DESIGN STUDY OF A PARTIAL SNAKE FOR THE AGS

M. Okamura[†], T. Katayama, T. Tominaka, RIKEN, Saitama, Japan
T. Ohkawa, Mitsubishi Heavy Industries, Ltd., Kobe, Hyogo, Japan
R. Gupta, A.U. Luccio, W.W. MacKay, T. Roser, E. Willen, BNL, Upton, New York, USA

Abstract

A superconducting helical dipole magnet, which will help preserve the polarization of a proton beam in the 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 magnet has a field of 3 T and an effective length of 2 m. Field shape and multipole components obtained by 3D field calculations are discussed. Also, the cooling system for this magnet is studied.

1 INTRODUCTION

The AGS synchrotron is equipped with a partial snake [1], that helps to overcome the imperfection resonances that appear during the acceleration of polarized protons. The existing partial snake is a solenoid magnet located in the C10 straight section of the AGS, with field that rises at the same rate of the AGS main magnet. The longitudinal (Bz) component of the solenoidal partial snake introduces linear coupling of the transverse coordinates of the beam, and consequently additional intrinsic resonances which affect the final polarization of the beam. In order to reduce the coupling caused by the solenoid magnet, an alternative partial snake composed by an helical dipole magnet, has been proposed [2]. The basic structure is similar to the RHIC snake magnets[3], but more complicated. A desired rotation angle of spin is 30 degrees. To achieve high polarization in RHIC, overcoming intrinsic resonance in the AGS is indispensable.

2 BASIC DESIGN

A 3D view generated by OPERA-3D[4] is shown in Fig.1. In order to increase the spin rotation angle in the limited space in AGS, the helix twist pitch changes in different sections as shown in Fig. 2 and Table 1. The effective magnetic length is 2.028 m and warm bore radius is 150 mm. Required magnetic field strength for 30 degree spin rotation at $G\gamma = 8.68$ beam is 3 T. Due to the use of a symmetric helical magnetic field, the overall beam deflection is canceled, so the extracted beam is parallel to the injected beam, on a different line. This beam shift in the horizontal plane will be cancelled by

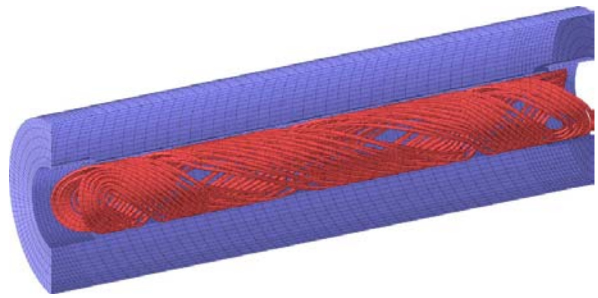

Figure 1: 3D view of the partial helical snake.

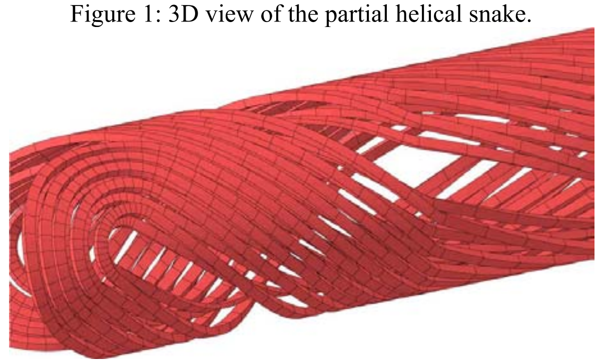

Figure 2: Coil structure.

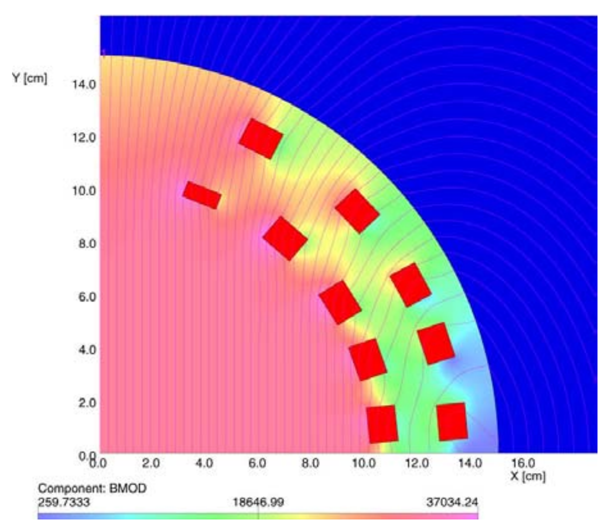

Figure 3: Cross-sectional view of the helical snake

trim coils, installed at main dipole magnets of the AGS on both side of the new AGS snake magnet. The structure of the magnet is complicated, so that 3D field analysis is needed. Figure 3 shows a cross-sectional view of the magnet. Each current block is supported by a machined cylinder of aluminum or stainless steel, and has 12 by 9 cable layers. Only the top current block in the inner layer has 5 layers of cable windings. To induce 3 T of magnetic field, 340 A of current is needed. Considering 3D-effects, length and outer diameter of the yoke were determined not to exceed 1.4 T of field strength in the outer surface region. The field excitation curve predicted by the 3D calculation is indicated in Fig.4.

Table 1: Design Parameters

Parameter	Value
Coils	
Current density (A/mm^2)	567
Operating current (A)	340
Total turns	2064
O. D. of Cable (mm) (6 around 1type)	1.0
Copper ratio	2.5
Total turns	1728
Inductance (H)	7.7
Stored energy (MJ)	0.45
Magnetic length (mm)	431, 1166, 431
Total angle (degree)	180, 243.5, 180
Helical pitch (deg./mm)	0.4176, 0.2088, 0.4176
Yoke	
I. D. (mm)	300
O. D. (mm)	740
Length (mm)	24000
Packing factor (%)	99

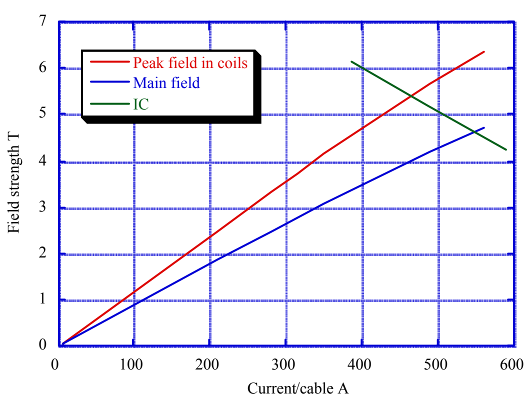

Figure 4: Peak field and IC curve.

3 FIELD QUALITY AND SHAPE

The field shape of the helical partial snake has unique distortions and then multipole components were computed by using 2D and 3D codes. Table 2 shows results with the 2D and 3D calculation models. In 3D case, these values are obtained at the center of the magnet. The assumed current was 350 A/cable. Discrepancies between 2D analysis and 3D(azim.) analysis, derived from azimuthal field component expansion, are due to 3D effects. The magnetic field flux in the iron runs not only in the transverse plane but also in longitudinal direction in the 3D structure and the saturated regions of the poles are slightly different in the 2D and 3D cases. The vertical component of the field is not the same as that derived from an expansion of the azimuthal field component, due to the presence of a longitudinal field component in the magnet[4].

Table 2: Multipole components

	2D	3D(azim.)	3D(vert.)
Dipole (T)	3.168	3.078	3.091
Sextupole / Dipole	5.6 x 10^{-4}	6.1 x 10^{-4}	-3.6 x 10^{-3}
Decapole / Dipole	-5.1 x 10^{-5}	-3.6 x 10^{-5}	-3.8 x 10^{-5}

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

The field shape along beam axis is shown in Fig. 5. The center of the magnet corresponds to z = 0. Major multipole components are indicated in Fig. 6. In the body of the magnet, these sextupole and decapole components are within +- 23 gauss. In order to suppress the sextupole component, a pair of additional correction sextupole windings will be designed based on magnetic field measurement at the test bench and installed at the ends.

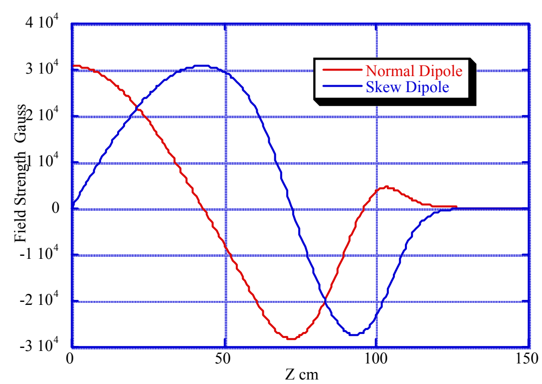

Figure 5: Dipole component.

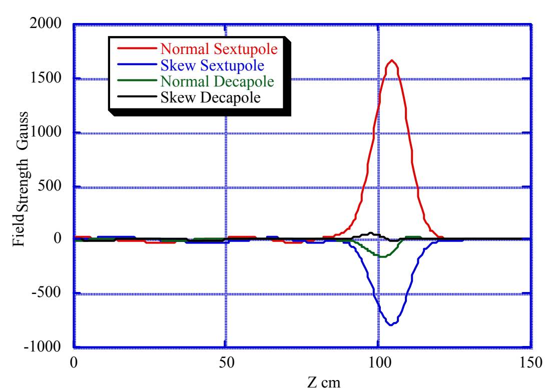

Figure 6: Sextupole and Decapole components

4 COOLING SYSTEM

For cryostat cooling, three systems (conduction cooling, re-condensation, pool cooling) were compared. We calculated the thermal load of the three systems, and estimated their annual cost listing advantages and disadvantages are listed. The comparison of cooling systems is shown in Table 3.

(1) Conduction cooling

(advantages)

- There is no need for liquid helium.
- Running cost is only for electricity to drive the cryocooler, so annual cost is low.

(disadvantages)

- It takes about 175 days to cool down the cold mass from room temperature (300K) to 4.2 K.
- Even if the cold mass is pre-cooled by liquid nitrogen, it takes about 60 days to cool down the coil from 77 K to 4.2 K.
- If the stored energy, for example 0.45 MJ, is released in a quench, it takes about 5 days to recover superconducting state.
- Cryocooler needs maintenance every 10,000 hours.

(2) LHe Re-condensation

(advantages)

- Liquid helium re-condensation system provides long-run operation of equipment for the elimination of evaporated liquid helium from the cryostat.
- Running cost is only electricity to drive the cryocooler, so annual cost is low.

(disadvantages)

- We need about 5700 L liquid helium for initial cooling.
- About 170 liter liquid helium evaporate if the stored energy, for example 0.45 MJ, is released in quench.
- Cryocooler needs maintenance every 10,000 hours.

(3) Pool cooling

(advantages)

- Pool cooling system is the most reliable.
- Structure of the cryostat is the simplest.

(disadvantages)

- Running cost is high.
- We need about 5700 L liquid helium for initial cooling.
- About 170 liter liquid helium evaporate if the stored energy, for example 0.45 MJ, is released in quench.

Conduction cooling systems present two serious problems. One is a very long initial cooling time, the other is a long quench recovery time. In conclusion, conduction cooling systems are not suitable for the cooling system of this cryostat. Selection of liquid helium re-condensation system or pool cooling system presents no serious problem. The evaporated volume of liquid helium at coil quench are reduced about one third if the coil is protected with an external resister of 4 Ω. Even if the coil quenches three times a day, only 170 liters liquid helium in the reservoir tank evaporates and there is no need for additional liquid helium injection. From the point of view of reliability, a liquid helium re-condensation system is a little inferior to pool cooling system, but its annual cost is lower. It seems reasonable to choose a liquid helium re-condensation system for the cooling system of this cryostat.

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)

[3] M. Syphers, et al "Helical Dipole Magnets for Polarized Protons in RHIC", PAC97, Vancouver, 12-16 May (1997)

[4] Vector Fields Limited, Oxford, UK

[5] T. Tominaka, et al "Analytical Field Calculation of Helical Dipole Magnets for RHIC Snake", PAC97, Vancouver, 12-16 May (1997)

Table 3: Comparison of cooling system

Item		Unit	Conduction Cooling	LHe Re-condensation	Pool Cooling
Thermal load	to 4K	W	1.8	2.3	3.3
	to 20K	W	12.2	12.2	-
	to 80K	W	92	92	93
4K Cryocooler	Refrigeration capacity	W	1.5 (4.2K) 35 (50K)	1.5 (4.2K) 35 (50K)	-
	Number		2	2	-
	Power requirement	kW/unit	6.5	6.5	-
Loss of LHe		L/h	-	-	4.6
Requirement of LHe for initial cooling		L	-	5700	5700
Initial cooling time	from 300K to 4K	day	175	10	10
	from 80K to 4K	day	60	5	5
Initial cost (cryocooler and LHe)		k$	154	179	90
Running cost		k$/year	43	43	150
Annual Cost		k$/vear	58	60	159