POLARIZED PROTON BEAM IN THE AGS [a]

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This paper summarizes the recent efforts of accelerating polarized protons in the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory. A coherent spin resonance excited by an rf dipole was used to overcome depolarization due to intrinsic spin resonances in the AGS. Significant spin flips were generated, without emittance growth, at several intrinsic resonances by adiabatically exciting a vertical coherent betatron oscillation using a single rf dipole magnet. In the latest run, a significant polarization loss occurred at 22GeV/c. It was found that the resonance strength was intimately connected with the horizontal closed orbit distortion. By correcting the horizontal closed orbit, the polarization was restored. The future plan is also discussed.

Acceleration of polarized protons in the AGS is challenged by numerous imperfection and intrinsic depolarizing resonances. A 5% partial Siberian snake has been tested successfully in the AGS to overcome the imperfection depolarizing resonances. Traditionally, the intrinsic depolarizing resonances are overcome with tune-jump method, but it causes emittance growth and requires sophisticated equipments. A novel scheme of using an rf dipole to overcome intrinsic resonances has recently been tested successfully in the AGS.

Since the intrinsic spin resonance strength is proportional to the betatron amplitude, the final polarization is an ensemble average of the Froissart-Stora formula over the betatron amplitude of the beam particles. The smaller the oscillation amplitude, the weaker the spin resonance strength. Therefore, after crossing a spin resonance, the spin vector for different particles spread out and the beam polarization is decreased. It is difficult to achieve a full spin flip for all particles since the resonance strength of the beam core is small.

[a] Work Performed Under the Auspices of the U.S. Department of Energy

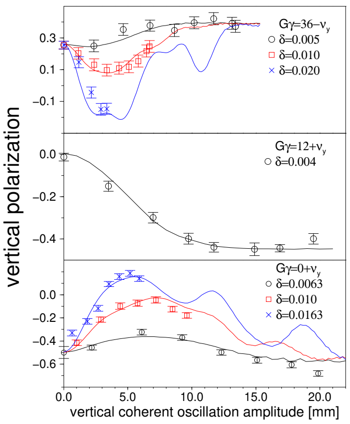

Figure 1: The measured proton polarization vs. the coherent betatron oscillation amplitude (in mm) for different tune separations at spin depolarizing resonances at $= 0 + \nu_y$(bottom plot), $12 + \nu_y$(middle plot), and $= 36 - \nu_y$(upper plot). δ stands for the separation between the modulation tune ν_m and the vertical betatron tune ν_y . The error bars show only the statistical errors. The resonance strength due to the rf dipole is proportional to the coherent betatron amplitude. The lines are the results of multi-particle spin simulations based on a model with two overlapping spin resonances.

Alternatively, if the beam is kicked to induce a coherent betatron oscillation so that the betatron oscillation amplitudes of all particles are large, a full spin flip can be attained. A pulsed dipole can induce a coherent betatron oscillation, but it causes emittance growth since this is a non-adiabatic process. An adiabatic coherent betatron oscillation can be excited and maintained without emittance growth by using an rf dipole magnet operating at a frequency close to a betatron sideband. An artificial rf spin resonance generated by this coherent motion is located at the modulation tune ν_m. If we choose the rf spin resonance location near the intrinsic spin resonance, the spin motion will be dominated by the rf resonance and the spin near the intrinsic resonance will adiabatically follow the spin closed orbit of the rf spin resonance. Fig. 1 shows the measured polarization at three energies versus the rf dipole strength, which is converted to the corresponding coherent betatron amplitude. Since the spin resonance at $12 + \nu_y$ was relatively weak, it is easier for the rf-induced spin resonance to dominate, giving a smooth dependence of the measured polarization on the rf dipole strength shown in the middle plot of Fig. 1. On the other hand, since the intrinsic spin resonance at $0 + \nu_y$ and $36 - \nu_y$ were strong enough to partially flip the spin, they strongly interfered with the coherent spin resonance induced by the rf dipole. In agreement with the numerical simulation, the upper and lower plots of Fig. 1 show complicated interference patterns when the tune separation δ is large. The experimental data show that measured beam polarization became saturated at large oscillation amplitude which indicates a full spin flip was achieved. A new type of spin resonance at $G\gamma = 60 - \nu_y - 9$ was found in the most recent polarized proton run at the AGS. This resonance was found to be associated with horizontal closed orbit distortion and can be understood as a second order effect of the spin precession tune modulation due to the horizontal focusing fields when large horizontal closed orbit distortion occurs. In the experiment, the horizontal harmonic correctors were employed to eliminate the horizontal closed orbit distortion and correct this second order intrinsic spin resonance.

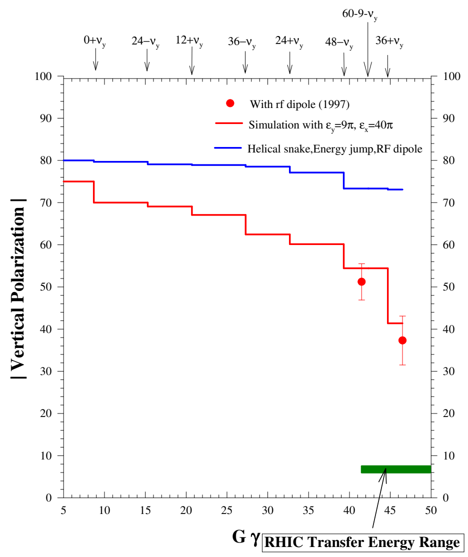

Figure 1: Results of AGS Polarization.

In the recent polarized proton run in the AGS, the beam polarization has reached 51% at 22 GeV/c with a input polarization of 75%. A simulation shows that much of the remaining depolarization occurring in the AGS is associated with the transverse coupling resonances, whereby depolarizing resonances are seen not only when the vertical tune is at an integer relation with $G\gamma$, but when the horizontal tune is as well. And, in fact, a major source of the transverse coupling is the strong solenoidal field of the partial Siberian snake. To combat the transverse coupling inherently produced by a solenoidal magnetic field, use of a helical dipole magnet in the AGS to generate a partial snake has been proposed[1]. The study shows that the level of the coupling is dramatically reduced. With a new source which can deliver 80% polarization[2], and a stronger rf dipole for the strong intrinsic resonances, and energy jump scheme for the weak intrinsic resonances[3], 70% polarization at the RHIC injection energy is feasible.

References

1. T. Roser, et al., AGS/RHIC/ Spin Note No. 72(1998).
2. A. Zelenski, these proceedings.
3. H.Huang, et al., Proc. of 12th International Symposium on High Energy Spin Physics, Amsterdam, 528-530(September,1996).