The 12th Symposium on Accelerator Science and Technology, Wako, Japan 1999

Design of CW Microtrons using a 500 MHz RF Cavity for Industrial Application

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Abstract

The CW microtrons with the 500 MHz RF cavity are proposed for industrial application: The acceleration beam energy and power are from 5 MeV to 16 MeV, and several tens of kW, respectively. A beam tracking study shows that the CW microtrons are practicable. Slow positrons of about 10^9 slow-e^+/sec can be produced using the 16 MeV CW microtron, according to an estimation based on previous measurement values.

1 Introduction

High power electron beams are necessary for industrial application: electron beam and X-rays irradiation. Maximum beam energy for the application is around 10 MeV. Application to slow positron production is also necessary for high power electron beams. The beam energy is from 15 MeV to several hundreds of MeV. Electrostatic accelerators and linear accelerators have been used for the application. However, development of accelerators operated in a continuous wave (CW) mode is of considerable practical interest for the industrial application because the accelerators require compactness. A CW accelerator RHODOTRON [1] has been developed by IBA, and the electron energy and the beam power are 10MeV and 200 kW, respectively. However, the energy would be too low for slow positron production.

A CW microtron with a 500 MHz normalconducting RF cavity is proposed to apply for these fields and a feasibility study has been made. The essential interests are compactness and low electrical efficiency. This paper describes results of the beam dynamics design. Attention will be paid mainly to effects of RF fields and space charge. An estimation result of slow positron production is also described.

2 CW microtrons

Figure 1 shows a schematic drawing of a 5 MeV CW microtron. An 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 at the injection line for a transverse beam focussing. The RF cavity is a conventional multi cell type, which is frequently used for an electron storage ring. The frequency is selected around 500 MHz that is determined by a capable input power of the RF cavity and the total size of the microtron.

The electron beam at the first turn cannot pass by outside the RF cavity after the first bending magnet. Therefore, an inverse-bending magnet (BM-) 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 focussing is obtained with only edge effects of the bending magnets and a QM near the RF cavity. Basic parameters of the CW microtrons are shown in Tab. 1.

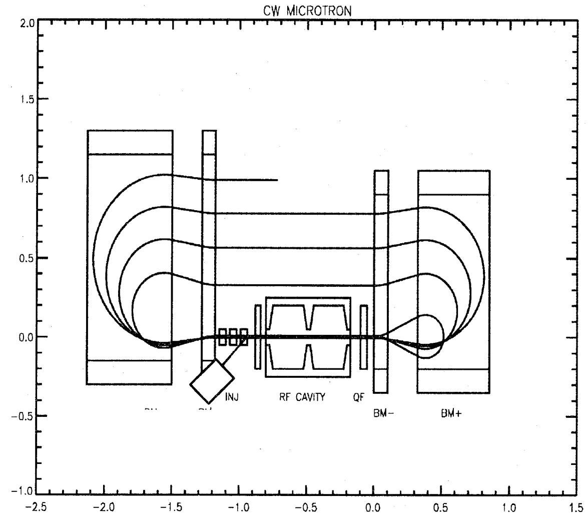

Fig. 1 A schematic drawing of a 5 MeV CW microtron.

Tab. 1 Basic parameters of CW microtrons.

Energy (MeV)	5	10	16
Application field	X-rays	Electron	Slow positron
Average Beam Current(mA)	6	9	5.6
The number of RF cells	2	4	4
The number of turns	5	5	8
Wall loss of an RF cavity (kW)	56 → 67	110 → 133	110 → 133
Footprint (m × m)	2.9 × 1.6	3.6 × 1.6	4.1× 2.1

3. Beam simulations of the CW microtron

Beam simulations were mainly done with the parameters of the 5 MeV CW microtron.

3.1 Injection energy

Injection beam energy is from 70 keV to 90 keV. A low RF field strength makes a low energy gain and large energy dispersion of an electron beam, when the beam crosses an RF cavity. The reason is that velocity of the low energy beam is much slower than velocity of light, and the phase slip is large. A beam tracking with 3 dimensional magnetic and electric fields was made. Figure 2(a) shows electron beam energy along a reference orbit, when the beam crosses a 2-cells RF cavity for the first time. Ten electrons were simulated whose initial acceleration phases are different every 5 degrees. The injection energy is 70 keV. Figure 2(b) shows horizontal beam orbits when the electrons are injected the RF cavity with r = 0.01 m and r' = 0 radian. The initial phase conditions are the same as the Fig. 2(a). The initial phase difference produces a difference of an energy gain and transverse beam focussing. Figure 3 shows energy dispersion as a function of the injection energy. A phase width of the beam is 30 degrees. Injection energy of a 2-cells type and a 4-cells type is needed to be more than 70 keV and 90 keV, respectively, in order to suppress the energy dispersion within 2 %.

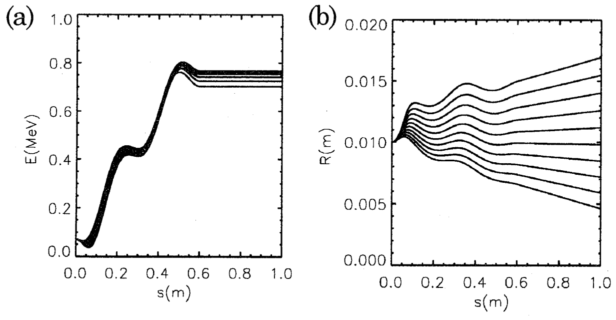

Fig.2 Energy and orbits in the RF cavity: Injection beam energy is 70 keV and initial acceleration phases are from –180 degrees to –135 degrees. (a) Electron beam energy along a reference orbit; (b) horizontal beam orbits.

3.2 Space charge effect

Injection energy is several tens of keV, and space charge effect is thought to be large when a high intensity beam is accelerated. The effect was simulated with a beam tracking. The tracking was done from an exit of the electron gun to an entrance of the RF cavity. Figure 4 shows horizontal phase spaces without and with space charge effect at the entrance of the RF cavity. Initial beam conditions are $\varepsilon_x = \varepsilon_y = 37 mm.mrad$, $\beta_x = \beta_y = 0.023$, and $\alpha_x = \alpha_y = 0$. The emittances are unnormalized sigma values.

Figure 5 shows horizontal beam emittances at the RF cavity as a function of an average beam current. The emittances were calculated from phase space distributions of 2000 particles. The space charge effect is negligible when an average beam current is around 10mA, and electron beam energy is 70 keV.

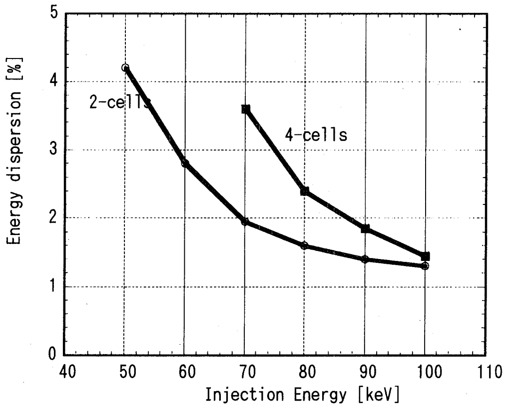

Fig. 3 Energy dispersion as a function of injection energy. An initial accelerating phase width is 30 degrees.

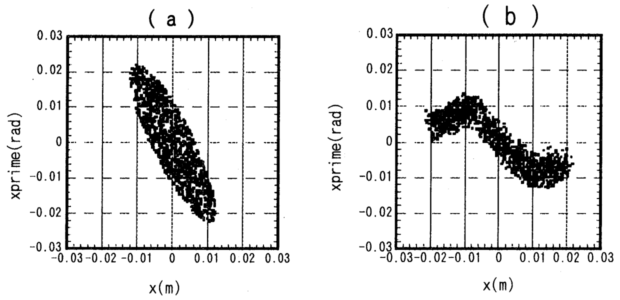

Fig.4 Horizontal phase spaces at the entrance of the RF cavity: Beam energy is 70 keV and average beam currents are 0 mA with (a) and 200 mA with (b).

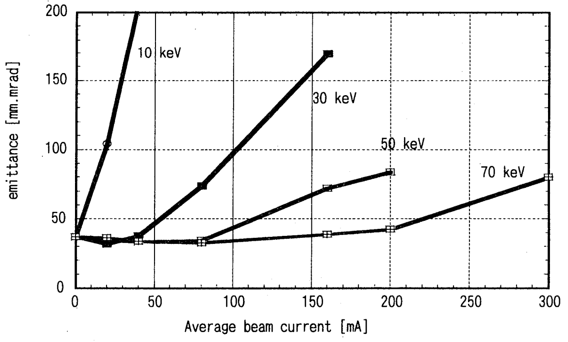

Fig. 5 Horizontal beam emittances at the RF cavity as a function of an average beam current.

3.3 Beam properties

Figure 6 shows roughly approximated beam envelopes of the CW microtron. Effects of RF electric and magnetic fields were not considered. Beam emittances of the horizontal and vertical coordinates are considered to ones after crossing the RF cavity for the first time. Energy dispersion is 2 %.

A beam tracking from the exit of the electron gun to the exit of the CW microtron was done. The following effects were approximately taken into account: (1) RF electric and magnetic fields, (2) space charge, (3) and, static magnetic fields. Figures 7(a)(b) show phase spaces at the exit of the CW microtron. Initial acceleration phase width is 30 degrees. Initial acceleration phases of the Figs. 7(a) and (b) are –160 degrees and –175 degrees, respectively. The maximum and minimum acceleration energy can be obtained using the parameters at the exit of the CW microtron. The electron beam can be accelerated with practicable beam sizes.

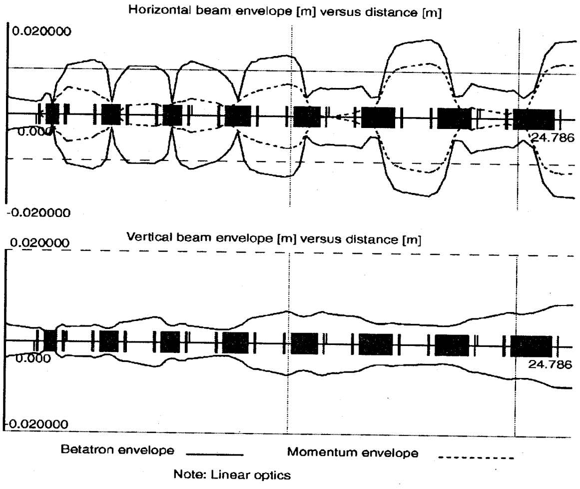

Fig. 6 Roughly approximated beam envelopes of the CW microtron. Energy dispersion is 2 %.

4. Production of slow positrons

Slow positron production using the CW microtron produces the following advantages: a linear storage section is not required, and, the amount of shielding is significantly reduced. It is difficult to estimate yields of positrons, that depend on shapes of targets, moderators, and transfer lines. Measurement values [2][3] which various laboratories have been done show that the production efficiency is roughly described the following equation between 15 MeV and 20 MeV:

$$N_{slow-positron} / N_{electron} = 2 \rightarrow 20 \times 10^{-12} E^{3}(_{MeV}) .$$

The coefficients (2 and 20) are minimum and maximum values, respectively. The number of slow positrons and footprint areas of the CW microtron are estimated and shown in Fig. 8. The electron beam power is 90 kW. Slow positrons of 10^9 slow-e^+/s can be obtained with the compact accelerator. Heat removal of the targets is the most difficult problem and rotate targets are required.

5. Summary and perspective

The CW microtron with the 500 MHz RF cavity is proposed and is found practicable. A recirculating accelerator with a different acceleration method can be proposed at the energy of around 5 MeV, which is more compact than the CW microtron. The feasibility study is in progress.

Acknowledgement

The author would like to thank Dr. T. Nakanishi, Dr. C. Tsukishima, Dr. Y. H. Pu, Mr. M. Kimura, and, Mr. T. Hirano of our company for helpful discussions.

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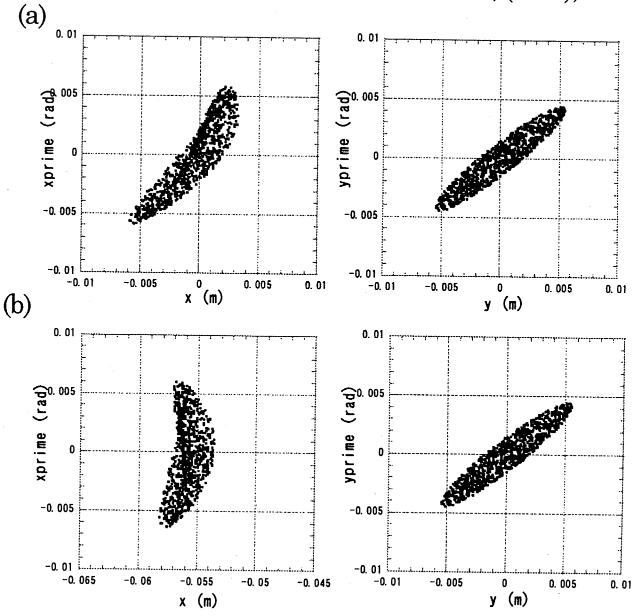

Fig. 7 Phase spaces at the exit of the CW microtron: the initial RF acceleration phases are –160 degrees with (a) and –175 degrees with (b).

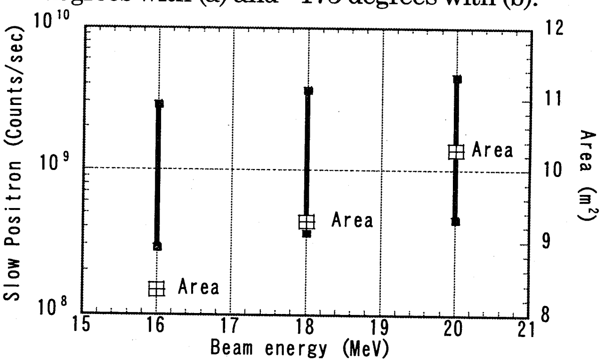

Fig. 8 Positron production amount (maximum and minimum estimation values) and footprint areas of the accelerators as a function of electron beam energy. The electron beam power is 90 kW.