

# SYNCHRONIZED RAMPING OF MAGNET POWER SUPPLIES FOR STREAMLINED OPERATION AT ENERGY RECOVERY LINAC (ERL) AND ELECTRON LENS (e-Lens)

P. Kankiya<sup>†</sup>, J. Jamilkowski, T. Samms  
Brookhaven National Laboratory, Upton, NY 11973 USA

## Abstract

Synchronous ramping of an assembly of magnets is critical for operation of beam in an accelerator. Magnet currents must remain within the operational limits to avoid dis-alignment of electron beam. In order to comply with the design specifications of ERL and e-Lens project, two different software control mechanisms have been developed. The ramp profile is automated and maintained by tracking current in all dipole magnets at ERL and superconducting solenoid magnets at e-Lens. This mechanism speeds up operations and adds a level of protection. The purpose of this application is to reduce unnecessary interlocks of the personnel protection system. This paper will describe the power supply arrangement, communication mechanism and the state machine algorithm used for feedback and control. A report on operating experience will be presented.

## INTRODUCTION

In year 2015 Energy Recovery LINAC project went under commissioning and their operations required design of special magnet ramp sequence to ensure compliance with accelerator design. The Energy Recovery LINAC (ERL) is designed to serve as a test bed for future projects such as LeReC, eRHIC and CeC. The lattice is unique and has been designed with a significant amount of flexibility in order to cover the required operational parameter space [1]. Another accelerator project with special ramp profile requirements is the RHIC electron lens (e-Lens) [2]. The Yellow and Blue e-Lens assemblies have a collection of 17 superconducting magnets. Current reference waveforms for these solenoids are generated by high level software applications and are preloaded to the VME based Waveform Function Generator (WFG) modules which are custom boards developed in-house.

## ERL MAGNET MANAGER

ERL's R&D prototype is currently installed with an assortment of magnets including several quadrupoles, dipoles and solenoids shown in Fig 1. The large beam size and very low longitudinal emittance of the e-beams dictate that the tolerances on the magnetic fields are very tight. Significant misalignment in the electron beam could lead to stray radiation; therefore very strict radiation safe functional bounds are enforced by an independent system called the Particle Accelerator Safety System (PASS). This system is designed to protect personnel working in

the areas near ERL by interlocking critical devices under specific abnormal conditions. In order to avoid unnecessary PASS interlocks due to mismatched critical dipole magnet currents, it was advised by the external reviewers of the project that software controls be modified. The intent is to reduce accelerator downtime, since each interlock of this type requires a sweep of the blockhouse by trained personnel. Another role of this software that has been added to the operational requirements is to manage magnet power supply controls and ERL e-beam orbit feedback corrections.

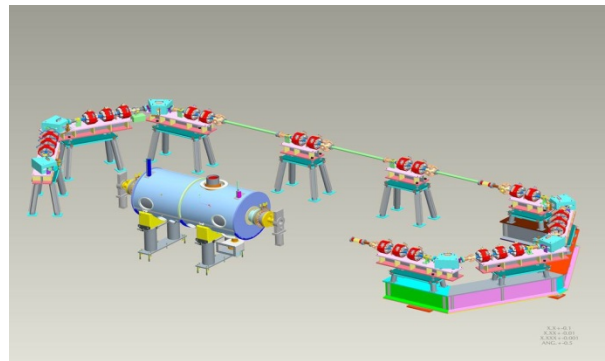


Figure 1: 3-D schematic of magnets in ERL beam line.

## Software Implementation

Different COTS power supply systems with small amount of customisation are purchased and mounted to interface with various magnets based their on functional specifications. These supplies communicate over TCP/IP by means of custom multiple types of software developed using the Accelerator Device Object ADO framework [3].

“erlMagMan” is a program consisting of two levels of object oriented entities controlling power supplies which interface directly with the magnets. The first level is an ADO class representing each magnet and consists of magnet properties such as bending angles of each dipole and nominal current at designed bending angle. These coefficients are provided by system experts and are obtained by direct measurements or simulations. Desired magnet currents are calculated at a given level of energy or at adjustment of trim angles. This energy will be entered manually by the shift operator or through the orbit correction program. Reverse conversion logic for translating magnet current to correction angles is also in place.

The second ADO layer acts as a governing class which interacts with all magnet ADOs simultaneously. It broadcasts the change of energy so all power supplies are configured with the correct current set point at the same time.

<sup>†</sup> pkankiya@bnl.gov \*Work supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. DOE

An asynchronous receiver client set up in the magnet ADO monitors the relationship between main dipole magnet output current and selected downstream dipoles. A threshold value of 2% less than PASS trip threshold is enforced and if any dipoles violate the limit, an alarm is generated alerting the machine operator to terminate beam in order to avoid a PASS interlock.

### e-Lens WFG MANAGER

Designed to improve the proton beam luminosity in RHIC, an electron lens (e-lens) magnet system has been built at BNL in the 10 o'clock Interaction Region at the RHIC [4]. For the e-lens to function efficiently and facilitate the necessary cooling of the proton beam, the electron beam must be generated with a comparable size and aligned parallel to the proton beam within the acceptable magnetic field region of the main superconducting solenoid (Fig. 2).

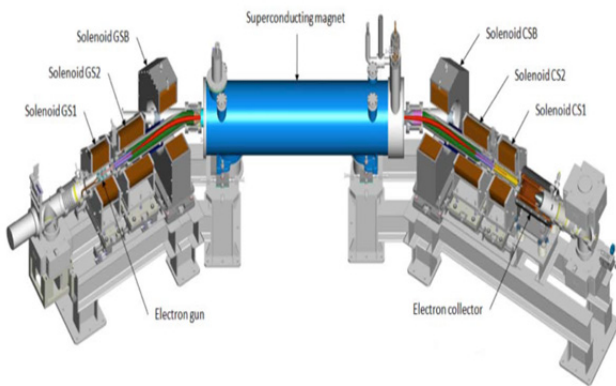


Figure 2: The Main superconducting magnet and corrector solenoids of blue e-Lens.

### Software Implementation

The ramp design parameters of the software are provided by power supply engineers who are responsible for setting up the power supplies and quench protection system. Four different operating modes are defined, involving which magnets (main and fringe) are to be controlled and which e-Lens (Blue or Yellow) is targeted. The ramp rate of each magnet varies at different stages and direction of the ramp, increasing or decreasing current. As listed in Table 1, the ramp rate of each magnet has been predetermined and must be maintained while ramping. This is critical to prevent the superconducting magnets from quenching, as each quench will lead to machine protection system interlocks of the e-lens as well as interrupt the operation of RHIC during recovery. The latter can be a costly affair and must be avoided.

Table 1: Maximum Ramp Rates for Stable Operation

Magnet Type	Ramp Rate (A/s)
Main Solenoid (Up/Down)	0.4/0.2
Fringe Solenoid	1

A test involving powering of all of the solenoids simultaneously to maximum power was performed. This situation proved to be problematic due to Quench Detector (QD) trips from large induced voltages generated by interactions between the coils and resulted in frequent trips of the anti-fringe solenoid QD and one quench of the main solenoid. In order to resolve this problem, system experts specified a new scheme such that the solenoid circuits will be ramped alternately in steps equal to 10% of the maximum test current. Hence, the software shall ramp main magnets first and fringe afterwards in an alternating fashion to reach the desired magnetic field level (see Fig. 3).

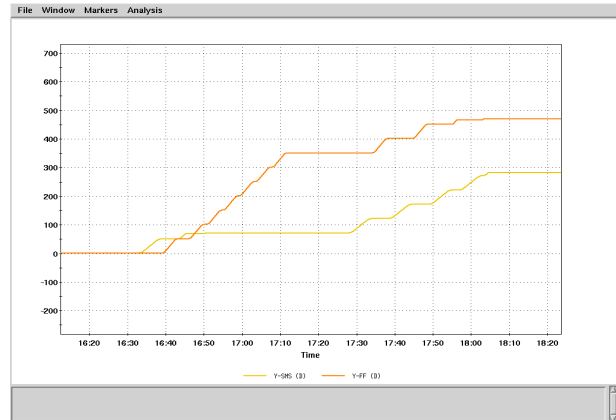


Figure 3: Ramp profile of yellow e-Lens main and fringe solenoids for 5 Tesla field. Each step is 50Amps.

The current set points of each magnet depend on the desired solenoid field, and these values have been established after systematic testing as described in [4]. Other software requirements include the ability to halt the ramping sequence.

### Class Description

A C++ ADO class known as `elensWfgControl` is constructed to control all magnet supplies which are also represented as ADOs in the Controls System. In order to reduce the complexity of ramp sequence, it is partitioned into elements of state machines based on concepts such as states, transitions, and actions. State machines for the fringe and main magnets are performed separately, although the two associated threads are executed simultaneously. When the main magnet is ramping the auxiliary coils are in and idle state. Ramp step size and wait time between ramps referred to as park time are configurable via the control ADO interface.

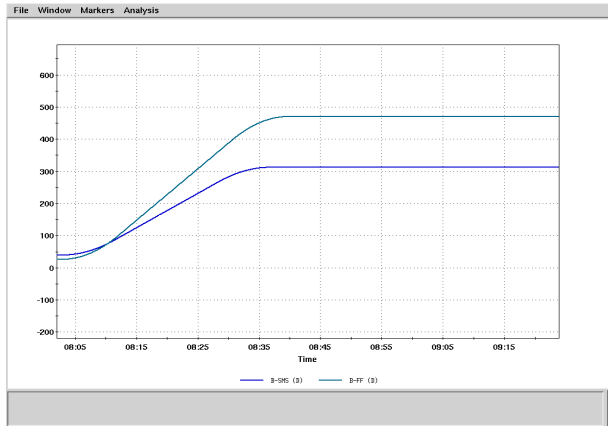


Figure 4: Ramp profile of blue e-Lens main and fringe solenoids with smooth ramp for 5 Tesla field.

### *Upgrades to e-Lens Wfg Manager Program*

Soon after commissioning of the ramp manager software, repeated testing showed that it is actually possible to ramp magnets in one step instead of 50Amps per step. The only caveat to this revelation is that the start of ramp has to be at a much slower rate. Keeping this in mind, a special scheme of slow ramps were implemented within the WFG code to reduce the current ramp rate by 20% during the first 20% of the ramp cycle. Figure 4 displays same level of magnetic field reached with significant reduction in ramp time using the smooth ramps.

### ACKNOWLEDGEMENTS

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### CONCLUSION

A software scheme to generate two unique sets of magnet current ramping profiles has been created and deployed. Both resulted in successful beam steering in case of ERL and in determining the electron beam size and trajectory by the field in the solenoid in case of e-Lens. During operations and considerably reduced expert man hours by reliably automating each set of processes. A similar software management scheme is under consideration for the corrector magnets associated with the e-Lens system.

### REFERENCES

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