Spin-dynamics Tests Preliminary to the Spin Splitter Experiment

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Abstract

The Spin-Splitter experiment is aimed at separating the two opposite spin states of the (anti)protons circulating in a storage ring. Preliminary tests, essential to the feasibility of the final experiment, have been performed at the Indiana University Cooler Ring using polarized protons of kinetic energy W=108 MeV ($a\gamma$=2). In presence of an either fully or partially excited Siberian Snake, we checked the long term stability of the polarization in the three principal cases: longitudinal (i.e. parallel), normal (i.e. vertical) and side (i.e. horizontal but orthogonal) to the spin stable solution $\vec{n}$ at the entrance of the Siberian Snake solenoid.

1. INTRODUCTION

The *Spin-Splitter method* [1],[2] aims at separating the two opposite spin states of (anti)protons circulating in a storage ring, by means of repetitive transverse impulses, or kicks, of the Stern-Gerlach force acting upon the magnetic moments of these particles. This adding up must be coherent, i.e. particles have to experience quite the same kick either turn after turn or every second revolution, depending whether the particle energy fulfils the relation $a\gamma$ = integer or half-integer, with $a = \frac{g-2}{2} = 1.7928$ for (anti)protons. On the other hand, the betatron tunes Q_H and Q_V must be different from integer and/or half-integer values, for the trivial sake of staying far from destructive resonances.

Having simultaneously incoherence in the ordinary betatron oscillations and coherence in the action of the Stern-Gerlach force requires some new ideas which, as thoroughly discussed in Ref.[3], consist mainly in making the beam polarization $\vec{P}$ rotate by a small angle δ about the spin stable solution $\vec{n}$ turn after turn. Therefore the feasibility of the Spin-Splitter method is crucially tested by checking if the polarization $\vec{P}$ is preserved when perpendicular to $\vec{n}$.

From a theoretical point of view this property is fully demonstrated; in fact by performing the time derivative of the scalar product of two polarization vectors $\vec{P}_1$ and $\vec{P}_2$ both fulfilling the spin precession equation

$$\frac{d\vec{P}}{dt} = \vec{\Omega} \times \vec{P} \qquad (1.1)$$

we obtain:

$$\frac{d}{dt}(\vec{P}_1 \cdot \vec{P}_2) = \vec{P}_1 \, \vec{\Omega} \times \vec{P}_2 + \vec{\Omega} \times \vec{P}_1 \, \vec{P}_2 = 0$$

as can be proven by applying twice the property of the mixed internal and external vector product. Setting then $\vec{P}_1$ and $\vec{P}_2$ respectively equal to $\vec{P}$ and $\vec{n}$ we have:

$$\vec{n} \cdot \vec{P} = \text{constant} \qquad (1.2)$$

Clearly eq. (1.2) allows a precession of $\vec{P}$ about the stable solution, depending on the angle α formed by the two vectors. For α=0, $\vec{P}$ is parallel to $\vec{n}$, no precession takes place and the polarization is fully preserved since it follows $\vec{n}$. This behaviour has been thoroughly checked (Experiment CE-16 [4],[5]) using polarized protons in the Indiana University Cooler Ring [6], properly endowed with a Siberian Snake, over time intervals of the order of the beam lifetime, i.e. 15-20 minutes.

Due to our purposes, we must check the polarization stability when $\vec{P}$ is perpendicular to $\vec{n}$ or when the constant of eq. (1.2) is zero ($\alpha=90^0$) and the whole polarization vector precesses around the stable solution $\vec{n}$. In order to achieve the required accuracy we needed quite a high intensity which was obtained by RF-stacking multiturn injection. Since this procedure implies a rather long-lasting debunching we had two situations.

$\vec{P} // \vec{n}$: polarized protons, of kinetic energy W=108 MeV ($a\gamma$=2), were injected turn after turn without any problem. In fact in this configuration $\vec{n}$ is longitudinal at the solenoid of the Siberian Snake and then particles entered the solenoid with their spins parallel to the magnetic field thus avoiding any precession. Therefore, when the RF is switched off, particles with different energy (momentum spread) can mix each other with their spin states remaining unaltered.

$\vec{P} \perp \vec{n}$: the former procedure is no longer viable, as every second revolution protons have opposite spin-states which can mix during debunching. Then we must build up our statistics by picking up data with single turn injection and by iterating this kind of measure several times.

2. MEASUREMENTS WITH POLARIZATION PERPENDICULAR TO $\vec{n}$

In the Autumn 1991 runs of Experiment CE-27 we injected (0.75) polarized protons with polarization both vertical, or normal, and horizontal, or side. Single-turn injected beams, with initial polarization either vertical or horizontal, have been made striking the polarimeter's counter system every second revolution, with the polarimeter itself duly gated, and taking data about 10 seconds after injection. We found that the measured vertical and horizontal components P_V and P_H were rather independent of the initial polarization. In fact, even with an initial vertical (horizontal) polarization, significant values of P_H (P_V) have been picked up; therefore we gathered these components, which are however perpendicular to $\vec{n}$, into the quantity

$$P_{\perp} = \sqrt{P_V^2 + P_H^2} \qquad (2.1)$$

which has been plotted versus the solenoid current I_S.

Thus the measured P_V, P_H are combined, according to eq. (2.1), to obtain the corresponding values of $P_{\perp}$ which are plotted as full circles with the error bars in Fig.1 together with I_S . Clearly these experimental points are gathered around three peaks. The central peak arises from those protons, fulfilling exactly the condition $a\gamma = 2$, which have their spins undergoing a 180^0 rotation while crossing the solenoid. The two sidebands are induced by the synchrotron oscillations, which make particles changing continuosly their energy so that the corresponding rotations in the solenoid can be alternatively bigger or smaller than 180^0. Therefore a horizontal (vertical) component arises if the initial polarization is vertical (horizontal); then the $a\gamma$ spin-tune, acting on the horizontal components, varies by small amount around 2 with the same frequency as the synchotron oscillations, causing the sidebands. A simple Fortran program has been conceived in order to simulate this behaviour: its output is shown in Fig.1 as a full line curve. The agreement is rather good: the distances among experimental and theoretical peaks are almost the same; the three heigths are quite equal in both cases. Instead the factor of 2 deserves a few comments. For simplicity and haste sake, in the program the polarization is assumed vertical and the energy variation effect appears only in the spin rotation inside the solenoid, i.e. there is not the further smoothing related to the horizontal component.

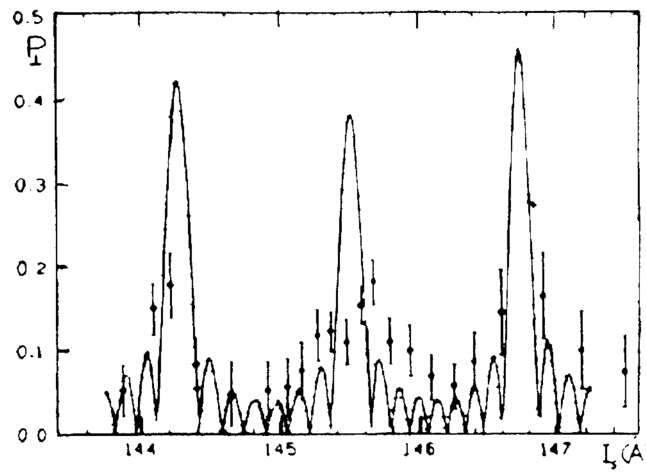

Figure 1 - Experimental values (full circles with error bars) and simulated plot (full line curve) of the transverse polarization $P_{\perp}$ as function of the solenoid current I_S .

3. CONCLUSIONS

We measured for the first time the oscillations of the polarization around the stable solution axis $\vec{n}$. We also found that these oscillations do not reduce the polarization, neither totally nor partially. Besides, these results demonstrate that future studies of the repetitive Stern-Gerlach effect in a storage ring are possible.

4. REFERENCES

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