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A. Turrin: ON THE FEASIBILITY OF STIMULATED RESONANT DEPOLARIZATION TECHNIQUES IN ELECTRON STORAGE RINGS.

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ON THE FEASIBILITY OF STIMULATED RESONANT DEPOLARIZATION TECHNIQUES IN ELECTRON STORAGE RINGS.

ABSTRACT -

The only mechanism conceived till now[1)] to depolarize selected electron bunches stored in a single ring is reanalysed. It is found that such a scheme appears to be impractical.

Recently, W. T. Toner proposed a technique[1] for observing collisions between polarized e^+ and unpolarized e^- in the single storage ring EPIC. This method consists in artificially producing a resonance between the proper frequency of the magnetic moment of the particle and the periodic perturbations due to few weak localized sole noidal magnetic fields, deliberately pulsed at suitable azimutal positions.

(Of course, with n bunches of electrons and n bunches of positrons stored, the field integral of the perturbation created by one of these fields must have a time derivative of the form

$$(B_{\parallel} \ell)\ \delta(t - k\frac{T}{n})\cos\left[\omega_c\left(\frac{g-2}{2}\right)\gamma\ t\right]\ , \text{(k any integer)}$$

in order to act on the e^- bunches, leaving the e^+ bunches unaffected (δ is the Dirac function and T is the revolution period)).

In this way, at every passage through the perturbed azimuthal position, the magnetic moment of the particle is rotated by a small angle toward the horizontal plane. Now, the existing horizontal component of polarization is still affected by the depolarization mechanism due to the random mixing among electron trajectories produced by synchrotron radiation[2], while the vertical component increases owing to the emission of synchrotron light[3]. Thus, if this proposal is to be useful, after a time of the order of the depolarization time constant[2] one may expect to have a more or less significant depolarization.

In what follows we will discuss the spin motion equations with inclusion of all the effects above. Reference is made to V. N. Baier's paper[4] for the basic theory.

In a reference frame (x, y, z) which is attached to the particle and which rotates about the main field direction z with angular velocity $\omega_c (\frac{g-2}{2}) \gamma_{res}$, the spin motion near the $(\frac{g-2}{2}) \gamma_{res}$ resonance may be described in first-order approximation by the equations

(1a) $$\frac{dS_x}{ds} = - \frac{1}{N_{DP}} S_x - \Delta S_y$$

(1b) $$\frac{dS_y}{ds} = \Delta S_x + \eta S_z - \frac{1}{N_{DP}} S_y$$

(1c) $$\frac{dS_z}{ds} = - \eta S_y - \frac{1}{N_P} (S_z - S_{z\,max}).$$

Here, s is the number of orbit revolutions;

$\Delta = 2\pi \gamma (\frac{g-2}{2}) \frac{E-E_{res}}{E}$ is the advance of angular precession/ /revolution about the main field (z axis);

η is the mean angular kick (about the x axis) received in one revolution by the polarization vector by effect of the perturbing field;

$N_P = \frac{c}{2\pi} \frac{8}{5\sqrt{3}} \frac{m_e c^2}{e^2 \hbar} \frac{\varrho^2}{\gamma^5}$ is the polarization buildup time constant[3] (expressed as a number of revolutions);

$S_{z\,max} = .924$ is the corresponding maximum polarization value that the circulating electrons can acquire.

At last,

$N_{DP} = (\frac{Lr}{E}) \left(\gamma (\frac{g-2}{2}) \alpha_2 (\frac{\widehat{\Delta\gamma}}{\gamma})^2 \right)^{-2}$ is the horizontal depolarization time constant[2] (expressed as a number of revolutions).

In this last expression $(\frac{Lr}{E})$ is the fractional energy loss per revolution sufferred by the single particle;

$\widehat{\Delta\gamma}$ is the r.m.s. value of the amplitude of phase oscillations;

α_2 is a constant determined by the storage-ring parameters.

For the EPIC case at 14 GeV[1] the numerical values of the coefficients appearing in the r.h.s. of Eqs. (1), listed in decreasing order of magnitude, are

$$\Delta = 2 \times 10^2 \frac{E - E_{res}}{E} \simeq 2 \times 10^{-3} \text{ rad, if } \frac{E-E_{res}}{E} = 10^{-5} ;$$

$$\frac{1}{N_{DP}} = 3 \times 10^{-6} \quad ; \quad \eta = 3 \times 10^{-6} \text{rad}$$

$$\frac{1}{N_P} = 4 \times 10^{-9} .$$

Assume for the moment that Δ do not depend on time. In such a case the asymptotic behaviour of S_x, S_y and S_z can be found merely by setting

$$\frac{dS_x}{ds} = 0 , \quad \frac{dS_y}{ds} = 0 , \quad \frac{dS_z}{ds} = 0 \quad \text{in Eqs. (1)} .$$

We get

(2a) $$S_x = - \frac{(N_{DP} \eta)(N_{DP} \Delta)}{1 + (N_{DP} \Delta)^2} S_z$$

(2b) $$S_y = \frac{N_{DP} \eta}{1 + (N_{DP} \Delta)^2} S_z$$

(2c) $$S_z = \frac{S_{z_{max}}}{1 + \dfrac{(N_P \eta)(N_{DP} \eta)}{1 + (N_{DP} \Delta)^2}} ,$$

so that we obtain with the parameter values listed above,

$$S_z \simeq S_{z_{max}} (1 - 2 \times 10^{-3}) ,$$

i.e. still a full polarization.

Moreover, if we put $\Delta = 0$ in Eqs. (2), we find the last formula of ref.[1)] we rewrite here below:

$$S_z = \frac{S_{z_{max}}}{1+(N_P\,\eta)\,(N_{DP}\,\eta)} \qquad (\text{giving } S_z \simeq 1 \times 10^{-3}).$$

Indeed, in his derivation of eq. above, Toner restricted the analysis to the case where $\Delta = 0$.

Our results mean that even with $\frac{E-E_{res}}{E} = 10^{-5}$ and $\eta \simeq 10^{-5}$ rad this resonant scheme is impractical. Newertheless, for the sake of completeness, the effects of rapid variations of Δ with time due to oscillations in energy will be considered very briefly.

Even with the most favourable assumption that $E-E_{res} = 0$, we must take account of time variation in Δ owing to phase oscillations. Hence if an electron undergoes phase oscillations, multiple rapid crossing[4)] of the spin resonance occurs. The corresponding vertical depolarization time constant (expressed as a number of revolutions) is given by

$$N_D \simeq \frac{\left(\frac{g-2}{2}\right)\gamma\left(\frac{\hat{\Delta\gamma}}{\gamma}\right)}{2\pi\eta^2} .$$

Taking $\frac{\hat{\Delta\gamma}}{\gamma} = 8 \times 10^{-4}$, $\eta = 3 \times 10^{-6}$ rad, we find at 14 GeV

$N_D = 4.5 \times 10^{8}$ revolutions, a figure uncomfortably close to N_P.

The author is unable to conceive any other usable depolarization mechanism.

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