5/6-9/91.

BNL--45389

"Siberian Snake" Solenoid for the AGS*

DE91 009826

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ABSTRACT

Recent experiments[1,2] at the Indiana University Cyclotron Facility (IUCF) have demonstrated that "Siberian Snakes" can be used to preserve the polarization of an accelerated polarized beam in a circular accelerator. Retrofitting full snakes into accelerators such as the Alternating Gradient Synchrotron (AGS) at Brookhaven is almost impossible due to space limitations, but a partial snake that can correct depolarization due to imperfection resonances with $1/20$ to $1/30$ of a full strength snake seems to present a viable option. We describe such a device for the AGS and give the design criteria in terms of simplicity of accelerator operation and level of achievable polarization.

INTRODUCTION

The major difficulty in accelerating polarized protons is the existence of depolarizing resonances. These must be corrected as was done at the ZGS,[3] AGS,[4] Saturne,[5] and KEK[6] or eliminated by lattice choices and/or devices such as Siberian Snakes.[7] The magnitude of the problem is illustrated by the fact that even with tested equipment and previous experience, it took 2-3 weeks to establish a reasonable polarization level in the AGS at 18.5 GeV/c. One had to correct five intrinsic and some 30 imperfection resonances. See Figure 1. Polarization stability varied during the running period by more than $\pm 5\%$ even with constant attention by the operations crew which prevented them from doing other things to improve operations, such as maximizing intensity,

extraction efficiency, and spill structure. Since the 30 imperfection resonances are caused by vertical closed orbit distortions which change with time, they cause much more retuning problems than the five intrinsic resonances whose corrections are relatively constant. Thus, a device to reduce 2-3 weeks of tuning to 2-3 days and which would mitigate the constant monitoring, makes the difference between an operational facility and an R&D effort. Fortunately, we have discovered that a "partial Siberian Snake" can eliminate the imperfection resonances and make machine turn on relatively painless.

Dipole
Currents

Pulsed
Quads

Magnet
Cycle

Figure 1. AGS Main Control Room oscilloscope trace showing the acceleration of polarized protons to 16.5 GeV.

SIBERIAN SNAKES

Siberian Snakes invented by Ya.S. Derbenev and A.M. Kondratenko are devices inserted into the lattice that are transparent to orbit and focussing parameters, but rotate the spin of a circulating proton as it traverses the snake by 180° around a horizontal axis.

*Work performed under the auspices of the U.S. Department of Energy.

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Thus, any effects of depolarizing resonances will be cancelled on successive turns through the snake. At high energy, a snake can be made up of a sequence of dipole magnets that deflect the beam horizontally and vertically in alternate magnets such that the trajectories are unchanged, but the spin is rotated by 180° . This is not practical at low energies since the deflections of each individual magnet would be too large to contain in a reasonable vacuum chamber. Instead, at low energy we can use a solenoid to rotate the spin 180° without any effect on trajectories. However, this is not useful at high energies since the current in the solenoid becomes impossibly large. Such a solenoid snake was used at the IUCF cooler ring to make the first experimental tests [1,2] of Siberian Snakes.

IUCF EXPERIMENTAL TESTS

Using both vertically and horizontally polarized protons, we were able to show that the snake solenoid was able to correct both intrinsic and imperfection resonances, as well as synchrotron depolarizing resonances. Figure 2 shows the correction at an intrinsic resonance.

Figure 2. The Siberian Snake overcoming the $G\gamma = -3 + \nu_y$ intrinsic depolarizing resonance.

But, more importantly, from the standpoint of accelerators in the 30 GeV range such as the AGS, was the fact that

we could maintain polarization at an imperfection resonance with only a small percentage of a 100% snake. Figure 3 shows that polarization was maintained with a very small snake excitation. Since these resonances occur about every 500 MeV, it rapidly becomes impractical to correct them without a snake and a full snake is far too large for the straight sections of accelerators in this energy range.

Figure 3. A partial Snake overcoming the $G\gamma = 2$ imperfection depolarizing resonance.

AGS REQUIREMENTS

The layout of the AGS requires a solenoid to fit into a 10' straight section and to accommodate a 6" i.d. vacuum pipe. It should have sufficient strength to correct $G\gamma = 48$ which is at an energy above the Relativistic Heavy Ion Collider (RHIC) transition energy and, thus, the AGS could be used to inject polarized protons into RHIC. In addition, this energy is one at which the AGS-RHIC transfer line does not depolarize the beam. Since the solenoid should be turned on and off on a flattop with a spin tune $\nu_{sp} = 1/2$ and should ramp between the two flattops, an air-core, room-temperature solenoid seems the best choice. At 24.84 GeV/c ($G\gamma = 47-1/2$), we need for an 180° rotation 93.2 T-M. To determine the precession angle (θ_p) needed for an AGS partial

snake, we use the data from our previous polarized beam runs to first determine the resonance strength ϵ and then calculate θ_p for a given ϵ and polarization survival percentage P_f/P_0 (see Figure 4). This is AGS specific, but will not differ too much for similar machines. Table I shows achievable polarization for various θ_p and AGS energies. From this we see that for a $P_f/P_0 = 90\%$ at 24.8 GeV/c, we need a $\theta_p = 8^\circ$ or a 4.5% snake. A 5% snake is needed for $P_f/P_0 = 100\%$.

Figure 4. Resonance strengths vs. polarization survival (P_f/P_0 from computer simulations for several different strength snakes).

Table I. P_f/P_0 for AGS Resonances at Several Snake Precession Angles.

Gy Range	P (GeV/c) At End of Range			
		$\theta = 4^\circ$	6°	8°
7-13	7.0	0.52	1.00	1.00
7-20	10.6	0.40	1.00	1.00
7-27	14.3	0.30	1.00	1.00
7-36	19.0	0.13	0.995	1.00
7-42	22.0	0.04	0.995	1.00
7-47	24.8	0	0	0.90

A solenoid of 90" length with 304 turns requires 12.6 KA for 9° . An end view and coil cross-section is shown in Figure 5. This would use about 200 V at 12.6 KA, but because of the ramped use, the RMS power is only 92 KW and the solenoid temperature rise can be easily held to $\Delta T \leq 30^\circ\text{F}$.

Figure 5. Schematic of coil and end view--not to scale.

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