DYNAMIC APERTURE, TUNE SPACE CHARACTERISTICS AND SEXTUPOLE DISTRIBUTION IN THE DARESBURY SRS

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Betatron resonances up to fifth order have a significant influence on beam behaviour in the SRS. Installation of a second superconducting wiggler magnet will necessitate relocation of one of the four chromatic sextupoles and break the corresponding four-fold symmetry arrangement. The severe consequences of the modified sextupole distribution on the dynamic aperture have been investigated and the best possible solution identified.

Introduction

The Daresbury SRS is a dedicated synchrotron light source, operating at 2 GeV but with injection at 600 MeV from a booster synchrotron. Since 1987 the facility, now known as SRS-2, has employed a higher brightness lattice modification based on a 16-fold FODO structure [1]. One undesirable feature of the lattice change was a less optimised arrangement of the chromaticity correcting sextupole magnets : previously these had been distributed in every FODO cell but there was insufficient space for this in the new scheme. Assessment of dynamic aperture then led to a choice of four symmetrically spaced magnets for the "D" family of sextupoles. Fortunately the "F" family was still permitted a complete set of one per cell.

A major development project now under way will provide a second superconducting wiggler of 6 T on the SRS [2] and its location in the ring is fixed by the requirement to include extensive new experimental facilities. The selected straight section includes one of the four D-sextupoles, a vacuum sector valve and a beam scraper. The scraper can be readily relocated but to move the valve would necessitate substantial changes to the vacuum controls system. Since many of the straight section components are immovable (eg main quadrupoles and correctors) a suitable free length for the wiggler (~1.2 m) could only be made available by removal of the sextupole. Studies of the consequences of such a change to the lattice have now been undertaken.

Resonances and Tune Space

For user beams at 2 GeV a working point (6.17,3.36) has been chosen to minimise the source dimensions [1], based on the somewhat surprising result that blowup even from fifth order betatron resonances can reduce both source brilliance and beam lifetime . As expected the chromatic sextupoles have a strong effect on third order lines, especially $3Q_V=10$ and $Q_R+2Q_V=13$, with closed orbit errors also playing an important role.

A series of experiments has been undertaken at the injection working point, which is displaced to about (6.22,3.26) to optimise beam stacking. The working point is moved through the energy ramp so as to minimise beam loss and the number of resonance lines in the vicinity can be seen in fig. 1. With low currents of less than 10 mA the third order lines $3Q_R=19$, $3Q_V=10$ and $Q_R+2Q_V=13$ each cause loss of beam and the lines $2Q_R-Q_V=9$ and $4Q_R=25$ result in enhanced beam dimensions. Resonance line widths vary from 0.002 for the weak cases to 0.02 for strong ones, although losses disappear when reducing the sextupoles to about 30% of their normal levels. With the sextupoles off the SRS is unstable with large vertical blowup even at a few milliamperes. At high currents of up to 300 mA additional losses and blowup occur, with all of the following causing loss :

$3Q_R = 19$
$3Q_V = 10$
$Q_R + 2Q_V = 13$
$2Q_R - Q_V = 9$

$4Q_R = 25$
$3Q_R + Q_V = 22$

$5Q_R = 31$
$4Q_R + Q_V = 28$
$3Q_R - 2Q_V = 12$

Additionally to these effects there are losses observed in high current beams at tunes which do not coincide with these resonance lines and a pickup signal from the beam then exhibits instability characteristics. In practice high current beams in the SRS must be threaded carefully between dangerous regions of tune space in order to reach the desired high energy working point.

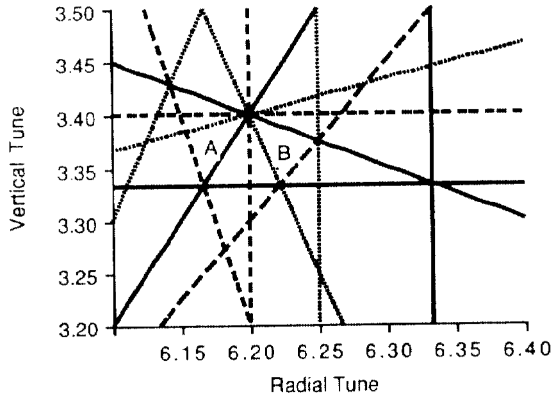

Fig. 1 Order 3, 4, 5 betatron resonances affecting SRS beams

Sextupole Patterns and the New Wiggler

Theoretical Studies

Tracking simulations have been carried out with the Daresbury lattice code ORBIT, concentrating on the most critical operation at the injection level. Particles starting (arbitrarily) in the centre of a bending magnet are tracked for several hundred turns to determine combinations of horizontal and vertical initial amplitudes that go unstable, thus defining the dynamic aperture of the SRS. In fig.2 a comparison is given between the original symmetric case and one where a sextupole is removed, showing the collapse of dynamic aperture in the latter asymmetric case.

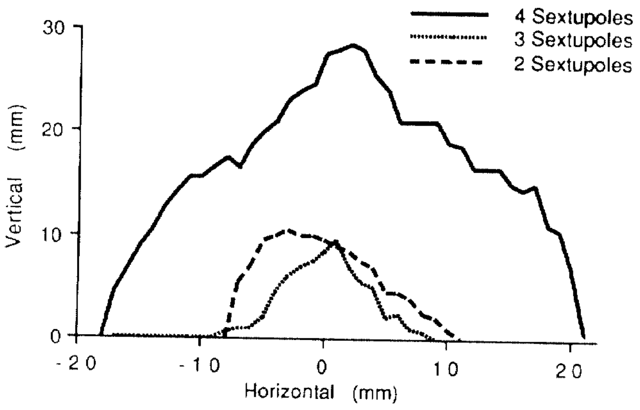

Fig. 2 Dynamic aperture with two, three or four sextupoles

Removal of a second magnet to introduce a more symmetric (two-fold) pattern gives little improvement, as is also shown in fig.2. At this location in the ring the physical half aperture is 20 mm by 7 mm, well in excess of the reduced dynamic aperture.

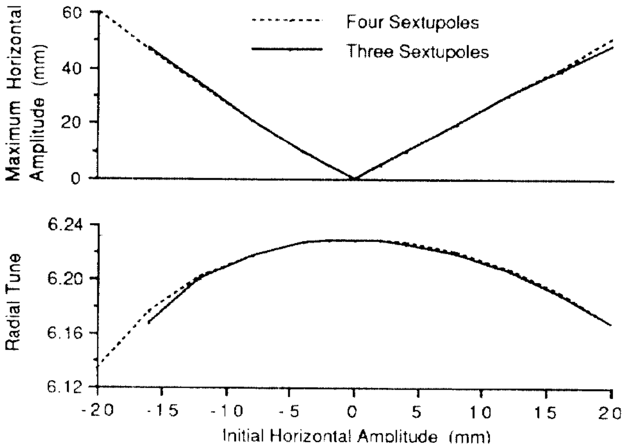

Fig. 3 Growth and tune shift induced by horizontal motion

An explanation of these results is indicated in figs. 3 and 4. The action of sextupoles transfers initial vertical motion into the horizontal but not vice versa. Removal of one magnet leads to increased growth and interaction with multiple resonance lines, as confirmed by the structure evolving on the Fourier-analysed vertical tune spectra in fig. 5.

In order to assess the influence of the various resonance lines particle tracking has been performed with two dimensional tune scans as presented in fig. 6, which is an example comparing the vertical blowup induced in the 3 and 4 sextupole cases. The symmetric case shows only the structure resonance $Q_R-2Q_V=0$, which is well away from the chosen operating points, whereas the broken symmetry reveals a multitude of excited resonances. Similar results are found for the horizontal case.

Alternative sextupole patterns have been explored and one example is relocation of a sextupole to an adjacent straight, a practical proposition in the SRS. This is labelled 4-7-12-16 in fig. 7 but is no better than the missing magnet pattern in fig. 2. A practical scheme with two magnets moved to improve symmetry (4-7-12-15) gave disappointing results. The best option is the 4-6-12-14 arrangement also shown in fig. 7, but this still has poor predicted performance and is also an impractical solution with the layout of SRS components. Tune scans have confirmed that the modified patterns have similar resonance characteristics to the three magnet case in fig. 6. In no case is acceptable beam behaviour restored in the required regions of working tune space.

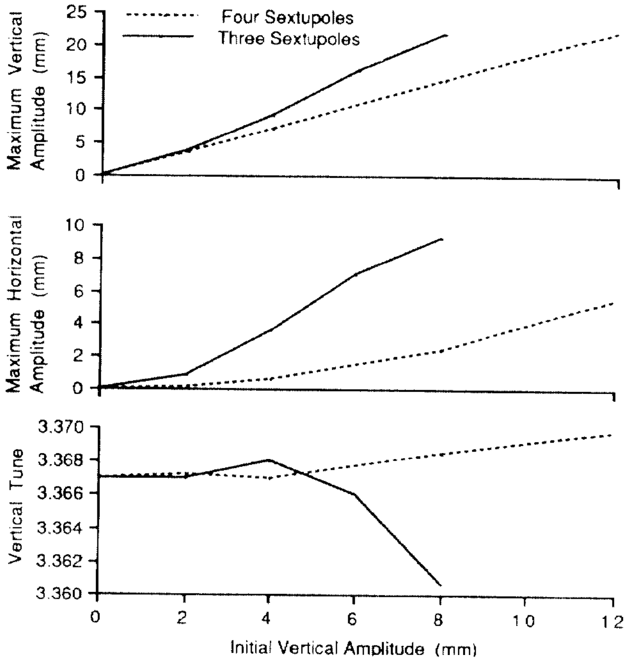

Fig. 4 Growth and tune shift induced by vertical motion

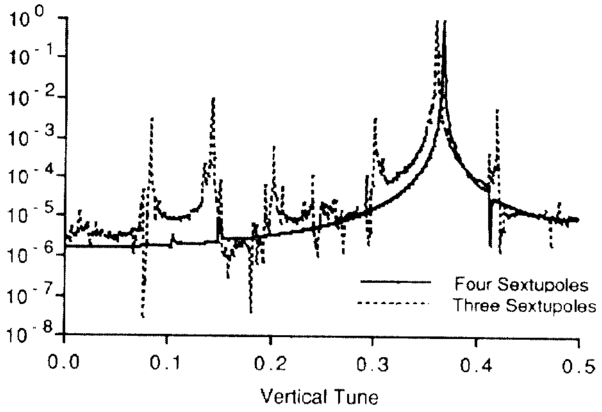

Fig. 5 Simulated vertical tune for three and four sextupoles

Experimental Studies

A programme of experiments has been carried out on the SRS, initially using a dynamic current shunt developed at Daresbury to allow 30% current variation through one sextupole of the family. The problem was seen to be as severe as the simulations had suggested, with significantly reduced injection rates. When the

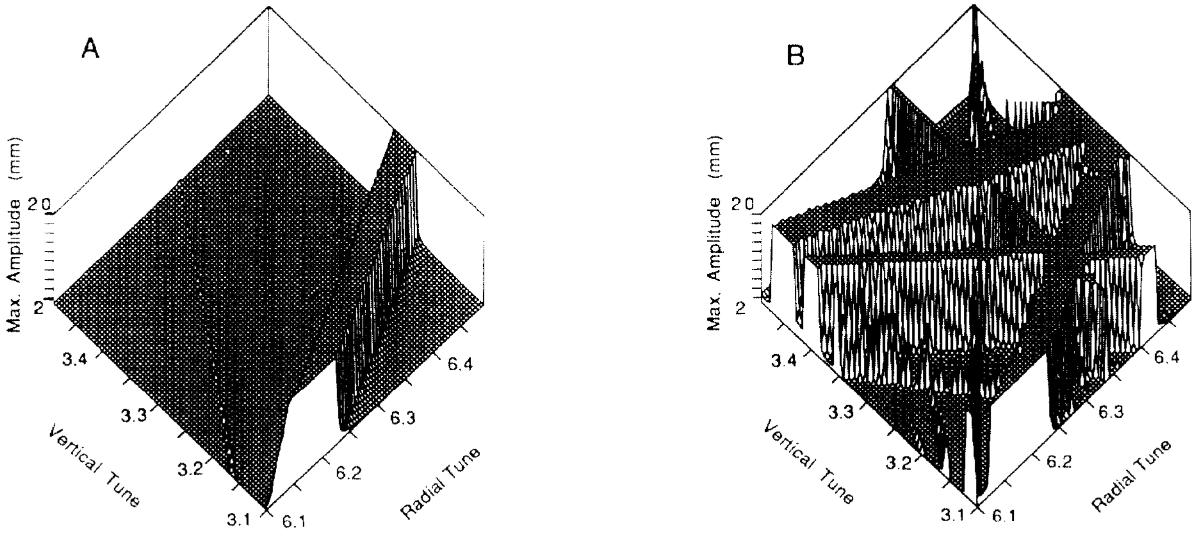

Fig. 6 Induced vertical blowup dependence on initial tunes for (A) four and (B) three sextupoles

magnet was completely shorted out of the circuit only small beam currents could be stored even after extensive reoptimisation. Tune shifts due to finite injection orbit offsets in the sextupoles also occurred, but the conclusion was that the SRS could not be operated satisfactorily with only three sextupoles powered.

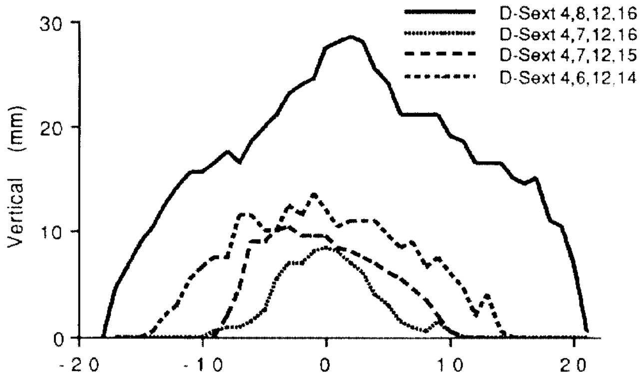

Fig. 7 Dynamic aperture for modified distribution of sextupoles

Consideration has also been given to possible use of only two sextupoles, despite their having insufficient strength to maintain zero chromaticity above 1.7 GeV. As expected (fig. 2) the reduced resonance driving of this pattern did give better beam performance. Although good stacking could still not be achieved with full chromaticity correction high currents were obtained in this mode and it has been demonstrated that a third magnet can be brought on at high energy without much loss of beam. However this 2-sextupole injection has very reduced flexibility in choice of tune points and may also have problems in operation of the SRS with the high single bunch currents that are sometimes offered to users, since full chromaticity correction has not been achieved.

An additional sextupole has been installed in the SRS lattice, separately powered from the main family. The magnet is located in a straight (7) adjacent to an existing sextupole (8) and allows experiments on the 4-7-12-16 pattern (see fig. 7). Once again it was impossible to stack beams at zero chromaticity settings and resonance line widths widened appreciably, even at reduced excitation levels in the new magnet. Overall the SRS performance seemed inferior to the 3-sextupole pattern and the available tune settings at injection became very restricted as the sextupole fields were progressively increased. In a related experiment a high beam current was stored with symmetric sextupoles and an attempt made to convert progressively to the asymmetric version (4-7-12-16) : this always led to large beam losses and an upper limit of about 50% of required sextupole strengths. Observed lifetime reductions in the absence of beam profile increases are further evidence that the losses are due to a reduced dynamic aperture, as predicted by the tracking simulations.

Conclusion

SRS beams are sensitive to resonance lines up to at least fifth order at the operating currents of 200-300 mA now routinely achieved. Their influence is significantly enhanced by any change to the optimised fourfold symmetric arrangement of the chromatic D-sextupole family, as is evidenced by a collapse of the dynamic aperture. Experiments have confirmed numerical tracking predictions that alternative practical redistributions of sextupoles to accomodate the new wiggler lead to a serious deterioration of the beam performance. It is essential to restore the fully symmetric pattern and this will necessitate movement of all four sextupoles by one straight and new injection kicker magnets of smaller size. Some of these changes will be introduced during 1991 and the cost and complexity illustrates the critical nature of the design of modern light sources.

References

[1] V. P. Suller et al, Proc. IEEE Part. Acc. Conf., Chicago, 1989
[2] M. W. Poole et al, Proc. IEEE Part. Acc. Conf., Chicago, 1989