COMMISSIONING 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 ring is completed for multi-turn operation of beams over a broad range of intensities and initial conditions. UMER is addressing issues in beam physics with relevance to any applications that rely on intense beams of high quality. Examples are advanced accelerators, FEL's, spallation neutron sources and future heavy-ion drivers for inertial fusion. We review the ring layout and operating conditions, and present a summary of beam physics areas that UMER is currently investigating and others that are part of the commissioning plan. We also emphasize the computer simulation work that is an integral part of the UMER project.

INTRODUCTION

The physics and motivation of the University of Maryland Electron Ring (UMER) was reviewed at PAC99 and PAC01 [1]. Progress reports have also been presented at more recent meetings and workshops [2, 3]. In short, UMER is intended for studies of space-charge dominated beam transport. Examples of projects underway elsewhere that address space-charge related issues are the high-current experiment (HCX) at LBNL, the Paul trap experiment (PTSX) at Princeton, and the Spallation Neutron Source (SNS) at ORNL [4].

Table I summarizes the beam and lattice parameters of UMER. The ring is designed for transport experiments over a broad range of beam intensities. A back-of-the-envelope design of a beam transport experiment involves five parameters: energy, current, emittance, zero-current phase advance per period, σ_0, and full lattice period, S. These parameters can be conveniently combined to define a dimensionless *intensity parameter* [1], $\chi = K/(k_0^2 a^2)$, where K is the generalized beam perveance, $k_0 = \sigma_0/S$ is the wave number of single-particle betatron oscillations in the uniform-focusing approximation of the lattice, and a is the average beam radius [5].

From Table I, the intensity parameter in UMER is $\chi \leq 0.98$, where $\chi = 1$ corresponds to the space-charge limit of beam transport. Beam transport near this limit is a fairly unexplored area, especially in circular machines.

Table 1: UMER parameters

Circumference	11.52 m
Full lattice period, S	0.32 m
No. of quads/peak gradient [1]	72 / 7.8 G/cm
No. of dipoles/nominal field [2]	36 / 15 G
Energy, $\beta = v/c$	$\leq$ 10 keV, 0.2
Current	$\leq$ 100 mA
Initial Emittance (norm. rms)	$<$ 3.0 μm
Average beam radius, a	$\leq$ 10 mm
Tune depression	$>$ 0.16
Pulse length	50-100 ns
Lap time	197 ns

[1] For $\sigma_0 = 76^o$, zero-current phase advance per period
[2] For 10^o bend, assuming earth's field compensation

In this regime, collective phenomena dominate over single particle dynamics. Some of the main issues for study are:

- Transverse dynamics: envelope and dispersion matching, beam stability and halo formation, emittance growth, space charge waves.
- Longitudinal dynamics: bunch capture and shaping, energy spread, space charge waves.
- Transverse/Transverse and Longitudinal/Transverse coupling: Montague resonances, asymmetric beams (with asymmetric focusing and/or emittances), equipartioning.
- Acceleration and resonance traversal.
- Chaotic dynamics and modeling of other physics (e.g., galactic dynamics).
- Detailed beam diagnostics and control (e.g., tomography of space-charged dominated beams.)
- Benchmarking of computer codes.

Specific issues like longitudinal dynamics, asymmetric beams and low-current operation of UMER are discussed in accompanying papers [6].

Since the inception of the project in 2000, research has been pursued in stages. First, characterization of the electron gun took several months; then, a matching/injection section was developed for DC injection. Experiments with a number of ring sections followed: two sections, four sections (70^0 net bend), 1/2 ring and 2/3 ring+pulsed injector at the end. Thus, construction and research have progressed

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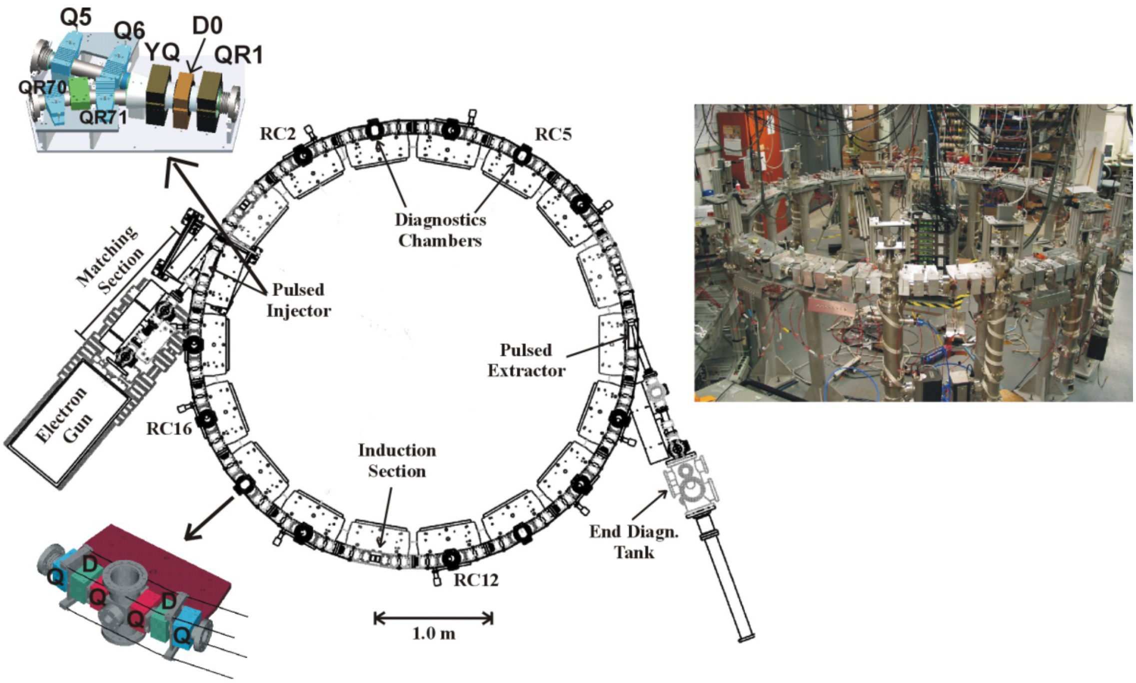

Figure 1: University of Maryland Electron Ring (UMER) layout and photograph. Details of ring section with center diagnostics chamber are shown on lower left corner. Q: DC quadrupoles; D: DC bending dipoles. Pulsed Injector section is shown on upper left corner. Q, QR70,71: DC quadrupoles; DO: pulsed dipole; YQ and QR1: long-pulsed quadrupoles. Steering elements, Helmholtz coils and induction modules are not shown.

side-by-side, with new insights guiding each new development.

Some research accomplishments in UMER so far are:

- Detailed beam characterization at the source [7].
- Beam transport studies over $<$ 1-turn.
- Matching of emittance as well as space-charge dominated beams.
- Study of evolution of photoemission-induced perturbations.
- High resolution measurements of energy spread.

Figure 1 shows the schematic of the final UMER layout. The current layout is the same except for the pulsed extractor and end diagnostics tank. Therefore, UMER is commissioned for multi-turn operation but with diagnostics limited to beam current and position monitoring. However, this will suffice at this stage when the emphasis is on optimized injection and matching. The extractor, which is under development, has a configuration similar to the existing pulsed-injector section. The end diagnostics tank, on the other hand, is fully developed and has been used in past experiments.

As illustrated in Fig.1, the basic UMER focusing/bending section consists of four quadrupoles (2 FODO periods) and two bending dipoles. These elements are based on printed circuits (PC) which provide the low gradient or fields necessary to focus/bend the low energy electron beam. The chamber at the center of each ring section houses a fast beam-position monitor (BPM) and fluorescent screen diagnostics. Injection is setup in a direction such that the earth's magnetic field provides 1/3 of the bending, approximately. While the earth's field helps to bend the beam smoothly around the ring, it also complicates beam alignment, especially on injection [8]. Helmholtz coils for earth's field compensation are used over the straight part of the matching/injection section; additional coils are laid along the ring chambers for minimizing the vertical deflection caused by the earth's field. An overview of the electrical system appears in these proceedings (B. Quinn et al, RPPE076).

The pulsed injector, also shown in some detail in Fig.1, consists of two large air-core magnetic PC quadrupoles, a wire-wound dipole and a number of steering elements (the latter not shown in Fig.1). The quadrupole labeled YQ is rotated (yaw angle) 20^0 relative to Q5-6; in this way, YQ acts both as Q7 and QR72. The injection dipole D0, on the other hand, is centered at the intersection of three lines: matching line ($\overline{Q6D0}$), RC1 ring line ($\overline{D0QR1}$), and RC18 line ($\overline{QR71D0}$).

UMER OPERATION

Results of pepperpot emittance measurements for DC injection experiments with 24 mA beam current (10 keV and $\sigma_0 = 76^0$) appear in Table II. The tune depression for this experiment is 0.3 ($\chi = 0.9$).

The measurements reveal no beam losses or serious beam degradation and hint to coupling of the dynamics in

Table 2: Emittance (4RMS, unnorm.) for 24 mA beam.

Location	$s(m)$	ϵ_x (μm)	ϵ_y (μm) [1]
Aperture plate	0	30±5	30±5
After 1/4 turn	3.8	30	36
After 1/2 turn	7.0	42	28
After 2/3 turn	9.0	33	51

the two transverse directions. Independent measurements with a slit-wire emittance meter confirm the results in Table 2 in at least one case (24 mA, 1/2 turn). A comprehensive account of experiments over 1/2 ring appears in [3].

The new experiments underway utilize the pulsed injector briefly described above. The injector depends on precise injection and steering so that quadrupole YQ can act as a combined-function element, i.e., for focusing and bending into the ring lattice [9]. The injection dipole, D0, is set up with a bending field that switches polarity before the beam completes one turn. The polarity swing is asymmetrical because the bending field opposes the action of the earth's field on injection, but adds to it for circulation. Details of the timing sequences and electronics can be found in the accompanying paper by M. Holloway [10].

A major short-term goal is to re-establish a first-turn baseline. So far, we have accomplished 100% current transmission over 360^0 for 0.7 mA, 10keV, and 85% for 24 mA, 10 keV. Currently, even though the lowest-current beam available is emittance-dominated, it still entails significant space charge (space-charge tune *shift* $\Delta\nu$=1.2). Thus, there are plans to operate at much lower currents, perhaps as low as 20 μA at 10 keV ($\Delta\nu$=0.27), which are achievable using the control grid in the triode electron gun or through collimation. By doing this, we will expand UMER's capabilities so it can operate across the full range of intensities, from the normal low-intensities of most accelerators to deep in the space charge dominated regime.

Figure 2 shows results for beams at chamber RC12 (2/3 turn) obtained in experiments with DC vs. pulsed injectors. Although the geometries for matching are similar, the demands of the pulsed injector for alignment and matching are more stringent, leading to the appearance of more extended halos. Improved steering for injection, refined matching calculation, and dipole corrections along the ring should lead to a better baseline for intense beam transport.

In short, the goal in UMER is to maintain a relative emittance growth $\Delta\epsilon/\epsilon_{init.} < 4$ while beam transport is realized with low-current over at least 100 turns, or with full-current over at least 10 turns, in both cases without acceleration. The commissioning plan involves the following challenges, in order of decreasing importance:

- Optimize injection and matching.
- Minimize bending dipole errors.
- Minimize ring quadrupole errors.
- Mitigate image forces for higher-current beams.
- Minimize skew quadrupole errors.

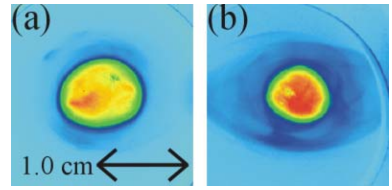

Figure 2: Beam pictures at RC12 (after 2/3 turn) for 24 mA, 10 keV beam with two different injectors: (a) DC injection, (b) Pulsed injection.

- Optimize tunes.
- Study and control of dispersion and chromaticity effects.

The first three items are essential for achieving closed-orbit conditions for relatively low-current beams. The fourth item is a requirement for closed-orbit with full current. (Although beam centroid and beam size are "uncoupled" for low current beams, it is not the case for high current beams where image forces can seriously offset and distort an already misaligned beam). The last two items would aim at maximizing the number of turns without acceleration.

Near the time of writing, multi-turn operation was demonstrated with an injected current of 24 mA at 10 keV. The beam survived for three turns, with a current transmission of ~30% for the first turn, and ~60% thereafter [8, 10]. Better beam steering and injection/recirculation timing should soon lead to improvements.

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REFERENCES

[1] M. Reiser et al, Proc. of the 1999 Particle Accel. Conf., New York, NY, p. 234 (1999); P.G. O'Shea et al, Proc. of the 2001 Particle Accel. Conf., Chicago, Il, p. 159 (2001).

[2] S. Bernal et al, Proc. of the 2003 Particle Accel. Conf., Portland, OR, p. 426 (2003); R.A. Kishek et al, Nucl. Instrum. and Meth. in Phys. Res. A, to be published (2005); S. Bernal et al, Proc. 11th Advanced Accelerator Concepts Workshop, Stony Brook, NY, AIP Conf. Proc. Vol. 737, p. 670 (2004).

[3] S. Bernal et al, Phys. Plasmas, 11, 2907 (2004).

[4] E.P. Gilson et al, Proc. PAC03, p. 2655 (2003); P.A. Seidl et al, Proc. PAC03, p. 536 (2003); J. Wei, Proc. PAC03, p. 571 (2003).

[5] Martin Reiser, Theory and Design of Charged-Particle Beams, Wiley & Son, New York (1994).

[6] J.R. Harris et al, MOPC010; K. Tian et al, TPAT067; S. Bernal et al, TPAT004; G. Bai et al, MPPE067; R.A. Kishek et al, TPAT066, these proceedings.

[7] I. Haber et al, these proceedings, TPPE046.

[8] M. Walter et al, these proceedings, FPAE021.

[9] H. Li et al, Proc. PAC03, p. 1676 (2003); M. Walter et al, Proc. PAC03, p. 1673 (2003).

[10] M. Holloway et al, these proceedings, RPPE075.

0-7803-8859-3/05/$20.00