DL/SCI/TM 23A

11687-2001

technical memorandum Daresbury Laboratory

DL/SCI/TM 23A

A SURVEY OF POSSIBLE LATTICE MODIFICATIONS FOR THE SRS

by

V.P. SULLER, Daresbury Laboratory

MAY, 1980

REF COPY.

Science Research Council

Daresbury Laboratory

Daresbury, Warrington WA4 4AD

1. INTRODUCTION

The SRS is the world's first, purpose built, high energy synchrotron radiation source and it was designed to meet several requirements specified by the user community. The spectrum needed to satisfy both the VUV user and the X-ray user, and this is reflected in the energy and size of the storage ring. The other major aspect of the storage ring, the particular type of lattice used, is a consequence of the following requirements:

a) A beam current of 1000 mA should be aimed at.

b) Good access to the radiation should be available, permitting beams with wide horizontal angles.

c) Users should have guaranteed access to the beam lines during stored beam conditions, at least for beams up to 20 mr wide.

The choice of lattice to meet these requirements was determined by the following logical arguments. Point a) means that the beam emittance must not be so small that, at the injection energy, the beam current is limited by the Touschek effect. Point c) implies, from considerations of electron loss processes and the resulting high energy radiation, that beam line tangent points must be at the centre of the dipole magnets. The positions of the resulting beam lines forces the lattice quadrupoles to lie well down the straight sections which follow the dipoles, as also does point b) since wide beams cannot be got through the apertures or side yokes of the quadrupoles.

A FODO lattice with the quadrupoles at the downstream end of the straight sections was therefore chosen because it meets all the requirements given above.

At the time of the design study user comments on the beam size were that it should be as small as possible in one plane. In most electron storage rings the vertical beam size is smaller than the horizontal and in the SRS it was decided to minimise the vertical beam size by the use of 16 well distributed skew quadrupole lenses.

In the meantime, following the design of the SRS, the world of synchrotron radiation has evolved with changed emphases. It has been realised that matching radiation beams with focusing mirrors to monochromators and other instrumentation is much easier for beams which have small emittances in both planes. Secondly a great interest has developed in devices such as undulators and free electron lasers which require storage rings with long straight sections with specific properties. Consequently the later generation of dedicated synchrotron radiation sources have included long straight sections for inserted devices and have stressed the importance of producing the smallest possible beam emittance in both planes. The achievement of large stored currents has not been emphasised.

As it stands the SRS is potentially an excellent synchrotron radiation source. Nevertheless, with the passage of time further developments in the synchrotron radiation field and competition from the new generation machines may result in pressure to consider modifying the performance of the SRS. The ways in which this could be done range between the extremes of simply adjusting the focusing strength of the quadrupoles to rebuilding the whole storage ring.

This paper will consider the improvements to the SRS performance which would result from a series of different modifications that have the common feature of leaving unchanged the ring of dipole magnets. The modifications will be made to the number and location of the quadrupole magnets which lie in the straight sections.

It is hoped that a clear indication is given of the improvements to the beam characteristics of the SRS which are feasible and may be worthwhile. The practical problems of getting beam lines past or through quadrupoles and of locating the other necessary storage ring equipment (r.f. cavities, injection kickers, etc) will require further study.

2. PRESENT SRS

The present SRS lattice is a FODO structure, which is shown in fig.1 with the major lattice functions. It has been shown[1] that these lattices produce the best beam brightness when operated at high phase advances. In accordance with this principle the SRS is designed to operate at phase advances which give betatron tune values of 3.25 in the horizontal plane

(Q_x) and 2.25 in the vertical plane (Q_y). With eight unit cells the lattice stability limit is at a tune value of 4.0. Figure 1 also gives the beam sizes calculated for the best low coupling condition.

A smaller horizontal emittance would result if the SRS was operated at tunes of $Q_x = 3.25$, $Q_y = 1.25$. However at this setting the vertical beam sizes at the tangent points are actually larger because the betatron amplitude function (β) has increased. The beam sizes for this operating point are also given in fig.1.

3. ACHROMATIC ARC LATTICE

The horizontal beam emittance in an electron storage ring is controlled by the value, within the bending magnets, of a slightly complicated function of the betatron amplitude function, the dispersion and the gradients of both these. One way of making a small emittance is to design the storage ring such that the dispersion is small, especially in the regions where the betatron amplitude function is large. This technique has been used in the design of the Brookhaven x-ray ring[2], the ESRF[3] and BESSY[4].

Such a lattice is built up from bending sections which are achromatic or non-dispersive between input and output. The bending sections are then linked together by straights containing quadrupoles which provide the focusing of the lattice. The dispersion in these straights is zero.

In its simplest form the achromatic section comprises a symmetric pair of dipole magnets with a focusing quadrupole placed in the centre of the straight between them. The function of the quadrupole is to focus the dispersed trajectories from the centre of the first magnet to the centre of the second.

The SRS could be converted to an achromatic arc lattice by placing a focusing quadrupole at the centre of alternate straight sections and a quadrupole triplet in the remaining four straights. This arrangement is shown in fig.2 together with the calculated beam properties.

It is apparent that a very low emittance could be achieved. There are however a number of drawbacks with this type of lattice. Firstly the working region in which the machine is stable is very small and thus the storage ring is very sensitive to errors. Secondly the chromaticity is very difficult to control due to the shape of the betatron functions and there is little space for the sextupoles where they are needed. Thirdly the gradients in the quadrupoles tend to be rather high.

A further criticism which could be levelled at the SRS modified in this way is that hardly any room is left for r.f. cavities, injection kickers etc. An attempt has been made to overcome these objections by studying a variation which would use a quadrupole doublet in place of the triplet. Although this would give more space the resulting lattice behaves very badly and exhibits large peaks in the vertical betatron function. Also the emittance is no smaller than can be achieved by other arrangements.

Therefore it appears that the lattice modified in the form of an achromatic arc lattice does not seem feasible, although this type of arrangement probably sets the standard for the lowest achievable emittance.

4. LATTICE WITH LONG STRAIGHTS

Although the distance separating the ends of the dipole magnets in the SRS is just over 3.8 m, by the time space has been allocated for quadrupoles, BPIs, pump tees, bellows, etc, there only remains about 1.5 m of free space. This is just about sufficient to accommodate a superconducting three pole wiggler.

A realistic undulator with enough poles to produce a reasonable line width (say 25 periods of length 100 mm) would require about 2.5 m of straight section length and this is clearly out of the question with the present SRS lattice. Therefore a modification has been considered in which alternate straights are left entirely free of quadrupoles, the lattice focusing being done by quadrupoles in the other eight straights. In principle these quadrupoles could be in the form of a doublet but in practise a symmetric triplet works much better.

properties. A useful reduction is achieved in both the emittance and the momentum compaction factor. The implication of the latter is that the bunch length is 15% shorter at 2 GeV or, given the same r.f. power, the storage ring could be operated up to 2.15 GeV.

The configuration of the vertical betatron function is quite suitable for an undulator since the value is reasonably high and constant through the long straight. On the other hand the ratios between the horizintal and vertical beta values imply that chromaticity control is likely to be tricky.

Of the eight long straights in the storage ring, two would be needed for r.f. cavities and two for injection leaving four for undulators.

5. TWO QUADRUPOLES PER STRAIGHT

The installation of an extra quadrupole at the upstream end of every straight section would convert the SRS from a FODO lattice with 8 unit cells to one with 16 cells. This would permit an increase in focusing power to achieve higher betatron tunes with a consequent reduction in the beta values and the lattice dispersion, and hence a reduction in emittance.

The unit cell structure is shown in fig.4 with a summary of the beam properties. A considerable reduction in emittance and momentum compaction factor is indicated. Due to the small momentum compaction the bunch length at 2 GeV would be reduced by about 55% for the same installed r.f. power. Alternatively, with the same r.f. power the machine could be operated at 2.5 GeV but consideration must be given to whether the magnets could produce the necessary field.

There is much to commend a FODO lattice of this type; it is stable and controllable, the chromaticity is easy to correct and the quadrupole gradients are moderate. For the SRS modified in this way the main concern would be in making sure that enough room was left for other necessary equipment (r.f. cavities, injection kickers etc) and in getting the radiation beams past or through the new quadrupoles.

Since the modified FODO lattice with 16 unit cells looks a little short of space for other equipment, a compromise approach has been studied. This has an extra quadrupole in only half the straight sections and so does not use up so much available space.

The arrangement is shown in fig.5. This lattice may be thought of as containing four unit cells each of which has two asymmetric quadrupole triplets; one triplet being F1A D1 F1B, the other D2A F2 D2B.

Consequently, although it is a very flexible lattice it needs six separate sets of power supplies for the quadrupoles. The lattice is quite well-behaved for such an odd arrangement, but it does not produce a very low emittance. It is interesting to note that the straights which contain only one quadrupole have a fairly low dispersion. This could be useful for installing high field wigglers since the emittance blow up from the wigglers would be fairly small.

7. CONCLUSIONS

Substantial reductions in horizontal beam emittance can be achieved by modifying the lattice to an achromatic arc type or by doubling the number of unit cells. The latter approach is preferred since it results in a much better behaved lattice.

The reduction in momentum compaction factor which also takes place would mean that the maximum energy could be increased to 2.5 GeV without needing more r.f. power. It is not clear if the bending magnets could be pushed to the necessary field level (1.5 T).

Other types of lattice modification can result in longer straight section free space, a range of adjustable beta values, or straight sections with low dispersion. These versions do not greatly reduce the horizontal beam emittance or the momentum compaction factor.

All modifications will call for installation of further quadrupoles into the existing lattice, and the problem of bringing a synchrotron radiation beam pipe past, or through, these quadrupoles remains to be solved. Other practical problems such as injection, the location of r.f. cavities, etc. have yet to be studied in detail. Many of these practical problems will be better assessed after experience has been gained in operating the storage ring in its present form.

REFERENCES

1. H. Wiedermann, in: Proc. Conf. for Synchrotron Radiation Instrumentation, Washington, June 1979. To be published.

2. J.P. Blewett ed., Brookhaven report, BNL 50595 (1977).

3. D.J. Thompson and M.W. Poole eds., European Synchrotron Radiation Facility. Supplement II. (European Science Foundation, 1979).

4. O. Einfeld and G. Mulhaupt, BESSY report TB 13/1979.

FIGURE CAPTIONS

Fig.1 Lattice parameters and beam sizes for the standard SRS lattice.

Fig.2 Lattice parameters and beam sizes for the achromatic arc lattice.

Fig.3 Lattice parameters and beam sizes for the lattice with long straights.

Fig.4 Lattice parameters and beam sizes for the lattice with two quadrupoles per straight.

Fig.5 Lattice parameters and beam sizes for the lattice with an extra quadrupole in every other straight.

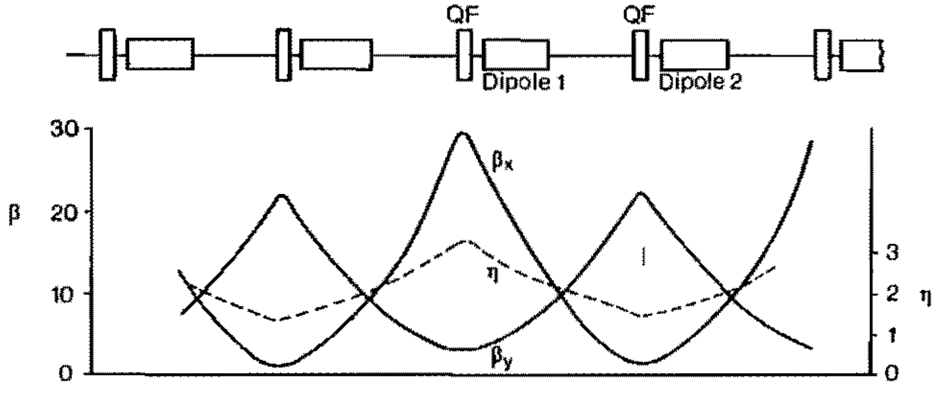

Fig.1

$Q_x = 3.25$, $Q_y = 2.25$

QF - Horizontally focusing quadrupole Gradient 3.58 T/m

QD - Horizontally defocusing quadrupole Gradient 3.51 T/m

$\epsilon_x = 1.5 \times 10^{-6}$ m.rads $\hat{\alpha} = 0.135$ $\frac{\sigma(E)}{E_o} = 0.67 \times 10^{-3}$

Dipole 1. $\sigma_x = 5.5$ mm $\sigma_y = 0.17$ mm

Dipole 2. $\sigma_x = 2.7$ mm $\sigma_y = 0.28$ mm

$Q_x = 3.25$, $Q_y = 1.25$

QF Gradient 3.54 T/m

QD Gradient 2.55 T/m

$\epsilon_x = 1.3 \times 10^{-6}$ m.rads $\hat{\alpha} = 0.126$ $\frac{\sigma(E)}{E_o} = 0.67 \times 10^{-3}$

Dipole 1. $\sigma_x = 5.2$ mm $\sigma_y = 0.22$ mm

Dipole 2. $\sigma_x = 2.5$ mm $\sigma_y = 0.30$ mm

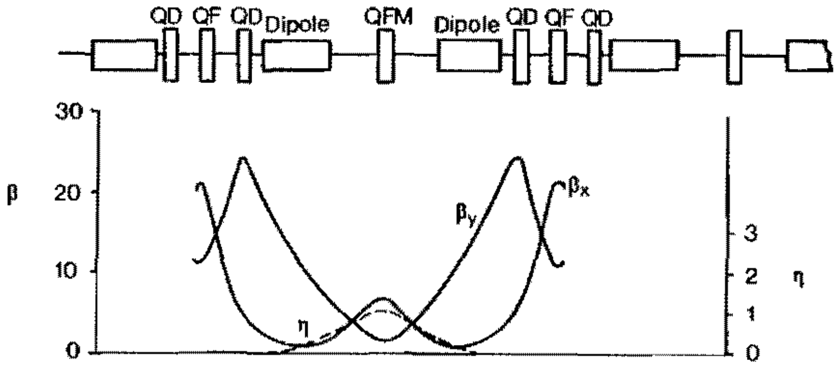

Fig. 2

$Q_x = 6.25$, $Q_y = 2.25$

QFM Gradient - 10.35 T/m

QF Gradient - 13.3 T/m

QD Gradient - 7.3 T/m

$\varepsilon_x = 8.2 \times 10^{-8}$ m.rads $\hat{\alpha} = 0.0093$ $\frac{\sigma(E)}{E_o} = 0.72 \times 10^{-3}$

Dipole $\sigma_x = 0.34$ mm $\sigma_y = 0.10$ mm

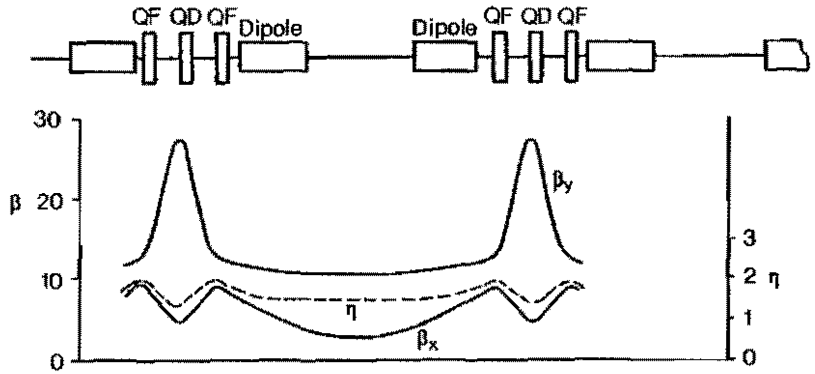

Fig. 3

$Q_x = 3.25$, $Q_y = 1.25$

QF Gradient - 8.0 T/m

QF Gradient - 8.1 T/m

$\varepsilon_x = 7.4 \times 10^{-7}$ m.rads $\hat{\alpha} = 0.10$ $\frac{\sigma(E)}{E_o} = 0.68 \times 10^{-3}$

Dipole $\sigma_x = 2.35$ mm $\sigma_y = 0.29$ mm

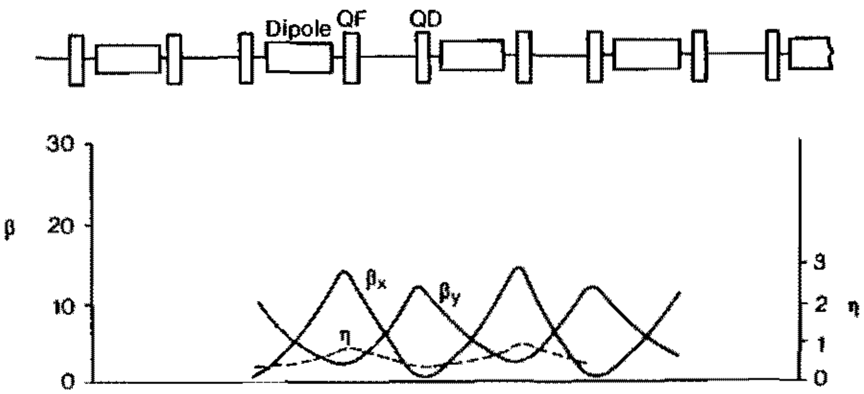

Fig. 4

$Q_x = 6.25$, $Q_y = 3.25$

QF	Gradient	-	9.45 T/m
QF	Gradient	-	7.05 T/m

$\varepsilon_x = 1.1 \times 10^{-7}$ m.rads $\quad \hat{\alpha} = 0.029 \quad \frac{\sigma(E)}{E_o} = 0.71 \times 10^{-3}$

Dipole $\quad \sigma_x = 0.78$ mm $\quad \sigma_y = 0.08$ mm

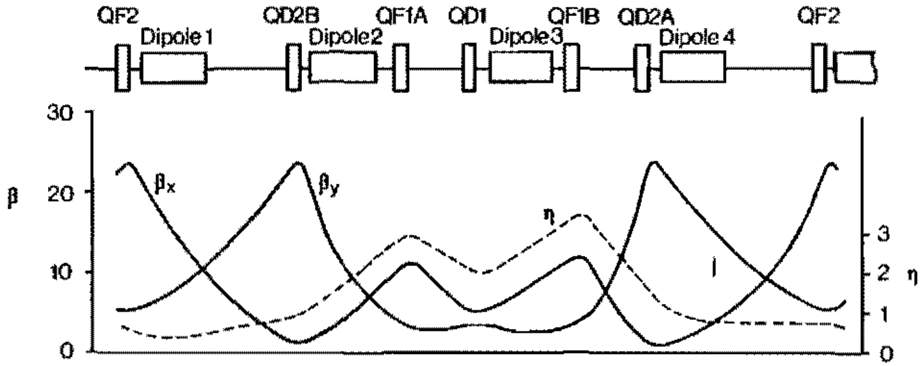

Fig. 5

$Q_x = 3.4$, $Q_y = 2.4$

QF1A	Gradient	-	5.6 T/m
QD1	Gradient	-	5.2 T/m
QF1B	Gradient	-	6.0 T/m
QD2A	Gradient	-	5.3 T/m
QF2	Gradient	-	4.2 T/m
QD2B	Gradient	-	4.6 T/m

$\varepsilon_x = 1.1 \times 10^{-6}$ m.rads $\quad \hat{\alpha} = 0.096 \quad \frac{\sigma(E)}{E_o} = 0.68 \times 10^{-3}$

Dipole 1	$\sigma_x = 4.1$ mm	$\sigma_y = 0.26$ mm
Dipole 2	$\sigma_x = 2.6$ mm	$\sigma_y = 0.30$ mm
Dipole 3	$\sigma_x = 3.5$ mm	$\sigma_y = 0.15$ mm
Dipole 4	$\sigma_x = 1.9$ mm	$\sigma_y = 0.37$ mm