An Optimized Low Emittance Lattice for SPEAR*

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Abstract

An alternate lattice for SPEAR is presented, which has a similar or smaller emittance and improved stability compared to the presently used Low Emittance Lattice. It allows the removal of one and the movement of another of the Low Beta quadrupole families. This creates two long drift spaces of up to 18 m, that can be utilized to accept special insertion devices including long undulators. A phased approach will be used to implement the new lattice starting in 1994.

1 INTRODUCTION

The SPEAR Synchrotron Light Source has been using a Low Emittance lattice (**LBLE**) [1] in recent years. The lattice had been developed from the high energy physics lattice, that was used for electron-positron collider experiments. The new lattice became possible after moving one of the two positron kickers to form a new three kicker injection bump for electrons in combination with the existing two electron injection kickers.

Two of the major advantages of the new lattice are a reduced emittance (by a factor of four) and a smaller dispersion function at the locations of the rf cavities. The latter made SPEAR much less sensitive to instabilities (esp. synchro-betatron coupling) and ended the times of regular beam loss during the energy ramp.

One of the features of the old colliding beam optics still remains in the new lattice: Low Beta insertions in the long straight sections.

During 1993 it became apparent that it would be desirable to replace the large power supply for one of the insertion quadrupoles (Q2) with a new, more modern device. A study of the maximum power requirements and of possible lattice modifications to reduce those requirements for that quadrupole family led to the development of the lattice modifications that are presented in this paper.

2 DESCRIPTION OF LATTICE MODIFICATIONS

SPEAR is using a FODO lattice with four-fold symmetry. Every quadrant consists of two regular arc cells, two matching cells and an insertion region. The arc cells and the first matching cell have a D/2-O-F-O-F-O-D/2 structure, the second matching cell has a D/2-O-F-D/2 structure and the insertion region is a D/2-O-F-O-D-O combination. There is a total of eight different quadrupole families involved.

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2.1 *New Insertion Section*

The major change towards the new lattice is the removal of one quadrupole family from the insertion region, reducing that region to a D/2-O-F-O structure. This will initially be done by turning off the existing de-focussing Q3 quadrupole. The five remaining quadrupole families in the insertion region and in the two matching regions can be adjusted to match the horizontal and vertical beta-functions and the dispersion function, and to minimize the emittance contribution of that part of the lattice. These quadrupoles also allow for tune adjustments in both planes.

The removal of one quadrupole family reduces the vertical beta-function in the remaining insertion quadrupoles, increasing it's value at the symmetry point. This results in a significantly smaller vertical phase advance in that region, thus reducing the vertical tune.

Another degree of freedom is the longitudinal position of the focussing quadrupole (Q2, or a new magnet QF0) in the insertion section. The center of that quadrupole is presently 4.24 m away from the symmetry point. We are considering to move it as far away as 9.4 m, which would create up to 18 m of quadrupole-free straight section.

Components that are presently located within this region, such as corrector magnets, BPMs, rotated quadrupoles and, in the north-west insertion region one of the three injection kickers, would have to be relocated and/or re-designed in order to be able to fully utilize that space.

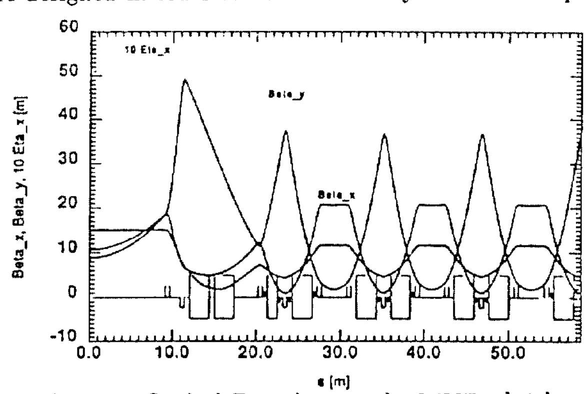

Figure 1: Optical Functions of the **MVD1** lattice.

2.2 *Emittance Contribution of the Arc Cells*

The modification to the insertion and matching region reduces the vertical tune by about 1.5 units while leaving the horizontal tune basically unchanged. That lattice (**NOQ3**$_0$) has the same optical functions in the arc cells as the present (**LBLE**) lattice and requires only minor modifications to the strengths of the injection bumps, which are described below.

The lattice has an increased emittance and the horizontal and vertical tunes are on opposite sides of an integer value, which brings the operating point in undesirable proximity to difference resonances. It is possible to cure both effects.

Table 1: Quadrupole focussing strengths in units of m^{-2}

	LBLE	NOQ3$_0$	NOQ3$_1$	MVD1
Q3	-0.932			
Q2/QF0	0.370	0.079	0.079	0.577
Q1	-0.254	-0.264	-0.263	-0.539
QFA	0.769	0.751	0.803	0.799
QDA	-0.721	-0.640	-0.656	-0.652
QFB	0.471	0.545	0.515	0.466
QD	-0.668	-0.668	-0.673	-0.673
QF	0.428	0.428	0.452	0.452

The horizontal phase advance per arc cell produces an emittance contributionthat is not the lowest possible. An increase of the horizontal phase advance reduces the emittance contribution to a minimum and is enough to compensate for the increased emittance contribution of the modified insertion section.

This modifications can be done for all considered positions of the focussing quadrupole in the insertion region. In this paper we will name the lattices with modified arc optics that correspond to the extreme positions of that quadrupole "NOQ3$_1$" and "MVD1", respectively. The k-values are listed in table 1. The optical functions of the MVD1 lattice are displayed in figure 1.

Table 2: Comparison of machine parameters that depend on the lattice modification

	LBLE	NOQ3$_0$	NOQ3$_1$	MVD1	
ν_x	6.820	6.760	7.200	7.200	
ν_y	6.720	5.300	5.300	5.300	
ξ_x^{nat}	-12.7	-10.0	-12.2	-10.7	
ξ_y^{nat}	-16.7	-13.0	-13.5	-13.4	
ϵ^{nat}	130.0	158.9	130.7	123.2	nmrd
α	1.68	1.61	1.49	1.54	10^{-2}
$\overline{\eta_x^{cav}}$	0.3	0.05	0.3	0.5	m
Dn Ap	22	62	58	62	σ
β_x^{sym}	3.7	34.8	46.4	8.9	m
β_y^{sym}	0.12	4.4	5.1	7.4	m

3 COMPARISON BETWEEN OLD AND NEW LATTICE

Table 2 lists parameters that depend on the change in lattices. The chromaticities, $\xi_{x,y}^{nat}$, are reduced and the momentum compaction, α, is smaller.

As mentioned above, one of the improvements that came with the LBLE lattice was the reduction of the horizontal dispersion function $\overline{\eta_x^{cav}}$ in the RF cavities. The LBLE lattice reduced the average value from 1.5 m down to about 0.3 m. The modified lattices keep that value or increase it only slightly.

Table 3: Horizontal Tune Sensitivity $k_x \frac{d\nu_x}{dk_x}$

	LBLE	NOQ3$_0$	NOQ3$_1$	MVD1
Q3	-2.05			
Q2/QF0	7.33	0.68	1.51	1.72
Q1	-0.29	-0.20	-0.18	-0.63
QFA	1.52	3.69	2.78	1.60
QDA	-0.14	-0.18	-0.10	-0.10
QFB	1.24	1.42	1.69	1.52
QD	-0.39	-0.39	-0.28	-0,28
QF	5.64	5.64	7.43	7.43

Table 4: Vertical Tune Sensitivity $k_y \frac{d\nu_y}{dk_y}$

	LBLE	NOQ3$_0$	NOQ3$_1$	MVD1
Q3	10.03			
Q2/QF0	-1.97	-0.29	-0.29	-1.95
Q1	0.54	2.40	2.40	4.54
QFA	-1.27	-1.67	-1.67	-1.53
QDA	4.26	4.22	4.22	3.95
QFB	-0.28	-0.31	-0.31	-0.28
QD	9.52	10.02	10.02	10.02
QF	-1.29	-1.37	-1.37	-1.37

The sensitivities of the betatron tunes to strength variations of the insertion region quadrupoles (See tables 3 and 4). The power supplies used for the SPEAR magnets are old and their stabilization is poor compared to modern standards.

The new lattices take quadruples out that are among the ones that contribute strong to tune movement and tune oscillations and reduces the impact of other quadrupoles, significantly.

The performance of the SPEAR synchrotron light source suffers from transverse beam position movements, the largest of them show a diurnal cycle dependence. The amplitude of the movement without corrective measures is in the order of millimeter. These movements have been traced down to fluctuations in the transverse positions of the Q2 and Q3 quadrupoles. Tables 5 and 6 list the orbit amplification factors. The lattice modifications remove the quadrupole familiy with the largest amplification factors and greatly reduce the amplification factors of other quadrupole families.

The dynamic aperture of the LBLE lattice is rather small, 22 σ or about 36 mm horizontally at the injection

Table 5: Horizontal Orbit Amplification Factors $\frac{dx_{co,rms}}{dx_{quad}}$

	LBLE	**NOQ3$_1$**	**MVD1**
Q3	4.70		
Q2/QF0	6.50	1.51	2.36
Q1	0.70	0.60	1.38
QFA	2.90	3.56	2.68
QDA	0.80	0.68	0.58
QFB	2.00	2.28	2.04
QD	0.40	0.38	2.00
QF	1.80	2.01	0.33

septum, barely enough to hold the newly injected beam. For the modified lattices the value is increased by almost a factor of three. The values are listed in table 2.

Table 6: Vertical Orbit Amplification Factors $\frac{dy_{co,rms}}{dy_{quad}}$

	LBLE	**NOQ3$_1$**	**MVD1**
Q3	7.30		
Q2/QF0	2.40	0.62	3.65
Q1	0.90	1.98	3.89
QFA	2.10	2.94	2.82
QDA	4.10	4.26	4.09
QFB	0.80	1.07	0.96
QD	2.00	1.90	1.91
QF	0.80	0.83	0.83

4 INJECTION

SPEAR uses injection into the horizontal phase space. A static four-corrector bump is used to support a fast three-kicker bump in moving the closed orbit towards the injection septum. The Septum is 57 mm away from the un-bumped closed orbit. Each of the bumps moves the beam presently about 15 mm towards the septum, still leaving injection oscillations with initial amplitudes of 25 to 30 mm at the septum. These oscillations will produce even larger amplitudes at the new higher-beta region of the **NOQ3** lattices in the insertion section (see β_x^{sym} in table 2), requiring a large beam-stay-clear. The existing vacuum chamber in the vicinity of the Q3 magnet, close to the symmetry point, had been designed with the low beta insertion in mind, optimized for colliding beam operation. A re-design of that part of the vacuum chamber is necessary in order to be able to inject into the **NOQ3** lattices. The relative magnet strengths for both injection bumps have been re-calculated for the new lattice and are listed in table 7. The total bump amplitude for the new lattices will be increased to reduce the injection oscillations. Note that the **NOQ3$_1$** lattice requires a polarity change for the central kicker.

Table 7: Kick strengths in slow and fast injection bumps.

	LBLE	**NOQ3$_0$**	**NOQ3$_1$**	**MVD1**	
K3S4	1.1	1.4	1.2	1.6	mr
K16S17	0.6	0.4	-0.5	0.1	mr
K14S15	1.3	1.3	1.4	1.3	mr
16BB2T	2.0	3.1	2.8	2.8	mr
16BB1T	-1.1	-0.9	0.5	0.4	mr
15BB2T	2.1	2.5	3.3	3.3	mr
15BB1T	1.0	2.0	1.7	1.7	mr
Ampl.	30	40	40	40	mm

5 INSTALLATION

We are in the process of installing the new lattice in a phased approach. First attempts, carried out in the beginning of 1994, to inject into the **NOQ3** lattice without any hardware modifications were unsuccessful due to the aperture limitations as mentioned above.

We are presently building a re-designed vacuum chamber for the insertion section that gives a significantly larger aperture and should allow to operate the **NOQ3** lattices with the Q3 magnet still in place. The limiting aperture will then be given by synchrotron radiation masks. This keeps the option open to switch back to the **LBLE** lattice in case unexpected problems occur. The new vacuum chamber will be installed during the shutdown in Fall of 1994.

The tests of the **NOQ3** lattice with modified hardware will be carried out early in 1995. If these tests are successful, more extensive hardware modifications could follow: the replacement of the Q2, Q3 magnets and power supplies by one smaller more efficient magnet and one smaller power supply. The implementation of the **MVD1** lattice depends on proposals to use the long straight sections.

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7 REFERENCES

[1] J. Safranek and H. Wiedemann, "Low-Emittance in SPEAR," in *Proceedings of the 1991 IEEE Particle Accelerator Conference, San Francisco*, pp. 1104–1106, May 1991. IEEE Catalog Number 88-647453 91CH6038-7.