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T. TAJIMA, K. ASANO, T. FURUYA, Y. ISHI, Y. KIJIMA,
S. MITSUNOBU, K. SENNYU and T. TAKAHASHI

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Beam Test of Ferrite Absorber in TRISTAN MR

T.Tajima, K.Asano, T.Furuya, Y.Ishi*, Y.Kijima*
S.Mitsunobu, K.Sennyu** and T.Takahashi

National Laboratory for High Energy Physics (KEK)
Oho 1-1, Tsukuba, Ibaraki, 305 Japan

*Mitsubishi Electric, Co., Ltd. and **Mitsubishi Heavy Industries, Co., Ltd.

Abstract
A study on the effect of beams on the ferrite absorber was performed using TRISTAN MR. The tested absorber consists of a 300 mm-diam. copper pipe with 4 mm-thick ferrite inner layer, which was fabricated with Hot Isostatic Press (HIP) technique. No spark, damage, or degradation were observed up to the highest available single bunch current of 4.4 mA, i.e. 2.8 x 10^{11} electrons per bunch, which is 8.5 times higher than that of KEKB low energy ring. The loss factor showed significant increase with bunch shortening, e.g. 2.6 V/pC at 4 mm was about 40 % higher than the value predicted by the calculation assuming Gaussian bunch and no incoming power from outside of the chamber.

Introduction

For future high current accelerators such as KEKB, the superconducting cavity is considered to be a reasonable choice due to a reduction of the number of cavities, i.e. lower cavity impedance and cost, and ease against the multi-bunch instability that arise from fundamental mode [1].

The associated HOM power increases with the square of beam current, thereby asking for some way to extract a power of a few kW for the beams of a few A. Following the concept similar to the one developed at Cornell [2], we designed a cavity that allows most HOM power to travel out from the cavity to the adjacent large beam pipes, then damped in lossy materials such as ferrite [3]. Calculation with a computer code SEAFISH and experiments using aluminum model showed that 4 mm-thick and 12-15 cm-long ferrite layer on the copper pipe, located at certain distances from the cavity, is enough to get sufficient damping characteristics [4].

Since there was no absorbing ferrite that could be made into a large diameter (~300 mm) and thin cylinder, and it was difficult to solder or weld flat pieces uniformly without cracking, we started developing a technique to make a full size absorber using Hot Isostatic Press (HIP) technique [5, 6]. Relatively low sintering temperature, 900 °C, made it possible to sinter and bond pre-sintered ferrite powder simultaneously on the inner surface of a copper pipe. To our knowledge, this is the first application of HIP to make a ferrite absorber in this way. We have been testing its power handling capability with 508 MHz coaxial line in air, and outgas property with a separate apparatus [6].

Since there had been no experience with this type of absorber in accelerators, we installed the full-size absorber in TRISTAN Main Ring (MR) and checked its feasibility. In addition, we measured the loss factor calorimetrically and compared it with the predicted value. In this report, those tests and results are described together with some bench tests done before it.

Bench tests before installation

Figure 1 shows detailed dimension of the ferrite absorber, which is the same size of larger one of the two absorbers to be used with the superconducting cavities for KEKB.

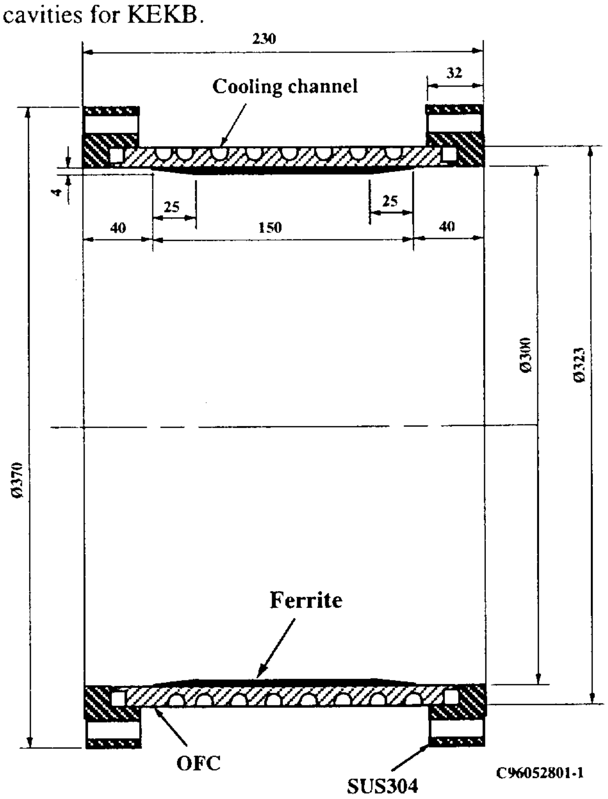

Fig. 1. Dimension of ferrite absorber. Unit : mm

Before installed in the beam line, this absorber underwent high power test with 508 MHz coaxial line in air and outgas rate measurement. In the high power test, it was tested up to 14.8 kW and no damage was observed [6]. Figure 2 shows the outgas rate per unit area of the absorber at several temperatures. It indicates that longer baking at 120°C can reduce the outgas rate further, e.g. 1 month of baking can reduce the outgas by an order of magnitude.

This absorber was connected with an extension pipe made of stainless steel on one end and tapers on both sides as shown in Fig. 3. Then, it was evacuated with a turbo molecular pump followed by a 100 l/s ion pump and baked at 120-130 °C for a week. The ultimate pressure after baking was 1.9 x 10^{-9} Torr at 23°C. However, with residual gas analyzer, it was 3 x 10^{-9} Torr due to the gas from analyzer.

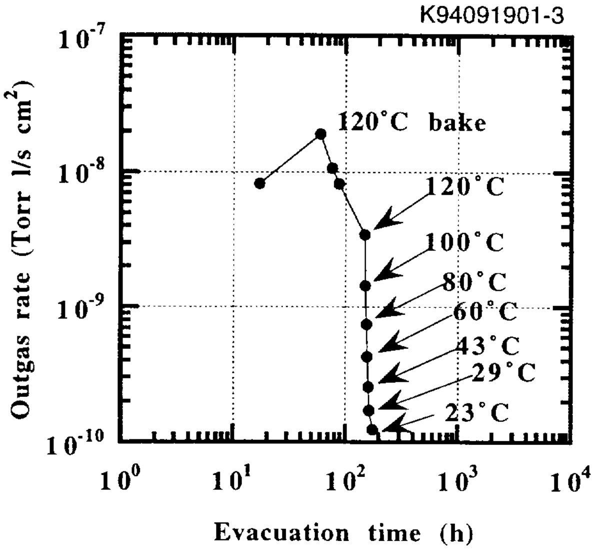

Fig. 2. Outgassing rate of the ferrite absorber. Total baking time was 5 days at 120°C. Ferrite powder was degassed at 400°C for 8 h in nitrogen gas before HIP process.

Installation in TRISTAN MR

The chamber with ferrite damper was installed at one of the colliding points in TRISTAN MR named Nikko. The chamber was vented with filtered N_2 and moved to the tunnel. Previous tests showed that it takes much less time to reach high vacuum in re-evacuation once it has been baked. In this test, it took about 11 hours to reach 3 x 10^{-8} Torr after turning off the 100°C x 6h baking with Residual Gas Analyzer (RGA) off. Then, after opening the end gate valves, vacuum reached 5.7 x 10^{-9} Torr right before beam tests. We did not try hard to lower the pressure since the gas produced by RGA alone exceeds the amount of gas produced by the chamber in very good vacuum.

Beam test

Along with vacuum level, gas species were measured with an RGA. Also, temperature distribution around the outer surface was measured with 30 copper-constantan thermo-couples. To calculate the loss in the ferrite, the inlet and outlet water temperatures were measured with Pt 100Ω resistors whose resolution is 0.1 °C. The loss was calculated by the following formula.

$$P_{loss}[W] = \Delta T[°C] \times F[L/\min] \times 69.93 \quad (1)$$

where ΔT is the increase of the water temperature and F the water flow rate.

Loss factor was calculated as follows using this loss.

$$k[V/pC] = \frac{P_{loss}[W] \cdot N_b \cdot f_r[kHz]}{\{I_b[mA]\}^2} \times 10^{-3} = \frac{P_{loss}[W] \cdot N_b}{\{I_b[mA]\}^2} \times 9.933 \times 10^{-2} \quad (2)$$

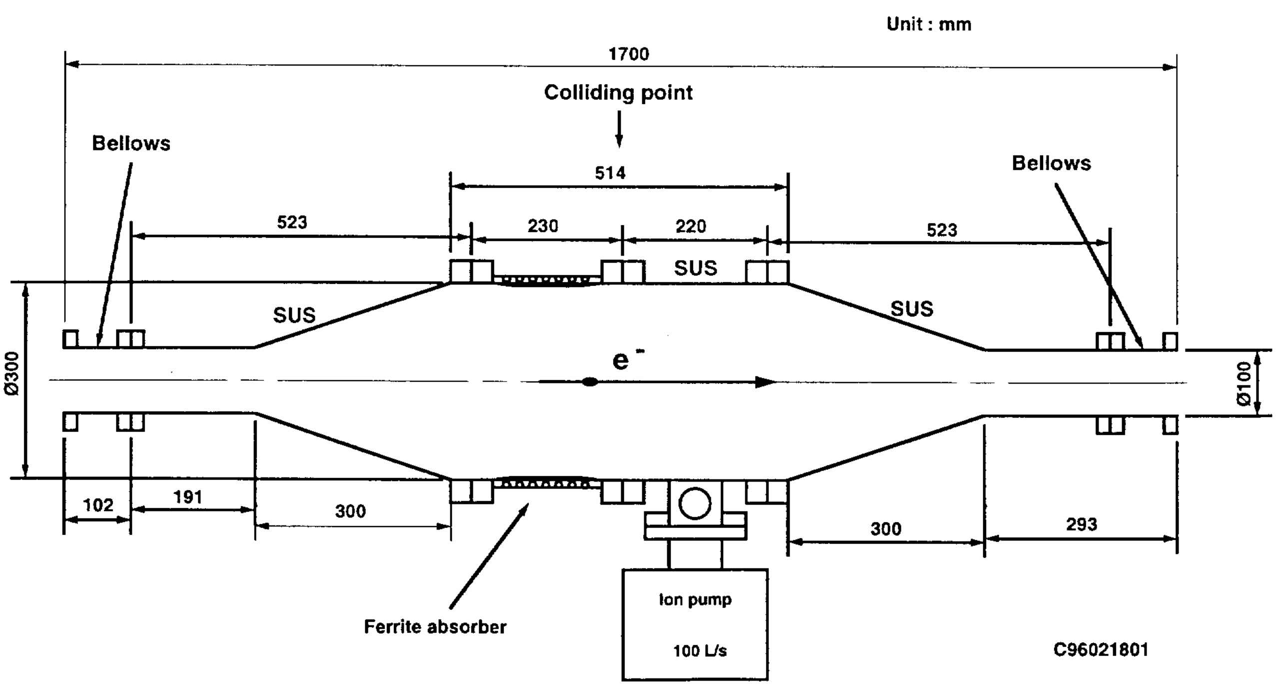

Fig. 3. Schematic of the chamber installed in TRISTAN MR.

where,
k : Loss factor
I_b : Beam current
N_b : Number of bunches
f_r : Revolution frequency (99.33 kHz)

In addition, RF signals were monitored at 12 locations, 4 each on tapers and 4 on the adjacent straight section with antenna type pick-ups.

The beam test was performed from May 29 through June 1st in 1995, consisting of five 8-hour shifts. At first, the temperatures and RF signals as well as outgas were monitored while increasing the current with single bunch of electrons. Then, the number of bunches was increased to produce more loss in ferrite. However, this could not increase current much because the max single bunch current became lower at multi-bunch operation than that at single bunch operation.

Finally, we studied the change of loss factor with shortening the bunch length by increasing the RF voltage. Moreover, we checked the effect of dipole mode loss by shifting the orbit horizontally by max 10 mm.

Results

Vacuum

Before first beam test, the pressure was 5.7 x 10^{-9} Torr at ~28°C after a 100°C x 6 h bake. Figure 4 shows the changes of pressure as a function of the absorbed power at the ferrite. The legend is written from up to down chronologically. There was one whole day (24 h) without beam between 1st and 2nd tests in the legend.

"off center" means horizontal shift of the beam orbit in the absorber. Positive sign is the outward shift and negative inward .

As shown in the figure, at the 2nd test, the pressure was lower at the same power, which indicates the beam aging effect.

As one can see, when the beam was shifted to +/- 10 mm off center, the pressure increased significantly, comparing to the centered beam. Analysis on the data on the temperature distribution showed that this pressure increase was probably due to the photo desorption and associated temperature rise at the tapers with the x-ray. Moreover, it was observed that the temperature at the tapers increased with current and became higher than that of the absorber, which must have contributed to the pressure rise. Though there was no cooling in this test, it should be important to consider cooling of tapers in the future tests and operations.

Components of outgas

The major gas components before running the beam was H_2O (28%), H_2 (27%) and CO (23%). With first beam running, when pressure increased, the increased gases were H_2 and CO. For example, When the pressure increased to 3.2 x 10^{-8} Torr at 3.8 mA, the gas consisted of H_2 (40%), H_2O (17%) and CO (17%).

When the orbit was shifted horizontally outward by 10 mm, the desorption of H_2 and CO_2 were enhanced, i.e. H_2 (51%), CO (27%) and H_2O (6%). As discussed above, this seems to be the gas components when the taper, made of stainless steel (SUS304), was irradiated by X-ray.

Since the maximum absorbed power in the ferrite was only 273 W, the average ferrite surface temperature was predicted to be lower than 35 °C. Therefore the outgas from the absorber did not seem to have contributed to the pressure rise much.

By the way, the major gases during baking at 120 °C in the previous bench test were H_2, H_2O, CO and CO_2.

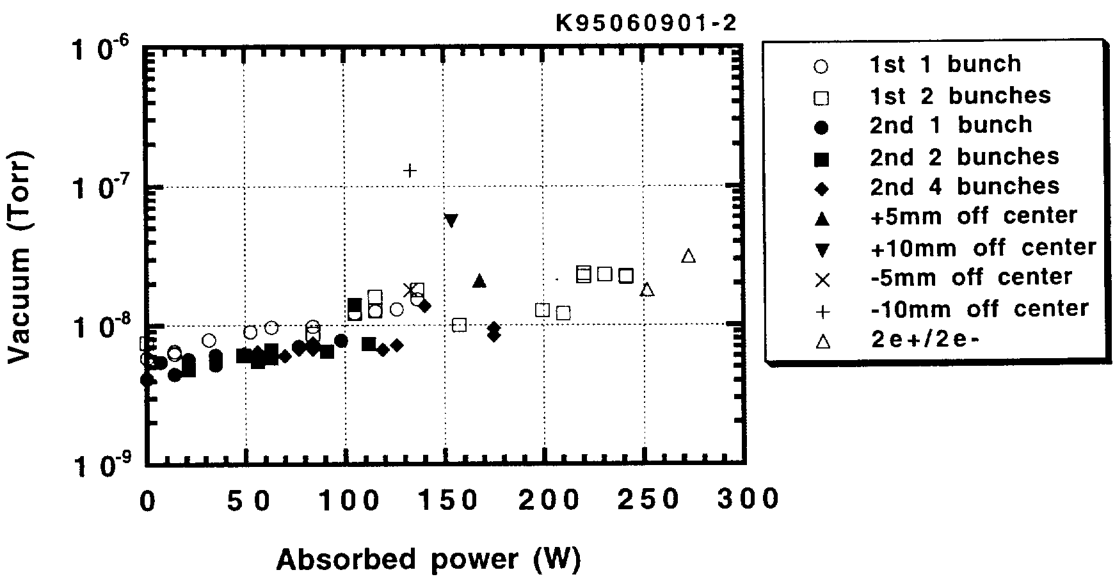

Fig. 4. Vacuum as a function of the absorbed power in the ferrite in different conditions.

Inspection of the ferrite after the test

The ferrite surface was inspected with eyes after the test. No change or damage was observed.

Loss factor

Figure 5 shows the loss factor as a function of bunch length. Here, bunch length was measured with a streak camera for the reason to be discussed below. In Fig. 5, the solid lines are the predictions. The lines designated as "structure" are the results from the calculation with ABCI, and "ferrite" calculated analytically.

As one can see, the measured loss factor increased with shorter bunches and it was about 40 % higher than the predicted value. On the other hand, it was lower for longer bunch length.

To check the accuracy of the bunch length measurement, the longitudinal profiles of the bunches were examined since the bunch length was calculated from full-width at half maximum (FWHM), i.e. bunch length = FWHM/2.35, whereas the ABCI calculation assumed a gaussian shape.

Figure 6 shows the longitudinal bunch profiles together with the gaussian profiles that have the same bunch lengths. As one can see, there is a tendency that as a bunch gets shorter the tail gets shorter, and sometimes the width of the bunch can be smaller than the gaussian profile near the top. This suggests that there are higher frequency components for shorter bunches and lower frequency components for the longer bunches compared to the Gaussian bunches, which might have caused the difference between the measurements and predictions. To know the shape effect on loss factor, calculations using the real shape with ABCI is being planned.

The unknown factor on the loss factor is how much of the power generated in the chamber went out of the chamber and how much of the power generated at other parts entered the chamber. The cut-off frequency of the end pipes is 2.3 GHz for TM01 mode, and theoretically the microwave that has higher frequency than this can pass through the end beam pipes. Taking this into account, it can be said that shorter bunch beam generates the microwave power having higher frequency components at the ring components such as bellows, as a result, there are more chances to get more entering power from other parts of the ring.

RF signals

The signals picked up through the antenna at tapers and extension beam pipe were analyzed with a spectrum analyzer. We searched excited modes up to 6.5 GHz. The maximum signal was obtained at 2.405 GHz and it was identified as a monopole mode using URMEL code, but there was a discrepancy on the Q value between the calculation with SEAFISH (87 at 2.412 GHz) and measurement (~1000 at 2.405 GHz).

Horizontal change of the beam orbit up to 10 mm did not show visible change of the RF signals.

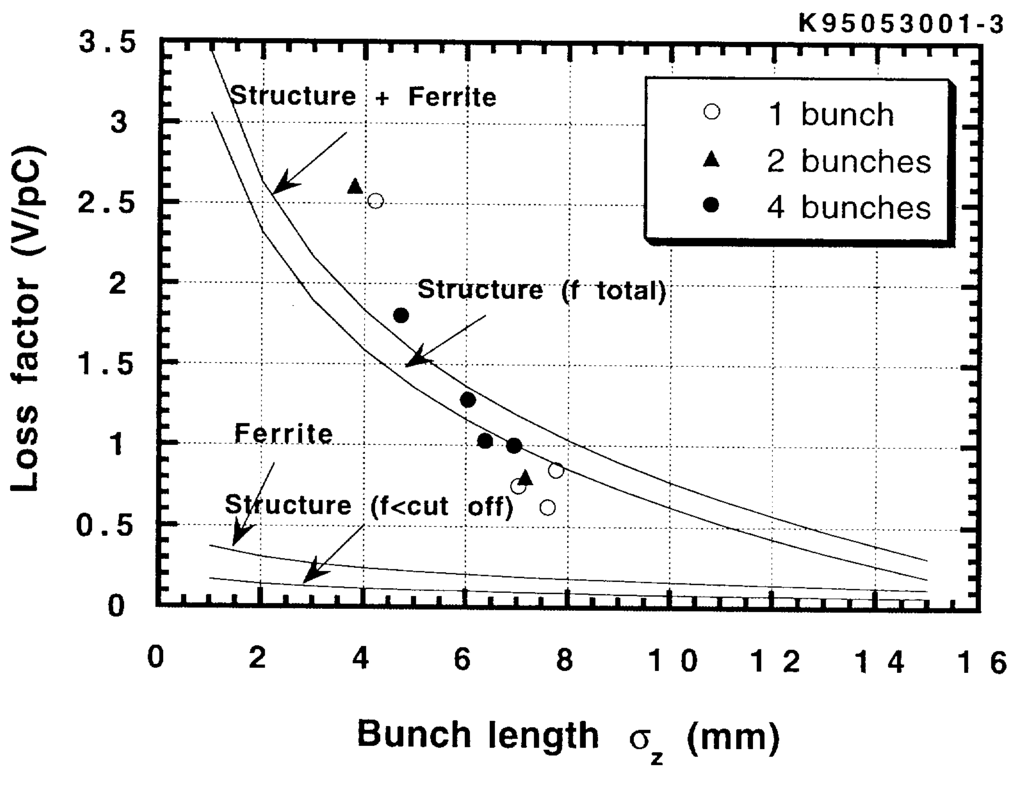

Fig. 5. Loss factor measured and predicted as a function of bunch length. The line named "Ferrite" is from an analytical calculation, "Structure (f<cut off)" and "Structure (f total)" from ABCI calculation at frequencies lower than the cut-off frequency of 100 mm-diam. beam pipe and for all the frequencies, respectively. "Structure + Ferrite" is the sum of the "Structure (f total)" and "Ferrite".

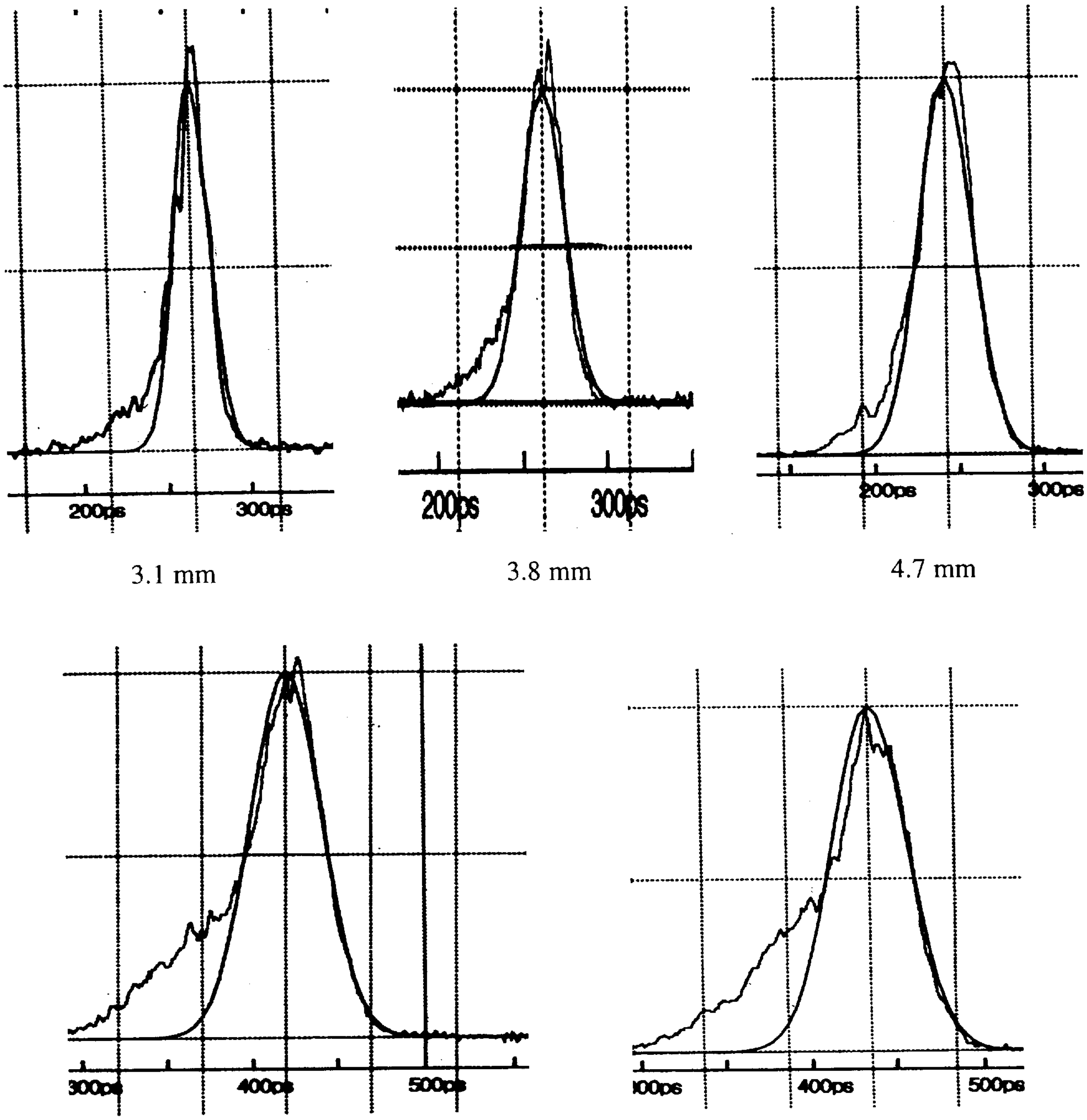

Fig. 6. Longitudinal bunch profiles measured by streak camera at various bunch length. The number under each profile is the bunch length calculated from the measured FWHM with a streak camera. In addition to the real profile, corresponding gaussian shape was drawn for comparison.

Bunch length measurements

Though we used the bunch lengths measured with a streak camera in analyzing the dependence of loss factor, we also measured bunch lengths with a bunch length monitor (BLM) which uses a ratio of the amplitude of frequency spectrum at 0.25 GHz to that at 1.75 GHz [7]. This method assumes Gaussian bunches and therefore, if the bunch is deformed, the obtained value can be different from the bunch length observed by streak camera. Figure 7 shows the bunch lengths measured with two methods. As one can see in Fig. 7, the values obtained with BLM are much higher than those with streak camera at higher bunch currents, which confirms the observation in a different measurement by Ieiri et al. [7], although the difference was bigger in our case. These results suggest that there are more lower frequency components at higher currents. It seems to be true because, as one can see in Fig. 6, there appear to have more low frequency components at longer bunches, which means higher currents in most cases, due to larger tails.

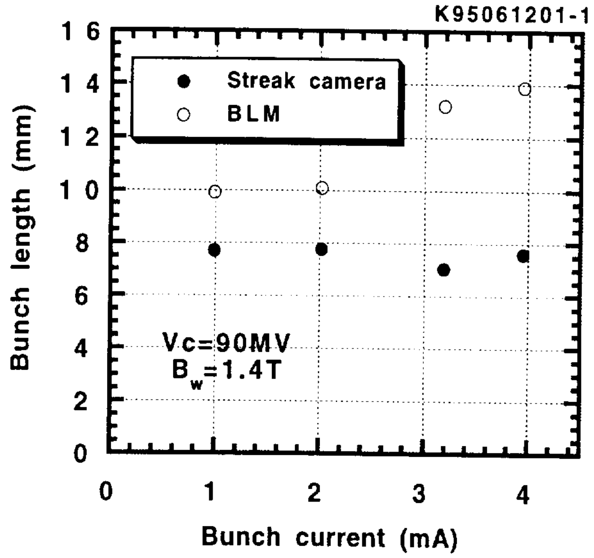

Fig. 7. Bunch length measured with Bunch Length Monitor (BLM) and with streak camera as a function of single bunch current. The circumference of TRISTAN MR is 3018 m.

Conclusions

The higher-order-mode (HOM) absorber for the superconducting cavities being studied for KEKB was installed and beam tested in the TRISTAN main ring (MR). It was the first test of the ferrite absorber that was made with Hot Isostatic Press (HIP) technique.

No spark, damage or degradation was observed during the 40-hour beam test. The only thing that should be noted was the necessity of cooling the tapers to reduce the outgas.

Loss factor increased very rapidly as bunch length became shorter. At 4 mm, which is planned for KEKB, it was 40 % higher than the value predicted assuming a Gaussian bunch and no incoming or outgoing power from the chamber.

For short bunches such as 4 mm at KEKB, it should be important to estimate the incoming power from the other parts of the ring as well as the effect of the bunch shape.

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References

[1] KEKB B-Factory Design Report; KEK Report 95-7 (1995).
[2] H.Padamsee et at ; Particle Accelerators 40, 17 (1992).
[3] S.Mitsunobu et al. ; Proc. 6th Workshop on RF Superconductivity 2 , pp. 1176-1183 (1993).
[4] T.Tajima et al. ; ibid. [3], pp. 962-980, KEK Preprint 93-153.
[5] T.Tajima et al. ; ibid. [3], pp. 1160-1175, KEK Preprint 93-152.
[6] T.Tajima et al. ; 1995 Particle Accelerator Conference, Dallas, U.S.A. (1995), KEK Preprint 95-77.
[7] T.Ieiri, et. al. ; International Workshop on Particle Dynamics in Accelerators, Emittance in Circular Accelerators, Tsukuba, Japan, Nov. 21-26, 1994.