BNL-79691-2007-CP

The EMMA Lattice

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To appear in the proceedings of the Ninth International Workshop on Neutrino Factories, Superbeams, and Betabeams, August 6–11, 2007, Okayama University, Okayama, Japan

November 2007

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Abstract. EMMA is a 10 to 20 MeV electron ring designed to test our understanding of beam dynamics in a relativistic linear non-scaling fixed field alternating gradient accelerator (FFAG). I will give a basic review of the EMMA lattice parameters. Then I will review the different lattice configurations that we would like to have for EMMA. Finally, I will briefly discuss the process of commissioning each lattice configuration.

Keywords: non-scaling fixed field alternating gradient accelerator
PACS: 29.20.-c,29.27.-a,41.85.-p

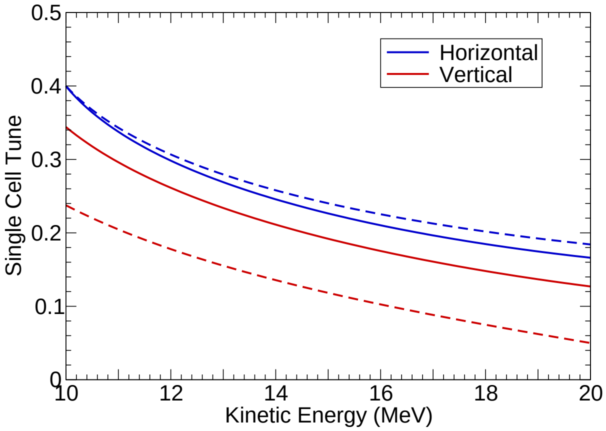

FIGURE 1. Tune as a function of energy for two different lattice configurations.

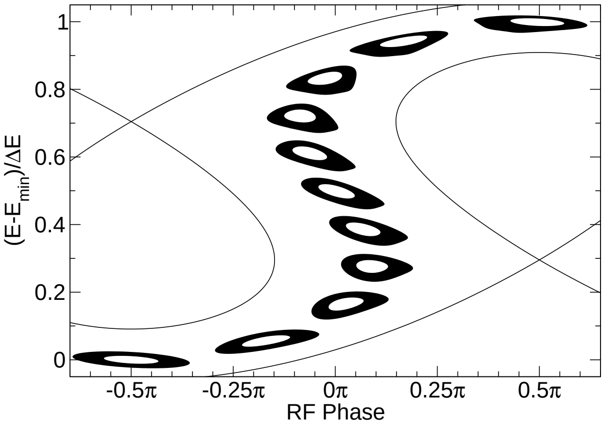

FIGURE 2. A bunch in longitudinal phase space for serpentine acceleration.

PURPOSE OF EMMA

EMMA will be the first non-scaling FFAG ever built. It will study the dynamics in linear non-scaling FFAGs at relativistic energies with rapid acceleration (around 10 turns) using high-frequency RF cavities. This is the configuration one would find when accelerating muons to the energies in a neutrino factory.

There are two important characteristics of this type of FFAG that will be studied in EMMA. First, since the tune varies with energy (see Fig. 1), one accelerates rapidly through a number of resonances (although “resonance” may not be precisely the correct word due to the high rate of acceleration). Second, in longitudinal phase space, one sees a “serpentine” behavior [1, 2, 3, 4] (see Fig. 2). The machine will study

- Emittance growth in the machine, and how it varies with which resonances are crossed
- How the longitudinal dynamics varies with machine parameters
- Effects of longitudinal-transverse coupling
- The effect of errors

THE BASIC MACHINE PARAMETERS

The EMMA lattice was previously described in [5, 6]. I will briefly review its characteristics.

Its basic machine parameters are shown in Tab. 1. The magnetic lattice consists of identical doublet cells with combined function magnets. The combined-function magnetic fields are created by displacing a quadrupole magnet. To be able to independently vary the dipole and quadrupole fields, the magnets are placed on horizontal sliders. The magnet doublet is shown in Fig. 3. The machine is furthermore capable of varying the RF frequencies of the cavities over a small range. This range of variability will allow the lattice to be precisely tuned and will

TABLE 1. Basic machine parameters.

Minimum kinetic energy	10 MeV
Maximum kinetic energy	20 MeV
Approximate RF frequency	1.3 GHz
Lattice cells	42
RF cavities	19
Lattice type	Doublet
Normalized transverse acceptance	3 mm
Nominal long drift length	210.000 mm
Nominal short drift length	50.000 mm
Nominal D magnet length	75.699 mm
Nominal F magnet length	58.782 mm

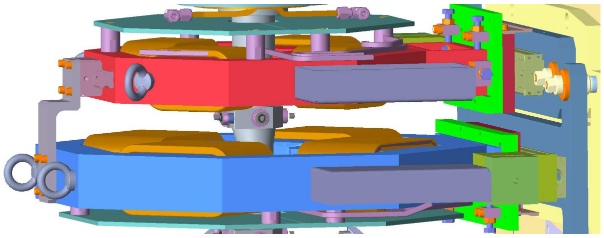

FIGURE 3. One of the EMMA doublets, shown sideways.

permit us to study a number of lattice configurations to confirm our understanding of the underlying beam dynamics. The range of parameters required for all lattice configurations are shown in Tab. 2.

LATTICE CONFIGURATIONS

The lattice configuration will be changed so that we can study the effect of resonances and the longitudinal dynamics in the machine. In the process, we will also confirm that we understand the relationship between the parameters that we vary and the energy-dependent linear lattice characteristics.

TABLE 2. Range of machine parameters required for all configurations.

	D	F	Cavity
Central axis shift			
Minimum (mm)	28.751	4.903	0.439
Maximum (mm)	48.559	10.212	0.439
Aperture radius (mm)	55.975	31.850	34.751
Vacuum chamber apertures			
Minimum horiz. (mm)	-7.416	-21.638	-16.936
Maximum horiz. (mm)	18.789	20.700	17.814
Half height (mm)	11.676	8.906	10.571
Max. gradient (T/m)	-4.843	6.847	—
RF parameters			
Min. freq. offset (kHz)	—	—	-4019
Max. freq. offset (kHz)	—	—	1554
Max. ring voltage (kV)	—	—	2286

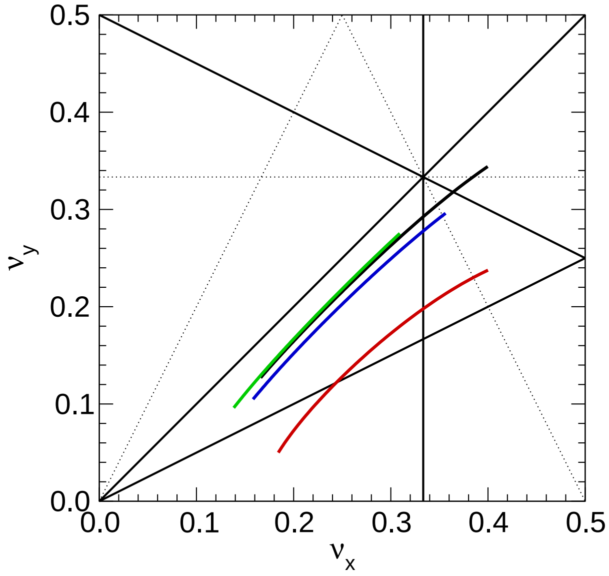

FIGURE 4. Single-cell tune for all energies for four different lattice configurations. Low energy has higher tune.

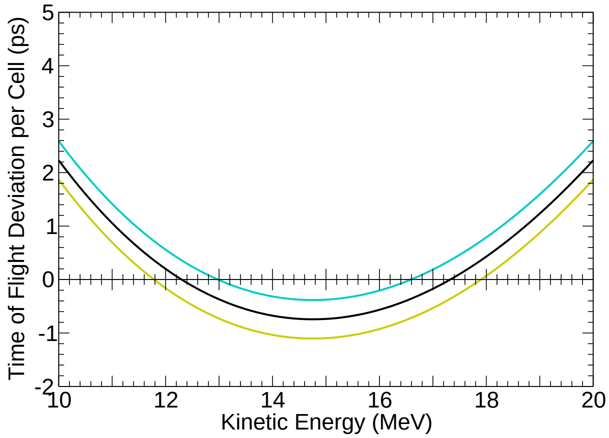

FIGURE 5. Time of flight as a function of energy for three different RF frequencies. Zero time of flight deviation is when the particle on the closed orbit at that energy is synchronized with the RF. The actual time of flight doesn't change between curves, only the RF frequency changes.

We will change lattice configurations so as to vary which low-order single-cell resonances the beam will cross during the acceleration process. Figure 4 shows the various tune ranges we are proposing to study. The different configurations cross different numbers of sextupole-driven resonances.

We will vary the RF frequency to adjust the energies at which the beam is synchronized with the RF, as shown in Fig. 5. Figure 6 shows the effect that this variations is ex-

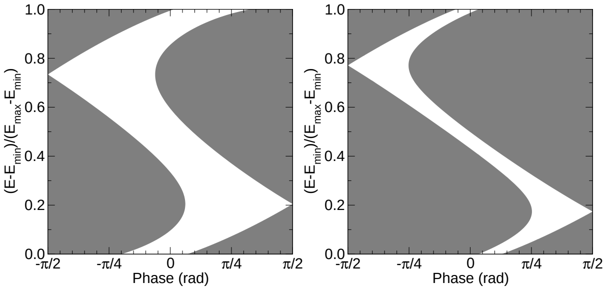

FIGURE 6. Longitudinal phase space for two lattices which differ only in their RF frequency. Particles are accelerated from the minimum to the maximum energy through the white area.

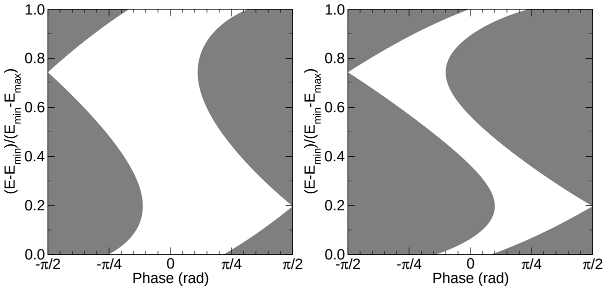

FIGURE 7. Longitudinal phase space for two lattices which differ only the RF voltage.

pected to have on the longitudinal phase space. Variation of the RF frequency will also be used in commissioning to change the fixed-point energy so we can find the linear lattice parameters as a function of energy.

We will vary other machine parameters that are expected to affect the longitudinal dynamics. We will vary the energy of the minimum in the time of flight. We will also vary the RF voltage (see Fig. 7).

COMMISSIONING PROCESS

Each lattice configuration is defined by three curves: time vs. energy, and two tunes vs. energy. Furthermore, one must center the beam in the beam pipe, considering the entire energy range and transverse emittance of the beam.

For each lattice configuration, the positions and currents of the two magnets are adjusted to obtain the desired tunes, time of flight, and beam position. The tunes and time of flight can only be fit at one energy (or equivalently, two tune constraints and one time of flight constraint). However, the tunes and times of flight must still be measured at all energies to determine the relationship between the dynamical behavior of the system and the expected behavior, well as to determine the expected longitudinal behavior (from the time of flight), and to determine which resonances will be crossed.

There are no simple relationships between the input parameters (measured positions and coil currents) and the measured values (tunes, time of flight, and position). Changing one input parameter changes all of the measured values. Furthermore, since the magnets are so close together, powering one magnet creates significant fields within both magnets. Thus, it is essential to get some practice in adjusting the input parameters to achieve the desired lattice configurations.

This commissioning process should therefore be studied using a simulation code such as ZGOUBI [7] which is capable of modeling the field maps of these doublets. It would be helpful to make modifications to the code to directly combine the separate overlapping field maps (one for the defocusing magnet powered, the other for the focusing magnet powered). Furthermore, the field map is parametrized by the horizontal distance between the magnet centers. The field map could be computed externally to the simulation code as well. One would simulate the process of measuring the tunes, time of flight, and position, and adjusting the input parameters to try to achieve the desired configuration.

ACKNOWLEDGMENTS

This work has been supported by US Department of Energy under contract AC02-98CH10886.

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