NONISOMAGNETIC 3rd ORDER BEAM DYNAMICS IN THE COMPACT STORAGE RING SXLS

L.N. Blumberg, H.O. Moser*, J.B. Murphy, M.F. Reusch[§], S. Sharma, S.S. Sidhu[$], and G. Vignola[&]

Brookhaven National Laboratory, National Synchrotron Light Source, Upton, NY 11973, USA

*Kernforschungszentrum Karlsruhe, Institut für Mikrostrukturtechnik, Postfach 3640, D-7500 Karlsruhe 1, Germany

[§]Grumman Space Systems, Princeton, NJ 08540-6620, USA

[$]Washington College, Chestertown, MD 21620, USA

[&] LNF-INFN, Divisione Macchine, C.P. 13, I-00044 Frascati, Italy

Abstract: Nonisomagnetic 3rd order symplectic tracking by means of NIN/SCB and MARYLIE shows an adequate dynamic aperture of the present SXLS lattice which includes superconducting bending magnets with gradient and sextupole in the bulk.

Introduction

The development of compact synchrotron radiation sources with superconducting bending magnets is worldwide under way[1], primarily for chip production by x-ray lithography, but also as more general-purpose sources. Some of these sources are already running[2].

Most of these machines are of the racetrack type involving two 180° superconducting bending magnets. SXLS, the superconducting x-ray lithography source[3], is a very compact racetrack. As a consequence, the bending magnet has not only a dipole field, but also quadrupole and sextupole contributions for vertical focusing and chromaticity correction which allow to save quadrupoles and sextupoles in the straight sections.

As has been shown previously[4], large-bore strongly curved bending magnets require a nonisomagnetic nonlinear treatment of beam dynamics to model their influence on the design orbit, the optics, and the dynamic aperture. The present work applies the tools developed in ref. 4,5 to SXLS and shows that the magnet design work performed so far has led to a satisfactory dynamic aperture.

Method

From the magnetic field data the real design orbit and the coefficients of the transfer map in the Lie algebraic formalism are computed by means of the code NIN/SCB[4,5]. This code gives the 3rd order map for the magnet referred to the real design orbit in a form suitable for use with MARYLIE[6]. Symplectic 3rd order nonisomagnetic tracking is performed to find the dynamic aperture. The code which was originally formulated in cartesian coordinates[4] has been supplemented by a version in cylindrical coordinates[5]. This was necessary because the cartesian version is restricted to bending angles less than 180°.

As in the cartesian version, NIN is first used to find the design orbit by integrating the canonical equations of motion subject to constraints, such as the required total bending angle or a given orbit location and direction at some place in the magnet. These constraints are satisfied by an iterative method which varies a scale factor multiplying the magnetic field or particle rigidity. The field itself is calculated with the commercial code TOSCA[7].

Given the design orbit, SCB then integrates the coefficients of the transfer map according to ref. 8, and writes the transfer map to a file which can be read into MARYLIE as a beamline element.

NIN and SCB incorporate a 7th order Fehlberg Runge-Kutta with fractional step size to start the integration and an 11th order Adams-Moulton predictor-corrector scheme for the main part. The correct performance of the codes has been verified using a scaling procedure[9]. The basic idea is to compare the result of the 3rd order mapping (involving the result of SCB and tracking with MARYLIE) with a more precise numerical integration (performed with NIN). The difference between the two should scale as the 4th power of the deviations. Using an analytic isomagnetic field with gradient, sextupole and octupole components this has been found to be the case. The tracking subroutine used in MARYLIE has been modified to allow an iterative determination of the stability limit of a trajectory.

Results and discussion

Bending magnet and field

Fig. 1 shows a schematic cross-section of the superconducting bending magnet. Two main coils and a trim coil, all of rectangular cross- section, are used to produce the desired field. In fig. 2, the vertical field component and it's first three transverse derivatives on the reference orbit are plotted versus the polar angle θ describing the longitudinal position in the cylindrical reference frame. 90° and 0° correspond to the center and the entrance of the ideal 180° circular arc, respectively, while -54° describes a location 89.65 cm outside the magnet where the field is considered zero.

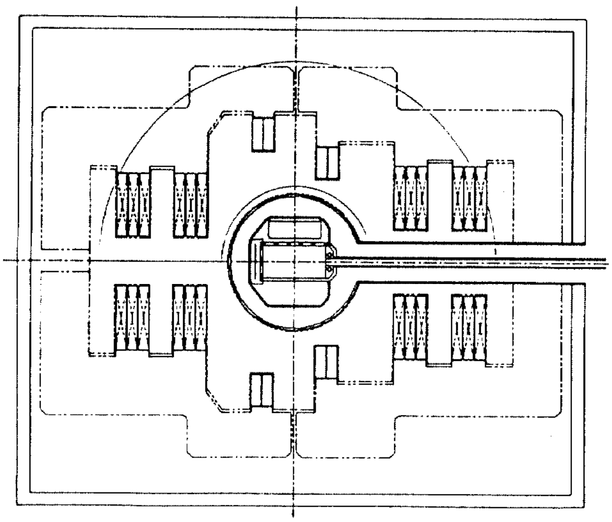

Fig. 1: Schematic cross-section of the superconducting bending magnet.

Design orbit

Fig. 3 shows the radial deviation of the real design orbit from the ideal reference orbit which is formed by a straight line and a circular arc versus the polar angle θ.

The particle starts outside the magnet on the reference orbit with a velocity directed parallel to the reference orbit. It is first deflected in the wrong sense because of the negative return field outside the magnet. As the field returns to it's normal polarity, the curvature of the deviation curve changes sign and the design orbit quickly approaches the reference orbit. At the entrance of the arc section the slope of the deviation curve diminishes but is still large enough so that the design orbit crosses the reference orbit. Since the radial field dependence in the arc section is weaker than 1/r, the deviation curve goes through a minimum on the inner side of the arc and then settles down at an almost constant deviation which is practically zero in the present case.

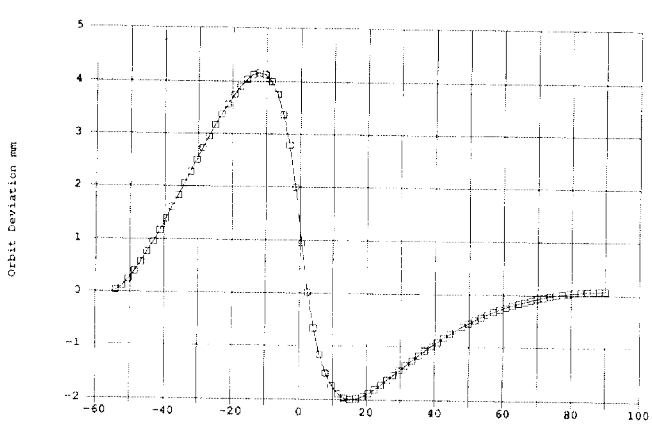

Fig. 3: Radial deviation of design orbit from reference orbit.

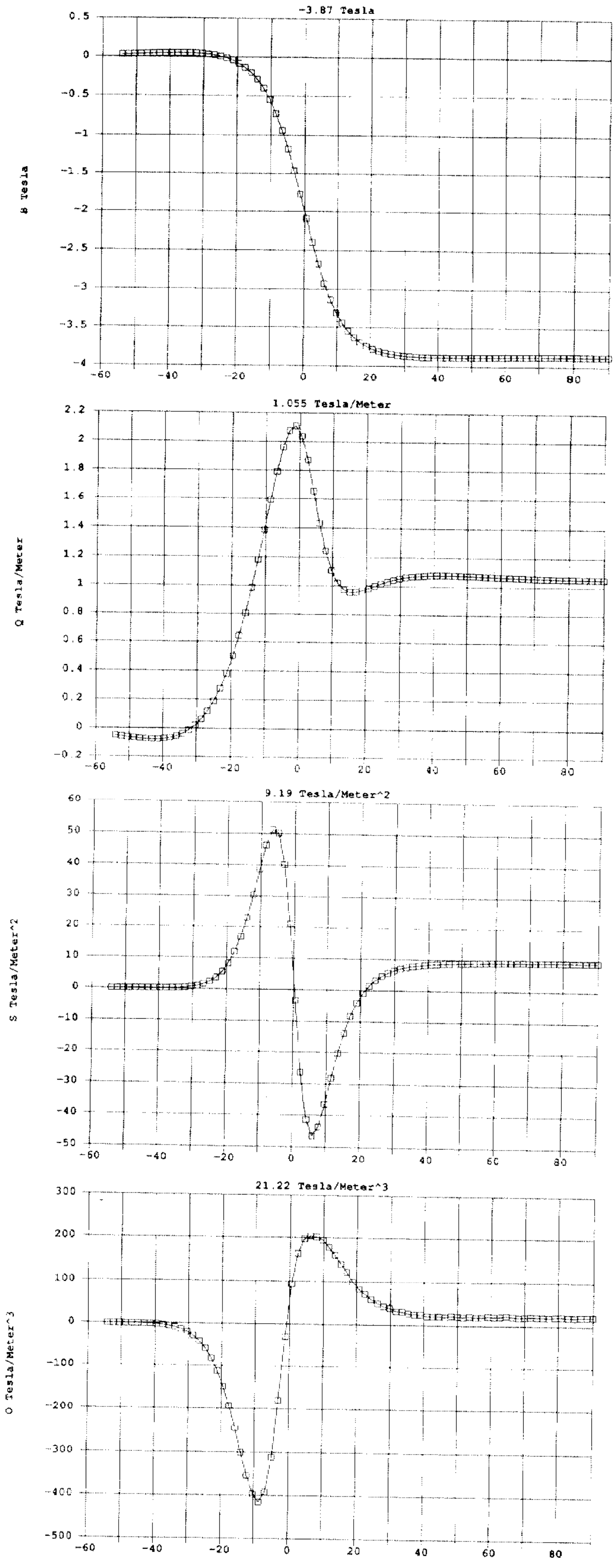

Fig. 2: Vertical field component and first three transverse derivatives on reference orbit.

Dynamic aperture

The dynamic aperture based on tracking 5000 turns using the one-turn map (Fig. 4) is sufficiently large to accommodate not only the damped final energy beam, but also the larger beam during injection. The protrusion showing up as one point in the total dynamic aperture (angular resolution π/30) is magnified and confirmed by doing a partial dynamic aperture in the range 13.5π/30 to 16π/30 with a resolution of 2.5π/900. From a practical point of view, however, this feature has no importance.

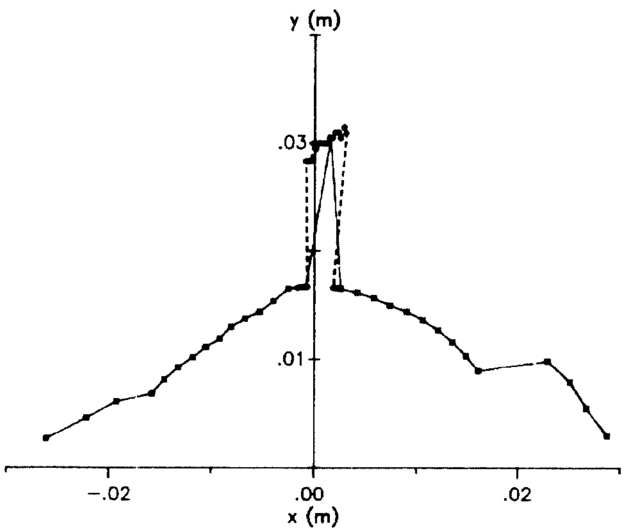

Fig. 4: Dynamic aperture based on tracking 5000 turns. Chromaticities compensated. Part of the curve is shown with better resolution (dashed line, circles).

Conclusion

Nonisomagnetic 3rd order symplectic tracking by means of NIN/SCB and MARYLIE shows that even for the complicated case of the SXLS bending magnet which has gradient and sextupole in the bulk, in addition to those in the end regions, a dynamic aperture adequate for the final beam as well as for injection can be obtained.

Work performed under the auspices of the U.S. Department of Energy and funded by the U.S. Department of Defense.

References

[1] see, e.g., J.B. Murphy, "X-Ray Lithography Sources: A Review", presented at the Particle Accelerator Conference, Chicago, IL, March 20-23, 1989; H.O. Moser, W. Ehrfeld, "Prospective non-lithographic applications of a synchrotron radiation source for deep-etch lithography", Rev. Sci. Instrum., vol. 60, pp. 2164-2166, July 1989.

[2] H. Yamada, T. Takayama, and T. Hori, "Operation Experiences of AURORA: The Compact Synchrotron Light Source", this conference; E. Weihreter et al., "Status of the Superconducting Storage Ring COSY", this conference; T. Hosokawa et al., "NTT superconducting storage ring - Super-ALIS", Rev. Sci. Instrum. , vol. 60, pp. 1783-1785, July 1989.

[3] J.B. Murphy et al., "The Brookhaven Superconducting X-Ray Lithography Source (SXLS)", this conference.

[4] H.O. Moser, A.J. Dragt, "Influence of strongly curved large-bore superconducting bending magnets on the optics of storage rings", Nucl. Instr. and Meth., vol. B24/25, pp. 877-879, 1987.

[5] M.F. Reusch, H.O. Moser, J.B. Murphy, "Nonisomagnetic Bending Magnet Hamiltonian Expansions for MARYLIE and their Application to the SXLS X-Ray Lithography Source", presented at the APS Spring Meeting, Washington, D.C., April 16, 1990.

[6] A.J. Dragt et al., "MARYLIE 3.0: A Program for Charged Particle Beam Transport Based on Lie Algebraic Methods", University of Maryland, College Park, MD 20742, 1985.

[7] Vector Fields Inc., 1700 N. Farnsworth Ave., Aurora, IL 60505.

[8] A.J. Dragt, E. Forest, "Computation of nonlinear behavior of Hamiltonian systems using Lie algebraic methods", J. Math. Phys., vol. 24, pp. 2734-2744, December 1983.

[9] A.J. Dragt, J. Milutinovic, private communication.