kW in 5000 bunch operation.

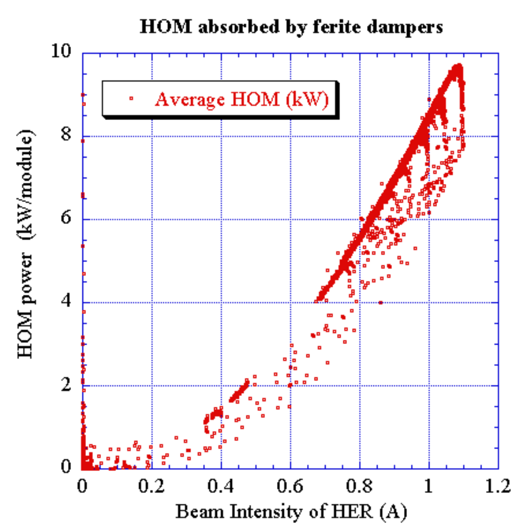

Figure 3: The total HOM power absorbed by a pair of ferrite dampers of one SC module.

SC-TRIP RATE

Because of a strong coupling between RF cavities and an accelerating beam, it is hard to find the real reason of RF-trips in high intensity accelerators. In KEKB, all trips have been monitored by a multi-channel oscilloscope with a time resolution of 5 µs, since the beginning of commissioning. All RF-trips or beam-aborts of every month are summarized in Figure 4. Frequency of trips is increasing as the beam intensity, however, trips due to RF have never been affected by the intensity. Both SC and NC cavities showed the trip rate of 0.5 times per day.

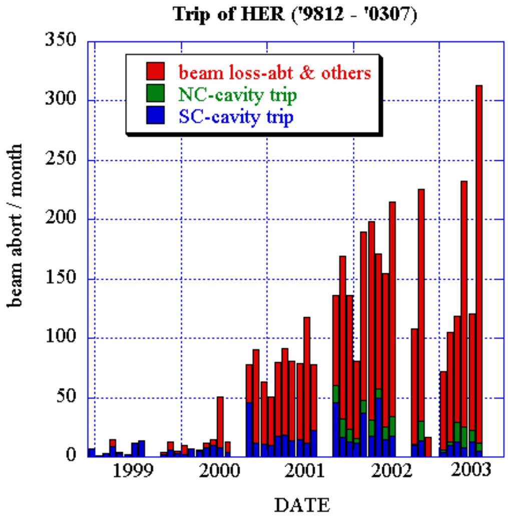

Figure 4: Total trips of KEKB-HER. The number of trips is increasing as the beam intensity improved, however, trips due to RF have never been affected by the intensity.

OPEARATION AT 2MV

As a demonstration of the acceleration performance, one of the SC cavity, D11B, was operated at various accelerating voltage for one year.

1) 1.6 MV from Sep. 2002 to Mar. 2003
2) 1.8 MV from Mar. 2003 to Jun. 2003
3) 2.0 MV from Jun. 2003 to Jul. 2003

During the test, power loading of D11B cavity was always kept at 300-350 kW by giving an appropriate offset to the station phase.

Figure 5 shows the RF input and reflection power of D11-cavities. The acceleration voltage of other cavities was 1.2 MV. The figure shows that the operation at 2 MV has an advantage from the view point of RF matching and saving a coupler power. On the other hand, high accelerating voltage reduces a bunch length and increases HOM power.

Comparison of the trip rate at various accelerating voltage showed no deference.

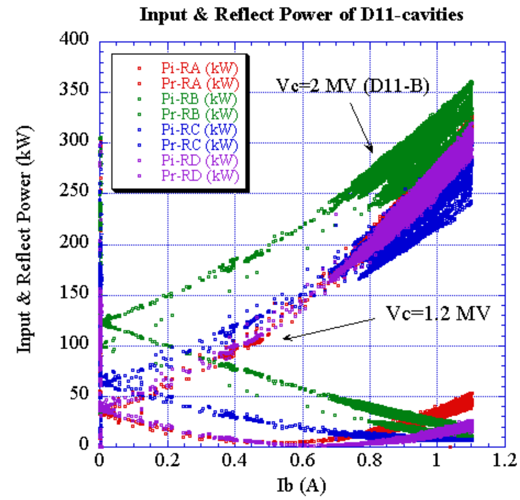

Figure 5: Coupler power of D11-cavities vs. the beam intensity (Ib) of HER. One of the D11cavities (D11B) was operated with the voltage of 1.6 MV, 1.8 MV and 2 MV as a performance test. No degradation of the trip rate was observed.

SUPER-KEKB

KEKB has achieved the design luminosity of 10^{34} $cm^{-2}s^{-1}$. Therefore the feasibility study has started to upgrade the luminosity by a factor of ten, i.e. 10^{35} $cm^{-2}s^{-1}$. In this scheme, well-focused beams of 9.4 A and 4.1 A are collided each other with finite crossing angle using a set of SC crab-cavities. The total beam power is estimated as 18 MW for LER and 16 MW for HER, respectively. The latest machine parameters of SuperKEKB are summarized in Table2.

Table 2: Machine parameters of SuperKEKB

Machine Parameters of the SuperKEKB

	LER	HER	
Horizontal Emittance	33	33	nm
Vertical Emittance	2.1	2.1	nm
x-y coupling	6.4	6.4	%
Beam current	9.4	4.1	A
Number of bunches	5018 (2% abort gap)		
Bunch current	1.87	0.817	mA
Bunch spacing	0.6		m
Half crossing angle	15		mrad
Luminosity reduction R_L	0.748		
ξ_x reduction $R_{\xi x}$	0.691		
ξ_y reduction $R_{\xi y}$	0.916		
Bunch length	3	3	mm
Radiation loss U_0	1.23	3.48	MeV/turn
Betatron tune ν_x / ν_y	45.515/43.57 ?	44.515/41.57 ?	
beta's at IP β_x^* / β_y^*	15/0.3	15/0.3	cm
beam-beam parameters ξ_x / ξ_y	0.068/0.05	0.068/0.05	
Beam lifetime	~150	~150	min.
Luminosity	1.0		$10^{35}/cm^2/sec$

To accelerate these beams, the RF system of LER needs to increase the number of NC cavities from 20 to 28, where each cavity delivers 650 kW to the beam. In HER, the RF system will be a combination of 12 SC cavities and 16 NC cavities delivering the power of 460 kW and 650 kW.

The most serious problem of the SC cavity is a HOM power induced by the 4.1 A beam with a bunch length of 3 mm that increases the loss factor of the existing SC module to 2.46 V/pC. The induced HOM of 83 kW will cause a considerable temperature rise of the ferrite dampers and out gassing. Power absorbing test at a test stand is to be carried out on test ferrite dampers.

SUMMARY

Since the commissioning of 1998, KEKB has continuously grown up both on hardware and on operation software, and achieved the design luminosity of 10^{34} $cm^{-2}s^{-1}$. The beam intensity of HER reached the order of ampere in 2002, and achieved the design value of 1.1 A in 2003. The KEKB-SC cavities opened the real application in the ampere class beam showing the superior performance of the accelerating voltage of 10 MV and the delivered power of >2 MW. Stable operation of D11B at 2MV (10 MV/m) showed no influence on the SC-trip rate under the beam of 1 A.

Now the SC-RF of KEKB shows a voltage capacity of 16MV, the maximum beam power of 2.2 MW and HOM of 10 kW/module. All of these performances have already overcome the predicted values.

The peak luminosity of KEKB is still growing up mainly by increasing the HER current. Therefore, power tests of both input couplers and HOM dampers are to be carried out again at a test stand to know the power limitation.

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