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# An Isochronous Lattice for PEP*

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*Abstract*

With $e^+e^-$ storage rings operating in a quasi-isochronous mode, it might be possible to produce short bunches with length $\sigma_z < 1$ cm. The unique characteristics of the short bunches could then be utilized for synchrotron radiation applications or colliders with mm-scale $\beta^*$. In principle, the design of a quasi-isochronous storage ring is relatively straight-forward, but experimental studies with electron storage rings in this configuration have not been carried out. The purpose of this paper is to demonstrate that an isochronous lattice design is compatible with PEP given a minimum of hardware modifications.

## I. Introduction

In addition to being a prime candidate for a B Factory, [1] PEP is well recognized as a high brilliance synchrotron radiation source. [2] To further explore new directions in B Factory design and the capabilities of PEP as a light source, [3] we have begun to investigate the potential for short bunch operation in a quasi-isochronous, or low momentum-compaction mode. Since we are working under the constraint that magnets may not be moved, the configuration requires periodically driving the dispersion function negative throughout the arcs to compensate for positive values. Using this approach, a preliminary solution has been found for the present PEP magnet arrangement. Following further refinement of the design, valuable short-bunch machine studies of interest to both the high energy physics and synchrotron radiation communities might be possible.

The principle behind using a low momentum-compaction lattice for bunch length compression proceeds from the observation that for high energy electron storage rings the bunch length scales as [4,5]

$$\sigma_l \propto \sqrt{\alpha} \qquad (1)$$

for a given RF voltage and frequency. Here, the momentum compaction factor

$$\alpha = \frac{\Delta L}{L} \times \frac{p}{\Delta p} = \frac{1}{\gamma_t^2} = 1/(2\pi R) \oint D_x/\rho \, ds \qquad (2)$$

gives (to lowest order) the path length deviation due to small energy excursions from the central value. If $\alpha$ is made sufficiently small, the phase slip factor

$$\eta = \frac{1}{\gamma^2} - \frac{1}{\gamma_t^2} \qquad (3)$$

tends to zero and the synchrotron oscillation amplitude is reduced. For PEP, the lowest value achieved to date is $\alpha = 1 \times 10^{-3}$ in a low-emittance configuration. [6] The isochronous condition implies a lattice with $\alpha = 1/\gamma^2 \approx 5 \times 10^{-5}$ at 10 GeV. In the following Section, a solution for a low-$\alpha$ lattice in PEP which maintains the proper phase advance between chromaticity correction sextupoles is discussed, and a two-family solution for sextupole strengths is found. In Section III, the bunch length is estimated based on an analysis of the longitudinal acceptance for a small, energy dependent, momentum compaction factor. [7,8]

The results are summarized in Section V along with recommendations for future work.

## II. Lattice Design

The PEP lattice consists of six long straight sections, connected by 2-cell dispersion suppressors to arcs containing 12 FODO cells. The regular FODO structure of each arc is broken at its center to accommodate a short 5 m "symmetry" straight. In the "colliding beams" mode the insertion quadrupoles, close to the center of each long straight, focus the beams to low $\beta$ values, while in the "low emittance" light source mode weak focussing is used across the interaction points. The basic constraint in designing any alternative lattice for PEP is not to move any magnets in the arcs. It is also advantageous not to exceed the power dissipation of the present magnets.

One way to obtain a low momentum compaction lattice [9,10] is to force the dispersion function $D_x$ to negative values through some of the dipoles to compensate for the positive values of $D_x$ in other dipoles. The requirement is that $\alpha = 1/(2\pi R) \oint D_x/\rho \, ds$ be close to zero for the whole ring. We achieve this by making super-cells, consisting of several FODO cells, that repeat in regular fashion through the arcs. We have found (so far) that the most suitable arrangement for PEP is a super-cell made of three PEP FODO cells and having betatron phase advance $\mu_x/(2\pi) = 0.75$ and $\mu_y/(2\pi) = 0.25$. There are thus four super-cells in one PEP arc. The phase advance is arranged so that self-compensating pairs of chromaticity correcting sextupoles can be placed with a phase advance of $(2n+1)\pi$ between them. The basic super-cell is shown in Fig. 1.

It was found that this particular super-cell matched nicely into the symmetry section and, through the disper-

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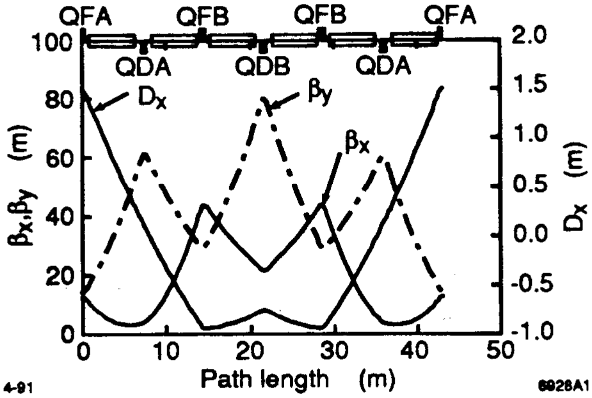


Figure 1. The standard supercell is made up of three FODO cells with symmetry about the middle of the center cell. The strong quadrupoles QFA drive the dispersion function through the center of QDA to negative values.

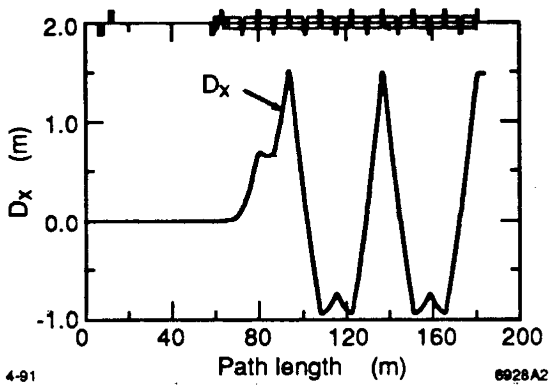


Figure 2. Dispersion Function for one half Superperiod.

sion suppressor, into the long straight sections (Figs. 2,3). The phase advance through the symmetry straight required an adjustment to the super-cell phase advance, so that the phase advance through the combination of super-cell and symmetry straight equalled $0.75(2\pi)$ and $0.25(2\pi)$. Figure 4 shows the phase advance between typical sextupole pairs.

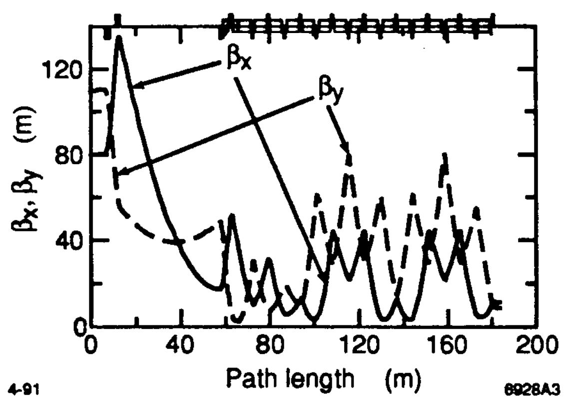


Figure 3. Beta Functions for one half Superperiod.The beta functions of the supercells match easily into the symmetry straight and into the long straight section.

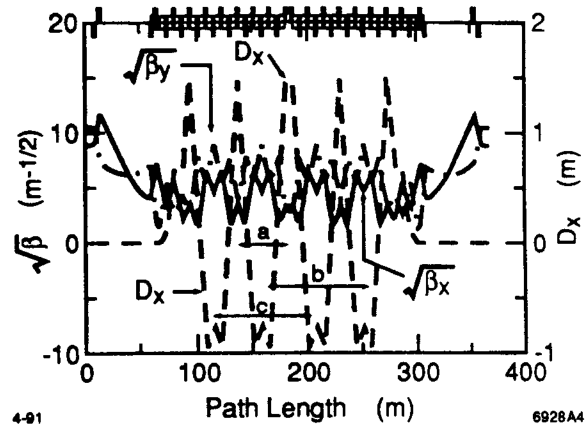


Figure 4. One of the six Sextants of PEP. (a) The phase advance is adjusted to be 90° and 270° across the supercell. (b, c) Chromaticity correcting sextupoles may be placed in pairs with phase advance of 0.5 and 1.5 times $2\pi$.

Some lattice parameters for the 6 superperiod PEP ring are:

$P = 9$ GeV

$Q_x = 25.526$ $\quad Q_y = 15.861$ $\quad Q_s = 0.0022$

$\xi_x = -38.32$ $\quad \xi_y = -39.13$ (uncorrected)

$V_{RF} = 15\ MeV/rev$ $\quad \sigma_E = 0.06\% \left(\frac{dp}{p}\right)$

Preliminary particle tracking results are promising, showing a dynamic aperture of $12\sigma_\beta$ for both on-momentum particles and those undergoing synchrotron oscillations with $6\sigma$ momentum deviation. The chromatic properties $(d\beta)/\beta)/(dp/p)$ and $(d\nu_{x,y})/(dp/p)$ were also good.

The lattice as shown is more of a demonstration of a lattice with zero $\alpha$ than a finished design. As explained in the following section, a lattice with $\alpha$ this small would not be stable in synchrotron motion at this energy deviation. A more realistic lattice design would have a larger value of $\alpha$. In addition, we must explore alternative ways of changing the betatron tune of the machine, either by adding quadrupoles in the long straight sections or by having a conventional FODO lattice in one or more of the arcs.

## III. Bunch Length Scaling

Analysis of the longitudinal dynamics for short bunches is inherently a non-linear problem and has been discussed by Pellegrini and Robin. [4, 7] In principle, since the bunch length scales as $\sigma \propto \sqrt{\alpha}$, a factor of $> 100$ reduction in momentum compaction is required to compress a 5 cm bunch into the range of interest for short bunch B Factory designs, or advanced synchrotron radiation applications. Expanding the momentum compaction as a function of energy deviation, $\alpha = \alpha_1 + \alpha_2\delta$ where

$$\alpha_1 = \frac{1}{2\pi R}\int D_x/\rho ds \quad , \quad \alpha_2 \approx \frac{1}{2\pi R}\int \frac{\langle D_x'^2\rangle}{\rho} ds$$

and $\delta = \Delta p/p$, the authors [4, 7] have found that the ratio $\alpha_1/\alpha_2$ gives a rough estimate of the longitudinal bucket size along the energy axis. To estimate the lower bound on $\alpha_1$, we assume the RF acceptance must exceed the energy spread of the bunch by a factor of 10 to preserve quantum lifetime.

Since $D_x$ can be energy dependent, we use the computer program MAD [11] to find the off-energy closed-orbit and plot $\alpha$ as a function of energy deviation. For our lattice, including chromaticity sextupoles, we find $\alpha_2 = 0.027$, as shown in Fig. 5. Imposing the lifetime condition $\alpha_1/\alpha_2 \sim 10\delta$, the lower bound on $\alpha_1$ is about $1.6 \times 10^{-4}$. The design bunch length is 3.3 mm for this lattice. By adding more families of sextupoles, it may be possible to reduce the longitudinal chromaticity ($\alpha_2$) and thus obtain shorter bunches.

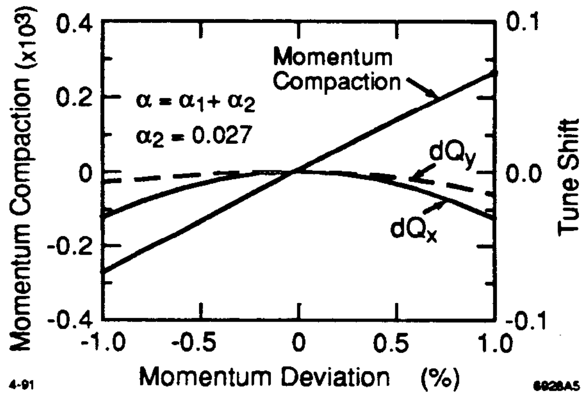


Figure 5. (1) $\alpha$ has an energy dependence $\alpha = \alpha_1 + \alpha_2 \frac{dp}{p}$ that governs the size of the RF bucket. (2) Two sextupole families (SD and SF) are used to correct chromaticity.

## IV. Conclusions

We have demonstrated the design of a low momentum-compaction lattice for PEP. The configuration is based on a succession of supercells (3 FODO cells each) with regions of negative dispersion and betatron phase advance between pairs of compensating sextupoles fixed at $(2n+1)\pi$. Although the configuration must be regarded as preliminary, it requires no magnet re-locations, no quadrupole polarity reversals, and does not exceed power load ratings for a 9 GeV beam. Some new bus work is required. Prior to experimental verification of the low-$\alpha$ lattice, further study of chromatic properties (including tracking with synchrotron motion), injection and tuning procedures, and longitudinal dynamics would be required. At this stage, the theoretical bunch length is about 3.5 mm at 9 GeV ($V_{RF} = 15$ MV), but smaller values could in principle be reached by correcting the longitudinal chromaticity with additional sextupole families.

## V. Acknowledegments

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