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## PRECESSING DEUTERON POLARIZATION

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The feasibility of the acceleration in the Nuclotron of deuterons polarized in the horizontal plane is considered. This horizontal polarization is named precessing polarization. The effects of the main magnetic field and synchrotron oscillations are included. The precessing polarization is supposed to be used in studying the polarization parameters of the elastic  $dp$  back-scattering and other experiments.

Рассматривается возможность ускорения в нуклотроне дейтронов, поляризованных в горизонтальной плоскости. Эта горизонтальная поляризация называется прецессирующей поляризацией. Включены эффекты ведущего магнитного поля и синхротронных колебаний. Прецессирующую поляризацию предполагается использовать для изучения поляризационных параметров в упругом  $dp$ -рассеянии назад и для других экспериментов.

### INTRODUCTION

When studying the spin structure of different reactions with a deuteron, very important information can be obtained using deuterons polarized in the horizontal plane. After acceleration of vertically polarized deuterons this may be done by means of a solenoid magnet followed by a dipole magnet. But, because of a small deuteron magnetic moment, for high energy beams this task becomes too difficult. The second way is to inject into an accelerator deuterons with horizontal polarization. With one-turn injection, it seems possible to look after the angle between vectors of velocity and polarization.

This horizontal polarization can be named *precessing polarization*.

It is known the successful attempt to accelerate horizontally polarized protons and deuterons by the cyclotron at Osaka, RCNP (65 MeV polarized protons and 56 MeV vector polarized deuterons) [1–3] and unsuccessful one at TRIUMF for 200 MeV polarized  $H^-$  [4]. It is necessary to note that  $G = -3.79$  for  $H^-$  and 1.79 for  $H^+$  compared with  $-0.143$  for  $D^+$ , which partly may explain those results.

The precessing polarization is supposed to be used to study the polarization parameters of the backward elastic  $dp$  scattering [5,6]. Realization of the complete experiment would permit one to separate the effects dependent on the deuteron structure from ones dependent on the reaction mechanism. The interest is connected with elucidation of the relative contribution of the  $S$  and  $D$  components of the deuteron wave function. It is interesting to measure the possible admixture of the  $P$  wave, which was predicted in some theoretical works connected with relativistic consideration of the deuteron, etc.

The precessing polarization could be used also for exact energy calibration of the extracted beam of order  $10^{-6}$ .

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### ACCELERATION OF HORIZONTALLY POLARIZED DEUTERONS AT THE NUCLOTRON

The polarization evolution in the magnetic field during acceleration is described with the equation of Bargmann–Michel–Telegdi:

$$\frac{d\mathbf{s}}{dt} = \frac{e}{m_d\gamma c} \mathbf{s} \times [\mathbf{B} + \mathbf{G}(\mathbf{B}_{\parallel} + \gamma\mathbf{B}_{\perp})], \quad (1)$$

where  $G = -0.143018$  for deuterons;  $m_d$  is the deuteron mass;  $\mathbf{s}$  is a unit vector of the polarization direction;  $\mathbf{B}_{\parallel}$  and  $\mathbf{B}_{\perp}$  are components of the magnetic field, parallel and perpendicular to the velocity direction, respectively.

As for betatron oscillations and magnetic field distortions, their influence on the horizontal polarization is identical (in linear approximation) to the action on the vertical polarization. Consequently, it is enough to take into account the effect of the main magnetic field and synchrotron oscillations.

As the magnetic field of the accelerator is perpendicular to the velocity, the spin rotates with an angular velocity  $\omega_{\perp} = (1 + \gamma G)\omega_c$ , where  $\omega_c = eB/m_d\gamma c$  is a cyclotron frequency. The angle of the spin rotation relative to the velocity is

$$\Phi = \int_0^T (\omega_{\perp} - \omega_c) dt = \int_0^T \gamma G \omega_c dt = \int_0^{\Theta} \gamma G d\theta, \quad (2)$$

where  $T$  is the duration of acceleration;  $\theta = \int_0^t \omega_c dt$  and  $\Theta = \int_0^T \omega_c dt$ . During the acceleration the particles produce the synchrotron oscillations with the frequency  $\Omega$ . Then

$$\Phi = \int_0^{\Theta} G \{ \gamma(\theta) + \Delta\gamma(\theta) \cos [\Omega(\theta)\theta + \alpha] \} d\theta, \quad (3)$$

or

$$\Phi = \int_0^T G \omega_c(t) \left\{ \gamma(t) + \Delta\gamma(t) \cos \left[ \Omega(t) \int_0^t \omega_c(\tau) d\tau + \alpha \right] \right\} dt, \quad (4)$$

where  $\Delta\gamma$  is the amplitude of the synchrotron oscillations. The parameter  $\Delta\gamma$  is expressed through relative momentum straggling  $\Delta p/p$ :

$$\Delta\gamma = \frac{\Delta p}{p} \times \frac{\gamma^2 - 1}{\gamma}. \quad (5)$$

Using the measured values of the Nuclotron parameters it is possible to find the straggling angle of spin rotation relative to the velocity vector depending on acceleration time  $T$  or momentum  $p$  and calculate the polarization value along its current direction. Supposing the homogeneous distribution of the  $\Delta\gamma$  from 0 to  $\Delta\gamma^{\max}$ , it is possible to consider that the depolarization factor  $D$  equals

$$D = 1 - \frac{1}{\pi} \int_0^{\pi} \cos(\Phi(\alpha)/2) d\alpha. \quad (6)$$

Computer calculations give the following values for depolarization:

$T$ , ms	$p$ , GeV/c	$D$
620	2.65	0.03
700	2.96	0.11
720	3.04	0.15
750	3.16	0.26
780	3.28	0.42
800	3.36	0.56

During the slow extraction of the beam at the fixed magnetic field of the accelerator the angle between the momentum direction and the polarization axis can be expressed as

$$\varphi_m = C + 2\pi m\gamma_m G, \quad (7)$$

where  $m$  is the number of beam turns in the accelerator, preceding to extraction of a particle initiating a scattering event;  $C$  is a constant connected to:

- the direction of polarization of particles injected into the accelerator,
- the history of growing of accelerator magnetic field,
- the total bending angle of the beam line for extracted particles.

The values of  $C$  and  $\gamma_m$  can be found as searched parameters during a fit procedure. Such a fit assumes that the history of growing of accelerator magnetic field is stable. If it is not so, the total number of accelerator cycles can be divided into groups with the same history. The amount of beam turns during the slow extraction is of about  $10^6$ , and so, the parameter  $\gamma_m$  (i.e., the absolute calibration of the accelerator) can be found with uncertainty of the order of  $10^{-6}$ . Following to the expression connecting cross sections for polarized and unpolarized beams

$$\sigma = \sigma_0(1 + AP_z), \quad (8)$$

where  $\sigma$  and  $\sigma_0$  are cross sections for polarized and unpolarized particles, respectively;  $A$  is an analyzing power;  $P_z$  is a projection of polarization onto a chosen axis, the minimum of a functional for making a fit can be written as

$$\sum_m \left( \frac{n(m)}{k} - 1 - A|P| \cos(\varphi_m) \right)^2 = \min, \quad (9)$$

where  $n(m)$  is a number of events having  $m$  preceding beam turns;  $k$  is a total number of events;  $\varphi_m$  is defined in Eq. (7).

It is supposed that there is an exact count of the turns during all the acceleration cycle and the magnetic field plateau at the extraction and reproducibility of the acceleration cycle.

The average value of the polarization projection on some chosen axis (say, the beam axis) is (separately for every sign of the projection)

$$\langle P_z \rangle = P_0(1 - D) \frac{1}{\pi} \int_{-\pi/2}^{\pi/2} \cos \phi d\phi \simeq 0.64P_0(1 - D), \quad (10)$$

where  $P_0$  is the polarization of the injected beam;  $D$  is the depolarization factor, defined in Eq. (6).

To check the precessing polarization of the extracted beam, the authors are planning to use a polarimeter with  $2\pi$  geometry using  $\text{CH}_2$  target as analyzer. Such the polarimeter POMME [7] was used successfully at National Laboratory SATURNE (Saclay, France). Its components, in part, will be used for the new polarimeter.  $2\pi$  geometry allows one to check either vertical or horizontal polarization with the same efficiency. To check the main magnetic field and the number of beam turns in the Nuclotron chamber during experiments a special module is elaborated. Its detailed description is given in Appendix.

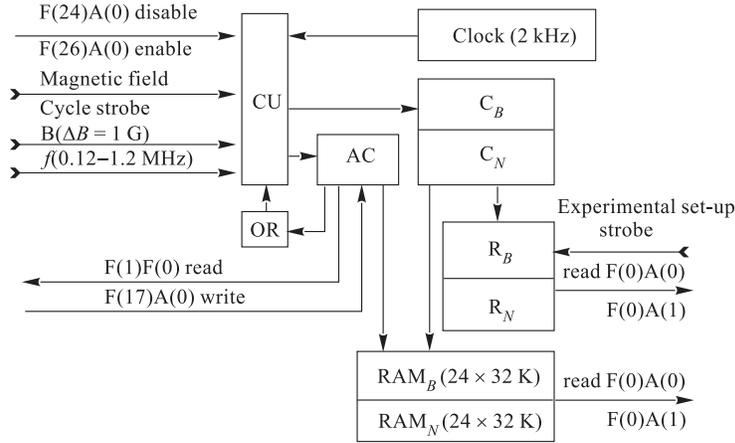
### CONCLUSION

Now, the available apparatus permits one to begin the first experiments. Also, the detailed calculations of the polarization behavior during the acceleration are in progress.

When many-turn injection into Nuclotron will be realized, the deuteron polarization after polarized ion source must be adapted to the polarization of the deuterons in the accelerator after one turn (a lag of  $0.143 \times 2\pi$ ).

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### APPENDIX. MODULE RBN (READ $B, N$ )



Structural scheme of module: CU — Control Unit; AC — Address Counter; OR — Overflow Register;  $C_B$  — Counter of  $B$  (magnetic field);  $C_N$  — Counter of  $N$  (turns);  $R_B$  — Register of  $B$ ;  $R_N$  — Register of  $N$ ;  $\text{RAM}_B$  — Random Access Memory ( $B$ );  $\text{RAM}_N$  — Random Access Memory ( $N$ )

### Module Structure

1. The control unit CU generates the operating signals for itself and determines the logic of external signals.

2. 24 bit counters,  $C_B$  and  $C_N$ , store the current values of the main magnetic field and the number of beam turns of the circulating beam in the Nuclotron vacuum chamber.
3. Registers,  $R_B$  and  $R_N$ , fix the current values of the magnetic field and number of beam turns when the strobe from the experimental set-up comes.
4. Information about the magnetic field and beam turn numbers during the period of beam circulation is stored in the memory devices,  $RAM_B$  and  $RAM_N$ , with the capacity of  $24 \times 32$  K each with the period of 500 ns.
5. The *Clock* generates the signals incrementing the address counter AC of the memory devices. The overflow register OR fixes the address counter status and transfers the commands to the control unit in order to interrupt the clock signals into AC in case of its overflowing.

### External Signals

1. The magnetic field signals (B) with 1 G step come from the control system of the Nuclotron magnetic field cycle (Building 1A).
2. The frequency signals of the circulating beam F are formed by the equipment of the control house in the Building 2 from the muster clock of the control system of the accelerator voltage.
3. The magnetic field cycle strobe is generated in the data concentrator located in Building 1. The strobe pulse front corresponds to the moment of the beam injection into the Nuclotron (294 G), the strobe pulse tail corresponds to the end of the magnetic field plateau. The pulse front clears counters AC,  $C_B$ , and  $C_N$  and permits transmission of the signals of *Clock*, B and F (if the CAMAC command allows the module to work). At the pulse tail the transmission of the signals of *Clock*, B and F are prohibited.
4. After strobe from the experimental set-up the current values of the counters,  $C_B$  and  $C_N$ , transmit into the registers  $R_B$  and  $R_N$ .

### CAMAC Commands

1. F(26)A(0) — permission of transmission of the magnetic field strobe and signals *Clock*, B and F.
2. F(24)A(0) — prohibition of transmission of the magnetic field strobe and signals *Clock*, B and F.
3. F(0)A(0) — reading of the  $C_B$  counter.
4. F(0)A(1) — reading of the  $C_N$  counter.
5. F(0)A(2) — reading of the  $R_B$  register.
6. F(0)A(3) — reading of the  $R_N$  register.

7. F(0)A(4) — reading of the RAM<sub>B</sub> with the increment of address counter.
8. F(0)A(5) — reading of the RAM<sub>N</sub> with the increment of address counter.
9. F(1)A(0) — reading of the address counter AC via R1...R15 bus-bars and of the overflowing register via R16.
10. F(17)A(0) — recording into the address counter AC via W1...W15 bus-bars and into the overflowing register via W16.

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