IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981

THE OPERATION OF MULTIPOLE MAGNETS IN THE SRS

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Summary

Multipole magnets capable of generating both a strong sextupole field for chromaticity correction and other correction fields ranging from dipole to decapole in any orientation have been installed in the Synchrotron Radiation Source (SRS) at Daresbury. The design of the magnets, the results of magnetic measurements and the method of computer control are described. Details of their operation during commissioning of the storage ring are presented.

Introduction

In the 2 GeV electron storage ring of the Daresbury Synchrotron Radiation Source the amount of straight section space available for correction magnets is limited and so from an early stage it was proposed to combine the various correction functions that were required in a single novel type of magnet[1]. Unlike multipole magnets built at other laboratories[2,3] this device has the unique feature of incorporating a separately controllable powerful sextupole field for chromaticity correction. A prototype magnet was first constructed and its successful operation demonstrated the feasibility of including such magnets in the storage ring[4]. Subsequently, after various minor design changes had been made, sixteen production magnets were built and tested. Full details of this phase of the project can be found in ref. 5. The magnets have now been installed in the ring and are presently being used during commissioning of the new facility.

The multipole magnet can generate and linearly superimpose fields ranging in type from dipole to decapole in both normal and skew orientations. Dipole fields will be used for correcting the closed orbit; in fact the multipole magnets are the only vertical steering elements in the storage ring. Skew-quadrupole fields are also important for control of the amount of coupling between horizontal and vertical oscillations. These two functions of the multipole magnet will therefore be used to control the source position and shape as viewed along the synchrotron radiation beam lines. The higher order octupole and decapole fields will be used in studies of various beam resonances and instabilities. The sixteen multipole magnets located in separate straight sections of the lattice are individually controlled allowing arbitrary distributions of each type of field to be set up.

The Multipole Magnets

Fig. 1 shows a simplified cross section of the magnet. The annular yoke, 30 mm thick and internal radius 181 mm, is formed in two halves to allow assembly of the components. Twelve simple rectangular faced poles project symmetrically from the yoke and result in an inscribed radius of 120 mm. Both poles and yoke are machined from the same low carbon forged steel and are 200 mm in length.

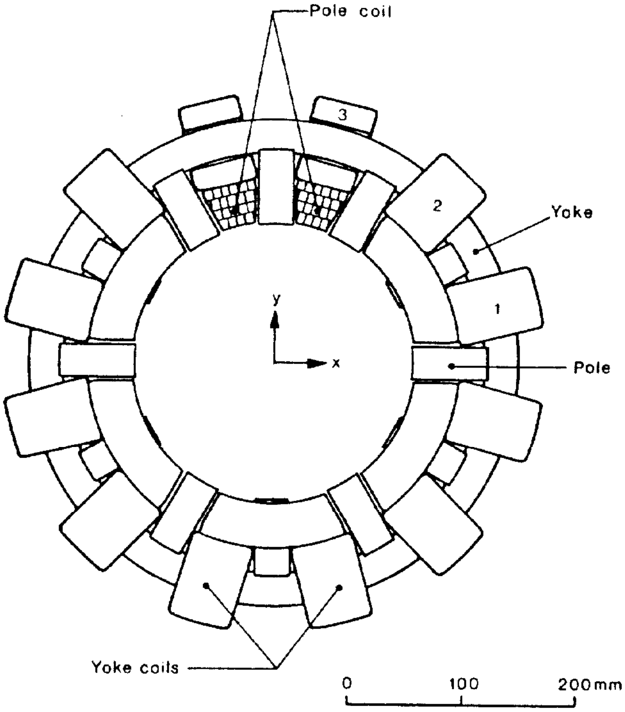

Fig.1 Cross-section of the multipole magnet

The larger of the two sets of coils positioned on six of the poles, are connected in series in such a way as to produce a sextupole field. Each of these coils consists of 20 turns of copper with a central water-cooling channel, and is capable of carrying a current of 500 A. The twelve smaller coils arranged around the yoke consist of 400 turns of enamelled conductor. Each coil can be powered separately with up to 4 A excitation. This corresponds to a maximum heat generation of 40 W per coil which is dissipated by natural convection.

The type of field generated by the yoke coils depends on the distribution of current in them. In Table 1 the currents used in producing normal fields ranging from dipole to decapole and also skew-quadrupole are shown, normalised to a maximum of 1.0. Only the three coils in the first quadrant (see Fig. 1) need be considered; the currents in the other coils follow from the symmetry of the desired field as shown in the table. The values for quadrupole, sextupole and octupole fields follow directly from symmetry considerations. Those for the remaining fields were first calculated approximately using a simple analytic technique which assumed infinite permeability in the steel[5] and then adjusted as a result of actual field measurements.

The simple pole shape that has been adopted is not optimum for any of the fields that the magnet can generate and the pole positions are correct only for a sextupole field. The effect of this is to introduce additional field harmonics related to the symmetry of the yoke coil currents, as shown in Table 1. In addition error fields of all types can be produced as a result of errors both in the construction of the magnet and in the setting up of the excitation currents. The fields produced by such a magnet are therefore relatively poor in quality compared to that of the main bending and focusing fields. The field quality needed for the magnets to perform adequately in the storage ring could not be accurately assessed and so this did not form a major part of the specification of the magnets. Instead it was decided to increase the bore radius as much as possible above the aperture required for the beam (± 80 mm) in order to improve field quality whilst still meeting the more definite requirements of field strength.

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Table 1

Required Field	Current in Multipole Windings			Reflection in x axis	Reflection in y axis	Other Fields present from Symmetry Considerations
	1	2	3			
Dipole	1.0	0.732	0.268	+	-	3,5,7...
Quadrupole	1.0	0.0	-1.0	+	+	6,10,14...
Sextupole	1.0	-1.0	-1.0	+	-	9,15,21...
Octupole	0.5	-1.0	0.5	+	+	8,12,16...
Decapole	0.288	-0.762	1.0	+	-	3,5,7...
Skew-quadrupole	0.333	1.0	0.333	-	-	6,10,14...

Magnetic Measurements

A comprehensive series of magnetic measurements was carried out on the first production magnet in order to confirm the design and to measure the detailed properties of all field types. As limited time was available a restricted set of measurements had to be carried out to determine the uniformity of the remaining magnets. The system that was used was a general purpose facility which employed a Hall plate to measure the vertical component of field, B_y, as a function of position along any pre-defined track in the magnet. Although not ideal for measuring this type of magnet the system had already been set up for measuring the other SRS magnets and offered the further advantage that measurements could be carried out for long periods under automatic control.

To measure the strength and quality of each field type scans were performed radially in the centre of the magnet, either along the x-axis for normal fields or along the y-axis for skew fields. Table 2 gives the strengths at maximum excitation of the main sextupole field and the various fields produced by the yoke coils, obtained by fitting the data with a polynomial. With this type of measurement the strengths of the error harmonics could not be determined independently and so the quality of the field was assessed by considering the derivative $\partial^{n-1}B_y(x)/\partial x^{n-1}$ which should be constant for a 2n-pole field. Figure 2 shows the results obtained for dipole, quadrupole and sextupole fields by this method. For higher order fields this is too strict a test of field quality and so an alternative method was devised based on the total field error. Each field had a linear excitation curve and furthermore it was verified that fields of different type could be superposed linearly.

Table 2

Field Type	Strength at Maximum Current	Magnetic Length (mm)
Main Sextupole	17.78 T/m^2	257.3
Dipole	30.67 mT	363.6
Quadrupole	0.2822 T/m	300.6
Sextupole	2.823 T/m^2	264.7
Octupole	16.12 T/m^3	246.6
Decapole	139.3 T/m^4	246.4
Skew-quadrupole	0.2162 T/m	-

In order to determine the integrated properties of the magnetic fields scans were also carried out in the axial (z) direction at various radial positions across the aperture. After numerically integrating the data a magnetic length for each field type was calculated:

$$L_n = \frac{\partial^{n-1}/\partial x^{n-1}\big|_{x=0} \int B_y(x,z)\,dz}{\partial^{n-1}/\partial x^{n-1}\big|_{x=0} \; B_y(x,o)}$$

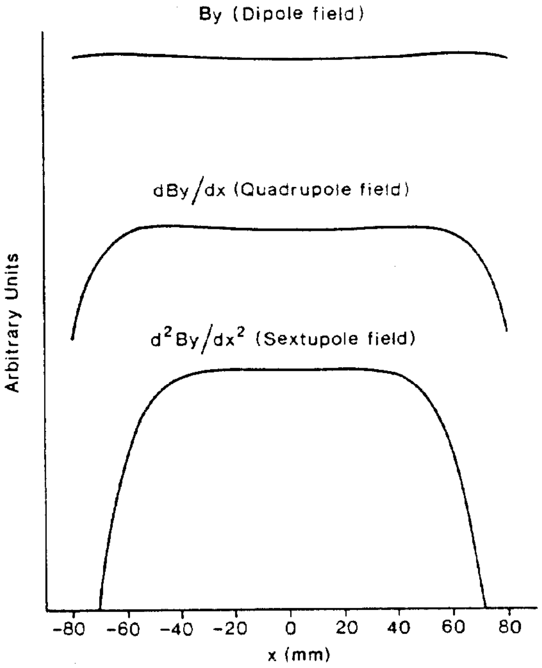

Fig.2 Radial variation for dipole, quadrupole and sextupole fields

An interesting feature of the results shown in Table 2 is the decrease in magnetic length with harmonic number. Further analysis of the data showed that the 2D distribution measured in the centre of the magnet accurately reflected the quality of the fields as a whole and that fringe field effects were therefore less important to the field distributions.

The programme of magnetic measurements showed that the strengths and quality of the fields were as expected, confirming the changes that had been made to the prototype magnet design. In addition no significant variation in properties between the 16 magnets was observed. The calibration data obtained has now been included in the lattice model and control program for the storage ring.

Computer Control

The high current sextupole windings of the 16 multipole magnets are connected in two sets of 8 magnets for control of radial and vertical chromaticity. The 192 low current windings however are powered individually from standard modules which each contain a 4A operational amplifier circuit. The need for a computer to set up the required currents for the desired distribution of field and to check that the power supplies are operating correctly is obvious. In common with other items of equipment on the SRS the multipole power supplies are interfaced to the control system by CAMAC.

Control stations containing DAC's to set the required reference voltages and ADC's to monitor the actual current in the windings using precision resistance shunts are linked by a serial data highway to the storage ring minicomputer. This in turn is connected to a larger "midi-computer" which has control over all sections of the SRS.

Each multipole coil is assigned a separate parameter name in the database which includes all items of equipment on the SRS. The windings can be individually controlled and monitored but this method would be too time consuming for setting up a number of different field types on the 16 magnets. Instead 16 "virtual parameters" have been defined for each field type which enable an operator to control for example the horizontal dipole field on a given multipole magnet in an identical fashion to any of the 12 constituent "real" parameters. The computer calculates the required coil currents using the information in Table 1 and superimposes them on any existing distribution with a check to make sure that the maximum current in any winding is not exceeded. The program also checks periodically that the sum of the currents in the twelve windings on each magnet is zero within a specified tolerance, otherwise an error message is produced. At present the system is limited to the control of fields on individual magnets but eventually it will be possible to set up for example distributions of skew-quadrupole field around the storage ring.

Initial Operation

In the initial period of commissioning the storage ring since June 1980 the main function of the multipole magnets has been the provision of 16 separate horizontal and vertical steering elements for correction of the closed orbit. At present the main method of minimising the closed orbit error employs compensated orbit bumps constructed from 3 adjacent magnets. A special computer program allows an operator to control the amplitude of the selected horizontal or vertical bump directly, the required coil currents being set up automatically. From the controls point of view this is the most complex use to which the multipole magnets have been put so far.

Recently the effect of skew-quadrupole fields has been investigated in the neighbourhood of the coupling resonance Qr - Qv = 1 which is close to the present working point (3.15, 2.20). Small changes in beam shape have been observed directly on a synchrotron light monitor but it has not been possible to use this method for accurate measurements. Instead measurements of the change in Q-values due to coupling have been taken using a non-destructive method described elsewhere[6]. In the presence of coupling both horizontal and vertical signals appear simultaneously in the spectrum from a pickup strip. Figure 3 shows the relation between the measured difference in Q-values as a function of current in a single multipole magnet energised as a skew-quadrupole for one experiment close to the coupling resonance. The theoretical coupling coefficient for a single magnet is given by

$$|C| = \frac{0.3}{E} \frac{dBx}{dx} \frac{L}{2\pi} \sqrt{\beta_r \beta_v} \,,$$

where L is the magnet length and E the energy in GeV. At 600 MeV this gives a value of $0.0117\ A^{-1}$ for the magnet energised in the experiment. The curve in fig. 3 is drawn assuming this value for the total coupling in the machine. By comparison with the experimental data it can be seen that above 2A coupling is due entirely to the skew-quadrupole field while below this figure the effect of natural coupling in the machine is significant. A further confirmation of the operation of the magnets was obtained by verifying that a magnet on the opposite side of the ring caused the coupling to increase when it was energised with opposite polarity, as expected for a first order difference resonance. The results also permit the following estimate of the natural coupling in the storage ring to be made: $|C| = 0.021 \pm 0.005$. The large error is dominated by uncertainties in the measured values of Qv with zero skew-quadrupole field. Further measurements are planned to investigate higher levels of coupling with more than one magnet energised and to produce a more accurate value of the natural coupling.

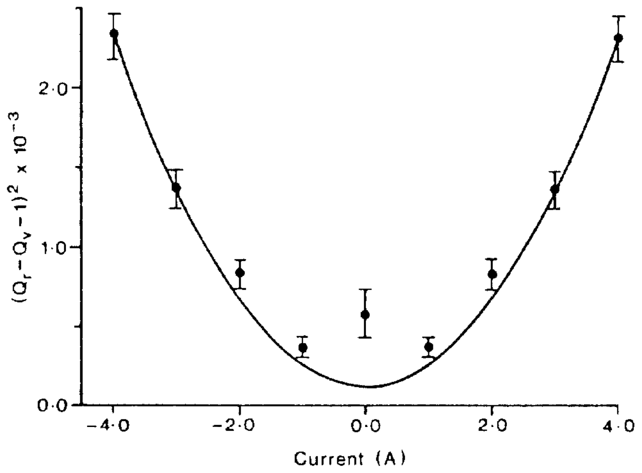

Fig.3 Difference in Q-values as a function of skew-quadrupole excitation.

Conclusion

The multipole magnets in the SRS storage ring are operational but as yet a limited number of field types have been investigated. In a sense the highest order field used reflects the state of commissioning of the storage ring as a whole. Horizontal and vertical dipole fields are now used routinely for closed orbit correction and recently an initial investigation of the effect of skew-quadrupole fields has been made but until now there has been no requirement for higher order fields. It is planned to operate the main sextupole windings in the near future and octupole and decapole fields at a later stage.

Acknowledgements

The author wishes to thank in particular the following: N. Marks conceived the idea of a multipole magnet and oversaw construction of a prototype and M.W. Poole had responsibility for the production magnet phase of the project; G.T. Wright gave engineering support and D.E. Poole has been concerned with computer control aspects.

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