WIGGLER TUNE SHIFT COMPENSATION ON THE DARESBURY SRS

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Abstract

The higher brilliance lattice of SRS-2 leads to an increased perturbation arising from the 5T superconducting wavelength shifter. In order to reduce this problem a new method of vertical tune correction has been introduced that minimises the residual beta function modulation around the ring. This is achieved by local correction on the member of the main quadrupole family immediately adjacent to the wiggler magnet. A high current, active shunt system has been developed and is now in routine use. Design and commissioning experience are described. The technique will be essential to the planned addition of a second wiggler in the SRS.

1. Introduction

In 1982 a 5T wiggler magnet[1] was commissioned and brought into routine operation on the SRS. This three pole wavelength shifter can be modelled to good accuracy for lattice calculations by hard-edged rectangular field geometries, and a comparison between prediction and measurements in the storage ring has previously been reported[2]. The effective lengths of each of the three poles are chosen to model the focusing contributions as closely as possible, giving accurate prediction of the tune shift and the vertical beta function modulation around the ring. This model is imperfect for higher order field integrals such as those contributing to emittance blow-up, but the residual error in this case was acceptably small (~ 1%).

2. Wiggler in New Lattice

After five years of successful operations the SRS was shut down for five months for major modifications. A new family of quadrupoles doubled the number of lattice cells and led to an order of magnitude emittance reduction in the new version, SRS-2. Every one of the existing straight sections was rebuilt with a completely new vacuum system, and other new components such as sextupole, octupole and vertical steering magnets were also added at this time. Full operational status for users was restored during 1987[3] and the latest performance and achievements are summarised in an accompanying paper[4].

A consequence of the lattice change has been an increase of vertical beta function (β_V) at the wiggler location, from 4.7 m to 7.3 m, that leads to a corresponding increase in the vertical tune shift. Since the depth of β-function modulation around the ring that remains after global correction of the tune is directly proportional to this tune shift, the standard method of adjusting the excitation of the D-quadrupole family is very unattractive. Furthermore, the SRS lattice has no zero dispersion positions so that the wiggler inevitably increases the emittance; in SRS-1 this effect was negligible[2] but in the new SRS-2 lattice it is an important contribution to reduced source brilliance in both planes for all the users. The effect of the wiggler is summarised in table 1, which includes the maximum β-function resulting from global correction of tune; the parameters are for the operating energy of 2 GeV at a nominal tune working point (6.25, 3.25). An exact calculation of the wiggler contribution to the I_5 synchrotron radiation integral[5] shows that the error in the wiggler model underestimates the emittance in SRS-2 by a greater amount: the more accurate emittance estimate with the wiggler energised is 0.140 mm-mrad.

Table 1

	Wiggler Off	Wiggler On
Vertical tune shift, ΔQ_V	-	0.052
Maximum vertical beta, β_V (m)	11.6	15.8
Horizontal damping time, τ_H (ms)	5.5	5.0
Vertical damping time, τ_V (ms)	5.0	4.6
Longitudinal damping time, τ_Z (ms)	2.4	2.2
Energy spread, σ_E/E ($\times 10^{-4}$)	7.1	7.6
Horizontal emittance, ε_H (mm-mrad)	0.104	0.136
Overvoltage, q (τ_q = 100h)	2.69	2.76
Bunch length, σ_t (ps)	68.5	69.1
Synchrotron frequency, f_s(kHz)	48	51

Shortly after commissioning of SRS-2 the tune shift at 2 GeV was measured as a function of wiggler excitation level, and the results are shown in figure 1 together with the predictions of the lattice calculation. The agreement is quite good, with a measured tune change of 0.049 at 5T wiggler level. The small discrepancy arises from a non-ideal value of the beta function which measurements indicate to be 5-10% lower than expected at the wiggler. The tune shift was removed by a suitable adjustment to the main ring quadrupoles. The wiggler has also been used with the SRS optic in a higher emittance mode for single bunch operations[3] with a working point (4.25, 3.25); in this case the measured tune shift at maximum wiggler excitation was 0.049 compared with a predicted 0.048.

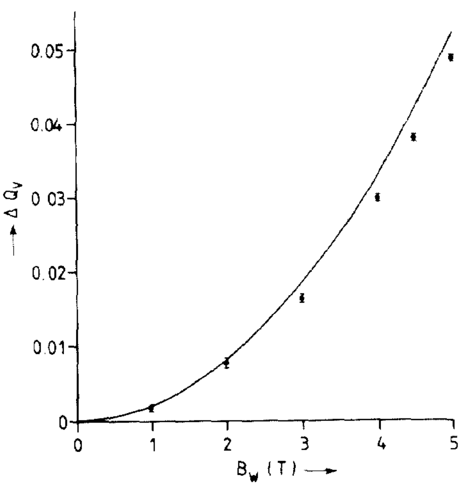

Fig. 1. Measured tune shifts at 2 GeV due to wiggler excitation in SRS-2 lattice. Continuous line is lattice calculation using hard edge model.

The combination of changes to both emittance and beta function has a very serious effect for the SRS user community: some beam lines suffer vertical source size increase in excess of 30% in addition to the inevitable horizontal increase of about 13%. The solution to this problem became even more important with the recent decision to construct and instal a more

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powerful second wiggler of 6T strength[6]. The beta modulation arising from the first wiggler would make critical the choice of location for the second device, since the combined effect of the two wigglers would depend on their relative betatron phase. Few straight sections remain available for new equipment and the preferred one was calculated to produce values of vertical beta as high as 24.1 m (the total tune shift is 0.183). In these circumstances it was judged essential to produce an improved compensation scheme.

3. Local Compensation Scheme

A possible solution to the problem is to build a matched insertion system, but this would require several additional quadrupole magnets for which there is no space in the crowded SRS. A much simpler alternative is to perform a local tune correction as close as possible to the source of the focusing perturbation, and this can be achieved using the main D-quadrupole adjacent to the wiggler.

Lattice computations with such a correction technique confirmed that it could restrict the maximum vertical beta increase to about 8% for the existing wiggler magnet. The associated change of horizontal beta was only 2% (due to the small radial beta-function at a D-quadrupole). Furthermore, the location of the second wiggler became uncritical and with both wigglers energised the predicted maximum vertical beta was only 13.7 m, or some 18% greater than the unperturbed lattice.

The required reduction in gradient of the single quadrupole magnet is about 1.3 T/m even for the existing 5T wiggler and to achieve this required the development of a high current, dynamic shunt capable of conducting up to 100 A (DC) with adequate safety protection, given that the quadrupole family is supplied from a 200 kW set delivering up to 500 A output. Current is diverted through a bank of 32 transistors mounted with emitter current sharing resistors on an air-blown heatsink; avoidance of water cooling allowed easy mounting of the system on the roof shielding above the wiggler, permitting ready access under stored beam conditions. Figure 2 illustrates some circuit details, including the use of a DCCT to monitor the shunt current; this has the advantage of providing electrical isolation and a ground referenced output that can be compared with the control system demand signal. The isolating drive module receives input from the error amplifier and translates this into a base current drive to the transistor bank, using a transformer-coupled chopper rectifier for amplification and necessary isolation. Fuses protect the shunt cable adjacent to the quadrupole and the shunt itself can be readily isolated whenever required for diagnostics or repair; high voltages on the contactor are avoided by a

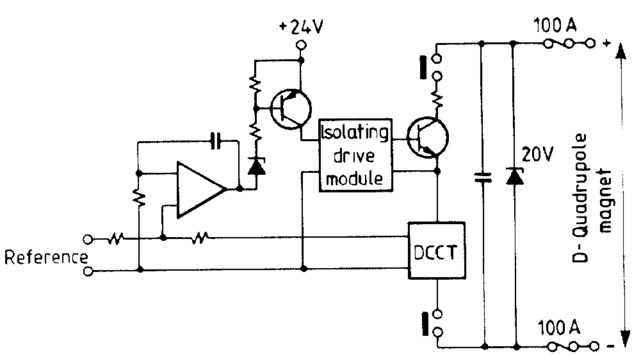

Fig. 2. Circuit diagram of dynamic shunt.

capacitor-zener combination to reduce DC arcing. Transistor power dissipation is reduced by series resistance as shown, conveniently provided by the feed cable to the magnet. The shunt operating regime is shown in figure 3, which confirms that up to 100 A can be successfully diverted around the magnet (although this reduces at lower magnet currents, when about 30% shunting is possible).

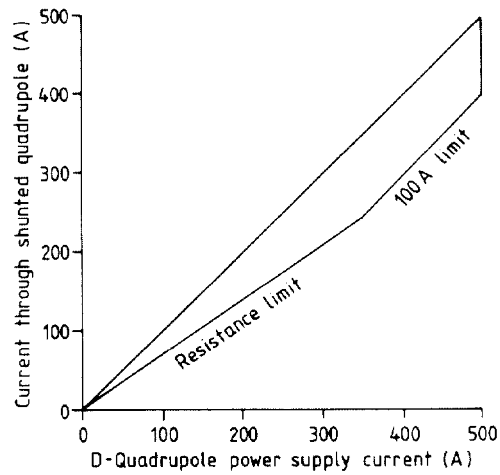

Fig. 3. Dynamic shunt operating regime.

The wiggler shunt has been successfully commissioned and is now in routine use for SRS operations. With the wiggler at 5T the shunt must transmit 50 A of the 414 A in the D-quadrupole circuit. In addition, the shunt has been programmed to ramp up in conjunction with the wiggler since the latter has to be energised after beam has been stored at 2 GeV. Results of an initial check of beam profiles on a beam line used for optical diagnostics[7] are given in table 2, which clearly demonstrates the effectiveness of the shunt compensation technique.

Table 2

	σ_H (mm)	σ_V (μm)
Wiggler off	1.07	155
Wiggler on, global correction	1.23	200
Wiggler on, shunt correction	1.22	165

In order to provide a more comprehensive confirmation of the wiggler compensation it has been necessary to measure the beta function in every lattice cell. In the earlier SRS-1 this had been achieved by the standard technique of a gradient perturbation on a quadrupole corrector in each cell. In SRS-2 this is no longer possible since no such corrector is close to the maximum beta location. As an alternative a similar procedure has been carried out using vertical steering magnets adjacent to each D-quadrupole and monitoring the resultant displacement at a beam position detector at the same location; good sensitivity has been obtained for deflections ~ 2 mT-m. Results at 2 GeV with a well-corrected orbit are shown in figure 4, which compares the change in beta function due to the 5T wiggler with and without the new compensation scheme. The considerable improvement can be clearly seen. The computed effect of the wiggler is given by the curves and it can be seen that the agreement is excellent in the case of the compensation scheme. The discrepancy in the global correction results seems to be a systematically smaller beta modulation than predicted, in line with the similar reduction in the measured tune shifts: at present this has not been explained.

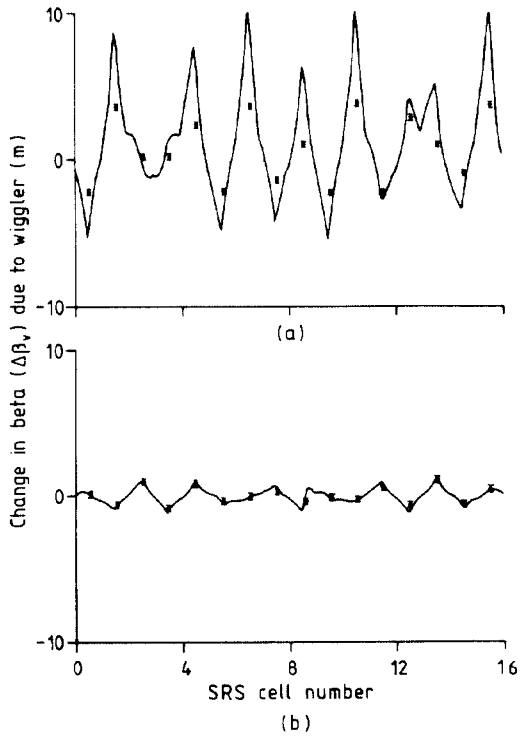

Fig. 4. Comparison of beta modulation due to wiggler after (a) global correction and (b) local shunt correction. Computed curve and experimental data points.

4. Conclusions

A good method of wiggler focusing compensation is essential to optimise the source properties of the SRS for all its beam lines. An active current shunt to achieve this is now in routine use and measurements have confirmed the predicted performance of the system. The technique will also be very useful in the future when the planned second wiggler is installed; the existing shunt design capability of ~ 100 A will be sufficient to correct for the effect of the proposed 6T wiggler magnet.

Acknowledgements

Initial assessment of the compensation scheme was carried out by R.P. Walker. More recent studies of beta modulation have been continued by S.L. Thomson.

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