USE OF SUPERIMPOSED ALTERNATING CURRENTS IN QUADRUPOLES TO MEASURE BEAM POSITION WITH RESPECT TO THEIR MAGNETIC CENTRE

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Abstract

The positional stability of the electron beam in a modern state-of-the-art synchrotron radiation source is critical, as the many experimental users require consistency in the position and dimensions of the incoming photon beams which are incident on their experimental samples. At the Daresbury Synchrotron Radiation Source (SRS), inaccuracies in the measurements of the positions of both beam position monitors and the lattice quadrupoles can be overcome by measuring the position of the electron beam with respect to the magnetic centres of the quadrupoles. This was achieved by superimposing an alternating (‘ripple’) current on the direct current excitation of a single lattice quadrupole and examining the resulting beam oscillations at remote positions in the storage ring. If the electron beam is then subjected to a local distortion at the position of this quadrupole, the amplitude of the beam oscillation induced by the superimposed current is minimised (nominally zero) when the beam is at the quadrupole's magnetic centre. This paper presents details of the electrical circuit developed to inject an alternating current into the coils of individual quadrupoles and gives details of the results achieved to date.

1 BEAM POSITION IN THE DARESBURY SRS

The Daresbury Synchrotron Radiation Source (SRS) is an electron storage ring which generates intense beams of electromagnetic radiation to support a wide range of experimental techniques. The facility parameters are given in Table 1.

Table 1: Basic parameters of the Daresbury SRS.

Electron beam energy	2 GeV
Circumference	96 m
Number of experimental stations	~ 40
Magnet lattice	FODO
Number of cells	16
Number of ‘F’ quadrupoles	16
Number of ‘D’ quadrupoles	16

The position of the electron beam in the storage ring and the emerging radiation beams are critical because:

- radiation must be supplied simultaneously to the many beam lines and users;
- users require very high beam positional stability throughout the period that they are accumulating experimental data;
- the lifetime of the stored beam should be maximised, which requires the electron beam to be accurately positioned in the centre of the narrow gap and other ring vacuum vessels.

The storage ring therefore contains vertical and horizontal electron beam position monitors (B.P.M.s) in each straight section and the beam lines have tungsten vane monitors (T.V.M.s) at their front ends for measuring the X-ray beam position. However, these all have alignment survey errors and consequentially their true positions are not known, a situation which also applies to the lattice magnets. Furthermore, it is known that all the storage ring elements move with time and hence, some time after a survey has been performed, there are even greater uncertainties concerning the positions of the B.P.M.s and the magnets. It is clear that an electron beam positioned centrally with respect to the B.P.M.s will not be central in the magnets. An off-centre beam in a dipole will not result in any first-order errors in the electron trajectories, but in the quadrupole, if the beam passes through the magnet at a vertical or horizontal position which is not coincident with the quadrupole’s magnetic centre, unwanted deflections will occur. Hence the true positions of the electron beam with respect to the magnetic centres of each quadrupole is very relevant to the efficient and stable operation of the storage ring and is required information. In the measurement method described below, a deliberately induced beam deflection is used to locate the centre of the magnet with respect to the beam.

2 EXPERIMENTAL METHOD

A circulating beam in the storage ring is corrected to a central orbit, as indicated by the B.P.M.s. A small, low frequency alternating current is then superimposed on the direct excitation current in the windings of the quadrupole under investigation. If the electron beam is not central in the quadrupole, the non-zero field at the beam position will induce a small closed orbit deflection of the beam around the complete storage ring lattice; this will have a d.c. component and an oscillating component at the frequency of the alternating ripple induced in the quadrupole. The signals from one or more B.P.M.s or T.V.M.s, at remote positions in the ring, are then examined and Fourier analysis of the signals used to extract the amplitude of this oscillation at the positions of the monitors. The beam position at the perturbed quadrupole is then adjusted by a static, local beam deflection (a 'beam-bump') and as the amplitude and polarity of this displacement is varied, the amplitude of the oscillation detected at the remote monitor will also change. The beam position is perturbed on either side of the magnet centre and the magnitude of the beam oscillation and the apparent beam position, as measured at the B.P.M. next to the quadrupole, is recorded.

When the beam is centred in the quadrupole, no deflection will occur and the induced positional oscillation will be at a minimum and ideally zero. Data obtained using this technique will indicate the displacement of the beam away from the magnetic centre of the quadrupole at the commencement of the measurement and the value of the bump needed to centre the beam in the quadrupole.

3 GENERATING THE SUPERIMPOSED OSCILLATING CURRENT

The circuit used to generate an alternating component, which is superimposed on the direct current in the quadrupole windings, is shown in Fig. 1.

The technique uses an active current shunt in parallel with the magnet, with a feedback circuit to control the bypass current. This design requires no additional power source, as it utilises the resistive voltage drop across the quadrupoles. It is therefore cheaper and simpler than circuits which inject an alternating current on top of the main direct current excitation.

The uni-directional bypass current is controlled by the mosfet shown in the centre of the circuit. This is driven from a high gain isolating operational amplifier, which takes an error signal from the difference of a sinusoidal, variable frequency, variable amplitude reference and a direct current transformer, which samples the bypass current. The design uses four shunts per sixteen series connected quadrupoles, with one shunt switched between four quadrupoles by means of the relays shown in the diagram.

The parameters of the system are given below; Table 2 gives the basic parameters of the F and D quadrupole magnets. Table 3 provides information on the ripple system.

Table 2: Storage Ring Quadrupole Parameters at 2 GeV.

	'F' Quads	'D' Quads
Operating direct current (A)	1021	423
Operating direct voltage (V)	378	115
Direct volts per quad (V)	23.6	7.2
Max volts to earth (V)	189	115
Inductance per quad (mH)	23.6	20.8

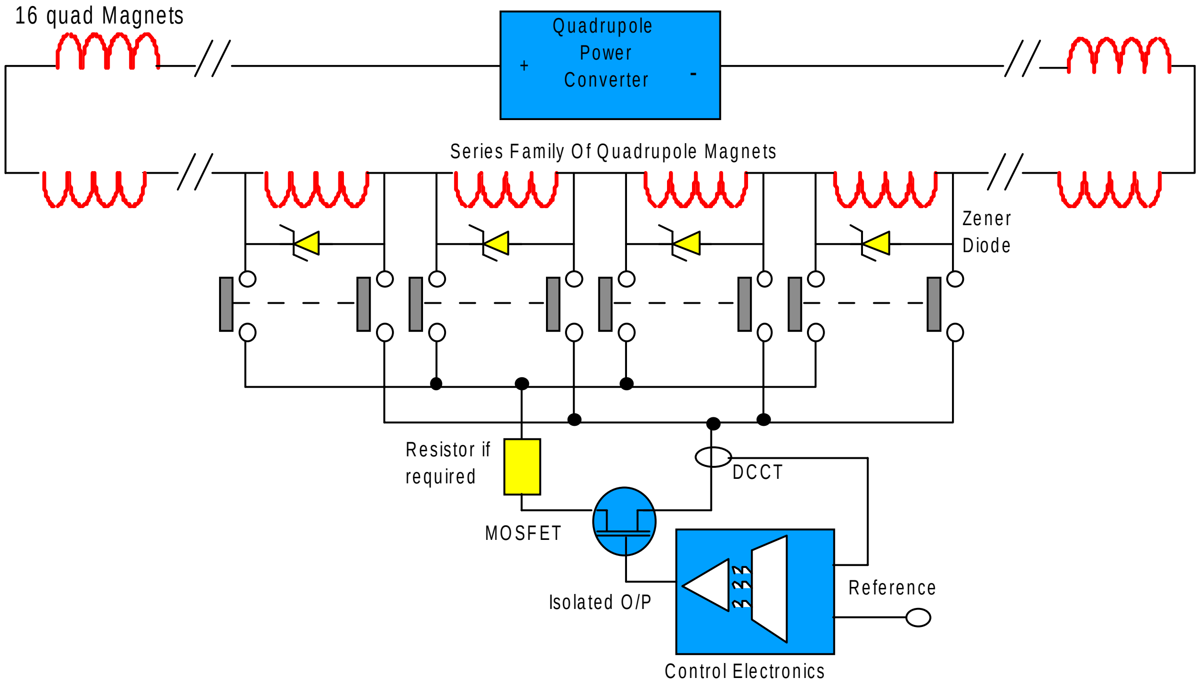

Figure 1: Circuit used to generate an alternating current in the quadrupole windings

Table 3: Ripple system parameters.

Peak to peak ripple current (A)	Variable, 0 -10
Ripple frequency (Hz)	Variable, 1 - 5
Peak to peak reactive volts demand, F-Quad (V)	7.4
Peak to peak reactive volts demand, D-Quad (V)	6.5
Hold-off voltage (isolating amplifier) (kV)	1.0

In the circuit utilised, the resistive direct voltage drop in the magnet coils drives the reduction in current in the inductive magnet during the descending part of the ripple sinusoid. This negative gradient is limited to the value of di/dt which is equal to the resistive voltage divided by the magnet inductance. At this value, the mosfet voltage drops to zero and no faster decrease can be obtained. During the positive gradient in the sinusoid, the mosfet will have a positive voltage which is in excess of the magnet's resistive direct voltage. It is necessary for the main quadrupole power supply, which is the source of direct current in the series connected magnets, to modulate its output voltage to withstand the raised voltage in the circuit without changing the direct current in the other series connected quadrupoles; i.e. the main power supply must remain a current source at the frequency of quadrupole ripple.

3 EXPERIMENTAL RESULTS

The ripple system has been used to measure the beam position in each of the 32 quadrupole magnets in the SRS storage ring, measuring horizontal positions in the 'F' quads (horizontal beam position indicators and beam-bumps) and vertical positions in the 'D' quads (vertical beam position indicators and beam-bumps). Settings used for the measurements were:

- Beam energy: 2 GeV;
- Ripple current amplitude: 10 A (p-p);
- Ripple frequency: 5 Hz.

For the measurement of the vertical alignment in the 'D' quadrupoles, the beam oscillations were observed on two tungsten vane monitors (T.V.M.s) at the up-stream end of a number of beam ports, whilst for the 'F' quadrupoles a horizontal pickup was used. With ripple current excited in a single quadrupole, the variations in the 5 Hz signals from the monitors were recorded as the local beam position at the quadrupole was varied using a beam-bump. The magnitude of the 5 Hz signal was then plotted against the beam position indicated on the B.P.M. located at the quadrupole under investigation.

The method was found to be sensitive and reproducible. In most cases, a linear regression of the excitation amplitude against beam position in the quadrupole gave a consistent and clear minimum. This is shown in Fig. 2.

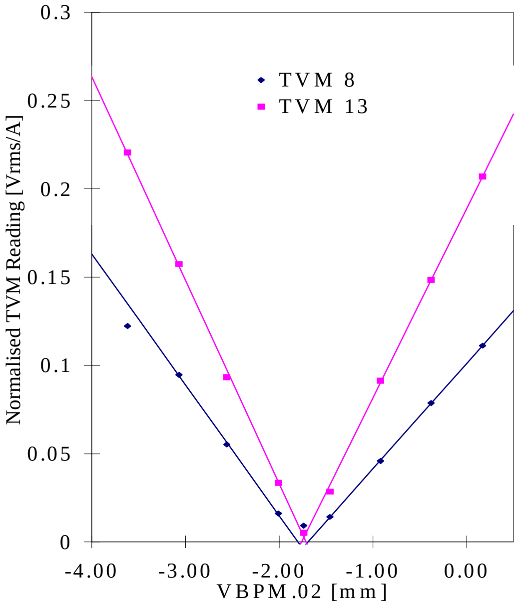

Figure 2: Variation of two TVM signals against beam position at D quadrupole 2.

If the linear regression on the two independent T.V.M. data sets indicated any inconsistency in the minimum position, or the quality of the fit was poor, quadratic fits to the square of the oscillation amplitudes gave more consistent results. The results obtained from the investigation of the vertical beam position in 'D' quadrupole 15 are shown in Fig. 3.

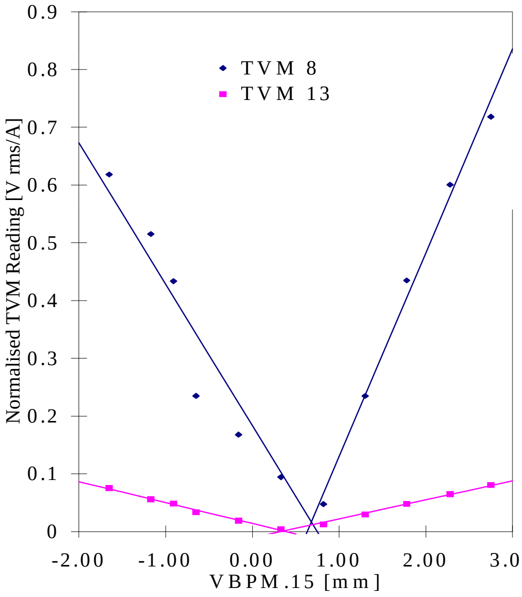

Figure 3: Variation of two TVM signals against beam position at D quadrupole 15.

For this measurement, data from T.V.M.s 8 and 13 were used. It can be seen that the linear fits to the data series from the two different monitors give a discrepancy of the order of 0.4 mm.

However, the analysis of the same data using a quadratic fit to the square of the 5 Hz oscillation amplitude, shown in Fig. 4, is far more consistent. Agreement between the two data series is of the order of 0.1 mm or better.

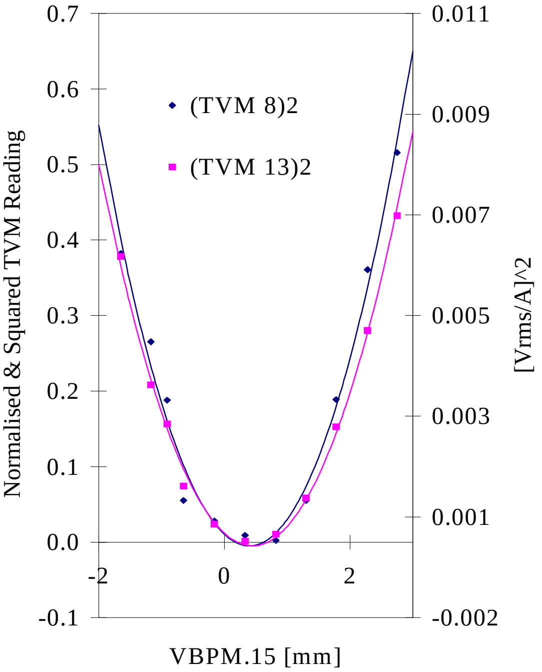

Figure 4: Variation of the square of two TVM signals against beam position at D quadrupole 15 (quadratic regression).

The differences measured between the nominal (B.P.M. determined) central orbit and the centre of the D quadrupoles determined using this technique are shown in Fig 5.

4 CONCLUSION

The quadrupole ripple system now provides accurate and informative data on the positioning of the B.P.M.s relative to quadrupole magnetic centres. The measurement can be done very quickly; all sixteen quadrupoles can be measured in one plane in one eight hour period. The technique has been shown to provide high sensitivity, of the order of 0.1 mm and it is expected that it will be used as a standard diagnostic tool during beam alignment exercises in the future. The technique also presents opportunities for the measurement of other lattice parameters. The dynamic shunt is also able to conduct a steady direct current away from a quadrupole.

This should enable the lattice amplitude functions (βx and βy) to be measured at each quadrupole by observing the small change in machine tunes as the individual quadrupole currents are perturbed.

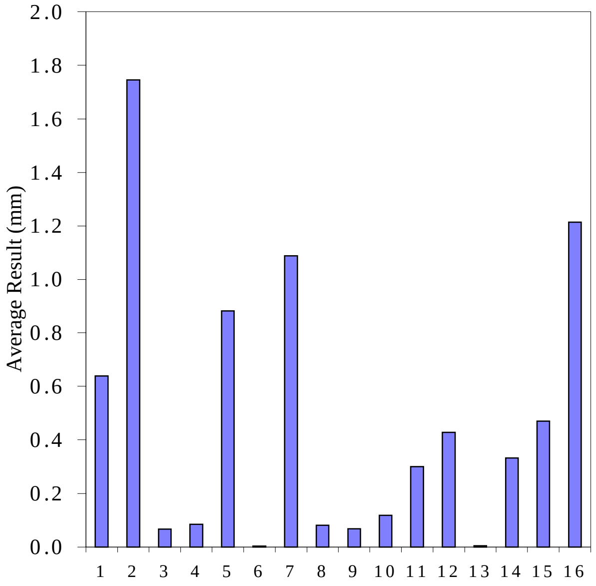

Figure 5: Differences between the nominal (B.P.M. determined) central orbit and the centre of the D quadrupoles.