DESIGN AND STATUS FOR THE ELECTRON LENS PROJECT AT THE RELATIVISTIC HEAVY ION COLLIDER*

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Abstract

The Electron Lens upgrade project at the Relativistic Heavy Ion Collider (RHIC) has reached an operational status, whereby intense, pulsed or DC beams of electrons are generated in order to interact with the RHIC polarized proton beams in both the Blue and Yellow Rings at the 10 o'clock Interaction Region. Interactions between the electrons and protons are utilized to counteract the beam-beam effect that arises from the desired polarized proton collisions, which result in a higher RHIC luminosity. A complex system for operating the e-lens has been developed, including superconducting and non-superconducting magnet controls, instrumentation systems, a COTS-based Machine Protection System, custom Blue and Yellow e-lens timing systems for synchronizing the electron beam with the RHIC timing system, beam alignment software tools for maximizing electron-proton collisions, as well as complex user interfaces to support routine operation of the system. e-lens software and hardware design will be presented, as well as recent updates to the system that were required in order to meet changing system requirements in preparation for the first operational run of the system.

E-LENS GOALS AND DESIGN

The Blue and Yellow e-lenses are installed in the RHIC Ring at Interaction Region 10, in order to partially counteract the head-on beam-beam tune shift effect on the colliding RHIC beams, and thus permit RHIC proton beam operations at higher beam intensities, and therefore higher colliding beam luminosities for the RHIC experiments [1]. First commissioned during the FY2014 run, both electron lenses were successfully operated on a routine basis in a DC mode during the FY2015 RHIC 100 GeV polarized proton run [2].

The main components of each e-lens are the electron gun, electron collector, and superconducting solenoid magnet, though a set of additional systems is required for their routine operation. Beam transport magnets of both superconducting and non-superconducting varieties are controlled through two separate sets of standard VME hardware and software: warm magnets use equipment (PSC, QFG, and PSI) developed for the Injector machines within the Brookhaven National Laboratory (BNL) Collider-Accelerator (C-A) Department, and the cold magnets utilize the RHIC equipment (WFG, MADC) for reference control and readback information. Another system of note is beam instrumentation, which is primarily comprised of BPMs, current transformers, YAG crystal-based beam profile monitors, pinhole raster scan beam profilers, as well as new electron backscattering detectors [3].

TIMING SYSTEM

The Blue and Yellow e-lenses must be capable of operating in two distinct timing modes: pulsed mode for beam diagnostic measurements and system commissioning, as well as DC mode for routine operations. Activity in pulsed mode must be synchronized with the RHIC Event and Beam Sync Links, such that the timing system is capable of pulsing electron beam from the e-lens as a desired RHIC hadron bunch is passing through the Blue or Yellow Ring in IR10. To achieve these requirements, both e-lenses are dependent on the existing RHIC timing links as shown in Figure 1.

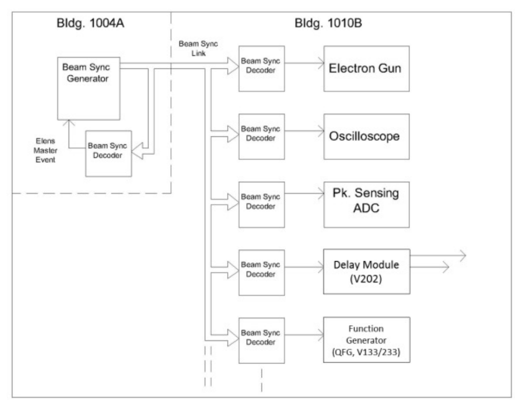

Figure 1: Schematic of the e-lens timing system, including RHIC components (building 1004A) and e-lens-specific components (1010B).

Software Interface

In order to enable the level of system flexibility required to operate the e-lens equipment under many different timing conditions while streamlining the user interface, a server-based ADO program is available to control the system that was written in the Java language. While it was not the first Java server written at the C-A Department, this software interface development project served as an important testbed for use of Java in developing ADO software interfaces rather than the standard C++ option.

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MACHINE PROTECTION

A total of seven independent e-lens subsystems have been identified that require automated protection from abnormal machine conditions. Thirty-seven quantifiable status conditions serve as inputs to the Machine Protection System (MPS) logic for inhibiting these systems. As the scope of the protection functionality inputs and outputs fits well with the capabilities of the familiar National Instruments cRIO FPGA-based platform, it was selected for the hardware implementation. The response time of the MPS logic in similar configurations was measured to be ~1µs, though this is dependent on the choice of input modules.

Software integration of the MPS with the Collider-Accelerator Controls System is achieved using the Simple Network Access Protocol (SNAP), which supports bi-directional communication between Accelerator Device Object (ADO) server-based software and LabVIEW software running on the cRIO device that incorporates the MPS logic.

BEAM INSTRUMENTATION

Beam position monitoring of the electron beam is achieved using RHIC-style dual-plane BPM electronics, which incorporate analog/digital integrated front ends (IFE) using 16 bit digitizers in order to achieve a 1µm resolution over a ±32mm range [4]. Data from the BPMs has been used for steering optimization of the e-lens electron beam relative to the IR BPM position readings for the hadron beams in the Blue and Yellow Rings.

Initially commissioned during the FY2014 RHIC Au-Au run, electron Backscattering Detectors (eBSDs) have become important diagnostic tools for aligning the electron beam from the e-lenses with the hadron beams in the Blue and Yellow Rings at RHIC [5]. Since the scaler readings from the eBSDs are proportional to the collision angle between the two beams, we have been able to successfully incorporate the new data into the existing RHIC Luminosity and IR Steering (LISA) application shown in Figure 2. This tool allows RHIC machine operators to optimize the impact of the e-lenses on the RHIC luminosity on demand.

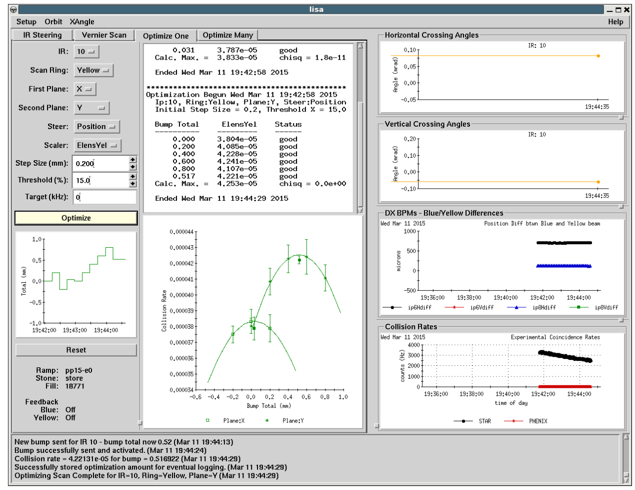

Figure 2: The RHIC Luminosity and IR Steering application (LISA) output after automated optimization of the Yellow e-lens beam alignment using eBSD data.

NEW USER INTERFACE

In addition to the more commonly used user interfaces within the Controls System at the Brookhaven National Laboratory C-A Department, the Syndi editor and display application has been adapted from the original version developed at FermiLab. Due to the compact and complex nature of the electron lenses, synoptic displays created through this toolset have evolved to serve an important role in the operation of the equipment. Figure 3 shows an example of the Blue e-lens Syndi display, which includes statuses of critical sub-systems as well as a select set of control points that are used during routine operations.

Development of the e-lens control pages themselves has migrated since their inception between the Syndi software developers, the project physicist, and ultimately to a member of the RHIC Operations group. While technically capable of embedding complex business logic within each page, we have elected to minimize the amount of such logic within the e-lens pages in favor of server-based software that leverages critical functionality, such as parameter caching. This also reduces the complexity of the page design, and thus improves reliability and maintainability. Our experience during RHIC run FY15 was that such a scheme allowed for maximum flexibility, while adding slightly more complexity over other more commonly used implementations at the BNL C-AD.

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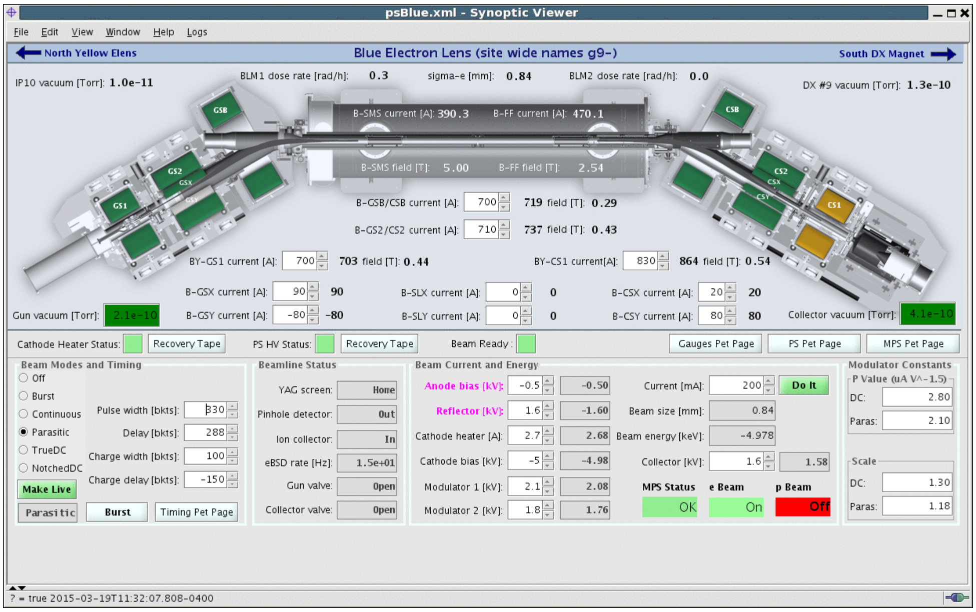

Figure 3: Synoptic user interface for the Blue e-lens created using the Syndi editor.

POWER SUPPLIES

Cryogenic magnet and power supply operations for the e-lenses require coordinated ramping methods, both to avoid unnecessary beam losses and to avoid quenching the superconducting magnets themselves. One method has been developed and exercised during the FY2015 run using ADO server-based software written in C++ that provides such functionality with a streamlined user interface [6] that is capable of controlling RHIC-style Wave Form Generators (WFGs).

CONCLUSION

The complex new Blue and Yellow e-lens systems have been successfully commissioned and operated using a hybrid design of existing controls systems with new equipment and software. COTS hardware is used to good effect as part of the Machine Protection System. Existing software tools, such as LISA, have been adapted to provide novel operating modes that contribute directly to of the new e-lens systems, synoptic interfaces have been developed using the Syndi display editor that have a synergistic relationship with existing interface options.the improvement of the luminosity of the RHIC colliding hadron beams. In order to better visualize the operation

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