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SIMULATION OF ELECTRON COOLING AND IBS AT EICC*

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Abstract

Electron Cooling will be considered in the future project EICC. In this high energy region, electron cooling is very different from the traditional low energy situation. For getting high luminosity, the high intensity and long lifetime of ion beam was required with the help of electron cooling. Electron cooling and IBS were simulated in the cases of high energy and high intensity for typical ion, proton and Uranium. Some initial parameters were obtained from the simulation. It will be helpful for the understanding of high energy electron cooling.

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 12~30 GeV will collide with electron beam with energy between 3~5 GeV in the collider. Both electron and ion beam are polarized. The luminosity will expect to achieve 4×10^{33}.

In the second phase, the energy of proton will upgrade to 60~100 GeV, and the energy of electron beam will increase to 5~10 GeV, 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 ion beam especially, the intra-beam scattering effect should be taken into account in the collider design. Some primary simulation on the electron cooling and intra-beam scattering were presented in this contribution.

SIMULATION OF COOLING

The cooling rate not only depends on the storage ring lattice parameters, the Betatron function, dispersion of the cooling section, initial emittance and momentum spread of ion, energy and charge state of ion beam, but also on the construction 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 electron cooling code SIMCOOL [2, 3], the cooling time of ion beam were extensive simulated in various parameters of the ion beam in the EicC, such as ion 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, electron beam current.

Ion Beam Parameters

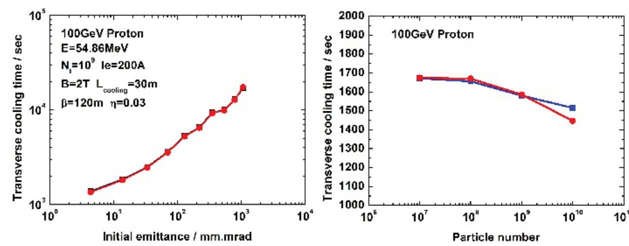

Figure 1: The transverse cooling time as a function of the initial emittance (left) and the particle number in the ion beam (right).

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

Electron Beam Parameters

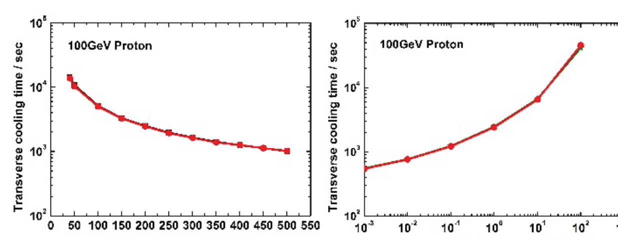

Figure 2: The transverse cooling time as a function of the electron beam current (left) and the transverse temperature of electron beam (right).

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 cooling time depends on the transverse temperature of electron beam. In

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the case of other fixed parameters, the transverse cooling time decreases with the increasing electron beam current and decreasing transverse temperature of electron beam.

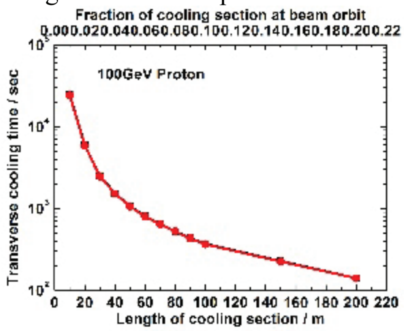

Figure 3: The transverse cooling time as a function of the length of the cooling section.

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

Magnetic Field Parameters

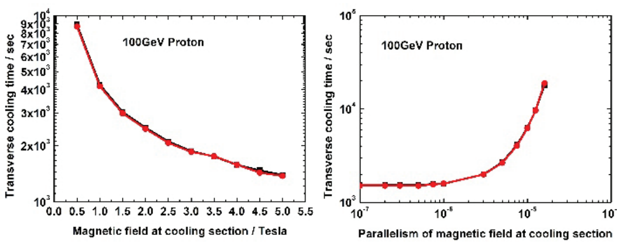

Figure 4: The transverse cooling time as a function of the magnetic field strength in the cooling section (left) and the parallelism of magnetic field in the cooling section (right).

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

Left 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. Right diagram of Fig. 5 presents the transverse cooling time as a function of dispersion. If the dispersion in the cooler position is positive, the cooling time becomes shorter than zero dispersion.

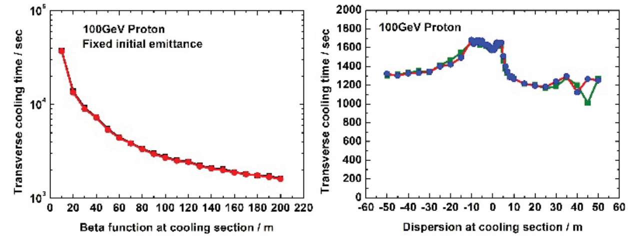

Figure 5: The transverse cooling time as a function of the Betatron function in the cooling section (left) and the dispersion function in the cooling section (right).

SIMULATION OF IBS

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

The ability of cooling was determine by the parameters of electron beam, such as electron beam density, temperature 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 and ion species. It is more serious and important in the situation of high intensity, high energy, high charge state of heavy ion beam.

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

Initial Emittance

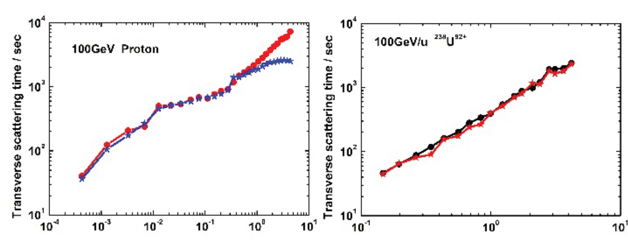

Figure 6: The transverse scattering time as a function of the initial emittance of proton (left) and uranium (right) ion beam.

The transverse scattering time as a function of the initial emittance of proton beam (left) and uranium beam (right) were illustrated in the Fig. 6. In the case of other fixed parameters, the transverse scattering time increases with the increasing initial emittance. The similar behaviour was observed in the two kind of ion beam.

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Particle Number

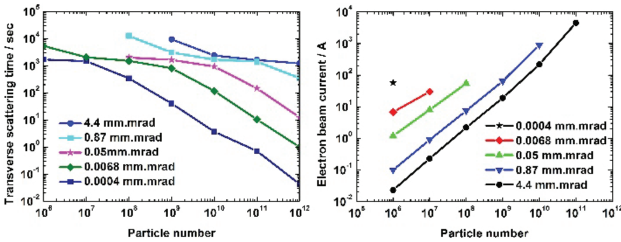

Figure 7: The transverse scattering time as a function of the particle number in the ion beam (left). The necessary electron beam current as a function of the particle number in the ion beam in order to keep the emittance constant in the case of different initial emittance (right).

The transverse scattering time as a function of the particle number in the uranium ion 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 ion beam.

Final Equilibrium Emittance

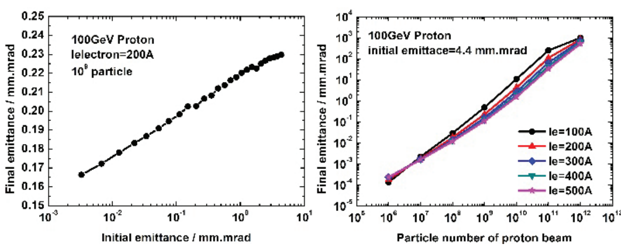

Figure 8: The final equilibrium emittance as a function of the initial emittance in the case of 200 A electron beam cooling (left). The final equilibrium emittance as a function of the particle number in the ion beam in the case of different electron beam cooling (right).

Left one of Fig. 8 shows the final equilibrium emittance as a function of the initial emittance in the case of 200 A electron beam cooling. Left one of Fig. 8 presents the final equilibrium emittance as a function of the particle number in the ion beam in the case of different electron beam cooling. The final equilibrium emittance was mainly dominated by the particle number in the ion beam.

Necessary Electron Beam Current to Keep the Emittance Constant

Right picture of Fig. 7 gives the necessary electron beam current as a function of the particle number in the ion beam in order to keep the emittance constant in the case of different initial emittance. The bigger electron beam current was needed in the case of large particle number.

SUMMARY

From the simulated results, the transverse cooling time of proton beam with 100 GeV is over 1000 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 and dispersion 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 ion beam.

In order to maintain the final emittance as constant value, the minimum electron beam current are different in the case of different emittance and particle number.

The emittance, particle number and longitudinal length of ion 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 100 GeV, 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 in the future.

In the interest of achieving the required luminosity from physics experiments, the parameters of ion 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.

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