MEASUREMENT OF VERTICAL DISPERSION AND COUPLING IN THE DARESBURY SRS

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Abstract

Vertical dispersion in synchrotron radiation sources is undesirable because it degrades the properties of the photon beam. This dispersion has been measured in the SRS at the user working point. The results agree well with a theoretical model of the SRS with realistic magnet misalignment errors included. The emittance coupling of the SRS due to difference resonances has also been measured and compared with theoretical predictions.

1 VERTICAL DISPERSION

The variation of horizontal closed orbit with momentum is determined by the horizontal dispersion function, η_x, in an electron storage ring. In an ideal lattice there is no vertical change to the closed orbit because the vertical dispersion is equal to zero. However, due to the presence of alignment and rotational errors in the lattice magnets, a finite vertical dispersion is always present. The dependence of the closed orbit on the momentum of the electron beam is given by:

$$\Delta x, y = \eta_{x,y} \frac{\Delta p}{p} \tag{1}$$

In order to measure the dispersion the momentum of the beam can be varied by altering the RF frequency:

$$\frac{\Delta p}{p} = -\frac{1}{\alpha} \frac{\Delta f_{rf}}{f_{rf}} \tag{2}$$

where α is the momentum compaction factor. Hence the dependence of the closed orbit on the RF frequency is given by:

$$\Delta x, y = -\frac{\eta_{x,y}}{\alpha} \frac{\Delta f_{rf}}{f_{rf}} \tag{3}$$

1.1 Experimental Measurements

The vertical dispersion of the SRS has been measured at each of the 16 BPMs in the storage ring. The RF frequency was progressively varied over a 100 kHz range while the beam orbit was recorded. A graph of closed orbit change against RF frequency change reveals a linear plot whose gradient is proportional to the dispersion. A typical result is shown in figure 1. The vertical dispersion measured in the SRS along the whole lattice is given in figure 2. Other light sources have measured similar vertical dispersion values [1]. Note that a value of 3 cm will increase the SRS vertical beam size by less than 2%.

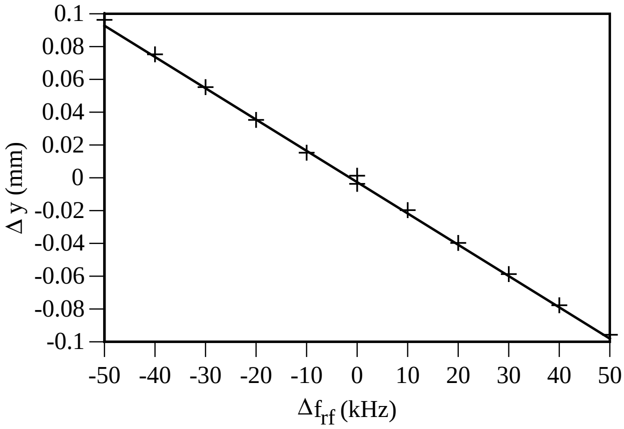

Figure 1. Typical measurement of vertical orbit change with RF frequency.

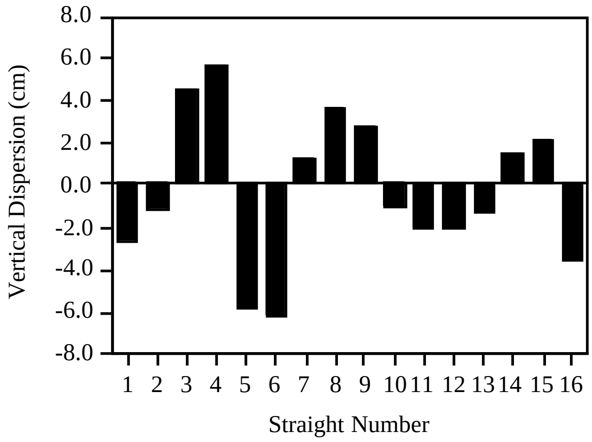

Figure 2. Measured vertical dispersion in the SRS.

1.2 Theoretical Modelling

To assess the implications of the measured vertical dispersion, with regard to the amplitude of the alignment errors in the SRS, a theoretical model of the lattice has been established. The model has been developed using the software MAD [2]. A sketch of the unit cell of the SRS is shown in figure 3. Each of the elements has been included in the model and each has been given realistic alignment and roll errors. The random errors assigned are based upon a Gaussian distribution with a user defined rms. The vertical dispersion is calculated after the program has corrected the closed orbit at the BPMs in both planes. To compare the dispersion values with those measured the Fourier Transform of both sets of data has been calculated. The result, for the rms error values given in Table 1, is shown in figure 4. The large third harmonic is due to the vertical tune value of 3.35.

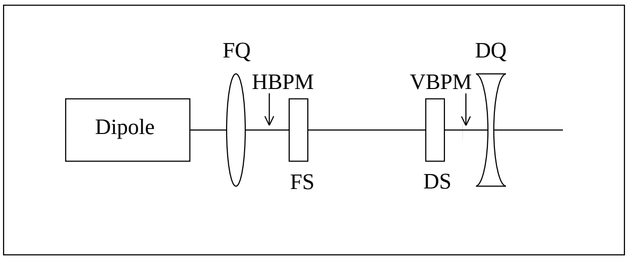

Figure 3. Schematic of the SRS unit cell.

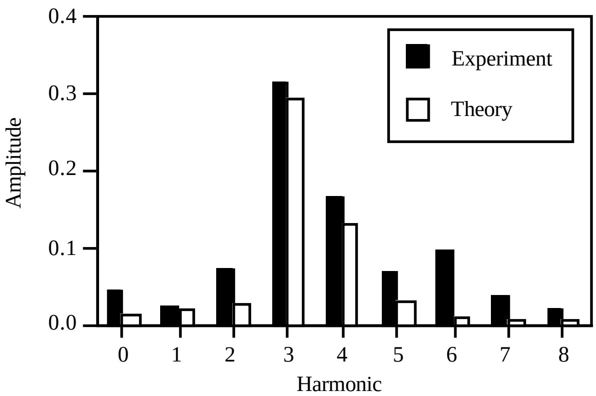

Figure 4. Theoretical and experimental Fourier transform of the vertical dispersion.

Element	Horizontal Alignment Error (mm)	Vertical Alignment Error (mm)	Rotational Error (mrad)
FQ & DQ	1.5	1.0	1.0
FS & DS	1.5	1.0	1.0
Dipole	0.0	0.0	1.0
BPMs	1.0	1.0	0.0

Table 1. Rms errors used in the theoretical model

2 COUPLING

2.1 Measurement

When the SRS is run in single bunch mode the tune point is deliberately set adjacent to a coupling resonance in order to increase the linear coupling. The increased coupling significantly improves the lifetime which is Touschek limited. Recently it has been observed that the coupling has reduced and so a series of measurements has been undertaken to explain this phenomena. The actual coupling due to the difference resonance Qr - Qv = 1 has been measured by recording the minimum approach of the two betatron tunes as the resonance is crossed. The emittance coupling ratio, g, can be written in terms of an integrated skew quadrupole term, k, and the non-integer part of the tune difference, Δ = Qr - Qv [3]:

$$g = \frac{\varepsilon_y}{\varepsilon_x} = \frac{(k/\Delta)^2}{0.5 + (k/\Delta)^2} \qquad (4)$$

The difference resonance Qr - Qv = 1 has been crossed by altering the defocusing quadrupole family current. The variation of the betatron tunes with the quadrupole setting is shown in figure 5.

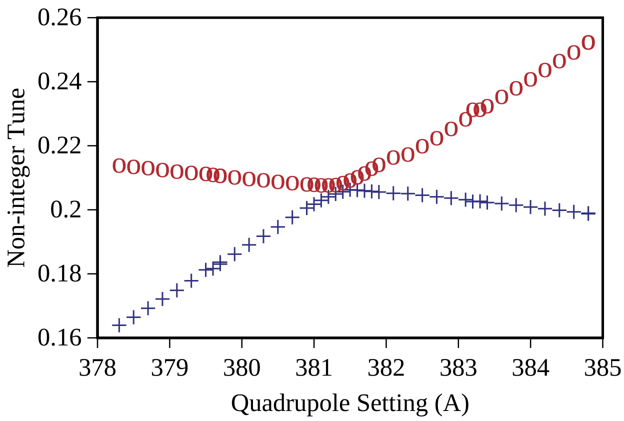

Figure 5. Variation of the radial and vertical betatron tunes with quadrupole setting.

The minimum tune difference of 0.0032 implies k = 0.0016 [3]. From this value a graph of coupling against tune difference can be drawn (figure 6).

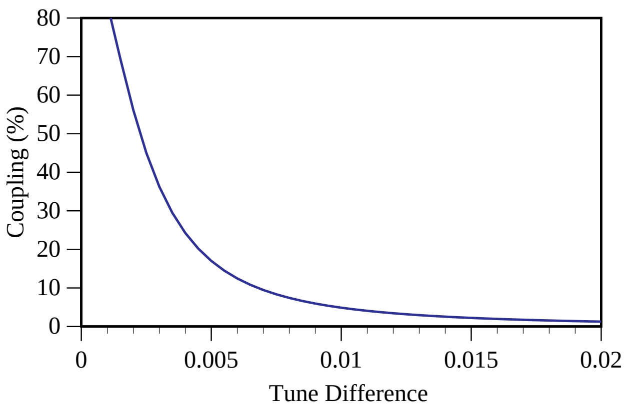

Figure 6. Variation of coupling with tune difference near the resonance Qr - Qv = 1.

2.2 Lifetime

Since the single bunch mode lifetime is Touschek limited an increased coupling improves the lifetime [4]. A measurement of the lifetime-beam current product has been made as a function of the coupling. The results, shown in figure 7, clearly demonstrate the advantage of running the SRS in a high coupling mode for time resolved studies. The plot is non-linear because of the non-negligible influence of the gas scattering lifetime.

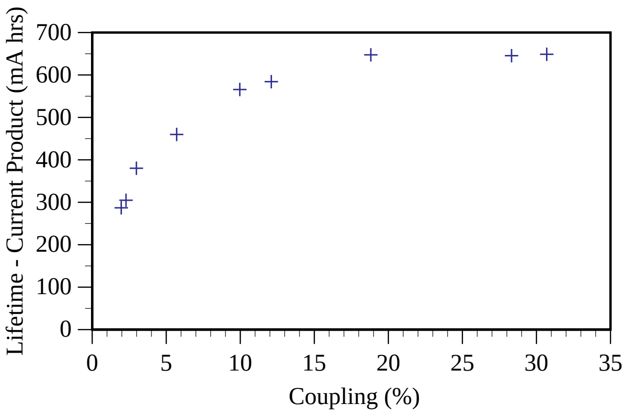

Figure 7. Variation of lifetime-beam current product as a function of coupling ratio.

2.3 Coupling Control

It has been observed on the SRS during operations that the coupling of the beam varies with the vertical orbit. An experiment has been performed to examine this variation. Using a visible synchrotron radiation beam size monitor as an indication of the coupling, the vertical orbit was varied locally with short three magnet bumps in turn all around the ring. Using this technique an optimum orbit was quickly found that minimised the coupling from the local resonance. With this orbit applied the minimum tune difference was very close to zero. Figure 8 demonstrates how the horizontal and vertical beam sizes vary with the tune difference with and without the coupling control orbit applied. Chromaticity correcting sextupoles act like a skew quadrupole field when the beam is vertically off axis and this is thought to explain these observations. A series of measurements is now being planned to confirm this by using the available skew quadrupole fields installed in the SRS.

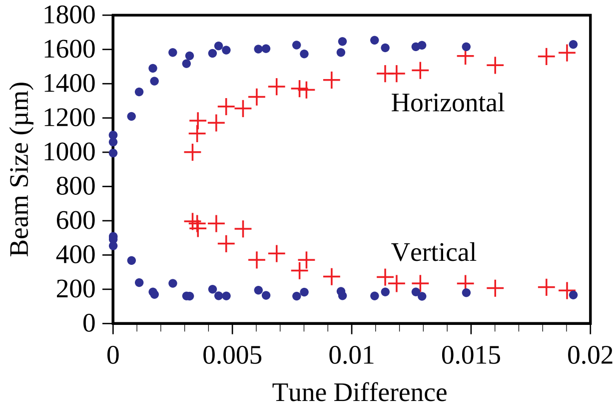

Figure 8. Beam size as a function of tune difference for low coupling orbit (•) and standard orbit (+).

3 CONCLUSIONS

Vertical dispersion and emittance coupling are both directly relevant to the performance of synchrotron light sources. Both of these parameters have been studied on the SRS. The vertical dispersion has been found to be finite but insignificant in terms of vertical beam size implications. The amplitude of the dispersion measured has enabled a theoretical model of the SRS to be developed that contains finite magnet alignment and roll errors. A model that produces a similar amplitude of vertical dispersion to that measured requires relatively large errors of approximately 1 mm transversely and 1 mrad of roll rms.

The emittance coupling due to a difference resonance has been estimated by measuring the minimum tune separation near the resonance. It has been demonstrated that the coupling can be altered significantly, giving good control of the Touschek lifetime. Furthermore the coupling due to the resonance can be virtually eliminated by setting an optimised vertical orbit around the lattice.

REFERENCES

[1] C. J. Bocchetta et al, ‘ELETTRA commissioning and operation’, Proceedings of the 4th European Particle Accelerator Conference, London (1994), p 579.

[2] H. Grote and F. C. Iselin, ‘The MAD Program’, CERN/SL/90-13 (AP), May 1995.

[3] G. Guignard, ‘Betatron coupling and related impact of radiation’, CERN 95-06.

[4] L.A. Welbourne et al, ‘Single bunch effects in the Daresbury SRS’, Proceedings of the IEEE Particle Accelerator Conference, Washington (1993), p 3672.