ELECTRON LENS CONSTRUCTION FOR THE INTEGRABLE OPTICS TEST ACCELERATOR AT FERMILAB*

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Abstract

The Integrable Optics Test Accelerator (IOTA) is proposed for operation at Fermilab. The goal of IOTA is to create practical nonlinear accelerator focusing systems with a large frequency spread and stable particle motion. The IOTA is a 40 m circumference, 150 MeV (e-), 2.5 MeV (p+) diagnostic test ring. Construction of an electron lens for IOTA is necessary for both electron and proton operation. Components required for the Electron Lens design include; a 0.8 T conventional water-cooled main solenoid, and magnetic bending and focusing elements. The foundation of the design relies on repurposing the Fermilab Tevatron Electron Lens 2 (TEL-2) gun and collector under ultra-high vacuum (UHV) conditions.

INTRODUCTION

The Integrable Optics Test Accelerator (IOTA) given in Figure 1 is a small storage ring (40 m circumference) being built at Fermilab [1–3]. Its main purposes are the practical implementation of nonlinear integrable lattices in a real machine, the study of space-charge compensation in rings, and a demonstration of optical stochastic cooling.

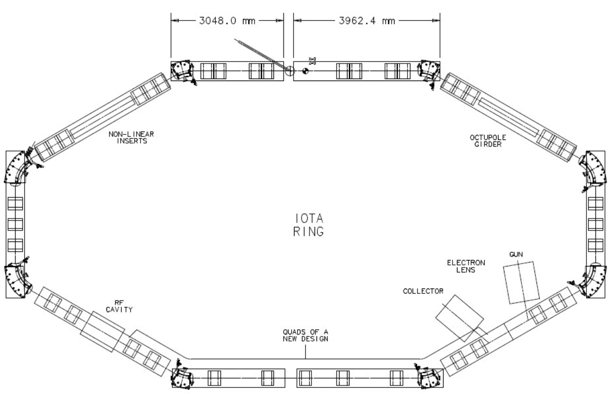

Figure 1: Layout of IOTA Ring.

The concept of nonlinear integrable optics applied to accelerators involves a small number of special nonlinear focusing elements added to the lattice of a conventional machine in order to generate large tune spreads while preserving dynamic aperture [4]. The concept may have a profound impact in the design of high-intensity machines by providing improved stability to perturbations and mitigation of collective instabilities through Landau damping [5].

Electron lenses are pulsed, magnetically confined, low-energy electron beams whose electromagnetic fields are used for active manipulation of circulating beams [6, 7]. One of the main features of an electron lens is the possibility to control the current-density profile of the electron beam (flat, Gaussian, hollow, etc.) by shaping the cathode and the extraction electrodes. Electron lenses were developed for beam-beam compensation in colliders [8], enabling the first observation of long-range beam-beam compensation effects by tune shifting individual bunches [9]. They were used for many years during regular Tevatron collider operations for cleaning uncaptured particles from the abort gap [10].

ELECTRON LENS

The purposes of the electron lens device for IOTA shown in Figure 2 are three fold: provide a nonlinear element for integrable optics, perform as an electron cooler; and work as space-charge compensator. Given the many possible functions of the electron lens for IOTA, there are also some interesting challenges. Each IOTA electron lens design capability has been applied, individually in various ways, however these have yet to be implemented within one compact device.

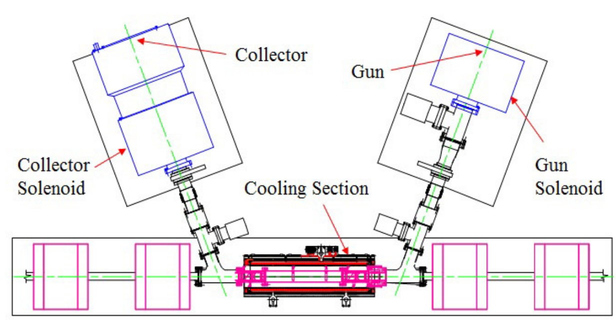

Figure 2: Plan view of electron lens section for IOTA.

The construction of the electron lens assembly will follow three phases: serial connection between gun and collector, installation of the main solenoid and bending sections, and commissioning. Currently, the serial connection between devices is underway in order to evaluate the gun and collector repurposed from the Tevatron Electron Lens 2 (TEL-2). Both the gun and collector were removed from the Tevatron in 2015 with their solenoids and power supplies. Table 1 provides a summary of the electron lens design parameters.

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Table 1: Typical Electron-Lens Design Parameters [5]

PARAMETER	VALUE
Amplitude function, β	3 m
Circulating beam size (rms), σ_ε	0.24 mm
Main solenoid length, L	0.7 m
Main solenoid field, B_z	0.33 T
Gun/collector solenoid field, B_g	0.1 T
Cathode-anode voltage, V	5 kV
Beam Current, I_e	1.1 A
Current density on axis, j_0	9 A/cm^2
Focusing strength, k_e	0.63 m^{-1}
Effective radius in overlap, a	2 mm
Maximum radius in overlap, $6a$	12 mm
Effective radius at cathode, a_g	3.6 mm
Maximum radius at cathode, $6a_g$	22 mm

ELECTRON LENS CONSTRUCTION

A major part of the IOTA electron lens involves the repurposing of the TEL-2 electron gun, collector and associated components. The layout for TEL-2 is shown in Figure 3. The electron gun emits an electron beam, focused by a solenoidal magnetic field with a potential of 5 keV to 10 keV. Three compact serial bending elements direct the electrons into the superconducting main solenoid. A relative magnetic field increase from the gun solenoid to the main solenoid of 3.1 T compresses the electron beam. Dipole correctors and BPMs are used in conjunction with the main solenoid to provide alignment of the electron beam. Finally, the collector which is maintained at the lowered negative potential for reduced power deposition receives the electrons [5].

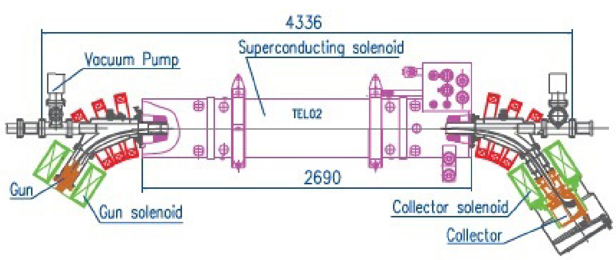

Figure 3: TEL II system layout.

We chose certain components from TEL-2 for IOTA, such as the gun/collector pair and associated solenoids. These solenoids will operate at a maximum solenoidal field of 0.4 T while passively cooled. The magnetic bending elements which are also passively cooled must be compact and fit into the current envelope without interfering with the adjacent quad and gun focusing element.

The gun and collector solenoids have a similar coil construction: inner diameter of 25 cm, outer dimeter of 47.4 cm and length of 30 cm [11]. A distance of 30 cm is required between the main solenoid and next focusing element (quad) within the IOTA ring, limiting the space for bending elements and orbit correctors. Smaller focusing elements are needed between these bends and the gun/collector solenoids. In all, the electron lens layout must be as compact as possible [11].

Overlap Region

The overlap region shown in Figure 4 consists of a main solenoid and internal components which include; electrodes, pickups, and upstream (US) and downstream (DS) BPMs. Parameters are summarized in Table 2 and other requirements include: water cooling, a soft-steel flux return, and corrector coils integrated at each end. The solenoid will be simply supported at 22% of length from each end.

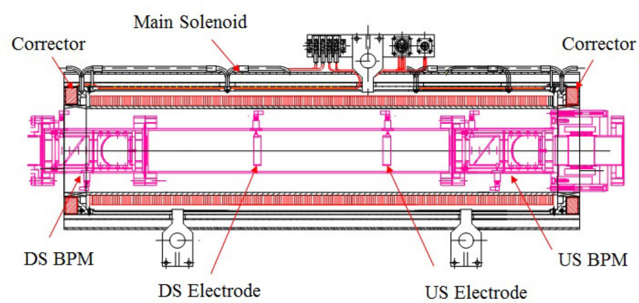

Figure 4: Layout of overlap region.

Table 2: Summary of Cooling Section Solenoid Parameters

PARAMETER	VALUE
Solenoid Field Strength Requirement	0.8 T
Current Density	6 A/mm^2
Field Straightness (within)	100 µm
Solenoid Length	0.8 m
Solenoid Aperture	142 mm (min.)

ULTRA-HIGH VACUUM

The IOTA Ring will operate under ultra-high vacuum (UHV) conditions with a design pressure of 2 x 10^{-10} Torr. This will be achieved using distributed ion/NEG pumps on a baked system, with a bakeout of 120 degrees C.

As the gun filament operates at 1,100 degrees C, the pressure at the gun will be higher. Therefore, the gun side of the electron lens will include a differential pumping section to compensate for this locally higher pressure. The gun will be isolated from the ring with a gate valve for easier maintenance access. Other elements of the gun section include a diagnostic cube, a bellows and focusing element. The collector-side consists of a gate (isolation) valve, a diagnostic cube, a bellows and the focusing element.

Evaluation of the gun and collector assemblies following their removal from the Tevatron began our work toward understanding the impact to the UHV status of the IOTA ring. This evaluation involved connecting the gun and collector serially with a vacuum spool, pumping down and baking the system to 150 degrees C. The final pressure after the bake was 3 x 10^{-9} Torr, and an RGA scan confirmed no contamination was present in the system. The pumping configuration for the gun and collector sides was based on these results as well as behavior history in Tevatron.

SUPPORT SYSTEM

The IOTA Ring consists of 10 floor girder support structures used to minimize relative motion between ring devices, such as dipoles, quad, octupoles and corrector magnets. A prototype girder was fabricated and the supporting surface was ground flat to within 50 µm. This prototype will help evaluate the installation procedure for the electron lens and other IOTA devices such as the adjacent quads [12]. The gun and collector will be supported on a single pedestal 1 m long floor girder as shown in Figure 5. The original adjustment systems for the gun and collector solenoids will be reused.

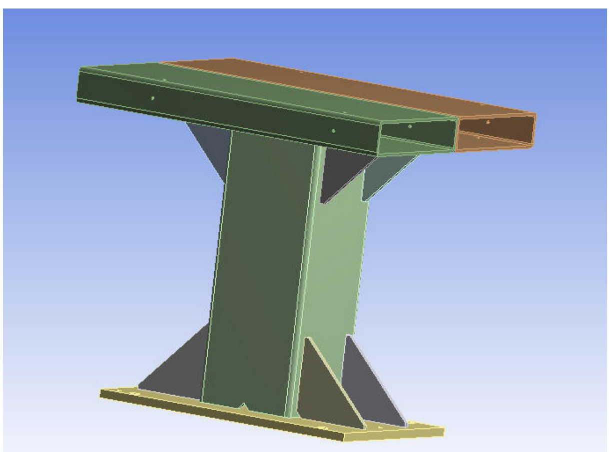

Figure 5: Pedestal support for gun and collector operation.

FUTURE WORK

The next steps of the IOTA electron lens project are the following: confirm complete function of gun and collector system in serial configuration, reposition gun and collector system in operational configuration, procure magnet elements, including the main solenoid, focusing solenoids and bending elements, and begin assembly of electron lens vacuum section under UHV specification and practices.

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