THE MEASUREMENT AND OPTIMISATION OF LATTICE PARAMETERS ON THE ISIS SYNCHROTRON

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Abstract

The ISIS Synchrotron accelerates a high intensity proton beam from 70 to 800 MeV at 50 Hz. Recent hardware upgrades to the diagnostics, instrumentation and computing have allowed turn by turn transverse position measurements to be made. A special low intensity beam can also be injected for detailed diagnostic measurements. The analysis of such data at many points around the ring has allowed the extraction of lattice parameters. This information will have significant application for improved beam control. The methods of analysis as well as some applications for setting up and optimising the machine are described in this paper. Future plans and relevance for high intensity performance is also given.

1 INTRODUCTION

The ISIS Synchrotron [1] accelerates 2.5×10^{13} protons per pulse at 50 Hz, corresponding to a mean current of 200 µA. To establish high intensity beam, particles are accumulated via charge exchange injection over 120 turns. Beam is then bunched and accelerated from 70 to 800 MeV in 10 ms, extracted in a single turn and transported to the target.

In optimising the machine, extensive use is made of special low intensity 'diagnostic' beams [2]. These are provided by 'chopping' the normal 200 µs injection pulse to ~100 ns (less than one turn) with an electrostatic kicker. The injection painting provides the initial 'kick', and measurement of the turn by turn, transverse motion at a position monitor then allows extraction of numerous ring parameters. Allowance has to be made for the apparent damping caused by the finite Q-spread in the beam. Fitting a suitable function allows the centroid betatron amplitude, the closed orbit position, the betatron Q and phase to be extracted.

This paper describes new measurements and beam control applications, made possible with recent upgrades to the synchrotron diagnostics data acquisition system [3]. These use the low intensity beam at injection together with the new facility to take turn by turn measurements at many position monitors around the ring. The relevance of these measurements to high intensity operation is described in Section 5.

2 PHASE SPACE MEASUREMENTS

2.1 Basic Measurements

On the ISIS Synchrotron we have two sets of beam position monitors separated by drift spaces, one set per transverse plane. By using the signals from these monitors, it is possible to reconstruct (y_n, y_n') on each turn. The apparent Q-spread damping over many turns can be removed with appropriate use of fitted parameters. The 'corrected' (y_n, y_n') are then fitted with a suitable ellipse to extract alpha, beta and centroid emittance.

Measured phase space ellipses for the vertical plane are shown in Figure 1. In this case measurements were taken with the lattice in two distinct configurations. The first under normal configuration, and the second, with a low field tuning (trim) quadrupole switched off.

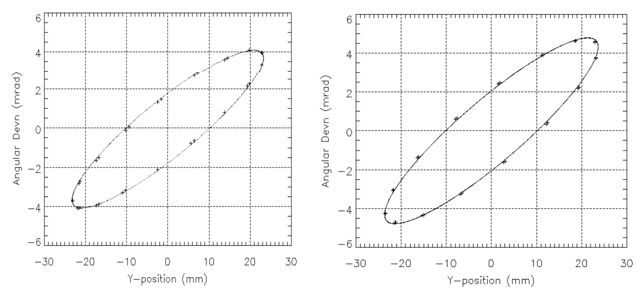

Figure 1. Measured Vertical Phase Space Ellipse.
Left: Normal. Right: Trim Quad off.

To check the measurement, the extracted parameters were compared with the results of a MAD model [4]. The results are shown in Table 1.

Table 1: Fitted parameters and MAD predictions.

	Alpha		Beta (m)	
Optics	**MAD**	**Measured**	**MAD**	**Measured**
Normal	-2.09	-2.05+/-0.2	13.37	13+/-1.0
TQ Off	-1.92	-2.1+/-0.2	12.43	11.5+/-1.0

This shows the measurement gives good agreement with theory. Systematic differences are consistent with measured lattice errors, see Section 4.

2.2 Further Work

Work is now continuing to extend these measurements to the horizontal plane, and with analysis techniques to take full account of the beam damping.

3 BETA AND PHASE FUNCTION MEASUREMENTS

3.1 Basic Measurements

To demonstrate the basic measurement of beta and phase, a set of measurements were made with the synchrotron in a normal configuration and then with one trim quadrupole (tq) switched off. It can be shown that the change in the horizontal beta function is given by:

$$\frac{\Delta\beta(s)}{\beta(s)} = -\frac{\Delta k(s_{tq})\beta(s_{tq})l}{2\sin 2\pi Q}\cos 2(|\phi(s_{tq})-\phi(s)|-\pi Q) \qquad (1)$$

where the notation is standard [5]. The change in the phase follows a similar form, although 90 degrees ahead of (1). The results of the experiment are shown in Figure 2, together with the fitted functions. The measurements were taken at equivalent lattice positions in each superperiod.

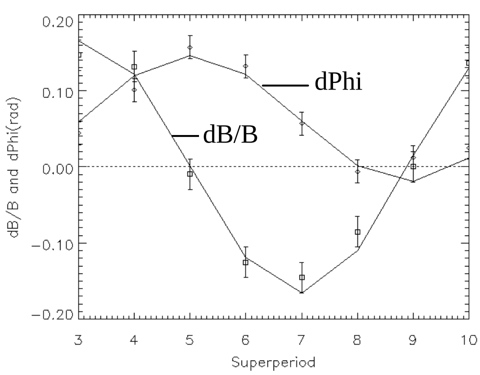

Figure 2: Δβ/β and change in phase (dPhi) around the ring with one trim quadrupole switched off.

The two measurements show the expected form and the extracted parameters agree well with expected values.

3.2 Future Plans

We plan to use these measurements to identify isolated lattice errors. Additionally, the measurement of lattice phase can also be used to calculate the transverse impedance around the ring [6].

4 BETA FUNCTION CORRECTION

4.1 Background

Perturbations in the beta function can be expressed in a harmonic formulation, which shows clearly the resonant nature of the system. From this, one sees the largest contributions to perturbations are given by lattice errors, $\Delta k_{Err}(s)$, distributed around the ring with spatial frequencies near 2Q. This is described by the following formulae [5]:

$$\frac{\Delta\beta(s)}{\beta(s)} = \frac{Q}{2}\sum_q \frac{F_q e^{iq\phi(s)}}{Q^2-(q/2)^2} \qquad (2)$$

where F_q is given by:

$$Q\beta^2(s)\Delta k_{Err}(s) = \sum_q F_q e^{iq\phi(s)} \qquad (3)$$

It follows therefore that we can make deliberate large changes to beta if the lattice is excited with an additional perturbation Δk(s) with the appropriate frequency q. This then forms the basis of a correction system, which cancels out the dominant harmonics of the lattice errors.

4.2 Application of Harmonic Perturbation

The ISIS synchrotron has 2 sets of 10 trim quadrupoles distributed at regularly spaced intervals around the lattice. These are connected to a system which can apply a modulation at a number of spatial harmonics (q), and thereby generate an additional harmonic focusing Δk(s) around the ring.

The modulation in the beta function due to the application of a single harmonic function of the form Δk_j= 0.0162 SIN (2π 0.8 j) m^{-2}, (where j is the j^{th} trim quadrupole) has been measured and is shown in Figure 3.

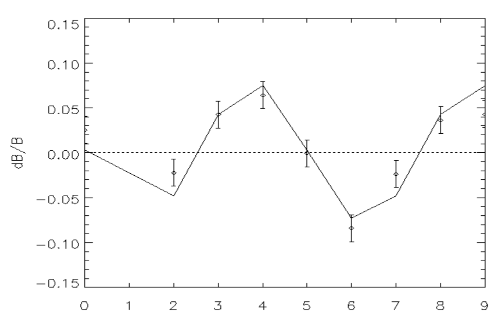

Figure 3: Application of a known perturbation with the predicted and measured changes in beta.

The result shows a strong induced oscillation at q=2, consistent with the expected undersampled or 'aliased' q=8. Thus the beta function resonates strongly as per equation (2) with Qh=4.31. Agreement between the predicted and measured data sets is good.

4.3 Normal Configuration

Using the above approach, we aim to develop a correction system to control the variation of the beta function in the ring. A typical measurement of beta perturbation during normal running is shown in Figure 4.

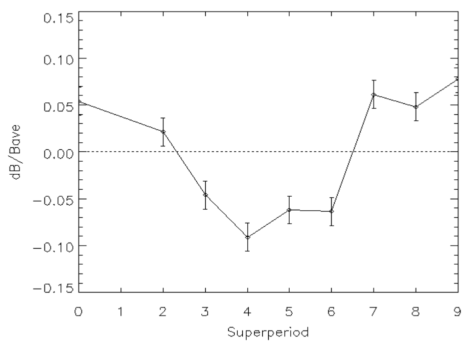

Figure 4: Variation of Horizontal beta function.

The data is from equivalent lattice positions in each superperiod, where values are expected to be the same. We can see that it varies by up to 10%, and shows a strong oscillation describing approximately one full cycle. The variation here is consistent with an aliased 9th harmonic, showing that under normal conditions the beta function is resonating strongly due to lattice errors near 2Q. The application of another 9th harmonic with the appropriate amplitude and phase could be used to cancel the driving errors.

4.4 Proposed Correction Method

A harmonic correction system for beta, based on the above ideas is presently being developed. The first step uses the low intensity beam to measure beta at equivalent points in each superperiod as in Figure 4. The aim is to minimise $\Delta\beta(s)/\beta(s)$. The required corrections $\Delta k(s)$ can then be estimated using the alternative formulation of equation.(2) [5]:

$$\frac{\Delta\beta(s_i)}{\beta(s_i)} = \mp\frac{1}{2\sin 2\pi Q}\oint \Delta k(\sigma)\beta(\sigma)\cos 2[\,|\,\phi(\sigma)-\phi(s_i)\,|\,-\pi Q]d\sigma \quad (4)$$

which can be expressed as a matrix equation:

$$\left(\frac{\Delta\beta}{\beta}\right)_i = M_{ij}\sum_j \Delta k_j \quad (5)$$

where i corresponds to the monitor, and j the trim quad. Parameters defining the correction coefficients M_{ij} are also measured.

The resulting Δk_j's are then fourier analysed to obtain the dominant harmonics of $\Delta k(s)$ required for correction. Once these values have been fed back into the system, the values of the beta function can then be re-measured, and thus form part of an iterative process.

4.5 Status and Future Plans

Preliminary attempts to control the beta function using this method have been promising. Once fully operational, the aim will turn to optimising the beta function to minimise beam loss. As part of a future upgrade, individually powered trim quadrupole units will allow alternative correction methods to be considered.

5 RELEVANCE TO HIGH INTENSITY OPTIMISATION

Low intensity diagnostic beam measurements provide much detailed information on the synchrotron set up, i.e. checks on the lattice and injection set up [2].

In principal many of the measurements described here are possible at high intensity, however high intensity effects modify beam motion and therefore measured parameters. It is therefore useful to have measurements at both low and high intensity: the former define machine set up, whilst the latter provide information related to minimising beam loss.

6 CONCLUSIONS

The use of low intensity beams, together with turn by turn position measurements at many points around the ring has enabled the determination of lattice parameters at injection. A system to correct the beta function using these measurements is in development. This work will improve the understanding and optimisation of the machine for high intensity operation.

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