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SIMULATION OF TRANSVERSE ELECTRON COOLING AND IBS OF 20 GeV PROTON BEAM AT EICC*

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Abstract

The transverse electron cooling and intra-beam scattering processes of 20GeV proton beam were simulated with the help of the code at Electron Ion collider in China. The transverse cooling time were obtained in the different parameter configurations of storage ring, proton beam, electron cooling device and electron beam. The scattering time of proton beam were presented in the cases of different initial emittance and particle number. The final equilibrium transverse emittance were estimated in the cases of different initial emittance and particle number. From the simulated results, the transverse cooling time of 20GeV proton beam is over 100 seconds. The transverse cooling time can be shorten with the help of proper configuration of the parameters.

INTRODUCTION

Based on the HIAF (the Heavy Ion High Intensity Accelerator Facility, approved in 2015 in China), a high luminosity polarized Electron Ion Collider facility in China (EicC) was proposed to study of hadron structure and the strong interaction and to carry out the frontier research on both nuclear and particle physics.

EicC will be constructed in two phases, EicC-I and EicC-II. In the first phase, the proton beam with energy between 15~20GeV will collide with electron beam with energy between 2.8~5GeV in the collider. Both electron and proton beam are polarized. The luminosity will expect to achieve $2\sim4\times10^{33}cm^{-2}\cdot s^{-1}$.

In the second phase, the energy of proton will upgrade to 60~100GeV, and the energy of electron beam will increase to 5~10GeV, the luminosity will expect to achieve 1×10^{35}. The primary design and some initial parameters of EicC will be found in the reference [1].

In order to obtain the expected luminosity in collider, the polarized proton beam should be cooled by various cooling methods among the whole energy range. In the case of high intensity high energy proton beam especially, the intra-beam scattering effect should be taken into account in the collider design. Some primary simulation on the transverse electron cooling and intra-beam scattering were presented in this contribution.

SIMULATION OF ELECTRON COOLING

The transverse electron cooling time not only depends on the lattice parameters of the storage ring, the Betatron function, dispersion of the cooling section, such as energy, initial emittance and momentum spread of proton beam , but also on the construction parameters of electron cooling device, the strength of magnetic field, the parallelism of magnetic field in the cooling section, the effective cooling length, and the parameters of electron beam, such as radius, density and transverse temperature of electron beam. These parameters are determined by the storage ring and the technology limitation, on the other hand, they are influenced and restricted each other.

With the help of the electron cooling simulation code SIMCOOL [2, 3], the transverse electron cooling time of proton beam were extensive simulated in various parameters in the EicC, such as proton beam energy, initial transverse emittance, and momentum spread. The influence of the machine lattice parameters-Betatron function, and dispersion function on the cooling time was investigated. The parameters of electron beam and cooling devices were taken into account, such as effective cooling length, magnetic field strength and its parallelism in cooling section, and electron beam current.

Proton Beam Parameters

Left diagram of Fig. 1 shows the transverse electron cooling time as a function of the initial emittance. Right diagram of Fig. 1 gives the dependence of transverse cooling time of the transverse direction on the particle number in the proton beam. In the case of other parameters were fixed, the transverse electron cooling time increases with the initial emittance and slightly decreases with the particle number in the proton beam.

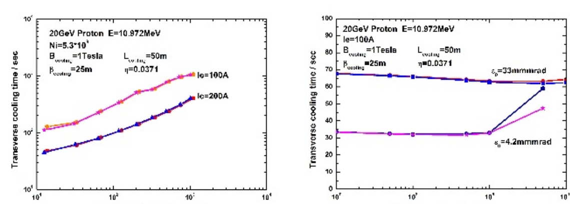

Figure 1: The transverse electron cooling time as a function of the initial emittance (left) and the particle number in the proton beam (right).

Electron Beam Parameters

In order to decrease the transverse cooling time, the current of electron beam and length of cooling section was set as a bigger value. Left diagram of Fig. 2 presents the transverse cooling time as a function of the electron beam current. Right diagram of Fig. 2 indicates the transverse cooling time depends on the transverse temperature of electron beam. In the case of other parameters were fixed, the transverse cooling time decreases with the increasing electron beam current and decreasing transverse temperature of electron beam.

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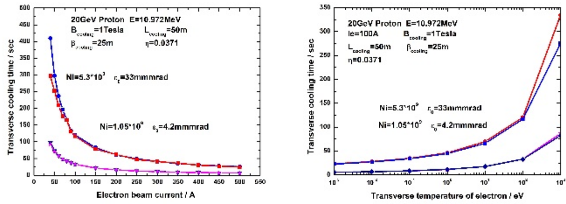

Figure 2: The transverse cooling time as a function of the electron beam current (left) and the transverse temperature of electron beam (right).

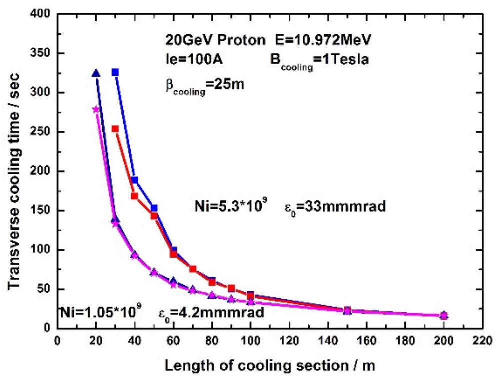

Figure 3: The transverse electron cooling time as a function of the length of the cooling section.

Figure 3 shows the transverse cooling time varies as a function of the length of the cooling section. In the case of other parameters were fixed, the transverse cooling time decreases with the length of the cooling section. The length of cooling section strongly influence the transverse cooling time.

Magnetic Field Parameters

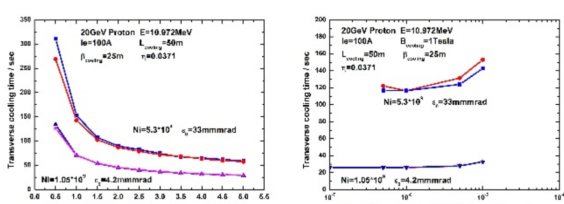

Figure 4: The transverse cooling time as a function of the magnetic field strength (left) and the parallelism of magnetic field (right) in the cooling section.

Left one of Fig. 4 shows the transverse cooling time as a function of the magnetic field strength in the cooling section, and right one of Fig. 4 presents the transverse cooling time as a function of the parallelism of magnetic field in the cooling section. In the case of other fixed parameters, the transverse cooling time decreases with the magnetic field strength in the cooling section. The transverse cooling time decreases with the increasing parallelism of magnetic field in the cooling section. From Fig. 4, one can see the magnetic field strength strongly influence on the cooling time. The cooling time becomes shorter when the magnetic field parallelism is higher in the cooling section.

Storage Ring Parameters

The diagram of Fig. 5 gives the dependence of transverse cooling time on the transverse Betatron function. The transverse cooling time decreases with the Betatron function in the cooling section.

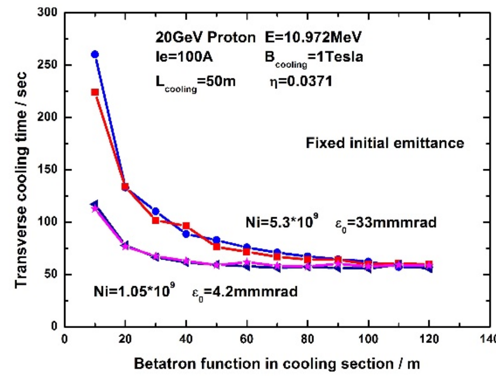

Figure 5: The transverse cooling time as a function of the Betatron function in the cooling section.

Initial Emittance and Particle Number

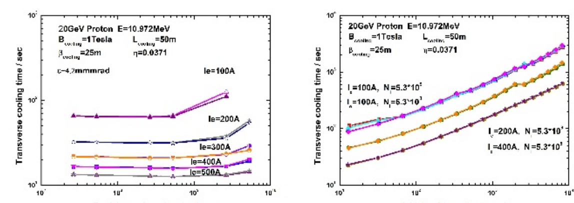

Figure 6: The transverse cooling time as a function of the particle number (left) and initial emittance (right) of proton beam under the cooling with different electron beam current.

The transverse cooling time as a function of the particle number and initial emittance of proton beam were illustrated in the Fig. 6. In the case of other parameters were fixed, the transverse cooling time increases with the increasing of particle number and initial emittance of proton beam.

SIMULATION OF IBS

The luminosity is determined by the quality of proton beam, and the quality of proton beam was determined by the final emittance, momentum spread and longitudinal size.

The ability of electron cooling was determine by the parameters of electron beam, such as electron beam density, temperature of electron and length of cooling section in the storage ring, but also depends on the magnetic parameters in the cooling section.

The effect of intra-beam scattering depends on the particle density of proton beam. It is more serious and important in the situation of high intensity, high energy proton beam.

In order to simulate the intra-beam scattering, the electron beam current was set as zero in the simulation code

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SIMCOOL. There is no cooling effect in this case, and only scattering effect in the simulation. The transverse scattering time was derived from the data fitting of simulation results.

In order to compare the simulated results, only one parameter was changed during the simulation, and the other parameters were kept as fixed.

In the case of fixed initial emittance, for the situation of bigger particle number, the proton beam scattered at the beginning, and then cooled, finally keep the emittance constant. The final emittance were different under the cooling by different electron beam current.

Transverse Scattering Time

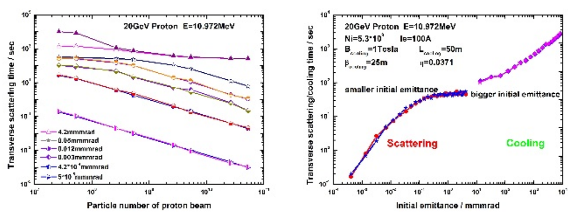

Figure 7: The transverse scattering time as a function of the particle number (left) and initial emittance (right).

The transverse scattering time as a function of the particle number in the proton beam was demonstrated in left of Fig. 7. In the case of fixed other parameters, the transverse scattering time decreases with the increasing particle number in the proton beam.

With respect to a certain particle number in the proton beam cooled by the 100A electron beam, the scattering effect is stronger than the cooling one in the case of smaller initial emittance, the proton beam presents the scattering process, and the scattering of smaller initial emittance is faster than the bigger one.

Final Equilibrium Emittance

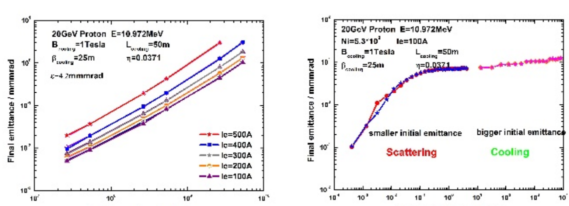

Figure 8: The final equilibrium emittance as a function of the particle number in the case of different electron beam cooling (left) and initial emittance(right).

Left one of Fig. 8 shows the final equilibrium emittance as a function of the particle number in the case of different electron beam cooling. Right one of Fig. 8 presents the final equilibrium emittance as a function of the initial emittance in the proton beam. The final equilibrium emittance was mainly dominated by the particle number in the proton beam.

SUMMARY

From the simulated results, the transverse cooling time of proton beam with 20GeV is over 100 seconds. The transverse cooling time can be shorten with the help of proper configuration of the parameters, such as smaller initial emittance and electron transverse temperature, higher magnetic field strength, parallelism of magnetic field in the cooling section, longer length of electron cooling section, stronger electron beam current, and bigger beta function in the cooling section.

With respect to IBS, the transverse scattering time not only depends on initial emittance, but also depends on the particle number. The final equilibrium emittance was dominated by the particle number in the proton beam.

The emittance, particle number and longitudinal length of proton beam should be optimized and compromise carefully in order to obtain the required luminosity. By the way, the strategy of cooling are important too, such as multi-stage cooling [4] at different energy or different period. The emittance should be cooled to the required value by the stronger electron beam in the first stage, and then the smaller emittance will be maintained by the weaker electron beam.

For the sake of obtaining and keeping the smaller emittance in the case of proton beam with energy 20GeV, the cooling should counteract the scattering at the different situation and period, and provide high quality proton beam for the higher luminosity in the storage ring. The detailed and exact simulation will be necessary for the real lattice design of the EicC storage ring in the future.

In the interest of achieving the required luminosity from physics experiments, the parameters of proton beam, electron cooling device and storage ring should be optimized carefully and compromised each other, and attempt the different configurations from the point of view of realizable technical solutions.

High intensity proton beam and short bunch length was expected to store in a collider with long lifetime and less loss. In order to increase the lifetime of proton beam and decrease the loss, longitudinally modulated electron beam [5] will be attempted to suppress the intra-beam scattering. The traditional DC electron beam in the electron cooler will be modulated into shorter electron bunch with different longitudinal distribution. The stronger cooling was expected in the tail of proton beam and the weaker cooling was performed in the core of proton beam. The proton loss will be decreased and the lifetime will be increased. The intensity of proton beam in the collider will be kept and maintained for long time.

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