DESIGN AND A BEAM TEST OF AN LEBT OF A CW MICROTRON

T. H. Kim, H. Tanaka, Y. Pu, Y. Makita, T. Nakanishi, and S. Nakamura
Mitsubishi Electric Corporation, Electromechanical Systems Dept., Advanced Technology R &D Center, 8-1-1, Tsukaguchi-honmachi, Amagasaki City, HYOGO 661-8661, Japan

Abstract

A low energy beam transport (LEBT) has been designed for a CW microtron and a beam test has been done. The LEBT transports a 500MHz - 80 keV electron beam to the CW microtron. A peak beam current is 100 mA. The LEBT consists of two solenoid magnets, a bending magnet, a quadrupole magnet, and a chicane magnet. Fringe fields of the bending magnets are optimised by adjusting gaps of auxiliary pole pieces (clamps) of the bending magnets. Calculation and measurement results of magnetic fields show that a field integral (FINT) related to the fringe field is proportional to the gaps of the clamps. A three dimensional calculation result of the FINT is within accuracy of 0.5 %. The beam test shows that measured emittances are in good agreement with a calculated emittance.

1 INTRODUCTION

High power electron beams are necessary for industrial applications: electron beam and X-rays irradiation. Electrostatic accelerators and linear accelerators have been used for the applications. However, accelerators operated in a continuous wave (CW) mode are more suitable for these applications. We have proposed a CW microtron with a 500 MHz RF cavity for the applications [1]. In the CW microtron system, an LEBT should be compact and has large acceptance for a high power electron beam. Therefore, a bending radius of a bending magnet of the LEBT is small, which has much effect on transverse beam focusing. Careful consideration of a fringe field of the bending magnets is necessary. Instruments of the LEBT have been designed and made. At the design of the LEBT, a calculated emittance [2] is used. Transverse beam emittances are important to design the LEBT. It is necessary to compare the measured emittances to the calculated emittance. Therefore, the beam test has been done to measure the emittances. This paper describes a lattice design of the LEBT, a design of the bending magnet, and the beam test results.

2 LATTICE DESIGN

Figure 1 shows a schematic drawing of the LEBT of the CW microtron. The LEBT transports a 500 MHz - 80 keV electron beam to the CW microtron. A peak beam current is 100 mA. The LEBT consists of two solenoid magnets (SOL1, SOL2), a bending magnet (BM1), a quadrupole magnet (QM) and a chicane magnet (BM2, BM3, BM4). An electron beam is injected to the CW microtron with the chicane magnet. Electron beam parameters at an exit of an electron gun are studied with

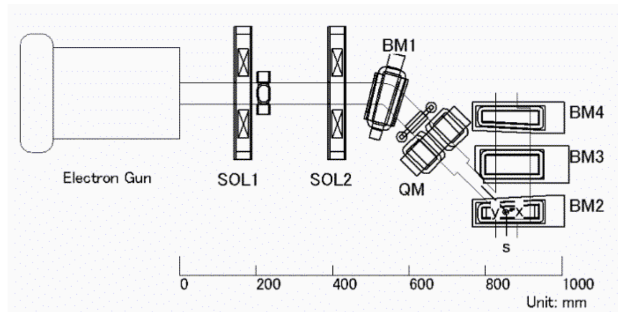


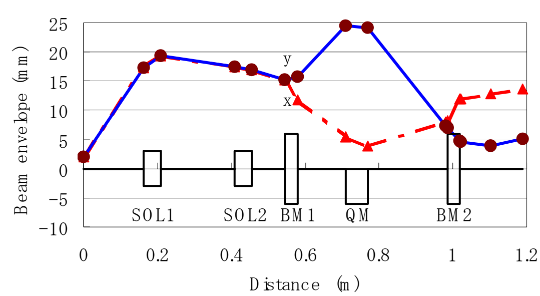
Figure 1: Schematic drawing of the LEBT of the CW microtron.

Table 1: Beam parameters at an exit of an electron gun.

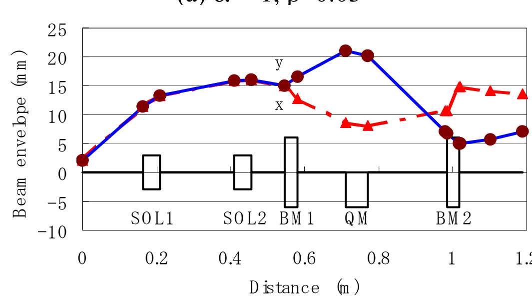
Beam energy		80 keV
Unnormalized emittance (100%)		51 π mmmrad
TWISS parameters	α	-3 ~ 0
	β	0 ~ 1

Table 2: Design beam parameters at an exit of the LEBT.

TWISS Parameters	α	-1 ~ 1
	β	0 ~ 2



(a) α =-1, β=0.03



(b) α =0, β=0.03

Figure 2: Two typical examples of beam envelopes of the LEBT. Emittances are 100 π mmmrad.

beam simulation and shown in Table 1 [2]. Table 2 shows design parameters at an exit of the LEBT. The LEBT is designed using MAD [3] and TRANSPORT [4]. In the LEBT, the length of the chicane magnet is determined by the layout of the CW microtron. The bending radius of the BM2 is small, which has much effect on transverse beam focusing. Edge angles and fringe fields of the bending magnets should be adjusted accurately. The fringe field effect is introduced into MAD and TRANSPORT as a field integral (FINT). Calculation results show that the FINT of BM1, BM2, and BM3 are 0.39, 0.33, and 0.33, respectively. Figure 2 shows two typical examples of beam envelopes of the LEBT. Instruments of the LEBT were designed and made based on these results.

3 BENDING MAGNET

Studies of the fringe fields of the bending magnets were done with a magnetic field calculation and measurement. The FINT is calculated with POISSON and TOSCA. The FINT is given by

$$FINT = \int_{-\infty}^{\infty} \frac{B_y(s)(B_0 - B_y(s))}{g \cdot B_0^{\,2}} ds \; ,$$

where By(s) is the magnitude of the fringing field on the magnetic mid-plane, B0 is the asymptotic value of By(s) well inside the magnet entrance, and g is the full gap of the magnet [5]. The FINT of the bending magnets are smaller than that of a typical magnet (0.45) [4]. Figure 3 shows a schematic drawing of the BM2. The BM2 has auxiliary pole pieces (clamps). Figure 4 shows calculation and measurement results of the magnetic field distributions. The magnetic field calculations were done with POISSON. The calculation result of the BM3 is in agreement with the measurement results. The calculation result of the BM2 is different from the measurement results significantly. Figure 5 shows calculation and measurement results of the FINT as a function of the gaps of the clamps. These results show that the FINT is proportional to the gaps of the clamps. The calculation results of the FINT of the BM2 and the BM3 are accuracies of 10% and 3%, respectively. A magnetic field calculation of a three dimensional model of the BM2 was

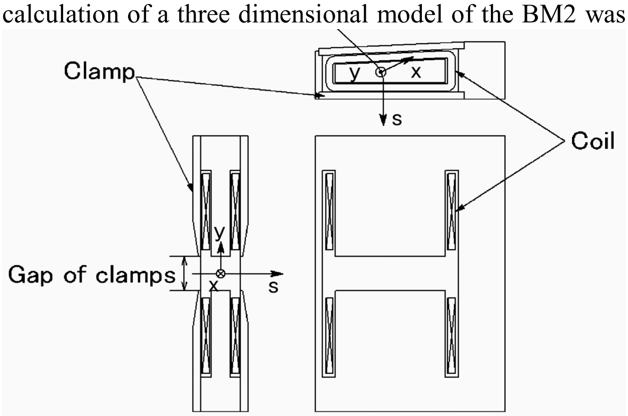
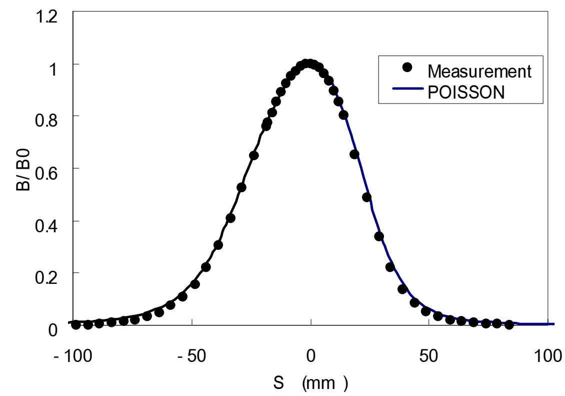
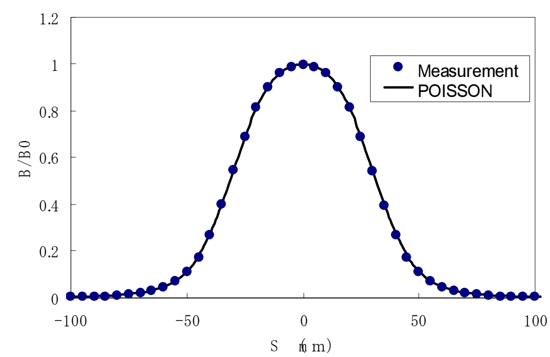


Figure 3: Schematic drawing of the BM2.

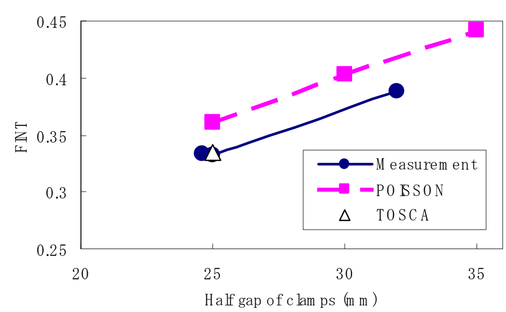


(a) BM2

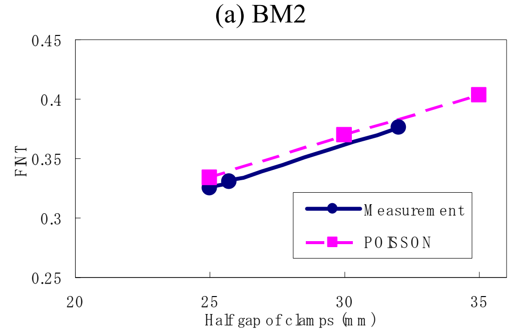


(b) BM3

Figure 4: Calculation and measurement results of the magnetic field distributions.



(a) BM2



(b) BM3

Figure 5: Calculation and measurement results of the FINT as a function of the gap of the clamps.

done with TOSCA. The FINT calculated with TOSCA is in agreement with the measured FINT, as shown in Figure 5. Difference between the accuracies of the calculations with POISSON is due to three dimensional effects of shapes of the bending magnets. Because the BM3 is an approximately rectangular bending magnet, the accuracy of the calculation results of the BM3 is better than that of the BM2. A bending magnet which is short along a beam orbit should be designed with a three dimensional magnetic field analysis program.

4 EMITTANCE MEASUREMENT

The transverse beam emittances have been measured and compared to the calculated emittance. A measurement beamline has been constructed to measure the emittaces of the electron gun. The beamline is straight and consists of the electron gun, the SOL1, the SOL2, the QM, and a beam profile monitor. A measured beam was a 500 MHz CW beam. A peak beam current was set to 5 mA, 10 mA, and, 20 mA. A beam size was measured with the profile monitor, as a quadrupole strength of the QM was varied. Figure 6 shows the beam size as a functions of the quadrupole strength. The measurement results are fitted with a parabolic function. The beam emittace is obtained

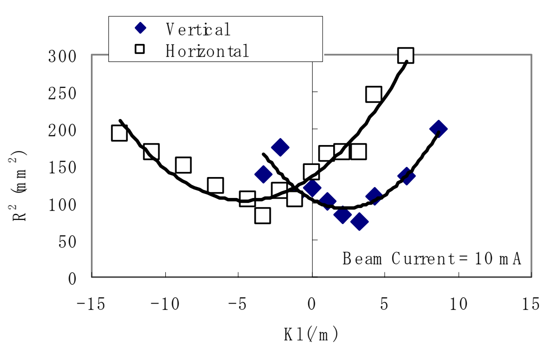


Figure 6: Measurement results of the beam size as a function of the quadrupole strength.

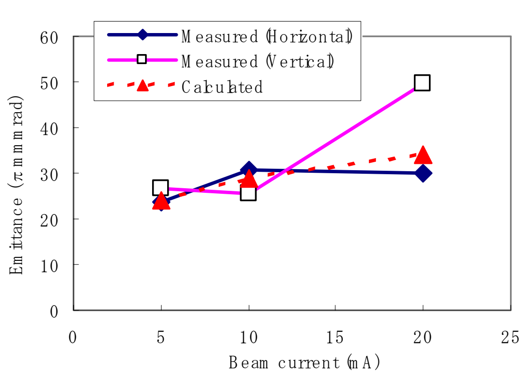


Figure 7: Beam emittances (100 %) as a function of the beam current.

from parameters of the fitted parabolic function. Figure 7 shows the measured 100 % beam emittances and the calculated 100 % beam emittance. In the calculation, a horizontal emittance is equal to a vertical emittance. At the peak current of 20 mA, the profile monitor was saturated. For this saturation, the measured beam size may be larger than the real beam size. The measured emittances are in good agreement with the calculated emittance except for a vertical emittance at the peak current of 20 mA. Therefore, the calculated emittance is reasonable for the design of the LEBT. A beam test of the LEBT shown in figure 1 will be done.

5 ACKNOWLEDGEMENTS

The authors would like to thank Mr. K. Ogata and Mr. N. Matsumoto of Tokin Machinery Corporation for measurements of the magnetic field of the magnets. They also wish to thank Mr. T. Hirano, Mr. K. Hanakawa, and Mr M. Yamada of our company for helpful discussions.

6 REFERENCES

[1] H. Tanaka, "Design of CW Microtrons using a 500 MHz RF Cavity for Industrial Application", Proceedings of the 12th Symposium on Accelerator Science and Technology, Saitama, Japan, 107, 1999.

[2] H. Tanaka, Y. Pu, T. H. Kim, Y. Makita, C. Tsukishima, T. Nakanishi, and S. Nkamura, "Beam Dynamics in a CW microtron with a 500 MHz RF cavity for Industrial Applications", Proceedings of the 13th Symposium on Accelerator Science and Technology, Osaka, Japan, 2001.

[3] H. Grote, and F. C. Iselin, "The MAD Program Ver.8.19 User's Reference Manual", CERN/SL/90-13, Geneva, Switzerland, 1996.

[4] D. C. Carey, K. L. Brown, and F. Rothacker, "Third-Order TRANSPORT with MAD input A Computer Program for Designing Charged Particle Beam Transport Systems", SLAC-R-530, USA, 1998.

[5] K. L. Brown, "A First- and Second-Order Matrix Theory for the Design of Beam Transport Systems and Charged Particle Spectrometers", SLAC-R-75, USA, 1982.