

Spin-Flipping a Stored Polarized Proton Beam with an rf Dipole*

B.B. Blinov[†], Ya.S. Derbenev, T. Kageya, D.Yu. Kantsyrev[‡],
A.D. Krisch, V.S. Morozov[‡], D.W. Sivers[§] and V.K. Wong

*Randall Laboratory of Physics, University of Michigan,
Ann Arbor, Michigan 48109-1120*

V.A. Anferov, P. Schwandt and B. von Przewoski

Indiana University Cyclotron Facility Bloomington, Indiana 47408-0768

Abstract. Frequent polarization reversals, or spin-flips, of a stored polarized high-energy beam may greatly reduce systematic errors of spin asymmetry measurements in a scattering asymmetry experiment. We studied the spin-flipping of a 120 MeV horizontally-polarized proton beam stored in the IUCF Cooler Ring by ramping an rf-dipole magnet's frequency through an rf-induced depolarizing resonance in the presence of a nearly-full Siberian snake. After optimizing the frequency ramp parameters, we used multiple spin-flips to measure a spin-flip efficiency of $86.5 \pm 0.5\%$. The spin-flip efficiency was apparently limited by the rf-dipole's field strength. This result indicates that an efficient spin-flipping a stored polarized beam should be possible in high energy rings such as RHIC and HERA where Siberian snakes are certainly needed and only dipole rf-flipper-magnets are practical.

INTRODUCTION

In a circular accelerator, each proton's spin precesses around the vertical magnetic fields of the ring's bending dipoles, with a frequency called the spin precession frequency f_s that is related to the proton's circulation frequency f_c by:

$$f_s = f_c \nu_s, \quad (1)$$

where ν_s is the spin tune, which is the number of spin precessions during each turn around the ring.

-
- *) Supported by grants from the U.S. Department of Energy and National Science Foundation.
 - †) Corresponding author.
 - ‡) also at Moscow State University, Moscow, Russia
 - §) also at Portland Physics Institute, Portland, Oregon 97201.

If there are only vertical magnetic fields, then the vertical beam polarization remains unchanged; however, whenever there is a periodic horizontal magnetic field whose tune is equal to the spin tune a depolarizing resonance occurs, which can destroy the polarization. Since the ν_s is proportional to the proton's energy via:

$$\nu_s = G\gamma, \quad (2)$$

where $G=1.792847$ is the proton's anomalous magnetic moment, and γ is the Lorentz energy factor, the protons will encounter many depolarizing resonances as they are accelerated to a high energy.

An elegant method to overcome these depolarizing resonances, proposed by Derbenev and Kondratenko in 1978 [1], involves using a spin rotator called a Siberian snake that makes the spin tune equal to $1/2$ independent of the beam energy. This energy-independent ν_s eliminates most of the depolarizing resonances.

Once a polarized proton beam is accelerated to a high energy and stored, it is important to be able to reverse its polarization direction in order to reduce the systematic error in various polarized scattering asymmetry experiments.

Studies at the IUCF Cooler Ring show that these polarization reversals (spin-flips) can be done using an rf magnet [2,3], which creates an rf depolarizing resonance:

$$f_s = f_{rf} + nf_c, \quad (3)$$

where f_{rf} is the rf magnet's frequency, f_c is the circulation frequency, and n is an integer. After crossing such a resonance, which is varying the rf magnet's frequency from a value below the resonance to a value above the resonance, the final beam polarization P_f is related to the initial beam polarization P_i via the Froissart-Stora formula [4]:

$$P_f = P_i [2e^{-\frac{(\pi\epsilon f_c)^2}{(\Delta f/\Delta t)}} - 1], \quad (4)$$

where ϵ is the resonance strength, and $\Delta f/\Delta t$ is the resonance crossing rate, while Δf is the frequency's range during its linear variation time Δt . If the resonance is sufficiently strong and/or the crossing rate is sufficiently slow, the final polarization is reversed with respect to the initial polarization, while its absolute value is the same; this is called spin flip.

I EXPERIMENTAL APPARATUS

The apparatus used for this experiment is shown in Fig. 1. The 120 MeV horizontally polarized proton beam in the Cooler Ring was obtained using the new Cooler Injector Polarized IOn Source (CIPIOS) [5] and the new Cooler Injection Synchrotron (CIS) [6]. Also shown are the Siberian snake solenoid with its eight

correction quadrupoles, the polarimeter and the rf-dipole magnet, which is one of the Cooler Ring's injection kicker dipoles. In order to increase the strength of the rf-dipole, we connected to it a variable capacitor to form a resonant parallel LC-circuit. The maximum r.m.s. voltage on the rf-dipole that we were able to reach was about 71 V; this corresponded to an $\int B \cdot dl$ of about 0.06 T·mm.

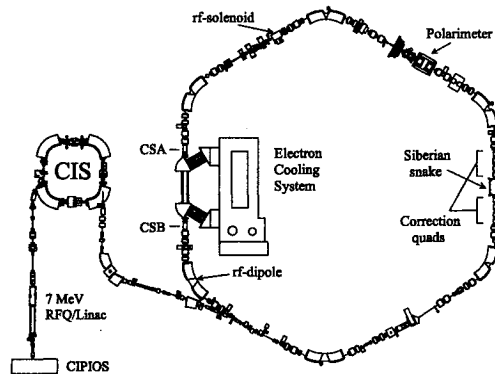


FIGURE 1. IUCF Cooler Ring and its hardware.

II RESULTS AND ANALYSIS

We first determined the rf depolarizing resonance's location by measuring the radial beam polarization at different rf-dipole's frequencies; this measured radial polarization is plotted against the rf-dipole's frequency in Fig. 2 [7]. The curve is a second-order Lorentzian fit to the data with a resonance frequency of 2384040 ± 90 Hz and a width 970 ± 20 Hz.

To study spin-flipping, we first set our frequency ramp range Δf to 10 kHz

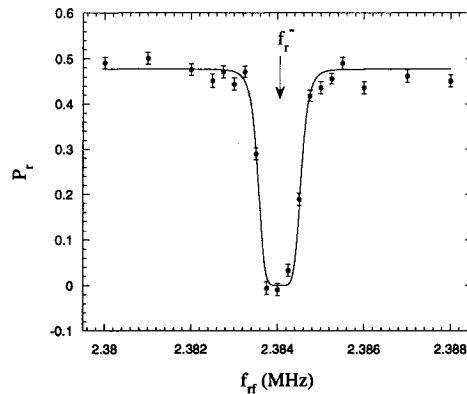


FIGURE 2. RF depolarizing resonance. The arrow shows the resonance's central frequency.

and crossed this rf-induced resonance by linearly ramping the rf-dipole's frequency from $f_r - 5$ to $f_r + 5$ kHz, with various ramp times Δt , while measuring the beam polarization after each crossing. Thus, we determined the optimal ramp time for the most efficient spin-flip. We then tried to further increase the spin-flip efficiency by varying the rf-dipole's frequency range Δf . After setting Δt and Δf to maximize the spin-flip efficiency, we more precisely determined this efficiency by performing many spin-flips. The measured radial beam polarization after several spin-flips is plotted against the number of spin-flips in Fig. 3. We fit this data using:

$$P_n = P_i \cdot \eta^n, \quad (5)$$

where P_n is the measured radial beam polarization after n spin-flips, P_i is the initial polarization, η is the spin-flip efficiency, and n is the number of spin-flips. The best fit gave a spin-flip efficiency of $86.4 \pm 0.5\%$ [7]. The spin-flip efficiency was apparently limited by the strength of the rf-dipole's field.

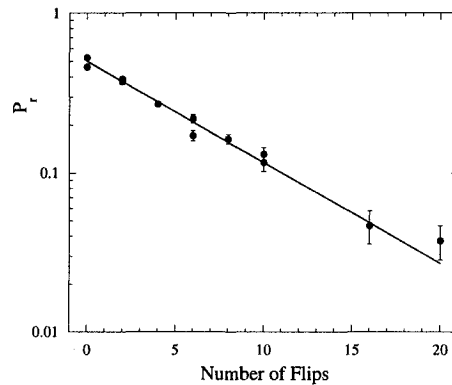


FIGURE 3. Multiple spin-flipping.

In conclusion, we have successfully demonstrated the feasibility of an rf-dipole magnet as a spin-flipper in a storage ring where a full Siberian snake is present. We are currently developing an rf-dipole spin-flipper for the MIT-Bates polarized electron ring.

REFERENCES

1. Ya. S. Derbenev and A. M. Kondratenko, *Part. Accel.* **8**, 115 (1978).
2. B.B. Blinov *et al.*, *Phys. Rev. Lett.* **81**, 2906 (1998).
3. V. A. Anferov *et al.* *Phys. Rev. ST-AB* **3**, 041001 (2000).
4. M. Froissart and R. Stora, *Nucl. Instrum. and Methods* **7**, 297 (1960).
5. V.P. Derenchuk and A.S. Belov, in *AIP Conf. Proc.* **421**, 422 (1998).
6. D.L. Friesel and S.Y. Lee, in *Proc. of 1997 Particle Accelerator Conf (PAC-97)*, Vancouver, 935 (1998).
7. B.B. Blinov *et al.*, Submitted to *Phys. Rev. Lett.* June 2000.