SIMULATIONS OF RACETRACK MICROTRON FOR ACCELERATION OF PICOSECOND ELECTRON PULSE[*]

M. Washio[#], R. Kuroda, Waseda University, 3-4-1 Okubo, Shinjuku, Tokyo

J. Yang. T. Hori , F. Sakai, Sumitomo Heavy Industries Ltd.,1-1-2 Yato-cho, Tanashi, Tokyo

Abstract

Low emittance sub-picosecond electron pulses are expected to be used in a wide field, such as free electron laser, laser acceleration, femtosecond X-ray generation by inverse Compton scattering, and pulse radiolysis, etc. In order to produce the low emittance sub-picosecond electron pulses, we are developing a compact racetrack microtron (RTM) with a new 5 MeV injection system adopting an laser photo cathode RF gun [1]. The operation of RTM is kept under the steady state of beam loading for long pulse mode so far[2]. We have investigated for the first time by numerical simulation in the case of short- and single-pulse acceleration. As the results, RTM is also useful to accelerate a picosecond electron pulse under a transient state of beam loading. In the simulation, a picosecond electron pulse is accelerated to 139 MeV in RTM for the injection of about 5 MeV pulse with pulse length of 3 picoseconds, charge of 1 nC per pulse, and emittance of 1.8πmm mrad, which corresponds of output of the RF gun.

1 INTRODUCTION

Ultra-short and low emittance electron beams are indispensable tool for the physical chemistry investigation in ionisation and excitation processes of various kind of materials. Further, high quality X-ray beam with the pulse length of the pico- to femtosecond time region can be generated by the Inverse Compton Scattering process between high-brightness and short pulse laser light and the high quality electron beam [1-3].

One of the most powerful methods to generate the high quality electron beam is considered to apply a photo cathode RF gun system in the combination with racetrack Microtron (RTM). Recent rapid progress of the photo cathode RF gun system conducted by the collaboration among the BNL, KEK and SHI[4] promises us to generate suitable electron beams to inject into the RTM with desired beam parameters. In such a way, we can generate short pulse and very low emittance electron beam with the energy up to 150 MeV[5].

The design of RTM has been established and been demonstrated as the injectors of compact SR rings, AURORA-1 and-2[6]. The already-existing design is, however, optimized for the output beam having

somewhat long electron pulse length at around a few microseconds and relatively low peak current, 10mA at the maximum. When we apply the combination of RTM with photo cathode RF gun as the injection system, we have to investigate the behaviours of electron beams on the condition of transient beam loading and effect of chicane magnets for the 5MeV electron injection. The system configuration is shown in Fig. 1. The effects of space charge and synchrotron radiation while acceleration would next be taken into account.

In the first step of the simulation, we have calculated the output beam characteristics obtained from photo cathode RF gun using MAGIC code. In the second step, we have calculated the final beam characteristics as the output from RTM using a modified SUPERFISH code to treat the time dependent acceleration field.
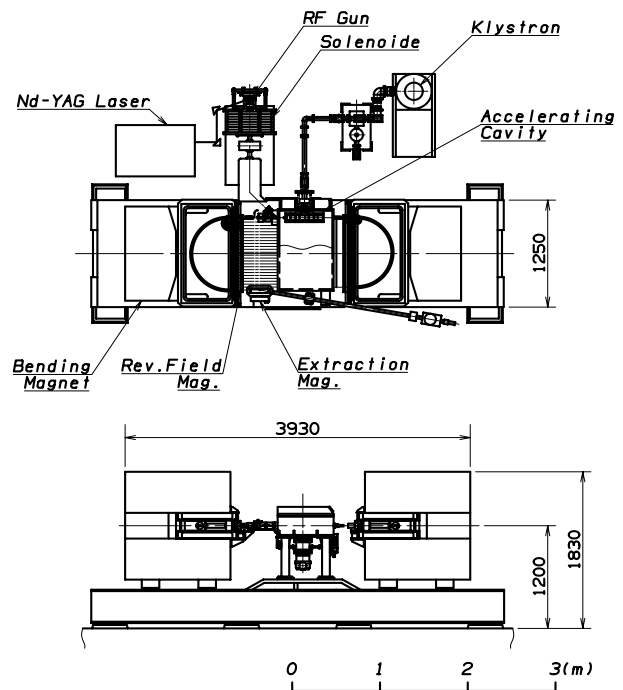

Figure 1 : Top view of 150-MeV RTM with RF gun injection system

2 RF GUN

RF gun using for our simulation is based on so-called BNL type, 1.6 cell s-band cavity structure. Fig 2 shows the typical emittance result obtained for the gun using the following parameters.

- Input laser pulse length : 10ps
- Laser beam spot size in diameter : 2.4mm
- Acceleration Field Strength : 100MV/m
- Resonance Frequency : 2854.62MHz as a π mode
- Energy Gain : 4.9375 ±0.0225 MeV
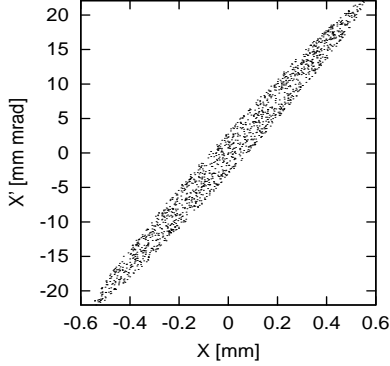- Electron Charge : 100 pC

Figure 2 : Normalized emittance of output beam from RF gun

The obtained normalized rms emittance is about 1.8mm mrad. with the pulse length of 3ps. This emittance value is not so small in the view point of RF gun characteristics. Better emittance can be obtained using other parameters by selecting the injection RF phase and laser light diameter, in the electron charge up to several hundreds of pC, however, acceptance of RTM is much limited and we selected the above parameters for the complete acceptance to RTM

3 MICROTRON

The major components of RTM are two 180 degree bending magnets placed on both end-sides with reverse field one in front of each, one s-band accelerating structure of 0.5 m long placed on the mid-portion of the first orbit near the injection point, and the RF gun as the injector. Here, except this new injection scheme, other sub-systems are precisely the same as the normal parameters of 150 MeV RTM. This means that the optimisation of parameters for high energy and low emittance electron injection does not carried out in this study. The principal parameters of RTM for the numerical calculation are shown in Table 1.

Circulating No.	23 laps
Energy Gain	6 MeV/lap
Bending Field	1.23 and 1.228 Tesla
Field Gradient	0.14 Tesla/m
Reverse Field	0.2919 and 0.2777 Tesla
Chicane Field	0.33 Tesla
RF Frequency	2856 MHz
Accelerating Gradient	15 MV/m
No. of Accelerating Cell	7 full + 2 half cells

Table 1: Parameters of RTM

4 SIMULATION RESULTS

For the simulation of single-bunch of 1nC, we have roughly estimated the stored energy in the acceleration cavity before and after the single-bunch acceleration. Originally, there is about 2 joules of stored energy in the cavity which consists of 7-full and 2-half cells of side coupled type. During the acceleration of 1nC electron bunch, it needs about 0.15 joule when accelerated to 150 MeV. Thus, about 7.5% of stored energy is taken away by the beam which enforces about 3.8% decline of electric field upon the cavity when no refill of RF power is assumed.

We have calculated the beam transmittance while circulating in RTM and the emittance after the acceleration are shown in Figs. 3 and 4 using the input parameters of Fig.2. Beam transmittance data shows that about 82 % of electrons are obtained at the acceleration energy to 139.55 MeV. The emittance data after the acceleration, we have obtained rms-εx, -εy are 0.12 and 0.037 πmm mrad., respectively. These are the smallest values which we have obtained by experiments and calculations[5], however, these are still larger than expected values.

The distribution of (E, ϕ) phase space of accelerated electrons within a bunch are shown in Fig. 5 (right) together with the histogram of energy distribution (left). From the figure, the beam energy after 23 laps of acceleration is read as 139.55 MeV and energy spread $\Delta E/E$ as ±0.07 %. The phase distribution is more clearly shown in Fig.6, where the final distribution are demonstrated. The phase spread is compressed to 1.5 ° after the acceleration, about a half of the initial spread. It is equivalent to 1.5 psec pulse length. When acceleration is performed up to 151 MeV, we can get smaller energy spread down to ±0.02 % of $\Delta E/E$.
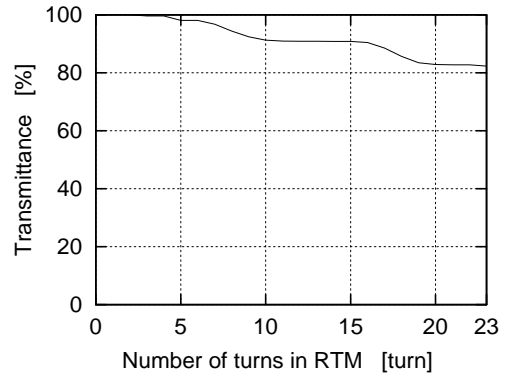

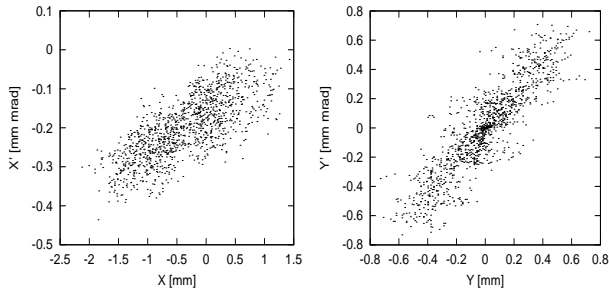**Figure 3 : Beam transmittance in RTM**
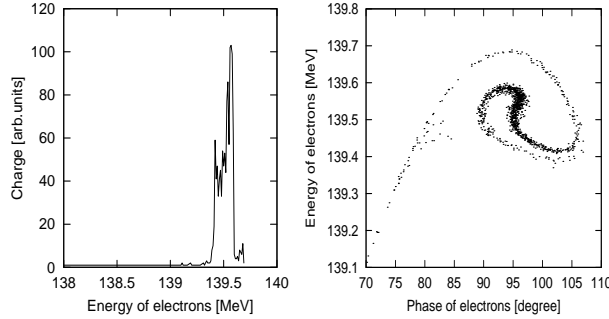
**Figure 4 : Final emittance of
output beam from RTM**

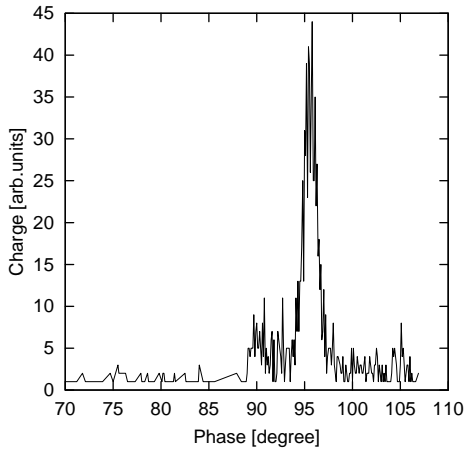**Figure 5 : Final energy spectrum and (E,ϕ)
distribution of accelerated beam**

Figure 6 : Final bunch length at 139.55MeV

5 CONCLUSION

It has been proved by numerical simulations that the acceleration of ultra-short single-bunch electron beam emitted from a photo cathode RF gun about 5 MeV was achieved. However, in the normal RTM parameter does not permit us conservation of normalized emittance. This may be considered that the reverse field of the first orbit is not perfectly arranged to get better ε_x. On the other hand, increase of ε_y may cause by lack of suitable lattice structures. Hence, we have two ways to upgrade the RTM for the acceleration of ultra-low emittance electron. One is to add focussing magnet for the conservation of

ε_y and fine tuning of beam orbit at the reverse field. Other and better way is to be change the system at the first orbit to avoid the reverse magnet and the beam can accelerate through the achromatic orbit.

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, Cengdu, China (1996)
[2] M. Washio et al., "Femtosecond X-rays Produced by Inverse Compton Scattering between a Low Emittance Electron Beam and an Intense Laser Light", J. Surface Sci. Soc. Jpn., Vol.19 No.2 pp23-29 (1998)
[3] J. Yang et al., "Evaluation of Femtosecond X-rays Produced be Inverse Compton Scattering under Linear and Nonlinear Interactions between a Low Emittance Electron Beam and an Intense Polarised Laser Light", Proc. EPAC'98 Stockholm, pp1082-1084 (1998)
[4] F. Sakai et al., "Development of High Duty Operation RF Photoinjector", Proc. 11th Symposium on Accelerator Sci. and Technology, Harima, Japan pp473-475 (1997)
[5] T. Hori et al., "Simulations of Ultra Short Single Bunch Operation on 150 MeV Microtron", Proc. Epac'98 Stockholm, pp517-519 (1998)
[6] T. Hori et al., "AURORA-2: Compact Advanced SR Ring as an X-ray Source", 4th Int'l Conf. On SR Sources & 2nd Asian Forum on SR, Kyongju, Korea, pp148-158 (1995)