BEAM TEST OF A SUPERCONDUCTING DAMPED CAVITY FOR KEKB

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Abstract

For the feasibility study of a superconducting damped cavity for KEK B-factory, a prototype module was constructed and tested in TRISTAN Accumulation Ring. This module accelerated the beam current of 500mA with the cavity voltage of 1 - 2MV, and 350mA with 2.5MV (10.3MV/m). These currents were limited by heating up of other ring components. The peak current of 573mA was achieved in 16 bunches with 1.2MV.

1 INTRODUCTION

Because of a heavy beam loading of KEKB, a new RF system which has sufficiently damped higher order modes(HOMs) is required to avoid beam instabilities. The desired RF voltages in a high luminosity operation are 5-10MV for the positron ring (LER) and 8-16MV for the electron ring(HER) under the beam currents of 2.6A and 1.1A, respectively. The maximum RF power transferred to the beam is estimated as 4MW in both rings[1]. For these requirements, the development on both superconducting (SC) and normal conducting damped cavities is in progress.

The SC damped cavity has a single cell structure with large-aperture beam pipes on both ends so that the HOMs can propagate out of the cavity and be damped by ferrite absorbers bonded on the inner surface of beam pipes[2]. Therefore, damping characteristics of the HOM dampers under high beam currents are the important factor as well as the cavity voltage and the input coupler power. A prototype cryomodule of the SC cavity was completed and cooled at a test stand in 1995. The field gradient of 11.4MV/m was obtained after several hours processing[3].

In 1996 the cavity was installed in the east RF section of TRISTAN Accumulation Ring(AR). The total beam injection extended for more than 1000hours and the SC cavity accelerated the beam for the half of the period. In this paper the summary of the test will be described.

2 CRYOMODULE

Before assembling the cavity was tested to 3.2MV (13MV/m) in a vertical cryostat. The gradient of 12MV/m in AR test is comparable but not continuously, because of a large amount of LHe consumption due to the cavity loss of more than 250W.

A coaxial antenna coupler was used as the input coupler. The length of the inner conductor was designed to obtain the coupling Q of 1 x 10^5. The aging to 430kW had been given at a test stand.

Table: 1 Parameters of the module.

R/Q of acc. mode	93 ohm/cavity
module total length gap length	3158 mm 243 mm
loaded Q	8.9 x 10^4
tuner stroke (motor tuner) (piezo tuner)	508.48 - 508.88 MHz 6.7 kHz
cryostat LHe volume static loss	290 liter 30 Watts
HOM damper for LBP for SBP	ferrite(IB-004) size 4t x 300ϕ x 150mm 4t x 220ϕ x 120mm
max. acc. voltage	2.9MV (12MV/m)

A pair of ferrite dampers was fabricated by the HIPping method. The RF power tests of 12kW and 15kW were made to the 220ϕ damper(SBP) and the 300ϕ damper(LBP), respectively. Further, the 300ϕ damper was

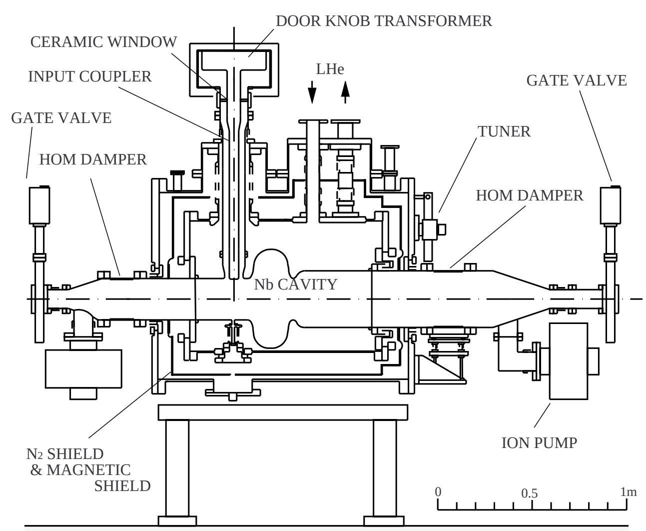

Figure 1: A sketch of the SC cavity module.

Table 2. The outline of the AR Beam Test.

	period	beam total	beam by SC	remarks
1st stage	Mar.28 - Apr.2	80 hours	30 hours	system tuning
				single bunch study up to 110mA(σ=8-9cm)
2nd stage	Jul.1 - Jul.22	340 hours	200 hours	multi bunch study to 500mA in 16 bunches
				acceleration to 3.5GeV
				frequent RF trips due to coupler arc
3rd stage	Oct.17 - Dec.2	600 hours	290 hours	improvement of dust vacuum on both side
				changing a door-knob transformer to a biased-type
				Max. current of 573mA with Vc=1.2MV
				500mA with 1- 2MV (4.1 - 8.2MV/m)
				350mA with 2.5MV (10.3MV/m)
				Max. HOM power absorbed by dampers was 4.2kW.

exposed to the beam of TRISTAN Main Ring before assembling[4]. During the beam test in AR, absorbed HOM power was monitored by the temperature rise and the flow rate of cooling water for each damper. The cavity was equipped with an ion pump of 300 l/sec on each side and evacuated to 2 x 10^{-9}Torr before cooling. Figure 1 is a sketch of the cryomodule and the parameters of the module are listed in Table 1.

3 RESULTS OF BEAM TEST

3.1 Summary of the Figures

The outline of the beam test is in Table 2. The 1st stage was spent mainly for the system tuning and the HOM study using a single bunch beam. The maximum current of 110mA was limited not by the cavity performance but by heating of HOM dampers of the normal conducting APS cavities in the west RF section. These APS cavities were removed before the 2nd stage.

In the 2nd stage, a beam of 500mA in 16 bunches was stored. The beam intensity was determined by the rate of injection and the loss due to the residual gas in the ring. As the vacuum pressure improved, the beam current increased and reached to the limitation set by heating up of the ring components. The maximum RF power transferred to the beam was 160kW which was obtained by accelerating the beam of 280mA to 3.5GeV. In the 1st and 2nd stage, the cavity was suffered from frequent RF trips due to vacuum bursts and arcs near the RF window. To continue the test, warming up to 85K or frequent aging processes had to be given to the cavity and coupler. A large quantity of gas came out from the cavity by the warming up. This suggested that the coupler arc was caused by the condensed gas around the coupler.

Before the 3rd stage, the improvement of vacuum circumstances was made on both neighboring beam ducts by increasing the number of pumping units and replacing the ducts to new ones which were chemically polished and rinsed with ozonized ultra-pure water[5]. These efforts improved the vacuum pressure near the cavity by a factor of ten and eliminated the arc trips except for a few trips at the beginning of the 3rd stage. The door-knob transformer of the coupler was replaced to a new bias-type which could supply a DC voltage to the inner conductor, however, the effect of the bias voltage was not verified because of few arc trips. The figures obtained at the beam test are as follows;

- the maximum of 110mA in single bunch(1.4 x 10^{-7} C/bunch) and 573 mA in 16 bunches;
- accelerating voltage of 2.5MV for 350mA and 1- 2MV for 500mA;
- current limitation was set by other ring components;
- RF power transferred to the beam was 160kW;
- absorbed HOM power of 4.2kW.

3.2 Cavity Loss

Cavity loss was estimated from a LHe consumption rate. The loss related to a beam intensity was observed as shown in Figure 2. Therefore, the cavity loss under various conditions were compared.

- beam acceleration (from 2.5GeV to 3.5GeV).
- change the bunch configuration (8,16,24 bunches).

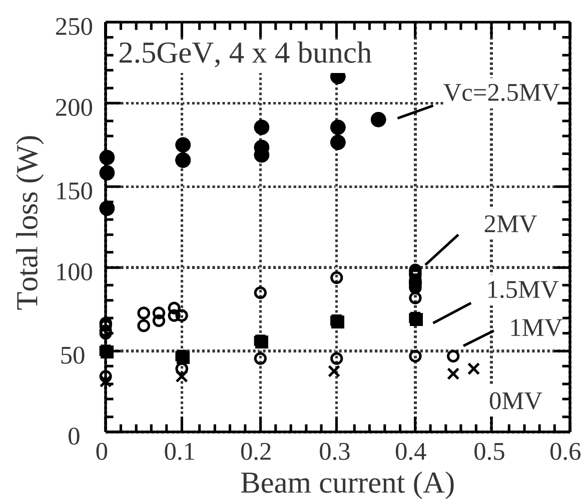

Figure 2: Additional loss related to beam currents.

- deflection of photo electrons by using small coils located on the beam ducts.
- supply a DC bias voltage to the input coupler.
- cavity detuning to change the input RF power.

These studies showed no difference of the additional loss. Though the mechanism of this loss is still not clear, it seems not to be a serious problem for 1.1A of HER. The Q-values in every steps are compared in Figure 3.

Loss factors measured in various bunch configurations are summarized in Figure 4. The results are agree with the calculated ones which contains the loss of ferrites as well as that of the cavity shape. The bunch length was obtained from the beam profiles measured by a streak camera.

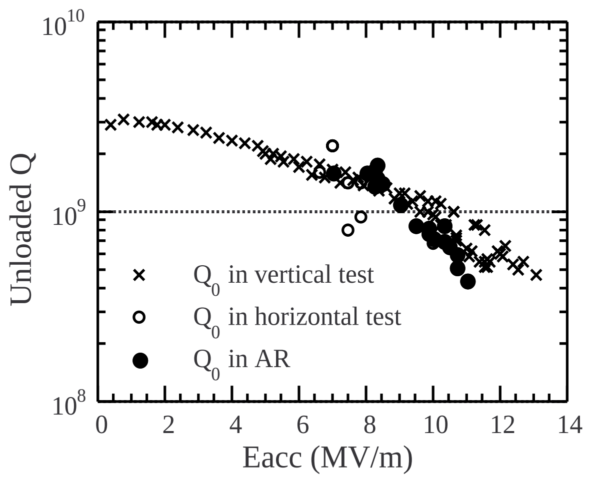

Figure 3: Summary of the Q_0 vs. Eacc.

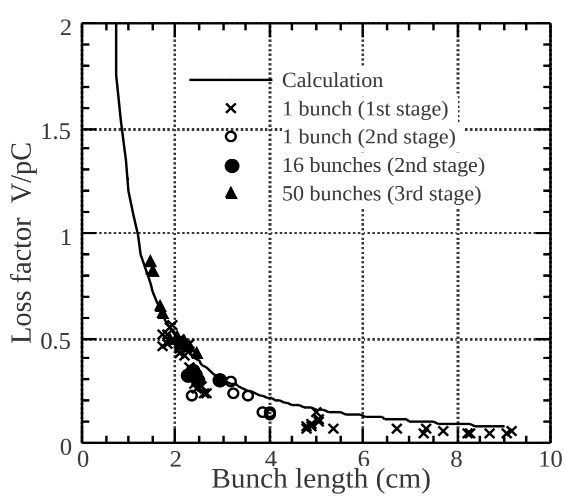

Figure 4: Loss factor vs. bunch length.

4 CONCLUSION

Stable operation of the cavity voltage up to 2MV with a 500mA beam and at 2.5MV with 350mA was obtained. The current limitation was not set by the SC cavity.

The HOM modes were damped sufficiently. No beam instability was induced by scanning the cavity frequency by 400kHz or deflecting the beam position by ±10mm in horizontal and ±4mm in vertical. The HOM power absorbed by a pair of dampers reached to 4.2kW. The surface temperature of the ferrite was estimated as 50˚C for the tested water flow rate of 2 l/min. In the designed flow rate of 5 l/min, this temperature rise corresponds to that for the total absorbed power of 8kW. Because of a large aperture of vacuum ducts in KEKB, a loss factor of the HER cavity is smaller than that of this test module. The beam of 1.1A with the bunch length of 4mm will induce the HOMs of 5-6kW for each cryomodule in HER, which is within reach of the dampers . The details of the damper tests will be described in Reference[6].

The coupler power of 280kW and the beam transferred power of 160kW are almost half the powers required in HER. The most serious problem is the RF trip due to coupler arcing. The trip was suppressed drastically by the improvement of vacuum pressure around the SC cavity(1 x 10^{-9} Torr). The bias-voltage of the coupler was tested with and without beams. The vacuum pressure at the ceramic window was measured as the cavity voltage, cavity tuning angle and the bias voltage. The best bias voltage of -500V was found, where the pressure was not influenced by other parameters. However, the effect did not confirmed because the trips have already been suppressed by the vacuum improvement. The tests on the coupler will be reported in Reference[7]

The results of the AR beam test verify the application of the SC cavities to high current accelerators. The Machine Advisory Committee of KEKB has recommended the use of SC cavities in HER. Four modules will be installed together with the normal conducting ARES cavities for the commissioning of 1998. The HER module has the same cavity shape except for the longer taper connections to the beam ducts for the reduction of the loss factor. The construction of the cavities is in progress.

5 ACKNOWLEDGMENTS

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