A BROAD-BAND RF BUNCHER CAVITY USING FINEMET CUT CORES FOR ION BEAMS

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Abstract

We have developed a broad-band and compact size buncher cavity using MA (magnetic alloy) cut cores. The operating frequency of the cavity ranges between 18 and 45 MHz. The cavity has been installed in the beam transport line of the HiECR ion source system in CNS (Cneter for Nuclear Study, University of Tokyo) and tested using 10 keV proton beam. Bunched-beam structure of 30 MHz was successfully observed.

INTRODUCTION

Presented in this paper is a buncher cavity which has been developed to install in beam transport line of the ion source, HiECR in the CNS of the University of Tokyo.

The HiECR [1] is intensively used for ion source research and also used for R&D's of ion beam monitors, which are applicable to existing and future cyclotrons in RIKEN. For the latter purpose, ion beam having bunched structure corresponding to the cyclotron frequencies is necessary.

We have developed a broad-band cavity using MA cores for bunch formation of the ion beams which are extracted from the HiECR. We chose *Q*-value of the cavity less than 1 because of the required large frequency range of 18 to 45 MHz.

When the capacitance of the cavity is assumed to be several tens pF, the inductance is required less than 1 μH to obtain the resonant frequency of 30 MHz. As the MA cores have large permeability, we adapt the cut core configuration [2-4] for the cavity to reduce the inductance.

DESIGN CONSIDERATION AND LOW POEWR MEASUREMENT

In order to investigate rf characteristics of cut-core-loaded cavity in the frequency range from 1 to 50 MHz, a test cavity shown in Fig.1 has been fabricated. It has a coaxial structure comprising of the outer conductor (O. D. = 270 mm) made of copper and the inner conductor (I. D. = 132 mm) made of aluminum. We adopted Finemet (FT-3M) as the core material, which is an iron-based nanocrystalline magnetic alloy made by Hitachi Metals, Ltd [5]. The core is made of thin tape wound into a toroidal shape. The tape is coated with SiO_2 for insulation. Size of the core,140 mm I. D., 200 mm O. D. and 25 mm height is the actual size to be used in the buncher cavity. We set distances between the core and the inner walls of the test cavity to be longer than 5 mm to keep the stray capacitance small.

The admittance *Y* (=*G*+*jB*) of the test cavity was measured using an impedance analyzer (HP4195A +HP41951A). The equivalent circuit of the cavity is expressed as parallel *LCR* circuit. The parasitic capacitance *C* is estimated to be approximately 25 pF. The shunt impedance *Rsh* (=*1/G*) is almost fully attributed to the core because the MA has much larger loss than the conductor in the frequency range of interest. We derived the *L* ($=1/\{\omega(-B+\omega C)\}$) and *Q* ($=Rsh/\omega L$) from the equivalent circuit [6]. Figure 2 shows the measured frequency dependence of *L* with the air gap width of the cut core as a parameter. *L* remains almost constant with frequency for the cut cores.

In the measurement using test cavity, we also confirmed that the *Q*-value of approximately 1 can be obtained at 30 MHz when the air gap width is less than 1 mm, and that values of *Rsh* are almost the same at a few tens MHz for various gap widths.

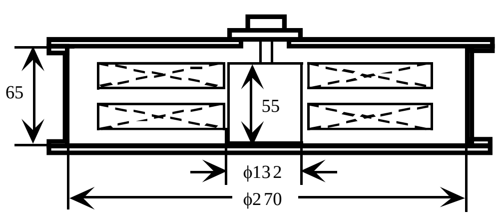

Fig.1. Cross section of the test cavity.

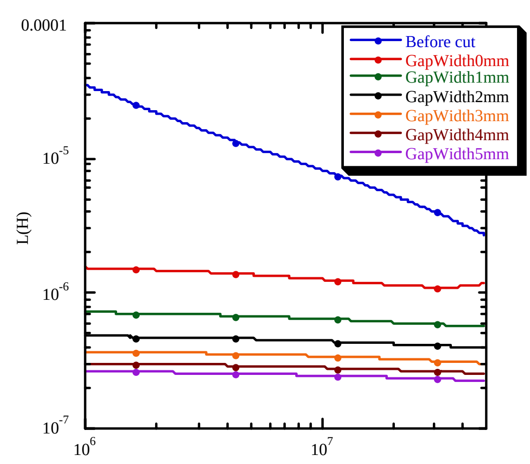

Fig. 2. Frequency dependence of inductance of the test cavity with the air gap width as a parameter.

On the basis of the test cavity measurement, we have designed a compact buncher cavity. Figure 3 shows cross section of the buncher cavity. The cavity has two sets of the Finemet cut cores with air gaps of 0.5 mm. A ring made of Macor is set at the acceleration gap for insulation. The size of the ring is the inner diameter of 86 mm, outer diameter of 114 mm and height of 10 mm.

We attached two parallel copper plates, one of which is with N-type connector, to the acceleration gap and we measured the rf characteristics of the cavity using the impedance analyzer. Figure 4 shows frequency dependence of the absolute value of the impedance and the phase. The *Q*-value of the cavity is 0.7 and the inductance is 0.7 μH at 30 MHz. Total gap capacitance including parasitic capacitance is estimated to be 40 pF. The measured characteristics of the buncher cavity agree well with the ones expected from the measured results of the test cavity.

To increase the transit time factor, two parallel mesh plates made of copper are placed at the acceleration gap shown in Fig. 3. The plates consist of mesh part with diameter of 75 mm and mesh-support frame with outer diameter of 95 mm. The mesh has hexagon shape [7] and the distance between the center of the hexagons is 2 mm. Width and thickness of the mesh are 0.1 mm. The distance between the mesh plates is 5 mm.

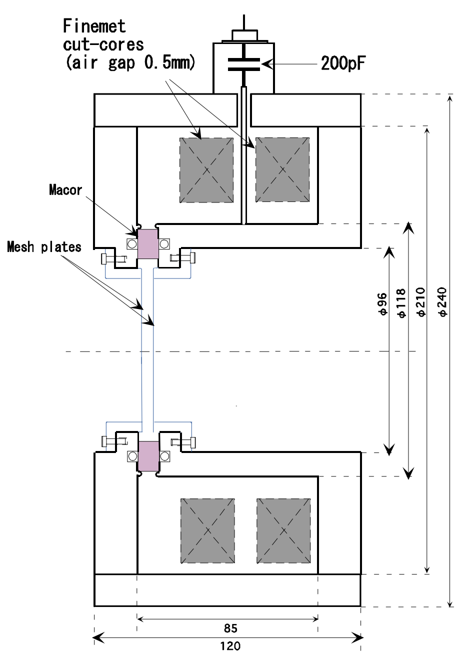

Fig. 3. Cross-sectional view of the buncher cavity.

HIGH POWER TEST OF THE BUNCHER CAVITY

We have carried out the high power test using 3 kW rf amplifier which feeds the power to the cavity though 50 Ω coaxial cable. To match the input impedance of the cavity to 50 Ω, a capacitor of 200 pF is connected in series with the cavity and the cut cores are set in parallel.

Input and reflection power were measured by a vector voltmeter (HP, 8508A) using directional coupler. Figure 5 shows frequency dependence of the voltage standing wave ratio (VSWR). They are kept less than 1.3 between 20 and 45 MHz.

Peak gap voltage dependence of the cavity dissipation power for several frequencies is shown in Fig. 6. The gap voltages were measured by a voltage probe (Tektronix, P5102). Each curve shows fitted results of square function of the voltage. The shunt impedance is approximately 133 Ω at 30 MHz.

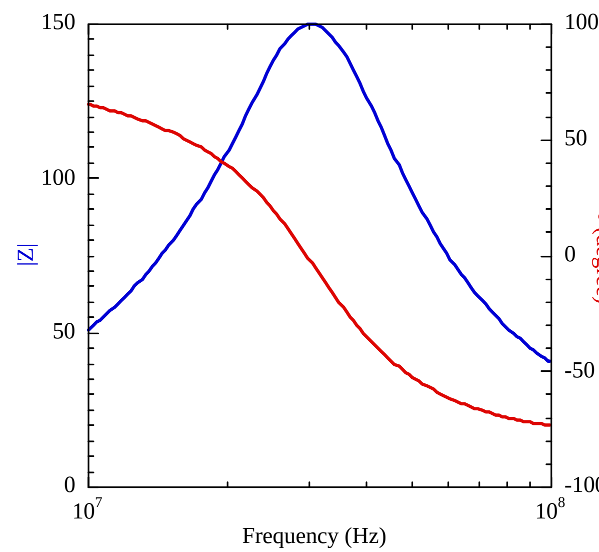

Fig. 4. Frequency dependence of absolute impedance and phase of the buncher cavity.

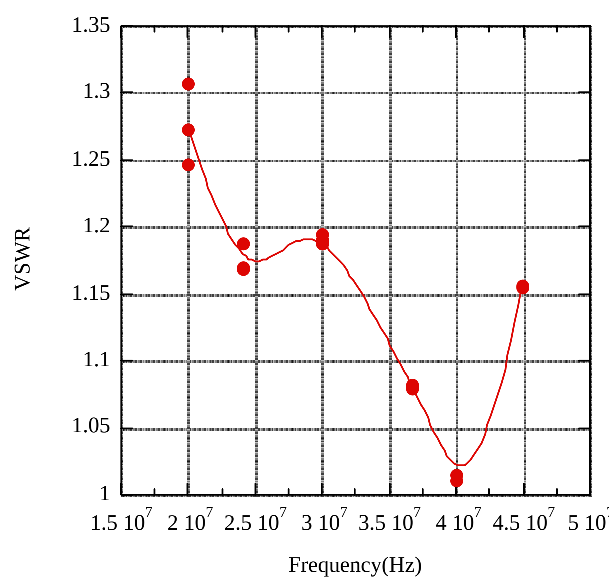

Fig. 5. Frequency dependence of the voltage standing wave ratio (VSWR) of the buncher cavity.

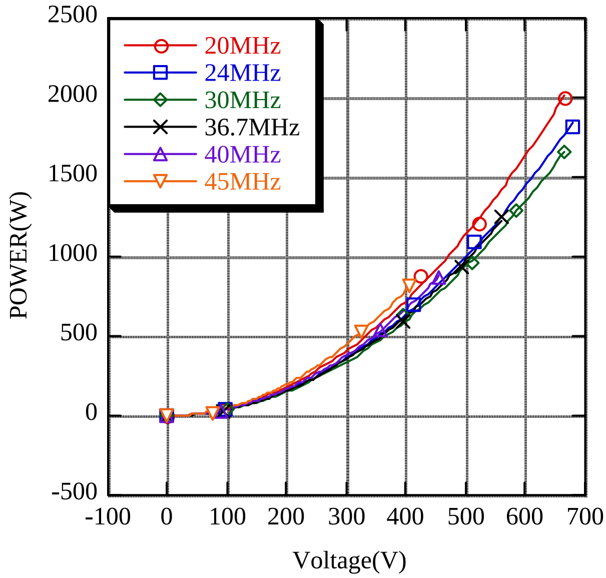

Fig. 6. Peak gap voltage dependence of the dissipation power of the buncher cavity.

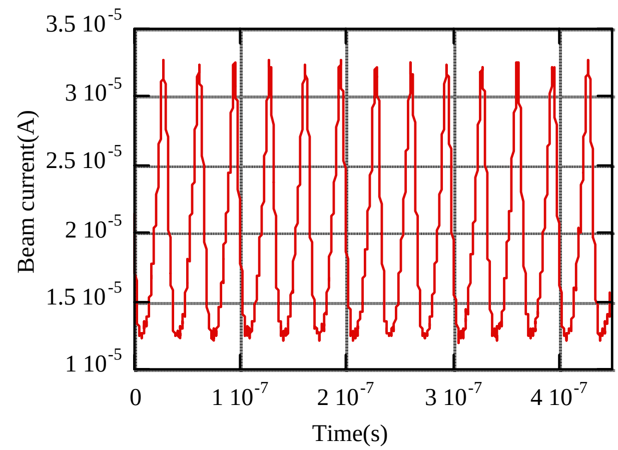

Fig. 8. Bunched beam current waveform.

BEAM TEST OF THE BUNCHER CAVITY

The buncher cavity has been installed in the beam transport line of the HiECR ion source system. Figure 7 shows a photograph of the cavity. The cores are cooled by an electric fan.

Figure 8 shows typical beam current waveform using the buncher cavity. The beam current was detected by a Faraday cup at 2.3 m down stream of the cavity. In this case, 10 keV proton beam with average current of 20 μA was used. Frequency and peak voltage of the cavity were 30 MHz and 150 V, respectively. As shown the figure, beam structure of 30 MHz with the peak current of 32.5 μA was successfully obtained.

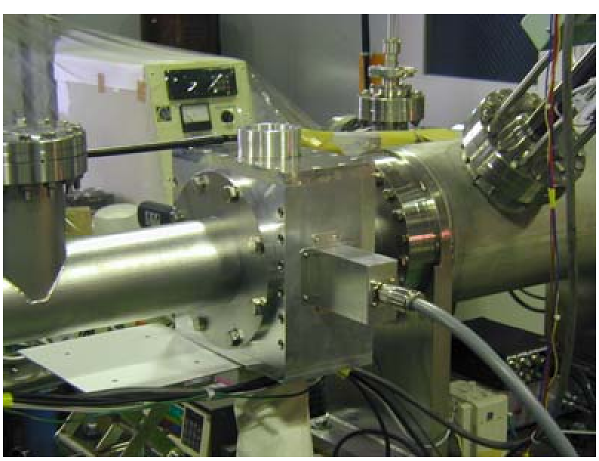

Fig. 7. The buncher cavity installed in the beam transport line of the HiECR.

CONCLUSIONS

We developed a compact size buncher cavity using Finemet cut cores with operating frequencies between 18 and 45 MHz. A capacitor of 200 pF is connected in series with the cavity and the cut cores are in parallel to match the input impedance of the cavity to approximately 50 Ω. The voltage standing wave ratio is kept less than approximately 1.3 between 20 and 45 MHz.

We installed the buncher cavity in the beam transport line of the HiECR ion source system for the beam test. Beam structure of 30 MHz was successfully observed for 10 keV proton beam.

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REFERENCES

[1] S. Watanabe *et al.*, CNS. Rep. **45**, (2002) 47.
[2] M. Yoshii *et al.*, Proc. of EPAC2000 (2000), p. 984.
[3] J. Dey *et al.*, Proc. of PAC2001 (2001), p. 882.
[4] M. Watanabe *et al.*, RIKEN Accel. Prog. Rep. **36**, (2003) 325.
[5] Y. Yoshizawa *et al.*, J. Appl. Phys. **64**, 10 (1988) 6044.
[6] M. Watanabe *et al.*,“Measurement of rf characteristics of magnetic alloys fo an rf cavity of Accumulator Cooler Ring”, accepted for publication in Nucl. Instrum. Methods A.
[7] K. Ikegami and A. Goto, RIKEN Accel. Prog. Rep. **22**, (1988) 213.