

# MULTI-TURN OPERATION OF THE UNIVERSITY OF MARYLAND ELECTRON RING (UMER)\*

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## Abstract

The University of Maryland Electron Ring (UMER) is a low energy, high current recirculator for beam physics research. The electron beam current is adjustable from 0.7 mA, an emittance dominated beam, to 100 mA, a strongly space charge dominated beam. UMER is addressing issues in beam physics relevant to many applications that require intense beams of high quality such as advanced concept accelerators, free electron lasers, spallation neutron sources, and future heavy-ion drivers for inertial fusion. The primary focus of this presentation is experimental results and improvements in multi-turn operation of the electron ring. Results of high current, space charge dominated multi-turn transport will also be presented.

## INTRODUCTION

The University of Maryland Electron Ring is a versatile experimental platform designed to cover a broad range of beam parameters [1,2]. The beam current may be varied in discrete steps from 0.7 mA to 100 mA. The current pulse length is adjustable up to a maximum of 100 ns. The beam is generated in a gridded Pierce gun with an energy of 10 kV, which has been described in detail [3]. The electron gun may be operated in thermal emission mode, as a photo cathode, or as a combination of the two [4]. The current pulse may be modified spatially and temporally using these methods.

The ring is composed of 18 sections, each spanning 20° of the ring arc. Currently, there are 14 ring chambers, 3 induction gap sections, and the injection Y. Four quadrupoles and two dipoles are mounted on each of the ring sections. Each ring section has a vertical steering magnet located on the upstream flange and independently controlled Helmholtz coils mounted in the horizontal direction to cancel the horizontal component of the earth's magnetic field. Located in each ring chamber is a beam position monitor (BPM) and imaging screen mounted on an actuator which allows diagnostic insertion and extraction without breaking vacuum.

The injection/matching line consists of a solenoid, 6 quadrupoles, and 6 sets of vertical and horizontal steering magnets. The unique method for beam injection and matching incorporates the combined effort of an offset quadrupole, and a pulsed dipole, to achieve the bending angle required [5,6].

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## FIRST TURN OPTIMIZATION

Beam steering through the injection line, offset quadrupole, and pulsed dipole was targeted at placing the beam at the centers of the first two ring quadrupoles, QR1 and QR2. This was chosen as a starting point for beam positioning in the ring because the magnetic center of any quadrupole may be easily found experimentally.

Construction of a response matrix and inversion of that matrix using singular value decomposition (SVD) is a well established beam steering method [7]. In UMER, because of the space-charge dominated beam physics, the focusing magnets are closely spaced leaving minimal space for BPMs. Our solution to the problem of having an insufficient number of BPMs has been to systematize and automate the quadrupole scans so that they may be used as “virtual” BPMs. If the steering corrections are kept small and the beam is near the center of the quadrupole the response matrix may be kept linear and inverted using a SVD method. This quadrupole scanning method assumes that all the elements between the scanned quadrupole and the measurement point are held constant. Results of these measurements in the horizontal plane over the first half of the ring are shown in Figure 1. The beam is not well centered at the first ring chamber, but the first two ring dipoles bring it back to the centerline

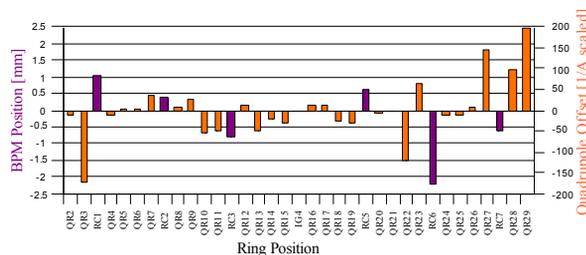


Figure 1: Beam position measured at the BPMs of chambers RC1 through RC7 (purple) overlaid with a scaled plot of offsets through each quadrupole (orange).

before QR4. The displacement in the first ring section may be due to the sensitivity to beam position in the offset quadrupole. Strong horizontal/vertical coupling and no vertical steering through the injection Y may also be a major factor causing this offset. With the present experimental setup the beam cannot be centered on all the elements of the Injection Y.

Another obstacle to steering the beam beyond RC6 is the noise produced by the dipole pulser in the injection Y.

As noted in Ref. 6, the current through the injection dipole must change polarity between the time the tail of the beam exits the dipole and before the time that the head of the recirculated beam arrives, which is approximately 100 ns. This fast current switching creates a large amount of noise that is picked up on the ground plane of the multiplexor. A new method of data collection has been implemented to minimize the pulser noise. The raw differential data signal is now sent directly to the oscilloscope and is digitally integrated after collection. The signal-to-noise ratio is reduced by more than an order of magnitude because shielded triax cable is now run directly from the BPM to the oscilloscope bypassing the multiplexor. Efforts are underway to provide a permanent solution to the noise problem that include redesign of the BPM electronics and multiplexing of the signals from all 15 BPMs.

Figure 1 also shows the relatively large displacements in the region after RC6 and beyond. Imaging of the beam on phosphorous screens in chambers 1 through 7, shown in Figure 2, clearly show a beam envelope mismatch and halo formation in this region. While the beam core is well centered in RC6, most of the halo from RC5 is not seen. The halo, which is outside the bounds of the imaging screen and therefore very close to the BPM plates, contributes a disproportionately large amount to the signal measured by the BPM thereby showing a large net offset from center.

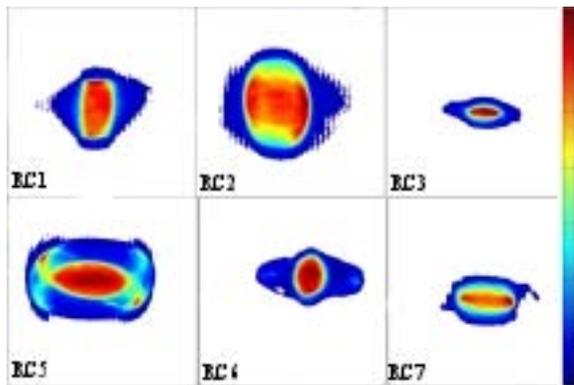


Figure 2: Beam image at RC1 through RC7. No imaging screen is mounted in RC4.

## MULTI-TURN RESULTS

Recent multi-turn results for the 20 mA beam are shown in Figure 3. Approximately 75% of the beam current is transported around the ring to begin the second turn. As seen in Figure 2 above, 20% of the current loss is occurring in the area between RC5 and RC6 due to mismatch and halo current impacting the vacuum boundary wall. Noise from the dipole pulser begins at approximately  $t=300$  ns.

The same steering solution was then used for the 5 mA beam. Results of the 5 mA beam transport are shown in Figure 4. The beam losses are greatly reduced in the 5 mA case. Over 90% of the beam current is transported to begin the second lap of the ring. It should also be

noted that the ring quadrupoles were reduced to 94% of their optimal value for a phase advance,  $\sigma_0$ , of  $76^\circ$ , for both the 20 mA and 5 mA cases shown.

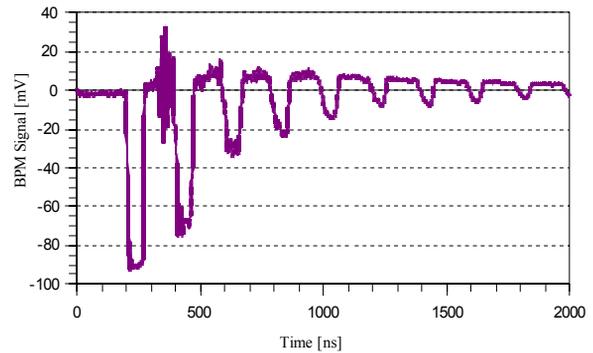


Figure 3: Total beam current transport measured by the BPM at RC2. Injected beam current ( $t=200$  ns) is 20 mA.

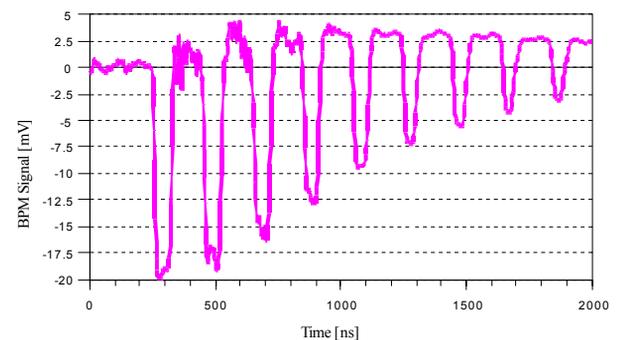


Figure 4: Beam transport measured with BPM at RC2. Injected current is 5 mA.

## DISCUSSION

Several key points about beam control and alignment on UMER should be highlighted from these experiments. Probably most important among these is alignment through injection Y. Vertical deflections of the beam due to the horizontal component of the earth's magnetic field contribute to the strong coupling of vertical and horizontal steering corrections from the last quadrupole in the injection line to the first quadrupole in the ring. A newly designed injection Y with beam position monitoring incorporated at critical locations is now a top priority.

The original diagnostics located at each chamber center, when operated individually, are not adequate for precise beam control and steering. Using the quadrupoles as virtual BPMs has allowed us to position the beam very precisely up to RC6. Presently, only the magnetic centers of the quadrupoles can be used for beam based alignment however, initial closed orbit calculations indicate that the beam must have a small but finite offset in each ring quadrupole. Efforts are under way to calibrate each quadrupole so that the change in beam position measured

downstream due to a change in quadrupole magnetic field can be correlated to the offset in the quadrupole. The beam position information from the quadrupoles will enable us to uniquely determine two points on each of the 36 straight sections of the ring.

Matching of the beam envelope must also be improved through a combination of improvements in simulation benchmarking and beam based matching. Improved simulation will then aid in answering questions about the tune of the ring and possible resonance crossings.

Recent improvements to the injection dipole pulser have reduced the settling time to near 100 ns, however noise on the BPM signals due to the pulser remains as a major issue. Digital integration of the raw BPM signal has permitted improved steering at large beam currents. Redesign of the BPM electronics is under way to permit reliable position information to be measured for smaller beam currents.

Upon completion of the first turn beam current transport optimization, reinjection of the beam into the pulsed dipole must be analyzed. Diagnostics installed in a redesigned injection Y will greatly aid in control of the recirculating beam. The steering response matrix can then be expanded by "unrolling" the ring elements such that the second pass through QR1 becomes QR73. The first ring dipole will also be treated as the 37th.

## CONCLUSIONS

Experimental work is continuing on optimization of the first turn transport of a high current (20mA), space charge dominated beam. Initial beam steering has been accomplished using the quadrupoles as virtual BPM.

Calibration of the quadrupoles will allow exact offsets required for a closed orbit to be achieved at each quadrupole. More than 75% of the 20 mA beam current has been successfully transported around the UMER. Over 90% of the 5 mA beam current has been sent around the first turn of the UMER.

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