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STEERING OPTIMIZATIONS FOR THE UNIVERSITY OF MARYLAND ELECTRON RING*

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Abstract

The **U**niversity of **M**aryland **E**lectron **R**ing is a dedicated research accelerator facility. UMER has the flexibility to set up alternative lattices for different research experiments. Existing beam-based alignment tools can take a significant amount of time to run and become difficult to process with a low ratio of BPMs to integer tune. The Robust Conjugate Directional Search (RCDS) optimizer is used to quickly obtain acceptable steering solutions for different lattice configurations and has been one of the techniques adopted for beam steering at UMER [1]. The algorithm optimizes steering magnets online to reduce scraping, correct equilibrium orbits, and increase beam lifetimes. We present some early steering results using this technique.

INTRODUCTION

UMER is a low energy (10 keV), high current (0.6-80 mA) electron storage ring. The machine is used to conduct scaled experiments applicable to larger accelerators. Most recently, studies on nonlinear beam dynamics [2].

Precision beam control is critical to the success of many experiments on UMER. Optimizing beam quality requires us to minimize closed orbits, maximize beam lifetime, and optimize injection. Traditional large accelerator facilities typically rely on orbit response matrix (LOCO) techniques to correct the machine's linear optics [3]. These techniques have been attempted at UMER, but did not offer satisfactory results due to limitations of the machine.

Figure 1: Left: Standard section with 4 quads (blue), 2 dipoles (green), and 1 vertical corrector (red). Right: Extra corrector section with 2 extra vertical correctors put in.

UMER has a low ratio of BPMs (14) to integer tune (6) making it difficult to apply steering corrections based off BPM measurements. The machine is also understeered due to a small number of corrector magnets. Each period of the lattice contains 4 quadrupoles, 2 horizontal correctors, 1 vertical corrector, and 1 BPM (Table 1). A few sectors have since been upgraded with more vertical correctors as seen in Figure 1. All magnets are printed circuit and have their own power supplies; this allows the dipoles to be used as horizontal correctors around the ring [4]. Imperfections in some printed circuit magnets cause higher order field terms to appear, further complicating steering in the machine.

Table 1: UMER Storage Ring Magnets

Magnet	**Total**
Quads	72
Horiz. Correctors (dipoles)	37
Vert. Correctors	31
BPMs	14

Due to the low energy of the beam, the earth's magnetic field has large effects on the machine. The non-constant earth's field, seen in Figure 2, contributes to 20%-30% of the bending force along the ring. As a result, dipoles are set to 70%-80% of their operating setpoints to compensate for the earth's field. Vertically, there are not enough correctors to fully compensate for the earth's field. This external field also makes it difficult to incorporate the machine into existing single particle tracking codes.

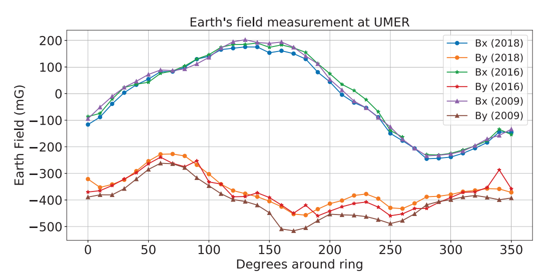

Figure 2: Measurements are taken at dipole locations around the ring.

The beam is injected into the ring using large pulsed magnets. Noise from these pulses couples onto the beam during the first few turns. The design trajectory for the beam also goes off center of a large quadrupole causing a significant kick to the beam. There have been observed nonlinear effects near injection as well. Because of this, the injection section at UMER has been difficult to model directly. Coupled with all the other complications mentioned above, optimized beam steering has been difficult to achieve.

RCDS OBJECTIVE FUNCTIONS

The RCDS optimizer has been incorporate into the UMER controls system and is used for online beam steering optimizations. In order for the optimizer to be effective, appropriate objective functions needed to be developed that could quantify the requiremenets for beam steering at UMER. The

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main components in these functions is a BPM matrix defined as:

$$B_{ij} = \sum_{i}^{\text{bpms}} \sum_{j}^{\text{turns}} BPM_{ij} \tag{1}$$

where BPM is a bpm measurement of the transverse position. One of the first objective functions we tried was to simply minimize the rms of the matrix B across turns and bpms:

$$\text{obj} = \min\left\{ \sqrt{\sum_{i}^{\text{bpms}} \left(\sqrt{\sum_{j}^{\text{turns}} (B_{ij})^2} \right)^2} \right\} \tag{2}$$

While this did result in a reduction in the orbit at BPM locations, we realize that the best orbit solution probably does not correspond to the beam going through the center of all BPMs. Next we tried an objective function that would minimize the tranverse position spread across turns, bringing the beam onto a closed orbit:

$$\text{obj} = \min\left\{ \sum_{i}^{\text{bpms}} \sqrt{\sum_{j}^{\text{turns}} (X_c - B_{ij})^2} \right\} \tag{3}$$

where X_c is some closed orbit that we are trying to minimize to. Similar to this, objective functions were also written to minimize current loss by looking at the BPM sum signal data across multiple turns. Often times minimizing against a single function will give bad results. If we ask the beam to minimize the closed orbit, it will due so at the cost of scraping the beam on purpose in order to get the beam to line up on a closed orbit. As a result it was necessary to minimize against multiple objectives at the same time. This was accomplished by simply adding weights to each objective.

STEERING RESULTS

We first look at trying to reduce the horizontal orbit in the ring. Since there are too many correctors to give RCDS at once, the correctors are split into 4 sections spread out around the ring. Each section's correctors are optimized one at a time. For this optimization we used the objective function from eq. (2). Results are in Figure 3.

The average RMS spread across 4 turns was reduced from 3.1 ± 0.3 to 0.42 ± 0.09 mm.. The new setpoints improve beam lifetime in the process by reducing the amount of scraping in the initial solution. Looking at the setpoints in Figure 3, we can see the biggest changes occured in the injection correctors. The correctors (dipoles) in the ring were not changed signifcantly from their initial setpoints.

For the vertical orbit we attempt to improve steering by moving the beam to a new closed orbit and optimizing said orbit. To do this the objective function from eq. (3) is used. Results are in Figure 4.

The large spread in setpoints vertically is in order to compensate for the large vertical force from the earth's field. While individual objective functions tend to give good results, combining them with weights adds an extra layer of

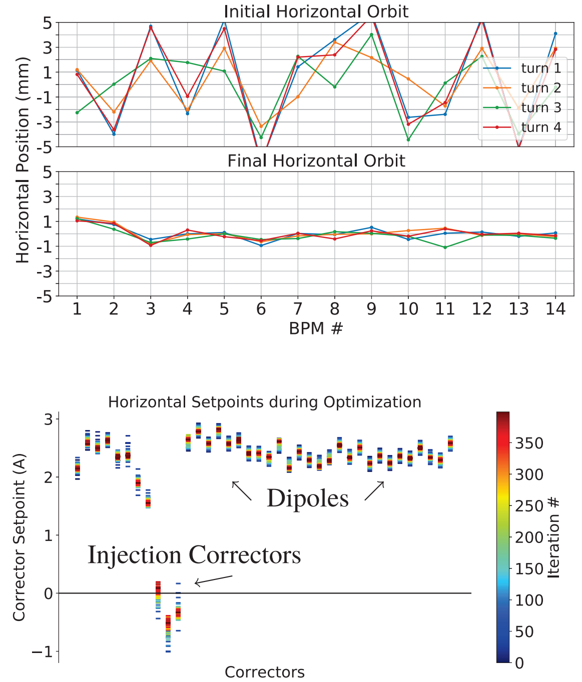

Figure 3: (top) Initial and final transverse horizontal positions at the BPM locations after running RCDS. (bottom) Changes in corrector setpoints while running RCDS.

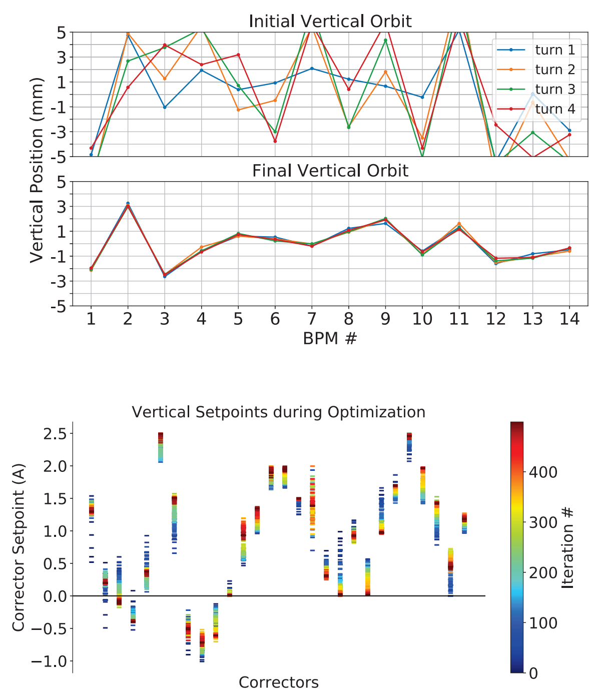

Figure 4: (top) Initial and final transverse vertical positions at the BPM locations after running RCDS. (bottom) Changes in corrector setpoints while running RCDS.

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control over what gets optimized. The smallest closed orbit in the BPM positions might not correspond to a solution with the least amount of scraping in the ring. As a result, adding weights to simultaneously reduce current loss and the closed orbit will yield better results. The difficulty comes in what weights to assign each objective; this is still actively being worked on.

NONLINEAR LATTICE STEERING

The printed circuit magnets on UMER allow the flexibility to change the machine lattice for different experiments. Recent nonlinear experiments on UMER have replaced a section of the ring with octupole magnets [2]. The experiment has required very precision beam steering. RCDS was used to find an acceptably small closed orbit and to increase the beam lifetime for the experiment. Figure 6 shows the change in BPM positions before and after steering while Figure 5 shows the increase in turns from the wall current monitor.

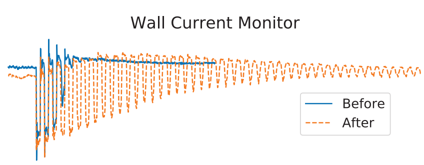

Figure 5: Wall current monitor before and after steering with RCDS.

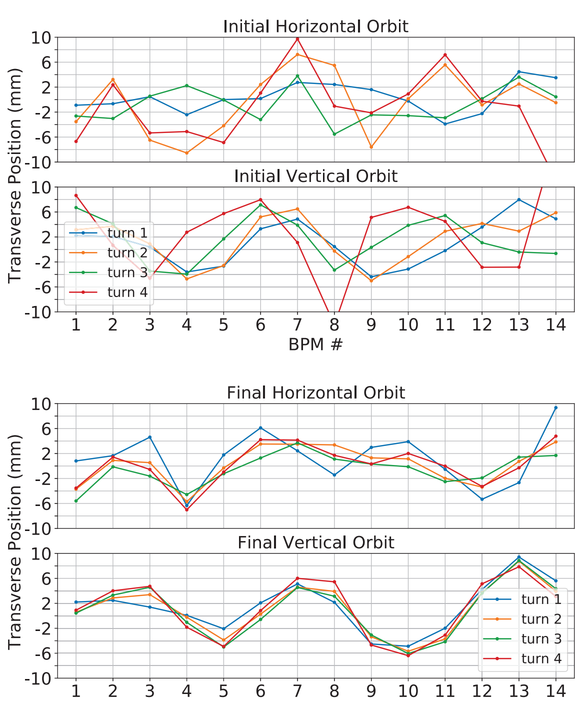

Figure 6: Transverse beam position before and after steering for the nonlinear octupole lattice.

FIRST TURN STEERING

In order for RCDS to work well the first turn has to be steered as close to the center of the quads as possible. Without this RCDS will come up with wacky solutions that have large oscillations inbetween BPMs. Before any RCDS steering run is done, we first center the beam through as many quads as possible on the first turn. Doing this somewhat constrains the amount of solutions RCDS can come up with. Results of centering through the quads are shown in Figure 7.

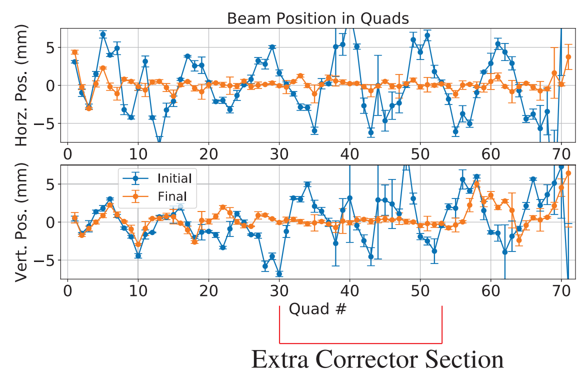

Figure 7: Centering the beam through the quadrupole magnets on the first turn.

Horizontally, the beam orbit is centered everywhere except around the injection section. Vertically, the first half of the ring only has 1 corrector per 4 quads. Between quads 30 to 50 the ring has extra correctors put in. There are plans to put more correctors into the ring in the future.

CONCLUSION

We demonstrate the use of RCDS to optimize beam steering at UMER. Different objective functions have been created based on the different steering goals. Further optimization of these functions with added weights will help improve steering. The technique has proven useful for nonlinear experiments that require precision beam control. There are plans to use the optimzer for tuning other key parameters of the machine such as beam matching on injection. A GUI interface will also be developed to allow operators to easily use the steering technique.

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