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ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
СО АН СССР

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SPIN FLIP OF PARTICLES IN A STORAGE RING BY A HIGH-FREQUENCY ELECTROMAGNETIC FIELD

Preprint 82 - 16

Новосибирск

Abstract

The possibility of flipping the particle spins in a storage ring is considered. The experimental data on adiabatic spin flip of electrons with a high-frequency electromagnetic field at VEPP-2M are presented.

In the experiments with polarized particles in storage rings it is of interest the possibility of altering a sign of polarization with the same remaining parameters of the beam (sizes, currents, energy, etc.). Spin flip can be performed by the action on the beam, of a high-frequency electromagnetic field resonant with a spin precession frequency around the guide field of a storage ring H_0 :

$$\Omega = \left(1+\gamma\, q'/q_0\right)\omega_0 = (1+\nu)\,\omega_0 \qquad (I)$$

where ω_0 is the particle revolution frequency in a storage ring, q' and q_0 are the anomalous and normal parts of the gyromagnetic ratio. It is known that the spectrum of spin motion, as a consequence of synchrotron oscillations of particle energy ($\gamma = \gamma_0 + \Delta\gamma \cos \nu_s \omega_0 t$), has a narrow central frequency and side bands at a distance of $n \nu_s \omega_0$ from the former where n is an integer, /1/. The central bandwidth is, in practice, determined by a low-frequency noise in the storage ring field and, if special measures are not taken, is of the order of $\Delta\Omega \approx 10^{-3}$.

On the other hand, conventional methods of particle energy calibration in a storage ring make it possible to find $\overline{\Omega}$ in advance with an accuracy not better than $\frac{\Delta}{\Omega} = \nu \frac{\Delta\gamma}{\gamma} \sim 10^{-3}$. To perform the coherent spin flip of all the particle, the precession frequency around the direction of a high-frequency field $\tilde{H} \perp H_0$ should satisfy the condition

$$\tilde{\omega} = \nu \frac{\langle \tilde{H} \rangle}{H_0}\,\omega_0 \gg \max\,(\Delta, \Delta\Omega) \qquad (2)$$

It is obvious that the spin flip will occurs during the time $\pi/\tilde{\omega}$ and the degree of polarization will be decreased by

$$\delta S \simeq S \frac{[\max(\Delta, \Delta\Omega)]^2}{\tilde{\omega}^2}$$

The satisfaction of the condition (2) seems to be complicated from the technical point of view. Application of more accurate methods of energy calibration (for example, the method of resonance depolarization /1/), suppression of noises and increase of the time of magnetic field stability simplify the satisfaction of this condition but complicated the problem as a whole.

More promising is the method at which the spin is flipped when crossing the resonance by scanning of the field frequency from $\bar{\Omega}+\varepsilon_0$ to $\bar{\Omega}-\varepsilon_0$. For the case $\varepsilon_0=\infty$, the degree of polarization is varied by

$$\delta S = 2S\left(e^{-2J}-1\right)$$

as a result/2,3/, where $J=\frac{\pi}{\nu}\frac{w^2}{\dot{\varepsilon}}$ characterizes the angle of rotation around $\widetilde{H}$ in the effective resonance zone $\varepsilon \leq [\max(w, \sqrt{\dot{\varepsilon}})]$, where ε is the mistuning of the exact resonance. In fast crossing $J \ll 1$, a variation of the spin vector is insignificant. In the opposite case when $J \gg 1$, the polarization is adiabatically inversed that is accompanied by an exponentially small variation of its degree.

For electrons and positrons, it is necessary to take into account the depolarizing action of quantum energy fluctuations during radiation. This effect, most dangerous in the effective resonance zone leads to the following limitation /4/

$$\dot{\varepsilon} \gg \nu^2 \frac{\omega_0^2}{w} \frac{d}{dt}\left(\frac{\Delta\gamma}{\gamma}\right)^2 \qquad (3)$$

where $\frac{d}{dt}\left(\frac{\Delta\gamma}{\gamma}\right)^2$ is the rate of energy diffusion because of quantum fluctuations of radiation.

Thus, for a correct choice of ε_0 , w and $\dot{\varepsilon}$, the adiabaticity condition $J \gg 1$, the expression (3) as well as a concrete form of the spectrum of spin motion needs to be taken into account. The initial mistuning ε_0 should exceed $\max(\Delta, \Delta\Omega)$ but it should be less than the distance to the first side resonance: $\varepsilon_0 < \nu_s\omega_0$. The amplitude of a high-frequency field is necessary to take such that the precession frequency w should be much larger than the spread of spin frequencies $\delta\Omega$ for the time of passage through the effective resonance zone ($\delta\Omega \lesssim \Delta\Omega$).

The experiment to demonstrate the possibility of adiabatic spin flip of electrons was carried out at the VEPP-2M storage ring. A high-frequency longitudinal magnetic field of up to 100 Gauss on a 40 cm length ($w = 10^{-4}\,\omega_0$) and with the frequency $f=\frac{\Omega-2\omega_0}{2\pi}$ = 7.95 MHz was generated by a spiral from 10 turns, supplied by a 5 kW RF generator. The control system allowed the generator frequency to be changed in the range $\pm 3\cdot 10^{-3}$ for the time $10^{-3} \div 10$ sec.

The degree of beam polarization was measured by registration of the elastic electron scattering inside a bunch /5,6/. The counting rate of this effect for a counter array, used in the experiment, was

$$\dot{n} \sim i^2\left(1-0.18\,S^2\right) \qquad (4)$$

where i - is the beam current in mA, S - the polarization degree.

The polarized beam ($i \simeq$ 5 mA) was produced due to radiative polarization at which the electron spins were arranged along the direction of a magnetic field /7/ and the degree of their polarization varied by the law

$$S = S_m\left(1-e^{-t/\tau_p}\right)$$

where S_m is as large as possible degree of polarization, which attains the magnitude $\frac{8}{5\sqrt{3}}$ = 0.924 in the absence of depolarizing factors; τ_p is the characteristic time of radiative polarization, it is equal approximately to an hour at VEPP-2M at an energy of 650 MeV.

By the beginning of measurements (Fig. 1) the degree of polarization achieved $S_1 = 0.85\cdot S_m \simeq 0.8$ for the period of time $t \simeq 2\tau_p$.

At the moment T a high-frequency field was switched on for $\simeq$ 0.5 sec, whose frequency changed with a constant rate within the range indicated above. A subsequent variation of the $\dot{n}/i^2$ - normalized counting rate may be accounted for by that the flipped spin state is radiation-unstable. Polarization occurs in this case under the initial condition $S_0=-S_1+\Delta S$, where ΔS is the magnitude of depolarization at and the degree of polarization is varied by the law

$$S = S_m - (S_m - S_0)\,e^{-t/\tau_p} \qquad (5)$$

At first, the beam is depolarized for the period of time equal approximately to 0.7 τ_p (the maximum $\dot{n}/i^2$, according to (4), corresponds to the state of complete depolarization) and then it is polarized to the stable state. In a period of about $2.5\ \tau_p$ from the moment T, the beam was depolarized via the switching on of a HF field on the resonance with violation of condition (3). The jump of the countining rate on the preceding maximum level confirm the validity of our interpretation of the behaviour of all the curve.

The experimental results have shown a good agreement of the counting rate variation with the analytical dependence (4) with due regard for eq. (5). The magnitude of depolarization did not exceed 10%. Once more two cycles of measurements yielded similar results, that was indicative of the fulfilment of the problem in view.

More complicated is the situation with two colliding beams if it is required to inverse the polarization of one of them. In this case, it is possible to arrange the separation of spin frequencies, as it is done in Ref. /8/ by the magnitude $\Delta\Omega^{\pm} \simeq 2\nu \frac{E}{H_0}\cdot\omega_0$, using a constant radial electric field. With a good energy calibration, the magnitude $\frac{\Delta\Omega^{\pm}}{\Omega} \simeq 10^{-3}$ is likely to be sufficient to flip the spins only in one beam.

The authors are indebted to P.V.Vorobjev, P.M.Ivanov, G.Ya.Kezerashwili, A.P.Lysenko and the staff of VEPP-2M for the participation in the experiment.

References

1. Ya.S.Derbenev et al. Particle Accelerators 10, 177 (1980).
2. M.Froisart, R.Stora. Nucl. Instr. and Meth. 7, 297 (1960).
3. Ya.S.Derbenev et al. ZhETF 60, 1216 (1971).
4. Ya.S.Derbenev et al. ZhETF 62, 430 (1970).
5. V.N.Baier, V.A.Hoze. Atomnaja energija 25, 440 (1968).
6. S.I.Serednjakov et al. ZhETF 71, 2025 (1976).
7. A.L.Sokolov, I.M.Ternov. DAN USSR 153, 1052 (1963).
8. S.I.Serednjakov et al. Phys. Lett. 66B, 102 (1977).

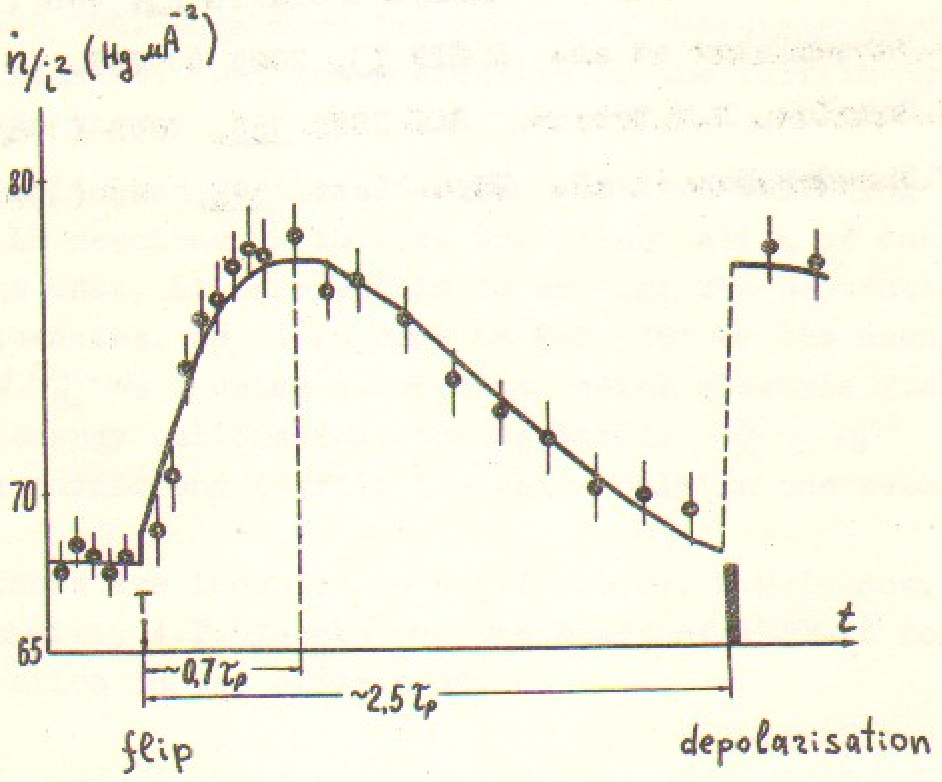

Fig. 1.

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Работа поступила - 27 января 1982г.
Ответственный за выпуск - С.Г.Попов
Подписано к печати 04.02.82г. МН 03085
Усл. 0,3 печ.л., 0,2 учетно-изд.л.
Тираж 290 экз. Бесплатно
Заказ № 16

Отпечатано на ротапринте ИЯФ СО АН СССР