DEVELOPMENT OF A MELCO HIGH INTENSITY MICROTRON FOR INDUSTRIAL APPLICATIONS

T. Nakanishi, H. Tanaka, Y. Pu, T. H. Kim, Y. Makita, A. Maruyama, C. Tsukishima, S. Yamamoto, and S. Nakamura, Mitsubishi Electric Corp., Advanced Technology R & D Center
8-1-1 Tsukaguchi-Honmachi, Amagasaki, Hyogo, 661-8661, Japan

Abstract

A high intensity microtron operated in a cw mode is under development at MELCO for industrial applications. The machine is of a racetrack type using a 500 MHz rf cavity with a total gap voltage of about 1 MV. Nonsynchronization by change of electron velocity of each turn can be compensated by adjusting orbit length of each turn by bending magnets with two sections. A 5 MeV-50kW machine, which is suitable for x-ray sterilization, is under construction to prove this new method. A 500 MHz cw gun has been also developed, and beam tests have showed that the emitted beam parameters agree well with the calculated results. The beam acceleration test will be carried out within this year.

INTRODUCTION

More application of a high intensity electron accelerator is expected since irradiation processing by electrons and x-ray is safe and environmentally friendly. High intensity accelerators such as Dynamitron of an electrostatic type with 5MeV-200kW, and Rhodtron of an rf type with 10MeV-150kW are used for irradiation [1].

The authors have been developing a compact machine of a self-shielding type which is of a racetrack microtron type and has a beam power of 50~100kW. Operation in a cw mode is effectual to supply a high intensity beam. A conventional racetrack microtron with an acceleration cavity of S-band, however, is not suitable for the cw operation because of heat dissipation in the cavity. Use of a cavity with a lower acceleration voltage can not satisfy the condition for synchronous acceleration because electron velocity changes every turn [2]. The authers have proposed a new method with adjusting orbit length of each turn by bending magnets with two sections and adopting a 500 MHz cavity [3]. An electron gun with 500MHz cw operation has been also developed for a longer lifetime. A 5 MeV-50 kW machine is under construction to prove this new method. Beam tests of the gun and a high power test of the cavity have been already finished.

This paper describes the design, the fabrication, and the tests of the 5 MeV-50kW machine.

BEAM DYNAMICS DESIGN

A 5MeV microtron is shown in Figs. 1 and 2. Main components are an 80 keV electron gun, two main bending magnets (BM), and an rf cavity. The height of the machine is as low as 1.1 m at the top of the cavity and therefore the self-shielding can be made easily. The operation frequency is selected to be around 500 MHz in consideration of suitability for the cw operation and the total size of the machine. The total gap voltage of the cavity is about 1 MV. A higher gap voltage results in a reduction in the electric power efficiency of the machine, where the power efficiency is very important for these industrial applications.

An 80 keV electron beam from the gun is injected using a chicane magnet with three bending magnets. The orbit radius in the BM is not large enough for the first orbit to clear the cavity because of a low energy gain of 0.7 MeV. The electrons after the first pass through the cavity, therefore, are displaced by an inverse bending magnet (IBM) and then directly reflected back into the cavity by the BM. The IBMs are also useful for the vertical focusing for every turn in the edge regions of the BMs. The transverse focusing is done by only the edge focusing and the two quadrupole magnets placed at both sides of the cavity.

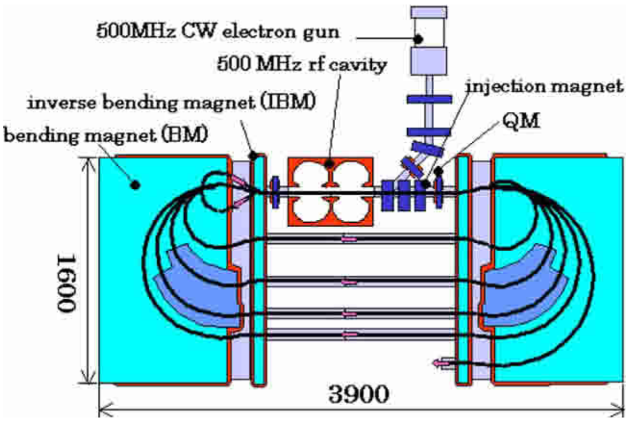

Figure 1: Schematic drawing of the 5 MeV cw microtron

Figure 2: Photograph of the 5 MeV cw microtron

This machine parameters can not satisfy the condition of synchronous acceleration like a conventional racetrack microtron because electron velocity changes every turn, where the energy gains per pass are around 0.85 MeV after the first pass. The nonsynchronization can be compensated by adjusting orbit length of each turn by the BMs with two sections as shown in Fig. 1, and the lower acceleration frequency such as 500 MHz assists the compensation. The section of the dark color of the BM in Fig. 1 has a larger gap and therefore a weaker field. The size and the field strength of the section are optimised with a beam simulation using the 3D field distribution so as to obtain a large phase acceptance. The optimised field strengths are about 0.025 T at that section and about 0.03 T at the other section, respectively. The optimised beam orbits are shown in Fig. 3 with calculated and measured fields. Dots in the figure are 1000 particles' simulation results using the measured magnetic fields. The calculation conditions are as follows: initial acceleration phases are 0, +10, and –10 degrees, and horizontal and vertical beam emittances are 50 π mm-mrad, respectively. The study shows that an electron beam can be accelerated up to 5 MeV with practical beam sizes (x= ±18 mm, y= ±12 mm). The phase acceptance considering the beam aperture is 15 degree with an energy spread of 1.4 % at FWHM.

An accelerated energy of 10 MeV can be obtained with the use of two acceleration cavities and a stronger bending field of about 0.06 T. This energy is the upper limit for direct electron irradiation. The beam power is 100 kW with the same beam current as the 5 MeV machine.

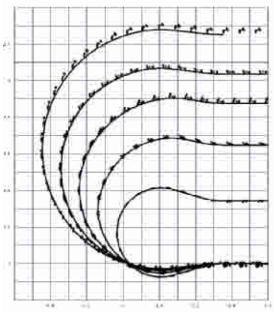

Figure 3: Beam orbits calculated using calculated magnetic fields (lines) and measured magnetic fields (dots). Calculation conditions of the dots: initial acceleration phases are 0, +10, and –10 degrees and a beam emittance is 50 π mm-mrad.

The basic parameters of the 5 MeV and 10 MeV machines are listed in Table. 1.

Table 1: Basic parameters of MELCO microtrons.

	5 MeV machine	**10 MeV machine**
Beam power	50 kW	100 kW
Beam current	10 mA	10 mA
RF frequency	500 MHz	500 MHz
RF power	90 kW	180 kW
Accelerator dimension	1600 × 3900 × 1100 mm	1600 × 4700 × 1100 mm
Weight	10 ton	11 ton

ELECTRON GUN AND INJECTION LINE

The gun is a conventional triode type with a 0.5 cm^2 dispenser cathode, and is operated in a cw mode. To obtain a pulse beam for a longer lifetime of the gun, the voltage between the grid and the cathode is oscillated by a 500 MHz signal synchronized with the acceleration frequency [4]. The peak current is changed by varying the grid bias and the rf voltages.

The 80 keV electron beam from the gun is transported through two solenoid magnets, a 45 degree bending magnet, and a quadrupole magnet, and is injected using a chicane magnet with three bending magnets.

BENDING MAGNET

The BM has a pole face as large as 1650 mm × 830 mm. The gap lengths are 46.0 mm and 54.25 mm, respectively. Several blocks of SUS316 are put in the gap to obtain the gap uniformity with an accuracy of ±0.05 mm. The large gap section of the pole was machined with a milling machine, and an additional pole was attached to the edge of the BM.

The magnetic field distribution on the beam orbit plane calculated with TOSCA is shown in Fig. 4. Ununiform region of the magnetic boundary between the two sections is 70 mm and small enough compared with an interval of adjacent beam orbits, about 120 mm, where the ununiformity is worse than ± 1×10^{-3}.

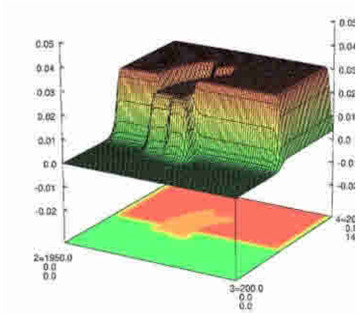

Figure 4: Magnetic field distribution of the bending magnet calculated with TOSCA.

500 MHZ RF SYSTEM

A schematic drawing of the rf cavity and a photograph of the rf cavity installed in the microtron are shown in Figs. 5 and 6. 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 outer diameter is 0.51 m and the length is 0.63 m. It is made of oxygen-free copper. Two inductive tuners are mounted to adjust the balance of the electric fields in the two cells and resonant frequency. They are also used to compensate a shift of resonant frequency due to variations of temperature. The required total gap voltage is about 1 MV. The cavity is evacuated within 1×10^{-4} Pa using a turbomolecular pump with a capacity of 500 L/s.

The rf source with two IOTs (Inductive Output Tube) generates 100 kW cw power, where the IOT is frequently used for broadcasting systems. The power is fed into the

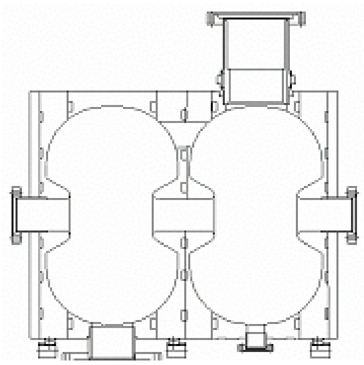

Figure 5: Schematic drawing of the rf cavity.

Figure 6: RF cavity placed in the microtron and a coaxial line for rf power feed.

cavity through a loop coupler and a coaxial line. A wave guide is not used for a compactness of the system.

A balance of the gap voltages in the two cells has been adjusted within 1 % using the tuners together with resonant frequency tuning of 500 MHz. The unloaded Q value measured 31000, which corresponds to 82 % of the calculated value. An rf power of 40 kW required for the designed total gap voltage has been supplied into the cavity[5].

BEAM TESTS OF THE GUN AND INJECTION LINE

Beam tests were performed with a straight line consisting of two solenoid magnets, a quadrupole magnet, and beam monitors which are a fluorescent screen and a Faraday cup. To observe the bunch structure, an N-type connector was used as the Faraday cup because the electric capacitance of the detecting part is very small, though it is smaller than the beam size. The detected signal is observed with a 50 GHz sampling oscilloscope as shown in Fig. 7. The bunch width is about 300 ps and about 60 degree in a phase length, which corresponds to the calculated value well. The phase stability of the beam measured within 1 degree.

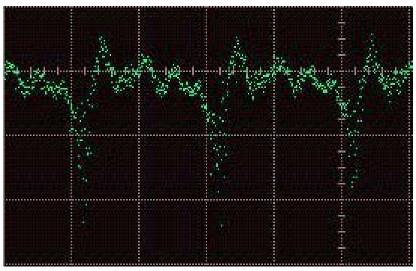

Figure 7: Bunch structures with a 50 GHz sampling oscilloscope: (1 ns/div. and 5 mV/div.).

A precise beam current from the gun was measured by replacing the connector type with a large Faraday cup. A peak current was evaluated from the average current measured and the above-mentioned bunch structure. Figure 8 shows the peak current measured as a function of the grid peak voltage together with the calculated values. It is found that they have a good agreement. A peak current of 250 mA is required for an average current of 10 mA giving the 50 kW beam power.

Figure 9 shows the emittance measurement results together with the calculated ones. They were measured by the use of the quadrupole magnet and fluorescent screen. The measured emittances are around 60 π mm-mrad for both the x and the y emittances, and agree well with the calculated results.

A beam transport test of the injection line was performed placing the beam monitors at a position of the cavity before the cavity was installed. The measured beam sizes of about ±5 mm horizontally and ±4 mm vertically correspond to the calculated ones, and a beam can be transported within an accuracy of ± 0.2 mm.

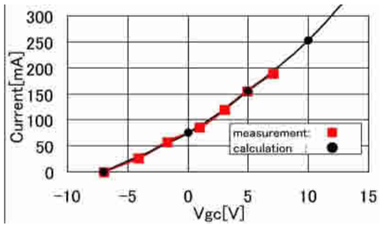

Figure 8. Measured and calculated peak currents as a function of the grid voltage.

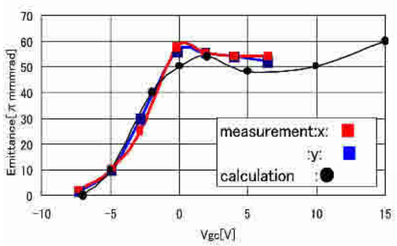

Figure 9: Beam emittances as a function of the grid voltage.

SUMMARY

The high intensity microtron operated in a cw mode is under development. The new method has been proposed for the cw operation. A 5 MeV machine is under construction and the beam tests of the electron gun and the injection line were done successfully. The beam acceleration test will be carried out within this year.

REFERENCES

[1] J. Pottier, “A new type of RF electron accelerator: the rhodotron”, NIM B 40/41, (1989) 943.

[2] P. Lidbjork, “Microtrons”, CERN 94-01, Vol. 2, (1994), 1994.

[3] H. Tanaka, “Beam Dynamics in a CW Microtron for Industrial Applications”, EPAC 2000, Vienna, (2000), 1005.

[4] 蒲 越虎 他, “熱陰極 500MHz-CW 電子銃の開発”, 第 28 回ﾘﾆｱｯｸ技術研究会,東海村,(2003).

[5] Y. Makita, et al., .,"HIGH POWER TEST OF A 500 MHZ RF CAVITY OF A CW MICROTRON FOR INDUSTRIAL APPLICATIONS", in these proceedings.