HELICAL SIBERIAN SNAKES

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Abstract

The helical dipole is a new type of magnet element for charged particle accelerators. Helical dipoles are long dipoles twisted into a helix; one can be constructed with laminations, each lamination is rotated by some small angle with respect to the previous lamination. Siberian snakes using helical dipoles would have several advantages: the closed orbit excursions within the snake would be smaller; there would be fewer magnets required; and potentially the snake could be shorted so it would require less space in the ring. Fabrication techniques are explained. Construction problems and their solutions are reviewed.

I. INTRODUCTION

Polarized proton beams, when accelerated in a circular ring, encounter various resonances in the motion of their spin, and that will ultimately lead to depolarization. Since there are generally many depolarizing resonances in a strong-focusing synchrotron, a polarized beam can not be accelerated without using several correction methods to suppress the depolarizing resonances. There are several methods to reduce the depolarizing effect of the resonance field harmonics, but the Siberian snake technique was demonstrated to be most effective in maintaining beam polarization. A snake is a configuration of magnets that, in the orbit frame, rotates the spin by 180^o about an axis which lies in the horizontal plane. This proposal has been made by Y.S.Derbenev and A.N.Kondratenko[1].

In low energy machines excursions inside a standard Siberian snake design become excessively big. For this reason it is necessary to find compact helical dipole magnets designs that minimize both excursions and length. A snake with very small orbit excursions is the helical snake proposed by E.D.Courant, Ya.S.Derbenev and A.N.Kondratenko[2,3]. One of the most compact snakes is a helical snake. This minimizes the orbit displacements.

Equations for the helical field and the conditions for π spin flip and orbit restoration schemes, see[3,4].

The trajectory in the helical magnet is determined by the equations

$$x" = -\frac{1}{\rho} sinks,$$

$$y" = \frac{1}{\rho} cosks.$$

General solution for the particle motion inside a helix contains spiral trajectory plus straight line solution with parameters depending on initial conditions of incoming beam.

By means of matching initial conditions at the helix with the pure spiral solution one can reduce orbit excursion inside the helix up to the value of $r = 1/\rho k^2$.

Table I

Major parameters of I and II type helical dipole magnets

Type of magnet	I	II
Maximum field [T]	1.7	1.7
Aperture [mm]	200	120
Power dissipation/magnet [kW]	1200	450
Total weight [kg]	57000	26000

II. HELICAL DIPOLE MAGNETS

We have designed two helical dipole magnets for use as Siberian snake in the accelerators Fig.1. Helical dipoles are long dipoles twisted into a helix; one can be constructed with laminations, each lamination is rotated by some small angle with respect to the previous lamination. Such a magnets design ensures a uniform field ($\sim 10^{-3}$) up to 1.7 T.

A plane and a helicoid are only complete surfaces of zero middle curvature. A helicoid is obtained as a result of two straight line motions: i.e. in one dimension with a constant speed and rotatory with constant angular velocity in the orthogonal to the translation vector plane. These mentioned mathematical qualities of the helicoid permit to work out the construction and manufacturing technology for the vacuum chamber, coils and magnet core of a helical dipole magnet.

The main parameters of the laminated helical dipoles are summarized in Table 1 for conditions corresponding to the nominal accelerator operating energy of ~8-10 GeV.

The most possible field error in the magnet gap is caused by the accuracy of pole profile. The field variation along the orbit may be produced by the fluctuation of the permeability and coercive force of the core materials. In high-field magnets, one important property of the iron is lost: the field-shaping property. As the relative permeability approaches unity, the iron surface is no longer equipotential. Field-shaping is now entirely due to magnet coil configuration, and correcting coils, is required.

Modern steels used in direct current magnets have an impurity content ($N_2+S+P+Al+Mo$) of less than 0.1%, ($Cr+Cu+Mn+Ni+Si$) of less than 0.7%. Carbon, which is the most dangerous impurity, is limited to 0.1%. Pure iron is costly and too soft to be machined and handled for magnet cores.

From our experience, the conclusion is that using laser cutting techniques to cut laminations may be a good method to built laminated magnet. The laser cutting technique is advertised to have a very high machining accuracy of 0.05 mm tolerance over a 1000 mm length.

The coil consists of the several section with square cross-section. In order to wind the rectangular wire helically, it is required to twist the wire continuously. The coil, located in gap, are designed of water-cooled cooper, insulated with epoxy resin and fiberglass and vacuum potted in an alumina-based epoxy.

Standard technique for insulating magnet coil is to use epoxy resin, reinforced with fiberglass. Standard resin systems, such as Novolac, or Bisphenyl-A, with NMA hardener, can be expected to tolerate 10^9 rad. By using a kapton layer between the coil and the core, one achieves a further ground insulation and also provides a slip plane to allow the coil to move in the core upon thermal expansion of either component.

The size requirements of the beam chambers are determined by the helix with radius $r = 1/\rho k^2$, beam emittances and energy spreads.

The vacuum chamber can be made from any metal, but, as it is usual in accelerative technique stainless steel is the most preferable material. The technology of manufacturing the chamber includes several stages.

The vacuum chambers of the helical dipole magnet is made from unrolling helicoids. These helicoids have as their return rib a spiral of a constant pitch on the circular cylinder. Four such elements which are preliminarily moulded as helicoids, are welded all over the return ribs. So the vacuum chamber of the helical dipole magnet is obtained.

The vacuum chambers experience atmospherical pressure all over it external surface. To reduce the vacuum chamber deformation we can install the hardness ribs on ot. But it is not efficient because the necessary dipole aperture increases. It is more expedient to apply helicoids as chamber elements, moulded in the cross direction as a sloping arch.

We have constructed a model of a helical dipole which could be used in a Siberian snake for the accelerators. Our purpose was to show the feasibility of constructing a helical dipole. The model was run in a low duty factor test; the low duty factor avoided the overheating during DC operation at 1.6 T of a $\sim 10\%$ mechanical scale model for which the current density is $\sqrt{10}$ larger than in a full scale model.

The model of the helical dipole magnet which we made, shown in Fig.2 has a four-turn coil with a copper conductor and copper water pipes brazed to its upper and lower ends. The current flow in the coils is in series whereas the coolant flow is in parallel.

The magnetic field properties of helical dipole magnet model were measured and found to be close to the design. The helical dipole magnet model was pulsed about 10^4 times in the IHEP laboratory without any incident.

III. CONCLUSION

The second variant of helical dipole has considerable advantages in use for accelerators.

In application to each specific accelerator project the helical dipole used needs careful consideration of beam dynamics both theoretically and by computer modeling.

The $\sim 10\%$ model fabrication, operation and demonstrated reliability has adwanced the technology of helical dipole magnets. Helical dipole magnets are now ready for applications in accelerators physics such as use in a ring at IHEP, PS (CERN) or Fermilab.

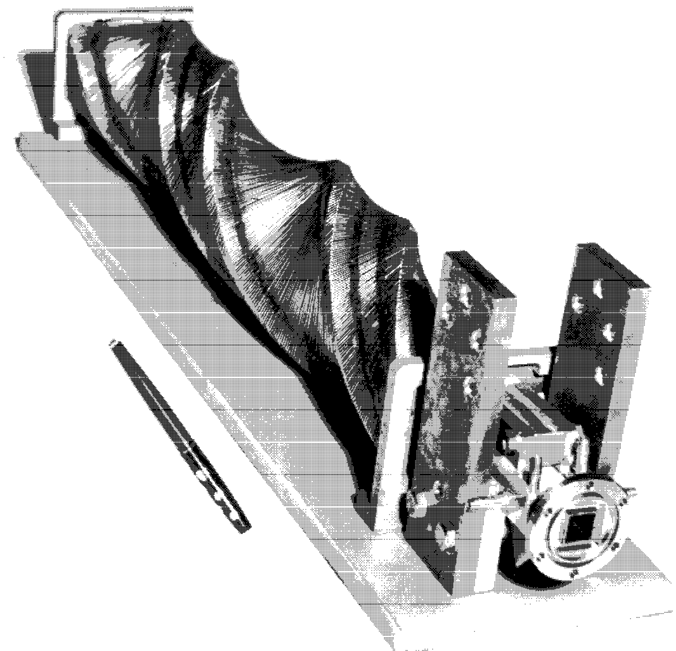

Figure 2. Helical dipole magnet.

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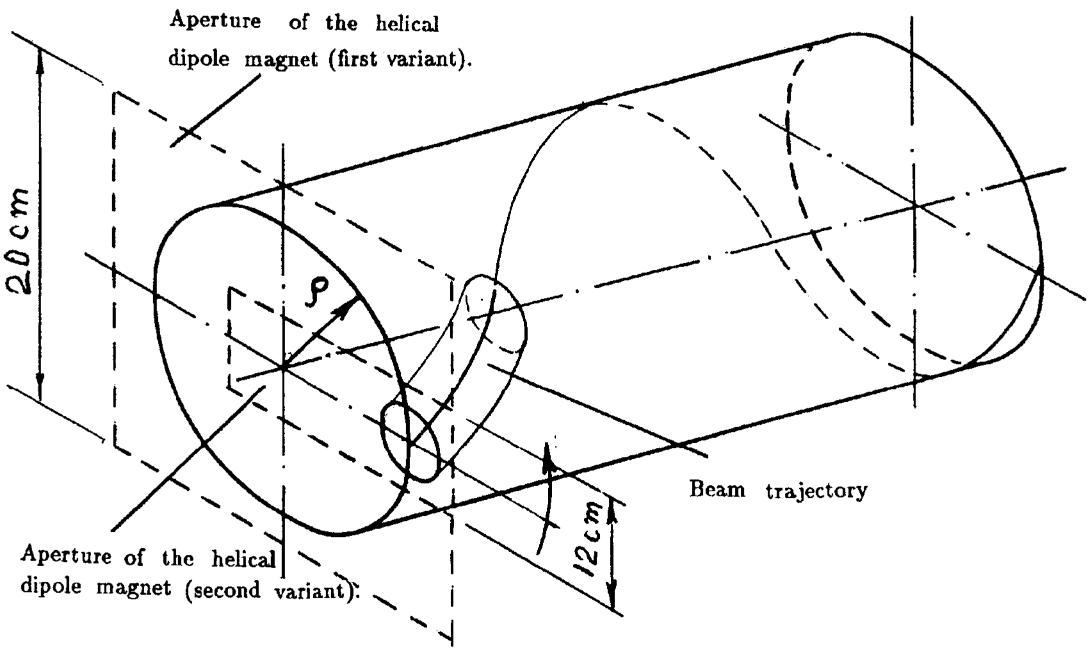

Figure 1. The magnet apertures. The aperture makes a (complete) revolution.