Chapter 3: Apparatus

3.1 UMER Layout

UMER is laid out as a 36-sided polygon, comprised of 18 modular 20^o sections. Each section houses 2 dipole magnets over 10^o pipe bends and 4 quadrupole magnets in a FODO (focusing-defocusing) arrangement.

3.2 UMER Beams

3.2.1 Generation and Detection of Low-Current Beam

3.3 Negligible space charge beam

For experimental nonlinear dynamics, it is desirable to start with a primarily emittance dominated beam, with smaller space charge concentrations than the lower-limit UMER beam (0.6 mA, $\frac{\nu}{\nu_0} = 0.85$), in order to isolate the space charge tune shift from the octupole tune shift. A nominally $50\mu A$ beam was produced by reducing the cathode grid bias to allow leakage current and longitudinally gating the DC electron beam with the pulsed injector dipole. This resulted in a high-emittance, low current beam that maintained a DC signal for over 1000 turns, ultimately limited

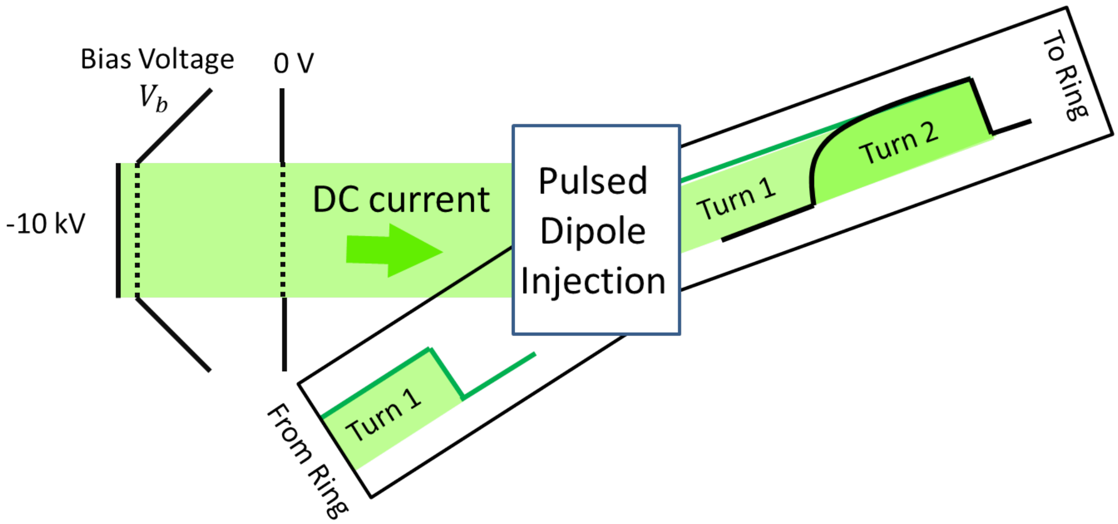

Fig. 3.1: Generation of variable current DC beam in UMER gun. Gate bias is lowered until DC current leaks through, pulse formation is done with injection dipole.

by the pulse length of the injection dipole. A low current, low emittance beam produced through photo-emission with a laser pulse is currently being explored as an additional UMER operating mode.

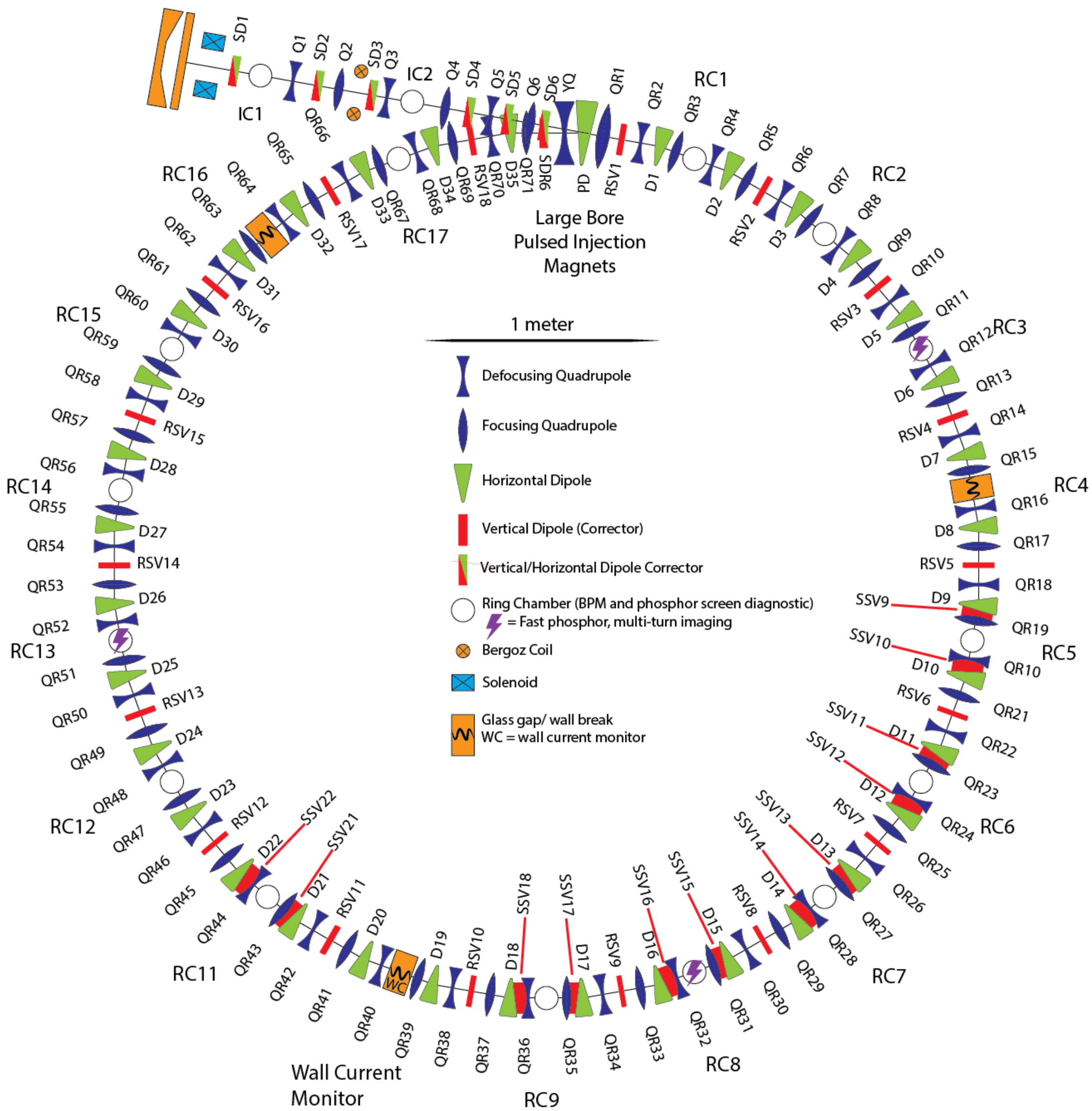

Fig. 3.2: UMER ring, with all magnets labelled.

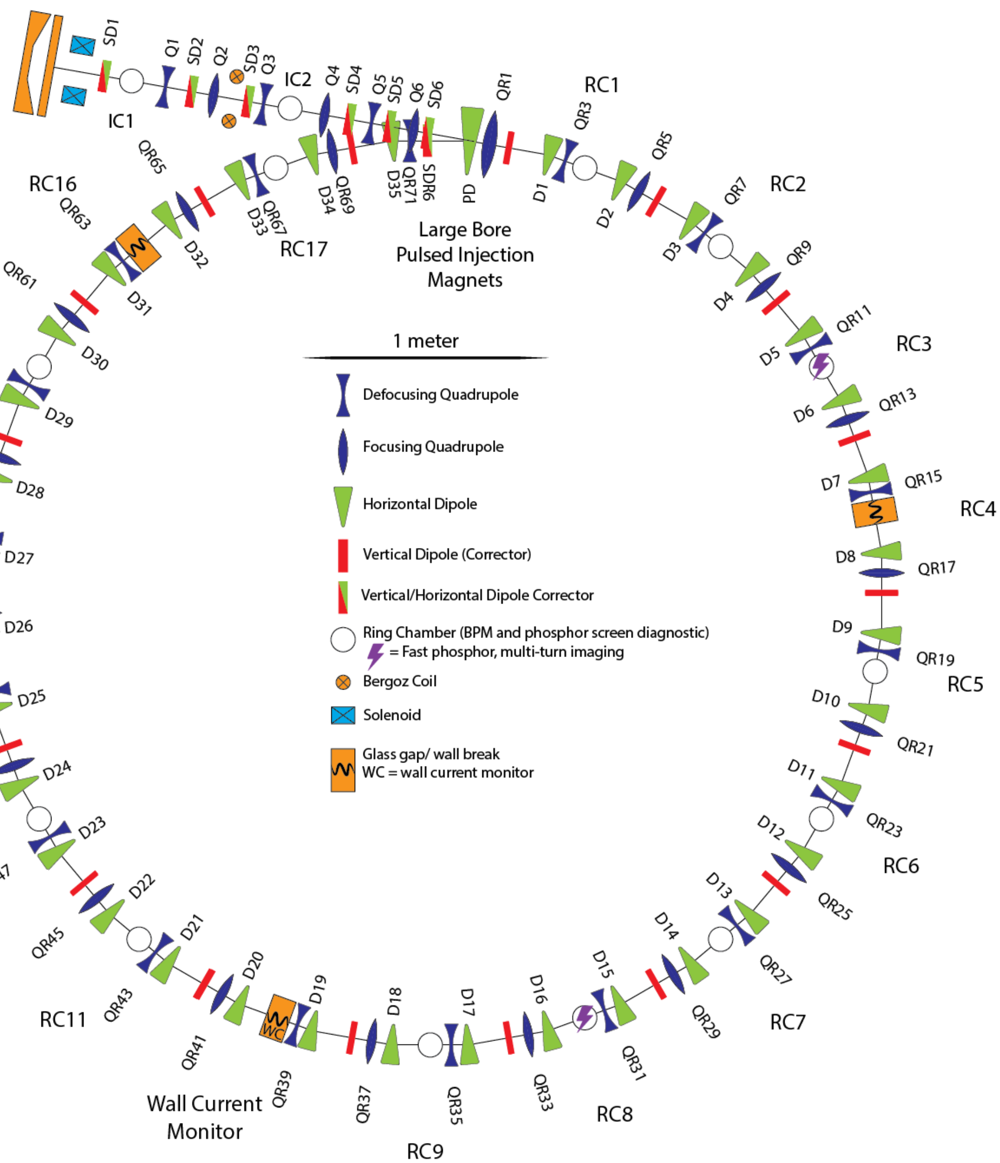

Fig. 3.3: UMER ring in alternative lattice configuration.

3.4 Lattice Configurations

3.4.1 FODO

3.4.2 Alternative FODO lattice

3.4.3 Octupole Lattices

3.5 Printed Circuit Octupoles

UMER utilizes air core flexible printed circuit magnets for focusing and steering. The printed circuits are cost-effective, lightweight and stackable, making any combination of multipoles possible. They can operate in DC or pulsed mode, and are easily tunable with no hysteresis as well as inexpensive and rapid to prototype.

The first generation of printed circuit octupoles has been produced and initial characterization made. The PC circuits, pictured in Fig **??**, are made in two double-layered halves, which fit inside the standard UMER quadrupole mount. Based on the similarity to existing UMER PC quadrupoles and dipoles, each magnet should easily be able to sustain 2 A DC with the existing mounts and up to 10 A with addition of water cooling. Maxwell 3D calculations show $75T/m^3/A$ peak fields in the octupole, with the 16-pole as the next significant multipole, against theoretical predicts that the 24-pole is the next highest allowed multipole. [1]

The magnet has been characterized using an integrated rotating coil measurement. A long coil rotating at 1 Hz sends EMF signal to an oscilloscope. The resulting scope FFT can be seen in Fig. **??**. The large dipole contribution is primarily due to the earths magnetic field. Sextupole and quadrupole terms are minimized by adjusting the transverse position of the octupole.

[2]

3.6 Simulation Codes

3.6.1 WARP

[3]

3.6.2 Elegant

[4]

3.6.3 VRUMER

3.7 Simulation Techniques

3.7.1 Frequency Map Analysis

A standard approach to understanding long term behaviour of single particle dynamics in an accelerator, particularly the effects of nonlinearities and resonances on dynamic aperture, is frequency map analysis (FMA). Originally applied to study of celestial mechanics, the technique has been successfuly applied to accelerator dynamics [[5]]. This is a powerful technique for simulation studies, but has also been applied to experimental data as well.

As applied to UMER lattices, many test particles are launched over a range of possible initial conditions and the orbits tracked over a long path length. I calculate fundamental orbit frequency, splitting the orbit into two halves ($t_o \rightarrow t_{mid}$ and $t_{mid} \rightarrow t_{final}$) to obtain two frequency values, ν_1 and ν_2. The difference between these values, $\Delta\nu = \nu_1 - \nu_2$ is a measure of chaos in the orbit. An orbit with irregular frequency will typically have a large $\Delta\nu$, while $\Delta\nu \rightarrow 0$ for regular orbits.

It can be useful to plot $\Delta\nu$ versus initial conditions, which indicates dynamics aperture. Lines of high $\Delta\nu$ indicate resonance structures, which may or may not contribute to aperture limitation through particle diffusion. Another approach is to plot $\Delta\nu$ versus fundamental frequency, which depicts the "tune footprint," or frequency space inhabited by the beam. Again, high $\Delta\nu$ will align with resonance lines in the tune diagram, allowing easy identification of harmful resonances.

In accelerators, position data used for frequency calculation is often limited in length. Frequency resolution using Fourier transformation scales as $\frac{1}{N}$ for number of sample points N. For higher precision, most algorithms use Numerical Analysis of Fundamental Frequency (NAFF), with a resolution $\propto \frac{1}{N^4}$.

FMA is built-in in many standard accelerator codes, including Elegant. While not included in standard WARP packages, I wrote an FMA module accessed at the Python level.

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