MA-LOADED CAVITY FOR BARRIER BUCKET EXPERIMENT

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Abstract

A barrier bucket scheme is a powerful technique to accumulate more particle in a synchrotron. An RF cavity loaded with Magnetic Alloy (MA) cores has been developed for this purpose. Because of the large inductance of the cores, the RF cavity can generate the required RF voltage of 40kV by an RF amplifier using two tetrodes, 4CW30,000A. The RF cavity and amplifier have been installed in the AGS for the barrier bucket experiment.

1 INTRODUCTION

A barrier bucket scheme is useful to accumulate more particle in the synchrotron[1,2]. In order to achieve the beam intensity of 10^{14} ppp at the AGS, the moving barrier technique has some benefits. In the case of the ordinary bucket-to-bucket transfer, the RF frequencies of the AGS and booster are same and the number of the bunches in the AGS is limited by the circumference ratio of both rings. However, the number of the injections can be increased by the barrier bucket scheme. Furthermore, it is possible to increase the bunching factor. The beam loss during the injection process is one of the main sources to reduce the beam intensity. It is expected that the beam loss will be reduced because the space charge tune shift is decreased.

For the barrier bucket experiment, one ferrite-loaded[2,3] and MA-loaded[4] cavities have been developed by BNL and by KEK, respectively. Both cavities have been installed in the AGS. Figure 1 shows a photograph of the MA-loaded cavity in the ring. Each cavity generates a single sine wave. One remains fixed in the phase space and the other is moved slowly to keep the adiabatic condition to avoid the emittance growth. The frequency of the sine wave is 2 MHz and the revolution one is 357 kHz. In this paper, the characteristics of the MA-loaded cavity are described.

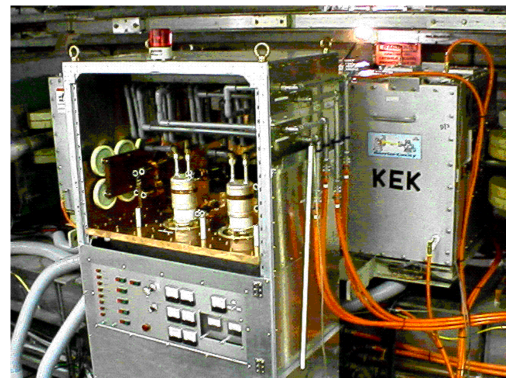

Figure 1: The MA-loaded cavity has been installed in the AGS for the barrier bucket experiment.

2 RF CAVITY

2.1 Magnetic Alloy Cores

MA-loaded cavities[5,6] have been developed for RF cavity of Japanese Hadron Facility[7,8]. The cavity has many advantages and is also suitable for the barrier bucket cavity because of the low Q-value and high stability for the RF voltage.

The required power to generate a single sinusoidal wave for the barrier bucket becomes much less than that for the ferrite-loaded cavity. The RF voltage and current are given by[2],

$$V(t) = \begin{cases} V_0 \sin \omega t, & if\ 0 < \omega t < 2\pi \\ 0, & otherwise \end{cases}$$

$$I(t) = \frac{V(t)}{R} + \frac{1}{L}\int_0^t V(t')dt' + C\frac{dV(t)}{dt}$$

$$= \begin{cases} \dfrac{V_0}{\omega L} + \dfrac{V_0}{R_P}\sin \omega t + V_0 \cos \omega t(\omega C - \dfrac{1}{\omega L}), & if\ 0 < \omega t < 2\pi \\ 0, & otherwise, \end{cases}$$

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[3] also Toshiba Co. Ltd.
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= \begin{cases} \dfrac{V_0}{R_P}(Q+\sin\omega t)+V_0\cos\omega t(\omega C-\dfrac{1}{\omega L}), & \mathit{if}\ 0<\omega t<2\pi \\ 0, & \mathit{otherwise}, \end{cases}
$$

where ω is the frequency of single sine wave. When the frequency of the sine wave is the resonant frequency of the cavity, the current is

$$
I(t) = \begin{cases} \dfrac{V_0}{\omega L}+\dfrac{V_0}{R_P}\sin\omega t, & \mathit{if}\ 0<\omega t<2\pi \\ 0, & \mathit{otherwise} \end{cases}
$$

$$
= \begin{cases} \dfrac{V_0}{R_P}(Q+\sin\omega t), & \mathit{if}\ 0<\omega t<2\pi \\ 0, & \mathit{otherwise} \end{cases}
$$

The currents required to generate 40kV for some cavities which have different Q-values are shown in Fig. 2. We assume that the number of gaps is 4 and the impedance of each cell is 1 kΩ. As shown in Fig. 2, the negative current is required for the case of the Q-value less than 1. Because of the Q-value of the MA-loaded cavity for the barrier bucket is about 0.6, the push-pull amplifier is required. As shown in Fig. 2, the required current to drive the MA-loaded cavity is much smaller than that for high Q cavity. This is an advantage of MA-loaded cavity which has low Q-value.

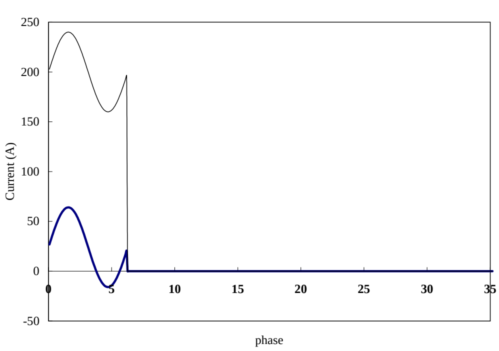

Figure 2: The required driving current for the barrier bucket. The thick and thin lines are for Q-values of 0.6 and 5, respectively. In the case of Q-value of 0.6, it is assumed that the resonant frequency is 1.5 MHz.

The characteristics of the MA core do not depend on the RF voltage. The preliminary test using a single gap cavity shows that the cavity could generate the barrier bucket voltage of 10kV by a 60kW push-pull amplifier although only 4 cores are loaded in the cavity. The result shows the possibility to develop a very compact barrier bucket cavity[9]. However, we adopt to use 48 cores because we need to generate 40kV by the 60 kW amplifier. The voltage is required for the beam experiment. Each core have been measured by a test cavity[10, 11]. The average shunt impedance and inductance are 89 Ω and 12 µH at 2 MHz.

2.2 Barrier Bucket Cavity

The schematic view of the cavity is shown in Fig.3. The cavity has 4 cells and each cell has 12 cores. Each cell is connected in parallel. The maximum RF voltage per gap is 10kV for the barrier bucket operation. The RF power is inductively fed on through a couple of the driving loops as shown in Fig. 3. The shunt impedance per gap is about 1 kΩ. The dissipation in the core is manageable with air cooling by a blower and the cavity shroud is cooled by the water. Because the duty factor is about 6% for 3 sec cycle operation, the power dissipation is about 0.6 W/cc at the peak and 0.04 W/cc in average, corresponding to 200 kW and 12 kW, respectively. The continuous 40 hours operation shows that the maximum temperature at the core surface is 60 degree C and it is much lower than Curie temperature (570 degree C).

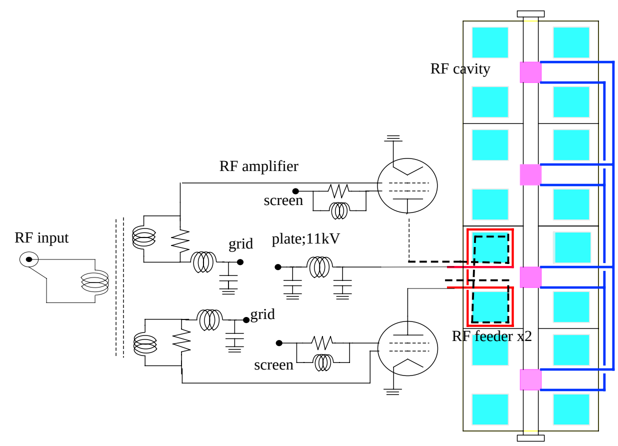

Figure 3: Schematic view of the cavity and amplifier.

2.2 Amplifier

In order to generate the barrier bucket voltage, the amplifier should have a wide bandwidth and 2 kW output power. Two sets of 1 kW solid state amplifiers (ENI-A1000 X 2) were combined and the bandwidth of this driving system is 10 MHz. It can be used under the condition of the large RF reflection from the load. Because the solid state amplifier can not amplify the DC, we used the half sine wave instead of a single sine wave to drive the solid state amplifiers to obtain the single sine voltage which is most suitable to drive the push-pull amplifier.

An 1:1.5:1.5 step-up transformer was used to drive two tetrodes of the push-pull amplifier[12]. The transformer has two output and each impedance is 200 Ω to match the output impedance of solid state amplifier (50 Ω). Because of the grid input capacitance of 180 pF, the bandwidth is limited to 4.4 MHz.

2.3 Parasitic Resonance

The barrier RF voltage includes many higher harmonics of the revolution frequency of 357 kHz. Therefore any parasitic resonance around the barrier frequency of 2 MHz should be damped. However, some resonances have been observed[4]. One has the frequency of about 12 MHz. It was found that the leakage inductance of the driving loops which coupled with the push-pull amplifier caused it. The leakage inductance could be reduced by replacing the driving loops of copper pipes by that of copper plate. Furthermore the dampers which consists of the inductance and resistance were put in series on the driving loops and the impedance of the resonance was reduced. Figure 4 shows the gap impedance after the damper was installed. The solid thick and dashed lines are real and imaginary parts of the impedance, respectively. The solid thin line is the phase of the impedance.

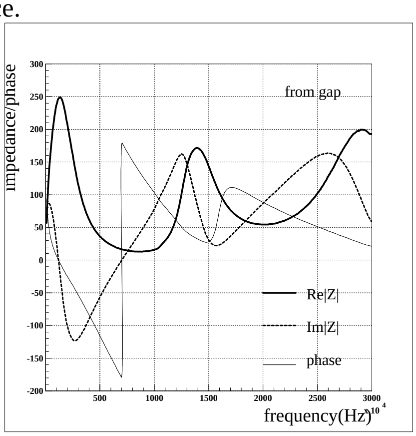

Figure 4: The gap impedance of the cavity.

3 BARRIER BUCKET OPERATION

3.1 RF Voltage

The barrier bucket voltage of 40 kV has been successfully obtained. Figure 5 shows the gap voltage of 10 kV. The voltage satisfies the required bucket height of 0.4 %.

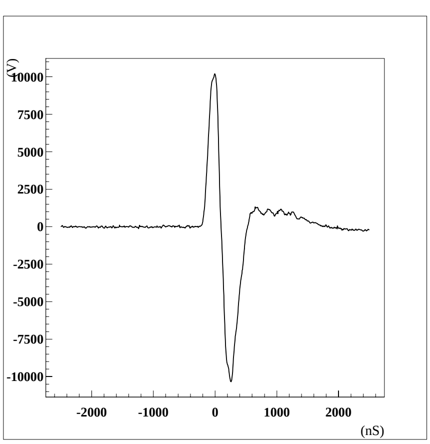

Figure 5: The gap voltage.

3.2 Driving Currents

The driving current has been measured by the current transformer in the push-pull amplifier. The peak current was 40 A for both tubes.

4 SUMMARY

An MA-loaded cavity has been developed and installed for the barrier bucket experiment in the AGS. The barrier bucket voltage of 40 kV has been achieved by a push-pull amplifier using two 30 kW class tetrodes.

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