THE MULTI PARTICLE SIMULATION FOR THE CYCLOTRON NIRS-930

M. Nakao#, S. Hojo, K. Katagiri, A. Noda, K. Noda, A. Sugiura, T. Wakui, NIRS, Chiba, Japan
V. Smirnov, S. Vorozhtsov, JINR, Dubna, Moscow, Russia
A. Goto, Yamagata University, Yamagata, Japan

Abstract

Simulation for the cyclotron NIRS-930 of many particles considering space charge effect has been performed and results are compared with experiment. NIRS-930 is used for producing radionuclide used as nuclear medicine and for providing beam for physical and biological experiment. To increase the yield of radionuclides, they need to increase beam intensity of cyclotron. For such a purpose, computer simulation using a code SNOP has been performed. The simulation of proton with 30 MeV of extraction energy with harmonic number of 1 was already performed and well simulated RF phase and extraction efficiency. Then we tried to apply SNOP to 18 MeV protons with harmonic 2. The bunch length of injection beam changes injection and extraction efficiency. This indicates optimizing buncher improves the efficiency. We optimized electric deflector and magnetic channel in order to maximize extraction efficiency. We show the phase space plot to visualize the improvement of efficiency. We intend to apply the parameters suggested by the simulation to actual cyclotron operation to improve beam intensity and quality.

INTRODUCTION

Simulation studies about the cyclotron NIRS-930 [1] (Thomson-CSF, K_b=110 MeV, K_f=90 MeV) have been carried out aiming to understand the beam behavior for increasing beam intensity. If we assume negative ion injection, beam intensity could become more than double. But it needs large scale upgrade of target and shielding. So we hope to improve the injection, acceleration and extraction efficiency to increase beam intensity.

We need to know what causes the beam loss though we can detect the lost beam current only at the probe experimentally. Therefore beam simulation study of the purpose of identifying the beam loss point and find parameters of cyclotron elements which can realize high efficiency.

SIMULATION METHOD

Simulation Program SNOP

Simulation program SNOP [2,3] simulates particle orbit from beam injection to extraction with the electric fields of the inflector, the Dee electrodes and the deflector; the magnetic fields of the main coils, the trim coils and the harmonic coils and the magnetic channel which were calculated by OPERA-3d [4]. The particle orbit was derived continuously from the beginnig point to the lost point (or successfully extracted), dividing to the regions of injection (inflector), acceleration, and extraction internally of the program. The particle orbit was solved by the fourth order Runge-Kutta method. The space charge effect was taken into account both by particle to particle method and by particle in cell (PIC) method using FFT and Poisson boundary. Results of both methods are compared and parameters such as time and space division are determined considering the consistency of the both methods.

Modeling of NIRS-930

Figure 1 shows the calculation model of the NIRS-930. The beam from the ion source sit on the cyclotron yoke is guided by a bending magnet and comes into the central part of cyclotron. The inflector injects the beam with the use of static electric field. NIRS-930 has 4 spiral sectors. Main coil, 12 pairs of trim coils, 4 injection harmonic coils and 4 extraction harmonic coils are utilized to form magnetic field of accelerating region. The beam is accelerated by the RF electric field by the dee electrode whose central angle is 86°. The extraction radius is 920 mm and there are an electrostatic deflector, a magnetic channel and a gradient corrector for beam extraction.

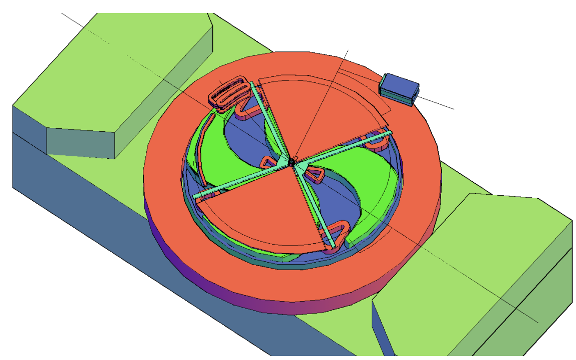

Figure 1: The half cut model of the cyclotron NIRS-930.

INJECTION AND EXTRACTION EFFICIENCY DEPENDENCE ON BUNCH LENGTH

Changing the RF phase difference of buncher and dee electrodes, the efficiency of injection and extraction depends on particle amount in phase acceptance varies. The experimental result is shown in Fig. 2. Injected beam intensity was measured by main probe inserted to the position of the radius of 10 cm and extracted beam intensity was measured by faraday cup at beam line just after extraction form cyclotron. The maximum extraction efficiency was 28 % and which was more than twice higher

ISBN 978-3-95450-131-1

than efficiency of 11 % of without buncher. Figure 2 indicates that the width of the peak is 1σ=66.3±3.0° at injection and 1σ=55.2±0.3° at extraction. This value is determined by the phase acceptance of the cyclotron and injected bunch length.

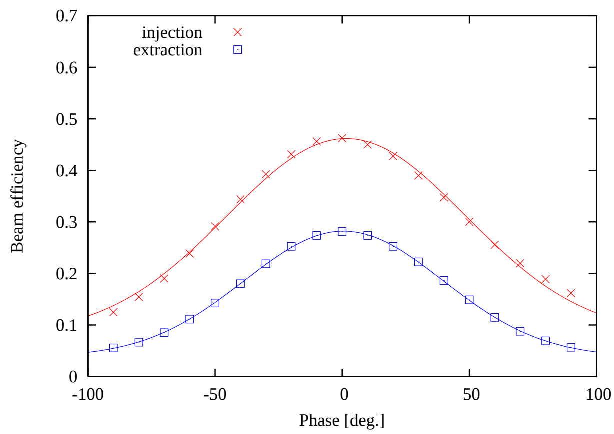

Figure 2: Experimental results of injection and extraction efficiency changing RF phase difference. Each width of the peak is 1σ=66.3±3.0° at injection and 1σ=55.2±0.3° at extraction.

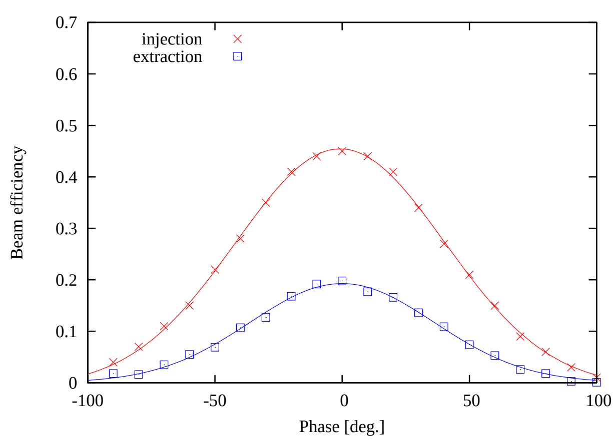

Figure 3: Simulation results of injection and extraction efficiency with a long (60°) bunch. Each width of the peak is 1σ=56.5±2.2° at injection and 1σ=57.0±4.7° at extraction.

Simulation result whose bunch length was 60° of RF period is shown in Fig. 3. The widths of the peaks of beam efficiency in Fig. 2 and Fig. 3 are almost consistent. The origin of Fig. 3 has pedestal is as follows: The particles in bunch distributes only in 60° region in simulation. By contrast, some particles still exist outside of the bunch in actual experiment.

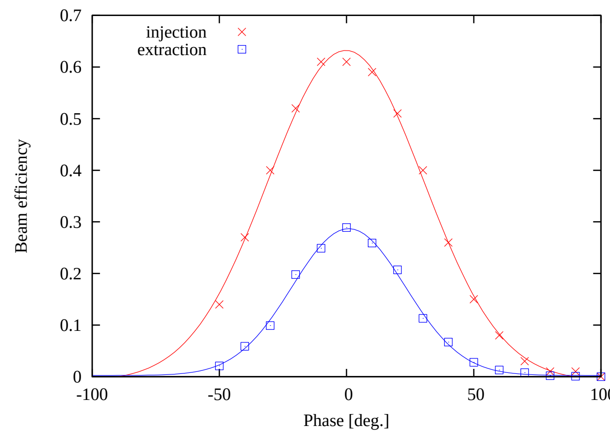

Figure 4: Simulation results of injection and extraction efficiency with a short (30°) bunch. Each width of the peak is 1σ=43.2±0.8° at injection and 1σ=31.4±0.7° at extraction.

Figure 4 shows the simulation result of bunch length of 30°. Figure 4 shows the peak injection and extraction efficiency is higher than that of Figure 3. This indicates shorter injection bunch can achieve more beam efficiency. If we add buncher RF wave form, which is a sine wave presently, to higher harmonics properly, the width of injection bunch will be shorter, and then injection and extraction efficiency can be increased.

ADJUSTMENT OF DEFLECTOR AND MAGNETIC CHANNEL

Figure 5 is a phase space plot just before deflector, showing a place where each particle will lose. The loss points are classified to magnetic channel, deflector electrode and deflector septum. For example, a particle passing rather outside and going outwards is shown in the upper right position of Fig. 5. Such particle will lose at deflector electrode. There is a long and narrow region in the center of Fig. 5, where the particles are lost at deflector septum. In left of that region, particles are going through the inside of deflector and they go around another turn. Such particles are expected to be accelerated by dee electrodes, which increases revolution radius.

Figure 6 shows the simulated single beam bunch of the same turn number overwriting to Fig. 5. Each bunch is ±10° wide, one (×; 0°) is at maximum extraction efficiency and the other (-; 20°) is 20° earlier than that. The expressed particles in Fig. 6 are in a certain time of one bunch. And particles pass before deflector next turn is not shown. Extraction efficiency of two bunches are 59% and 38%, respectively. Although radial spread of 0° bunch is larger than that of 20°, they can be extracted in multiple turns. On the other hand, spread of beam direction of 0° is smaller than that of 20°, which make the extraction efficiency better.

ISBN 978-3-95450-131-1

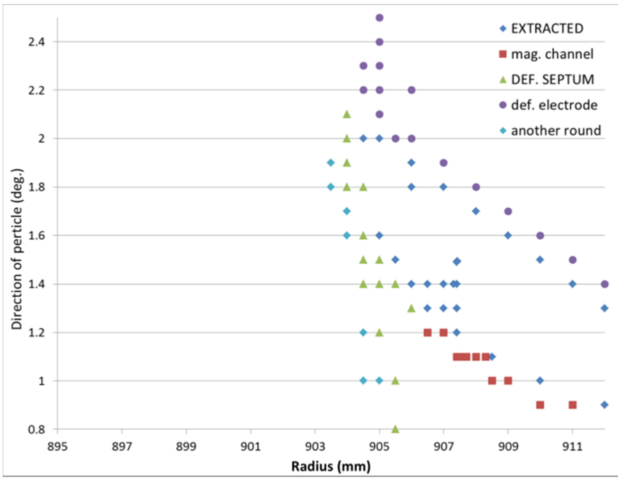

Figure 5: Phase space plot just before deflector, showing a place where each particle will lose.

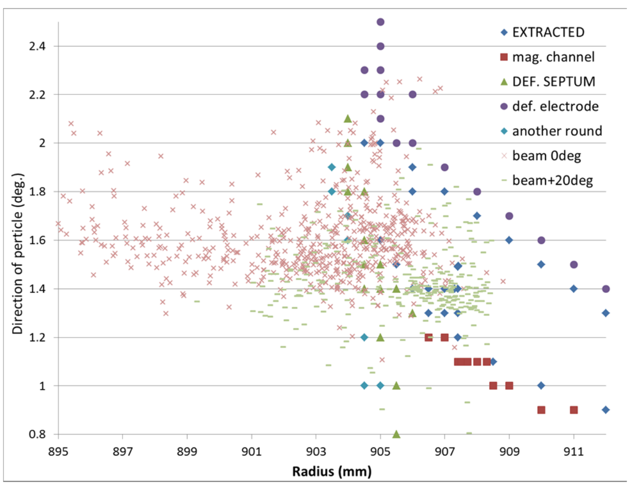

Figure 6: Phase space plot just before deflector, showing a place where each particle will lose. There is also plotted bunch (×) at maximum extraction efficiency and bunch (-) 20° earlier than it.

Calculating tracks of the particles which are lost at magnetic channel, it was found they collided to the slit of right side at the entrance of the magnetic channel. To pass such particles, magnetic channel was shifted inside 5 mm to radial direction. Then each point of Fig. 5 changed to be shown in Fig. 7. It shows the particles lost at magnetic channel in initial situation made to extract. Such an improvement is also possible to the parameters of deflector position and applied voltage in similar way.

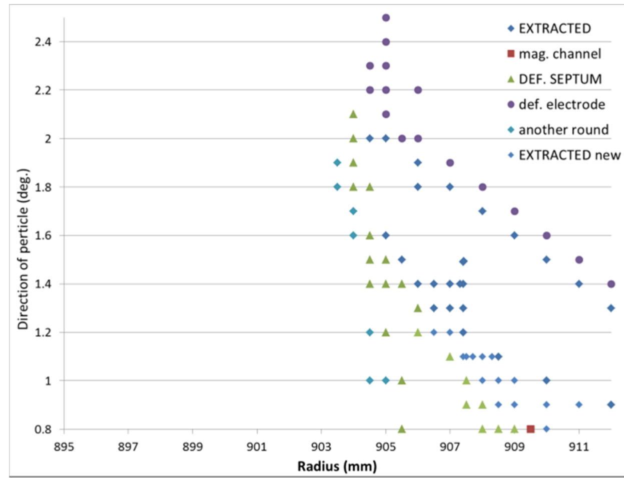

Figure 7: Phase space plot just before deflector showing a place where each particle will lose. Magnetic channel was shifted 5 mm radially outward from the positon of Fig. 5.

CONCLUSION

Simulation study of beam in the cyclotron NIRS-930 was carried out by the use of simulation program SNOP. The simulation suggested if the buncher could collect to the particle in a shorter bunch, the injection efficiency would increase. What is more, it was confirmed and graphically-demonstrated that the beam bunch had to be adjusted to the inside of extraction acceptance in the phase space.

REFERENCES

[1] S. Hojo, et al. "Progress on the upgrade for TRT at NIRS cyclotron facility" In these proceedings HIAT2015 MOPA07 (2015).
[2] V.L. Smirnov, S.B. Vorozhtsov, Proc. of RUPAC2012 TUPPB008 325 (2012).
[3] V.L. Smirnov et al., Proc. of IPAC2012 292 (2012).
[4] OPERA-3D, Cobham plc http://www.cobham.com/

ISBN 978-3-95450-131-1