BEAM DYNAMICS IN A CW MICROTRON WITH A 500 MHz RF CAVITY FOR INDUSTRIAL APPLICATIONS

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Abstract

A CW microtron with a 500 MHz rf cavity is proposed for industrial applications. The machine is of a racetrack type. The acceleration energy and the beam power of a prototype machine are 5 MeV and 30 kW, respectively. The rf cavity is a conventional normal-conducting 2-cell cavity with coupling slots. The injection energy is 80 keV, and a 500 MHz CW gun is used. The bending magnets are divided into two subsections to adjust the acceleration phases of every turn. Beam tracking studies show that the transverse beam stability can be obtained with fringe fields of the bending magnets and two QMs near the rf cavity. The studies also show that the CW electron gun is practicable, and an 80 keV - 30 π mm-mrad electron beam can be obtained.

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 the industrial applications [1] [2]. The CW microtron with a 500 MHz normal-conducting rf cavity is proposed to apply for these fields [3]. The essential interests are compactness and high electrical efficiency. A key issue of designing the microtron is that the injection energy is 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 bending magnet with a new structure is proposed to adjust beam orbit length of each turn, and acceleration phases can be adjusted appropriately. This paper describes results of the beam dynamics design of the CW microtron. The main subjects are a design of a CW electron gun for the CW microtron, and transverse beam stability of the CW microtron.

2 CW MICROTRON

Figure 1 shows a schematic drawing of the 5 MeV CW microtron. An 80 keV electron beam is injected with a chicane magnet from an injection line. In order to match an accelerating rf frequency, the electron gun is pulsed at the rf frequency. There are two solenoid magnets and a QM magnet at the injection line for a transverse beam focusing. The chicane magnet is composed of three bending magnets. The rf cavity is a conventional 2-cell cavity with nose cones and inductive coupling slots, which is frequently used for an electron storage ring. The frequency is selected around 500 MHz that is determined by an input power of the rf cavity and the total size of the microtron.

The electron beam after passing the rf cavity for the first time cannot pass by outside the rf cavity after the first bending magnet. Therefore, an inverse-bending magnet (BM3) is situated near the bending magnet. The electron beam crosses the rf cavity for the second time in the inverse direction of the first crossing. A transverse beam focusing is obtained with only edge effects of the bending magnets and two QMs near the rf cavity.

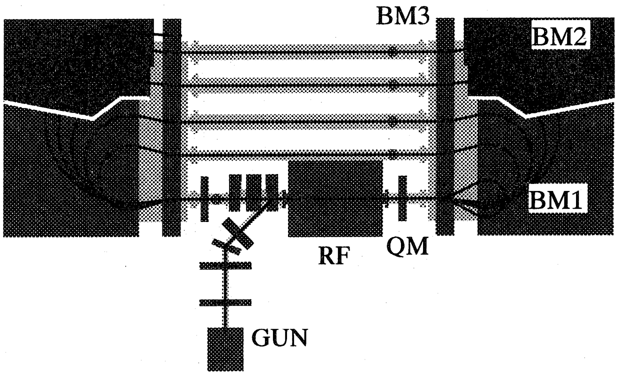

Figure 1: Schematic drawing of the CW microtron.

Table 1: Basic parameters of the CW microtron.

Energy	5 MeV
Number of turns	6
Average beam current	6 mA
Injection energy	80 keV
rf frequency	500 MHz
Number of rf cells	2
Wall loss of the rf cavity	40 kW

A fixed relation among magnetic fields of bending magnets, an rf frequency, and energy gain at an rf cavity is needed for synchronous acceleration in a conventional microtron [4]. 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. Therefore, the rf acceleration phase slip becomes large, when a conventional bending magnet is used. We propose a bending magnet with a new structure to adjust beam orbit length of each turn. The bending magnet is divided into two subsections described as BM1 and BM2 in Fig. 1. The two subsections have different magnetic fields, and bending angles of the two subsections is adjusted so that beam orbit length of each turn is appropriate for the acceleration. The parameters are optimized with a computer optimization program so that an electron beam with the widest acceleration phase can be accelerated. Basic parameters of the CW microtron are shown in Tab. 1.

3 BEAM SIMULATION STUDIES

3.1 CW electron gun

The 80 keV electron gun is a conventional triode type with a 0.5 cm^2 dispenser cathode. A 500 MHz CW emission is made 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. Two sections were made to optimize a shape of the triode: 1) a section from a cathode to the grid, 2) a section from the grid to an exit of the electron gun, because the former section is very fine structure as compared with the latter section. The optimization of the triode was done with a beam tracking in combination with the two sections in consideration of space charge effect.

The simulation method was confirmed by comparing calculation results with measured results of an electron gun. The gun is a conventional pulse electron gun of a triode type, which is used for a linear accelerator. Figure 2 shows a beam current as functions of grid voltage (Vg) and acceleration voltage. The figure shows that the calculation results agree with the measured results.

Figures 3 and 4 show a beam current and a normalized beam emittance of the CW gun as a function of grid voltage (Vg), respectively. A maximum beam current needed is estimated to be 100 mA on account of attaining an average beam current of 6 mA. Figure 3 shows that the grid voltage needed is below +2 V. Figure 4 shows that a normalized beam emittance is calculated to be 30 πmm-mrad. A phase width of the CW emission is estimated to be about 70 degrees, when an rf power of 60 W is supplied.

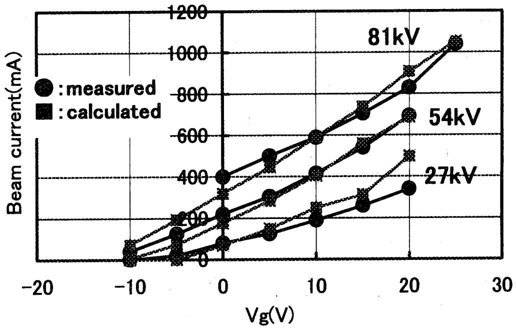

Figure 2: Beam current of the pulse electron gun as functions of grid voltage and acceleration voltage.

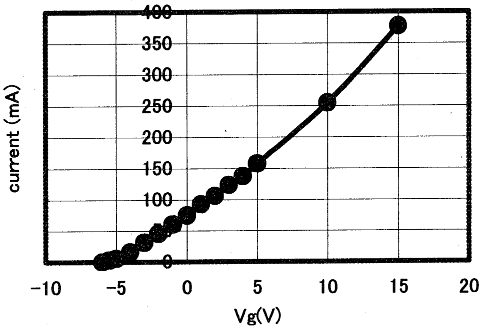

Figure 3: Beam current of the CW electron gun as a function of grid voltage.

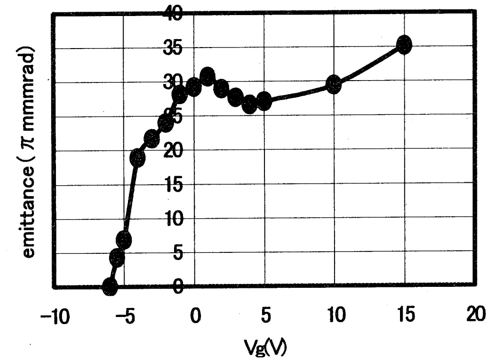

Figure 4: Normalized beam emittances (100 %) of the CW electron gun as a function of grid voltage.

3.2 Transverse beam stability

Figure 5 shows electric field pattern for a TM010 mode in the rf cavity. Figure 6 shows electromagnetic field patterns for a TM010 mode along the beam axis for various radii. The rf fields have much effect on the transverse beam focusing at the low energy. Figure 7 shows horizontal beam envelopes on different initial acceleration phases, when the beam passes through the rf cavity for the first time. Figure 8 shows horizontal phase spaces at the exit of the rf cavity. The initial acceleration phases are as the same as those in Fig. 7, and twiss parameters at the entrance of the rf cavity are $\alpha=0$, and $\beta=2$ in all cases. The initial acceleration phase difference produces a difference of transverse beam focusing significantly.

A beam tracking from the CW electron gun to the exit of the microtron was done. Figure 9 shows energy dispersion of the electron beam at the exit of the CW microtron. The energy spread is calculated to be ± 2.2 %. The study also shows that an electron beam can be accelerated up to 5 MeV with practicable beam sizes: ± 20 mm, ± 4 mm in the horizontal and vertical coordinates, respectively, and a capable acceleration phase width is more than 20 degrees.

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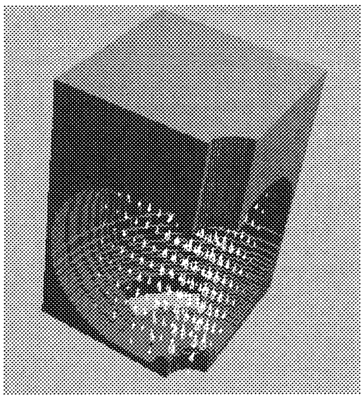

Figure 5: Electric field pattern for a TM010 mode in the rf cavity.

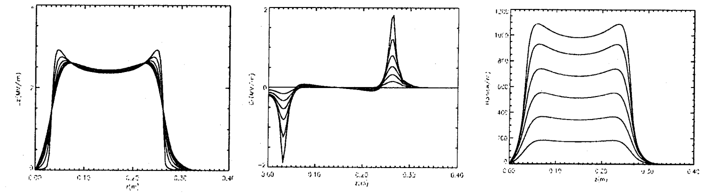

Figure 6: Electromagnetic field patterns for a TM010 mode along the beam axis for various radii: z=0 is the center of the rf cavity.

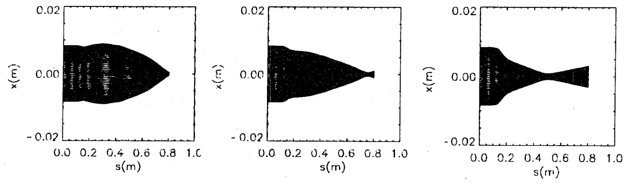

Figure 7: Beam envelopes at the rf cavity (first turn). Initial acceleration rf phases are -290 ° (right), -275 ° (center), and -260° (left).

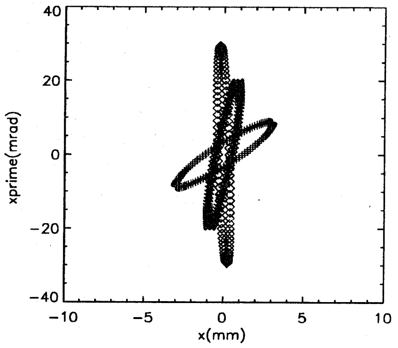

Figure 8: Horizontal phase spaces at the exit of the rf cavity. Initial acceleration rf phases are -290°, -275°, and -260°.

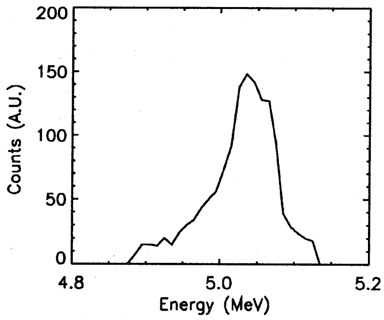

Figure 9:Energy spectrum at the exit of the CW microtron.