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# INFLUENCE OF ENERGY SHIFT OF ELECTRON BEAM ON THE ELECTRON COOLING AT EicC*

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*Abstract*

The cooling process of 20GeV proton beam was simulated in the case of different energy shift of electron beam. The changes of horizontal emittance and longitudinal momentum spread of proton beam with time was presented. The different performances in horizontal and longitudinal direction were observed comparing with the traditional low energy electron cooling. The final emittance and minimum momentum spread was demonstrated in the different parameters configuration. In order to achieve expected cooling requirements, the energy shift of electron beam should be paid enough attention in the case of high energy electron cooling, especially considering a RF accelerator as electron cooling device.

## INTRODUCTION

The basic requirement of electron cooling is that the longitudinal average velocity of the electron beam is equal to that of the ion beam. In order to ensure the desired cooling effect, the energy of the electron beam should be set precisely and accurate matching of longitudinal velocity of the ion beam [1, 2].

The deviation of electron beam energy from the optimal value reflects two requirements. On the one hand, the energy of an electron beam needs to be measured accurately in the electron cooling commissioning and operation. On the other hand, in order to meet the parameters required for cooling, the energy stability and energy spread of the electron beam are required in the design and manufacture of electronic cooling devices.

In future projects, electron cooling plays an important role. It is a necessary means to obtain high brightness and long lifetime ion beams. The performance of electron cooling is related to many parameters, such as ion beam, electron beam, storage ring, electron cooling device, etc. The energy shift of the electron beam is an important indicator. The effects of energy shift of electron beam on the transverse and longitudinal cooling processes should be simulated previously. In particular, the effect on longitudinal cooling, the simulation results have reference value for the design and operation of electron cooling devices in the future.

The 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 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.

The performance of electron cooling is not only related to the ion beam parameters of the storage ring, but also related to the electron beam parameters of the electron cooling device. The important parameters of the electron beam are the transverse and longitudinal temperature of the electron beam.

The electron cooling process of 20 GeV proton beam in EicC was simulated in cases of variety of parameters in the previous studies [3, 4], the longitudinal temperature of the electron beam was not involved in the simulations. The energy shift of the electron beam was not taken into account.

During the optimization of electron cooling process, the average velocity of an electron and an ion is required to be equal. In the case of the given distribution of the ion beam, the energy spread of the ion beam is about the same order of magnitude comparing with the electron beam.

The energy shift of the electron beam is a very important parameter in the electron cooling process, especially in high-energy electron cooling [5, 6]. And the energy shift of the electron beam determines the final parameters of the proton beam after electron cooling, so the effect of energy shift of electron beam on electron cooling is necessary.

The RF accelerator is the option for high-energy electron cooling [7, 8]. The electron beam generated by the RF accelerator has a large energy spread. The necessary measures are needed to reduce the energy spread of the electron beam.

From the experience and experimental results from LEReC BNL [9-11], the longitudinal temperature of the electron beam should be paid enough attention in the case of high energy electron cooling.

The influence of electron beam energy shift on electron cooling process should be investigated. It is useful to understand the requirements for electron cooling, and provide the guidance for design parameters of high energy electronic cooling.

## MOTIVATION

In order to get the required brightness in the future EicC project, not only does it require an intense proton beam, but also it requires a small emittance and momentum spread. Electron cooling can increase the density of phase space and improve the quality of proton beam, Electron cooling plays an important role.

In the second phase of EicC, 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 $1\times10^{35}$.

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With this parameter, conventional electrostatic cooling device cannot meet the requirements. The radio-frequency accelerator system must be used. There are requirements for the quality of electron beams generated by RF accelerator systems in the transverse and longitudinal both directions. The emittance and energy spread of the electron beam are two important parameters.

In this paper, the transverse and longitudinal cooling of a proton beam were simulated with the help of simulation program. The image of the cooling process was obtained. The main parameters of the electron beam were proposed.

## ELECTRON COOLING SIMULATION

A typical transverse cooling process were illustrated in Fig. 1. The normalized horizontal emittance was plotted in the case of the energy shift of electron beam in the order of magnitude of $10^{-3}$. The proton beam was not cooled in the longitudinal direction. As one can see, the transverse cooling present different behaviour at the different energy shift of electron beam.

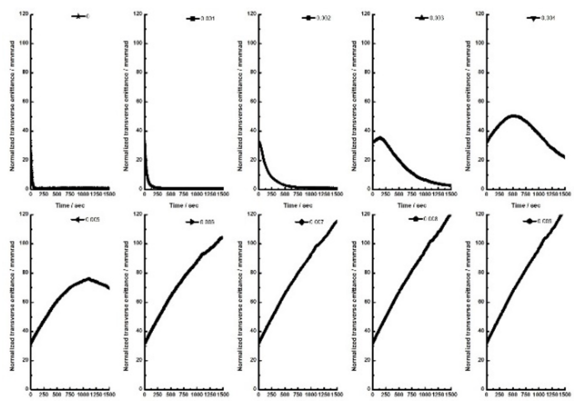

Figure 1: The normalized emittance as a function of the time in the case of different shift of electron energy.

The longitudinal cooling process was presented in Fig. 2. The momentum spread of proton beam was plotted in the case of the energy shift of electron beam in the order of magnitude of $10^{-4}$.

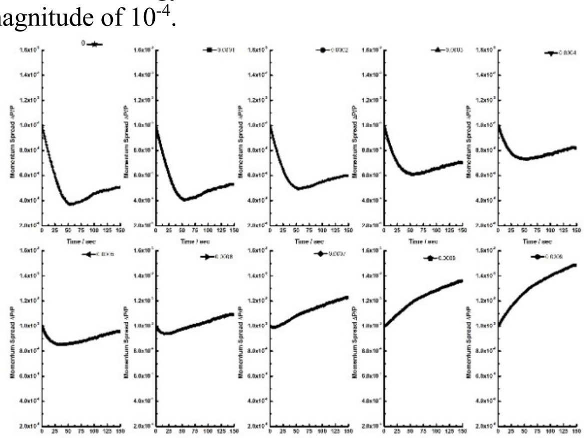

Figure 2: The momentum spread as a function of the time in the case of different shift of electron energy.

As mentioned in the previous paragraph, the proton beam was cooled down in the transverse direction. The longitudinal cooling process was different from the transverse one. During the initial cooling, the momentum spread drop rapidly, and then get to the minimum. And then the momentum spread start to grow. It bounce back from the bottom. The proton beam was not cooled when the energy shift of electron beam bigger than a certain value.

In this parameter configuration, the transverse cooling behaved differently from longitudinal cooling. The transverse emittance decreased exponentially. It was not a standard exponential function of decay or increase in the longitudinal direction. There was a deviation in the fitting process.

In order to compare the simulation results, the same calculation time was used.

In the longitudinal direction, due to the cooling happened firstly and then scattering happened later. So only the cooling part was fitted. The longitudinal cooling time was replaced by the time when the momentum spread reach its minimum.

## RESULTS AND DISCUSSION

The transverse cooling time as a function of the shift of electron energy was demonstrated in Fig. 3. The transverse cooling time became longer with the increasing of the energy shift of the electron beam.

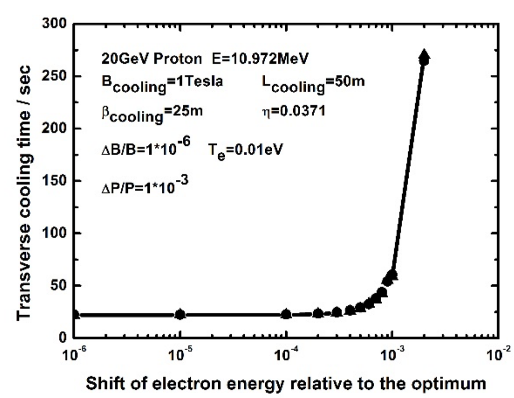


Figure 3: The transverse cooling time as a function of the shift of electron energy.

The minimum normalized emittance as a function of the shift of electron energy was illustrated in the Fig. 4. The minimum normalized emittance became bigger with the increasing of the energy shift of the electron beam.

The time approaching minimum momentum spread as a function of the shift of electron energy was demonstrated in Fig. 5. The time to reach the minimum value was almost the same. It did not change with the energy shift of the electron beam.

The minimum momentum spread as a function of the shift of electron energy was illustrated in Fig. 6. The minimum momentum spread became bigger with the increasing of the energy shift of the electron beam.

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From these simulation results, the transverse and longitudinal cooling time and the minimum emittance and momentum spread were analysed. The longitudinal temperature of the electron beam has influenced the final transverse emittance and longitudinal momentum spread of the proton beam.

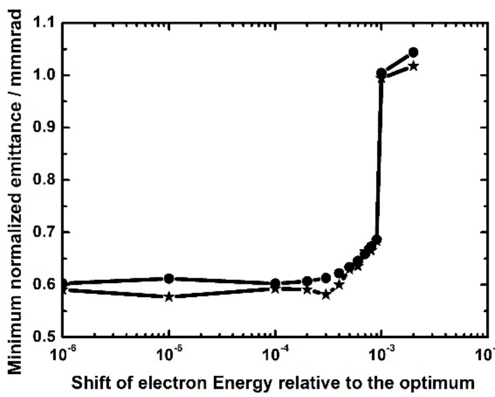


Figure 4: The minimum normalized emittance as a function of the shift of electron energy.

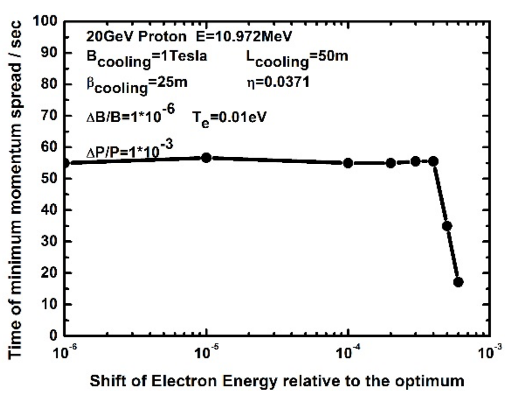


Figure 5: The time approaching minimum momentum spread as a function of the shift of electron energy.

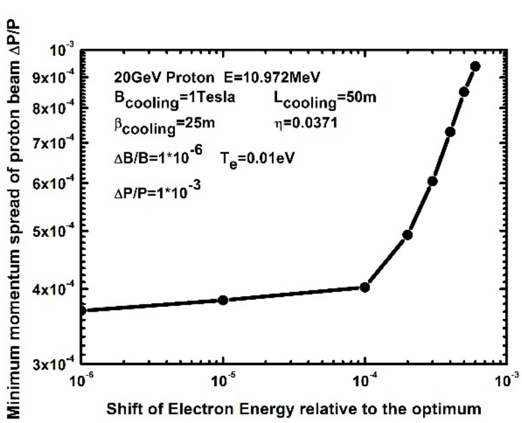


Figure 6: The minimum momentum spread as a function of the shift of electron energy.

When the energy shift of the electron beam was bigger than a certain value, the proton beam cannot be cooled in both transverse and longitudinal directions.

When the energy shift of the electron beam was smaller than another value, the proton beam can be cooled in the transverse direction, but not be cooled in the longitudinal direction.

When the energy shift of the electron beam was smaller than the third value, the proton beam can be cooled in both transverse and longitudinal directions.

In the case of high energy electron cooling, the longitudinal velocity of the electron beam was much greater than the transverse velocity. In the cooling simulation calculations, the same time interval was used for both transverse and longitudinal. Proton beams travelled at different path lengths during the same time interval in the transverse and longitudinal directions. The electron beam has about the same size in the transverse and longitudinal directions. There may be the cause of the unexpected results in the simulations.

By the way, the cooling forces vary with the absolute value of velocity difference, not relative value.

## SUMMARY

The longitudinal cooling behaviour is different from the transverse one. After the balance is achieved in the transverse direction, the emittance remain unchanged. But the longitudinal momentum spread shrink rapidly at the beginning and then bounces back from the bottom.

If the proton beam was expected to be cooled in the transverse direction, the energy shift of electron beam must be smaller than $2*10^{-3}$.

To achieve longitudinal cooling, the energy shift of electron beam has to be smaller than $5*10^{-4}$.

The longitudinal cooling force is not enough to counteract the longitudinal scattering effect in the different cooling period.

The electron beam produced by the traditional electrostatic accelerator has a smaller energy spread. The electron beam generated by the RF accelerator has a larger spread of energy. In high energy electron cooling, the energy spread of electron beam is an important parameter to be concerned.

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