OUTPUT BEAM CHARACTERISTICS OF 150 MEV MICROTRON

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Abstract
Sub-picosecond electron pulses are desirable for generating femtosecond X-ray pulses. By numerical simulation, it has become clear that racetrack microtron (RTM) has unique features to produce very short electron bunches by itself. In addition, it has proved experimentally that RTM has beneficial characteristics to accelerate only an excellent quality beam in both emittance and energy spread. The measured and calculated results of such distinctives are shown in this paper.

1 INTRODUCTION

High quality X-ray beam of the pico- to femtosecond pulse width is an indispensable tool for the investigation of various phenomena in the same time scale. Thomson Scattering between electrons and laser beams is considered to be the most promising to generate such the excellent X-ray pulses[1]. For such the purpose, it is inevitable to obtain a high quality electron beam of very short and low emittance pulses.

RTM has been proved to be the best candidate to realize the above interaction because of its compactness which is essential in those experiment. When we adopt new technology of RF gun with photo cathode[2] in the injection system of conventinal RTM, sub-picosecond electron pulses will be extracted as an output beam with no other sophisticated technology such as the bunch compressing magnets system.

In order to acquire the basic knowledge of such the conventional RTM[3,4], which is popular as the injectors of many compact SR rings, we have carried out the measurements of 150 MeV beam. We also performed various simulations numerically and compared the results with measured ones. Those simulations have shown us the new concept, which was bunch shortening effect of RTM. It becomes very advantageous when we intend to product femtosecond electron bunches in the future.

2 EMITTANCE MEASUREMENTS

Figure 1 shows the top view of 150 MeV RTM. It has two 180 deg. bending magnets (BM) with reverse field ones in front of them, one accelerating cavity of 0.5 m long placed on the first orbit near the injection point, and the 80 keV low energy injection system using a thermionic gun. While circulatng RTM, vertical focusing is mainly given by the effect of field gradient of BM and horizontal focusing by the only single quadrupole (QSF) on the same axis as the cavity (see Figure 2). Main parameters of 150 MeV RTM are listed in Tabel 1. We have manufactured four RTMs since 1988, the principle values of them are the same up to now, suitable for a injector of SR rings and not for making as short pulses as possible. We once measured the emittance of low energy 80 keV beam from the thermionic gun keeping the record about 50~100π mm.mrad since then.

Emittances (εx, εy) of the 150 MeV beam were evaluated from the measurement of various beam profiles (σx, σy) observed on the screen monitor #2 of the beam transport line (BT) in Figure 2. Profiles were controlled by changing the focusing force of two quadrupoles, Q1 and Q2. The measured (σx, σy)'s are fitted to the following equations by the rms method;

$$\sigma_x = \left(\varepsilon_x \cdot \beta_x + \eta^2 (\Delta p/p)^2\right)^{1/2}$$

$$\sigma_y = \left(\varepsilon_y \cdot \beta_y\right)^{1/2},$$

where the dispersion η = 0.854 m at the exit of 150 MeV RTM. An example of the fitted results is shown in Figure 3 as a function of Q1 strength.

Thus, Twiss parameters and emittances were obtained at the entrance of the extraction magnet. We compared various calculated values and concluded the followings as the most probable value;

(εx, εy) rms = (0.11π, 0.07π) mm.mrad

ΔE/E = ±0.06 %

There exists a possibility, however, that those values may vary about a factor of 2 or so for the horizontal parameters, εx and ΔE/E, because of their coupled effects. On the contrary, there is little room to vary for the vertical parameter, εy, because it behaves independently.

Figure 4 shows the simulation results assuming the initial emittance of the 80 keV beam as 100π mm.mrad, where ellipses in the figure represent the calculated rms emittance at the extraction magnet. In the figure, εx looks much larger than •y because of the momentum dispersion. The simulated results are;

(εx, εy) rms = (0.035π, 0.015π) mm.mrad

ΔE/E = ±0.05 %

Compared both the emittances, the measured values are slightly larger than the calculated ones by a factor 3~5 except the energy spread. When taking into account the difference of both situations, that is, simulations have been carried out under the ideal condition, it should be reasonable to find such the level of mismatch in the characteristics of accelerated beam.

3 BUNCHING EFFECT

We have done much simulations of RTM so far. The most innovative discovery among them is the bunch shortening effect of the normal RTM. This fact suggests us the possibility to have much the shorter pulses than the length normally expected from the width of its orthodox longitudinal acceptance, which lies at around 32 degree. It is equivalent to 32 picosecond when the common S-band 2856 MHz is adopted as the frequency of accelerating cavity. From Figure 5, we can see the evidence of this effect, that is, even the 100π mm.mrad initial emittance, the main part of the accelerated electrons are gathered together rather in a short range of the phase. We investigated the relationship between initial and final phases of the beam, limitting the initial emittance of 80 keV beam to 10π mm.mrad. Figure 6~7 are obtained from such the condition. If looking precisely into the distribution of final phase in Figure 6 excepting the tails dropping out to both the sides, we can extract the substance of the bunching effect in Figure 7. Here the bunch shortening effect is much more obvious, 1σ of this peak is estimated to 0.36 degree, which corresponds to 0.7 picosecond FWHM. As seen in Figure 7, when limitted the initial phase within 4 degree which is to be a width of the beam from an RF gun, initially the broad beam in phase becomes the very sharply bunched beam finally.

4 CONCLUSION

The low emittance beam of RTM was proved by the measurements of the 150 MeV accelerated beam, which agreed slightly well to the values prospected by numerical simulations. The results predict that we can easily have sub-picosecond electron pulses in hand when the conventional thermionic gun is replaced by an RF gun with photocathode.

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REFERENCES

[1] M. Washio, et al., "Femtosecond X-ray Pulse Generation Using a Low Emittance Electron Beam and a High Power Laser", 7th China-Japan Bilateral Symp. on Radiation Chem., Oct. 28, '96, Chengdu, China.

[2] D. T. Palmer, et al., "Microwave Measurements of the BNL/SLAC/UCLA 1.6 Cell Photocathode RF Gun", PAC95, May 1-5, 1995, Vol.2, pp.982-984.

[3] T. Hori et al., "Improvement of 150 MeV Racetrack Microtron", PAC91, May 6-9, 1991, Vol.5, pp.2877-2879

[4] T. Hori et al., "Racetrack Microtron : Injector for Compact SR Light Source AURORA"(in Japanese), Sumitomo Heavy Ind.'s Tech. Review, vol.39, No.116, Aug. 1991, pp.46-62.

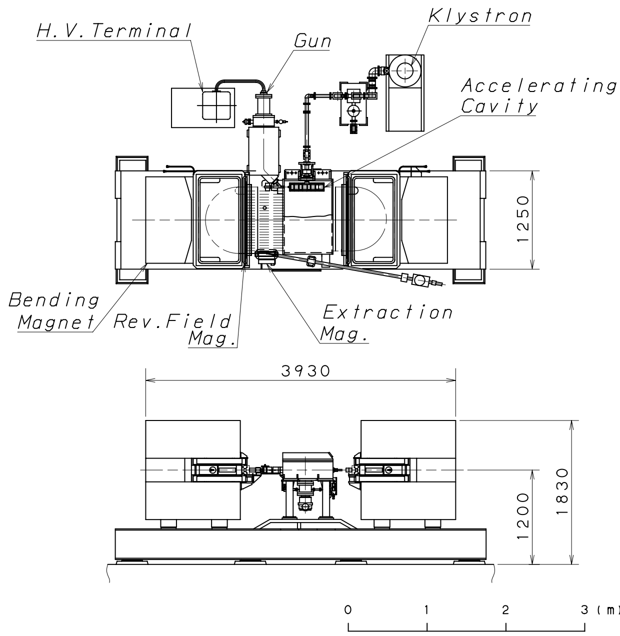


Figure: 1 Top view of 150-MeV microron with conventional injection system.

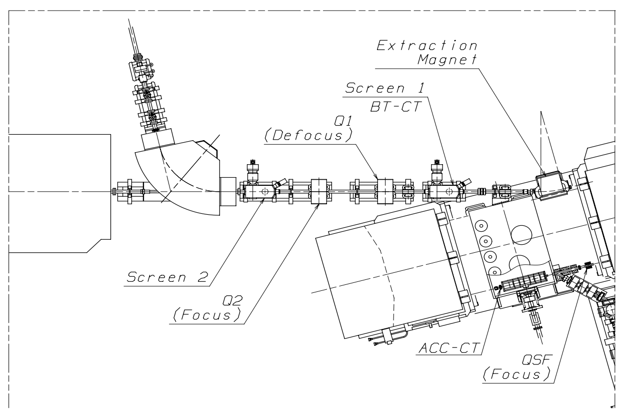


Figure: 2 Device layout used in emittance measurements.

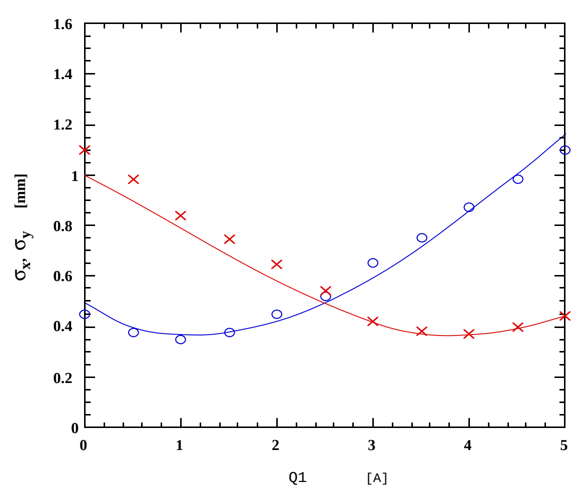


Figure: 3 One of many fitted results derived from measured beam profile.

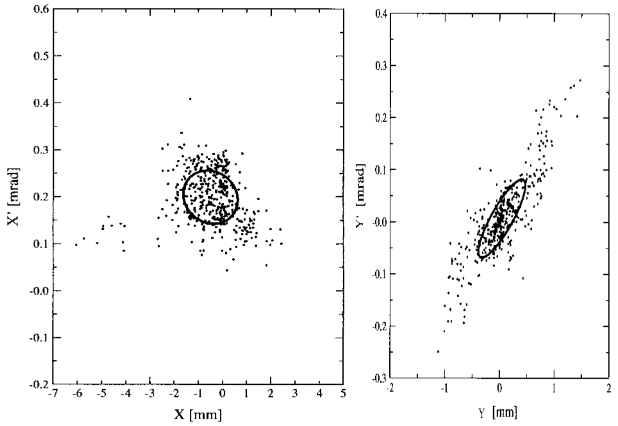
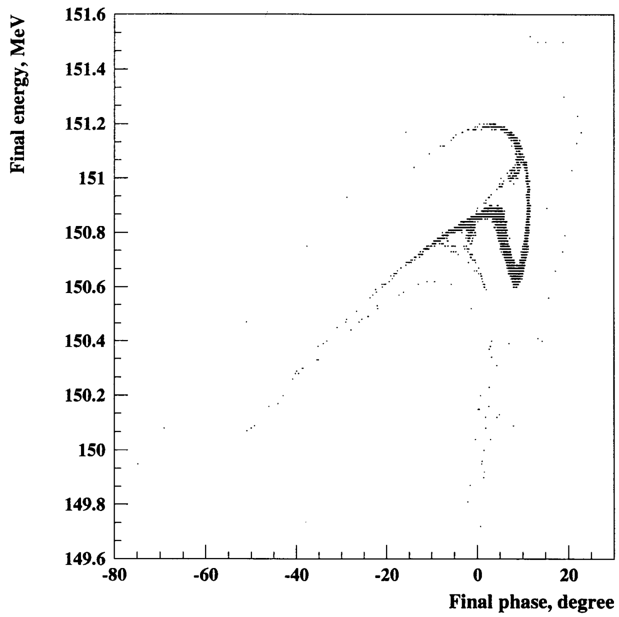


Figure: 4 Caluculated εx and εy (rms) of 150 MeV beam.



Figur: 5 Energy vs. phase of 150 MeV beam.

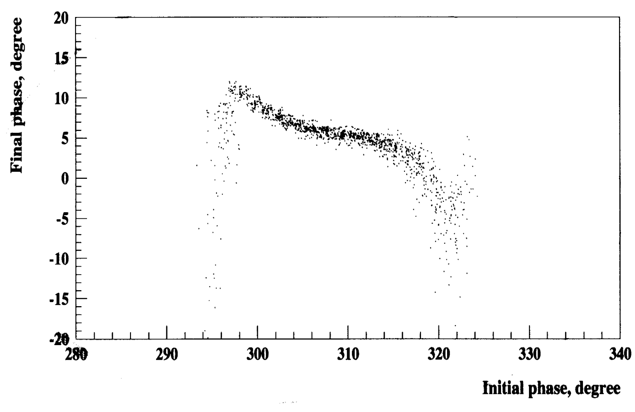


Figure: 6 Correlation between initial and final phase.

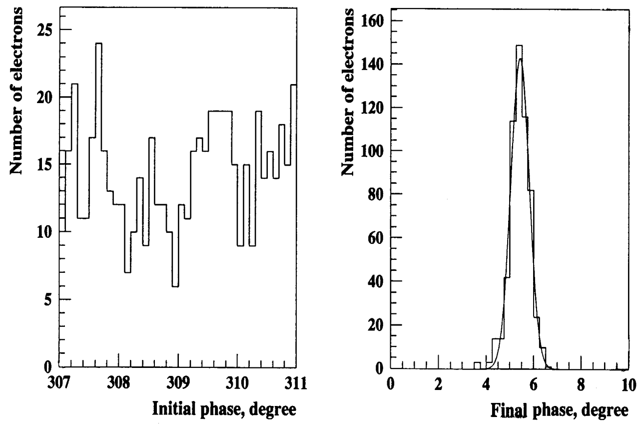


Figure: 7 Effective bunching of RTM from broad initial phase to narrow final phase.

Injection Energy	80	keV
Final Energy	150	MeV
Peak Current	10	mA
Pulse Width	0.1~4.0	μsec
Repitition Rate	1~100	Hz
Emittance	<1π	μm.rad
Energy spread	±0.1	%
Circulating No.	25	laps
Energy gain	6.0	MeV/lap
Bending Field	1.23	Tesla
Field Gradient	0.14	Tesla/m
Reverse Field	0.3	Tesla
RF Frequency	2856	MHz
RF Pulse Width	6.0	μsec
Acc. Tube Type	S.C.C.	
Accelerating Gradient	15	MV/m
Bohr Diameter	1.0	cm
RF Power Source	6.0	MW

Table: 1 Principal parameters of 150 MeV microtron