UPDATED SIMULATION FOR THE NUCLEAR SCATTERING LOSS ESTIMATION AT THE RCS INJECTION AREA

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Abstract

We have updated our simulation for a more realistic beam loss estimation at the RCS(Rapid Cycling Synchrotron) injection area of J-PARC (Japan Proton Accelerator Research Complex). At the injection area, the beam loss caused by the nuclear scattering together with the multiple Coulomb scattering in the charge-exchange foil is the dominant one. A precise estimation of the beam loss can give direct feedback for a smooth operation strategy of RCS towards its goal of a 1MW class machine. The simulation code GEANT3 to take into account the scattering part and the realistic space charge simulation code SIMPSONS were used together for the present purpose. A precise loss together with the loss point identification can thus be obtained from the present method. We are in a stage of making the model more intelligent mainly concerning the CPU time when handling with relatively large number of macro particles for very precise calculation and will present here the interim report.

INTRODUCTION

Like any other high intensity machine, the RCS of J-PARC also has the key issue of keeping the beam loss to a controllable limit in order to achieve its goal of 1MW output power at the extraction energy of 3 GeV, when the injection energy from the Linac is 400 MeV. For the hands on maintenance, the RCS is required to keep the beam loss less than 1W/m, except for the collimation area [1]. At the first stage, the RCS will have injection beam energy of 181 MeV, where the expected output power is 0.6MW at the extraction energy of 3 GeV. Fig. 1 shows the general layout of RCS, which is a three-fold symmetric lattice with a circumference of 348.333m. Each super-period comprises two 3-DOFO are modules with missing bends and a 3-DOFO insertion. The H^- injection and the collimation system are together in the one insertion, where the extraction and RF systems are in other two insertions separately. The insertions are designed to be dispersion free. The RCS will operate with a repetition rate of 25Hz, where the first 500 μsec is for the multi-turn H^- painting injection(about 235 turns with 0.181 MeV injection). Four horizontal paint bump magnets located in the injection area have the role to sweep the closed orbit for paint injection in the horizontal plane, where two vertical paint bump magnets located at the last part of the Linac beam line can perform painting in the vertical plane by sweeping the vertical injection angle. Due to the multi-turn injection, hitting the charge-exchange foil by the circulating beam cannot be avoided. The circulating beam will then be scattered with some probability due to the nuclear and multiple Coulomb scattering. The scattered particles with large angular distribution will hit the beam pipe promptly resulting an uncontrolled beam loss. Particles with small scattering angles will move forward and can be collected in the collimator section. The scattered particles distribution is a function of the particle energy and the foil thickness. A precise estimation of the beam loss from the scattering effect, especially the uncontrolled one is very important to know in order to optimize and control as there are several other uncontrolled beam loss sources in the injection region, for which there may have no room for the optimization or control [2]. As for the optimization and control the scattering effect, it can be designing of the charge-exchange foil, including thickness and size, the injection system, especially the falling time of the bump magnets after the injection is finished, painting process, etc.

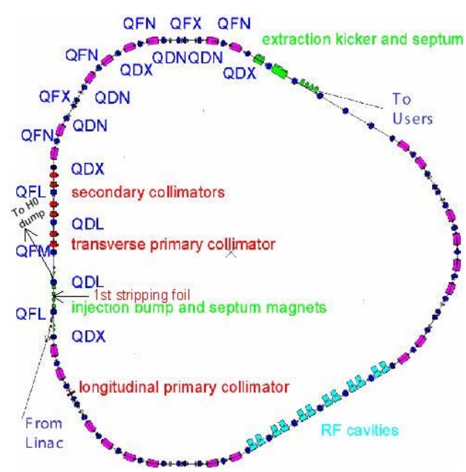

Figure 1: General layout of RCS.

The present work is an updated and a more realistic approach from that reported earlier [3], concerning a realistic beam loss estimation from the scattering effect. In ref. [3], we could not perform the real painting process but assumed a beam distribution having an emittance of 216π.mm.mrad(painting area) in both horizontal(X) and vertical(Y) planes and hits the foil 20 times(average foil hit was calculated to be 20 times by the ASSICM simulation code with the 400 MeV injection [4]). The tracking in the ring was done using SAD [5], where no acceleration as well as space charge effect was taken into account. These information are very important for a realistic beam

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loss estimation, especially for the present purpose. In order to satisfy all the above requirements, we have succeeded to use SIMPSONS [6]. The present method in detail is described in the following section. For the scattering part, we are using GEANT3, same as earlier.

SIMULATION TOOLS AND APPROACH

As mentioned earlier, we have succeeded to use GEANT3 and SIMPSONS together for the realistic purpose of the present work. The scattering effect simulated by GEANT3 directly used in SIMPSONS in order to have the more precise estimation of the beam loss in RCS, especially the uncontrolled beam loss at the injection area due to the scattering effect. The reliability of GEANT3 for the present purpose was already found very satisfactory as reported earlier [3]. The SIMPSONS can track the beam in a ring by calculating the 6-D phase space coordinates taking into account the realistic space charge effect with injection process and is widely used among accelerator physicist [7].

As the present model is in the preliminary stage, for simplicity and to speed up the CPU time, the space charge calculation in SIMPSONS was turned off and moreover, a relatively small number of macro particles were used. The Linac beam energy was considered to be 181 MeV, where the charge-exchange carbon foil with a thickness of 200 μgm/cm^2 was used. The charge exchange efficiency with this condition becomes 99.6%. At each turn, particles hit the foil were identified from the beam distribution in the real space at the foil location as seen in Fig. 2. The foil dimension was 32$\times$36 mm^2. The injection beam emittance was 6π.mm.mrad having almost equal twiss parameters of β_x and β_y(about 10m). Those particles hit the foil are then simulated by GEANT3 in order to know the change of their momentum vectors(P$_x$, P$_y$, and P$_z$), taking into account the nuclear scattering, multiple Coulomb scattering and the energy loss. For the next SIMPSONS run, these 3 parameters including the total momentum and position were updated for those particles when they are in a position of the foil. The idea of updating momenta was exactly same as the way of space charge kick is applied in SIMPSONS for each macro particle. As for the RCS parameters, the nominal betatron tune (Q$_x$=6.68, Q$_y$=6.27) was used and the corresponding multipole field components of the bending and quadrupole magnets were used based on the measured data. The painting method was so-called correlated painting [1]. The present simulation corresponds to the RCS operation of 0.3MW at 3 GeV with the Linac beam power and energy of 18kW and 181 MeV, respectively. The real apertures of all bending and quadrupole magnets as well as the transverse primary collimator were set as designed. A more detail procedures of SIMPSONS together with main parameters can be found in Ref. [8]. The present simulation taking into account the scattering effect was finished upto 50 turns with using relatively small number of macro particles (30,000 and 10,000), however, using a relatively large macro particles(100,000) but without considering the scattering effect the simulation was done until 250 turns(when no foil hits occurs any more) in order to get the average foil hit in the whole injection period plus some additional time during the shift bump magnets fall after the injection is finished. In 500 μsec of injection time, the number of turns is about 235, for the 181 MeV injection, where the Shift bump falling time is about 100 μsec for a bump orbit of about 90mm($\sim$ 1mm/μsec). So, the bump orbit goes down for about 30mm in additional 15 turns after the injection.

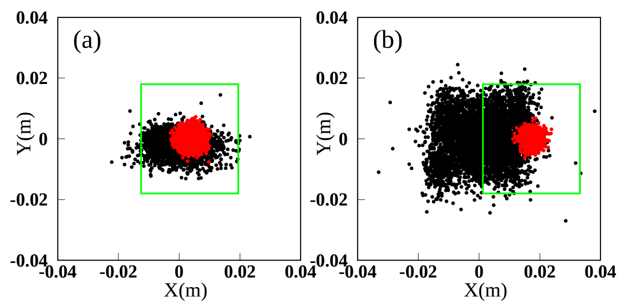

Figure 2: Circulating(black dots) and injection(red dots) beam distributions in real space(X vs. Y) at the foil location [at the beginning of 3rd turn(a) and 50 turn(b)]. The green box is the foil with a dimension of 32$\times$36 mm^2. In the present simulation, injection beam was moved and injected with a speed that bump orbit moves as seen in the figure. That's why the foil was also moved in such a way so as to check the foil hit. In addition to the beam inside the foil, outside beam at the right side of the foil were also considered as hit. In the present foil system, those beam hitting the foil cannot be avoided as the foil will be hang from that side.

RESULTS AND DISCUSSIONS

At first, without taking into account the scattering effect but with a relatively large number of macro particles(100,000), we checked the average foil hit and the beam loss turn by turn upto 250 turns and was done for both space charge OFF and ON. The results show an average foil hit of 23.7 and 23.4 with space charge OFF and ON, respectively, where no beam loss occurred at any point in the ring for both cases. The average foil hits in 50 turns were found to be 15.5 and 15.3 with space charge OFF and ON, respectively. Then, taking into account the scattering effect but with no space charge and with a macro particles of 30,000, the present simulation was finished upto 50 turns. The average foil hit was found to be 15.5 in 50 turns, which was very consistent and moreover exactly same as the upper calculation with a large number of macro particles. The beam loss in 50 turns was found to be about 22W. The RCS operation of 0.3MW at 3 GeV with Linac beam power of 18kW at 181 MeV was considered. All the particles were found to be lost at the primary transverse collimator, located at about 14 meter with betatron phase advance of about 90 degrees from the charge-exchange foil. As the average foil hit in 50 turns(15.5) by taking into account the scattering effect in the present simulation was found to be exactly same as with using a relatively large number of macro particles, we can use the value 23.7 for the average foil hit in 250, in order to draw a conclusion about the total beam loss in 250 turns when considering only the scattering effect(no space charge). The total beam loss then becomes,

(22W in 50 turns) $\times \frac{23.7}{15.5}$ = **34W** in 250 turns.

In order to further check for the fluctuation in average foil hit as well as the beam loss, we performed the same simulation with much less number of macro particles(10,000) for 50 turns. The average foil hit in this case also found be exactly same as the previous case(15.5) but the total beam loss was found to be slightly different and was about 38W. The difference may be due to the fluctuation or the accuracy of GEANT3 related to the input events. The important point in both cases may be is that the large scattering events which will be loss just near the foil were not seen at all as they have very small cross section and thus need a relatively large number of input(macro particle) to generate in GEANT3. Based upon the total cross section due to nuclear scattering only, the loss from the large scattering events was found to be about 2W(with same operation condition) and lost promptly near the foil. However, together with multiple Coulomb scattering the situation may change and is the main concern as well as the interesting part of the present study. We are trying make a model in which SIMPSONS can generate exactly the same distribution as the GEANT does so as the scattering effect can be taken into account inside SIMPSONS and speed up the calculation even with a large number of macro particles. The direct use of GEANT3 as in the present way with a large number of macro particles is also in concern. We can then perform the full simulation of RCS taking all relevant effects.

At this stage we can conclude that the total beam loss with considering only the nuclear scattering and multiple Coulomb scattering (but no space charge) becomes about 35W, where all are found to be lost at the transverse primary collimator. The scattered particles with large scattering angles, which will lost promptly near the foil are not seen due to a small number of macro particles is used at present. The beam loss from the scattering effect will increase almost linearly as a function of the Linac beam power. However, when the foil thickness is fixed considering the charge-exchange efficiency together with the unstripped beam dump limit, an well controlled Linac beam can reduce very much the circulating beam hitting the foil by minimizing the foil size as can be understood from Fig. 2. A speedy falling of the bump magnets after the injection is finished can also reduce the foil hit.

It may be better to mention that considering all relevant effects(except scattering effect) with RCS of 0.3MW operation, the total beam loss becomes 62W(0.34%) [8]. The loss from the scattering effect itself seems almost comparable and would be interesting to see as a total with including the scattering effect in the full simulation and remains as our next challenge.

SUMMARY AND FUTURE PLAN

We have studied the realistic beam loss estimation directly taking into account the nuclear scattering together with the multiple Coulomb scattering at the RCS charge-exchange foil during the multi-turn injection. The GEANT3 simulation code for the scattering part, where the 6-D space charge simulation code SIMPSONS for the beam dynamics part were used together for the present purpose. Due to the time limitation, the simulation was done for only 50 turns with relatively small number of macro particles and moreover without space charge effect. A total of about 35W(in 250 turns) beam was found lost at the primary transverse collimator, with the RCS operation of 0.3MW at 3 GeV, considering Linac beam power and energy of 18kW and 181MeV, respectively. A more advanced study concerning the upgrade of the present simulation model is in progress, where we would like to handle with relatively a large number of macro particles to precisely identify the loss distribution, especially for the uncontrolled one due to the large angle foil scattering, which will lost promptly at the injection area. The present study can give direct feedback in designing the charge-exchange foil size and thickness, the injection bump system, collimation system concerning the design limit and more over an operation strategy for an already designed machine like RCS for the future upgrade, if necessary.

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