STRUCTURE AND DESIGN OF THE ELECTRON LENS FOR RHIC*

A. Pikin, W. Fischer, J. Alessi, M. Anerella, E. Beebe, D. Gassner, X. Gu, R. Gupta, J. Hock,
R. Lambiase, Y. Luo, C. Montag, M. Okamura, Y. Tan, J. Tuozzolo, P. Thieberger,
W. Zhang, Brookhaven National Laboratory, Upton, NY, USA

Abstract

Two electron lenses for a head-on beam-beam compensation are being planned for RHIC; one for each circulating proton beam. The transverse profile of the electron beam will be Gaussian up to a maximum radius of r_e=3σ. Simulations and design of the electron gun with Gaussian radial emission current density profile and of the electron collector are presented. Ions of the residual gas generated in the interaction region by electron and proton beams will be removed by an axial gradient of the electric field towards the electron collector. A method for the optical observation of the transverse profile of the electron beam is described

INTRODUCTION

Incorporating electron lenses in RHIC can increase the proton luminosity and reduce the beam decay during store [1,2,3]. The design of the Electron Lens for head-on beam-beam compensation of proton beams in RHIC is based on formulated parameters [1] for two identical lenses on both rings next to each other. The structure of the e-lens is similar to the structure of TEL-2 in Fermilab [4] and contains the same essential elements: electron gun, electron collector and magnetic structure. Some differences are caused by stricter BNL requirements on field quality and maintenance considerations.

E-LENS STRUCTURE

The overall view of the BNL E-lens is presented in Fig. 1.

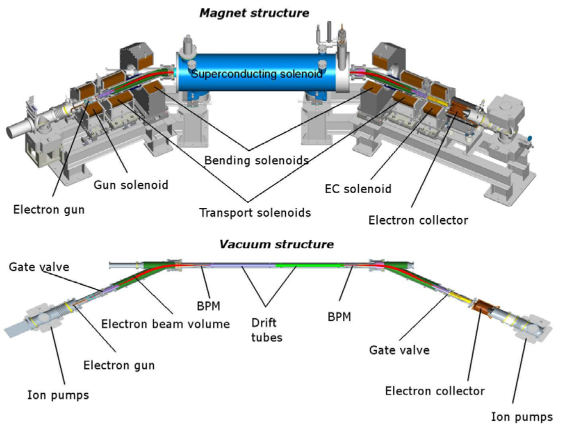

Figure 1: Vacuum and magnetic structures of E-lens.

The angle between the axis of the injection and extraction arms with axis of the RHIC beam pipe is chosen to be 30^0 to minimize power consumption in magnets and errors in a beam positioning.

A versatile magnet control with transverse dipole coils on both injection and extraction arms allow precise positioning of the electron beam in the interaction region.

Table 1: The Main Parameters of E-Lens

Max. electron current	1.5 A
Max. electron energy in interaction region	15 keV
Magnetic field in the interaction region	2.0 – 6.0 T
Max. deviation of magnetic axis from straight line	50 μm
Magnetic field on the cathode of electron gun	0.2 - 0.8 T
Minimum magnetic field on e-beam path	0.3 T
Max. transverse displacement of e-beam in inter. region	5.0 mm
Range of electron beam σ in the interaction region	0.28–0.8 mm

ELECTRON GUN

To match the circulating proton beam with approximately Gaussian transverse profile the current density profile of the electron beam also needs to be Gaussian with ratio of radius to Sigma $r_{el}/\sigma_{el}\approx3$. The method of producing the required current density distribution is similar to that used in the Fermilab electron lenses [4]. The cathode of the electron gun is immersed in the controlled magnetic field and the electron beam is confined by the magnetic field up to its entrance into the collector. In this case the profile of the electron beam in the interaction region is determined by the profile of the emission current density from the cathode of the electron gun. The degree of electron beam compression is determined by the ratio of magnetic fields on the cathode and in the interaction region. The electron gun has an additional electrode (Fig. 2) similar to Tevatron E-lenses [4] to control the emission from the cathode.

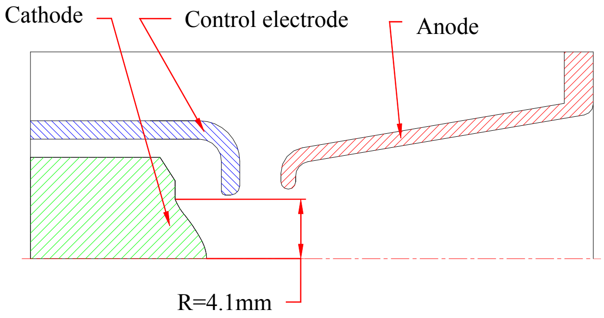

Figure 2: Model for computer simulation of the e-lens Gaussian electron gun.

The shape of the cathode emitting surface was adjusted to generate the needed Gaussian radial distribution of the emission current density. The diameter of the cathode is determined by the operating range of the electron beam diameter in the interaction region, available magnetic fields and cathode lifetime considerations.

As one can see from Fig. 3 the simulated radial profile of the emission current density follows a Gaussian distribution with good precision and the ratio of the beam radius to σ of Gaussian distribution is $r_{el}/\sigma_{el}=3.2$.

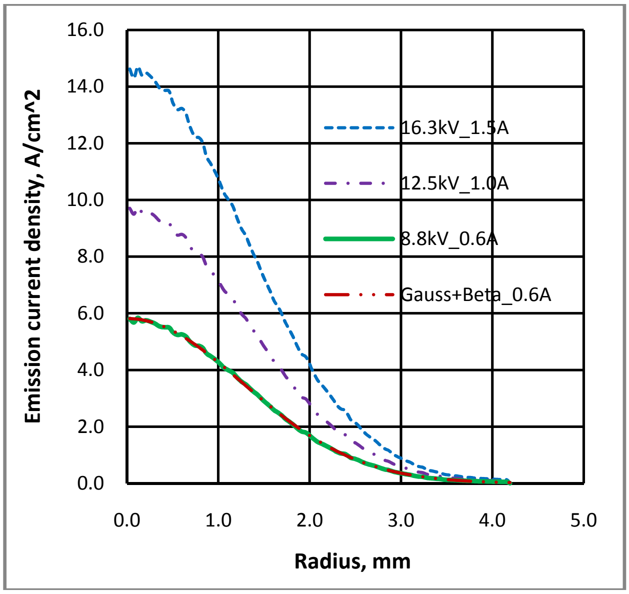

Figure 3: Simulated emission current density profiles of the electron gun for different anode voltages and zero bias voltage on the control electrode with respect to the cathode.

For an electron current $I_{el}=1.5$ A the maximum emission current density is 14.5 A/cm^2 and the only choice for this electron gun is a high-temperature thermionic cathode. The cathodes for BNL e-lens are manufactured of IrCe by the Budker Institute of Nuclear Physics and have an expected lifetime more than 20,000 hours. These cathodes can also operate in a regime of short pulses with acceptable lifetime.

ION CONTENT CONTROL

Ion accumulation in the interaction region can neutralize the electron charge making e-lens ineffective and at high levels of neutralization can disrupt electron and proton beams by the two-beam drift instability. In the RHIC e-lens the ions generated by the electron beam from the residual gas are removed from the interaction region by the axial gradient of the electric field produced by the potential distribution on the drift tubes and the charge of the generated ions on their way out. The axial potential distribution inside the e-lens interaction region (Fig. 4) practically does not have potential well capable of trapping ions. The small potential wells on the extraction side of the e-lens are produced by the space charge of the expanding electron beam, which propagates inside cylindrical drift tubes; these wells are shallow and for the most part outside of the proton beam. The ions generated inside the interaction region are expelled to the electron collector and can be detected on an ion collector located behind the electron collector.

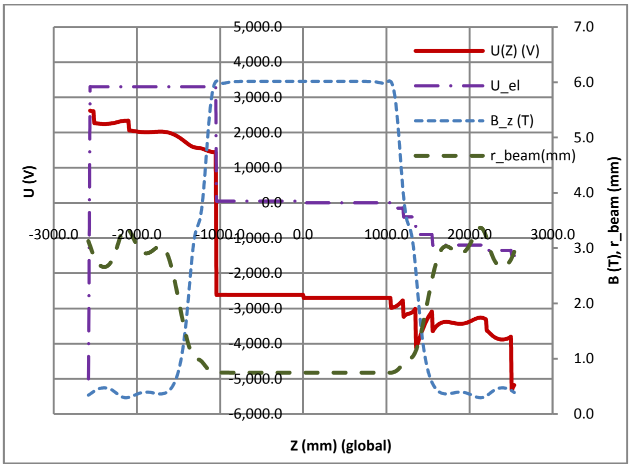

Figure 4: Calculated axial distribution of magnetic field B_z, electron beam radius r_beam (mm), applied potentials on the drift tube electrodes (U_el) and potential on the axis with electron beam space charge (U(Z)). $I_{el}=1.0$ A, $B_{center}=6.0$ T.

To measure the amount of the accumulated ion charge it is planned to expel all ions within the interaction region over time longer than needed for accumulation equilibrium by bringing the potentials of these drift tubes up with a slope towards the electron collector. By adjusting the axial potential distribution on the drift tubes it will be possible to minimize the total accumulated ion charge. It is expected that the potential distribution of the electron beam will be modified by the space charge of ions generated in an interaction region and moving towards the electron collector by less than 0.1% at pressure of the residual gas 1×10^{-10} Torr.

The current and energy of the electron beam in the interaction region are controlled independently. The anode and collector power supplies are located on the cathode platform, which is biased with respect to the ground. This solution also allows having a controllable potential of the electron collector with respect to the cathode and to the ground.

ELECTRON COLLECTOR

The main requirement to the electron collector (EC) is its ability to dissipate the electron beam power reliably in any regime of e-lens operation. Considering that during tuning the electron beam can deposit its energy to EC surface asymmetrically with large azimuthal variations of power density distribution the EC has been designed with safety factor of 4.

One of the important parameters is high vacuum compatibility. When the electron beam hits EC surfaces a large amount of gas is released and can be dumped into the RHIC volume. To restrict the gas load from the EC to the RHIC beam line an EBIS concept of EC with vacuum separation on the entrance diaphragm and pumping on the rear has been adopted. In this geometry the primary electrons dissipate their power on the cylindrical surface (Fig. 5), which is easy to cool.

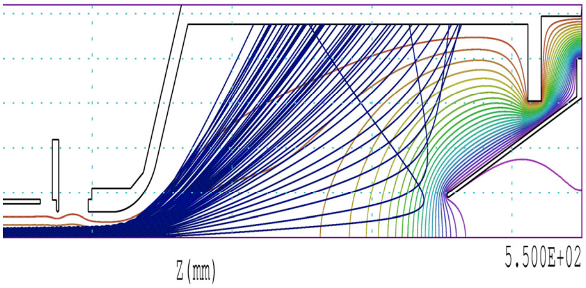

Figure 5: Simulations of electron beam transmission inside EC. I_{el}=1.0A, E_{el}=4.0 keV.

This solution also limits the flux of secondary and backscattered electrons from EC towards the interaction region because the EC volume is magnetically shielded. The EC is electrically isolated from the rest of E-lens with a ceramic high voltage break and is equipped with several beam diagnostics devices (Fig. 6).

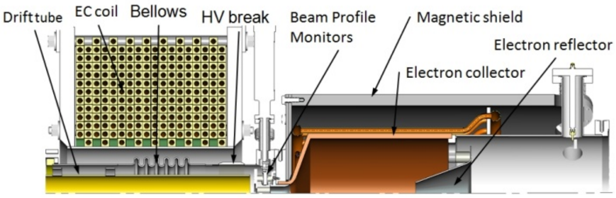

Figure 6: Design of the electron collector.

This EC concept allows a direct visualization of the electron beam at the entrance into EC with an CCD camera equipped with appropriate telescopic zoom lens and located on the axis of EC in the atmosphere.

ELECTRON BEAM PROFILE MONITORS

There are two types of beam profile monitors in e-lens located at the entrance into EC: a visual monitor with a YAG crystal and CCD camera, and a pinhole detector, which consists of a collector behind the shield with a 0.2 mm pinhole. (Fig. 7). By scanning the electron beam across this detector one can measure the 2D current distribution of the electron beam.

Both detectors can be inserted on the EC axis remotely or retracted when not needed. Both detectors can operate only with short (1 – 10 µs) electron beam pulses and are protected from DC electron beam. With visual monitor the 2D distribution of the electron beam current will be displayed in real time and processed within 1 second. Data acquisition with the pinhole detector will be done automatically with speed of 10 points per second. Both detectors measure the same quality of the electron beam, present current distributions in several planes, and are intended for independent verification of each other.

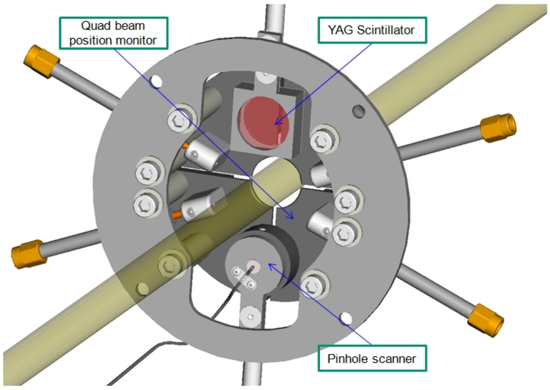

Figure 7: Electron beam detectors at the entrance into electron collector.

VACUUM

Considering that the pressure of the residual gas in the RHIC beam line is 1×10^{-11} Torr the vacuum requirements for the e-lens design, choice of materials and technology of assembly and cleaning/thermal treatment are strict. The units with the largest gas load (electron gun and collector) have vacuum separations consisting of a diaphragm and additional ion vacuum pumps on the side of poor vacuum. In-line gate valves (Fig. 1) separate both gun and collector units from RHIC beam line, making it possible to replace the gun, diagnostic units or electron collector without venting a large portion of RHIC beam line to atmosphere. The entire surface of e-lens vacuum jacket will have heating blankets and thermocouples, similar to the rest of RHIC.

REFERENCES

[1] Y. Luo and W. Fischer, Outline of using an electron lens for the RHIC head-on beam-beam compensation, BNL C-AD AP Note 286, August 2007.
[2] Y. Luo, W. Fischer, N. Abreu, E. Beebe, J. Beebe-Wang, C. Montag, M. Okamura, A. Pikin, G. Robert-Demolaize, Head-on beam-beam compensation with electron lenses in the Relativistic Heavy Ion Collider, Proceedings EPAC-08, MOPC113 (2008).
[3] Y. Luo, W. Fischer, X. Gu, Optimization the electron beam parameters for head-on beam-beam compensation in RHIC, Proceedings PAC11, MOODN2 (2011).
[4] V. Shiltsev et al., Tevatron electron lenses: design and operation, Phys. Rev. Special Topic – Accelerators and Beams, 11, 103501 (2008).