EXPERIMENTAL TEST OF THE SIBERIAN SNAKE PRINCIPLE*

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Abstract

The first experimental test of the Siberian Snake method of avoiding depolarizing resonances is being carried out at the Cooler Ring of the Indiana University Cyclotron Facility. A superconducting solenoid Type I Snake, which will rotate the proton spin 180° about the longitudinal direction, will be installed along with orbit compensating quadrupoles. An imperfection resonance at $G\gamma = 2$ at a kinetic energy of 108 Mev and an intrinsic resonance at $G\gamma = -3 + \nu_y$ at 179 Mev will be studied to see if the Snake eliminates polarization loss on resonance traversal. A future program will include study of the recently predicted Snake generated resonances.

Introduction

This is a brief report on an experiment[1] which is just commencing which will study the Siberian Snake idea of avoiding depolarizing resonances by precessing the spin 180° about a horizontal axis.

I would first like to emphasize the necessity of having some mechanism like the Siberian Snake to avoid the effects of the depolarizing resonances in the acceleration of a polarized beam. The present methods are brute force solutions.

Intrinsic resonances at $G\gamma = nP \pm \nu_y$, P being the machine periodicity.

With depolarization coming from horizontal quadrupole fields which are seen in the free vertical betatron oscillations, the resonances are handled by rapid traversal with an abrupt shifting of the vertical betatron tune or, with a strong enough resonance, by spin-flipping.

Imperfection resonances at $G\gamma = k$.

Here the depolarizing fields are directly from the machine imperfections and from the quadrupole fields experienced by the particle along the imperfection driven distorted closed orbit. They are handled by correction or possibly spin-flip.

The resonances which have to be crossed at the Brookhaven AGS are shown in Fig. 1. The resonance strengths, ϵ, were calculated by Courant and Ruth.[2] The imperfection resonance spacing is .52 GeV.

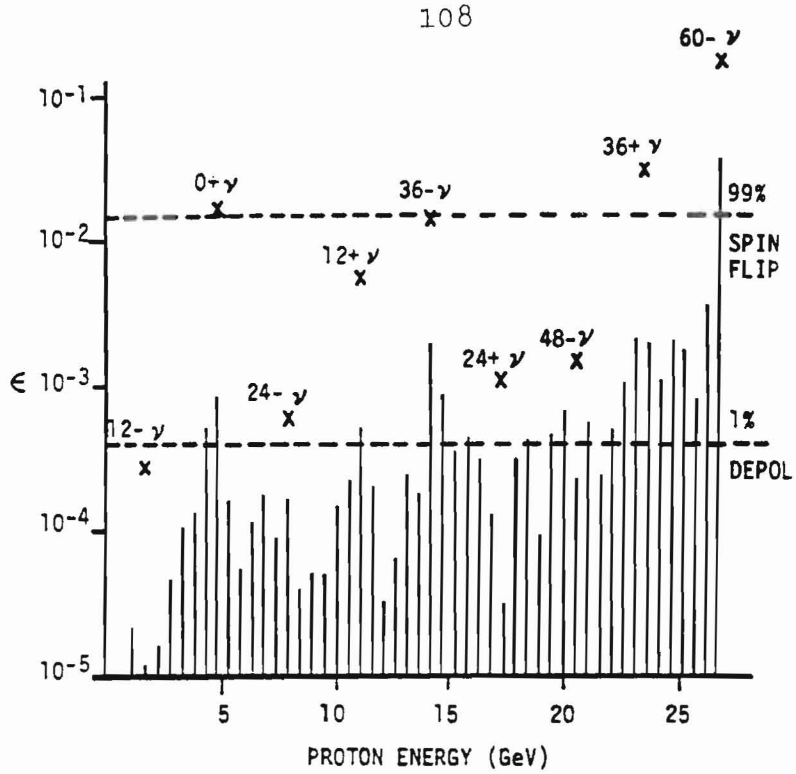

Fig.1. AGS Resonance Strengths. The crosses are intrinsic resonances, the lines imperfection resonances.

Fig. 2 is a scope photo showing the resonance handling process at the AGS.[3] The top trace shows a monitoring of the imperfection resonance corrections. At each imperfection resonance a harmonic correction is applied by a set of 95 horizontal field dipoles around the machine. The trace shows the current pulse at one of the magnets. The spacing is about 10 ms. The amplitude and phase of the required correction to eliminate polarization loss is determined experimentally at the start of the polarized beam running period. Some 35 imperfection resonances had to be corrected to get to 22 GeV/c at the AGS. The second trace shows the current pulses being applied by 10 tune shift quadrupoles around the machine at the intrinsic resonances. The sensitive experimental adjustment here is the timing of the crossing. Five pulsed quadupole firings were needed to get to 22 GeV/c. The commissioning process required to determine the necessary corrections and timing has up to now taken well over a week.

For higher energy machines, these brute force methods will get progressively more difficult. The resonance strengths increase with energy, requiring larger corrections and faster tune jumps. When the strengths become large enough, resonance overlapping will probably preclude the spin-flip approach. In addition, the number of resonances that must be traversed becomes prohibitive if any action is needed at each one: 38,000 resonances are crossed at the 20 TeV SSC.

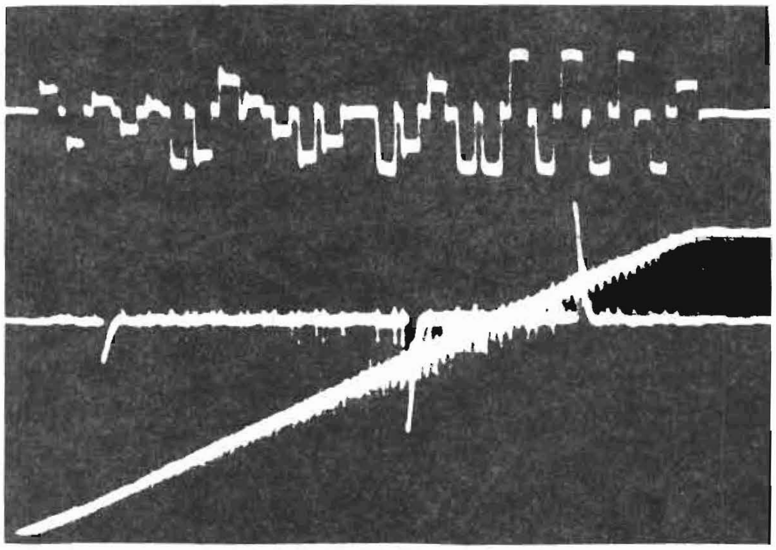

Fig. 2. Scope Traces for AGS Polarized Proton Acceleration.

a) Top: pulsed dipole current

b) Center: pulsed quadrupole current

c) Bottom: magnetic guide field

The imaginative "Siberian Snake" solution to this impasse was proposed by Derbenev et al.[4] in 1977. Their solution was a 180° spin rotation about a horizontal axis: the depolarization generated on one revolution would be removed on the next. The rotator could be a longitudinal field solenoid at low energies, or a set of transverse field dipoles at higher energies, causing an orbit distortion, hence "Snake". This concept has had extensive theoretical investigation since its inception and the basic idea has held up, even though there are some new Snake generated resonances. In 1985 an Ann Arbor "Workshop on Polarized Beams at SSC"[5] concluded that the 180° spin rotation idea looked very good, with strong theoretical support, but there should be an experimental test before any commitment. Such a test would be a major enterprise on a high energy machine, requiring a substantial straight section and considerable construction and accelerator time. A test of the basic principle would be easier with a solenoid design at low energy. The Cooler Ring[6] at the Indiana University Cyclotron Facility, which has been under construction since 1983 and is now in the beam commissioning phase, has turned out to be an excellent place for such a low energy test. The Cooling Ring will be used extensively for polarized beam experiments so the Indiana University Cyclotron group is very interested in such a test and will be a major part of the Snake test collaboration.

Experimental Test of the Snake

The experiment has been approved for the IUCF Cooler Ring and will run from now probably into 1989. The participants are listed in Table I.

Table I. Experiment Participants

University of Michigan	A.D. Krisch R.S. Raymond T. Roser J.A. Stewart K.M. Terwilliger
Indiana University	H.O. Meyer R.E. Pollock F. Sperisen E.J. Stephenson
Brookhaven National Laboratory	E.D. Courant S.Y. Lee L.G. Ratner
Fermi National Laboratory	S.R. Mane

A schematic of the Cooler Ring is shown in Fig.3. The injecting cyclotron can go to 2.2 T-m, about 200 MeV for protons. The 87 meter circumference Cooler Ring can accelerate to 3.6 T-m or 500 Mev. The polarimeter, constructed by our Indiana University colleagues, is installed. Part of the Cooler program will use stripping for injection; stripped ions have been injected onto orbit and electron cooling successfully demonstrated. Since the laboratory at present has only a positive polarized hydrogen ion source a pulsed dipole magnet kicker is required for polarized proton injection. At the University of Michigan we have constructed two ferrite dipole kicker magnets. A photo of one of these kickers is shown in Fig. 4. One kicker has been installed and is shown on the diagram.

Single turns of polarized protons have been injected onto orbit in preliminary tests, but to date no definitive intensity or polarization measurements have been made. Detailed injection studies are tentatively scheduled for this summer in late July. If the single turn intensity is not sufficient it is possible that the second kicker can be used to carry out multiturn beam stacking. When the intensity is satisfactory for polarization measurements we will inject vertically polarized protons and study the position and strength of the two resonances available in the Cooler range:

$G\gamma = 2$, imperfection resonance at 108 MeV,

$G\gamma = -3 + \nu_y$, intrinsic resonance at 179 MeV, for $\nu_y = 5.135$.

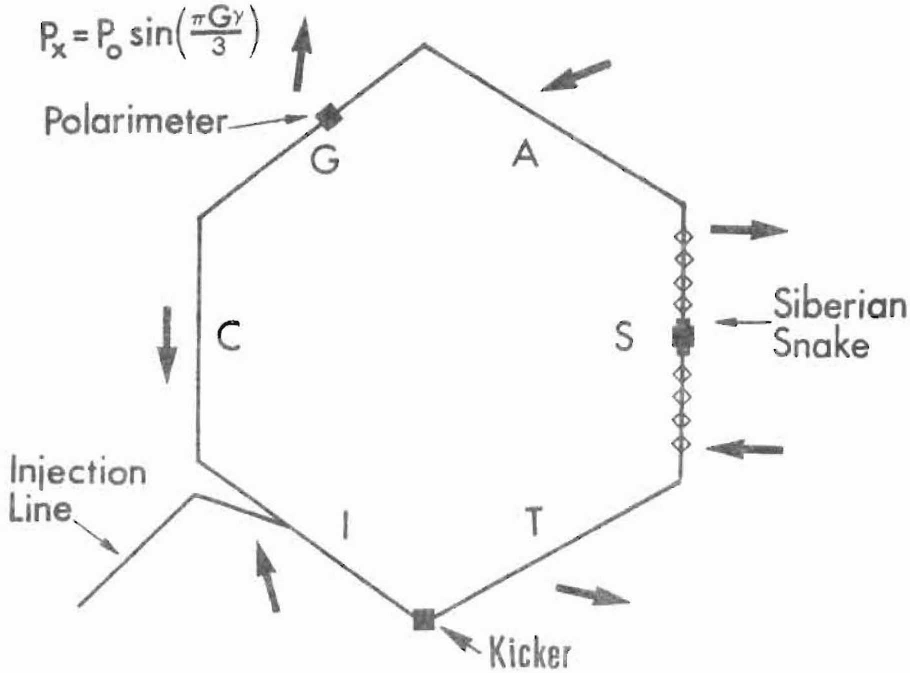

Fig.3. Schematic of the IUCF Cooler Ring. The positions of the pulsed injection kicker magnet, the Siberian Snake solenoid with compensating quadrupoles (to be installed), and polarimeter are indicated. The arrows show the equilibrium spin direction, which is in the horizontal plane, for $G\gamma = 2\,1/2$. All directions are energy dependent except opposite the solenoid.

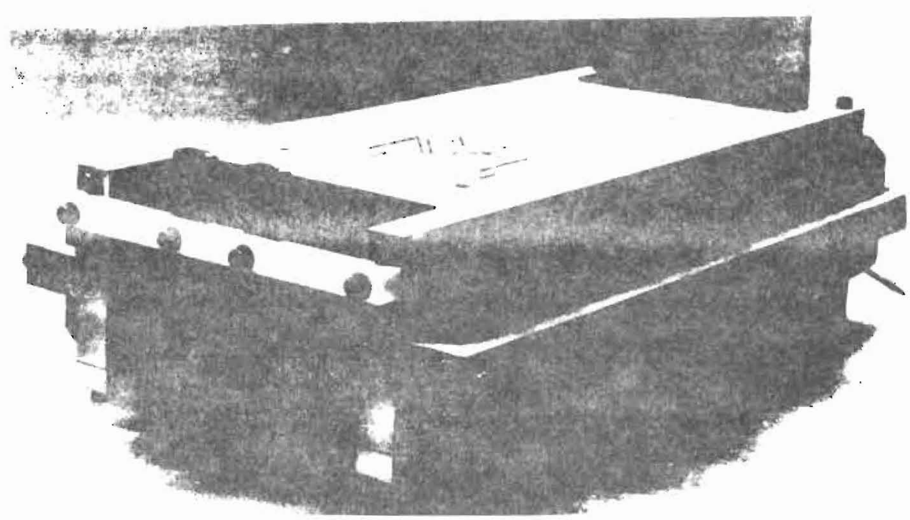

Fig.4. Ferrite Pulsed Dipole Kicker Magnet.

Following the studies of the depolarizing resonances in the unmodified Cooler Ring, the solenoid Snake, required strength 3.75P(GeV/c) T-m, will be installed along with orbit compensation quadupoles. The solenoid, a superconducting neutron spin rotator on loan from Los Alamos, has the capacity to go to the lower energy resonance (1.74 T-m) and possibly the higher (2.27 T-m). Our original intention was to use a pair of University of Michigan superconducting solenoids, but they are unshielded and would require considerable work. The solenoid, which rotates the spin direction 180° about the beam axis, also rotates the plane of the beam about 32°, coupling the horizontal and vertical motion, and adds significant focusing. A solution which compensates for the orbital effects of the solenoid has been worked out; it requires four pairs of quadrupoles, as shown in Fig 5, with parameters given in Table II. The vertical beta function with and without the Snake is shown in Fig. 6. The solution adds an extra integer to ν_x in the Snake area (26 to 32m on Fig. 6), but the orbits are unaffected outside that region. A solution was also found with two quad pairs, but it had large excursions in the region of the Snake. With the Snake and compensating quadrupoles in position, the unpolarized beam will be used to verify that the orbits outside the Snake region have been unaffected.

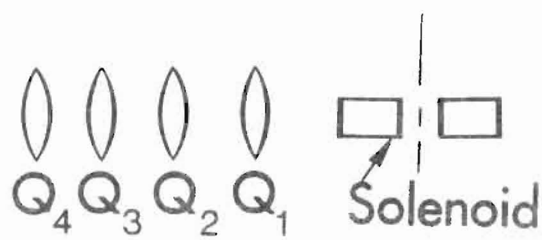

Fig.5. Solenoid with Compensation Quadrupoles

Table II. Parameters for Quadrupole Compensation of Solenoids

	Centerpoint to centerline distance [m]	focal length m^{-1}	skew rotation angle
4-pair solution			
Solenoid	0.56	–	–
Q_1	1.04	1.50	14.2°
Q_2	1.62	1.18	-29.5°
Q_3	2.32	-1.57	0°
Q_4	2.85	1.33	0°

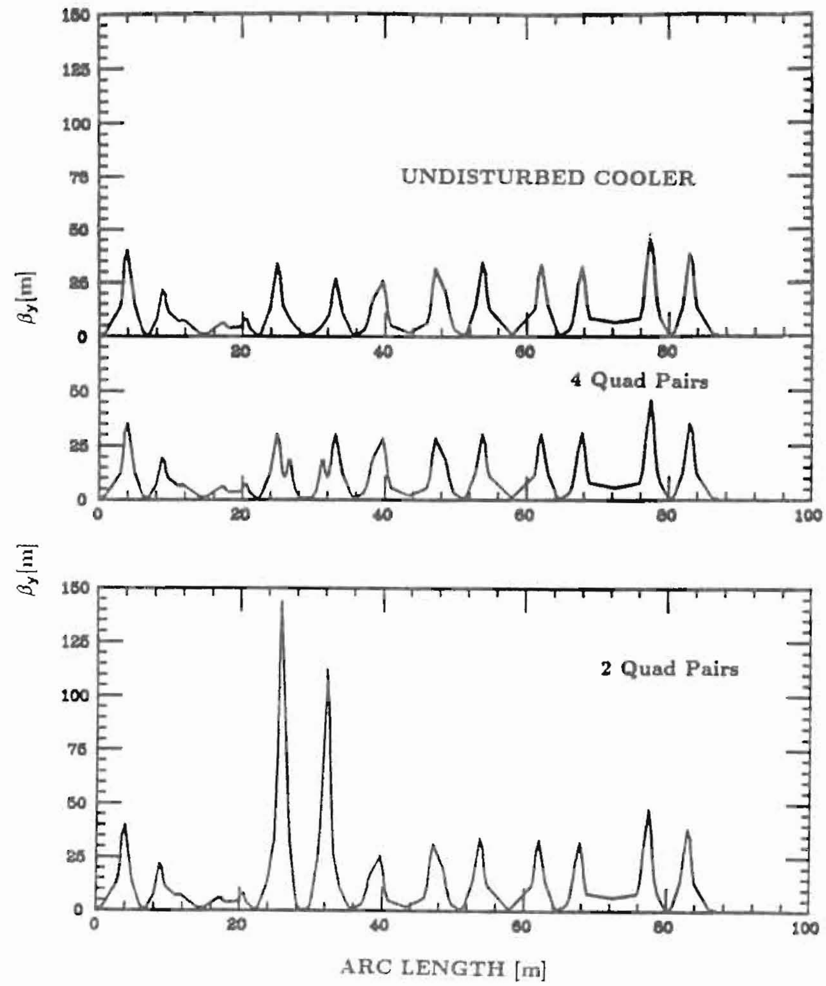

Fig.6. Vertical Beta Function in the Cooler Ring. The orbits are unaffected outside the Snake region for both of the compensating two and four quadrupole pair solutions.

We will then be able to carry out the central proof-of-principle test of the experiment which will be to inject horizontally polarized beam into the Cooler Ring with the Snake and compensating quadrupoles installed and see if the polarization is preserved at the two resonances. With a single solenoid (Type I) Snake the stable equilibrium spin direction is in the horizontal plane, and has a fixed direction (along the beam) independent of energy only at the point opposite the Snake (Fig. 3). The spin tune is 1/2 about the equilibrium spin direction. Injecting close to the equilibriuim spin direction will require proper preparation of the incoming beam polarization vector. We should be able to preserve the polarization if we inject directly at the resonance energy or accelerate across it.

Vertical polarization is predicted to be unstable with a single solenoid Snake. We would like to investigate this situation, to see if the Snake has removed one component of the correction necessary to handle the $G\gamma = 2$ imperfection resonance, which has been suggested.[7]

The above program has been approved for running at the Cooler. If it is successful, we intend to submit a proposal to carry out further studies investigating the Snake behavior in more detail, looking at Snake generated resonances[8] and the possibility of adiabatic turn-on of a Snake while preserving the beam polarization.[9] A summary of our program is shown in Table III.

Table III. Summary

Step	Condition	Purpose	Time Requested	Hardware Required
1	Vertical $p_\uparrow$ No Siberian Snake	Test polarimeter Check depolarizing resonances	8 shifts @ 100 MeV 5 shifts @ 170 Mev	2 Injection kickers* 1 Power supply* Polarimeter+ Internal target+
2	Unpolarized beam with Siberian Snake No acceleration	Test solenoid/quad configuration Measure ν_y	3 × 2 shifts	Superconducting solenoid+ Compen. quads.+ Quad power supplies‡
3	Horizontal $p_\uparrow$ Siberian Snake No acceleration	Test elimination of depol. resonances by Siberian Snake	8 + 11 shifts	Spin rotator in injection line+
4	Vertical $p_\uparrow$ Siberian Snake Correction Dipoles	Test elimination of depolarizing resonances	8 shifts	Programmable correction dipoles+
5	Horizontal $p_\uparrow$	Study Snake resonances	(15 shifts) Not now requested	Nothing new

* provided by Michigan ‡ cost shared equally by Michigan and Indiana

\+ provided by Indiana

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