BEAM TEST OF A CW MICROTRON WITH A 500 MHZ RF CAVITY FOR INDUSTRIAL APPLICATIONS

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Abstract

A CW microtron is made and the first beam test is done. The machine is of a racetrack type. The acceleration energy and the beam power are 5 MeV and 50 kW, respectively. The RF cavity is a conventional normal-conducting 2-cell cavity with coupling slots. The injection energy is 80 keV, and a 500MHz CW gun is used. The bending magnets are divided into two subsections to adjust the acceleration phases of every turn. A beam test of the 500 MHz CW gun shows that a peak current is about 200 mA, and a phase width of the gun emission is about 60 degrees. The beam emittances measured agree well with the calculation results. Injection beam sizes at the center of the RF cavity are about 5 mm and 4 mm in the horizontal and vertical coordinates, respectively.

1 INTRODUCTION

High power electron beams are necessary for industrial applications: X-rays irradiation and electron irradiation. Development of accelerators operated in a continuous wave (CW) mode is of considerable practical interest for industrial applications [1]. The CW microtron with a 500 MHz RF cavity is proposed. The essential interests are compactness and low cost. A key issue of designing the microtron is that the injection energy is as low as 80 keV ($\beta = 0.5$), and the velocity of an electron beam changes with every turn. Hence the energy gain from the RF cavity in each passage changes. A new shaped bending magnet is proposed to adjust beam orbit length of each turn, and appropriate acceleration phases can be adjusted when an electron beam passes the RF cavity. This paper describes manufactured results of the CW microtron. The first beam tests of the CW electron gun and the LEBT are also shown.

2 CW MICROTRON

Basic parameters of the CW microtron are shown in Table 1. Figure 1 shows a schematic drawing of the 5 MeV CW microtron, and Fig. 2 shows a photograph of the CW microtron and the RF power source.

2.1 CW electron gun and LEBT

A 500 MHz CW electron gun and an LEBT are shown in Fig. 3. In order to match an accelerating RF frequency, the 80 keV gun is pulsed at the RF frequency. The gun is a conventional triode type with a 0.5 cm^2 dispenser cathode. A CW emission is modulated by varying a grid voltage in the triode. A signal source of the grid voltage is a pick-up signal of the RF cavity, and the grid voltage is biased to a DC level. The 80 keV electron beam is injected with a chicane magnet from an injection line (LEBT). There are two solenoid magnets and a QF magnet at the LEBT for a transverse beam focusing. The chicane magnet is composed of three bending magnets.

Table 1: Basic parameters of CW microtrons.

	5 MeV Accelerator	**10 MeV Accelerator**
Beam power	50 kW	100 kW
Beam current	10 mA	10 mA
RF frequency	500 MHz	500 MHz
Accelerator dimension	1600 × 3900 × 1100 mm	1600 × 4700 × 1100 mm
Weight	10 ton	11 ton

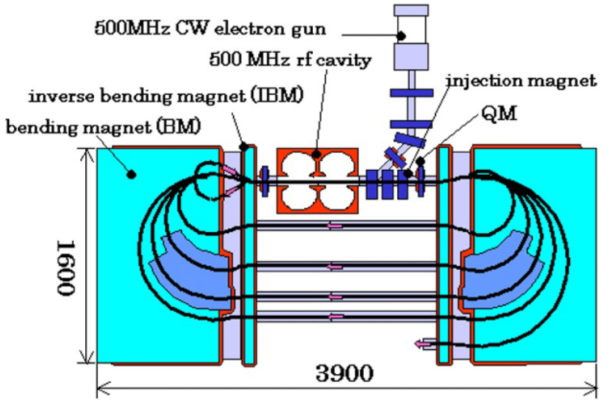

Figure 1: Schematic drawing of the 5 MeV CW microtron.

Figure 2: CW microtron and the RF power source.

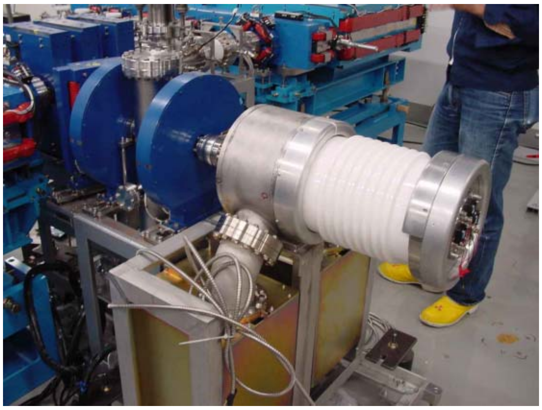

Figure 3: 500 MHz CW electron gun and an LEBT.

2.2 500 MHz RF cavity

The RF cavity is a conventional 2-cell cavity with nose cones and inductive coupling slots as shown in Fig. 4, which is frequently used for an electron storage ring. There are one coupler and two tuners. The frequency is selected around 500 MHz that is determined by a capable input power into the RF cavity and the total size of the microtron. The power supply (100 kW) uses two IOTs (Inductive Output Tube, CPI: K2H50), which are frequently used for broadcasting systems. The RF cavity was designed for a total gap voltage of 1 MV at 40 kW dissipation. A high power test of the cavity has been successfully done, and all measured parameters agree well with the design values.

2.3 Magnets

An electron beam after passing the RF cavity for the first time cannot pass by outside the RF cavity after the first bending magnet (BM). Therefore, an inverse-bending magnet (IBM) is situated near the bending magnet as shown in FIg.1. The electron beam passes the RF cavity for the second time in the inverse direction of the first passing. A transverse beam focusing is obtained with only edge effects of the bending magnets and two QMs near the RF cavity.

In a conventional racetrack microtron, a fixed relation among the magnetic field, the RF frequency, and amplitude of the acceleration voltage is needed for synchronous acceleration under an almost light velocity of a beam [2]. As for the proposed microtron, the electron velocity, however, changes with every turn, and the energy gain from the RF cavity in each passage changes. The RF acceleration phase slip becomes large, when a conventional bending magnet is used. Therefore, we propose a new shaped bending magnet to adjust beam orbit length of each turn [3]. The bending magnet is divided into two subsections described as Fig. 5. The two subsections have different magnetic fields, and the bending angles of the two subsections are adjusted so that beam orbit length of each turn is appropriate for the acceleration. The parameters are optimised with a computer optimisation program so that an electron beam with the widest acceleration phase can be accelerated. Figure 6 shows electron orbits calculated with a numerical integration of exact equations of motion using 3-D magnetic and electric fields. Lines shown in the figure are horizontal beam orbits using calculated 3-D magnetic fields. Dots in the figure are 1000 particles' simulation results using measured magnetic fields. Calculation conditions are as follows: initial acceleration phases are 0, +10, and –10 degrees, and an unnormalized beam emittance is 50 π mm-mrad. The study shows that an electron beam can be accelerated till 5 MeV with practicable beam sizes (x= 18 mm, y= 12 mm).

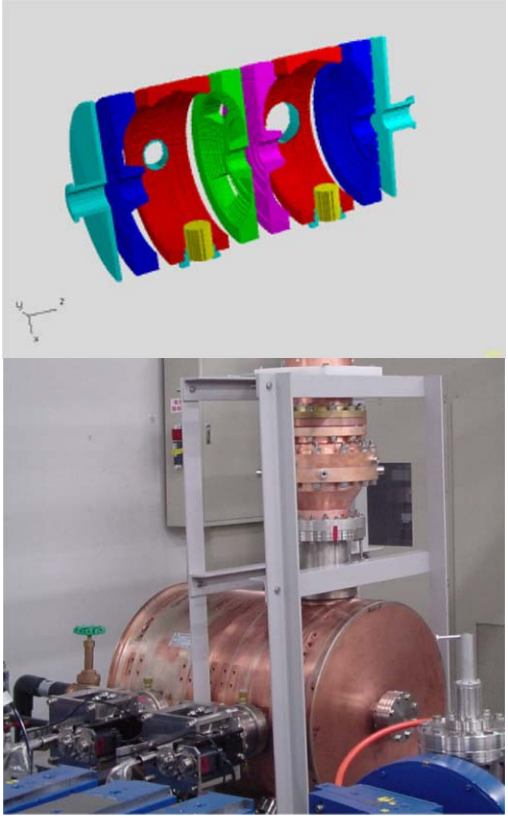

Figure 4: 500 MHz RF cavity and a coupler.

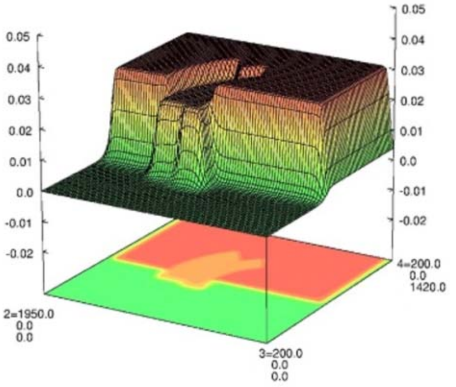

Figure 5: Magnetic field distribution of the bending magnet calculated with TOSCA.

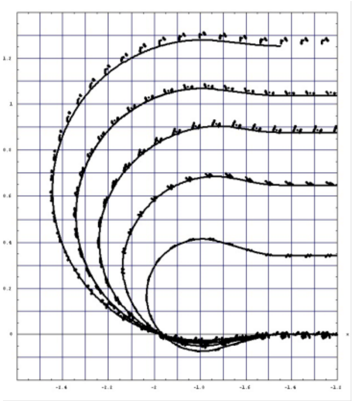

Figure 6: Beam orbits calculated using calculated magnetic fields (lines) and measured magnetic fields (dots). Calculation conditions of the dots: initial acceleration phases are 0, +10, and –10 degrees and an unnormalized beam emittance is 50 π mm-mrad.

3 BEAM TEST

3.1 500MHz CW beam production

The beam test was done with the following diagnostics: 1) a fluorescent screen which is movable along the axis, 2) the Faraday cup which can be measured fast beam signals. Figure 7 shows a beam bunch signal measured by the Faraday cup. The figure shows that a 500 MHz pulsed beam is produced, and the bunch length is about 300 ps (phase width: 60 degrees), that is in good agreement with simulation results.

Figure 8 shows calculated and measured peak beam currents as a function of the grid-cathode voltage. The calculation was done with a beam tracking in consideration of space charge effect. The simulation model was divided into two sections: 1) a section from the cathode to the grid, 2) a section from the grid to an exit of the electron gun, because the former section is a very fine structure as compared with the latter section. A maximum current needed is estimated to be 200 mA on account of attaining an average acceleration current of 10 mA. The figure shows that measured results agree well with the calculation results.

Figures 9 shows unnormalized beam emittances as a function of the grid-cathode voltage (Vgc). The measurement was done with the fluorescent screen and a quadrupole magnet. The measured results agree well with the calculation results, and show that the unnormalized beam emittance is about 60 π mm-mrad.

3.2 Beam injection

An injection beam test was done before an acceleration beam test. The fluorescent screen and the Faraday cup were situated at a position of the RF cavity. The beam test shows that injection beam sizes at the center of the RF cavity are about 5 mm and 4 mm in the horizontal and vertical coordinates, respectively, and beam centering within ± 0.2 mm accuracy can be done.

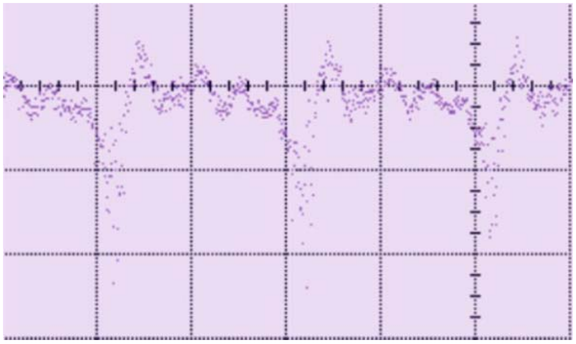

Figure 7: Beam signal with an 80 GHz sampling oscilloscope: (1 ns/div. and 50 mA/div.).

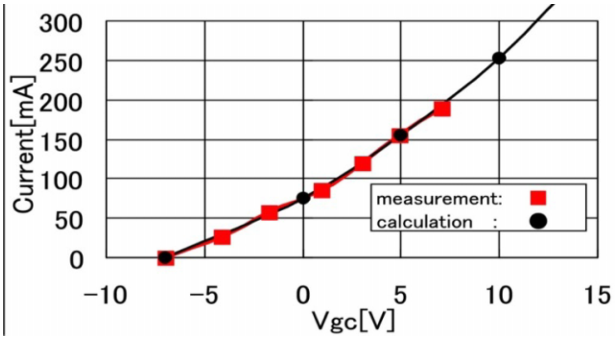

Figure 8: Measured and calculated peak currents as a function of the grid-cathode voltage.

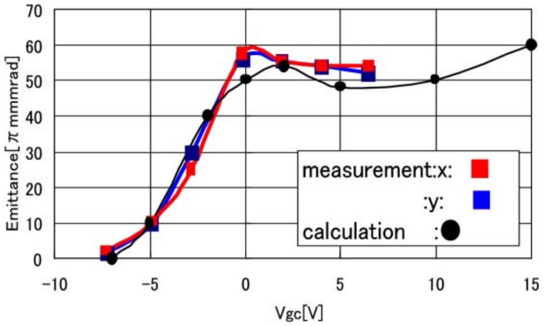

Figure 9: Unnormalized beam emittances as a function of the grid-cathode voltage.

4 SUMMARY

The CW microtron with the 500 MHz RF cavity was made and the first beam test was done. The production of 500 MHz CW beam and the injection into the microtron have been successfully done. Acceleration beam test will be done within this summer.

REFERENCES

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