AN IMAGINARY γ_t LATTICE FOR THE FERMILAB PROTON DRIVER*

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Abstract

This paper describes the lattice design of the Fermilab Proton Driver. Its main features are: (1) an FMC (flexible momentum compaction) lattice using $270^\circ/270^\circ$ FODO modules, (2) transition-free (imaginary γ_t), (3) large momentum acceptance ($\pm 2.5\%$), (4) large dynamic aperture ($\geq$120 mm-mrad) and, (5) zero dispersion in straight sections.

1 INTRODUCTION

The Fermilab Proton Driver is a high intensity (3×10^{13} protons per pulse) rapid cycling (15 Hz) synchrotron. The maximum beam energy is 16 GeV. The beam power is about 1 MW. The main parameters can be found in Table 2.1 and 2.2 of Reference [1]. This machine calls for high beam brightness in both longitudinal and transverse planes. In the longitudinal plane, the Proton Driver must deliver bunches with very short length (about 1 ns r.m.s.) at exit. In the transverse plane, the brightness will reach the space charge limit at injection. In order to minimize emittance dilutions during the cycle and to avoid the negative mass instability that could be caused by the space charge, a transition-free FMC lattice has been chosen [2, 3].

To make short bunches, a bunch rotation in longitudinal phase space is necessary. This requires large momentum acceptance of $\pm 2.5\%$. To keep space charge tune spread under control, the transverse charge distribution of the injected beam will be made as uniform as possible by the painting technique. As a result, the beam emittance will be enlarged to 60π mm-mrad (normalized, 100%). The dynamic aperture of the lattice is required to be twice this value for the entire momentum spread range. Moreover, to avoid any possible synchro-betatron coupling resonance, the straight sections, in which the rf cavities will be located, are made dispersion free.

2 LATTICE CANDIDATES

Various types of lattices have been considered but only one meets all the requirements.

1. The simple FODO lattice is ruled out because it is impossible to make it transition-free at 16 GeV.

2. A doublet lattice was proposed. The merit is its simplicity. Only two types of quadrupoles are needed. However, the required quad strength, 20 T/m, is far above a realizable value. Another serious defect is the lack of suitable locations for sextupoles.

3. Several racetrack lattices were studied. They can use the same modules as in a triangular lattice as described in the next section. However, it causes complication to put injection, collimation and extraction in the same long straight. Besides, a racetrack lattice uses more modules (16) than a triangular one does (12).

4. Various choices of phase advance in FODO or DOFO modules were tried, including $\mu_x/\mu_y = 270^\circ/135^\circ$, $270^\circ/180^\circ$ and $270^\circ/270^\circ$, respectively. The first two choices fail due to the lack of suitable locations for sextupoles. Only the last one ($270^\circ/270^\circ$) provides the needed momentum aperture as well as the dynamic aperture.

5. Both the $270^\circ/270^\circ$ FODO and DOFO modules meet all the lattice requirements. However, the maximum dispersion of a DOFO module is almost twice as large as that of a FODO one. Therefore, the FODO module in the arcs is the final choice.

3 LATTICE DESCRIPTION

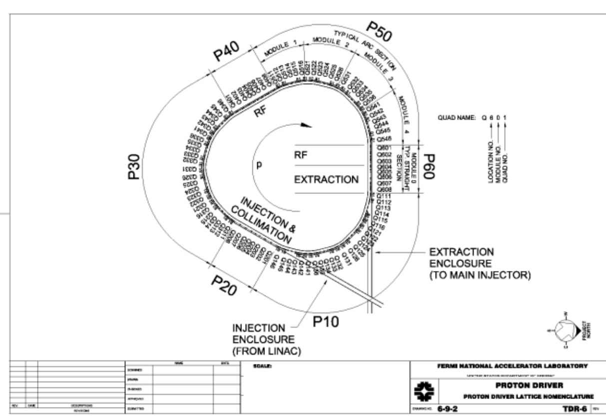

Figure 1: Layout of the Proton Driver Ring.

The Proton Driver lattice has a triangular shape. It has three arcs (P10, P30, P50) and three straight sections (P20, P40, P60), as shown in Figure 1. The circumference is 711.3 m, which is exactly 1.5 times the size of the present Booster. Each straight section is about 64 m long. They will be used for injection, collimation, rf cavities and extraction. The three straights are made identical in order to maintain a 3-fold superperiodicity. Each arc consists of four $270^\circ/270^\circ$ FODO modules. So the phase advance in each arc is 6π, which automatically assures zero dispersion at

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both ends of the arc.

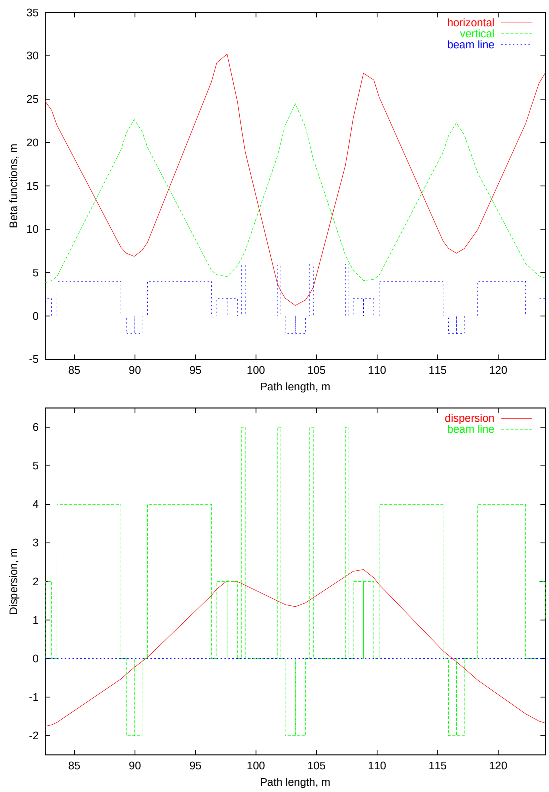

Figure 2: β functions and dispersion in the arc module. (The narrow tall rectangles in the beam line are sextupoles.)

Each module is made of three different FODO cells, as shown in Figure 2. The first cell has two regular dipoles, the second cell no dipoles, the third cell one regular and one short dipole. The short dipole, which is 270° away from the entrance of the module, also serves as a dispersion suppressor. There are two horizontal and two vertical chromaticity sextupoles in the mid-cell of each module, also shown in Figure 2.

Among the four modules in an arc, the second module is an mirror image of the first one, whereas the two half-arcs are identical. The lattice functions are shown in Figures 2 and 3.

Each straight section has a FODO structure. But the cell lengths are varied according to the requirements of injection and collimation as well as of extraction. The straights are also used for tune variation and control (tune trombone). Because the phase advances in the arcs are fixed.

4 LATTICE ANALYSIS

This lattice has excellent chromatic properties as shown in Figure 4. Its momentum compaction factor and transition γ are shown in Figure 5. It has large dynamic aperture as shown in Figure 6. Figure 7 is the tune diagram. A main consideration in the choice of tunes is to avoid resonance of the type $2\nu_x - 2\nu_y = 0$, which could be caused by the space charge. Thus, the horizontal and vertical tunes are split by

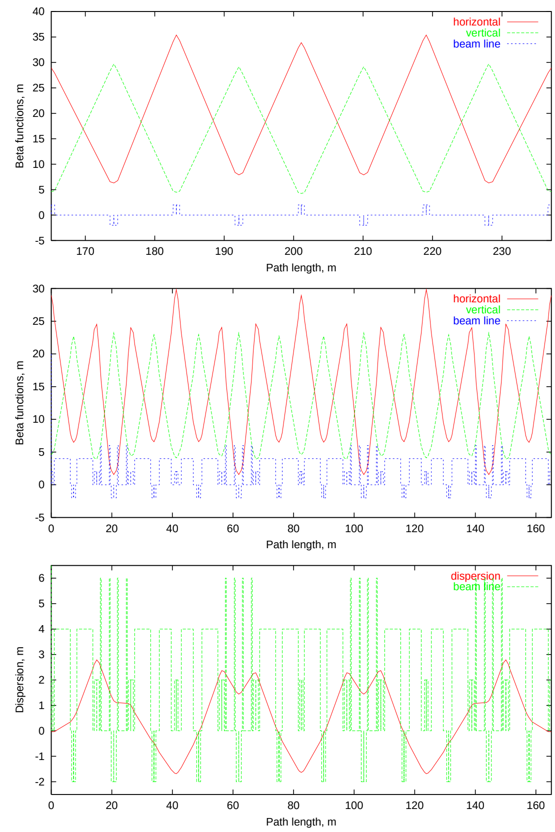

Figure 3: β functions in the straight section (top), β functions (middle) and dispersion in the arc (bottom).

one unit. In addition, the fractional part of ν_x is larger than that of ν_y by 0.05 so that the operating point stays below the coupling resonance line. The nominal design tunes are 12.43 in horizontal and 11.38 in vertical. The performance of the real machine will eventually decide the working point at each stage during the cycle (tune ramp).

5 REFERENCES

[1] W. Chou, C. Ankenbrandt and E. Malamud, editors, "The Proton Driver Design Study", Fermilab-TM-2136, Dec. 2000. http://fnalpubs.fnal.gov/archive/2001/tm/TM-2136.html

[2] S. Y. Lee et al., Phys. Rev. E48 , p.3040 (1993).

[3] U. Wienands et al., Proc. 1992 HEACC (Hamburg), p.1070.

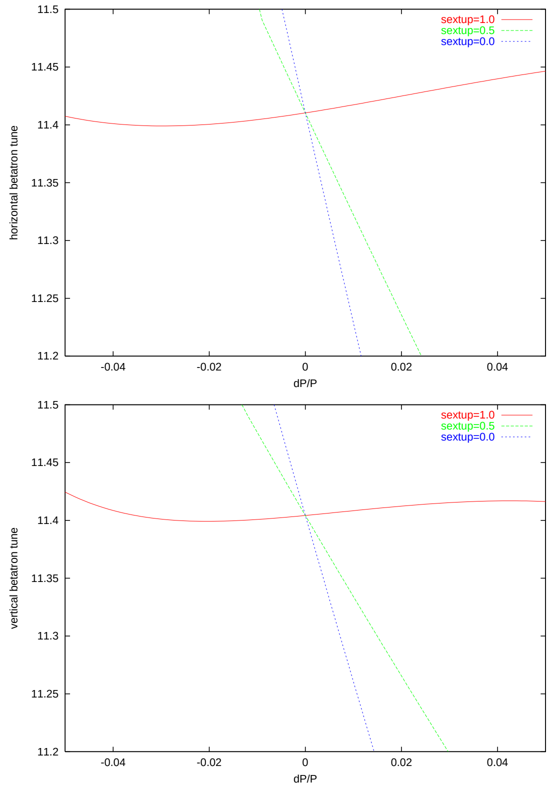

Figure 4: Horizontal (top) and vertical (bottom) betatron tune.

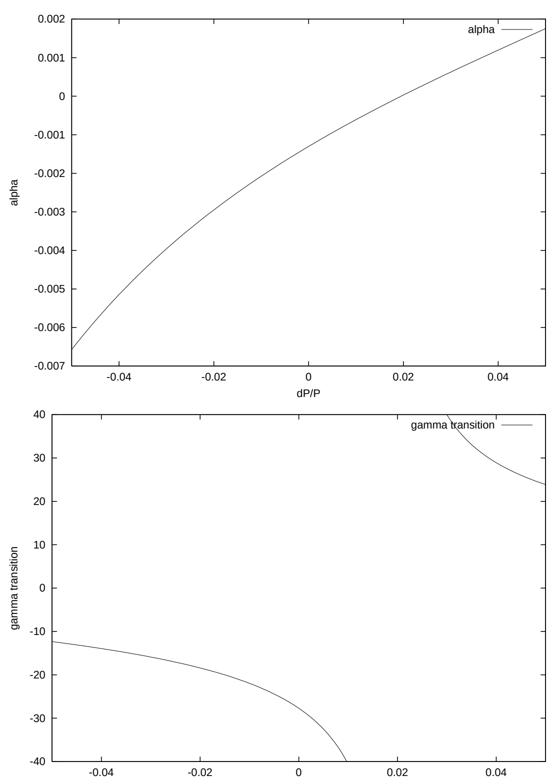

Figure 5: α (top) and γ transition (bottom).

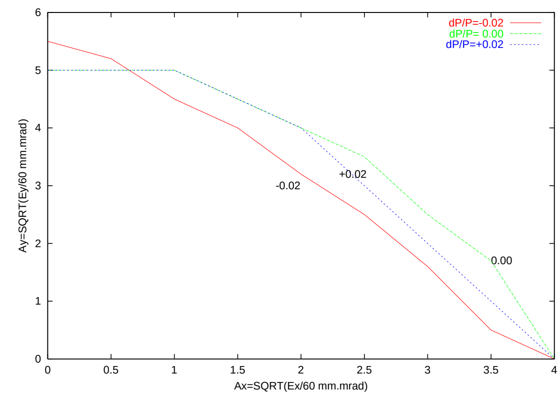

Figure 6: Dynamic aperture at injection. One unit of A_x and A_y corresponds to the full beam size in the x and y plane respectively after painting.

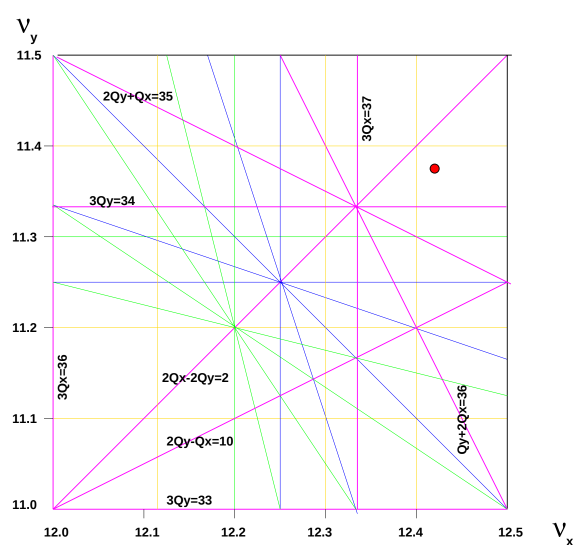

Figure 7: The working point on a betatron tune plane.