Low-Emittance in SPEAR*

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Abstract

This paper describes the characteristics of a low-emittance configuration and it's implementation in SPEAR at the Stanford Synchrotron Radiation Laboratory (SSRL) to increase the photon beam brightness. The new lattice has an emittance of 129 πnm*rad at 3 GeV compared to the present emittance of 510 πnm*rad.

I. Introduction

The storage ring SPEAR is now fully dedicated to the production of synchrotron radiation at SSRL. Efforts have been made and continue to optimize SPEAR as a synchrotron radiation source including the construction of a dedicated full energy injector[1]. First beam from this injector was injected into SPEAR in November 1990. To further optimize the photon beam quality at SPEAR, studies have been conducted to maximize the photon beam brightness by reducing the particle beam emittance. Low emittance configurations have been proposed previously for SPEAR[2] [3][4], but injection into such configurations was not possible in a reproducible way because of limitations in the injection components. As part of the injector project a third kicker was installed in SPEAR to accommodate beam injection into a new low emittance configuration[5], a configuration designed with the constraint that no significant hardware changes were necessary for its implementation. The emittance in the new low emittance (LE) lattice is reduced by nearly a factor of 4 compared to the presently used high energy physics (HEP) optics.

II. Lattice Design

A. Linear Optics

The main criteria for designing the linear optics of the LE lattice was to maximize the photon brightness from undulators given by:[6]

$$\mathcal{B} = \frac{\mathcal{F}}{(2\pi)^2 \Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}}$$

where $\mathcal{F}$ is the integrated flux and

$$\Sigma_u = \sqrt{\sigma_u^2 + \frac{\lambda L}{8\pi^2}} \qquad \Sigma_{u'} = \sqrt{\sigma_{u'}^2 + \frac{\lambda}{2L}}$$

where u is either x or y; σ_x, $\sigma_{x'}$, σ_y, and $\sigma_{y'}$ are electron beam dimensions; λ is the photon wavelength; and L is the length of the undulator. For maximum brightness we require the dispersion to vanish in the undulator, $\eta_x = \eta_x' = 0$, the betatron functions to be

$$\beta_x \approx \beta_y \approx \frac{L}{2\pi}$$

and the beam emittances ϵ_x and ϵ_y to be minimized. For the layout of magnets in SPEAR, it is impossible to satisfy the first criterion exactly but we were able to reduce

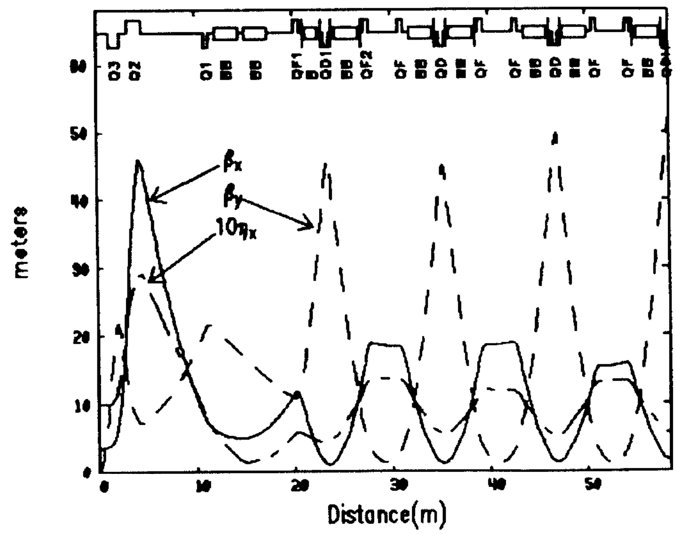

Figure 1
Linear optics of the LE lattice.

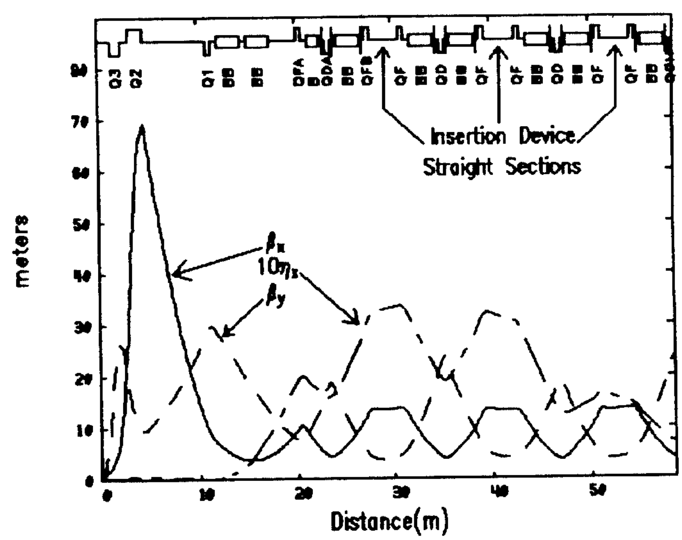

Figure 2
Linear optics of the HEP lattice.

the dispersion in the insertion straights by up to a factor of three (see figs. 1 and 2). The second criteria, the constraint on β_x and β_y gives a much broader maximum with respect to β_x than with respect to β_y. This can be attributed to the fact that the magnitude of the vertical electron emittance, ϵ_y, is closer than ϵ_x to the diffraction limited photon beam emittance from a single electron, $\lambda/4\pi$. For the LE lattice β_y is 1.1 meters in the insertions, which is very close to the optimum value. This small β_y also has the advantage of allowing smaller undulator gaps without reducing the beam lifetime, and it reduces the perturbation

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of the electron optics from wiggler and undulator vertical focusing and nonlinearities.

Minimization of the horizontal emittance is achieved by minimizing the integral of $\gamma_x \eta_x^2 + 2\alpha_x \eta_x \eta_x' + \beta_x \eta_x'^2$ in the bending magnets. In the arcs, where most of the bend magnets are located, there are only two independently powered quadrupole magnet strings, QD and QF. The emittance is rather insensitive to the strength of the QD's but varies significantly as a function of the strength of QF as shown in fig.3. We note that the LE lattice emittance is very close to the minimum possible emittance for SPEAR. Table 1 compares the emittance with that of other machines of comparable energy.[7] The emittance in the LE lattice is smaller than in other operating synchrotron radiation sources, but is still much larger than in new sources under construction. To achieve such low beam emittances in SPEAR the magnet lattice must be significantly modified. Such modifications are possible without perturbing the location of existing photon beam lines and insertion devices[8] resulting in a beam emittance of 28.5πnm*rad.

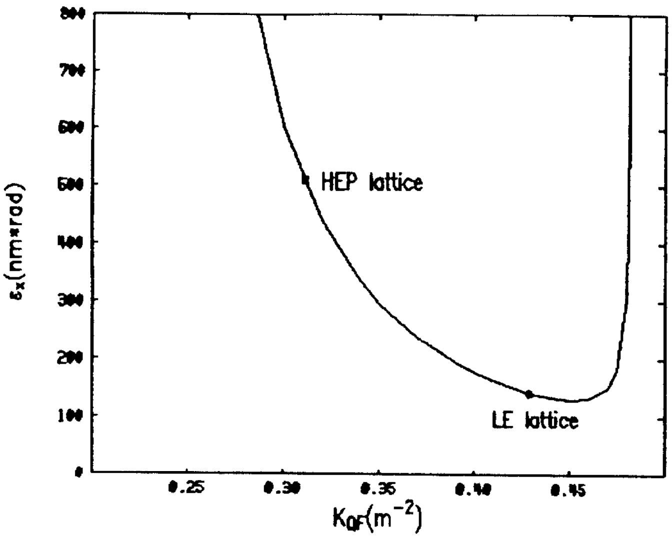

Figure 3
Horizontal emittance vs QF strength with QD strength held constant.

Table 1
Comparison of beam emittances at 3 GeV.

Lattice	ϵ_x @3GeV (πnm*rad)	Status	Design Energy
Beijing	270	Running	2.8GeV
SRS2	243	Running	2.0
Photon Fact.	185	Running	2.5
NSLS X-Ray	152	Running	2.5
SPEAR LE	**129**	Commissioning	**3.0**
Pohang	30	Construction	2.0
Trieste	16	Construction	2.0
ALS	14	Construction	1.5

B. Dynamic Aperture

The LE lattice requires strong quadrupoles with associated large natural chromaticities (see Table 2) requiring strong sextupoles. With careful choice of tunes and some reconfiguring of the sextupole distribution in SPEAR, the dynamic aperture could be preserved to assure beam stability (see fig.4). Tracking studies with PATPET[9] show that this dynamic aperture remains large for off-energy particles and when tracking with magnet strength and alignment errors. Table 2 gives a summary of the properties of the LE lattice. Two previously proposed low emittance SPEAR lattices, the high-beta low-emittance (HBLE) lattice[3] and Blumberg's lattice[4], are included for comparison. The large physical and dynamic apertures in the LE lattice provides for easier injection.

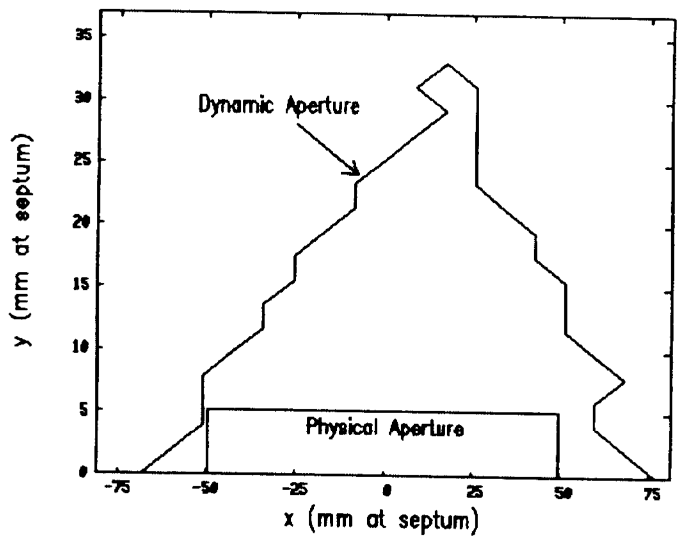

Figure 4
LE lattice dynamic aperture.

Table 2
Comparison of lattice parameters. The emittances are for 3 GeV electrons. The apertures are given in millimeters at the septum, and the dynamic apertures are for 400-turn tracking and with $\xi_x = \xi_y = 3$.

Lattice	LE	HEP	HBLE	Blumberg
ϵ_x(πnm*rad)	129	511	141	142
β_y(m) @ ID's	1.1	3.8	2.8	2.2
η_x(m) @ ID's	1.3	2.7	1.2	1.3
Dyn. Aper.(mm)	72	130	51	27
Phys. Aper.(mm)	50	35	19	35
ξ_x	-12.2	-11.2	-8.8	-11.9
ξ_y	-21.3	-11.2	-9.6	-15.6
ν_x	6.87	5.27	6.25	6.27
ν_y	6.8	5.14	5.19	6.16

C. Lifetimes and Current Limitations

Calculations indicate that bremsstrahlung, Coulomb scattering, Touschek, and quantum lifetimes will all be at least 18 hours in the LE lattice for single bunch currents below 15 mA. From ZAP[10] calculations we conclude that the single bunch current will be limited by reduction of the longitudinal quantum lifetime from turbulent bunch lengthening. For an rf-voltage of 2.5 MV at 3 GeV, the quantum lifetime will be reduced to 5 hours for a single bunch current of approximately 28 mA.

III. Injection Scheme

Injection into the HEP lattice uses two kickers separated by π in horizontal phase advance. In the LE lattice the phase advance between these two kickers is much larger than π, so a third kicker is needed to produce a local orbit bump for injection. A location was found for this third kicker with the same aperture and strength requirements as for the other kickers. This made it possible to move one of the now obsolete positron injection kickers to this new location to inject electrons. Fig.5 shows the injection scheme. A static bump using the trims on the

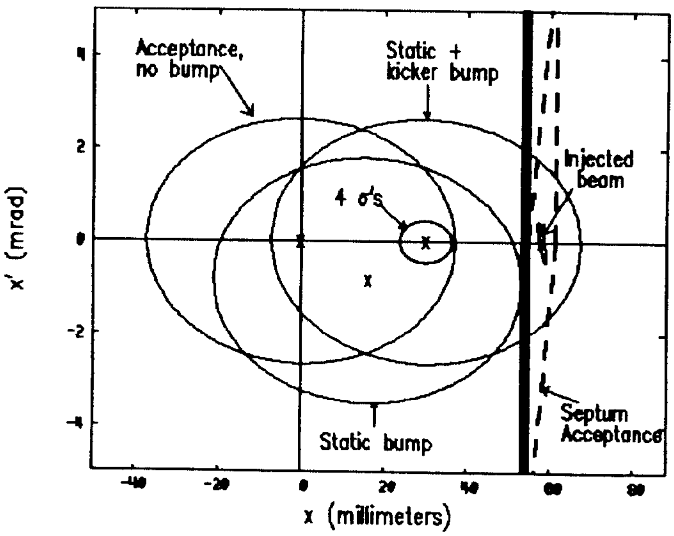

Figure 5
Injection scheme

two bend magnets on either side of the septum corrects the slope of the kicker bump and moves the stored beam acceptance close to the edge of the septum. The pulsed kicker bump the moves the SPEAR acceptance over the septum to accept the injected beam. This figure shows that the cross-section of the septum acceptance and the stored beam acceptance is much larger than the injected beam size, so there is ample room for steering errors of the injected beam. It also shows that the four-sigma ellipse of the stored beam is far from the septum. Scraping four sigma's of the stored beam on the septum is about the point where as much stored beam is lost as injected beam is accumulated. The significant distance of the stored beam from the septum allows for orbit errors and safe margin for reliable injection into this lattice.

IV. Commissioning Results

The first attempt to inject into the LE lattice was made during a 24- hour period on April 23, 1991. Single electron pulses from the SPEAR injector were stored in the lattice with lifetimes on the order of hours, although beam accumulation was not achieved yet. A preliminary measurement of the emittance of the stored electron beam was made by digitizing the signal from a video camera aimed at the synchrotron light monitor (SLM) (see fig.6). The

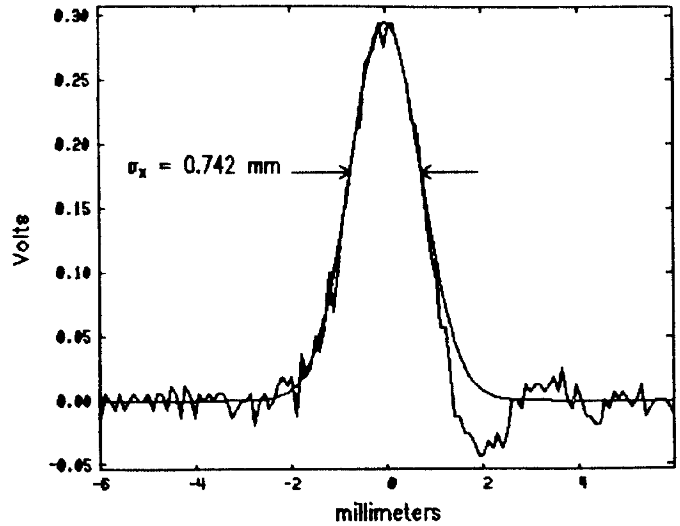

Figure 6
Emittance measurement of 83πnm*rad at 2.27 GeV in the LE SPEAR lattice.

horizontal betatron function at the SLM is $\beta_x = 6.63$ m, and correcting for the theoretical beam energy spread we derive from fig.6 an emittance of 83 πnm*rad at 2.27 GeV compared with a predicted emittance of 76 πnm*rad.

V. Acknowledgements

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