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Performance Study of Superconducting Bending Magnets with Iron in a Compact Synchrotron Light Source

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Abstract

Magnetic field calculations for a superconducting bending magnet with an iron shield and nonisomagnetic 3rd order symplectic tracking in a compact storage ring composed of four of those magnets show that the dynamic aperture is adequate between injection and final energy. Four field levels and two different iron shields are studied. It is found that the iron contribution to the dipole field of 4 T can be as high as 0.6 T without degrading the dynamic aperture.

Untersuchung des Einflusses von supraleitenden Ablenkmagneten mit Eisenabschirmung auf eine kompakte Synchrotronstrahlungsquelle

Zusammenfassung

Die Berechnung des Magnetfeldes eines supraleitenden Ablenkmagneten mit einer Eisenabschirmung und nicht-isomagnetische, symplektische Bahnverfolgungsrechnungen 3. Ordnung für einen kompakten Speicherring, der aus vier solcher Magnete aufgebaut ist, zeigen, daß die dynamische Apertur ausreichend groß ist von der Injektions- bis zur Endenergie. Vier Feldwerte und zwei verschiedene Eisenabschirmungen werden untersucht. Es zeigt sich, daß der Eisen-Beitrag zum Dipolfeld von 4 T bis zu 0.6 T betragen kann, ohne daß die dynamische Apertur heruntergesetzt wird.

1. Introduction

Superconducting bending magnets with iron have found widespread use in existing and planned storage rings [1]. Besides the contribution to the field amplitude and the reduction of stray field the iron can also influence the nonlinear behaviour of a magnet. The contribution of the iron shield will depend on its geometry and on the total field level. The iron should be as close as possible to the coil in order to get a large contribution to the dipole field and to reduce both the influence of the coil end fields and the stored magnetic energy. On the other hand, a close iron shield may induce undesired field- dependent multipoles. For the conceptual design of a compact light source [2] we calculate the dynamic aperture for two iron geometries which are the limiting cases allowed by the mechanical layout of our magnet design. The calculations are performed for the four field levels 0.4, 1.33, 2.66, and 4.0 T. They are quasistatic in the sense that time-varying effects like eddy-currents etc. are not taken into account.

2. Method

The magnetic field contribution of the coils is calculated as described previously [3] using the law of Biot and Savart. To compute the iron contribution we use an integral method which has the advantage that it does not need a mesh outside the iron where we are mainly interested in the field. The torus is enclosed in a regular array of curved volume elements. For each element the magnetic moment is calculated as a function of the magnetization of all the other elements and the coil field.

In this way, we get the coefficients of the Fredholm equation of the second kind which we solve in two steps: first, we start with a crude mesh (typically 200 elements for a quarter of the 90^0 bending magnet) using a direct method with Gaussian elimination and a Newton-Raphson iteration updating the permeability at each step. Then, the magnetization values are distributed in a finer mesh (typically 1400 cells) as starting values for a Gauss-Seidel iteration.

From the magnetic field data the coefficients of the transfer map in the Lie algebraic formalism are computed by means of the code NIN/SCB [4] . This code gives as a result the 3^{rd} order map for the magnet referred to the real design orbit in a form suitable for subsequent use of MARYLIE [5] to do a symplectic nonisomagnetic 3^{rd} order tracking of the particles.

3. Results and discussion

3.1 Bending magnet

A schematic 3D view of the bending magnet is shown in fig. 1. The air coil consists of several coils distributed over two annular layers each 1 cm thick. In contrast to a former design[6] the cross-section of the windings is symmetric to a plane perpendicular to the midplane and tangential to the reference orbit. The inner and outer radii of the coil layers are 6 and 8 cm, respectively. Two iron shields with inner radii R_i of 14 and 12 cm and maximum thicknesses of 11 and 13 cm, respectively, are investigated. In the longitudinal direction, the coil and the iron shield extend over an angular range of 90^0 and 80^0 , respectively.

3.2 Magnetic field

Fig. 2 shows the transverse field contribution from the two iron shields versus the current density in the coils. A nonlinear behaviour of the field can be seen, but it is not too strong, for the iron is far enough away from the coil and relatively thin . The maximum contribution of the iron shield at 4 T for the inner radii being 14 and 12 cm is 0.429 and 0.623 T, respectively. The main differences in field behaviour along the electron orbit are found in the coil end region as illustrated by fig. 3. Here, the longitudinal dependence of the vertical field component normalized to its value on axis in the center of the magnet is plotted for the two cases 0.4, and 4.0 T for both iron geometries. The negative field overshoot arising from the coil return is reduced at lower field strength, most significantly for R_i = 12 cm.

3.3 Dynamic aperture

Fig. 4 and 5 show 5000 turn dynamic apertures at different field levels for 14 and 12 cm inner radius of the iron shield, respectively. The sextupoles for chromaticity correction are set to zero. For the present cases, both field strength and iron shape have only a minor influence on the dynamic aperture which is large enough in view of a satisfactory beam lifetime.

4. Conclusion

Magnetic field calculations for the case of a 90^0 bending magnet with superconducting coils of cylindrical cross-section surrounded by an iron shield show nonlinear variations of the field depending on the integral field strength and the iron shape . Dynamic apertures obtained from symplectic nonisomagnetic 3^{rd} order tracking in the lattice of a conceptual compact synchrotron light source are adequate and depend only weakly on the field strength and the iron geometry. A closer iron shield appears favourable because its contribution to the dipole field is higher and the stored magnetic energy smaller.

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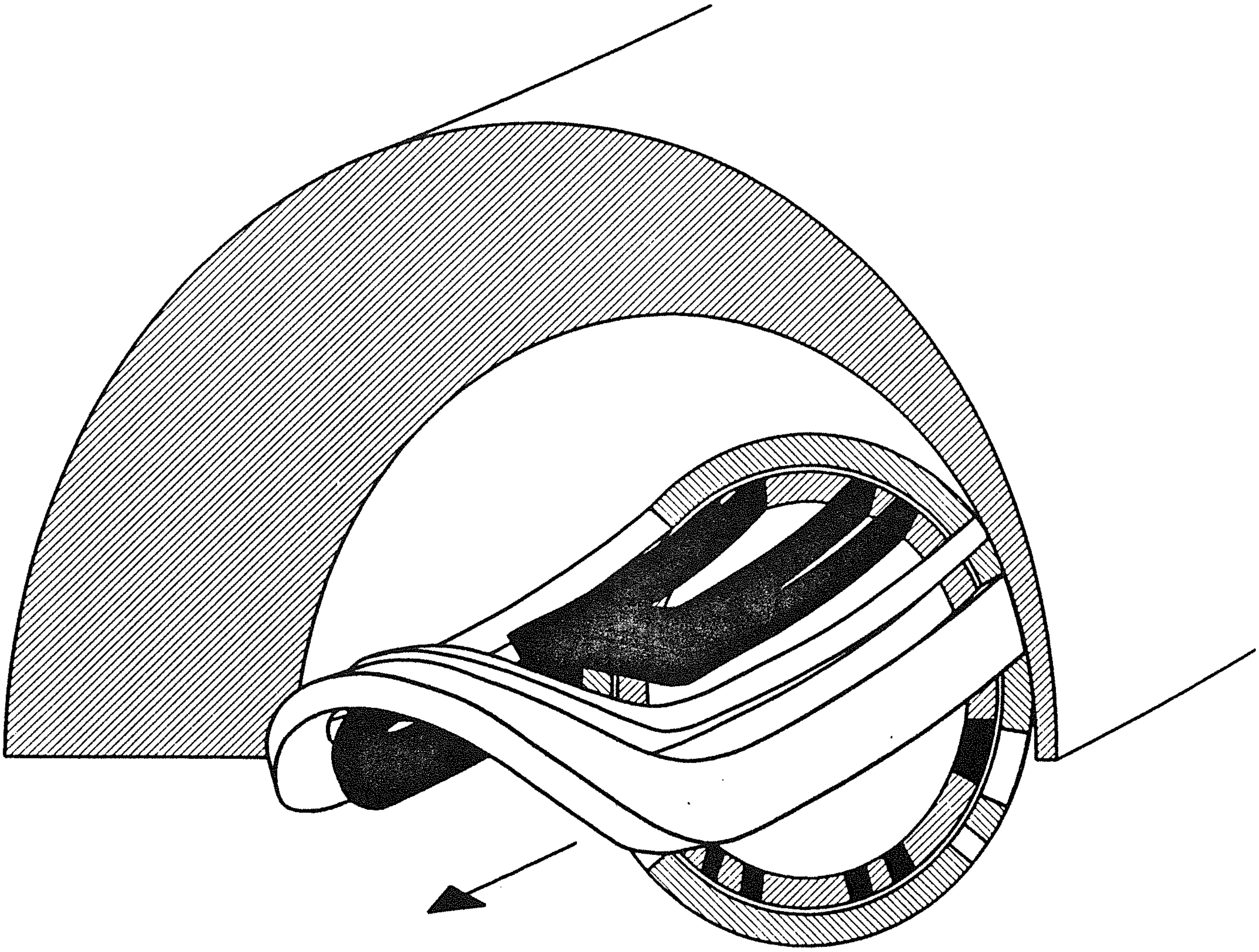

Fig. 1 : Schematic 3D view of the end of the superconducting bending magnet.

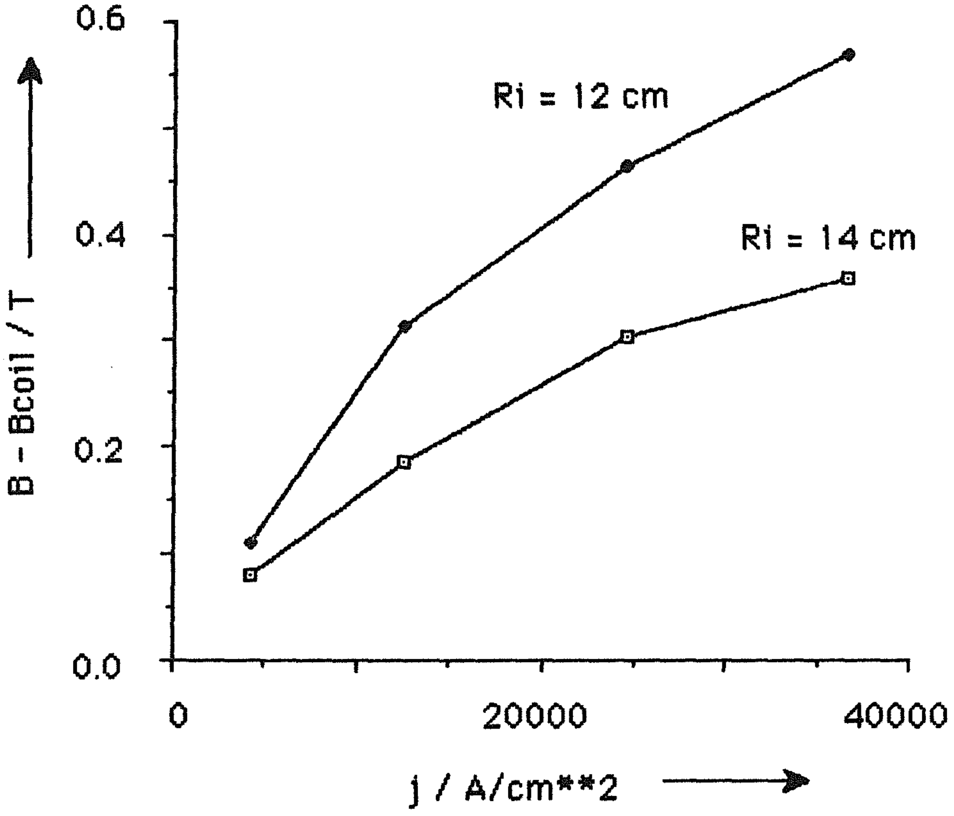

Fig. 2: Iron contribution to the dipole field versus current density in the coils.

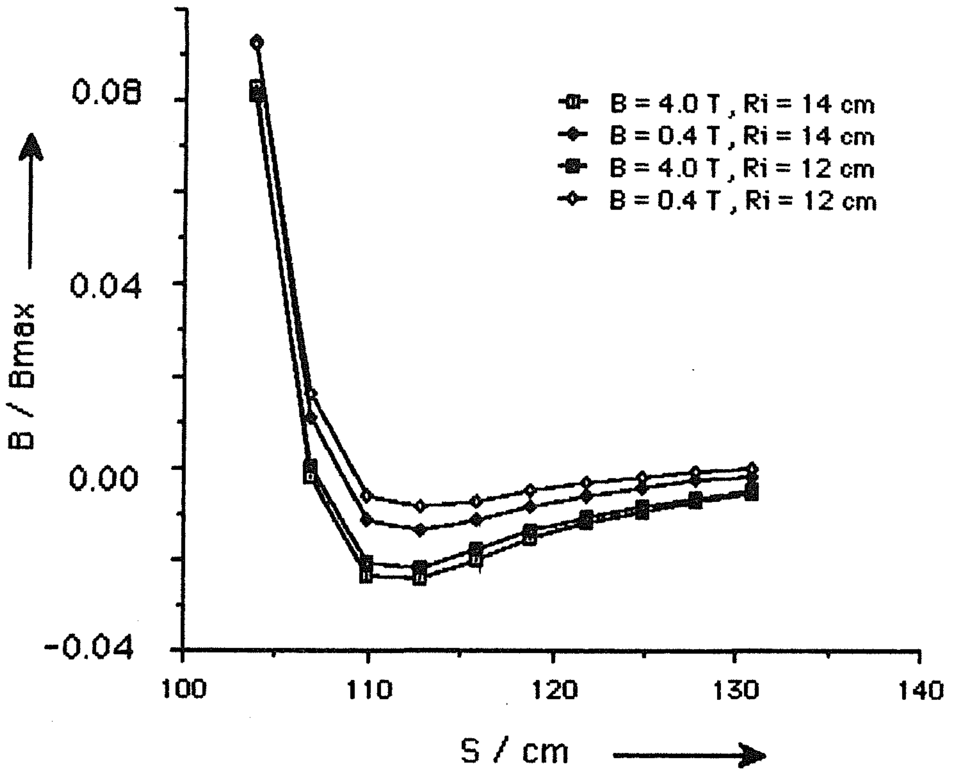

Fig. 3: Field along the reference orbit. s = 0 corresponds to the center of the magnet.

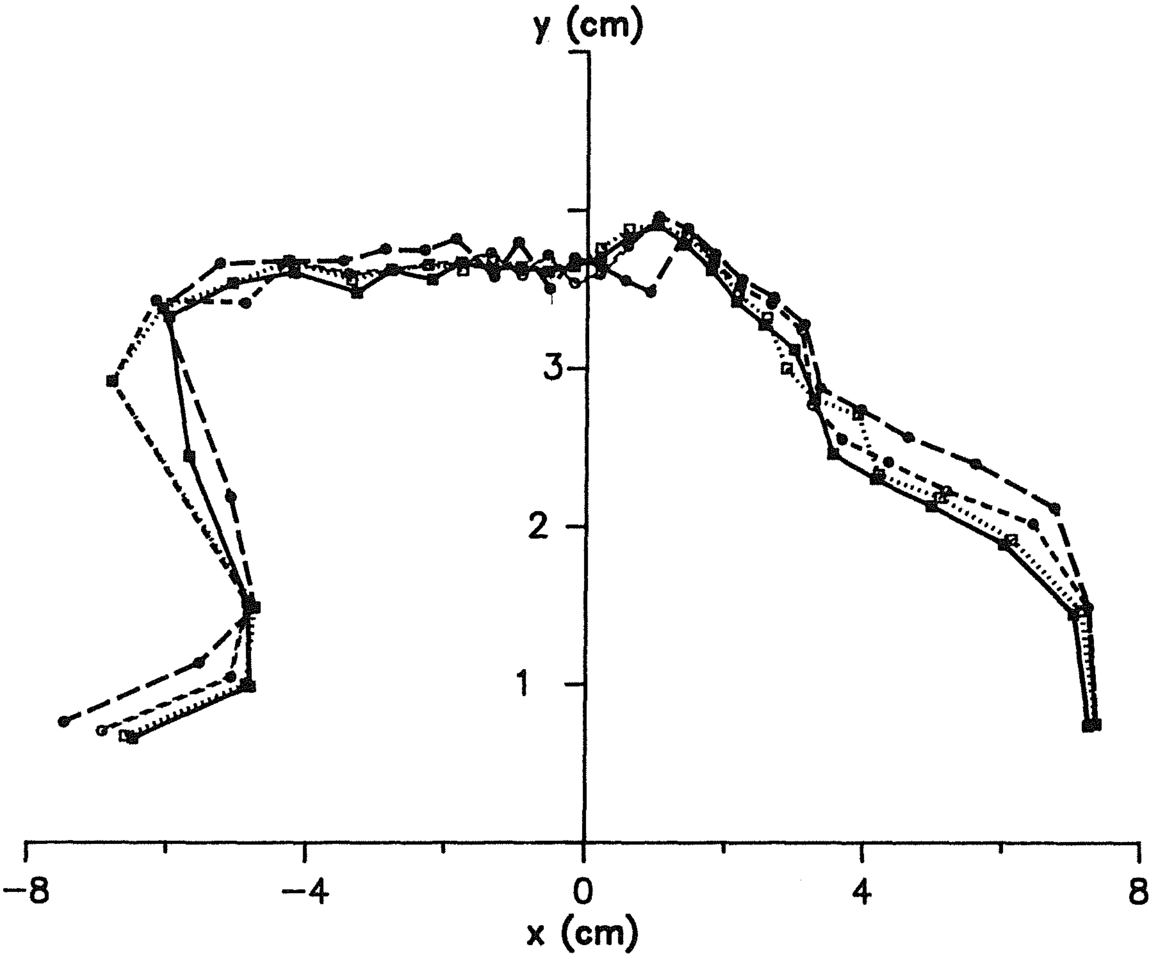

Fig. 4: Dynamic apertures for the field levels 4.0 (solid), 2.66 (dotted), 1.33 (short-dashed), and 0.4 T (long-dashed) with chromaticity compensating sextupoles set to zero. Inner radius of iron shield is 14 cm.

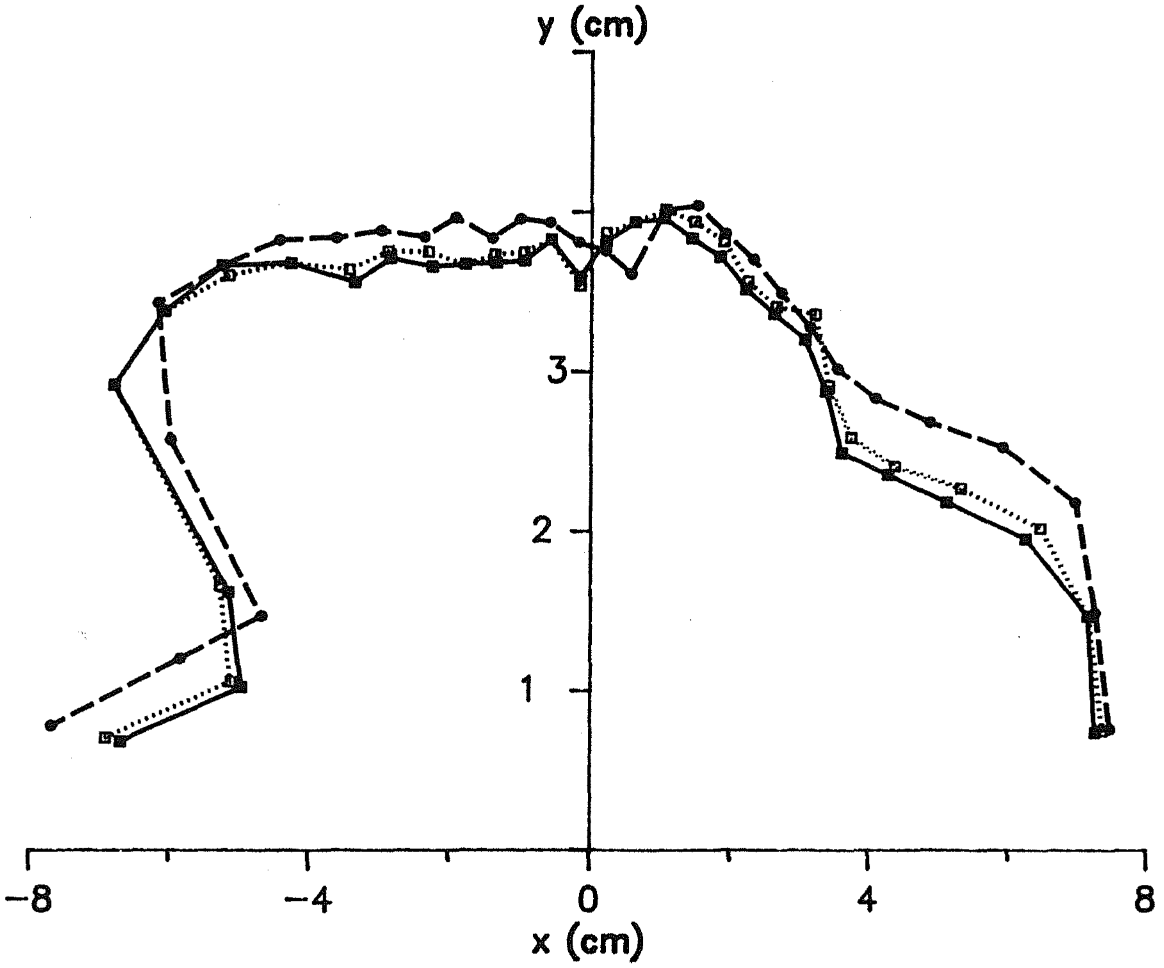

Fig. 5: Dynamic apertures for the field levels 4.0 (solid) , 2.66 (dotted), and 0.4 T (long-dashed) with chromaticity compensating sextupoles set to zero. Inner radius of iron shield is 12 cm.