

THE E-LENS TEST BENCH FOR RHIC BEAM-BEAM COMPENSATION*

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Abstract

To compensate for the beam-beam effects from the proton-proton interactions at IP6 and IP8 in the Relativistic Heavy Ion Collider (RHIC), we are fabricating two electron lenses that we plan to install at RHIC IR10. Before installing the e-lenses, we are setting-up the e-lens test bench to test the electron gun, collector, GS1 coil, modulator, partial control system, some instrumentation, and the application software. Some e-lens power supplies, the electronics for current measurement will also be qualified on test bench. The test bench also was designed for measuring the properties of the cathode and the profile of the beam. In this paper, we introduce the layout and elements of the e-lens test bench; and we discuss its present status towards the end of this paper.

INTRODUCTION

To achieve higher polarized proton luminosities in 2012 and beyond, we will install two electron lenses (e-lenses) at IR10 [1-4] to compensate for the head-on beam-beam effect in the Relativistic Heavy Ion Collider (RHIC). Before placing these e-lenses we designed an e-lens test bench to test some elements of the e-lens hardware, their controls and some application software. Fig. 1 illustrates the layout of our test bench; it encompasses some magnet coils, an electron gun, an electron collector, a diagnostics chamber, a CCD camera system, and some power supplies.

The e-lens test bench facility is located at and is based upon the existing Test Electron Beam Ion Source (EBIS) facility [5]; this minimized cost and saved time. Figure 1 illustrates the superconducting solenoid, collector coil, gun dipoles, main dipoles, collector dipoles, drift tube, and their power supplies, all taken from the Test EBIS. All Test EBIS power supplies are controlled by the Test EBIS control system, except for the collector dipole power supplies, which use new power supplies, and are controlled by the test-bench control system. The power supplies controlled by the Test EBIS system are excluded from the e-lens test bench Machine Protection System (MPS).

The collector power supply originates from the Test EBIS and its parameters are displayed on the test bench control panel and included in the test bench MPS. To prevent interference by secondary electrons produced at the pinhole detector and the YAG screen, we also use the Test EBIS drift tube system, along with its power supplies and vacuum chamber.

The gun coil, electron gun (including the cathode heater, control electrode, anode modulator), the pinhole dipoles, diagnostics chamber, collector (including the electron reflector and collector), the CCD camera, and their power supplies were designed specifically for the e-lens, and can be controlled from the test bench control system. They are all part of the MPS.

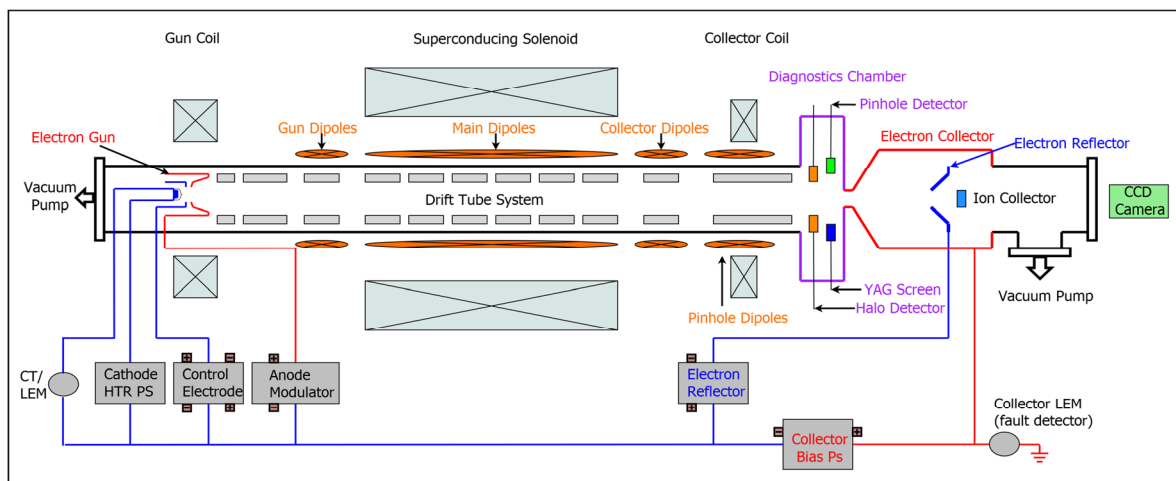


Figure 1: Schematic depiction of the layout of the electron lens test bench.

* Work supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy
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THE MAGNET COILS

In the test bench, the electron beam is transported from the e-gun to the collector. Three magnet coils on the test bench are responsible for this transport, viz. the gun coil, the superconducting magnet, and the collector coil. The electron gun is in the center of the gun coil. The beam size at the collector entrance is controlled by changing the ratio of the magnetic field strength between the gun coil and the collector coil.

Several pairs of dipole coils (both vertical and horizontal) steer the electron beam; they are the gun dipoles, the main dipoles (inside the superconducting solenoid) and the collector dipoles.

The collector dipoles are also used for scanning the electron beam profile on a pinhole detector. However the strength of the collector dipole is insufficient to scan the full beam size. Therefore, to provide enough strength for a one directional full beam-size scan, we designed and fabricated a new vertical only dipole steerer and placed it inside the collector coil. It is connected in series with the vertical collector dipole.

THE ELECTRON GUN

The electron gun [3] is a critical element for the e-lens. To assure electron-proton beam-beam compensation in RHIC, both beams should be of the same size and have the same transverse Gaussian profile [6]. The shape of the cathode surface was designed to satisfy this requirement. After designing and manufacturing the cathode, its shape was measured by projecting it onto a two-dimensional cross-sectional profile. Then, the electron beam transverse profile was simulated again with the measured cathode profile with the 2D program TRAK, and compared with the model-designed beam profile.

Furthermore, for sufficient beam-beam compensation, the electron beam must have enough current to provide enough compensation strength.

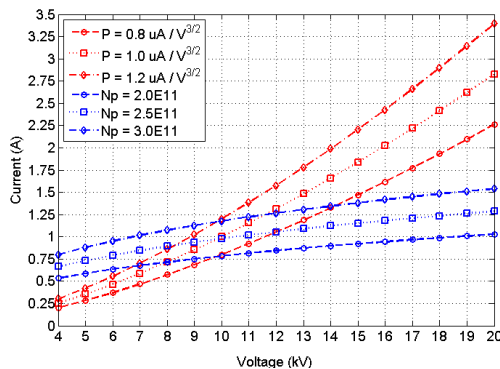


Figure 2: Simulated e-beam current vs. anode voltage (red) and required current as a function of bunch intensity (blue).

Figure 2 shows the current requirement (blue) for beam-beam compensation with different proton bunch intensities [6] and the maximum current (red) provided

from an electron gun for different perveances, including a space-charge limit.

According to the simulation, the perveance of our electron gun is about $1 \mu\text{A}/\text{V}^{3/2}$, and it will be measured on the test bench. The perveance can be increased by reducing the gap between the anode and the cathode.

THE MODULATORS

For the beam-beam compensation, the electron beam was designed to be operated in the DC-mode. However, a pulsed beam is also needed, especially when it is operated in the diagnostic-, parasitic-, or setup-mode. Accordingly, a modulator that can be operated at four modes was designed, fabricated and will be tested on the test bench; they are a mode for normal beam-beam compensation (DC-mode), two 100 Hz pulsed modes for electron BPM average beam position measurement (diagnostic- and setup-mode), and a 78.8 kHz pulsed mode for single proton bunch compensation testing (parasitic-mode).

To assure sufficient electron-beam current, the modulator should offer adequate voltage on the anode. For the test bench, the voltage on the anode from the modulator can be as high as 15 kV.

There are two BPMs in the e-lens that will measure the positions of both the proton and electron beam. To obtain a good resolution of the position of the electron beam, and to fit the rise time between 2 RHIC bunches, we designed the rise and fall times of the modulator to be as short as 50 ns.

Due to restrictions of the modulator hardware the minimum length of the modulator trigger pulse is about 300 ns, i.e. sufficient for the e-lens test bench. The pulse length is adjustable; it can be increased or decreased in steps of 100 ns.

THE COLLECTOR

The collector is another important element of the e-lens [3]. At the collector, we can measure the electron beam current with the DC current transformer (CTs) and the pulse current transformer (LEMs) [7]. Inside the collector, there is a removable ion collector intended for stopping and measuring the ion beam current.

The maximum temperature on the collector will be measured by Resistance Temperature Detectors (RTDs) at the highest DC load. These RTDs are distributed around the outside of the water-cooled electron collector.

THE DIAGNOSTICS CHAMBER

To measure the electron beam profile, we constructed a diagnostics chamber encompassing a pinhole detector, a YAG screen and a halo monitor [7].

By scanning the collector dipoles and recording the electron beam current passing through the pinhole detector, we can measure the 2D electron beam transverse-density profile. We developed a program for this scan and tested it online with simulated timing beam.

The YAG screen and the CCD camera imaging system are also used for measuring the transverse density profile

of the electron beam. To save space in the diagnostics chamber, we mounted the screen perpendicular to the electron beam direction, instead of using a 45-degree mount. Thus, the CCD camera is located 1.2 m downstream of YAG screen, behind the electron collector. By synchronizing the CCD camera to the electron beam, the YAG screen and CCD camera system can measure the electron beam profile shot-by-shot. This approach is much faster than the scanning via the pinhole detector. Also, we developed a program for acquiring and processing the images.

The halo monitor is a fixed-position four-quadrant molybdenum plate. It aids in steering the electron beam into the entrance of collector, and detects the beam loss around the diagnostics chamber.

PRESENT STATUS OF THE TEST BENCH

Presently, we have assembled all individual elements of the test bench, including the power supplies and racks, and installed them on the test-bench stand (Figure 3). All the TEST EBIS power supplies have been tested and calibrated with the control system. Evaluations and tests of the collector power supply and the gun coil power supply are also finished. The cathode heater power supply has been calibrated and can be connected to the cathode heater.

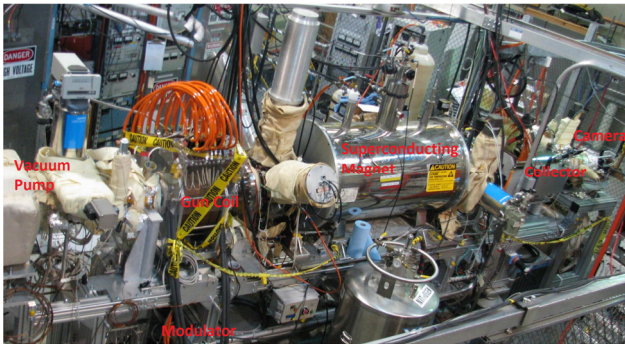


Figure 3: The test bench installation

The YAG screen and camera imaging system, including its software, were tested online without electron beam; now, they are ready for the test bench. The pinhole detector and its application are also ready. The pulse CT and DCCT of the collector are ready; those for the collector fault current (beam-loss detector) will be available very soon.

The anode modulator that can be operated at DC mode and 100 Hz pulse mode is operational, and has been tested offline. Now they are connected to a real load for evaluation. The 10 kV test of another modulator that also includes 78.8 kHz pulse mode has been completed: it will be installed in the test bench latter.

The cooling water system was validated and is in use; vacuum components were baked and, using ion pumps on the gun and collector side, the vacuum pressure has reached 10^{-10} Torr. The test bench lock-out and operating procedures are also completed.

We finished designing and testing the test bench control system. The controls system provides a variety of convenient graphical user interface windows to allow viewing, control, and logging of all parameters for the following systems; power supplies, instrumentation, current measurement, cooling water, vacuum, and MPS. The MPS tests are completed and it is online.

SUMMARY

The fabrication and installation of the e-lens test bench has been completed. Most elements, including power supplies, controls, and the Machine Protection System, were tested individually. These will be combined, and tested simultaneously very soon. After commissioning, the electron gun perveance and the electron beam profile will be measured, and several cathodes will be selected for the e-lens. Based on these test bench results, the application software, the control system, the MPS and even some hardware for the e-lens can be improved if necessary.

ACKNOWLEDGMENTS

The authors would like to acknowledge the help of J. Galarraga, B. Schoeffler, J. Pepe, P. Young, J. Pomaro, J. Adessi, R. Zapasek, K. Mirabella and M. Costanzo. The authors are also grateful to our accelerator components & instrumentation group, vacuum group and control group. We appreciate valuable discussions with the FNAL TEL staff, in particular with V. Shiltsev, A. Valishev, and G. Stancari.

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