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ON THE METHOD OF THE POLARIZATION MEASUREMENT BY THE SPECTRAL DENSITY OF SYNCHROTRON RADIATION

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A b s t r a c t

The possibility is discussed to measure the transversal polarization of electrons in the storage ring by detection of the spin-dependent contribution to the synchrotron radiation intensity. The detector is proposed enable to measure the polarization degree at the energies higher than 50 GeV both with colliding beams and one bunch.

Introduction

The problem of obtaining and measuring the beam polarization at high energies has recently become actual due to the design and construction of the electron storage rings for the energy higher than 50 GeV.

It is known that quantum fluctuations of the radiation mix stochastically particle trajectories in inhomogeneous fields, causing thereby the spin diffusion at a rate quickly growing with energy. This effect is negligible in the ideal storage ring with closed plane orbits having strictly vertical magnetic fields.

In real cases the spin diffusion can exceed the polarizing action of the radiation and depolarize the beam. The radial magnetic field, its radial gradient as well as the longitudinal field at the orbit are dangerous. The detailed analysis of the spin behaviour in the non-ideal storage ring has been presented in refs. 1-4, in which the requirements for the accuracy of the structure location have been obtained. It may happen that these conditions are not met in a given storage ring. In that case special methods are needed to avoid depolarization[4]. One of the evident methods is the compensation of the dangerous harmonics of the perturbation, the compensation efficiency being controlled by the polarization degree of the beam.

Thus, one needs a possibility of operative measurement and control of the beam polarization without its destruction.

At the present time two methods of measuring the beam polarization in the storage ring are available: observation of the polarization dependence of the cross section of internal scattering for the particles inside a bunch[5] and observation of the asymmetry in the Compton scattering of laser photons by the colliding polarized beam[6].

However, the efficiency of these methods falls quickly with the growth of the storage ring energy, and at the energies higher than 50 GeV both methods can hardly be used. Recently a method of measuring the transverse beam polarization with the help of synchrotron radiation (SR) has been proposed in ref. 7. Its idea consists in the determination of the spin correction to the SR radiation. This article deals with a specific variant of such a method for the LEP energies (50-120 GeV).

Present now the expression for the total (i.e. integrated over angles and wavelengths) intensity of the radiation of transversely polarized electrons with an energy $E = \gamma mc^2$, moving along a circle of a radius R in a transverse magnetic field H.

For the intensity of the radiation (without spin-flip) linearly polarized in an orbit plane one has according to /8/:

$$W_\sigma = W_0 \left[7/8 - \left(\frac{25\sqrt{3}}{12} + \eta \right) \chi + \dots \right],$$

$W_0 = 2/3 \frac{e^2 \gamma^4 c}{R^2}$, $\chi = 3/2 \frac{\hbar \gamma^2}{mcR}$ - is a small expansion parameter, η characterizes the direction of an electron polarization.

For the radiation polarized perpendicularly to the orbit plane the expression for the intensity has the following form/8/:

$$W_\pi = W_0 \left[1/8 - \frac{5\sqrt{3}}{24} \chi + \dots \right] .$$

One can see that the total radiation probability $W = W_\sigma + W_\pi$ depends on the orientation of the electron spin already in linear over χ approximation due to the term $\eta W_0 \chi$.

Consider now the dependence of the spectral density of the radiation for the transversely polarized electron on the photon energy. According to ref. /8/:

$$W_\sigma \sim \frac{e^2 c \gamma^4}{R^2} \int_0^\infty \frac{y F_\sigma(y)\, dy}{(1+\chi y)^4},$$

where $F_\sigma(y)$ characterizes the spectral composition of a σ-component of the radiation ($y = \lambda_c/\lambda$, $\lambda_c = 4\pi R/3\gamma^3$ is a critical wavelength).

At $y \gg 1$ with the accuracy up to χy terms has:

$$F_\sigma(y) \simeq \sqrt{\frac{2\pi}{y}} \exp(-y)\, (1 + \chi y - \eta \chi y).$$

Therefore, the ratio of the η-dependent terms of the first order in χ to that of the zero-order in χ is $\eta \chi y$. Correspondingly, for a polarized and unpolarized beam of electrons in a storage ring the ratio of intensities in a hard part of the spectrum must differ by $\pm \xi \chi y$, where ξ is a polarization degree of the beam, while a sign is determined by the spin direction with respect to a magnetic field in the radiation point. Thus, a relative spin correction to the intensity of SR with an energy $\hbar\omega$ is equal to:

$$\delta \simeq \frac{\hbar\omega}{E} .$$

Choosing ω in such a way, that a flux of SR photons be still high ($\sim 10^{10} \div 10^{11}$ sec^{-1}) one can obtain quite observable $\delta \sim 10^{-3}$ at the electron energy of 50-120 GeV.

Detector lay-out

To measure and control the beam polarization in a storage ring one must measure the flux of γ-quanta in the hard part of the SR spectrum. Let the detector detect N γ-quanta with the energy ω in a range $\varkappa = \Delta\omega/\omega$, radiated by the beam on one turn. Then:

$$N \simeq A E \left(\frac{\omega}{\omega_c}\right)^{1/2} \exp\left(-\frac{\omega}{\omega_c}\right) \varkappa (1 + \xi \delta),$$

$$\frac{\omega}{\omega_c} \gg 1 \qquad \omega_c = B H E^2$$

where A is a dimensional coefficient depending on the beam current and a solid angle of the photon detection, ω_c is a critical SR energy, H is a value of the magnetic field in the radiation point, E is a storage ring energy.
The factor $(1 + \xi\delta)$ characterizes the variation of the γ-quanta flux with the polarization degree of the beam. From the formula above one can see that main difficulties in extracting

the small quantity $\xi\delta$ are due to the strong dependence of N on ω, H and E :

$$\frac{dN}{N} \simeq -\frac{\omega}{\omega_c}\frac{d\omega}{\omega}, \quad \frac{dN}{N} \simeq \frac{\omega}{\omega_c}\frac{dH}{H}, \quad \frac{dN}{N} \simeq 2\frac{\omega}{\omega_c}\frac{dE}{E}.$$

If $\frac{dN}{N} \leq 10^{-4}$ the following restriction is obtained:

$$\frac{d\omega}{\omega} \leq 10^{-5}, \quad \frac{dH}{H} \leq 10^{-5}, \quad \frac{dE}{E} \lessapprox 5\cdot 10^{-6}.$$

To satisfy these requirements one can use the fact that the sign of the spin correction $\xi\delta$ depends on the mutual direction of the spin and the magnetic field in the radiation point. The ratio of the signals from two identical detectors measuring the SR intensity from the orbit regions with the opposite direction of the magnetic field depends on the beam energy considerably weaker and equals:

$$N^-/N^+ = \left(\omega^-/\omega^+\right)^{1/2}\left(H^+/H^-\right)^{1/2}\exp\left[-\frac{\omega^-}{BE^2H}\left(1-\frac{\omega^+ H^-}{\omega^- H^+}\right)\right](1+2\xi\delta),$$

where the index $\pm$ designates the spin direction with respect to the magnetic field. Varying the storage ring energy one can choose the detector thresholds so that $\left(1-\frac{\omega^+}{\omega^-}\frac{H^-}{H^+}\right)\simeq 0$, eliminating thereby the detector sensitivity to uncontrollable beam energy variations. From the presented expression for N^-/N^+ it also follows that besides the condition $\left(1-\frac{\omega^+}{\omega^-}\frac{H^-}{H^+}\right)\simeq 0$, the ratios ω^+/ω^- and H^-/H^+ must be constant. Naturally, the ways by which is achieved depend on a specific detector. One of the possible schemes is given in Fig. 1.

The γ -quanta from magnets (1), hitting thin targets (2), produce e^+e^- pairs. To avoid additional scattering of charged particles the convertor thickness must not be large. It is better to make the magnets (1) in a form of completely compensated triplets (a middle magnet is short and has a large field), in order not to change the value of the field in the magnets during the energy variation.

Positrons with the energy ω are selected by the spectrometer (3) with a focusing by an angle of $\mathcal{T}$. Ionization cham-

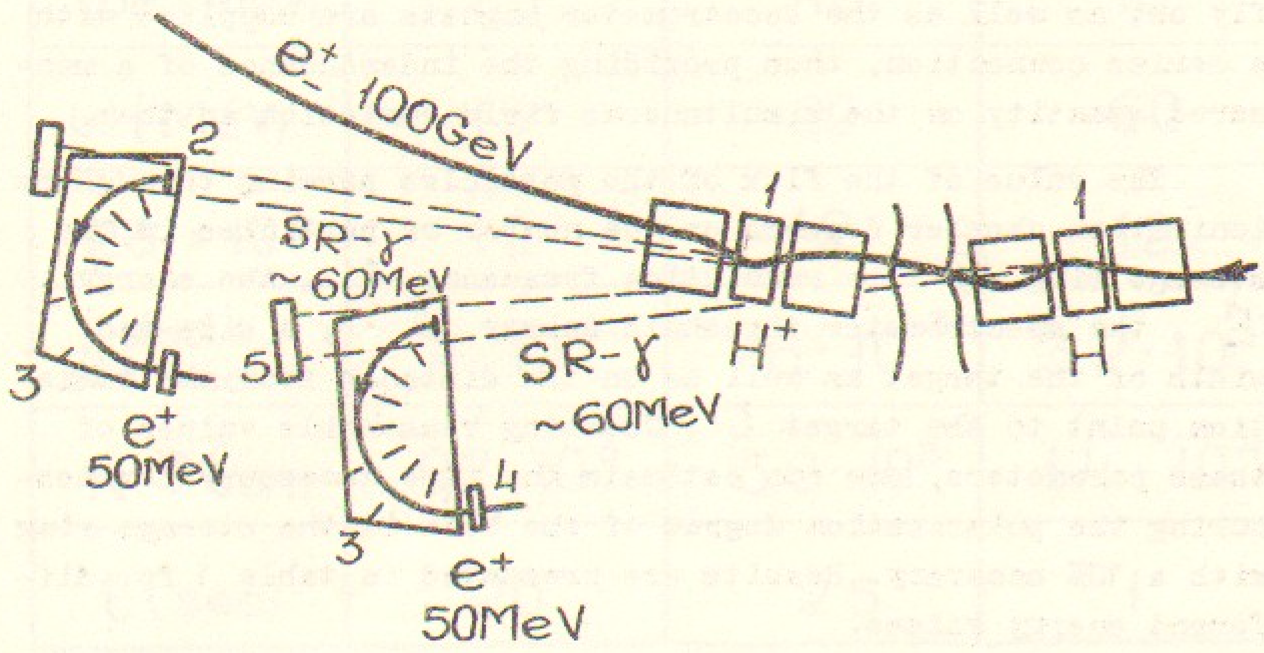

Fig. 1.

1. Magnet
2. Converter
3. Magnetic spectrometer
4. Ionization chamber
5. Synchrotron radiation receiver.

bers (4) measure the flux of charged particles in the mode of the total integration. The choice of ionization chambers is due to their high stability. A width of the SR beam in the orbit plane is much greater than a corresponding target size to exclude the influence of the beam position on the detector threshold. The magnets from which the detected γ -quanta fly out as well as the spectrometer magnets are supplied with a series connection, thus providing the independence of a measured quantity on the simultaneous field variation in them.

The value of the flux of the particles passing through an ionization chamber depends on the number of particles in the storage ring N_0, a revolution frequency f, the energy E, the spectrometer threshold energy ω, a size and width of the target as well as on the distance from the radiation point to the target L. Choosing reasonable values of these parameters, one can estimate the time necessary for measuring the polarization degree of the beam in the storage ring with a 10% accuracy. Results are presented in table 1 for different energy values.

This detector can be used to measure the polarization degree at the energies higher than 50 GeV both with colliding beams and one bunch, as well as for the calibration of the storage ring energy by the resonance depolarization method.

Another method of measuring a spin correction to the SR intensity proposed in ref. 9 is based on the determination of the ratio of SR intensities for two bunches (one polarized and another unpolarized), simultaneously circulating in the storage ring. The relative variation in the intensity of the radiation of the bunches during the change of the sign of the triplet field gives a necessary effect. As the same detector is used for measuring SR intensities of both bunches, all slow instabilities of the storage ring parameters, magnetic fields etc. are compensated. However, an additional bunch hampers using of this technique in the case of two colliding beams.

E (GeV)	50	70	100
H (kG)	15	15	15
ω_c (MeV)	2.5	4.9	10
ω (MeV)	15	29	60
$2\delta \times 10^3$	1.2	1.2	1.2
Δ Units / L rad	$4 \cdot 10^{-4}$	$1.6 \cdot 10^{-3}$	$3.2 \cdot 10^{-3}$
N e/turn	$0.7 \cdot 10^3$	$5.6 \cdot 10^3$	$1.4 \cdot 10^4$
t (sec)	20	2.5	1

Table 1.

Revolution frequency $f = 10^4$ sec^{-1}
Current 1.6 mA
$\Delta\omega/\omega$ of the spectrometer $5 \cdot 10^{-2}$.
The angular acceptance of the detector in the orbit plane for SR γ -quanta is about 10^{-3}. N is a number of charged particles hitting an ionization chamber per one revolution of the bunch in the storage ring.
t is a measurement time.

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