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INFLUENCE OF TRANSVERSE DISTRIBUTION OF ELECTRON BEAM ON THE DISTRIBUTION OF PROTON BEAM IN THE PROCESS OF ELECTRON COOLING*

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Abstract

The electron cooling process of 20 GeV proton beam in EicC was simulated for the eight transverse distribution of electron beam with the help of electron cooling simulation code. The transverse cooling time was obtained in the different transverse distribution of electron beam. The final transverse distribution of proton beam was demonstrated. The simulated results reveal that the transverse distribution of electron beam influences the distribution of proton beam in the process of electron cooling. In the future, this idea was expected to apply to the longitudinal distribution of electron beam. The longitudinal distribution of proton beam was attempted to be controlled by the longitudinally modulated electron beam. As a result, the peak current and longitudinal distribution of proton beam will be controlled by the electron beam. The loss of proton beams will be reduced, and the stored lifetime of proton beam in the storage ring will be extended. The intensity of the proton beam will be maintained for a longer time.

INTRODUCTION

The electron cooling process of 20GeV proton beam in EicC was simulated in cases of variety of parameters [1].

The transverse electron cooling time [2] 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.

As mentioned in the reference [3, 4], As a result of electron cooling, the core of beam distribution is cooled much faster than the tails, producing a denser core. To account for a core collapse of ion distribution. The core directly impacts luminosity in a collider.

From the experiments results from LEReC BNL [5], Application of electron cooling directly at the collision energy of the hadron beams brings some challenges. Of special concern is control of the ion beam distribution under cooling in order not to overcool the beam core. As a result, most of the ions experienced linear part of the friction force without overcooling of ion beam distribution. Providing transverse cooling appeared to be more beneficial for collider operations compared to the longitudinal cooling. This is because longitudinal cooling led to higher peak currents of ions, affecting the ion beam's lifetime due to the space-charge effects.

MOTIVATION

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 [6, 7] 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 longer time.

ELECTRON BEAM DISTRIBUTION

The distribution of electron beam was uniform in the transverse direction in the traditional simulation of electron cooling. The electron density was uniform in the radial direction.

In order to investigate the influence of transverse distribution of electron beam on the distribution of ion beam in the process of electron cooling, eight kinds of electron beam profiles were attempted in the simulation shown in Fig. 1.

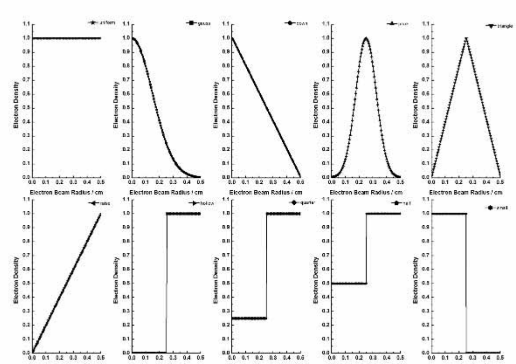

Figure 1: The transverse distribution of electron beam.

Due to the distribution of electron beam in the transverse direction was axial symmetry, only half distribution was described in the simulation.

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Half, half of Gaussian distribution, the electron density presents one complete gauss shape in the radial direction.

Peak, two Gaussian distribution, the electron density appears two complete gauss shapes in the radial direction.

Uniform, solid beam, the electron density presents uniform in the radial direction.

Hollow, the electron density is zero in the half central region, and the electron density is uniform in the edge region.

Raise, the electron density increases with radial coordinate from the centre of electron beam.

Down, the electron density decreases with radial coordinate from the centre of electron beam.

Triangle, similar as hollow beam, the electron density emerges two triangles in the radial direction. The electron density increases with radial coordinate from the centre of electron beam in the central half part, and decrease with radial coordinate in the edge part.

Small, smaller radius beam, the electron density is uniform in the central half part, and no electrons in the half edge part.

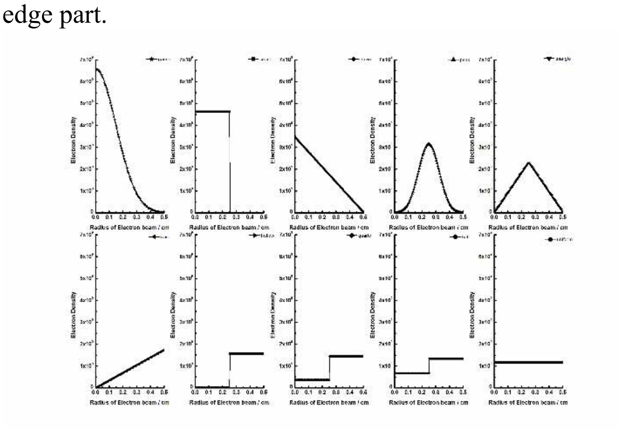

Figure 2: The radial density distribution of electron beam.

During the simulation of hollow beam, the proton beam was not cooled due to zero electron density in the central part of electron beam. Two compromise distributions were considered for the hollow electron beam.

Half, the electron density is one second in the half central region, and the electron density is uniform in the edge half region.

Quarter, the electron density is one fourth in the half central region, and the electron density is uniform in the edge half region.

In order to compare the cooling results, the electron beam current is set as the same in the different transverse distributions. As a result, the electron density is not same at the different radial position. The radial density distribution of electron beam was present in Fig. 2.

SIMULATION OF COOLING

The transverse cooling time under the different transverse distribution of electron beam is shown in Fig. 3.

The electron density is higher in the central region. Where the electron density is higher, the cooling is stronger, and the cooling time is shorter.

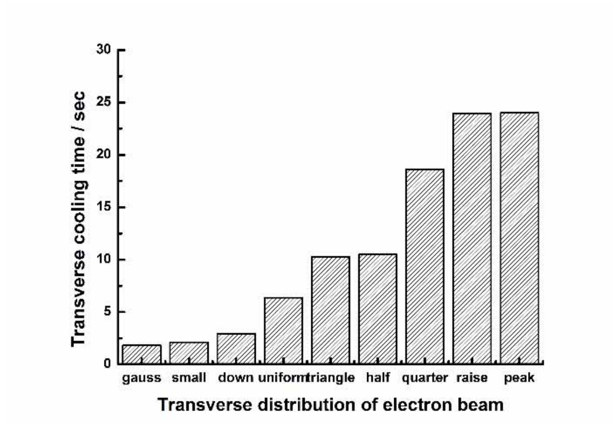

Figure 3: The transverse cooling time under the different transverse distribution of electron beam.

The protons experience the varying strength cooling in the different region. The cooling force was stronger in the region with higher electron density, the cooling force was weaker in the region with lower electron density. No cooling was experienced in the electron empty region. But the effect of intra-beam scattering will expand the proton beam and final distribution becomes wide.

DISTRIBUTION OF PROTON BEAM

The transverse full width at half maximum of proton beam after electron cooling is demonstrated in Fig. 4.

The proton experienced the stronger cooling in the central region. Where the electron density is higher, the cooling is stronger, and the width of proton beam is narrower.

In the case of hollow beam, the proton beam was not cooled due to zero electron density in the central part of electron beam. The effect of intra-beam scattering will expand the proton beam and final distribution becomes wider.

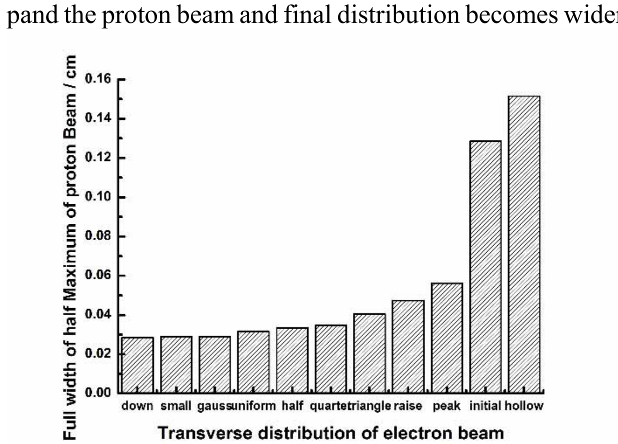

Figure 4: The transverse full width at half maximum of proton beam after electron cooling.

The final transverse distribution of proton beam under the cooling of the different transverse distribution of electron beam was illustrated in the Fig. 5.

As a result, the final distribution of proton beam present the different width because the proton was cooled by the diverse electron density in the different region in the same period.

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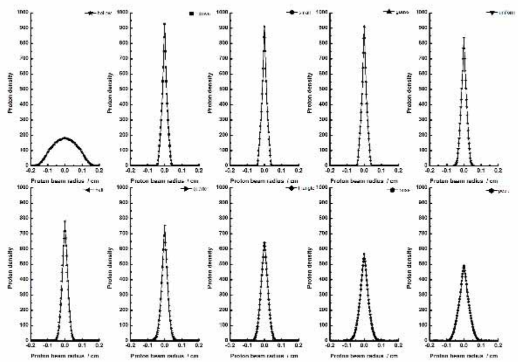

Figure 5: The final transverse distribution of proton beam after cooling.

RESULTS AND DISCUSSION

The distribution of proton beam has been influenced by the transverse distribution of electron beam in the process of electron cooling from the simulation results. This idea will be extended to the longitudinal direction. The proton beam bunch with Gaussian distribution was expected to be cooled by the different distributions of electron bunches in the longitudinal direction [8, 9]. The longitudinal distribution of proton beam was expected to be controlled by this method in the process of electron cooling. The peak current of proton beam will be decreased and the lifetime of proton beam will be extended. The intensity of proton beam will be maintained.

Differences exist between transverse and longitudinal distribution of electron beam. The transverse distribution of electron beam is axial symmetry. Due to the actions of electric field of space charge in the electron beam and magnetic field, the drift velocity of electron is not same in the different radial position. In the centre of electron beam, the drift velocity is minimum. The relative velocity between proton and electron is also small too. The cooling force is varying in the different radius.

The electron beam is direct current, the longitudinal distribution is uniform. This is the distinction between the transverse and longitudinal direction.

The longitudinal distribution of electron beam is uniform in the traditional electron cooling. The ion beam is coasting beam.

Due to the lack of the setting of longitudinal distributions of proton and electron beams in the existing simulation code, the longitudinal distribution of proton was not presented in the results.

SUMMARY

The influence of transverse distribution of electron beam on the transverse distribution of proton beam in the process of electron cooling was presented in the paper. In order to obtain the influence of longitudinal distribution of electron beam on the longitudinal distribution of proton beam in the process of electron cooling, the necessary improvement was needed in the electron cooling simulation code. The input of longitudinal distribution of electron beam should be added. The longitudinal distribution of proton beam with the time in the process of electron cooling should be output in the simulation. The final information of the longitudinal distribution of proton beam should be provided.

In the future work, the simulation code will be modified, and the setting of longitudinal distributions of proton and electron beams will be added in the simulation. The longitudinal distribution of proton beam will be demonstrated in the process of electron cooling. The final longitudinal distribution of proton beam will be obtained after electron cooling.

In the future high energy electron cooling, the electron beam was produced by the RF accelerator, and the electron beam will be not direct current, it will be consisted by pulsed electron bunches. The ion beam will not be coasting beam, it will be multi-bunch configuration in the storage ring.

The cooling process in the longitudinal direction should be investigated furtherly.

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REFERENCES

[1] X. D. Yang, “Simulation of electron cooling and IBS at EicC”, in *12th Workshop on Beam Cooling and Related Topics (COOL2019)*, Novosibirsk, Russia, pp. 77-79. doi:10.18429/JACoW-COOL2019-TUPS01

[2] X. D. Yang, “Simulation of transverse electron cooling and IBS of 20 GeV proton beam at EicC”, in *13th Workshop on Beam Cooling and Related Topics (COOL2021)*, Novosibirsk, Russia, pp. 70-73. doi:10.18429/JACoW-COOL2021-P1002

[3] A.V. Fedotov, I. Ben-Zvi, Yu. Eidelman, et al., “Simulation of high-energy electron cooling”, in *Proceedings of 2005 Particle Accelerator Conference*, Knoxville, Tennessee, USA, pp. 4251-4253.

[4] A.V. Fedotov, I. Ben-Zvi, Yu. Eidelman, et al., “IBS for ion distribution under electron cooling”, in *Proceedings of 2005 Particle Accelerator Conference*, Knoxville, Tennessee, USA, pp. 4263-4265.

[5] A. V. Fedotov, Z. Altinbas, S. Belomestnykh, et al., “Experimental Demonstration of Hadron Beam Cooling Using Radio-Frequency Accelerated Electron Bunches”, *Phys. Rev. Lett.* Vol. 124, p. 084801, 2020. doi:10.1103/PhysRevLett.124.084801

[6] X. D. Yang, L. J. Mao, J. Li, et al., “Investigation on the suppression of intrabeam scattering in the high intensity heavy ion beam with the help of longitudinal double-bunch of electron”, in *13th Symposium on Accelerator Physics (SAP2017)*, Jishou, China, pp. 67-69. doi:10.18429/JACoW-SAP2017-MOPH18

[7] X. D. Yang, L. J. Mao, J. Li, et al., “Investigation on the suppression of intrabeam scattering in the high intensity heavy ion beam with the help of longitudinal multi-bunch of electron”, in *11th Workshop on Beam Cooling and Related Topics (COOL2017)*, Bonn, Germany, pp. 58-60. doi:10.18429/JACoW-COOL2017-TUP14

ISBN: 978-3-95450-265-3 doi:10.18429/JACoW-SAP2023-TUPB025

[8] M.W. Bruker, S. Benson, A. Hutton, et al., "Demonstration of electron cooling using a pulsed beam from an electrostatic electron cooler", *Phys. Rev. Accel. Beams*, vol. 24, 012801, 2021. doi:10.1103/PhysRevAccelBeams.24.012801

[9] He Zhao, Lijun Mao, Jiancheng Yang, et al., "Electron cooling of a bunched ion beam in a storage ring", *Phys. Rev. Accel. Beams*, vol. 21, p. 023501, 2018. doi:10.1103/PhysRevAccelBeams.21.023501