ALIGNMENT AND STEERING FOR INJECTION AND MULTI-TURN OPERATION OF THE UNIVERSITY OF MARYLAND ELECTRON RING (UMER)*

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Abstract

The injection line and main lattice for the University of Maryland Electron Ring (UMER) has been completed. The electron beam has completed more than three full turns of the ring. Beam steering and matching in the injection line are achieved with six quadrupole magnets and several small steering dipole magnets. The dipole component of an offset quadrupole and a pulsed dipole are combined to achieve the 10 degree bend required from the injection line into the ring. The pulsed dipole is designed to operate with a short pulse (2 kV, -30 A, 100 ns flat top duration) for injection superimposed on a long pulse (300 V, 15 A, 20e-6 s duration) for multiple beam passes. The beam is controlled in the recirculating ring with a regular lattice of 35 dipole and 72 quadrupole magnets. Initial experimental results of the beam transport and control are presented.

INTRODUCTION

The University of Maryland Electron Ring (UMER) is a low energy (10 kV), high intensity (100 mA),recirculating electron ring designed to explore the physics of space charge dominated beams.[1,2,3] As can be seen in Fig. 1 the injection line consists of one solenoid, six independently controlled quadrupoles (Q1-Q6) and six sets of horizontal and vertical steering magnets (SD1-SD6). A large set of bucking coils negate the earth's magnetic field over the region from SD1 to SD4.

The injection line is positioned at a 10° angle from the ring. The beam is bent by the combined effort of the offset quadrupole (PQ) and a pulsed dipole (PD). Specifications for these pulsed elements are described in detail in Ref. 4. Beam position and angle into the pulsed elements is primarily controlled by SD6.

The storage ring is comprised of 18 separate sections with 35 bending dipoles (D1-D35). Each dipole provides a 10° bend. A vertical steering element is installed between each section. The last magnet the beam encounters on the first lap of the ring is a horizontal steering magnet positioned prior to PQ which controls the angle and position as the beam reenters the pulsed elements PQ and PD. The electrical systems for all the magnets are described in detail in Ref. 5.

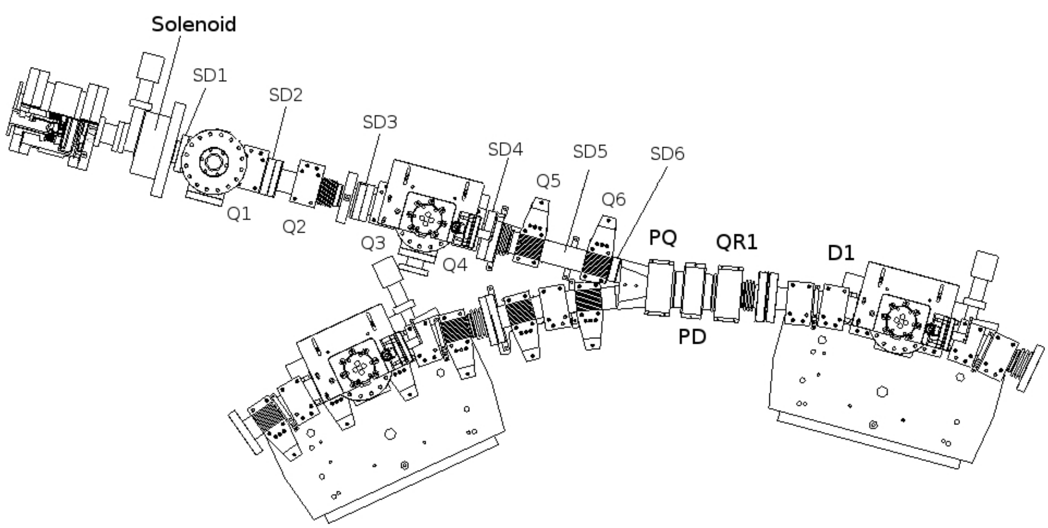

Figure 1: UMER injection line with quadrupoles Q1-Q6 and steering magnet SD1-SD6 positions labelled.

EXPERIMENTAL SETUP

A new control interface using LabView under a Linux operating system has been written for nearly all the magnets described above [6]. Polarity switching of the steering magnets has been incorporated into the LabView

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programming. The pulsed elements are not yet computer controlled due to limitations of their power supplies. Data acquisition from the beam position monitors has also been integrated into the LabView control interface.

General Procedure – Injection Alignment

Previous efforts to steer the beam through the injection line have utilized optical data from a phosphorus screen inserted into the second chamber of the injection line [7]. Because the ring is now a closed loop and multi-turn operation is at hand all steering efforts described herein use only signals from the beam position monitor (BPM) installed in the second injection chamber and 14 BPM's in the ring [8]. Accuracy of the optical alignment was limited by the camera resolution of approximately 0.1 mm/pixel. Accuracy of the BPM-based alignment is limited by the signal conditioning electronics. With the amplifiers currently installed, a measurable 100 μV signal from the BPM corresponds to approximately 0.04 mm resolution.

Figure 2 presents a schematic representation of the injection line with the steering and focusing elements included. Injection steering efforts are now based on the following sequence:

- adjust SD1 to center the beam in Q2, ignoring any offset in Q1,
- adjust SD2 to center the beam in Q3, (which creates a small misalignment in Q2),
- repeat the steps above until the misalignment in Q2 caused by SD2 is below our detectable threshhold,
- sequentially adjust SD3 to SD5 to center the beam in Q4 to Q6, respectively.

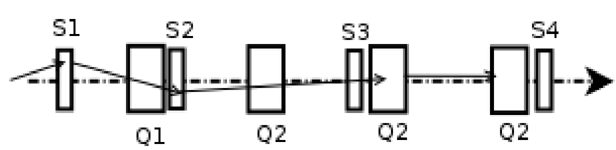

Figure 2: Schematic representation of the injection line with steering elements S1-S4 and quadrupoles Q1-Q4. The ideal beam line is shown as the dotted line.

It should be noted that we have made no effort to align the beam in Q1. This is because the beam origin has both some angular deviation and radial displacemnt from the ideal center line and there is only one steering element before Q1. The best solution is to use S1 to aim the beam at the center of S2, then use S2 to correct the beam angle to the ideal beam path. If, however, the magnetic centers of Q2 and Q3 do not lie exactly on the ideal beam line, S1 should be tuned so that the beam intersects the plane of S2 at the point where the line segment between the magnetic centers of Q2 and Q3 intercepts that same plane. Correction of the beam misalignment through the solenoid and Q1 will require mechanical adjustment of component placement.

Procedure – Recirculation

The primary goal of UMER is to store the electron beam in the recirculating ring. To that end a closed loop steering solution must be found. The singular value decomposition (SVD) method will be used to generate a closed loop solution for the steering matrix [9,10]. This solution method requires the construction of an orbit response matrix, **M.** The elements of the matrix **M** are measurements of the beam deflection in each BPM as a function of each steering element. In the case of UMER, **M** will be a 14x74 matrix when complete.

As of the time of this report only a small portion of the orbit response matrix has been generated because computer control of the pulsed elements used in injection (PQ, PD, and QR1) has not been established. Additionally, Helmholtz coils will be added in the near future to each ring section to provide smooth vertical beam corrections.

RESULTS

The beam current of UMER is controlled by apertures on the anode of the electron gun. Initial experimental efforts at steering have been concentrated on the 24 mA beam aperture setting. While still being a space charge dominated beam, past experience indicates that the steering matrix for this current value is nearly identical to that of lower current, emittance dominated beam current settings. Of the apertures currently available on UMER, the 24 mA beam is also near the lower limit for signal detection on the BPM's with the current signal conditioning electronics installed. As much as 90% of the beam current for the 24 mA beam has been transported around the ring to chamber number 17.

Figure 3 is a plot of the beam current as a function of time measured by the BPM in the first ring chamber. The

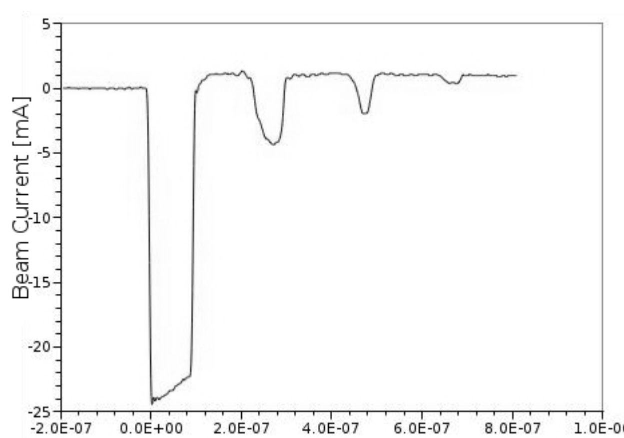

Figure 3: Results of the first multi-turn attempt on UMER (date: 5May'05). Beam current as a function of time measured at the first ring chamber.

beam transit time for one lap of the ring is 197 ns. The fall time of the pulsed dipole circuit was slightly greater than 100 ns so the beam pulse has been shortened to approximately 60 ns from the usual 100 ns. Improvements in the pulsed dipole circuit design are targeted at reducing it's fall time below 100 ns thereby allowing the beam pulse length to remain at 100 ns.

It should also be noted in Figure 3 that the beam has only coarse steering in the ring because the beam response matrix and closed loop steering solution have not yet been generated. Beam steering solutions have been completed through the injection line for the 24 mA and 85 mA beams. The next items to be added to the LabView interface must be the pulsed elements PQ, PD, and QR1 in order to build the beam response matrix and closed loop steering solution. This will require an upgrade to the power supplies used for these elements.

CONCLUSIONS

A new LabView interface has been completed which controls all the quadrupole and steering elements of the electron ring. Control algorithms have been written which enable scanning of any individual quadrupole and determine when the beam is at the magnetic center of the quadrupole. Beam steering solutions have been generated in the injection line for the 24 mA and 85 mA beam currents. Over 90% of the beam current with the 24 mA beam has been transported as far as the 17th ring chamber, i.e. 340 degrees of the loop. Generation of the orbit response matrix has begun in order to generate a closed loop solution for the recirculating ring. Partial beam transport has been achieved for over three complete revolutions (>30 m beam path) of the ring.

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