© 1985 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.



# A LOW EMITTANCE CONFIGURATION FOR SPEAR

L.N. Blumberg
Brookhaven National Laboratory
NSLS, Bldg. 9-11
Upton, NY 11973

J. Harris, R. Stege
SLAC, PO Box 4349
Stanford, CA 94305

J. Cerino, R. Hettel, A. Hofmann, R.Z. Liu,#
H. Wiedemann and H. Winick
SSRL*, PO Box 4349
Stanford, CA 94305

## ABSTRACT

The quality of synchrotron radiation beams from SPEAR, in particular the brilliance of undulator radiation, can be improved significantly by reducing the emittance of the stored electron beam. A reduction of the horizontal emittance by a factor of 3.5 to a value of 130 nanometer-radians (nm-r) at 3 GeV has been achieved by using stronger focussing, mainly in the horizontal plane. The low emittance configuration also reduces the dispersion and vertical beta functions in the straight sections, making them more suitable for wigglers. The higher betatron tunes lead to a larger phase advance between the two kickers, which has to be corrected during injection by shunting current from some quadrupoles. The configuration was optimized within SPEAR hardware limitations and tested for dynamic aperture with the tracking program PATRICIA. After implementation of this scheme, beam was successfully injected and accumulated. The measured emittance of the stored beam was in agreement with calculations. Presently the configuration is being made operational.

## INTRODUCTION

SPEAR was designed as an $e^+,e^-$ collider, and has an emittance of 50 nm-r/GeV², or 450 nm-r at 3 GeV, the usual operating energy for synchrotron radiation research. Although this is comparable to most other presently operating multi-GeV synchrotron radiation sources (e.g. the Daresbury SRS with 1500 nm-r at 2.0 GeV, DCI with 1500 nm-r at 1.8 GeV, DORIS with 270 nm-r at 3.7 GeV, ADONE with 225 nm-r at 1.5 GeV, the Photon Factory with 500 nm-r at 2.5 GeV), a reduction in emittance would benefit users by increasing the brilliance of synchrotron radiation beams, particularly those from undulators.

The importance of low emittance in optimizing the brilliance of synchrotron radiation from undulators and other sources has been discussed by several authors[1], and is now widely recognized. It was a primary consideration of R. Chasman and K. Greene in designing the lattice of the NSLS rings at Brookhaven (e.g. the X-ray ring with 80 nm-r at 2.5 GeV), and groups in Europe, Japan and the United States are now proposing new 5-6 GeV rings with emittances of about 7 nm-r. Many of the presently operating synchrotron radiation sources have programs to reduce their emittances.

We report here on the status of a project to reduce the emittance of SPEAR by about a factor of 3.5. This can be accomplished by strengthening the horizontal focussing, i.e. using a higher tune configuration. A study was made[2] identifying some low emittance configurations for SPEAR, followed by some preliminary experimental work carried out by C. Y. Yao, a visitor from Hefei, China. Some success was achieved in demonstrating that the emittance could be reduced. However no configuration looked promising enough to pursue because the higher tunes resulted in an increase in betatron phase advance between the two injection kickers, from the optimum 180 degrees to as high as 270 degrees. This makes injection very difficult or impossible.

SPEAR is made up of standard cells in the arcs, low beta interaction regions, and transition sections which match the two (figure 1). To achieve a low emittance in a symmetric configuration it is necessary that the focussing be increased in the standard cells, resulting also in the injection problem. In early 1983 Blumberg and Liu[3] proposed that this problem could be circumvented by using a high tune asymmetric injection configuration that preserves the 180 degree phase advance between kickers, followed by a gradually stepped transition to a low emittance symmetric configuration after the beam has been injected and stored.

The procedure, then, is to fill the ring using high current in the horizontally focussing quads, but with some current shunted from the four horizontally focussing quads between the kickers to preserve the proper phase advance. This breaks the ring symmetry but it can be restored by reducing the shunted current to zero after accumulation. A carefully devised step by step procedure was calculated to make this transition, keeping the tunes constant and paying attention to matching requirements. Although the process is complex, its essential features have all been successfully tested experimentally. Several improvements are now underway to increase the reliability and efficiency of the process so that it can be used routinely for dedicated synchrotron radiation operation of SPEAR.

## DESCRIPTION OF LOW EMITTANCE AND STANDARD CONFIGURATIONS

TABLE 2 summarizes the parameters of several SPEAR configurations of interest: SPEAR II, which is the optic upon which the reported tests were performed; SPEAR III, the so-called mini-beta optic which was installed in summer 1984; and a high beta variation[4], which requires additional hardware to be implemented (scheduled for summer 1985).

In addition to a lower emittance, these configurations are characterized by dispersion and vertical beta functions in the SPEAR straight sections that are lower by approximately a factor 2. This improves the performance of wigglers in these locations both by reducing vertical aperture requirements and by reducing the disturbance of the beam by the wiggler.

\# Visiting scientist at SSRL from the University of Science and Technology, Hefei, Peoples Republic of China.

* Work supported by DOE contract DE-AC03-82ER-1300.

TABLE 3 is a tabulation of the strengths of focussing magnets in normalized units, from the injection configuration (LEINJ) to the final low emittance symmetric configuration (LEC) for SPEAR III with a value of beta-y at the interaction point of 10 cm.

## EXPERIMENTAL RESULTS

In the spring of 1984 a series of machine physics experiments was carried out to study the low emittance configuration and prepare its implementation. A single pulse of electrons was injected on-axis without accumulation. This mode of injection does not require the correct phase advance between kickers and does allow the study of the symmetric configuration. The emittance, tunes and chromaticities were measured and were found to be in agreement with expectation. The injected current was too low to permit closed orbit measurements.

Next the asymmetric (shunted) configuration was set up and accumulation was achieved. The closed orbit was measured and corrected using the existing orbit correction scheme. The distribution of correctors was not dense enough to obtain a good orbit for such a high tune, yet a beam lifetime of greater than 2 hours was achieved. It was not possible to turn on sextupole magnets while injecting, thus stored current was limited to about 1 mA per bunch by fast head-tail instabilities. By filling several bunches, approximately 20 mA was stored and sextupoles were then powered.

Finally, the transition to the symmetric configuration was made, and the beam energy was ramped up to 2.9 GeV, the nominal operating energy for synchrotron radiation.

## FUTURE WORK

During the spring and summer of 1985, the machine physics program will continue with studies of low emittance on the SPEAR III optic using an expanded orbit correction system, a more sensitive orbit measurement apparatus, and an improved magnet control system. These changes are expected to greatly improve the accumulation of low emittance beam by allowing the operation of sextupoles and better orbit correction during injection, and by enabling a higher degree of orbit and tune control during transition and ramping. Once reasonable currents have been stored and ramped to operating energy, the synchrotron radiation beams will be delivered to experimenters so that the quantitative effects of lower emittance beams can be determined. Finally, a new configuration (High Beta LEC) has been calculated which has no low beta waist in the interaction regions and hence has lower chromatic correction requirements. Further tracking studies will be done with PATRICIA[5] to establish the dynamic aperture. Injection into this configuration is expected to be easier and its operation more forgiving. A new power supply (scheduled for summer 1985 installation) is required for implementation of the configuration.

References:


1) A. Hofmann: Nucl. Instr. & Meth. 152, 17, (1978)
H. Winick, G. Brown, K. Halbach & J. Harris: Physics Today, 34, 50, (1981); G. Brown, K. Halbach, J. Harris, & H. Winick: Nucl. Instr. & Meth. 208, 65, (1983)

2) A. Garren, M. Lee and P. Morton: "SPEAR Lattice Modifications to Increase Synchrotron Radiation Brightness" SPEAR Report 193, April 7, 1976.

3) R. Blumberg and R. Z. Liu: "A Low Emittance Solution for SPEAR with π Horizontal Phase Shift Between the Injection Kickers" SSRL Technical Note 83/01, April 13, 1983

4) K. Wille, SLAC/AP-9 (1984)

5) H. Wiedemann, PATRICIA, SLAC PEP-NOTE 220 (1976)


*SSRL is supported by the Department of Energy, Office of Basic Energy Sciences and the National Institutes of Health, Biotechnology Resource Program, Division of Research Resources.*

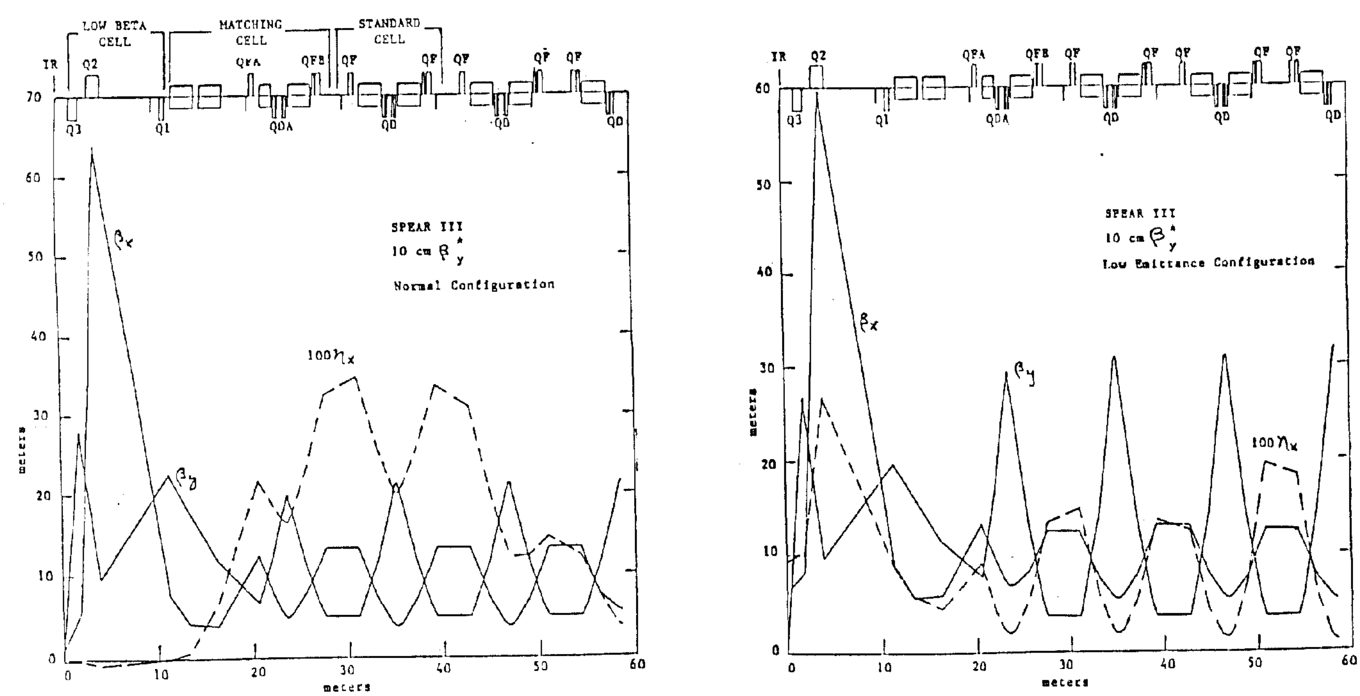


Figure 1 SPEAR lattice configurations, normal and low emittance, for one quadrant.

Table 2

PARAMETERS OF SPEAR CONFIGURATIONS

| Configurations | Tunes $\nu_x$ | Tunes $\nu_y$ | Emittance in mm-mrad GeV$^2$ ($\varepsilon_o/E^2$) | Center of 3m sections $\beta_x$ | Center of 3m sections $\beta_y$ | Center of 3m sections $\eta_x$ | Interact. Point $\beta_x$ | Interact. Point $\beta_y$ | Interact. Point $\eta_x$ | Max. in ring $\beta_x$ | Max. in ring $\beta_y$ | Max. in ring $\eta_x$ | Max. in cells $\beta_x$ | Max. in cells $\beta_y$ | Max. in cells $\eta_x$ | Phase advance between two Kickers | Natural Chromaticities $\xi_x$ | Natural Chromaticities $\xi_y$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SPEAR II ( before Oct. 1984 ) 10 cm $\beta_y^*$ Configurations | | | | | | | | | | | | | | | | | | |
| Normal | 5.27 | 5.16 | 0.050 | 13.4 | 4.8 | 2.7 | 1.4 | 0.105 | 0 | 60. | 63. | 2.7 | 13.6 | 20.7 | 2.7 | $180^o$ | - 9.4 | -16. |
| LEC | 7.2 | 6.2 | 0.014 | 16.7 | 1.96 | 1.25 | 1.3 | 0.094 | 0.4 | 64. | 71. | 1.25 | 17. | 33. | 1.25 | $271^o$ | -13.5 | -23. |
| LEINJ | 7.2 | 6.2 | 0.0345 | 13~17 | 2~4 | -0.3~2.4 | 1.3 | 0.1 | 0.68 | 67. | 69 | 2.6 | 19. | 39. | 2.6 | $180^o$ | -14.1 | -22. |
| SPEAR III Colliding Beam Configurations | | | | | | | | | | | | | | | | | | |
| Mini-β | 5.29 | 5.16 | 0.050 | 13.4 | 4.9 | 2.6 | 0.9 | 0.03 | 0 | 74. | 90. | 2.7 | 13.6 | 22. | 2.7 | $180^o$ | -11.6 | -26.1 |
| SPEAR III 10 cm $\beta_y^*$ Configurations ( Being Studied ) | | | | | | | | | | | | | | | | | | |
| Normal | 5.29 | 5.19 | 0.061 | 13.4 | 3.7 | 1.4~3.2 | 0.9 | 0.1 | 0 | 66. | 29. | 3.5 | 13.6 | 22. | 3.5 | $180^o$ | -10.9 | -11.7 |
| LEC | 6.27 | 6.16 | 0.016 | 14~19 | 2.1 | 1.3 | 6.1 | 0.105 | 0.9 | 62. | 32. | 2.7 | 20. | 32. | 1.3 | $253^o$ | -11.8 | -15.7 |
| LEINJ | 6.27 | 6.16 | 0.031 | 11~17 | 2~3.6 | 0.4~3. | 4.1 | 0.11 | 1.35 | 55.5 | 36. | 4.7 | 17.5 | 36. | 3. | $180^o$ | -10.9 | -15. |
| SPEAR III High β Configurations ( Future Development ) | | | | | | | | | | | | | | | | | | |
| Normal | 4.29 | 4.16 | 0.054 | 11.6~15 | 5. | 2.4~3. | 20. | 35. | 1.6 | 36. | 35. | 3. | 16. | 25. | 3. | $180^o$ | - 4.1 | - 5.5 |
| LEC | 6.27 | 5.16 | 0.016 | 12~25 | 2.8 | 1.24 | 32. | 36. | 1.8 | 54. | 36. | 2.4 | 26. | 28. | 1.4 | $248^o$ | - 8.9 | - 9.4 |
| LEINJ | 6.27 | 5.16 | 0.040 | 12~15.4 | 2.2~3 | 0.2~3.2 | 22.5 | 29.4 | 4. | 40. | 33. | 5.6 | 20. | 33. | 3.2 | $180^o$ | - 8.4 | - 9.5 |

Table 3
MAGNET STRENGTHS IN TRANSITION FROM LEINJ TO LEC (SPEAR III 10 cm $\beta_y^*$)

| Configurations | Quadrupoles around Interaction Points Q3 | Q2 | Q1 | QFA | QDA | QFB | Quadrupoles in the cells QF | QD | QFS QF Shunted | Sextupoles SF | SDA = SDB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEINJ (for injection) | 0.931 | -0.370 | 0.253 | -0.769 | 0.715 | -0.457 | - 0.396 | 0.6156 | - 0.316 | -0.722 | 0.651 |
| Transition from 1-Fold (asym) to 4-Fold (sym) | Unchanged | | | | | | Adjusted to keep tunes unchanged | | Increased towards QF | Adjusted when necessary | |
| LE First Symmetric Config. | 0.931 | -0.370 | 0.253 | -0.769 | 0.715 | -0.457 | - 0.380 | 0.6153 | - 0.380 | -0.681 | 0.663 |
| Transition to LEC | Reduced to allow stronger focussing in the cells while tunes are the same | | | | | | Strengthened and adjusted for tunes | | Always same as QF | Adjusted when necessary | |
| LEC (Low Emittance Config.) | 0.911 | -0.358 | 0.221 | -0.697 | 0.668 | -0.367 | -0.424 | 0.652 | | -0.695 | 0.686 |

Note: Quadrupole strengths are $\frac{-1}{(B\rho)_o} \frac{\partial B_y}{\partial x}$, in m-2. Sextupole strengths are $\frac{-1}{(B\rho)_o} \frac{\partial^2 B_y}{\partial x^2} \cdot$ length, in $m^{-2}$.