EXPERIMENTAL TEST OF THE SIBERIAN SNAKE CONCEPT*

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Abstract

We are now beginning an accelerator physics experiment[1] at the Indiana University Cyclotron Facility (IUCF) proton Cooler Ring, which will be the first experimental test of the Siberian Snake concept for dealing with depolarizing resonances. If this test is successful, Siberian Snakes may allow the acceleration of polarized beams to very high energies at facilities such as the 20 TeV SSC, the 3 TeV UNK, the 800 GeV Tevatron and the 100-200 GeV RHIC. Siberian Snakes might also be used at facilities such as the 30 GeV AGS, the proposed Kaon Factories, and the 70 GeV Serpukhov U-70.

Introduction

We hope to someday be able to accelerate and store polarized protons in very high energy devices such as the 20 TeV Superconducting Super Collider. At the Ann Arbor SSC Accelerator Workshop in December 1983, we proposed that "Siberian Snakes" might allow the acceleration of polarized protons at the SSC at a relatively small incremental cost.[2] We then organized the June 1985 Ann Arbor Workshop on Polarized Beams at the SSC, which produced a fairly detailed plan for adding polarization capability to the SSC.[3] In Fall 1987 we submitted a request to the SSC/CDG to leave 50 10-meter long straight sections in the the SSC lattice for the installation of Siberian Snakes.[4]

The basic concept of the Siberian Snake, which was proposed around 1975 by Derbenev and Kondratenko[5], is to rotate the spin by 180° about a horizontal axis on each turn around the ring. This rotation should result in any spin precession which occurs during one turn being exactly cancelled by the opposite precession during the next turn. This technique would eliminate the depolarizing resonances which are otherwise encountered during the acceleration of polarized beams. The technique of correcting and jumping depolarizing resonances was first developed at the ZGS[6] and is now used at the AGS[7], KEK[8], and Saturne[9] to cross a moderate number of resonances (< 50). However, this time consuming technique seems impractical for very high energy accelerators; at the SSC each 20 TeV ring would have about 36,000 depolarizing resonances!

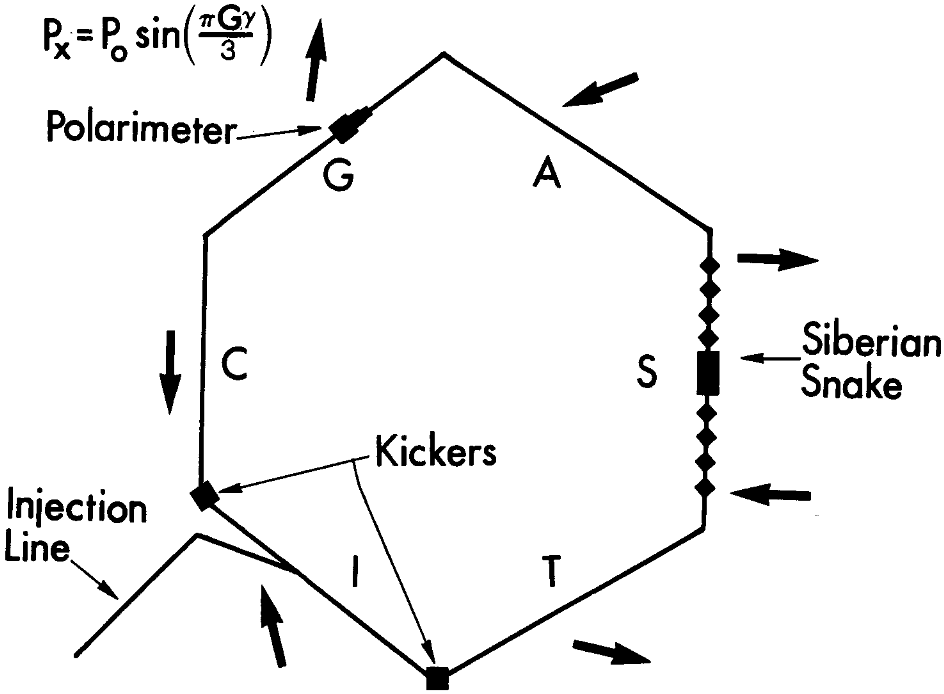

Fig. 1. Schematic diagram of the IUCF Cooler Ring showing the location of the kicker injection magnets, the CE-01 detector used as a polarimeter and the Siberian Snake magnet system. The arrows indicate the polarization direction for the horizontal polarization at $G\gamma = 2.5$.

had an initial polarization of 65% at 180 MeV just above the $G\gamma = -3 + \nu_y$ intrinsic depolarizing resonance. In spite of a serious background problem, the IUCF group was able to find a measured asymmetry of 17 ± 8%. Assuming no depolarization, this implies that the effective analyzing power of the polarimeter is 26 ± 12% for 180 MeV p-Nitrogen scattering events with a scattering angle $\geq 5.7°$. This effective A is consistent with rough estimates made by integrating the measured $A(\theta)$ and $d\sigma/d\Omega(\theta)$ for angles greater than 5.7°. We believe that this measurement is the first experimental indication that electron cooling does not seriously depolarize a beam of polarized protons.

The basic element of our Siberian Snake is a superconducting solenoid which is able to rotate the spin by 180° about the longitudinal axis. As shown in Fig. 2 we must also install 8 symmetrically placed quadrupoles to compensate for the orbit focusing and rotation caused by this strong solenoid. Four of the quadrupoles are partially skew and restore the 32° orbit rotation caused by the solenoid; the other four are not skew and compensate the strong solenoid focusing. With the solenoid and all 8 quadrupoles properly adjusted the snake straight section should have the same beam transport matrix as an empty straight section. We have calculated the quadrupole parameters necessary to give this "empty" transport matrix while the solenoid rotates the spin by 180°.

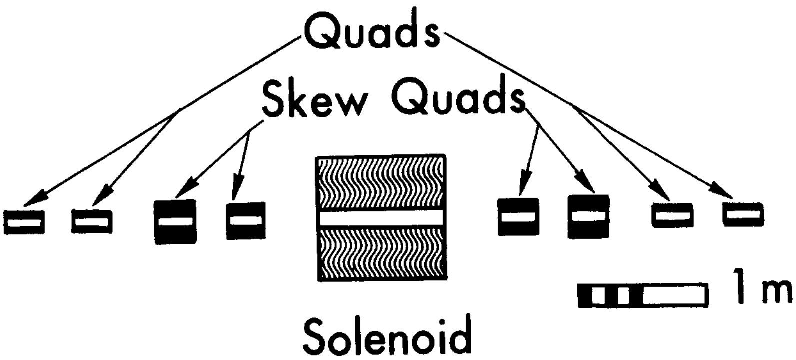

Fig. 2. The Siberian Snake with 8 quadrupoles which compensate for the orbit rotation and focusing caused by the spin rotator solenoid.

All hardware for the Siberian Snake was finished in early Fall 1988 and should be installed during the January 1989 Cooler shutdown. Our main data taking should then begin in Winter of 1989. As can be seen from the table, we will first study the depolarizing resonances with no Siberian Snake to calibrate the energy of the Cooler Ring and to determine the strength of each resonance. We will next set the strengths and skew angles of the 8 compensating quadrupoles to the calculated values and then experimentally adjust them to exactly cancel the orbit distortions caused by the solenoid.

We will then be ready to study our Siberian Snake's ability to eliminate the depolarization caused by the intrinsic $G\gamma = -3 + \nu_y$ and imperfection $G\gamma = 2$ depolarizing resonances. We plan to sweep through the $G\gamma = 2$ resonance by taking 1 MeV energy steps. We plan to sweep through the $G\gamma=-3+\nu_y$ resonance by sweeping ν_y using the Cooler quadrupoles. Our goal is to study these resonances with both a horizontally and vertically[12] polarized beam. We also plan to test the ability of a partial Siberian Snake to eliminate the depolarization due to relatively weak depolarizing resonances.[13] Later we may also study other properties of snakes. We hope to have a preliminary test of the Siberian Snake concept by Summer 1989.

If the Siberian Snake concept really works then one could do spin experiments with very high energy polarized protons by appropriately modifying any accelerator. Therefore, we feel that a "proof of principle" experiment for the Siberian Snake concept is quite important. An experimental verification of the Snake concept would provide the detailed scientific basis which would let one properly plan for the use of Siberian Snakes in high energy accelerators.

After reviewing all existing polarized proton facilities we concluded that the new Cooler Ring[10] at IUCF is especially appropriate to test the Siberian Snake concept for the following reasons:

1. Its 6 m long straight sections allow the insertion of a type 1 Siberian Snake spin-rotator (superconducting solenoid).
2. The Cooler Ring could soon have polarized protons injected from the existing cyclotron polarized beam.
3. The Cooler ring has both types of 1^{st} order depolarizing resonances within its energy range:

Imperfection:	$G\gamma = 2$	T = 108 MeV
Intrinsic:	$G\gamma = -3 + \nu_y \approx 2.135$	$T \approx 179$ MeV

where G = (g - 2)/2 = 1.79285 while g is proportional to the magnetic moment of the proton, $\gamma = E/m = 1 + T/m$, and ν_y is the vertical betatron tune. Both depolarizing resonances are expected to be rather strong and should provide a good test of the Siberian Snake concept.

Experiment

Our proposal was approved in June 1987 with top priority and is now Exp. CE-05 at IUCF. The IUCF Cooler Ring is shown in Fig. 1, along with the special apparatus which had to be provided for this Siberian Snake test. We constructed at Michigan two ferrite injection kicker magnets and one power supply which gives one kicker a fall time of about 180 ns. Both kickers and one power supply were installed in the Cooler ring early this year. The Cooler team first successfully stored and cooled 45 MeV protons in April 1988. During our first run in May 1988 the kicker magnet was successfully used for single turn injection of 148 MeV polarized protons into the Cooler ring. The Cooler team then was able to cool these polarized protons using their electron cooling device.

During a July 1988 Cooler run, 180 MeV polarized protons were injected and cooled; an IUCF group[11] then measured the polarization using a Nitrogen gas jet and the CE-01 detector which also serves as the CE-05 polarimeter. The polarimeter has cylindrical symmetry and can, thus, measure the beam polarization in either the horizontal or vertical direction. The injected protons

Step	Condition	Purpose	Time Requested	Hardware Required
4.1 a/b	Vertical $p_\uparrow$ No Siberian Snakes	Test polarimeter Check depolarizing resonances	8 shifts @ 100 MeV 5 shifts @ 170 Mev	2 Injection kickers 1 Power supply CE-01 detector Internal target
4.1 c	Unpolarized beam with Siberian Snake No acceleration	Test solenoid/ configuration Measure ν_y	3 x 2 shifts	Superconducting solenoid Compen. quads. Quad power supplies
4.1 d	Horizontal $p_\uparrow$ Siberian Snake No acceleration	Test elimination of depol. resonances by Siberian Snake	8 + 11 shifts	Spin rotator in injection line
4.1 e	Vertical $p_\uparrow$ Siberian Snake correction dipole	Test elimination of depolarizing resonances	8 shifts	Programmable correction dipoles
4.2	Horizontal $p_\uparrow$	Study Snake resonances	(15 shifts) Not now requested	Nothing new

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