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A.E.Bondar, E.L.Saldin

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ON THE POSSIBILITY OF USING OF THE SYNCHROTRON RADIATION FOR MEASURING THE ELECTRON BEAM POLARIZATION IN STORAGE RING

A.E.Bondar, E.L.Saldin

Institute of Nuclear Physics
630090, Novosibirsk 90, USSR

Abstract

The possibility is discussed to measure the transverse polarization of electrons in the storage ring by detection of the spin-dependent contribution to the synchrotron radiation intensity. A Čerenkov counter is proposed to be a detector. Numerical estimates are presented for the electron energies of 5 GeV and 70 GeV.

I. INTRODUCTION

In paper [1] a new method to measure the electron beam transverse polarization using the synchrotron radiation (SR) have been proposed. The essential point of this method is that one measures the spin-dependent correction δ to the intensity of SR.

The magnitude of this corrections is of the order of the ratio of SR - photon energy to electron energy:

$$\delta \simeq \pm \frac{\hbar \omega}{E} \tag{1}$$

The sign of δ is determined by the sign of projection of magnetic field direction on the direction of electron spin at the orbit point where this SR - photon is radiated.

As it is seen from eq. (1) δ should be measured at hard end of SR - spectra. Let us remind that SR - spectrum is the universal function of $y = \omega / \omega_c$, where ω_c is the critical frequency of SR ($\omega_c \sim HE^2$). So, if one fixes $y \simeq 10$, the photon flux rate is still sufficiently high ($10^{10} \div 10^{11}\ \mathrm{sec}^{-1}$) in order to have the necessary statistics.

While y is fixed, δ grows linearly with the electron energy E. At $E = 10 \div 100$ GeV and $H \simeq 10$ kG one has

$$\delta \simeq 10^{-4} \div 10^{-3}$$

Since the photon flux is chosen rather high, one expects the corresponding measurement time to be about of some seconds. So far as the sign of the effect depends on the sign of projection of magnetic field on the direction of electron spin, one can measure the beam polarization without its destruction.

The aim of this work is the consideration of topics, related to the concrete realization of the method for the storage ring energies $10 \div 100$ GeV. In particular, some problem arises to reject the hard end of SR-spectra where the threshold energy of photons should be chosen in the range of $0.5 \div 50$ MeV. In the Čerenkov counter considered below this threshold is provided by the choice of the refraction coefficient of radiator.

II. The spin dependence of SR

Let us write out an expression for the total (integrated over angles and wavelengths) radiation intensity of transversally polarized electrons with the energy $E = m\gamma$. These electrons travel in a transverse homogeneous magnetic field H along a circle of radius R.

The expression for the linearly polarized radiation intensity in the orbit plane (with out spin-flip) is [2]:

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

where $W_0 = \frac{2}{3} \frac{e^2 \gamma^4}{R^2}$, $\chi = \frac{3}{2} \frac{\hbar \gamma^2}{m R}$ - is the small parameter of expansion, η is characterized by electron polarization direction(for example $\eta = 1$ when the spin is directed along the field).

The intensity of emission of radiation with polarization, perpendicular to the orbit plane, without spin flip is given by formula [2]:

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

It is seen from this expression that the total radiation intensity $W = W_\sigma + W_\pi$ depends on the electron spin orientation even in linear in χ approximation since W contains the term $W_0 \chi \eta$.[1)]

[1)] Note, that this term has a classical analogue. As a function of angular momentum $\vec{S} = \hbar \vec{\zeta}/2$ it does not contain the Planck constant $\hbar$ and so one can obtain it using the classical theory of radiation for a particle with the electric charge, magnetic dipole moment and internal angular momentum.

Let's consider the dependence of the spectral density of the transversally polarized electron's radiation on the photon energy.

$$W_\sigma = \frac{const \cdot \gamma^4}{R^2} \int_0^\infty \frac{y F_\sigma(y)}{(1 + \chi y)^4} dy ,$$

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

$$F_\sigma(y) = (1 + \tfrac{1}{2}\chi y)^2 \left[\int_y^\infty K_{5/3}(x)dx + K_{2/3}(y) \right] + \\ + \tfrac{1}{2}\chi^2 y^2 \int_y^\infty K_{1/3}(x)dx - \eta(2 + \chi y)\chi y K_{1/3}(y).$$

For $y \gg 1$

$$\int_y^\infty K_{5/3}(x)\,dx \simeq K_{2/3}(y) \simeq K_{1/3}(y) \simeq \sqrt{\frac{\pi}{2y}}\, e^{-y}$$

Therefore, the ratio of the η - dependent term of the first order over χ to the term of zero order over χ is simply $\eta \chi y$. Correspondingly, the difference between the intensities of hard part of spectrum for polarized and unpolarized electron beams is $\pm \zeta \chi y$, where ζ is the polarization degree.

III. Polarization measurements on VEPP-4

On the storage ring VEPP-4 there is a proposal to measure the SR intensity from the compensated one-period wiggler with the field intensity of 22 kG in the central magnet and the pole length of 20 cm. The alternating magnetic field results in the variation of the SR intensity:

$$I_+/I_- \simeq (1 + 2\xi\chi y).$$

The background due to the weak field of the storage ring and of the compensation magnets of the wiggler is negligible because the measurements are performed in the hard tail of the SR spectrum produced by the central magnet with the several-fold field intensity.

To measure the variation in intensity the Čerenkov counter is proposed with the radiator of 1.475 refraction index. The 50% water solution of sugar may be used as the radiator. The Čerenkov radiation in optical range is emitted by the electrons whose kinetic energy $T > T_{th}$ = 184 keV. The photon of the energy $\hbar\omega$ can produce the compton-scattered electron with the maximum energy of

$$T = \frac{2\hbar^2\omega^2}{m} \Big/ \left(1 + \frac{2\hbar\omega}{m}\right),$$

hence the counter will detect only those γ - quanta whose energy $\hbar\omega$ exceeds 328 keV.

The photons of the energy below the threshold when absorbed in the radiator can cause its scintillations. To suppress this effect the filter is proposed (Pb 1 cm) to cut-off the soft tail of the SR spectrum. The calculated yields for the Čerenkov light and for the scintillations in the counter are summarized in the Table 1 and fig. 1.

The effect being small ($\simeq 2\cdot10^{-4}$), the high accuracy and time-stability in measuring I_+/I_- is required. Thus the most reliable method appears to be the measurement of the relative SR intensities from the 2 electron bunches (one of them polarized the other not), which rotate in the storage ring. Then the relative variation of the radiation intensities from the two bunches resulting from the field altemating in the wiggler appears to be the effect in question. For these measurements it is desired to have equal currents in the 2 bunches. The experience with the storage ring VEPP-4 demonstrated the simplicity of the current equalization to less than 10^{-3} difference (by means of the tunable knock-out at one of the 2 bunches).

The proposed scheme of the measurement is shown in fig. 2. The measurement of the Čerenkov light intensity by the PM is done in the counting mode. Fig. 3 shows the dependence of the discriminator triggering by the bunch passage through the wiggler on the value of the threshold amplitude.

Maximum steepness of the curve slope is determined by the width of pulse height distribution of PM signals (i.e. a number of Čerenkov photons collected at the photocathode). At the beam current 1 ma, coefficient of light collection in the Čerenkov counter 0.2 and PM quantum sensitivity about 0.1, a number of photoelectrons per one bunch passage is about 500. Thus, the width of the pulse height distribution $\Delta \simeq 4\cdot10^{-2}$. For a sensitivity of the method to be maximum the probability of discriminator triggering per one bunch passage should be about 0,5. In this case a ratio of the counting rates from the first and second bunches characterizes the relative variation of the SR intensity of two bunches. Such a measurement scheme allows the compensation of all slow unstabilities of a measurement path, beam parameters as well as wiggler magnetic fields.

Proceed now to estimation of the measurement time. One has

$$\delta = (I_+/I_- - 1) \simeq \Delta\left(\frac{N_1^+ N_2^-}{N_2^+ N_1^-} - 1\right),$$

where $N_1^{\pm}$ and $N_2^{\pm}$ give a number of discriminator triggerings in coincidence with a phase of the 1st and 2nd bunches during the time t, a superscript ($\pm$) designates field direction in a wiggler. A statistical error in a ratio N_1/N_2 is about $N_1^{-1/2}$ ($N_1 \simeq N_2 \simeq f_0 t/2$, where f_0 is a revolution frequency).

If it is required that the value of the observed jump be equal about 3 statistical errors then the measurement time is equal to

$$t \simeq \frac{36\,\Delta^2}{f_0\,\delta^2}\,.$$

For $f_0 \simeq 10^6$, $\delta \simeq 2\cdot10^{-4}$, $\Delta \simeq 4\cdot10^{-2}$ one obtains $t = 1$ sec.

One can see from the expression above that the measurement time depends on the quantity of light in a counter, a revolution frequency and a size of effect.

It is supposed to use in the experiment the natural radiative polarization of particles in the storage ring VEPP-4. At the energy 5.5 GeV the polarization time is about 0.5 hour. Before the measurement one of the bunches is depolarized by a special selective depolarizer. Because of a small revolution frequency of the storage ring no technical difficulties arise while constructing such a depolarizer.

In conclusion we shall discuss the possibilities to apply the proposed method at high energies. For the 70 GeV electrons (LEP project /3/) at $\lambda_c/\lambda = 10$ the spin-dependent correction comes to $\delta \simeq 10^{-3}$ with the wiggler field of 10 kG. The SR intensity here should be measured at energies of the γ - quanta above 30 MeV. The gas Čerenkov counter (ethylene C_2H_4) can be used as a detector. In contrast to the case of low energies the problem of suppressing scintillations in the radiator should be studied more carefully. As the use of filters at these γ - quanta energies is no more possible, we propose to convert γ - quanta in a target first, then to separate the "hard" electrons by a magnetic spectrometer. The electron flux then will be measured by the gas Čerenkov counter with the focusing optical system (see fig. 4). The γ energy threshold is now determined by the magnetic spectrometer. The counter threshold can now be set at about 13 MeV (C_2H_4 at the pressure of 1 atm), in order not to degrade the Čerenkov light yield.

In the proposed scheme the soft γ - quanta and electrons can occure in the Čerenkov detector only due to multiple scattering at the construction elements. This fact together with the low scintillation level in the ethylene make it possible to avoid the low-energy γ background.

The counting time in this detector is of the order of 1 sec at the storage ring energy 70 GeV, the current in one bunch of 0.2 mA, wiggler field of 10 kG, magnet pole length of 10 cm and the revolution frequency of 10^4 sec^{-1}. The tungsten converter thickness in this calculation is taken $\simeq 0.14$ g/cm^2, $\Delta E/E$ in the spectrometer is ~ 0.2. The number of electrons incident in the counter per one pass of the beam through the wiggler comes to 10^3. The respective number of the Čerenkov photons is $3.5\cdot10^4$ in the wavelength range of 3500-5000Å.

Here the effect is stronger than that at VEPP-4, therefore the polarization is likely to be measurable even for one bunch mode in the storage ring by fast alternations of the wiggler field.

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2. N.M.Ternov et al. ZhETF 1964, 1, 374.
3. Design study of a 22 to 130 GeV e^+e^- colliding beam machine (LEP). CERN/ISR-LEP/79-33.

Figure captions

Fig. 1. Čerenkov light output from radiator with n = 1.475 per a beam turn in the storage ring.

1. SR spectrum
2. SR spectrum after the filter (1cmPb).
3. Čerenkov light output.
4. Number of scintillation photons in radiator (50% sugar solution).

Fig. 2. a) Amplitude distribution from PM.

b) Trigger probability vs. discriminator threshold.

Fig. 3.

1. Main magnet of the wiggler (H = 22 kG)
2. Compensation magnets of the wiggler.
3. Čerenkov counter
4. PM (Photomultiplier)
5. Threshold discriminator
6. Coincidence circuit
7. Counters
8. PM gain stabilization arrangement
9. HV supply
10. The signal synchronized with the moment of 1-st (2-nd) bunch the passage through the wiggler.

Fig. 4. Detector layout for 70 GeV

1. SR beam
2. Magnet spectrometer
3. Gaseous Čerenkov counter
4. PM.
5. SR absorber.

Tab. 1

J (mA)	1
E (GeV)	5.5
H (kG)	22
ω_c (keV)	44.3
n	1.475
N_c^{γ}	$2.5 \cdot 10^4$
$N_{ph.e.}$	$\sim 10^3$
χ	$8 \cdot 10^{-6}$
δ	$1.6 \cdot 10^{-4}$

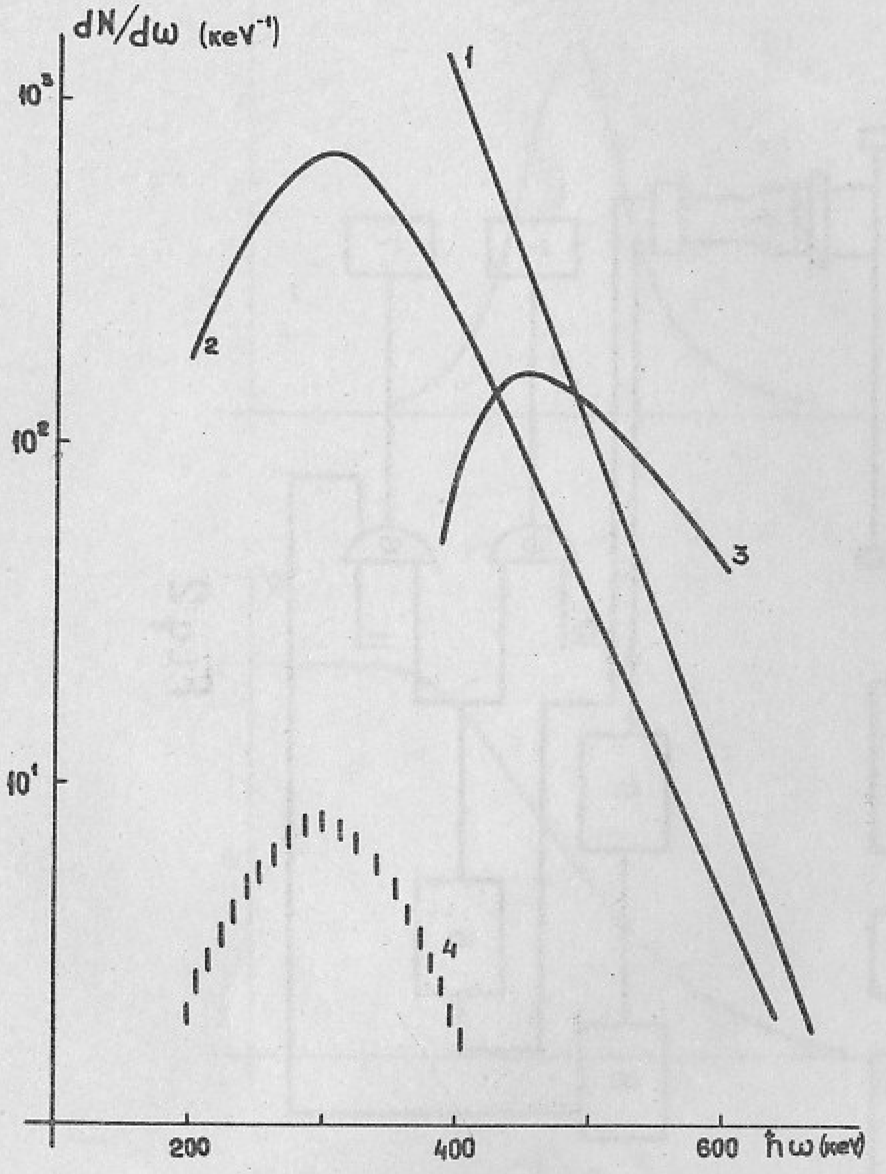

Fig 1

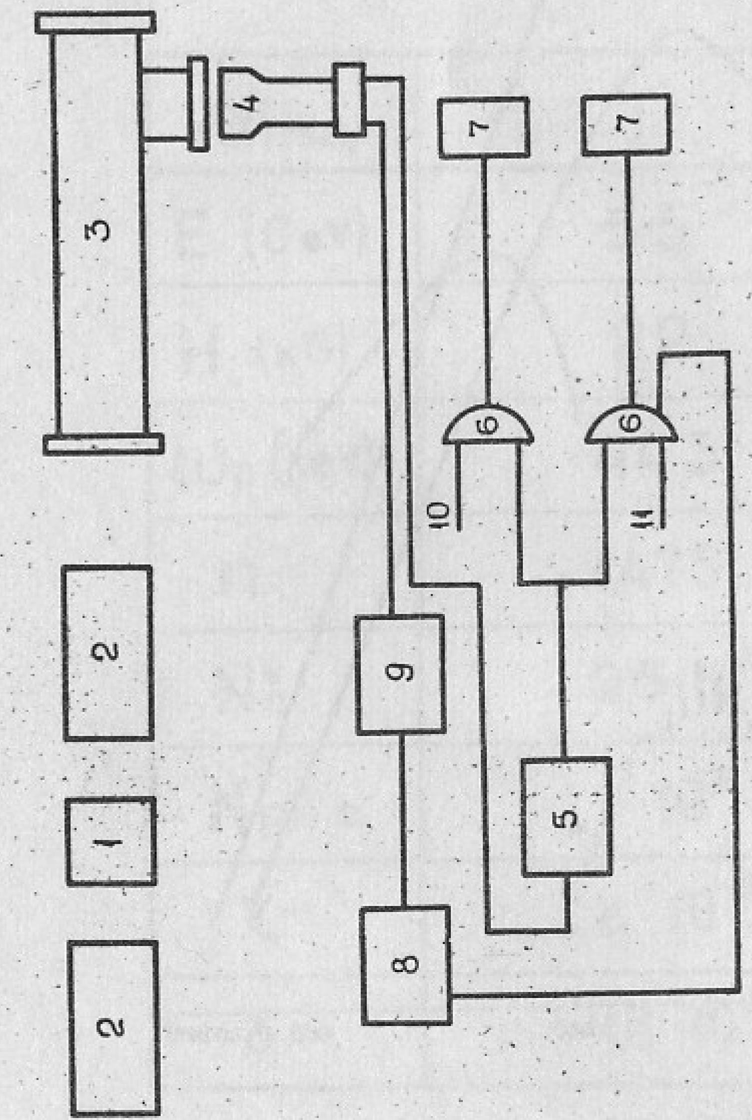

Fig 2

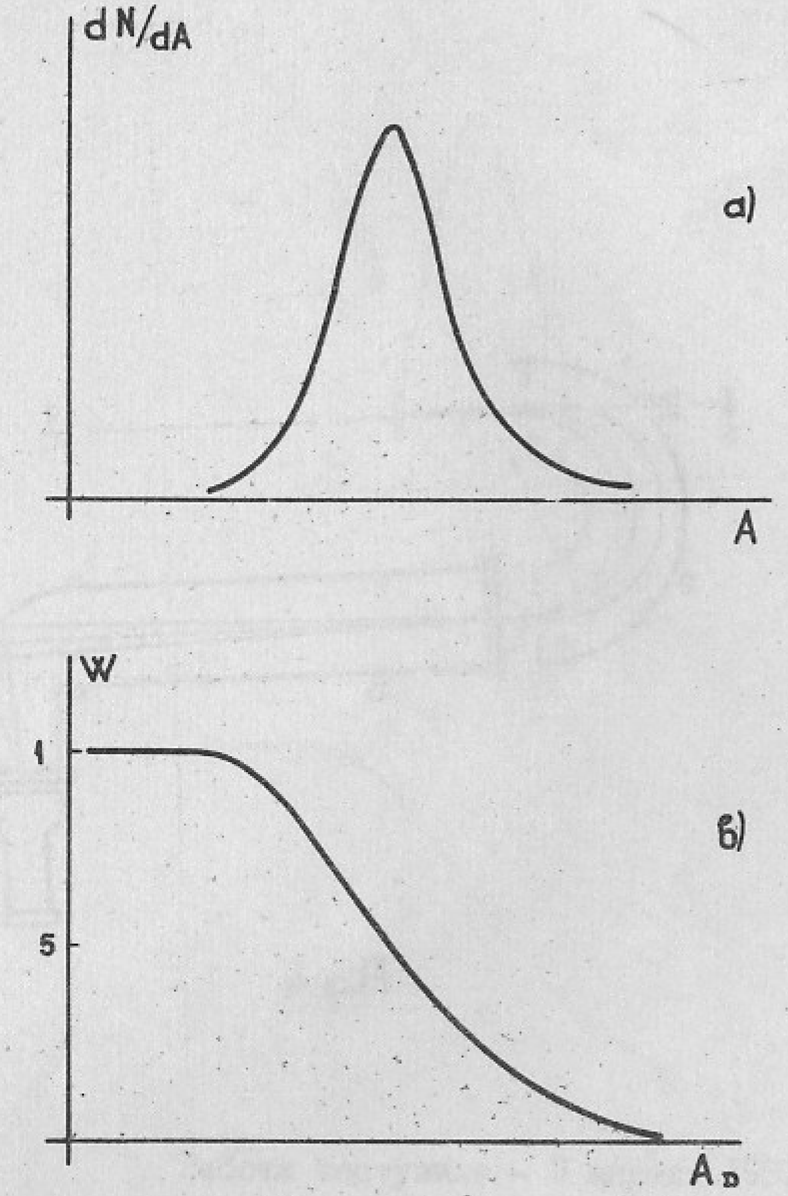

Fig. 3

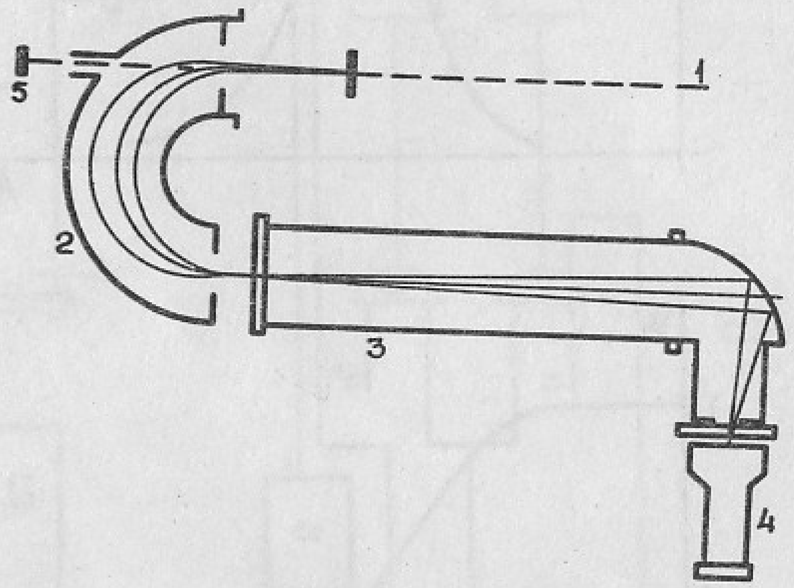

Fig. 4

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