International Workshop on Advanced Fusion Science Research,
Taejeon, Korea, 6/21-24/95.

BNL-61818

CONF-9506242--1

Polarized Proton Acceleration Program at the AGS and RHIC*

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Abstract

Presented is an overview of the program for acceleration of polarized protons in the AGS and their injection into the RHIC collider. The problem of depolarizing resonances in strong focusing circular accelerators is discussed. The intrinsic resonances are jumped over by the fast tune jump, and a partial Siberian Snake is used to compensate for over forty imperfection resonances in the AGS. Two sets of full Siberian Snake and spin rotators will be employed in RHIC.

I. INTRODUCTION

Since the importance of polarization in high energy proton-proton collisions is discussed in numerous papers,[1] only the program of accelerating polarized protons in strongly focusing accelerators will be discussed, especially at the AGS and RHIC. Figure 1 shows the schematic view of the program.

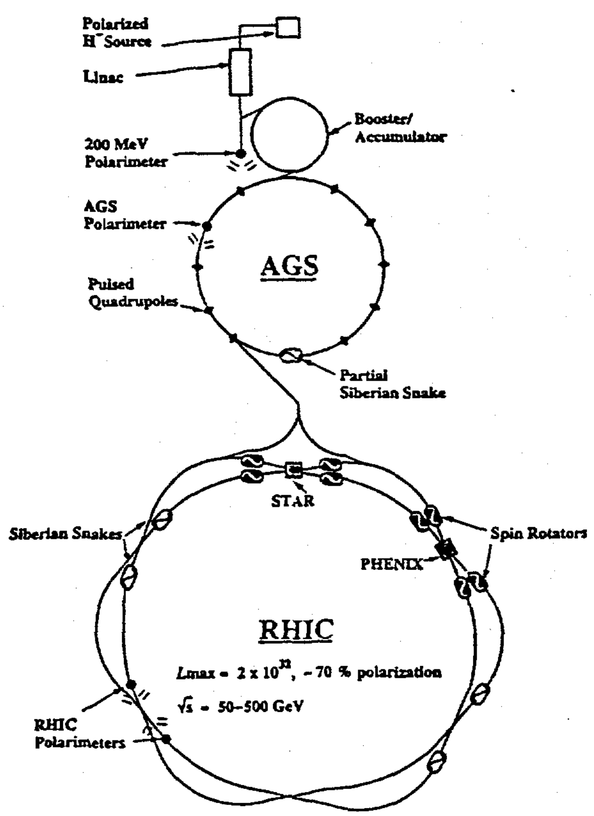

Fig. 1. Polarized proton program at BNL.

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

The system consists of the polarized ion source, 200 MeV linear accelerator, 1.5 GeV Booster, which is also capable of accumulating multiple linac pulses of the polarized protons, the AGS with the devices to avoid depolarization, beam transfer line between the AGS and RHIC, and RHIC with two sets of full Siberian Snakes. The system also consists of a set of polarimeters at each accelerating stage, and the spin rotators for the experimental setups.

II. ION SOURCE

The polarized ion source at the AGS is a colliding beam type[2] negative ion source, capable of producing 35 μAmperes of about 80% polarization in 350 μsec pulses at a repetition rate of 5 Hz. Figure 2 shows a sketch of the ion source.

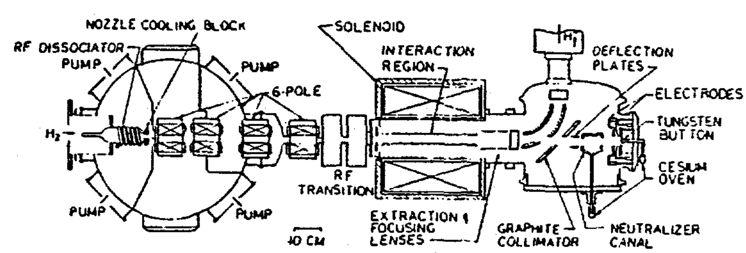

Fig. 2. Polarized H^- ion source.

An atomic beam is produced in the dissociator section and travels through a sextupole channel to select the electron spin state by focusing one while defocusing the other state. Since the effective radial force acting on the atomic hydrogen is proportional to the magnetic field gradient, a sextupole magnet is ideal for this purpose, namely

$$B \propto r^2$$
$$B' \propto r$$

The focused beam with electron polarization next goes in the rf transition section where the electron spin is transferred to the proton polarization. With a suitable magnetic field and rf frequencies, one can choose the proton polarization by taking different transitions of the states. Polarized hydrogen atoms enter a charge exchange section where they collide with a neutral Ce beam. A Ce gun produces about 40 kV positive Ce ions, which are neutralized by resonant charge exchange with Ce vapor. Negative hydrogen ions are produced in the reaction $H^{\circ} + Ce^{\circ} \rightarrow H^{-} + Ce^{+}$. The polarized negative hydrogen is extracted by the extractor through the electrostatic deflection channel. Through a solenoidal field, the proton polarization is turned into the vertical direction.

A Radio Frequency Quadrupole (RFQ) accelerator bunches and accelerates the beam to 750 keV. After accelerating the beam to 200 MeV through the linac, the polarization is measured by the 200 MeV polarimeter.

III. ACCELERATION THROUGH THE BOOSTER AND THE AGS

When polarized protons are accelerated through a circular machine, there are two major types of depolarizing resonances in the first order.

1. $G\gamma = kp \pm n \cdot Q_y$
2. $G\gamma = k$

where k and n are integers, p is the periodicity of the accelerator of interest, Q_y is the vertical betatron tune of the machine, γ is the Lorentz factor, and G = 1.793 is the anomalous magnetic moment of a proton. Resonance of the first kind is dependent on the basic structure of the accelerator lattice and is called the intrinsic resonance, and the other is dependent on the kth harmonic of the vertically bending field and is called an imperfection resonance. It is mainly caused by the misalignment of the focusing elements. When protons are accelerated through a resonance, the resultant polarization can be described[3]

$$P_{final}/P_{initial} = 2e^{-\pi\epsilon^2/2\alpha} - 1$$

where ε is the driving field or strength of the resonance, and α is the speed of the resonance crossing. E. Courant studied a possibility of accelerating polarized protons at the AGS in 1956,[4] and found that it would be very difficult to have such a precise alignment of the focussing element in order to suppress the imperfection resonances. The equation indicates that there may be two ways to deal with the problem other than eliminating or reducing the strength of the resonance. One way is to have the speed of crossing sufficiently fast to preserve polarization or sufficiently slow to flip the spin completely.

Figure 3 shows an estimate of the strengths of the resonances at the AGS by Courant and Ruth,[5] x's are the intrinsic resonances and the vertical bars indicate the probable imperfection resonance assuming the rms misalignment of the AGS magnets of 0.1 mm. There are 10 ferrite core fast quadrupoles at the vertical bat maximum locations at the AGS to change the vertical tune of the AGS about 0.25 units in the time of one revolution. Thus, effectively crossing the intrinsic resonance fast enough to preserve the polarization.

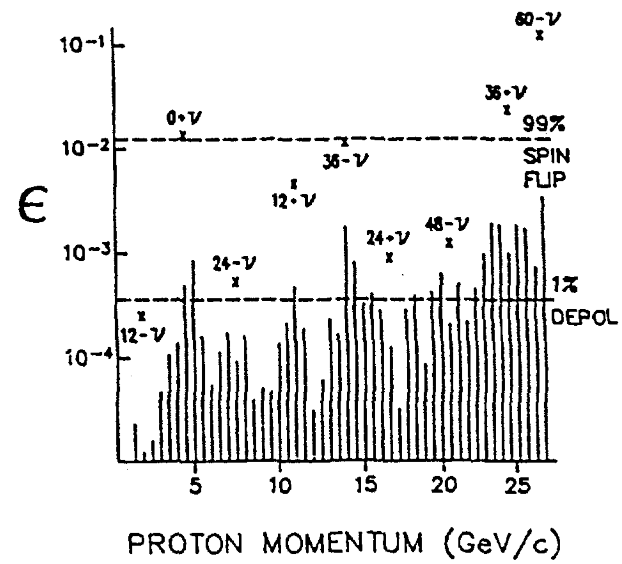

Fig. 3. Calculated resonance strength at the AGS.

Figure 4 shows the resultant polarization after crossing one of the intrinsic resonances as a function of the main magnetic field as the quadrupoles are pulsed. As shown in the figure, it almost depolarizes completely when the timing of the pulse is too early, sin flip occurs when the quadrupole decay line overlaps the resonance line and effectively crosses the resonance very slowly, and complete survival of the polarization when the timing of the pulse is right. This method worked for most of the intrinsic resonances except the ones at 36 + Q_y and 60 - Q_y where some loss of the polarization may not be avoidable. For imperfection resonances, the original plan was to cancel the imperfection harmonics using 92 correction dipoles. This method worked up to a point, but very tedious tuning of the imperfections requires up to two weeks of machine time. Moreover, a large number of the resonances cause a significant decrease in the polarization at the end; namely, a small percentage loss due to imperfect correction in each of the 40 resonances, come significant.[6]

In 1977, Ya. Derbenev and A.M. Kotratenko[7] proposed the 180°spin rotating horizonal axes (Siberian Snake) to overcome depolarizing resonances. It is easy to see that a spin precession in one revolution is cancelled by the next revolution. Therefore, spin in each revolution amounts to one 180° precession in the Snake axis, i.e., effectively modifying the spin tune to 1/2. the sin is reversed in each successive turn. In general, two Siberian Snakes are used; however, it is easy to see that one should not utilize two identical snakes for they make spin tune an integer. In

order to avoid such a problem, one uses two snakes of two different precession axis, one in the longitudinal (first kind) and the other in the radial (second kind) axis for example. The snakes are constructed with a series of dipoles[7-9] (or helical dipoles), which cancels the transverse motion but rotates the spin in a desired axis. However, there is considerable transverse excursion of the particles inside a snake and the motion is inversely proportional to the beam energy. Therefore, this kind of snake is not practical for low and medium energy accelerators like the AGS. A solenoidal field can rotate the spin in the longitudinal axis; however, the amount of field required is proportional to the beam energy.

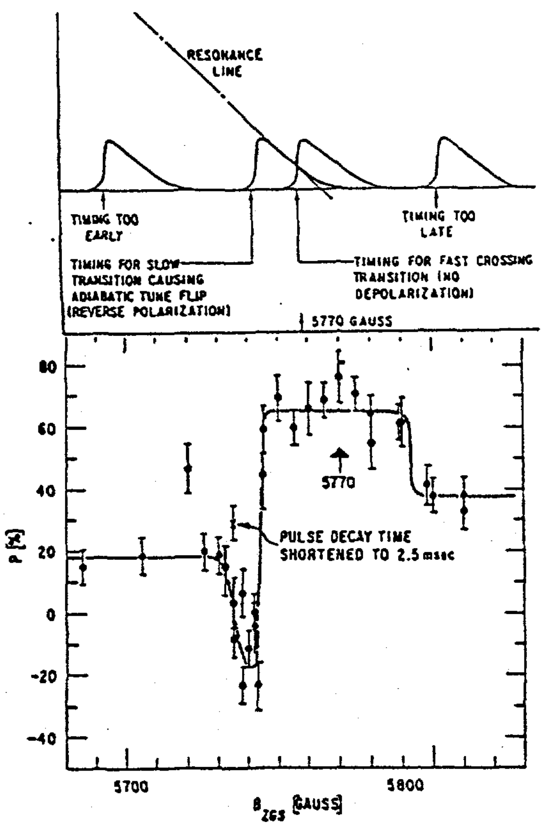

Fig. 4. Jumping through an intrinsic resonance.

For the AGS energies, neither snakes are practical because of the lack of adequate straight sections. In 1989, T. Roser proposed a partially exited snake to overcome the imperfection resonances.[10] Roser noticed that only a 5% snake is sufficient to overcome all imperfections in the AGS and keep the spin tune away from an integer, thus avoiding the resonance completely. The solenoid partial snake capable of ramping to 4.7 T-m was installed in one of the 10 foot straight sections and tested for spin preservation. Figure 5 shows the results of the test. A complete depolarization occurs when the snake was off while the polarization was preserved when the snake was on, except where the beam encountered intrinsic resonances, where the tune jumping system was not employed in this test.

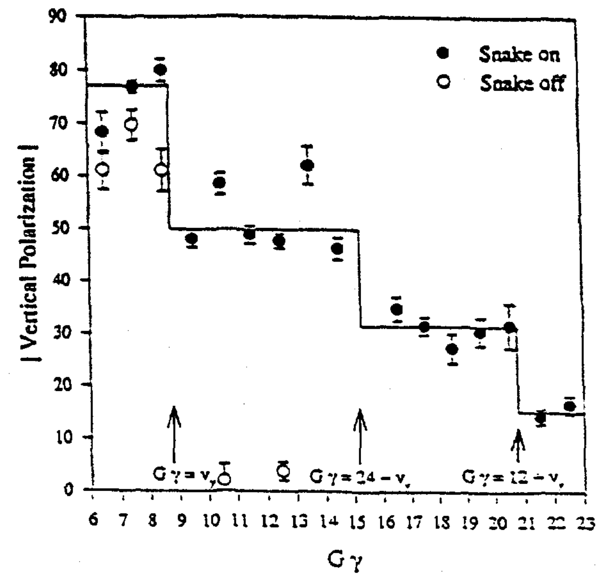

Fig. 5. Partial snake experiment.

IV. RHIC

Since the AGS and RHIC are not on the same plane, the beam transfer requires a series of horizontal and vertical bends. A mixture of horizontal and vertical bends rotates and effectively reduces the polarization. A calculation shows that there is the magic momentum here the transfer line keeps the polarization intact at $\gamma = 26.75$. A 90% polarization can be kept at the beam energy between $\gamma = 25.1$ and $\gamma = 27.8$. The proton energy corresponding to those limits is acceptable for RHIC injection. There is a proposal to minimize the effect of the transfer line[11] by introducing three horizontally bending dipoles around a vertical bend.

A calculation shows that by inserting two full Siberian Snakes on opposite sides of each of the two RHIC rings (see Fig. 1), one can avoid both intrinsic and imperfection resonances up to 250 GeV. The snake axis chosen is 45° from the beam direction in the horizontal plane, one pointing inward and the other pointing outward. The advantage of this choice is that construction of both snakes is identical. The Siberian Snake planned for RHIC is the helical magnet type.[12] There are several advantages of utilizing helical magnets, some of which are: (a) maximum transverse excursions are smaller, (b) allow an easier control of the snake axis, (3) identical construction can be used for both the snakes and the spin rotators. In addition to the snakes, there are sets of spin rotators for each interaction region in order for the experimenter to choose the spin orientation, horizontal or transverse, and to compensate for the effect of the final bending before the crossing point.

ACKNOWLEDGEMENT

Dr. Thomas Roser's help through many invaluable discussions is greatly appreciated.

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