SPIN FLIPPING WITH A FULL SIBERIAN SNAKE IN A COOLER RING *

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Spin-polarized beam experiments in storage rings such as the IUCF Cooler Ring, HERA, and RHIC require frequent reversals of the beam polarization direction to reduce the systematic errors in the measured asymmetry. An rf solenoid was used earlier to spin-flip a vertically polarized proton beam stored in a ring with no Siberian snake[1]. Since any very high energy ring will need full Siberian snakes[2] to maintain the proton beam polarization[3], it is important to develop spin-flipping capability in the presence of a full snake. We recently studied the spin-flipping of a 104.1 MeV polarized proton beam stored in the IUCF Cooler Ring with a nearly full solenoidal Siberian snake. Using an rf solenoid, we made the first spin-flipping demonstration of a stored polarized proton beam with an efficiency of 91±1%[4]. We then tried to improve the spin-flipping efficiency by eliminating possible synchrotron sidebands and using a weak rf-dipole.

With a nearly full Siberian snake in the ring, the spin tune ν_s is very close, but not exactly equal to, 0.5. Thus, there should be two closely spaced rf depolarizing resonances around $1.5 f_c = 2.2574$ MHz. We excited these rf depolarizing resonances by operating an rf solenoid and an rf dipole near 2.25 MHz. The rf solenoid's amplitude was set at 6 kV, which corresponds to $\int B{\cdot}d\ell = 1.6$ T·mm. The single turn horizontal kicker was operated as an rf dipole at its maximum 23 V amplitude. The measured radial polarization is plotted against the rf solenoid and rf dipole frequency in Fig. 1. The rf solenoid's induced resonance frequency and width were $f_1 = 2,275,410 \pm 43$ Hz and $w_1 = 2,270 \pm 90$ Hz. For the rf dipole's induced resonance, they were $f_2 = 2,275,530 \pm 10$ Hz and $w_2 = 540 \pm 30$ Hz.

To study spin-flipping with a nearly full Siberian snake, we crossed the snake rf induced resonance by linearly ramping the frequency of the rf solenoid

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or rf dipole through the resonance frequency f_r at various ramp times Δt.

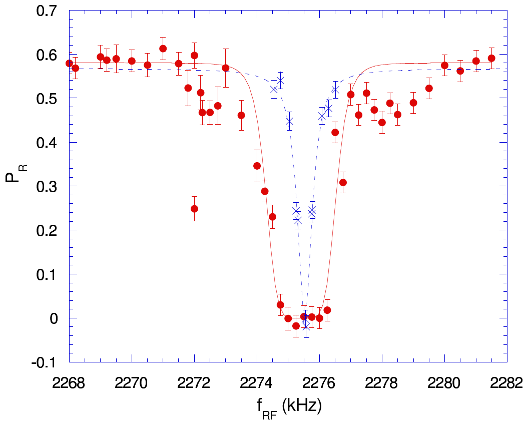


Figure 1: The measured radial proton polarization at 104.1 MeV is plotted against the frequency of the rf solenoid and of the rf dipole. The rf solenoid's data are marked with • and fitted with third-order Lorenzian (solid curve). The rf dipole's data are marked with × and fitted with first-order Lorenzian (dashed curve).

The Froissart-Stora equation [5] gives the ratio of P_f, the polarization after crossing the resonance, to the initial polarization P_i,

$$P_f = P_i \left(2 \exp \left[\frac{-(\pi w)^2}{4\Delta f / \Delta t} \right] - 1 \right), \tag{1}$$

where w is the resonance width in Hz, and $\Delta f / \Delta t$ is the resonance crossing rate with Δf being the frequency range during the ramp time Δt. To eliminate

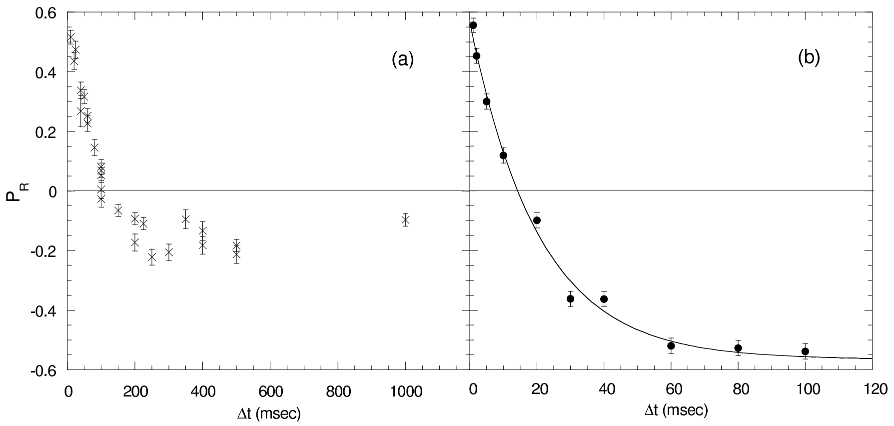


Figure 2: The measured radial proton polarization at 104.1 MeV is plotted against the rf dipole's (a) and rf solenoid's (b) ramp time Δt. The frequency ranges Δf were 3 kHz for the rf dipole, and 12 kHz for the rf solenoid. The curve is a fit to the data using Eq. (1).

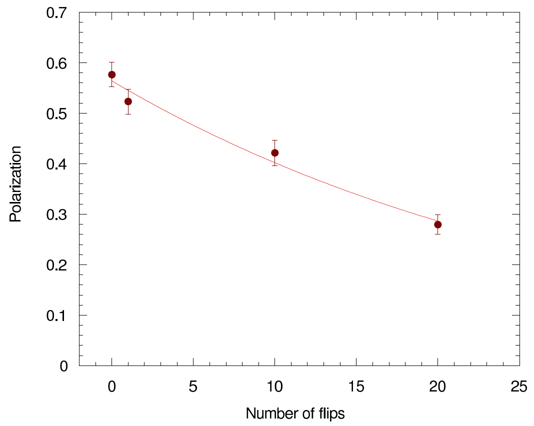
the effect of possible weak synchrotron sidebands, the RF acceleration cavities were turned off and shorted before each ramp. The measured radial beam polarization is plotted against ramp time in Fig. 2. Clearly the spin-flip efficiency is much better with the rf solenoid than with the rf dipole. By comparing the measured polarization of 58.2±2.1% at $\Delta t = 0$ with the average of $20 \pm 3\%$ at long dipole ramp times, we found a 34±4% dipole spin-flip efficiency.

To more precisely estimate the solenoid's spin-flip efficiency, we measured the beam polarization after many spin-flips. We varied the number of spin-flips, while keeping the ramp time, the frequency range and the rf voltage fixed. The data are shown in Fig. 3. We fit the data using the equation

$$P = P_i \cdot \epsilon^n, \tag{2}$$

where P_i is the initial polarization, ϵ is the spin-flip efficiency, and n is the number of spin-flips. The best fit to the spin-flip efficiency is 97±1%. We plan to study further the spin-flipping technique for both a nearly full and an exactly 100% Siberian snake.

Figure 3: The measured radial proton polarization at 104.1 MeV is plotted against the number of spin-flips. The rf solenoid's ramp time Δt is 60 msec; its frequency range Δf is 3.5 kHz. The curve is a fit to the data using Eq.(2).



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