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# Lattice design and optimization for the PEP-X ultra low emittance storage ring at SLAC

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ABSTRACT

SLAC is developing a long-range plan to transfer the evolving scientific programs at SSRL from the SPEAR3 light source to a much higher performing photon source. One of the possibilities is a new PEP-X 4.5GeV storage ring that would be housed in the 2.2 km PEP-II tunnel (Hettel et al., 2008 [1]; Hettel et al., to be published [2]). The PEP-X is designed to produce photon beams having brightness near $10^{22}$ (ph/s/mm$^2$/mrad$^2$/0.1% BW) at 10 keV with 3.5 m undulators at beam current of 1.5 A. This report presents an overview of the PEP-X baseline lattice design and describes the lattice optimization procedures in order to maximize the beam dynamic aperture (Wang et al., 2010 [3]). The complete report of PEP-X baseline design is published in SLAC report (Bane et al., 2010 [4]).

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## 1. Introduction

One of the design goals of the PEP-X 4.5 GeV light source storage ring is to attain a horizontal emittance of less than 100 pm-rad and vertical emittance of 8 pm-rad in order to reach the diffraction limit of 1-Å X-rays. This will produce a higher brightness than in the most recent mid-energy storage ring light sources in operation or under construction such as PETRA-III, NSLS-II and MAX-IV [5–7]. To reduce the cost of construction, the PEP-X ring will be housed in the existing PEP-II tunnel. For this reason, the design adopts the same ring geometry with six arcs and six long straight sections as in PEP-II and has the same circumference of 2199.32 m. The baseline design presented in this paper uses a hybrid lattice which includes double bend achromat (DBA) cells in two arcs that provide 30 straight sections for insertion device (ID) beamlines in two experimental halls, theoretical minimum emittance (TME) cells in the remaining four arcs, and 90 m of damping wiggler in a long straight section for the final reduction of horizontal emittance to 86 pm-rad at zero current [1,2]. Fig. 1 shows the schematic of the PEP-X ring layout. The baseline design provides a reference for attainable photon brightness against which future designs can be compared.

## 2. Lattice design

The main types of cells used in the PEP-X lattice are DBA, TME and FODO. Each cell type has its special function to help achieving the design goal.

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### 2.1. DBA supercell

DBA supercells will be used in two of the six arcs in order to provide dispersion-free straights for the IDs. Each supercell is composed of two standard DBA cells where one of the two ID straights is adjusted for low $\beta$−functions. In total, the 16 DBA supercells in two arcs provide 16 ID straights with $\beta_x/\beta_y=3.0/6.1$ m and 14 straights with $\beta_x/\beta_y=16.0/6.3$ m suitable for 3.5 m ID devices. Phase advance in the supercell is optimized to $\mu_x=3\pi(1+\frac{1}{64})$, $\mu_y=\mu_x/3$. This provides nearly $-I$ transformation between consecutive supercells which helps to compensate the second order geometric aberrations from DBA sextupoles. The slight phase detuning from $n\pi$ allows to avoid a build-up of higher order resonance driving terms from sextupoles and non-linear field magnet imperfections. Lattice functions of one DBA supercell are shown in SLAC report [4, Fig. 2.2].

### 2.2. TME cell

The main function of the other four arcs is to minimize the PEP-X emittance while maintaining sufficiently large dynamic aperture. This is achieved by using a TME cell optics. In general, the TME cell is capable of reaching three times lower emittance than the DBA cell by optimizing $\beta$−functions and dispersion in the dipole. Note that the dispersion is not zero in the TME cell, therefore it is not suitable for the IDs. Each of the four TME arcs will contain 32 regular and 2 matching cells. Phase advance in the TME cell is optimized to $\mu_x=(3\pi/4)(1-\frac{1}{192})$, $\mu_y=\mu_x/3$ for the same reasons as for the DBA supercells. Lattice functions of one TME cell are shown in SLAC report [4, Fig. 2.3].

### 2.3. FODO cell

PEP-X has six 123 m long straight sections. Five of them will have identical FODO lattice with 21 quadrupoles per section with average $\beta-$function of $\approx 13$ m. They will contain the 16 PEP-II RF accelerating cavities, the 90 m of damping wiggler, and the optics systems for betatron tune adjustment and coupling correction. An option of FEL partial lasing in a straight section near the experimental hall is also under study. The last straight section-10 will contain the injection system based on the PEP-II High Energy Ring (HER) design and existing magnets as shown in Fig. 1, but it changes the injection from vertical to horizontal plane.

### 2.4. Damping wiggler and emittance

The PEP-X equilibrium emittance at 4.5 GeV, zero current, and without damping wiggler is 379 pm-rad. The fractional change of emittance due to the damping wiggler can be estimated by the formula in Ref. [10] with modification of considering two types of dipoles in PEP-X:

$$\frac{\varepsilon_w}{\varepsilon_0} = \frac{1+\dfrac{4C_q}{15\pi J_x} N_p \dfrac{\langle \beta_x \rangle}{\varepsilon_0 \rho_w}\gamma^2 \dfrac{\rho_T \rho_D}{\rho_w(2/3\rho_D+1/3\rho_T)}\theta_w^3}{1+\dfrac{1}{2} N_p \dfrac{\rho_T \rho_D}{\rho_w(2/3\rho_D+1/3\rho_T)}\theta_w} \qquad (1)$$

where $\varepsilon_0$ is the emittance without damping wiggler, $C_q = 3.83\times 10^{-13}$m, $\gamma$ is Lorenz factor, $J_x$ is the horizontal damping partition number, $\langle \beta_x \rangle$ is the average horizontal beta function in the wiggler, $N_p$ is the number of wiggler periods, $\rho_w$ is the bending radius at the wiggler peak field, $\rho_T$ and $\rho_D$ are the bending radius of TME and DBA cell dipoles respectively, $\theta_w = \lambda_w / 2\pi\rho_w$ is the peak trajectory angle in the wiggler, and $\lambda_w$ is the wiggler period length. The wiggler efficiency for emittance reduction is determined by the wiggler period length $\lambda_w$, the wiggler peak field $B_w$, and the total wiggler length $L_w = N_p\lambda_w$. The emittance dependence on these parameters had been analyzed and the following optimal values were selected: the total wiggler length of $\approx 90$ m, wiggler period of 10 cm and peak field of 1.5 T. This yields a reduction of the zero current emittance to 85.7 pm-rad. However,

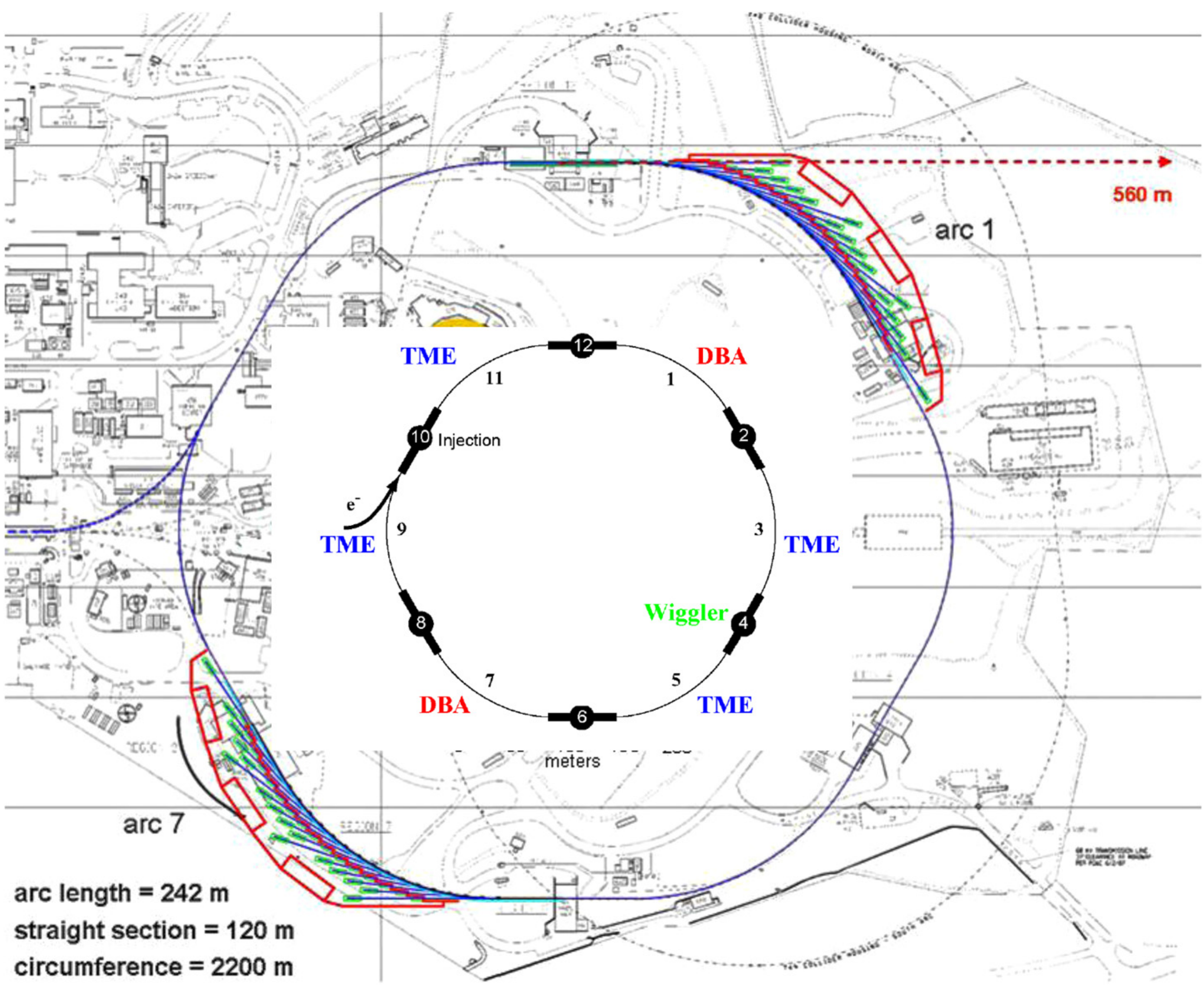


**Fig. 1.** Conceptual PEP-X layout with 2 DBA arcs, 4 TME arcs and 6 straight sections.

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