Electron Model: Lattice and Performance

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Lattice and performance aspects of an electron model for an FFAG ring accelerating muons are discussed. Aims and scope are presented. Acceleration outside buckets, lattice cells, tunes and circumference are shown.

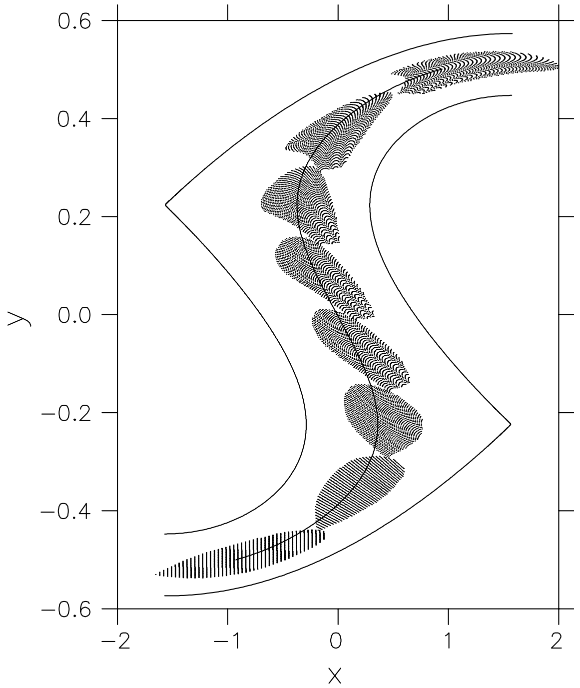

Figure 1. Bunch motion in longitudinal phase space, which is periodic in x with period 2π, and symmetrical around $x = \pm\pi/2$

1. AIM AND SCOPE

The goal is simulating the rapid acceleration of relativistic muons in a non-scaling FFAG ring [1] in a small relativistic electron ring [2]. We use magnetic elements with field and gradient [3]. We do not consider models with nonlinear fields, and slow acceleration of non-relativistic particles [4,5].

2. ACCELERATION

The RF system of the electron models runs at constant frequency $f_{\mathrm{RF}} \approx 1.3$ GHz. Fig. 1 shows the two strings of stable and unstable fixed points at $y \approx \pm 0.2$, where the electrons are synchronous to the RF system, and where we put the origin of the time of flight ΔT. The abscissa is the phase in the interval $|x| \leq \pi/2$. The ordinate y is an energy scale, $y = \pm 0.5$ correspond to 10 and 20 MeV. The boundaries of the gutter for acceleration outside buckets pass through the unstable fixed points at $x = \pm\pi/2$ and $y \approx \pm 0.2$, are symmetrical around $x = \pm\pi/2$, and have period 2π in x. The bunch centres are accelerated from $(x, y) \approx (-1, -0.5)$ to $(x, y) \approx (+1, +0.5)$ along the centre of the gutter. Bunches starting with invariant area 10^{-4} eVs, length ±0.125 ns, and energy spread ±0.25 MeV get distorted.

3. LATTICE CELLS

Fig. 2 shows a schematic layout and the orbit functions of a lattice cell. We prefer doublets over triplets. The straight section provides space for an RF cavity. The magnets provide enough aperture for electrons with momenta from 10 to 20 MeV/c. Their lengths are adjusted such that their pole tip field remains below $B \approx 0.2$ T. We adopt rectangular magnets with parallel end faces, because they have a smaller tune spread ΔQ than sector magnets, as shown in Fig. 3. The magnets resemble offset quadrupoles more than dipoles. The reversed field in the F magnet reduces the dispersion D_x and ΔT.

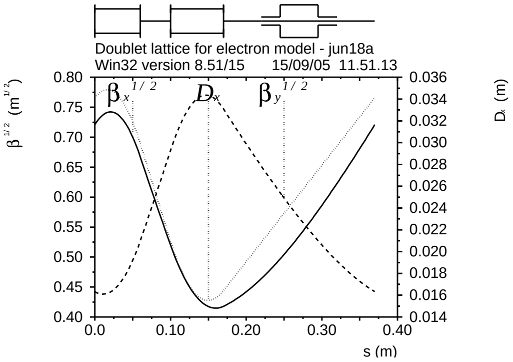

Figure 2. Schematic layout and orbit functions

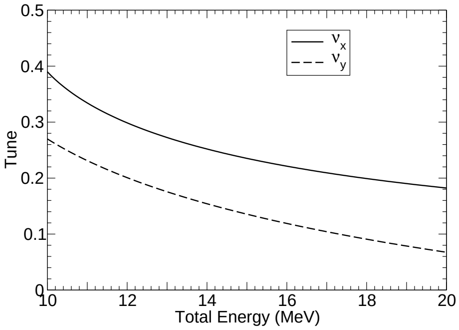

Figure 3. Cell tunes vs. $\Delta p/p$

4. TUNES IN A LATTICE CELL

We achieve a small D_x and a small spread in the time of flight ΔT by letting the horizontal cell tune ν_x at 10 MeV approach 0.5 from below, thus avoiding the half-integral stopband and the associated rise in the horizontal orbit function β_x. We improve ΔT by using $\nu_y < \nu_x$. In a linear lattice such as ours, we have essentially $\nu_x \propto \nu_y \propto 1/E$. Edge focusing in the magnets can be used to control the tune variation $\nu(E)$ without nonlinear field components. Fig. 3 shows the cell tunes ν_x and ν_y vs. $\Delta p/p$. The total tune variation in 42 cells is many units during acceleration. Hence the tunes Q_x and Q_y cross many resonances at $n_xQ_x + n_yQ_y = k$, with order of resonance $|n_x| + |n_y|$, and harmonic k around the circumference, which are driven only by errors in field shape, excitation, and alignment.

5. CIRCUMFERENCE

Number of lattice cells N_p and circumference C are determined by two dimension-less parameters $a = e\hat{V}/2\pi f_{\mathrm{RF}}\Delta T\Delta E$ and $b = T_0/\Delta T$ [6] with peak RF acceleration $\hat{V}$, time of flight spread $\Delta T \propto 1/N_p$, both taken for a lattice cell, acceleration ΔE from 10 to 20 MeV and minimum time of flight $-T_0$ near 15 MeV. By choosing $\hat{V}$ and the exact f_{RF}, a and b can be adjusted. Observing that $N_p \propto \sqrt{M_c}$, we design the model for $M_c \approx 500$ cell traversals with $a = 1/12$, $b = 1/5$, cell length $L_p = 370$ mm. We picked $N_p = 42$, a multiple of 6, and $C = 15.54$ m. We choose the transverse emittances ε_n such that the divergences x' and y' are close to those in muon rings.

6. SUMMARY AND OUTLOOK

The choice of parameters is well advanced. Simulations will be continued and/or launched to confirm the feasibility of the model with the parameters shown above. The limit on the emittance increase due to crossing resonances yields alignment and excitation tolerances. Analytical estimates [7] indicate that the emittance inscrease is small enough. Bunch distortion and particle loss due to acceleration with finite longitudinal emittance must be quantified. Fig. 1 assumes vanishing ε_n. Finite ε_n adds kinematic terms due to divergences x' and y', and makes things worse. By how much needs to be found. Fringe fields due to the aperture being approximately equal to the magnet length may drive systematic nonlinear resonances, and are under study.

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