DESIGN STUDY OF HELICAL PARTIAL SNAKE MAGNET FOR AGS

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Abstract

A normal conducting helical dipole magnet, which will improve depolarization of polarized proton beam in Alternate Gradient Synchrotron (AGS), has been proposed. Replacing an existing solenoid type Siberian Snake with the helical magnet, the strength of the remaining intrinsic resonances, which are due to transverse coupling, can be reduced. This new type magnet has 360 degree rotation and 1500 mm of effective length. Field shape and the coupling effect of the magnet are discussed using 3D field calculation.

1 INTRODUCTION

The AGS synchrotron has introduced a partial snake [1], which helps to overcome the imperfection resonances that appear during the acceleration of polarized protons. The existing partial snake is a solenoid magnet which is located at the C10 straight section of the AGS and its field rises with the same rate as the AGS main magnet. The longitudinal (Bz) component of the solenoidal partial snake introduces linear coupling of the transverse coordinates of the beam. This linear coupling appears on the single turn first order transfer matrix of the AGS and one of its effects is to introduce additional intrinsic resonances which affect the final polarization of the beam. In order to reduce the coupling caused by the solenoidal magnet, an alternative partial snake which is a helical dipole magnet, has been proposed [2]. Unlike the helical dipole magnet Snakes used in RHIC[3], which each consist of four 2.4 m long super conducting magnets, the AGS partial helical snake would be composed of a single normal conducting helix with steering magnets on either side. To achieve high polarization in RHIC, overcoming intrinsic resonance in the AGS is indespensable.

2 BASIC DESIGN

Three dimensional view generated by OPERA-3D[4] is shown at Fig.1. The effective magnetic length is 1500 mm and bore is 150 x 150 mm, square shape. Required magnetic field strength for 9 degree spin rotation at $G\gamma$ = 8.68 beam is 1.61 T. Due to the use of a helical structure with a 360 degree rotation of magnetic field, deflections of beam orbits will be canceled. However, considering fringing fields in the real magnet, there should be right rotation angle which is less than 360 degree. Using OPERA-3D, TOSCA, the rotation angle which enables net transverse field along beam axis zero, was computed.

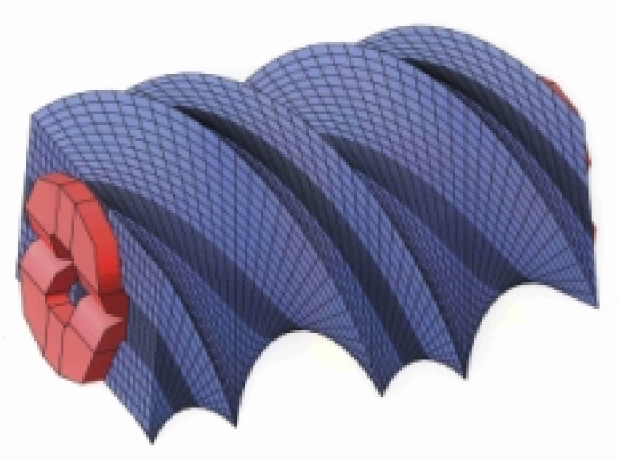

Figure 1: 3D view of the partial helical snake.

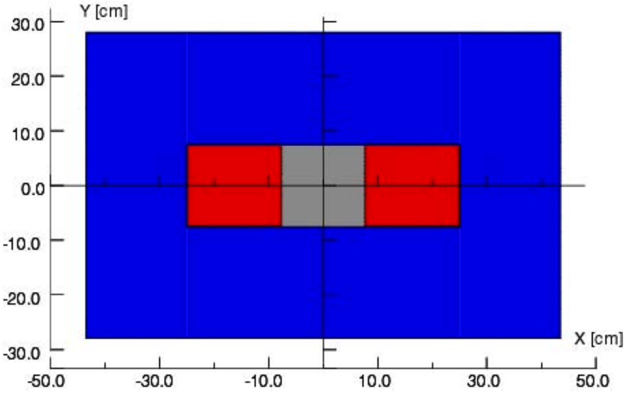

Figure 2: Cross-sectional view of the helical snake.

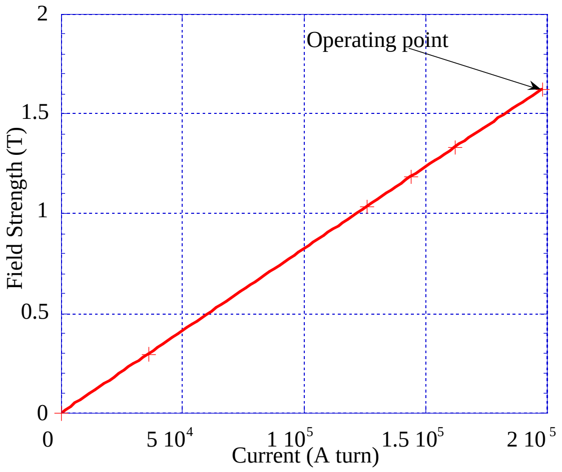

Figure 3: Field excitation curve.

The optimized rotation angle of the iron pole is 334.67 degree and its length is 1393.2 mm. Figure 2 shows cross-sectional view of the magnet. Considering 3D-effect, the size, height and width, of return yoke was determined not to exceed 1.5 T of field strength in the iron, except pole face region,. The yoke would be laminated, in order to form such a complex twisted structure. Assumed current is 198000 A turn for 1.61 T. The field excitation curve predicted by the 3D calculation is indicated at Fig.3. The design parameters are summarized at Table 1.

Table 1: Design Parameters

Parameter	Value
Coils	
Current density (A/cm^2)	754
Total current (A turn)	198000
Power dissipation (kW)	19
Conductor size (mm)	11.5 x 11.5
Diameter of hollow (mm)	7.5
Total turns	1728
Inductance (mH)	95
Numer of turns	168 (14 x 12)
Yoke	
Height (mm)	560
Wiidth (mm)	870
Rotation angle (degree)	334.67
Length (mm)	1393
Packing factor (%)	99

3 THE COUPLING STUDY

The transverse coupling strength has been computed and compared [2] to that of the solenoidal magnet. The magnetic fields required in the computations carried in Ref. 2, were based on analytical fuctions which do not take into account the entrance and exit fringe fields of the magnets and the effects introduced by the saturation of the iron. In this section we present similar results as in Ref. 2 but with the calculations based on the 3D magnetic field computations. The formalism to calculate the linear coupling of the helical partial snake is similar to the one in Ref. 2 and the procedure of the calculations are outlined below.

1. Create a 3D field map from the 3D results of the helical partial snake.
2. Using the 3D map from step 1, perform the computations described in steps a, b, c below.

a) The trajectory of the central ray and the fields along the central trajectory (see Figure 4). This step is necessary to help determine the strength of the vertical dipoles placed at the entrance and exit of the partial snake. These two vertical dipoles compensate for the vertical displacement of the central ray, so that it exits the second dipole along the ideal orbit.

b) The directional cosines of the spin-rotation-axis and the spin rotation angle about this axis for the helical partial snake (v-dipole, helical dipole, v-dipole).

(see figure5a Sy versus Sx 300 rays)

(see figure5b Spin-Rotation-Angle vs. Sx 300 rays)

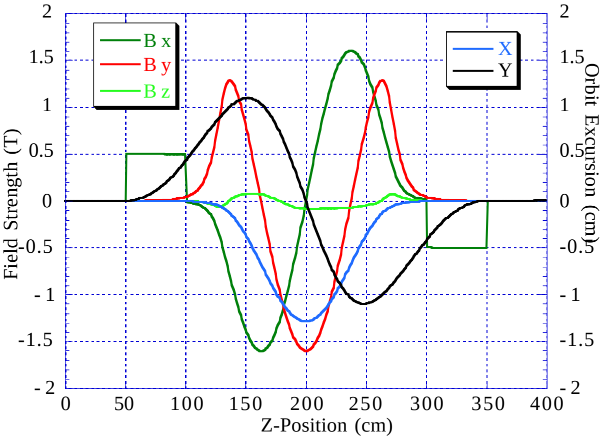

Figure 4: Field and orbit in the helix.

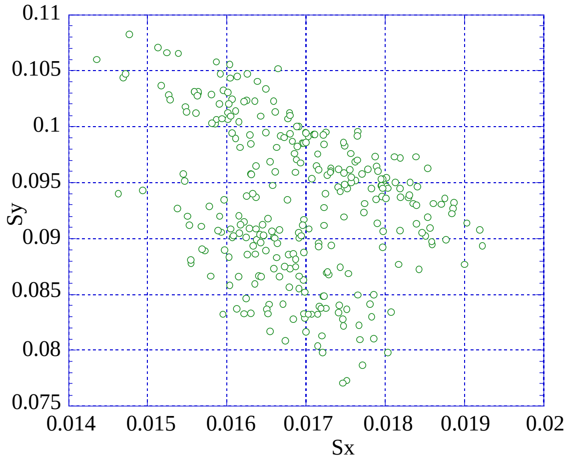

Figure 5a: Sy versus Sx.

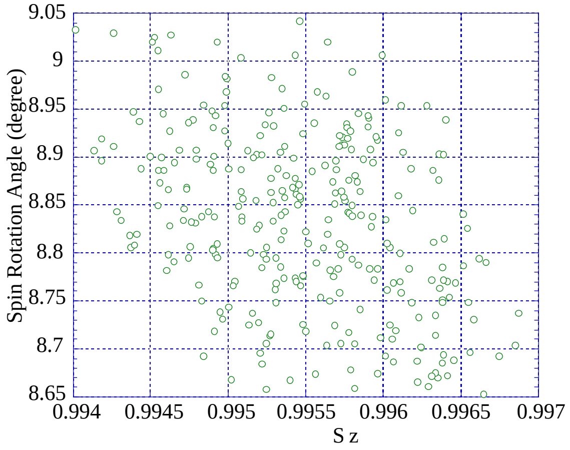

Figure 5b: Spin-Rotation-Angle vs Sx.

c) The 6x6 first order transfer matrix (R-matrix) of the helical partial snake. For this computation 102 rays are used, and the R-matrix computed is correct to fourth order. Complete second and third order transfer matrices are also computed.

Helix 9.0 deg G*gama=8.68

$$\begin{pmatrix} 0.97396 & 3.94435 & -0.01065 & -0.03181 & 0.00000 & -0.00015 \\ -0.01218 & 0.97788 & 0.00006 & -0.01623 & 0.00000 & -0.00012 \\ 0.00459 & 0.00722 & 0.97465 & 3.97692 & 0.00000 & -0.00019 \\ 0.00160 & 0.00296 & -0.01236 & 0.99138 & 0.00000 & -0.00024 \\ -0.00018 & -0.00034 & -0.00003 & -0.00021 & 1.00000 & -0.00143 \\ 0.00000 & 0.00000 & 0.00000 & 0.00000 & 0.00000 & 1.00000 \end{pmatrix}$$

3. Introduce the R-matrix of the helical partial snake into C10 straiht section of the AGS and compute the one turn tranfer matrix of the AGS with the helical partial snake.

$$\begin{pmatrix} -1.265416 & -10.925394 & -0.016420 & 0.214983 & 0.000000 & 1.987590 \\ 0.184545 & 0.804907 & -0.000475 & -0.010250 & 0.000000 & -0.347420 \\ -0.014422 & -0.113130 & 1.559522 & -19.670786 & 0.000000 & 0.022555 \\ -0.007617 & -0.061052 & 0.170455 & -1.510182 & 0.000000 & 0.012168 \\ -0.073199 & -2.202480 & -0.000010 & 0.000885 & 1.000000 & -11.543514 \\ 0.000000 & 0.000000 & 0.000000 & 0.000000 & 0.000000 & 1.000000 \end{pmatrix}$$

4. Using the formalism of the Ref. 2, the effect of the coupling is calculated $\Delta\nu$=3.48E-03 (theory $\Delta\nu$=0.95E-04 in Ref. 2) The obtained value is still less than one fourth of the ideal solenoidal snake.

Figure 5a indicates that the helix intruduces a small spin rotation about the x-axis. To eliminate this spin rotation about x-axis the body of the shole helix will be rotated by an angle ~9.0 degrees.

4 FIELD QUALITY CORRECTION

The field quality in the helical partial snake has unique distortion and then multipole components were computed by using 2D and 3D codes. Table 2 shows results with the 2D and 3D calculation models.

Table 2: Multipole components

	2D	3D(azi.)	3D(ver.)
Dipole (T)	1.655	1.613	1.622
Sextupole / Dipole	4.2×10^{-4}	-4.0×10^{-3}	-9.3×10^{-3}
Decapole / Dipole	9.1×10^{-5}	6.1×10^{-4}	5.9×10^{-4}

Reference radius is set to 50 mm. All the values are based on normal components.

Discrepancy between 2D analysis and 3D(azi.) analysis which was extracted from azimuthal field component expansion is due to 3D effect. The magnetic field flux in the iron goes not only on transverse plane but also to longitudinal direction in 3D structure and the saturated regions of the poles are slightly different in the 2D and 3D cases. If the iron saturation can be neglected, those two values should be same. In the case of the 3D helical structure, the multipoles derived from the expansion of the vertical component of the field are not the same as those derived from an expansion of the azimuthal field component, due to the presence of a longitudinal field component in the magnet. In this case, 1500 mm rotation pitch, the discrepancy in sextupole component is 5.5×10^{-3}, which was estimated analytically[4], and consistent with the values listed in Table 2. In order to calibrate the distortion of the field uniformity caused by mentioned above, the pole shape was optimized using 2D code to minimize the multipole components that will be given by 3D vertical component expansion. Revised shape is shown at Fig. 6.

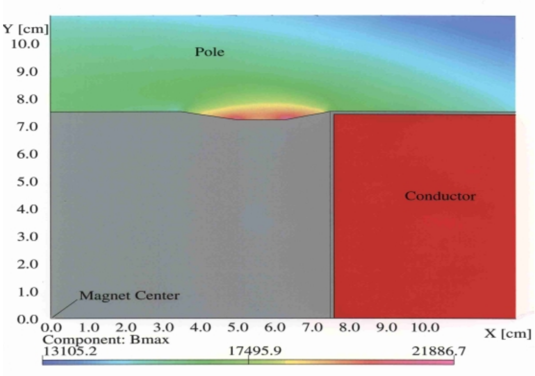

Figure 6: The pole shape with shim.

The sextupole component with the pole shape shown in Fig.6 is 8.9×10^{-3} which is based on 2D code. The 3D calculation gave the ratio of sextupole is 5.8×10^{-4}.

5 CONCLUSION

The new partial snake which consists of the normal conducting helical dipole magnet was designed using the 3D magnetic calculation. The estimated coupling effect is less than one forth of the existing solenoidal snake. We believe that the new snake system is effective to reduce depolarization in the AGS.

REFERENCES

[1] H. Huang, et al “Preservation of Proton Polarization by a Partial Siberian Snake”, Physical Review Letters 73, 2982(1994)
[2] T. Roser, et al “Helical Partial Snake for the AGS”, AGS/RHIC/SN-72/BNL (1998)
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