AN RF CAVITY FOR BARRIER BUCKET EXPERIMENT IN THE AGS

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Abstract

A barrier bucket experiment in the AGS is planed in 1998. An accumulation of the beam, which intensity of 1.0×10^{14}ppp is, acceleration after the injection with a barrier bucket scheme and other RF gymnastics experiments will be studied. An isolated RF pulse of 40kV per cavity is necessary for the experiment. The RF frequency is 2MHz and the isolated pulse is generated at the repetition rate of the revolution frequency of 357kHz. We have developed the barrier cavity for this experiment. The cavity is loaded with FINEMET core. It has low Q value but high shunt impedance. It makes the necessary power less than that of ferrite-loaded cavity for an isolated RF pulse.

1 BARRIER BUCKET EXPERIMENT

A barrier bucket scheme is considered to accumulate more particles in the Ring[1][2]. In the case of the ordinary injection(bucket-to-bucket transfer), the number of the bunches in the main ring is limited by the circumference ratio between the main ring and the booster. However the number of the injection is independent of the ratio in the case of the barrier bucket. The bunching factor can be increased with this scheme. The beam loss during injection is decreased because the tune shift by space charge is reduced.

Figure 1 shows the longitudinal phase space during the injection with this scheme. A couple of isolated RF pulses is provided at the revolution frequency(a). A bunch is injected between them and spread longitudinally(b). One of the RF pulses remains fixed in the phase space, the other is moved adiabatically to conserve the emittance. After debunching except the gap(c), one of the RF pulses moves again from the fixed phase as repelling the bunch to make an empty bucket. The next bunch is injected into the empty bucket(d) and merged in the circulating beam. The above procedure is repeated. It is important to accumulate the beam without the emittance blow-up. If the emittance is grown, the rest of the longitudinal phase space for next bunch decrease.

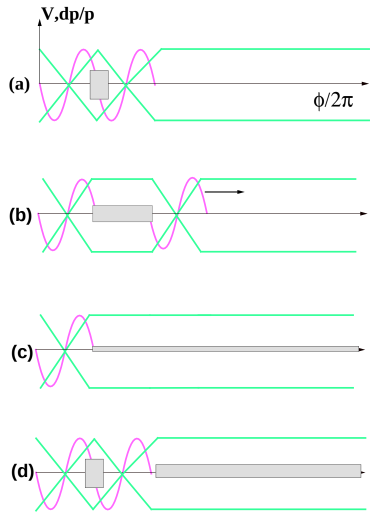

Figure 1: A barrier bucket scheme.

A barrier bucket experiment is planned in the AGS. The goal is to increase the beam intensity from 6.0×10^{13}ppp to 1.0×10^{14}ppp . As an isolated RF pulse, a single sine wave is used. It is necessary for the experiment to prepare two cavity which provide a single sine wave of 2MHz at the repetition rate of 357kHz. The peak voltage of 40kV is required per cavity. The cavities have been developed in KEK and BNL. In this paper, the characteristics of the KEK barrier cavity are reported.

2 BARRIER CAVITY

2.1 Magnetic cores

The barrier cavity is loaded with FINEMET cores. The FINEMET core is one of the Magnetic Alloy(MA) cores. The MA core has some advantages, which enables to make the structure of the cavity simple[3]. The required power to generate a single sine wave becomes less because of the low Q value and high impedance. The necessary voltage and current are given by,

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* also : HITACHI Co. Ltd.
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‡ also : TOSHIBA Co. Ltd.
§ also : CNS, University of Tokyo.
¶ also : RCNP, Osaka University.

$$
\begin{aligned}
V(t) &= V_0 sin\omega t, \quad 0 < \omega t < 2\pi \\
&\quad 0, \qquad otherwise \\
I(t) &= \frac{V_0 sin\omega t}{R_p} + \frac{V_0}{\omega L_p} \\
&\quad + V_0 cos\omega t \left(\omega C - \frac{1}{\omega L_p} \right), \\
&\qquad 0 < \omega t < 2\pi \\
&\quad 0, \qquad otherwise
\end{aligned}
$$

The peak current is presented as follows,

$$I_{peak} = V_0 \left(\frac{1}{R_p} + \frac{1}{\omega L_p} \right) = \frac{V_0}{R_p} (1 + Q)$$

The inductance of the MA core is about 20 times larger than that of the ferrite. The shunt impedance is equal as that of ferrite at low B_{RF}. It becomes larger than it above B_{RF} of about 100 gauss. If the R_p 's are same, the peak current of the MA-loaded cavity is lower than that of the ferrite-loaded cavity to acquire same barrier voltage of a single sine wave.

The Q value is so low that the tuning loop is not necessary to tune the cavity. Because the Curie temperature is high as about $600°C$, we can make the system for cooling the cores simple.

2.2 Components of the cavity

The schematic view of the cavity is shown in Figure 2.

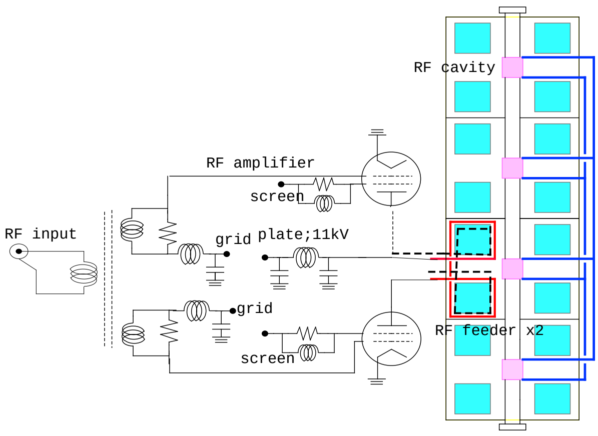

Figure 2: Schematic view of cavity and RF amplifier.

The cavity has 4 cells and each cell has a acceleration gap. There are 12 MA cores per cell, in totality 48 cores per cavity. The cores are put at a distance of 10mm to keep the space for air flow and cooled by air from a blower. The cover of the cavity is cooled by water. The RF power is inductively fed on through a couple of the driving loops. These driving loop are wound around 12 cores.

2.3 RF amplifier

The power amplifier uses two EIMAC 4CW30,000A 30kW tetrodes in the grounded-cathode configuration[4]. The amplifier operates push-pull in class B and it is biased to cut-off except a single pulse of 2MHz. The duty is about 6% of the repetition period. The RF power of 2kW for the drive amplifier is required and the two 1kW solid state amplifiers(ENI A1000) are combined. The RF voltage from them is stepped up twice through a transformer for the grid circuit.

2.4 Parameters

The parameters of the barrier cavity system are listed in Table 1.

Table 1 : Parameters of cavity.

$Total Voltage\ [kV]$	40
$RF\ frequency\ [MHz]$	2.0
$Number\ of\ gaps$	4
$Number\ of\ cores\ [/cavity]$	48
$Length\ of\ cavity\ [m]$	2.6
$peak\ B_{RF}\ [T/core]$	0.12
$peak\ P_{in}\ [W/core]$	750
$Q\ value$	0.6
$Cavity\ resistance\ [k\Omega]$	4.0
$Tetrode\ resistance\ [k\Omega]$	2.3
$Beam\ impedance\ [k\Omega]$	3.6

3 IMPEDANCE

The shunt impedance per gap is about 1kΩ at 2MHz. The tube impedance of about 2.3kΩ is quadrupled when it is seen from a gap. Therefore the cavity impedance seen by beam becomes about 3.6kΩ.

A single sine wave includes broad Fourier components, as from the revolution frequency to twice of the RF frequency. Therefore any parasitic resonance around the RF frequency should not be in the impedance of the barrier cavity system. However some parasitic resonances have been observed. One of them, which resonant frequency of 12MHz was, could be seen in the waveform of the gap voltage. We found that the leakage inductance of the driving loops which coupled with the power amplifier caused it by the measurement. This resonance was disappeared when the driving loops were removed. The shift of the parasitic resonant frequency was measured when the external capacitance was inserted between the plates of the tetrodes and the RF ground potential[5]. The relation between the resonant frequency and the capacitance is linear and presented, as $\frac{1}{f^2} = (2\pi)^2 L(C + C_{ex})$. The gradient shows the inductance and the fragment means the capacitance. The result is shown in Figure 3.

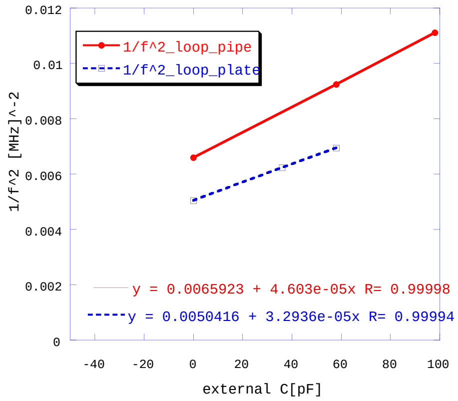

Figure 3: shift of the parasitic resonant frequency.

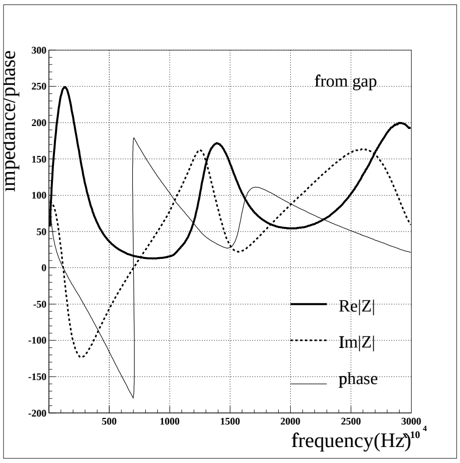

Figure 4: the impedance from the gap.

It was found that the leakage inductance and the capacitance which caused the parasitic resonance of 12MHz was about 1μH and 175pF, respectively. The value of the capacitance was generally equal to the sum of the output capacitance and the gap capacitance. To reduce the inductance and the impedance, the physical size of drive loop was changed, as from the copper pipe of the diameter of 6mm to the copper plate which was $30\times2\text{mm}^2$. In Figure 3, the solid line means the result in the case of the pipe and the dashed line is in the case of the plate loop. The inductance decreased by 20 % and the impedance became 350Ω. Furthermore the L and R in parallel were put in series between the driving loops for dumping higher mode parasitic resonance. So that the impedance of the 12MHz decreased as 170Ω and the phase did not cross 0 degree. As the waveform of the gap voltage, the component of 12MHz was reduced so much. Figure 4 shows the impedance seen from the gap. The horizontal axis is frequency and the vertical axis is impedance and phase. The solid thick line and the dashed line show the real and imaginary part of the impedance, respectively. The solid thin line is the phase.

There are still some parasitic resonances. The gaps are shorted except the accumulation during the experiment in the AGS. However some instability might be excited by them. Making efforts to dump those resonances has been continued.

4 BARRIER VOLTAGE

The peak voltage of 40kV per cavity has been achieved. Figure 5 shows a single sine wave of 10kV per gap. The RF voltage satisfy the necessary bucket hight of 0.4% and the area.

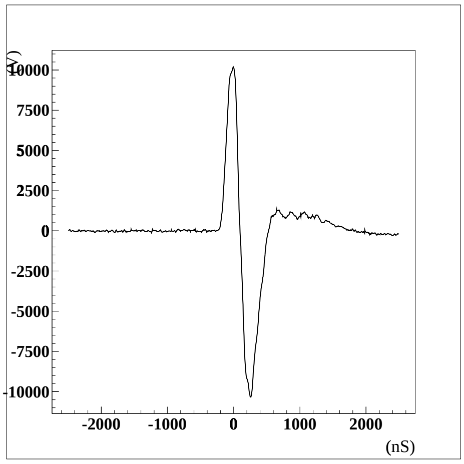

Figure 5: gap voltage.

5 CONCLUSION

An RF cavity has been developed for the barrier bucket experiment in the AGS. The 48 MA cores have been inserted into the cavity. The cavity requires less RF power than that of the ferrite-loaded cavity because of the low Q value but high shunt impedance. A single sine wave of 40kV per cavity is a design value and it has been achieved.

6 ACKNOWLEDGMENT

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