BEAM LOADING EXPERIMENT WITH SHORT BUNCHED ELECTRON BEAMS FOR NEW TYPE OF ACCELERATING RF SYSTEM OF HIGH INTENSITY PROTON SYNCHROTRON

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Abstract

Beam loading effects on rf system is one of the most difficult parts of high intensity proton synchrotrons. To investigate the effects, beam loading test experiment using an intense electron beam has been carried out. The wake voltages induced by an actual electron beam have been measured at an accelerating gap of an rf cavity. The electron beam used in the experiments was modulated with the frequency of about 3 MHz and the pulse width can be variable in due consideration of the circulating beam of the JHF synchrotrons. The maximum beam current is about 9 A. The beam loading compensation also has been tried.

1 INTRODUCTION

In the JHF(Japan Hadron Facility) proton synchrotrons [1], the beam loading effects are severe problems for the rf acceleration because the circulating beam currents are high(Average: $\sim$ 7 A). An MA(Magnetic Alloy) loaded cavity is a candidate of the cavity for JHF because of many advantages.

Since MA has high stability at large rf amplitude [2], very high field gradient can be achieved and the total impedance becomes low, so it is suitable for high intensity machines. A High Gradient MA-loaded cavity [3, 4] has been developed and achieved high accelerating field gradient of 50 kV/m.

From the view point of longitudinal beam instabilities, this type of cavity is useful to suppress coupled bunch instability [5] and transient beam loading [9] because of low Q value(Q:1$\sim$5). On the other hand, wake voltage is composed of both fundamental component and higher harmonics, so the effects of higher ones are not well, especially in the case of short bunched beam.

In order to investigate the beam loading effects on the MA-loaded cavity, we have constructed the beam loading test system by using an intense electron beam. With the system, the wake field caused by actual passing beam has been measured, some beam loading compensation techniques was applied, and the efficient schemes for real machine has been studied. Up to now, the electron beam current has been achieved to about 9 A.

2 ELECTRON BEAM SYSTEM

The beam loading effects on the MA-loaded cavity were investigated with a thermionic type electron gun. The schematic view is shown in Fig. 1. For producing an intense electron beam, the EIMAC Y-796 grid-cathode assembly is installed on its cathode stem. The shape of its electrodes is basically the same as the electron gun for the positron source of KEK-B Factory [6]. The high tension gun pulse of about 5 μsec is fed to between a grid and an anode electrode of the gun with 180 kV maximum peak voltage. The repetition rate of the gun pulse is 1-5 Hz. Since the EIMAC's grid-cathode assembly has coaxial structure, the grid electrode is placed at the outer conductor and grounded. The grid pulse should be fed to the cathode electrode with negative voltages against the grid electrode.

Supposing JHF synchrotron beam, emitted electron beam should be modulated about 3 MHz. For such a reason, pre-grid pulser (HP214B) excited by gate-burst mode can generate a pulse train of about 15 μsec width. The width of micro pulse can be varied from several ten to 150 nsec and the pulse duration is variable from 150 nsec to 400 nsec. Then such pulses are amplified by double cascaded rf amps.(ENI240; 200 W + JRL2000F; 1 kW) and fed to the cathode as a grid pulse. Achieved voltage of the pulse was about $-$150 V.

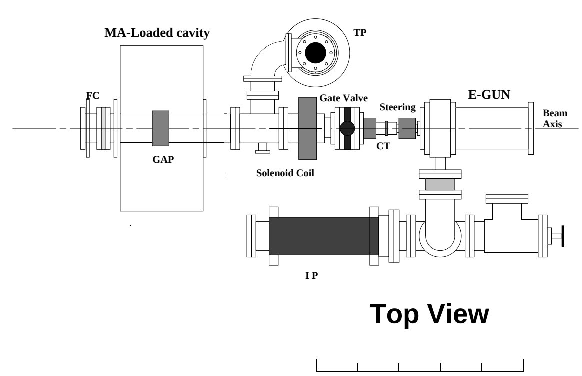

Figure 1: Schematic view of the electron beam system

A differential pumping system is employed for keeping high vacuum on the cathode surface. The anode hole of the gun also fulfills an orifice for vacuum isolation because of its 20 mm small aperture. In a gun chamber the degree of vacuum is kept from 4×10^{-9} torr(beam off) to 2×10^{-8} torr(beam on) with an ion pump of 500 ℓ/s pumping speed. On the rf cavity side, the pressure in the chamber is about 10^{-7} torr order kept by a turbo molecular pump of 500 ℓ/s pumping speed.

On the beam transport line there are steering magnet and solenoid magnet for beam focusing. They are placed at 110 mm and 600 mm downstream from the anode, respectively. The solenoid magnet can be excited up to 240 Gauss along the beam axis. By using such fields, the electron beam 160-180 keV has been transferred to about 1.8 m far from the solenoid magnet without any more focusing elements.

For the beam monitor, a fast current transformer(FCT) is set at 220 mm downstream from the anode and the faraday cup(FC) having 105 mm aperture is put at the end of the beam transport. The FCT has the role of picking up the beam current and the longitudinal beam shape in good accuracy, because of being used as the feed-forward signal in the case of the beam loading compensation test. The features of the FCT made by Bergoz are 1.25 V/A at 50 Ω output/input ratio, about 500 psec fast rising and the good widely signal band 100 kHz-1 GHz. The wake voltage at the acceleration gaps is measured with high voltage probes(1:1000).

The maximum energy of the electron beam was about 180 keV and the peak current has reached about 9 A in the case of multi-bunched beam lately, and beam transmission rate(FC/FCT) is almost 90 %.

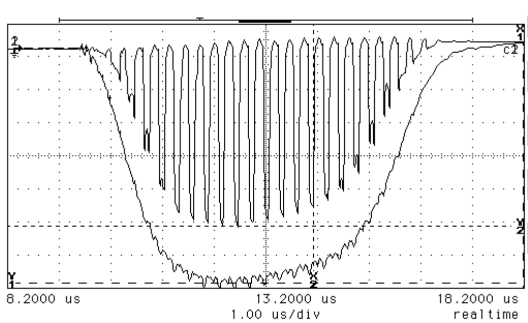

Figure 2: Typical bunch train measured by the FCT(upper) and the gun pulse shape of 180 kV(lower). Peak current of the beam pulse is about 8.6 A.

3 THE MEASUREMENT OF THE WAKE VOLTAGE

The beam signal measured by the FCT and its spectrum are shown in Fig. 3 (a) and (b), respectively. In this measurement, the peak intensity of the beam current was 4 A, the bunch width was 100 nsec, and the bunch interval was 300 nsec.

The measured wake voltage and reconstructed wake voltage are shown in Fig. 4(a) and (b), respectively. The reconstructed voltage was calculated by multiplying the beam spectrum by the cavity impedance in the frequency domain. The MA-loaded cavity in this measurement has the peak impedance of 440 Ω at 1.6 MHz and the Q value of about 0.5. The wake voltage of 800 V was measured, and its reconstructed wake voltage was almost consistent with the measured one.

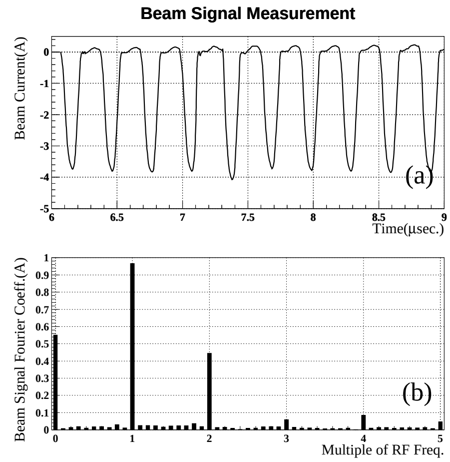

Figure 3: The beam signal measured by the FCT and its frequency spectrum.

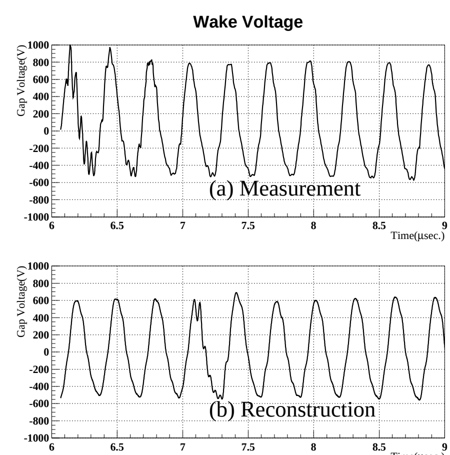

Figure 4: Measured wake voltage and reconstructed one.

4 BEAM LOADING COMPENSATION TEST

Since the beam signal has some higher harmonic components, the wake voltage also has higher harmonics considerably due to the broad-band impedance of the MA-loaded cavity. From analytical estimations [7] and simulations [8, 9], it was found that compensation of the beam loading was fairly effective for the stable acceleration in the very high intensity proton synchrotrons, especially in the case of short bunched beam.

Therefore, the compensation of the beam loading has been tested by the feed-forward method using the electron beam. A schematic setup of the compensation is shown in Fig. 5.

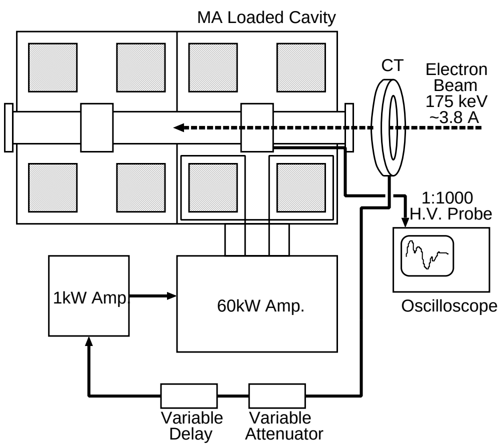

Figure 5: Setup of the compensation test.

The beam signal picked up by the FCT is attenuated and delayed by cable line arbitrary, then fed into the cavity through amplifiers. When the attenuation and delay can be optimized, the wake voltage is compensated clearly. In this compensation test, we adjusted the attenuation and delay to make the wake voltage minimize. The compensation was done in one bunch delay(300 nsec).

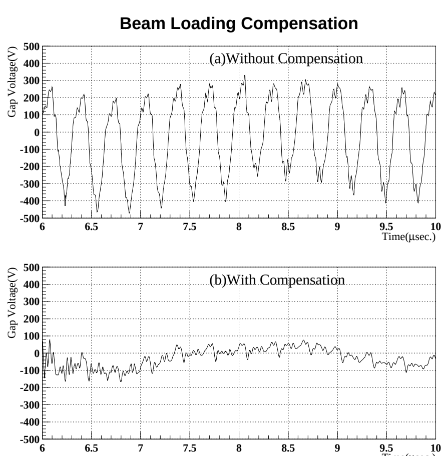

Figure 6: Measured gap voltage.

The measured voltage of the cavity gap without compensation and with compensation are shown in Fig. 6(a) and (b), respectively, and each spectrum is shown in Fig. 7. White bar is the spectrum without compensation, and black one is the spectrum with compensation. As clearly seen in Fig. 7, the fundamental component of the gap voltage is significantly decreased about one thirtieth, and higher harmonic components are also decreased about one half. Further study using a filtering method is planned to compensate the higher harmonics effectively.

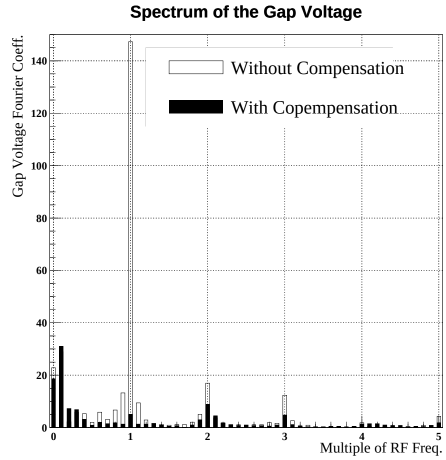

Figure 7: Spectrum of the gap voltage.

5 SUMMARY

The beam loading effects has been able to study using multi-bunched electron beam of 9 A. In the test of the beam loading compensation by the high intensity electron beam, the wake voltage could be compensated on the MA-loaded cavity with feed-forward method.

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