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E.B.Dokukin, Yu.V.Nikitenko

ON VARIANTS OF THE NEUTRON ADIABATIC SPINFLIPPER

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1. Introduction

Bloch [1] is the first who has raised the possibility of the adiabatic following of a neutron spin the effective magnetic field in the presence of the constant and rotating magnetic fields. Abragam [2] consideres in details this problem in the special case that the constant magnetic field passess through a resonant value due to neutron flying. The possibility of using the adiabatic following for ultracold neutrons(a wavelength of neutrons is λ=1000 A) is stated by Luschikov (see [3]).
Later such a spinflipper was used in experiments with ultracold neutrons [4]. Hereafter,to increas a bandwidth of neutron wavelengths a magnetic field of a certain shape was being used [5](also see in this context [6]). In [7] it is already stated that the adiabatic flipper for neutrons with a wavelength λ > 2 A is in successful operation. A less effective " tangentially " shaped magnetic field is proposed in [8]. Calculations of the neutron adiabatic spinflipper with such dependence of the magnetic field are performed in [9].

Other ways of creation of a broadband adiabatic neutron spinflipper are described in this paper.

2. The broadband adiabatic spinflipper.

The neutron adiabatic spinflipper has a region of following of the length L in the direction of a neutron beam (e.g. for the axis x) in which the spin of a neutron follows the effective field $\vec{H}'_e(t)$. The gradient magnetic field H(x) and perpendicular to it the magnetic field H_1 , rotating with frequency w are in this region . The effective magnetic field $H'_e(t)$ has two components $H' = H - w/\gamma$ and H_1 in the rotating with such frequency and in the rest-frame of the neutron (marked by the stroke in fig. 1). With time t =x/v , where v is neutron velocity, the effective field H'_e rotates in the plane $Z'X'$ with frequency $\Omega = vH_1(dH'/dx)/H'^2_e$.

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At the same time if $\eta = \Omega / \gamma H'_e < 1$, where γ is a giromagnetic relation, the neutron spin follows the effective magnetic field. At linear dependence of H(x) the quantity $\eta(t)$ has a maximum value in the middle of the region of following when $H'_e = H_1$ (let's mark this moment of time t_0). In this case the average value of $\eta(t)$ over the interval $\pm\ 1/ ((\gamma H'_e)^2 + \Omega^2)^{1/2}$ in the neigbourhood of t_0 determines primarily the quality of the spin following the effective magnetic field. The moments of time beyond this interval due to the small value of $\eta(t)$ do not play a significant role . At the same time since the value of $\Omega(t)$ is small the time of spin following T increases essentially. In this context an increase of $\eta(t)$ in this part of the region of following in order to fulfil the condition $\eta(t) = \eta_{max}$ = const decreases the time of following T. Simultaneously all the moments determine equally the quality of the spin following the effective magnetic field. Since the condition v = L/T is fulfilled, the spinflipper becomes more broadband.

In [5] the solution of the problem at η=const has resulted in the next spacedependence of the magnetic field H(x):

$$H(x)=H_1 \cdot x/(x_0^2 - x^2)^{1/2}, \qquad (1)$$

where $x_0 = \beta/H_1$, $\beta = v / (\eta\gamma)$. There x is measured from the center of the spinflipper. The spinflipper with the field dependence (1) is the first variant of the adiabatic broadband spinflipper.

It should be noted that the field dependence (1) cannot be practically realized because it is impossible to create a magnetic field with an unlimited value. In practice H(x) always has a finite value and the region of following starts and ends, respectively, with the arising and disappearing of H_1.

Two new dependences of the effective magnetic field which are easy to realise in practice are proposed.

Let's consider the first case that the region of following is divided into two parts. In the first part of the region at $|x| < x_c$ the rotary motion of the effective field takes place due to the change of H(x) according to equation (1), whereas at $|x| > x_c$ it is connected with the change of $H_1(x)$. Since the condition η = const is fulfilled in both parts of the region of following the magnetic field can be written as :

$$H_1=H_{1max}\ ,\quad H(x)=H_{1max} \cdot x/(x_0^2 - x^2)^{1/2} \quad \text{for } |x| < x_c\ ,$$

$$H=H_{max}\ ,\quad H_1(x)=H_{max} \cdot x/(x_1^2 - x^2)^{1/2} \quad \text{for } |x| > x_c\ , \qquad (2)$$

where $x_0=\beta/H_{1max}$, $x_1=\beta/H_{max}$. Using the equalities $H(x_c)= H_{max}$ and $H_1(x_c) = H_{1max}$ one obtains the relation between maximum field values :

$$H_{1max} = H_{max} \cdot (x_0^2 - x_c^2)^{1/2} / (L/2-x_c) \qquad (3)$$

As it is seen from (3) there exist strong possibilities in variations of the parameters x_0, x_c, L.

The second new dependence of the effective field is realized by the simultaneous change of the fields H (x) and H_1 (x). It follows from the conditions H'_e = const and Ω = const (at η=const) :

$$H - w/\gamma = H'_e \cdot \cos(\Omega t) \quad \text{and} \quad H_1 = H'_e \cdot \sin(\Omega t), \qquad (4)$$

where $\Omega = \pi v/L$.

The three considered dependences of the effective field satisfy one condition η = const and differ only by the length of the region of following L :

$$\int^{L} H'_e \, dx = \pi\ \beta \qquad (5)$$

If , for example , one takes one value H_{1max} and for the second variant $H_{max} = H_{1max}$ and $x_c = L/4$, then the sizes of the regions of following are in the ratio $1 : 2^{1/2} : \pi/2^{3/2}$.

As is seen from above the difference in sizes is insignificant. It is clear from (5) that L is also determined simply by the absolute value of the effective field.

If η = constant, then one gets the analitical formula for the efficiency of flipping $\varepsilon = S_z(x=L/2)/S_z(x=-L/2)$. It is true that in the second rotating coordinate system (marked by two strokes in fig. 1) the vector of the effective field $H''_e = (H'^2_e + (\Omega/\gamma)^2)^{1/2}$ retains its direction. It is well known that in this case the neutron spin vector precesses around H''_e. Having this solution (see, for example, [10]) and performing back transformation in the system XYZ, one obtains :

$$\varepsilon(t) = \cos(\phi)\cdot(1+\eta^2\cdot\cos(\phi\cdot(1+\eta^{-2})^{1/2}))/(1+\eta^2) +$$

$$\eta\cdot\sin(\phi)\cdot\sin(\phi\cdot(1+\eta^{-2})^{1/2})/(1+\eta^2)^{1/2}, \qquad (6)$$

where $\phi = \int^t \Omega(t')\,dt'$. For our purposes we are interested in a special case $\phi = \pi$, when the effective field vector is in a direction opposite to Z axis :

$$\varepsilon(\phi=\pi) = -(1+\eta^2\cos(\pi(1+\eta^{-2})^{1/2}))/(1+\eta^2) \qquad (7)$$

3. Conclusions

It seems that the second variant of the spinflipper is preferable for realization. But it is essential to fulfil the Maxwell equation rot $(\vec{H}) = 0$. Hence the efficiency of the spinflipper is also determined by other field components. Thus, one can draw a final conclusion only after testing the working models of the neutron spinflipper.

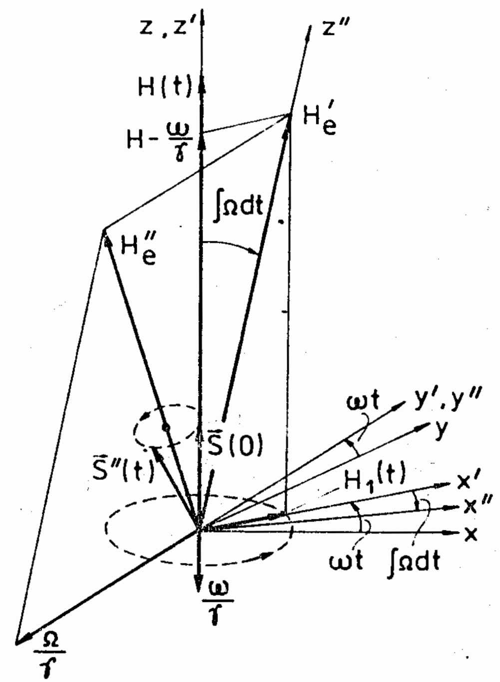

Fig. 1 The vectors of the magnetic field and of neutron spin in the neutron rest-frame and laboratory system XYZ, in the system of $X'Y'Z'$, rotating with frequency w about XYZ, in the system of $X''Y''Z''$, rotating with frequency Ω about $X'Y'Z'$.

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