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

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Abstract

A broad-band and compact size rf cavity as a buncher of ion beams has been developed. Operating frequencies of the cavity is between 18 and 45 MHz. The cavity was installed in the beam transport line of the Hi-ECR ion source system in CNS for the beam test. Beam structure of 30 MHz was successfully observed for 10 keV proton beam.

INTRODUCTION

We have been studying a broad-band buncher cavity using MA (magnetic alloy) cut cores in the frequency region around 30 MHz. The buncher cavity was designed to install and test in an ion source named Hi-ECR in the CNS (Center of Nuclear Study) of the University of Tokyo. The Hi-ECR [1] is intensively used for ion source research and also used for R&D's of ion beam monitors, which are applicable to the present and future cyclotrons in RIKEN. For the latter purpose, ion beam having bunched structure corresponding to the cyclotron frequencies is necessary.

We chose the Q-value of the buncher cavity less than 1 because of the required large frequency range. 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 buncher cavity to reduce the inductance.

RF CHARISTERISTICS OF THE FINEMET CUT-CORE-LOADED CAVITY

We fabricated a test cavity to investigate rf characteristics of cut-core-loaded cavity in the frequency range from 1 to 50 MHz. The test cavity shown in Fig.1 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. The core material is FINEMET (FT-3M) 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. The size of the core of 140 mm I. D., 200 mm O. D. and 25 mm height is the actual size to be used in the rf cavity as the buncher. 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.

We measured the admittance Y of the test cavity using a impedance analyzer (HP4195A+HP41951A). The admittance Ye of the equivalent circuit is expressed as

$$Ye = 1/Rsh + j(\omega C - 1/\omega L), \qquad (1)$$

where, ω is angler frequency and L is inductance. The parasitic capacitance C is estimated to be approximately 25 pF. The shunt impedance Rsh is almost fully attributed to the core because of the large loss of the MA in the frequency range of interest.

Equating Ye to Y, we can derive the L ($=1/\{\omega(-B+\omega C)\}$) and Q ($=Rsh/\omega L$). Figure 2 shows the frequency dependence of L with the air gap width as a parameter. As can be seen in Fig. 2, L remains almost constant with frequency for the cut cores. Figure 3 shows gap dependence of the Q-value. The Q-value of approximately 1 can be obtained at 30 MHz when the air gap width is between 0 and 1 mm. Rsh obtained almost the same values at a few tens MHz for various gap widths.

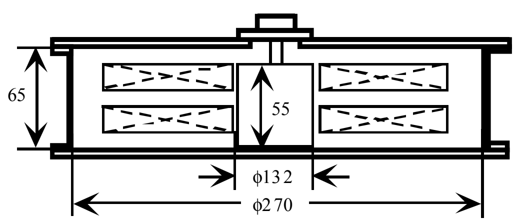

Figure 1: Cross section of the test cavity.

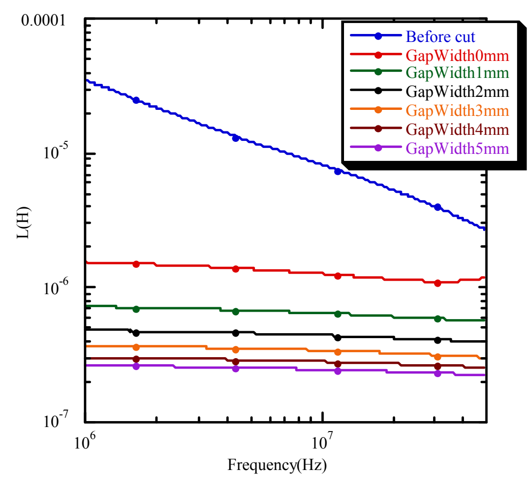

Figure 2: Inductance vs frequency of the test cavity with the air gap width as a parameter.

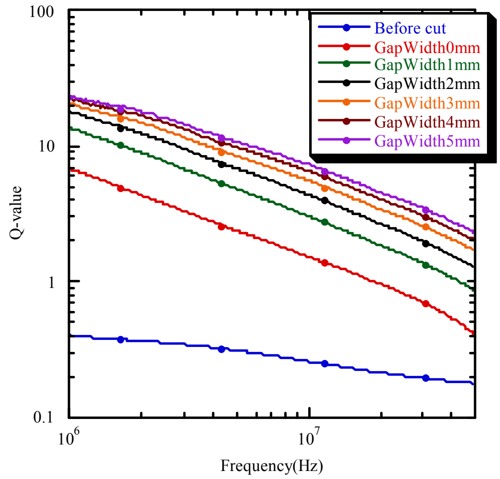

Figure 3: Q-value vs frequency of the test cavity with the air gap width as a parameter.

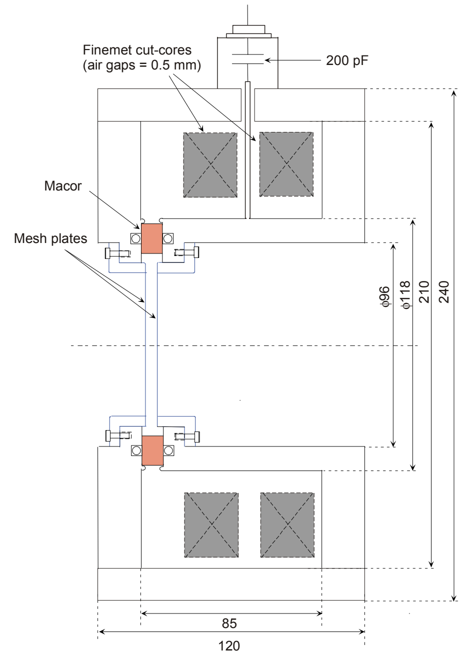

Figure 4: Cross section of the buncher cavity.

Figure 5: Photograph of the buncher cavity.

DESIGN CONSIDARATION AND HIGH POWER TEST OF THE BUNCHER CAVITY

On the basis of the measurement using the test cavity, we designed and fabricated a compact buncher cavity. Figure 4 shows the cross section of the buncher cavity. Two Finemet cut cores with air gaps of 0.5 mm are used. We placed a ring made of Macor 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.

Two parallel mesh plates made of copper are placed at the acceleration gap to increase the transit time factor. 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 [6] 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.

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 in parallel.

Figure 5 shows a photograph of the rf cavity. The cores are cooled by an electric fan.

The admittance of the acceleration gap of the cavity was measured by the impedance analyzer. In this measurement, two parallel copper plates were attached to the gap substituting for the mesh plates. The resonance frequency and the Q-value of the cavity are approximately 30 MHz and 0.7, respectively. The inductance is approximately 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.

Figure 6 shows frequency dependence of the absolute value of the input impedance. The voltage standing wave ratio is kept less than 1.3 between 20 and 45 MHz.

An rf amplifier feeds rf power to the cavity though 50 Ω coaxial cable. Peak gap voltage dependence of the cavity dissipation power for several frequencies is shown in Fig. 7. The gap voltages were measured by a voltage probe (Tektronix, P5102) and a digital oscilloscope. Input and reflection power was measured by a vector voltmeter (HP, 8508A) using directional coupler.

In Fig. 7, each curve shows fitted results of square function of the voltage. The shunt impedance is estimated to be 133 Ω at 30 MHz.

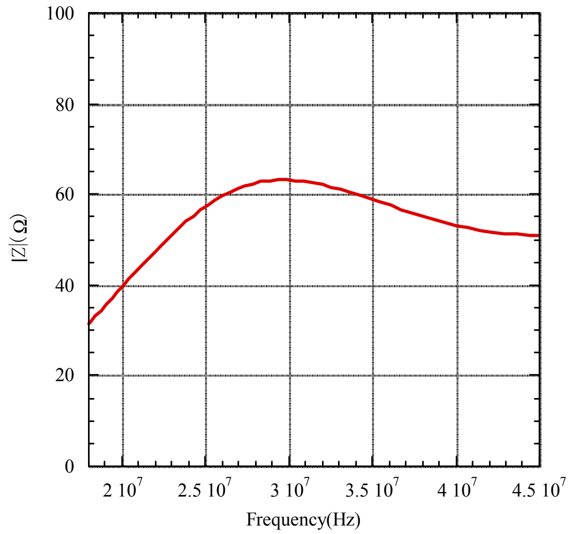

Figure 6: Absolute value of input impedance vs frequency of the buncher cavity.

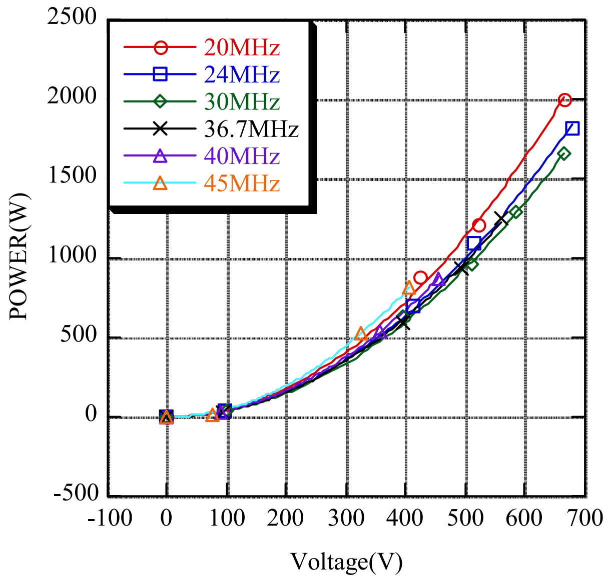

Figure 7: Peak gap voltage dependence of the dissipation power of the cavity.

BEAM TEST USING THE BUNCHER CAVITY

Recently the buncher cavity has been installed in the beam transport line of the Hi-ECR ion source system for the beam test. Figure 8 shows typical beam current waveform using the buncher. 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 rf 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.

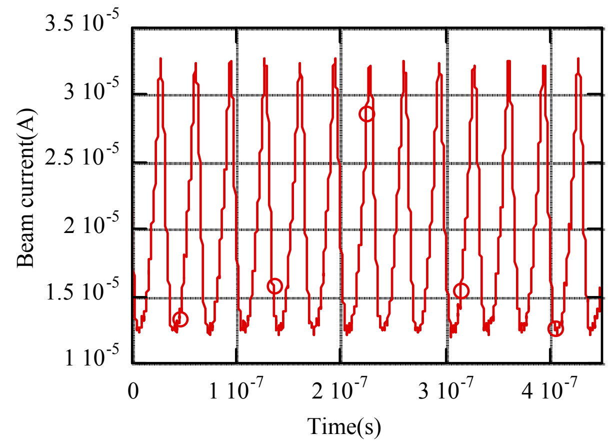

Figure 8: Bunched beam current waveform.

CONCLUSIONS

We developed a compact size buncher cavity using Finemet cores with operating frequencies between 18 and 45 MHz. The measured characteristics of the buncher cavity agree well with the ones expected from the measured results of the test cavity. 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 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 Hi-ECR ion source system for the beam test. Beam structure of 30 MHz was successfully observed for 10 keV proton beam.

ACKNOWLEDGMENTS

Part of this work was supported by a collaboration program between CNS and NIRS (National Institute of Radiological Science). The authors sincerely thank Dr. K. Noda for his support. They are also grateful to Mr. S. Yamaka for his contribution to operating the ion source.

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