BEAM TRACKING IN THE 3D DISTRIBUTED MAGNETIC FIELDS

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Abstract

In case that large bore magnets were placed within a short distance, the fringe fields interfere with each other and it is difficult to predict the exact beam behavour because of a non-linear effect. We developed the particle tracking code which can take into account a 3D distributed magnetic field. The 3D distributed magnetic field can be obtained from the commercial application program such as TOSCA which is used for the magnet design. The beam tracking results of the J-PARC RCS injection with a realistic fringe field are presented not only for the injected proton beam but also for the stripped electrons.

EXPANSION OF THE PARTICLE TRACKER TRACY-II

The particle tracker code 'TRACY-II' was developed originally for the simulation of the KEK-PS slow extraction process and it has been applied to the JHF project[1]. The code is written in C which is more extendable and which has more platform portability than Fortran. In order to take into account the realistic firinge field from the large bore magnets, more general particle tracking code 'GenericSolver' which can trace the particle motion in the 3D distributed magnetic field was developed as an additional feature of the TRACY-II. The 3D magnetic field is defined as the 3D vectors on the 3D lattice structure. The particle only sees the 8 vectors on the 8 lattice points around oneself. The field at the particle position is interporated by using the extended Lagrange formula. The interpolation method is updated to more accurate way than the nearest neighbour method [1] though the extended Lagrange formula is also a linear interporation method. Particle trajectory is calculated by solving the Lorentz equation with the 4th order Runge Kutta method[2].

MAGNETIC FIELDS OF THE 3GEV RCS

The beam injection line in the 3 GeV RCS[3] is shown in Fig. 1. There are two bump systems. One is the shift bump and the other is the paint bump. The shift bump system will be fully excited during the whole injection period. On the other hand, the paint bump has a time dependency in order to paint up the RCS beam aperture of 216 π mm mrad with the LINAC beam of 6 π mm mrad. The injection process continues about 320 turns. Each bump system has four bump magnets and they are called as SB1, SB2, SB3, SB4 for the shift bump and PB1, PB2, PB3, PB4 for the paint bump, respectively. There is a carbon stripping foil between SB2 and SB3. Here is the injection point.

[1]J-PARC project in the present day.

[2]The numerical integration module will be replaced by the simplectic integrator. The simplectic integrator insures the simplecticity and has an advantage in the calculation time.

[3]It is still under minor updating.

Field Interference

As seen in Fig. 1, the bending fields to form a bump orbit interfere with the neighbouring magnet because the shift bump magnets are lined closely with respect to their apertures. Moreover the shift bump system is located between two quadrupole magnets QFL and QDL. Because the SB1 is closely aligned to the QFL, the fringe field interference also occur in this area. The situation is the same for the SB4 and QDL. The magnetic field calculation of the shift bump area is carried out applying the whole magnet system including QFL and QDL in order to represent the realistic fringe field interference. Generally the magnet is divided to the mesh elements during the field calculation on the computer. The dividing point must be chosen carefully when the different types of magnets are treated at one time because the pole shapes are quite different for dipoles and quadrupoles. Though it is not so difficult to fit the magnet shape when the mesh size is small, the number of mesh elements which can be treated is limited by the magnet design program in many cases. This is the main difficulty on the magnetic field calculation. In order to reduce the number of mesh elements required in the calculation, the step size along the z (or s) axis is set larger than those of the x and y direction because a simple shape is assumed in z direction. The field was checked with two step sizes of Δz = 100 and 25 mm. It was found that there is no obvious difference on the Δz. It was found that the step size of 100 mm is enough[4] in z direction.

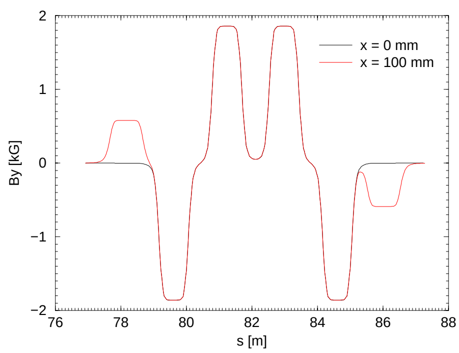

Figure 2: B_y distribution in the shift bump area at x = 0 and +100 mm and y = 0.

[4]If the Rogowski cut was introduced, the step size of z direction also should be small.

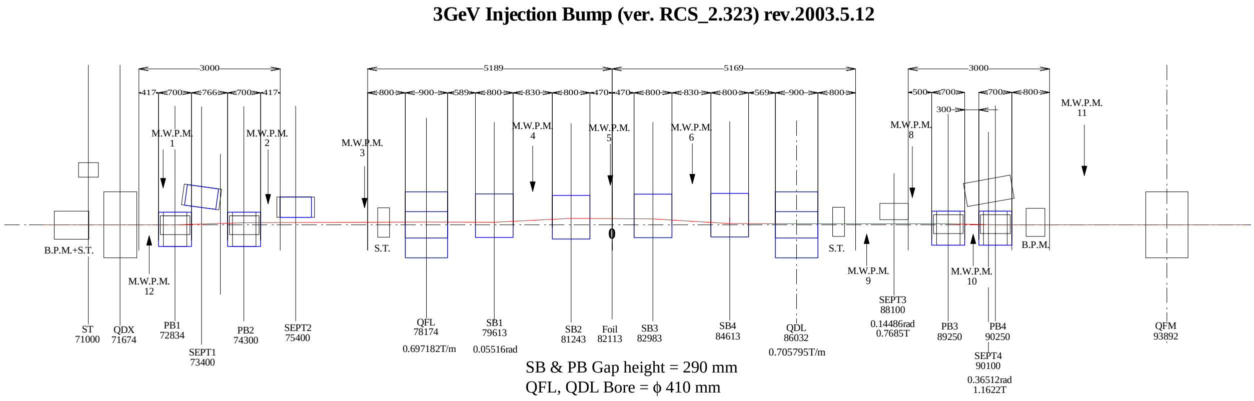

Figure 1: Layout of the beam injection line of the 3GeV RCS.

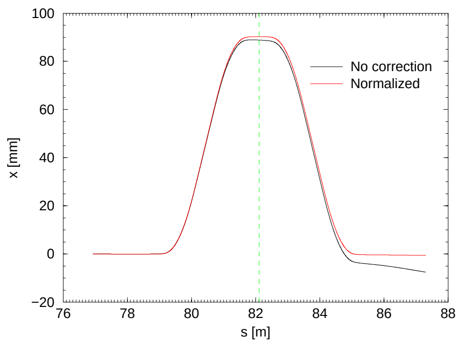

Figure 3: Central orbit trajectory in the shift bump area which started from $x = y = 0$. The black line show the COD, the red line is after the Bl correction and the green dashed line indicates the stripping foil position.

Fig. 2 shows the B_y field in the shift bump area. The black line of $x = y = 0$ mm shows only the shift bump field because there is no quadrupole field with this condition. The field interference between shift bump magnets can be seen here. The magnetic field between SB2 and SB3 does not descend to zero because there are two fringe fields overlapping on the same direction.

Bump Magnet

Four dipole magnets are connected in series in order to form a shift bump orbit. The Bl values obtained from the 3D magnetic field data are listed in Table 1. The field edge is defined as the zero cross point between SB1 and SB2, SB3 and SB4, and the local minimum point between SB2 and SB3. In order to distinguish the dipole field of SB1 and SB4 from the quadrupole field, the field tail faced to the quadrupole magnet is cut off. The effect from this cut off is less than 0.1 mm on the bump orbit.

Due to the fringe interference, the balance in the four bump magnets is broken and it causes the closed orbit distortion as shown in Fig. 3. The effective Bl of SB1 and SB4 are about 1% smaller because the field tail becomes short due to the quadrupole magnet core. The Bl correction is required in order to cancel the Bl unbalance. The red line in Fig. 3 shows the bump orbit after the Bl normalization. The residual COD can be suppressed less than 1 mm. In actual, some shim pieces will be required on the magnet for the real Bl correction.

Table 1: Bl values of shift bump magnets. Design value = 0.175587 Tm

Name	SB1	SB2	SB3	SB4
Bl **[Tm]**	0.1737257	0.1754762	0.1755115	0.1736490

Quadrupole Magnet

In similar way of the dipole fields, quadrupole fields also have an error due to the field interference. In case of quadrupole fileds, the field error becomes a gradient error Gl. The focusing gradient error mainly causes the horizontal tune shift and the defocusing gradient error mainly causes the vertical tune shift. The gradient error is sometimes more harmful than the dipole one. The gradient error can be corrected in the same way as the bump magnets. Fig. 4 shows the betatron tune deviation in vertical phase space comparing to the design matrix after the gradient error normalization.

Though there is no tune difference on the step size along the z-axis, about 1% gradient error still remains between the design matrix and the distributed fields. It might be thought that the origin of this deviation comes from the very long fringe length.

TRACKING RESULTS

Injected Proton Beam

The injection parameters are as follows:

- 400 MeV proton $\Delta p/p$ = ±0.3%
- $\epsilon_x = \epsilon_y$ = 6 or 30 [π mm mrad]
- (x, x', y, y') = (131, -5.5, 0, -3.7) [mm, mrad] on foil
- painting area is 216 π mm mrad

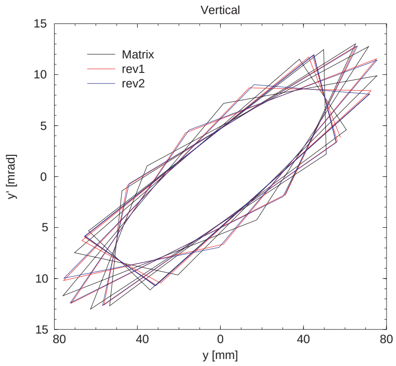

Figure 4: Vertical tune deviation in phase space. rev1 corresponds to Δz = 100 mm mesh and rev2 corresponds to Δz = 25 mm mesh.

For the first step, the 300 turn simulation result is shown in Fig. 5 without paint bump. The particles were put on three emittance ellipses of 216, 162 and 108 π mm mrad. It was found that there is no critical effect from the fringe fields though a small diffusion can be seen in phase space.

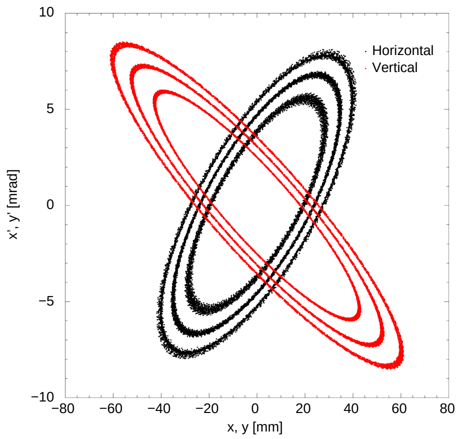

Figure 5: The poincaré map at the center of PB1 during 300 turns without paint bump.

Stripped Electron

The stripped electron from the injection beam brings about the 145W thermal damage. The electron catcher plays a very important roll for the H^- injection. In order to design the electron catcher, the trajectories of stripped electrons are investigated. When the stripped electron has the same speed as the injected proton, the corresponding electron momentum becomes 518.147 $\sim$ 521.266 keV/c. Fig. 6 shows the electron track after the stripping foil. There is a focus point at x = +285 mm in the horizontal motion and the trajectory diffuses in vertical. It indicates that the electron catcher should be placed at x = +285 mm with 80 mm height parallel to the s direction. The cross section view at x = +285 mm is shown in Fig. 7.

Fig. 8 shows the B_x, B_y, B_z at (x, y) = (131, 10) [mm].

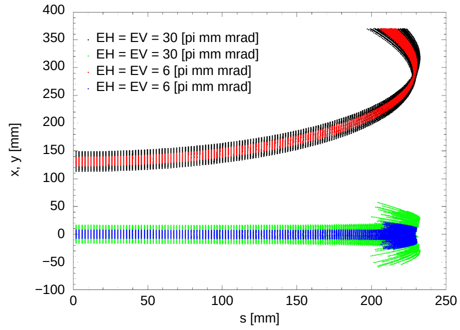

Figure 6: Stripped electron trajectory. The stripping foil is put at s = 0. Horizontal: black and red, Vertical: green and blue.

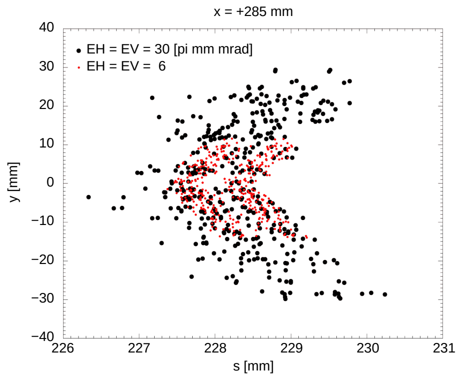

Figure 7: Stripped electron distribution in y-s plane at x = +285 mm.

The amplitude of B_x and B_z is not changed in the range of x = 0 $\sim$ 131 mm. Around the neighbouring of the carbon stripping foil, B_x is almost zero. The B_z is dominant for the diffuse on the vertical direction.

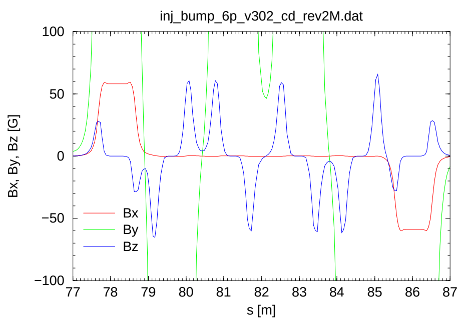

Figure 8: B_x, B_y, B_z distribution in the shift bump area at (x, y) = (131, 10) [mm]. The stripping foil is put at s = 82.113 m

REFERENCES

[1] M. Shirakata et al., Proceedings of EPAC2002, June, 2002(1670-1672)