核物質非破壊検知用 220MeV マイクロトロンの空間電荷効果

SPACE CHARGE EFFECTS ON 220-MeV MICROTRON FOR NON-DESTRUCTIVE NUCLEAR MATERIAL DETECTION SYSTEM*

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Abstract

A nuclear material detection system (NMDS) based on neutron / γ-ray hybrid approach has been proposed for the container inspection at sea ports [1, 2]. While neutron is to be used for a fast pre-screening, quasi-monochromatic γ-ray beam from the laser Compton scattering (LCS) source will be used for an isotope identification on the precise inspection of the cargoes. Nuclear resonance fluorescence method is going to be employed for the isotope identification because of its superiority in high selectivity and in high penetration capability through the shielding objects. In the system a high energy electron beam of good quality is required for LCS. A 220-MeV racetrack microtron (RTM) is one of the most promising candidates as an electron source for such the practical use. Suppose a few nC/bunch of electrons are accelerated, space charge effects (SCEs) on the RTM are investigated using the tracking code Parmela [3].

INTRODUCTION

At present four sets of 150-MeV RTM are in operation starting from 1990 [4]. While three of them are for the injector of electron storage ring, the fourth is for various experiments including LCS at JAEA. On the contrary to the former three RTMs which have a thermionic gun as the electron source, the fourth has an RF gun as the source. Therefore in principle the fourth accelerates a single bunch at a time. Higher energy RTMs typically 220 MeV for NDMS have been considered on the basis of this well-established machine designing [5-7]. Simulations under no SCE were carried out so far, calculations including SCEs have been executed as shown below.

We suppose around 1 nC charge in a single bunch is necessary for this purpose. However, if much the charge could be accelerated without significant emittance growth, the situation might be much the better. Thus we have investigated the effects of space charge on output beam quality by the simulation code Parmela.

The configuration of RTM was somewhat modified in order to fit for Parmela calculations (Fig.1). Differences between the actually designing RTM and this simulation are described below. The major difference lies on the focusing method.

- The magnetic field in two 180° bendings (1.4 Tesla) is flat, no n-value is added. It means they cannot generate vertically focusing force in the bendings.
- There are no reverse field magnets in front of the bendings. Thus, no edge focus effects are expected which are effective on early circulations in low energy region.
- In compensation, Q-doublets are introduced on every turn. The field gradients of both QF and QD are equal, dB/dx=83 G/cm for the common Q-magnets on the linac axis. The strength of Q-doublets on the back straight sections is decided proportional to the energy of passing beam. Those Q-doublets keep the focal length about the same in all orbits.

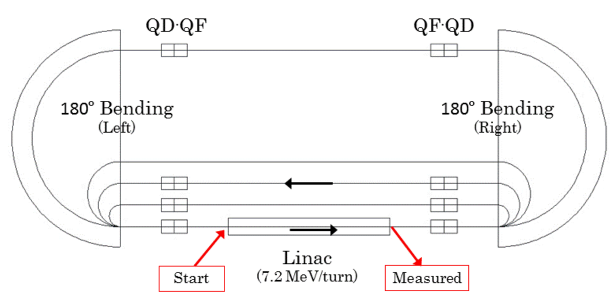

Figure 1: Components layout used in the Parmela simulation, keeping the left-right symmetry.

Simulations were executed with 5000 particles starting from the entrance of the linac at $E_{initial}$=7.2±0.06 MeV, and $\Delta\phi_{initial}$=±9°. Accelerated beam qualities were evaluated at the exit of the linac (Fig.1).

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SPACE CHARGE EFFECTS

The simulation results by the tracking code "mic" [8] excluding SCE were previously reported [6, 7]. Even without SCE, emittance growth was apparent especially enhanced in horizontal phase space (Fig. 2). This results suggest when the smaller initial emittance be assumed, the smaller final emittance would be obtained.

When initial normalized $\varepsilon_{x,y}$(rms)=10 mm· mrad, they come to 12, 15 mm· mrad, respectively, at 223 MeV after 30 times circulation. It should be noted that ε_x(rms)=15 mm· mrad at 223 MeV is the value observed on the linac side. On the contrary, previously reported ε_x(rms)=29 mm · mrad (=0.066 unnormalized) in ref. 5, et al. is the value observed on the back straight side (opposite side from the linac). Because of dispersion free on the linac side, the horizontal emittance on the linac side is estimated about a half of the opposite side's.

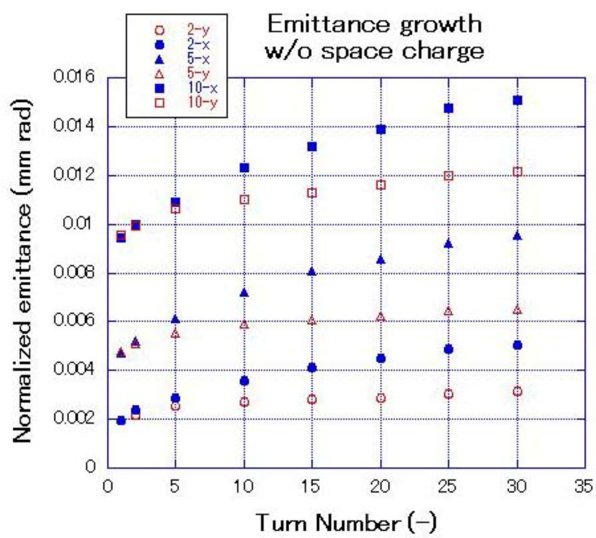

Figure 2: In comparison with Parmela simulations, "mic" results w/o SCE are shown in three cases, where initial normalized $\varepsilon_{x,y}$(rms)= 2, 5, 10 mm· mrad, respectively. Shown are all on the linac side.

SCEs on emittance growth are evaluated up to 3 nC/bunch by the particle tracking code Parmela. The results at 223 MeV after 30 times acceleration are shown in Fig.3 for two cases, one evaluated for the initial normalized $\varepsilon_{x,y}$(rms)=0.2 cm· mrad (B, C) , and the other for $\varepsilon_{x,y}$(rms)=1.0 cm· mrad (D, E). When starting from $\varepsilon_{x,y}$(rms) =1.0, it seems no significant influence appeared on the emittance of the output beam until 1 nC/bunch. Over 1 nC/bunch, however, the effects increase linearly up to 3 nC/bunch. When starting from a smaller emittance like $\varepsilon_{x,y}$(rms)=0.2 cm· mrad, SCEs appear strongly even below 1 nC/bunch. It suggests that when we expect 1nC/bunch for the intensity of output beam, then the initial $\varepsilon_{x,y}$(rms)=1.0 cm· mrad might be adequate, and smaller than this value would not be meaningful.

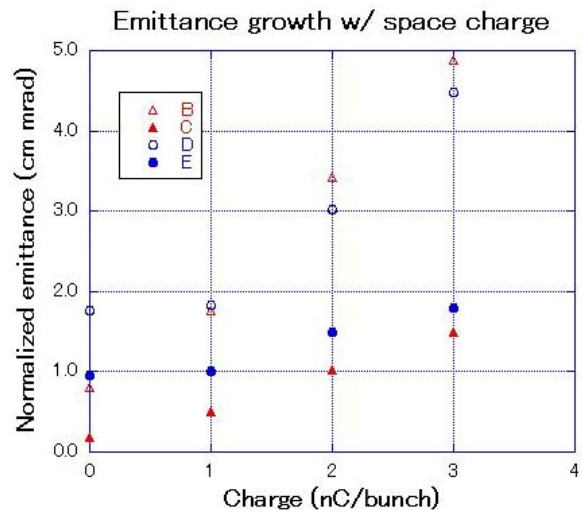

Figure 3: SCEs on emittance growth are evaluated up to 3 nC/bunch by Parmela. The results at 223 MeV after 30 times acceleration are shown.

B=ε_x(rms) / C=ε_y(rms) :
For the case initial $\varepsilon_{x,y}$(rms)=0.2 cm· mrad.
D=ε_x(rms) / E=ε_y(rms) :
For the case initial $\varepsilon_{x,y}$(rms)=1.0 cm· mrad.

Judging from both the calculations, Parmela and mic, with no SCE, the obtained results are about the same, namely, emittances of the output beam ε_x(rms)=1.8 cm· mrad and ε_y(rms)=1.0 cm· mrad from Parmela, and ε_x(rms)=1.5 cm· mrad, ε_y(rms) =1.2 cm· mrad from mic. It suggests that the estimation of SCE by Parmela under the modified configuration shown in Fig.1 might be suitable.

OUTPUT BEAM QUALITY

Output beam qualities acquired by the Parmela calculations are shown (Fig. 4). Distributions of 5000 particles in three phase spaces are plotted on the typical case of 1nC/bunch charge, in summary ε_x(rms)=1.9 cm· mrad, ε_y(rms)=1.0 cm· mrad, and $\sigma(\Delta E, \varphi)$=(0.07MeV, 3.5°).

Up to 1nC/bunch, there is no beam loss while 30 times acceleration. All 5000 particles survived. However, for the case 3 nC/bunch acceleration, transmission efficiency decreases down to 90%. Major beam loss occurs in the bending (right) at low energy circulation. SCEs make vertical beam size significantly large in the bending, resulted in the beam loss eventually. In general, when beam loss occurs, calculated emittance of the output beam tends to be small. Therefore, to compare the emittance around ~100% accelerated beam, the gap of bending is enlarged from 1.0 to 2.0 cm for such the case.

Assuming straight accelerations 30 times to 223 MeV like a long linac with 1nC/bunch charge, there are no emittance growths for the initial $\varepsilon_{x,y}$(rms)=1.0 cm· mrad.

While some increasing found for the initial $\varepsilon_{x,y}$(rms) =0.2 $\rightarrow$ 0.6 cm· mrad.

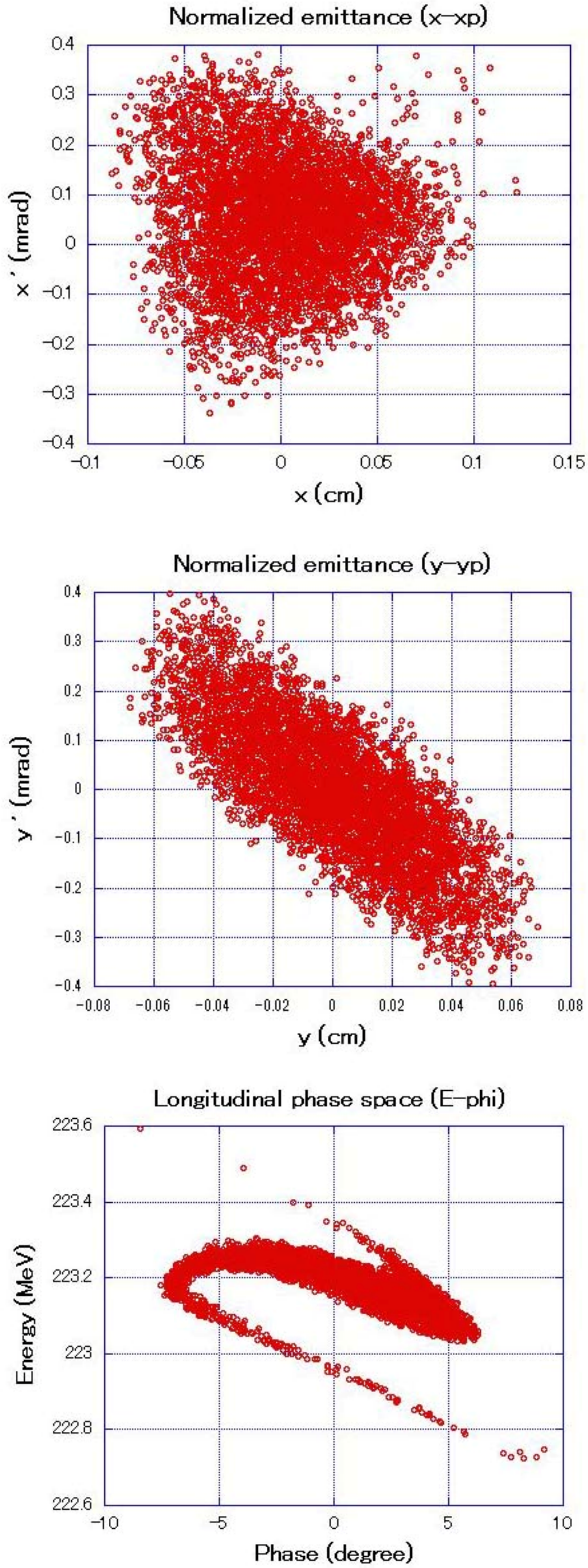

Figure 4: Distributions of 5000 particles at 223 MeV after 30 times acceleration for the case 1 nC/bunch of space charge (Parmela calc.).

Above results suggest us when considering the 223 MeV acceleration by RTM, the expected beam intensity ~1nC/bunch seems appropriate. We do not need to worry about the bad influence of SCE. However, the influence of SCE might be not negligible when considering the acceleration of the charge 2nC/bunch or more.

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