POLARIZATION MEASUREMENT IN STORAGE RINGS OF THE INSTITUTE OF NUCLEAR PHYSICS (NOVOSIBIRSK)

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Polarization measurement is a necessary part of the experiments with polarized beams in storage rings.

At the Institute of Nuclear Physics (Novosibirsk) a number of polarization measurement techniques and devices intended for polarization control have been suggested and tested at the VEPP-2, VEPP-2M, VEPP-3 and VEPP-4 storage rings.

The paper presents a brief description of the used techniques and experience of performing experiments with the polarized beams.

1. Polarization measurement by means of the intra-beam scattering effect (IBS)

The idea of the method has been suggested in Ref. /1/, and its realization has first occured at the VEPP-2 /2/ and ACO /3/ facilities. This method is based on the dependence of the particle scattering cross section in a bunch on a relative orientation of their spins. The measurements are made using special counters which detect the pairs of particles lost from the beam due to IBS and having after interaction, the momenta different from the equilibrium one ($p+\Delta p$ and $p-\Delta p$). The contribution from polarization to the IBS decreases with increasing the transverse momentum of the interacting particles and increases at large momentum transfers. The counting rate of events also slows down as the transverse momentum and size of the beams grow. In view of this, the use of the IBS is justified within the low-energy range only.

The method is analyzed in detail in Ref. /4/.

Two different versions are possible to construct a IBS-based polarimeter.

In the first version (VEPP-2M, ACO) the particles are detected, which strongly vary their momentum and leave the storage ring's aperture already behind the first bending magnets. The set of counters is located outside the aperture and the events from a limited azimuthal section of the storage ring are detected. In this case, the effect is more significant but the counting rate is low. For example, in the measurements at the VEPP-2M the momentum variation was $\Delta p/p \approx 0.2 \div 0.3$, the effect constituted about 20%, and the counting rate at currents of about 20 mA was equal to dozens of Hz.

In the second version, the events with a small momentum transfer are detected so that both particles remain in the storage ring chamber after interaction. The counters are placed within the aperture and detect the events available from the whole perimeter of the storage ring. In this case, the counting rate is high but the effect becomes much smaller. Therefore, the beam sizes and the other parameters, determining the counting rate, need to be strongly stable. In the experiments at the VEPP-4 (see Ref. /5/), while measuring the masses of the Ψ - and Ψ' -mesons, we have obtained the magnitude of the effect about 2% at a counting rate of 2-4 kHz.

For normalization, it has seemed convenient to have two bunches of the same intensity: polarized and non-polarized ones. This eliminates the necessity for an accurate normalization of the counting rate per squared number of particles.

2. Laser Polarimeter

The idea of a laser polarimeter has been suggested in the paper /6/ for the first time. A first laser polarimeter has been installed at SPEAR. At the VEPP-4 (Ref. /7/) we have used a laser with a wavelength of 5300 A, repetition frequency 20 kHz and power 3 W. To measure the scattered-beam asymmetry, the detector, which is designed on the basis of a proportional chamber with a 120 resolution, is employed. The detector is 20 m distant from the scattering region.

With the aim of increasing the detection efficiency with low scattering on the converter, use is made of a many-chamber system consisting of five converters and chambers placed one after another. The total radiation length is about 2.5 Xo. This provides a detection efficiency of about 80%. The Na-based total-absorption counter for measuring the photon energy, is located behind the chambers. With a current of 3 mA in the storage ring the counting rate of γ-quanta is about 10 kHz. This ensures a 10% accuracy of polarization measurement during a period of about 100 s. The measurements involving the laser polarimeter have been made in an energy range of 4.7-5.2 GeV.

3. Polarization Measurement by Scattering of Synchrotron radiation (SR) circularly-polarized photons on a colliding beam

The idea of the method and its description are given in the paper /8/. The method has been used for the energy calibration of the masses of the Υ -, Υ' - and Υ'' -mesons at the VEPP-4.

As known, outside the orbit plane the photons of synchrotron radiation has a circular polarization of different signs above and below the orbit. In view of this, if the electron and positron orbits are vertically separated, then the circularly-polarized photons will be mainly involved in the Compton scattering. Unlike the laser technique, the present method gives a larger magnitude of asymmetry. The maximum asymmetry occurs at the energy of incident photons in the electron-system of rest, $\approx mc^2$. This corresponds to an energy of photons of 25 eV for the electrons with an energy of 5 GeV. The photons having such an energy and a high degree of circular polarization are emitted at an angle of about $\sim 6\cdot 10^{-4}$ to the orbit plane. The selection of the required photons from the entire SR spectrum is made by measuring the energy of scattered γ-quanta by a total-absorption counter.

The experiment is schematically shown in Fig. 1. The up-down asymmetry has been

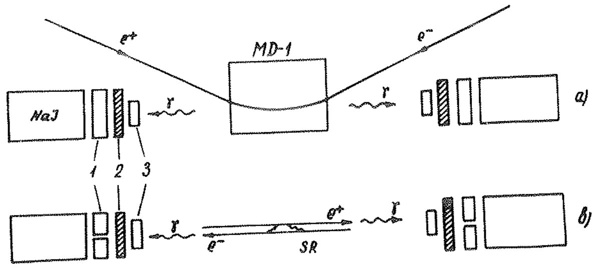

Fig. 1. Lay-out of the installation for polarization measurements by scattering of SR circularly-polarized photons.

a) view from the top;
b) side view.

1 - Counter for measuring up-down asymmetry.
2 - Converter.
3 - Paired ionization chamber.

measured by two scintillation counters (1) with a 1-mm gap between them. The counters are 1- m distant from the collision point in the transverse-field detector MD-1. The electron and positron directions are both used. To compensate the asymmetry caused by the vertical instability of the orbit, a special feed-back system using a computer has been designed. As the detectors, the ionization chambers have been employed in pairs (3), which operate in the soft part of the synchrotron radiation spectrum. The chambers are placed in front of the counters measuring the asymmetry. In the standard cycles of Υ-meson measurements the magnitude of the asymmetry constituted $4.6\pm 1\%$ at a 55% degree of beam polarization. This is in good agreement with the calculated value $(4\pm 0.5)\%$. The typical counting rate is ~ 1 kHz. The behaviour of the asymmetry as a function of time is shown in Fig. 2. (1 and 2: SR scattering on e^- and e^+ beams, 3: laser light scattering on e^- beam. A = (up-down)/ (up+down)).

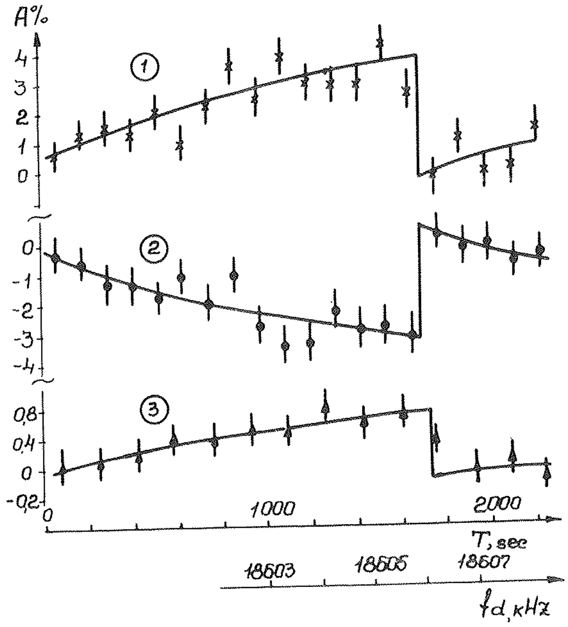

Fig. 2. Time dependence of the asymmetry.

4. Measurement of radiative polarization by a hard part of SR

The idea of the method has been advanced in the paper /9/, and various variants of its possible applications have been discussed in the papers /10/ and /11/. The first experimental results are given in paper /12/.

The essence of the method consists in measuring a spin correction to the SR intensity. This correction is equal by order of magnitude, to the ratio of the energy of the detected photons to the energy of electrons:

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

Note that a sign of δ is determined by a sign of the magnetic field at radiation point.

For the VEPP-4, $\omega/\omega_K = 7$ (ω_K is the critical SR frequency) and $\delta \approx 5\cdot 10^{-5}$ if the field is $B = 20$ kG and the energy is $E = 5$ GeV.

To observe so small correction, a special technique has been developed, which includes the following:

a) Relative variation of the SR intensity has been observed caused by two bunches of approximately equal current ($\Delta I/I \approx 10^{-5}$) during the change of the polarization degree of one of the bunches.

b) A special selective depolarizer enables any bunch to be depolarized.

c) The SR intensity generated by each bunch is measured in the counting regime by means of a scintillation counter. It should be noted that the threshold of a discriminator has been chosen so that the counting rate from each bunch be about a half of the revolution frequency. The latter circumstance is connected with the fact that at a large number N of photons in the detector at each revolution the pulse-height spectrum has a relative width $\sim 1/\sqrt{N} \ll 1$. In this case when a discriminator threshold coincides with the most probable pulse height the detector sensitivity to the mean number of photons is maximum.

A schematic view of the experiment is given in Fig. 3. The SR, emitted by a special "snake", is extracted at a counter. The ratio of the counting rate from two bunches is measured. The feed-back system stabilizes, through a slight variation of the field in the "snake", the counting rate from one of the bunches at a level of $0.5 f_0$. The typical results of the measurements with the variation of the field polarity in the "snake" and without its variation are presented in Fig. 4.

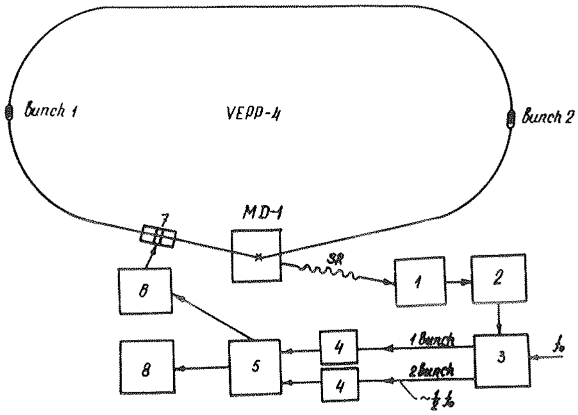

Fig. 3. 1 - Scintillation counter,
2 - discriminator,
3 - commutator,
4 - counters,
5 - computer,
6 - "snake" power supply,
7 - "snake",
8 - display.

5. Forced depolarization. A depolarizer

A fast forced depolarization is useful for polarization measurements. As a rule the resonant excitation of one of the frequencies has been used:

$$f_d = (K - \nu) f_0$$

(ν is the spin precession frequency, K is an integer).

We make use of several types of depolarizers.

1) The depolarizer with a longitudinal magnetic field is a loop surrounding the vacuum chamber (VEPP-2, VEPP-2M). It follows from the spin motion kinematics that the efficiency of the depolarizer decreases with increasing the energy.

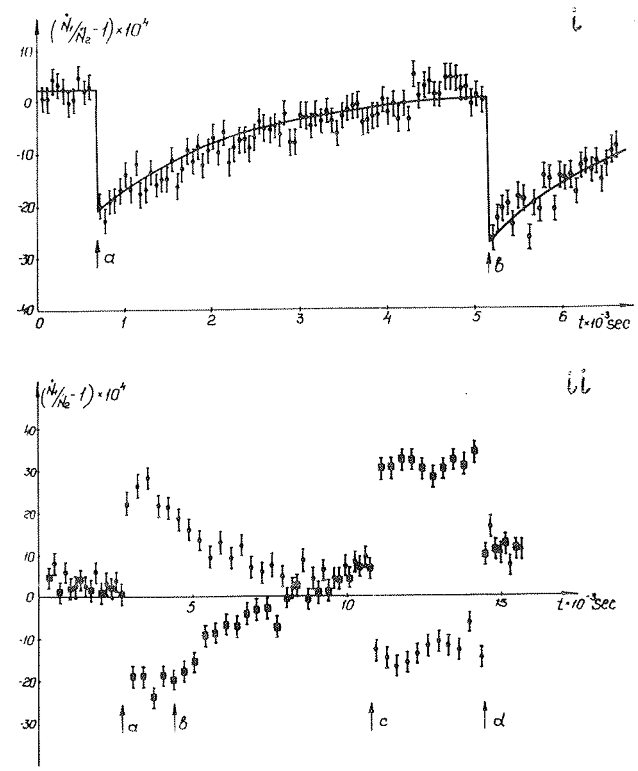

Fig. 4. i) Results of the measurement of SR intensity dependence on the beam, polarization degree ($\dot N_1/\dot N_2$ is a ratio of counting rates of photons from 2 bunches). In points (a) and (b) a fast depolarization of one of the bunches has been performed. The measurement time is 60 sec per point. The polarization time of a bunch is $\tau_p = 1740 \pm 20$ sec ($\xi = 0.726$).

ii) Results of the measurement of SR intensity dependence on the field direction in a "wiggler".

ф - a field sign in a central gap of a "wiggler" coincides with a sign of a guiding field in the storage ring;

ɸ - a field sign is opposite. a+b -depolarizer on ($\dot N_2$); b+c -dep. off; c+d -dep. on ($\dot N_1$); after d both bunches are depolarized.

2) The depolarizer with a radial magnetic field keeps, in a first approximation, its efficiency as the energy increases. However, it is worth emphasizing that this efficiency is a complex function of energy and of the location of the depolarizer in the magnetic structure of the storage ring.

As has been shown in the paper /13/, the perturbative action of a radial magnetic field is determined by the function characterizing the response of perturbation in the spin motion.

Fig. 5 shows the experimental results which demonstrate the different efficiency of the transverse-field depolarizer at two energies of the VEPP-4.

The transverse-field depolarizer has been in use at the VEPP-3 and VEPP-4 facilities. Usually, a pair of vertically-separated plates switched on to a rf generator has served as a depolarizer.

3) The single bunches can be depolarized

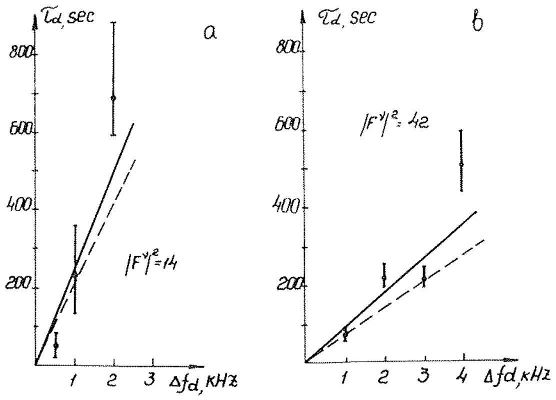

Fig. 5. The time of forced depolarization as a function of the deviation amplitude Δf_d of the depolarizer frequency at two values of $|F^{\nu}|^2$.

a) $|F^{\nu}|^2 = 14$ (E = 4930 MeV)
b) $|F^{\nu}|^2 = 42$ (E = 4980 MeV).

A solid line is an experiment, a dashed line is a calculation ($\tau_d^{-1} \sim \Delta f_d^{-1} |F^{\nu}|^2$).

by a selective depolarizer with the time modulation of the depolarizing field.

Also useful for the polarization measurements can be the flip-technique (Ref. /14/) which enables a spin of particles to be flipped without the distortion of their degree of polarization.

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