

HIGH-EFFICIENCY POLARIMETER BASED ON INTRA-BEAM SCATTERING*

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Abstract

High-efficiency polarimeter based on a spin dependence of the effect of mutual scattering of beam particles is described. It has been designed and successfully commissioned at VEPP-4M collider for using in the new experiment on a refinement of the J/Ψ -, Ψ' - meson masses and for the proposed measurement of the tau lepton mass by the resonance depolarization method.

1 INTRODUCTION

The cross section of mutual scattering of electrons in the polarized beam circulating in the storage ring is some less than in the unpolarized one. To observe the polarization of an extension ζ one needs to depolarize the beam using an external spin resonance and determining the fact of depolarization by the jump $\propto \zeta^2$ in the counting rate of scattered beam particles [1]. Until recent time only a specific measurement scheme was considered as well studied and proved in experiment. In this scheme the particles scatter over a straight section, pass the bending magnet and then are registered [2, 3]. The magnet separates trajectories of the Touschek pair electrons by a sign of their momentum deviation from an equilibrium momentum. It allows to observe the pairs with a relative large momentum deviation (from a few up to ten percents) that provides a strong polarization effect (\sim ten percents) in the counting rate. In 2001 the polarimeter based on Touschek scattering was designed and commissioned at VEPP-4M for experiments on high-precision measurement of J/Ψ -, Ψ' - mesons and τ -lepton masses [4]. The location of the polarimeter at VEPP-4M corresponds rather to a general case when the registered electrons are scattered over a whole ring and their momentum deviation is not so large (\sim one percent). In our paper we present the results of calculations and experiments which show that even in such a case it is possible to provide a high efficiency of the polarimeter by varying the position of the counters for Touschek electrons in respect to the beam orbit.

2 OBSERVATION PARAMETERS

A scintillation counter is moved inward the aperture of vacuum chamber at the distance A from a closed orbit position. In accordance with the theories of intra-beam scatter-

ing in storage rings [5] and polarization effects in electron-electron scattering [6], the counter can register Touschek electrons with a rate (non-relativistic approximation in the center-mass system)

$$\dot{N} = \frac{\sqrt{\pi} r_0^2 c N^2}{\gamma^5 V_b (\sigma_E/E)^3} (I_1 + \zeta^2 I_2).$$

Here, N is a beam population; V_b is a beam volume; r_0 is the electron radius; γ is a relativistic factor; σ_E/E is a relative energy spread; ζ is a beam polarization extent;

$$I_1 = \int_{\varepsilon_1}^{\varepsilon_2} \frac{1}{\chi^2} \left\{ \frac{\chi}{\varepsilon_1} - 1 + \frac{1}{2} \ln\left(\frac{\varepsilon_1}{\chi}\right) \right\} e^{-\chi} d\chi +$$

$$+ \int_{\varepsilon_2}^{\infty} \frac{1}{\chi^2} \left\{ \chi \left(\frac{1}{\varepsilon_1} - \frac{1}{\varepsilon_2} \right) + \frac{1}{2} \ln\left(\frac{\varepsilon_1}{\varepsilon_2}\right) \right\} e^{-\chi} d\chi,$$

$$I_2 = \int_{\varepsilon_1}^{\varepsilon_2} \frac{1}{2\chi^2} \ln\left(\frac{\varepsilon_1}{\chi}\right) e^{-\chi} d\chi + \int_{\varepsilon_2}^{\infty} \frac{1}{2\chi^2} \ln\left(\frac{\varepsilon_1}{\varepsilon_2}\right) e^{-\chi} d\chi,$$

$$\varepsilon_{1,2} = [\Delta p_{1,2}/(\gamma\sigma_p)]^2;$$

Δp_1 , and Δp_2 are respectively an upper limit and a lower one of the deviation of a particle momentum from an equilibrium one; σ_p is the rms radial component of particle momentum. Quantity Δp_1 is a minimal momentum deviation, needed for particles to fall on the counter. Generally, a particle may make many turns in the storage ring before it would occurs. For simplicity, we consider the possibility to detect the particle during only a first turn after the scattering. A contribution of particles detected at succeeding turns is not so significant since the magnitude $\Delta p/p > 1\%$ being of interest exceeds the RF separatrix size ($\sim 0.6\%$ at $E=1550$ MeV). The upper momentum limit Δp_2 is determined by an geometric aperture limit. There exist the "dead zones" with a total azimuthal length $\tilde{\theta}$ starting from which the scattered particles never reach the counter. In our calculations (see Fig1) the limit $\Delta p_1/p$ and the reduction factor $K = \tilde{\theta}/2\pi$ ($\dot{N} \rightarrow K\dot{N}$) are tabulated as polynomials depending on A ($\Delta p_1/p \approx 0.9\%$ and $K \approx 0.8$ at $A = 1$ cm). Polarization effect is a ratio

$$\Delta = \frac{\zeta^2 I_2}{I_1} < 0$$

which appears as a "jump" in the counting rate if a fast depolarization of a beam occurs (Fig.2). As follows from formulae above, the greater Δp_1 the larger jump $|\Delta|$.

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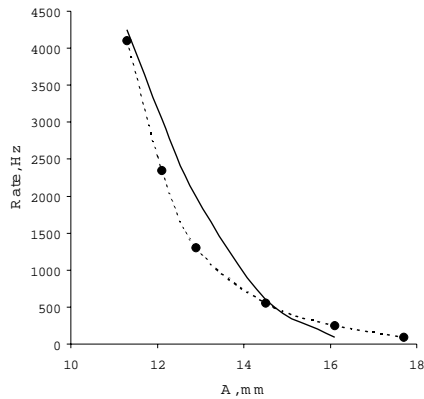


Figure 1: Design (the solid line) and measured (circles) counting rates of Touschek electrons vs. the distance A at $I_b = 2$ mA, $E = 1548$ MeV.

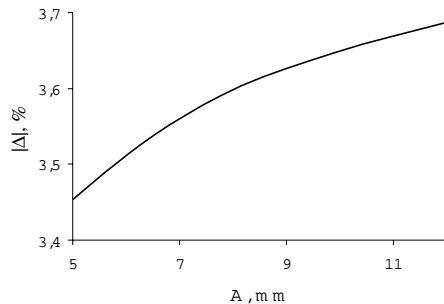


Figure 2: Magnitude of the jump vs. the distance A .

To exclude the influence of changes in beam sizes, the closed orbit variations as well as the beam lifetime fluctuations, we apply the method of "two bunches". The quantity $S = 1 - \dot{N}_2/\dot{N}_1$ is under observation where \dot{N}_1 and \dot{N}_2 are respectively the counting rates of the polarized bunch and the unpolarized one spaced at one-half turn. Numbers of particles in the bunches are equalized with the accuracy $\varepsilon = (N_2 - N_1)/N_1 \sim$ a few percents. Behaviour of S with time t before the "jump" occurs may be described by a crude formulae ($t < \tau_T, \tau_T \ll \tau_p$)

$$S(t) \approx \Delta - 2\varepsilon + 2\tau_T^{-1}(\varepsilon - \Delta) \cdot t,$$

where τ_T is a beam lifetime determined by the Touschek scattering, τ_p is a characteristic time of polarization relaxation. Particularly, a slope of the dependence $S(t)$ is positive and $S(0) < 0$ if $\varepsilon = 0$ but $\Delta \neq 0$. Determination of the slope sign helps to verify a presence of the beam polarization. Note, the first proposal [7] to find the beam polarization in storage rings just implied the beam lifetime measurement.

3 DESIGN AND CONTROL FEATURES

The polarimeter device is installed in the technical straight sections of VEPP-4M. It is based on a $\varnothing 85$ mm

cylindrical section of vacuum chamber of length 830 mm (Fig.3). There is a pair of scintillation counters at the both ends of this section. Counters of each pair can be moved from opposite sides of chamber inward the aperture in the horizontal plane and register the electrons scattered at the most part of the ring. Every counter is inserted in a stainless

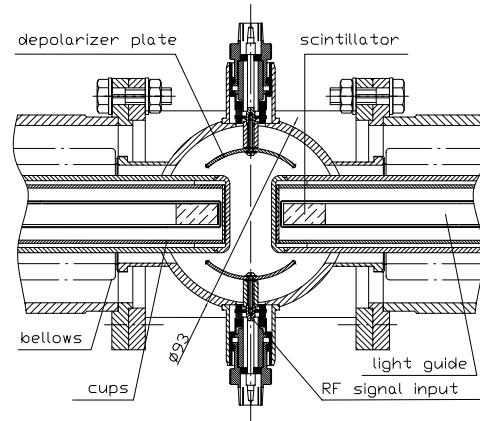


Figure 3: Vacuum chamber profile with the polarimeter components.

cup. The latter in its turn is enclosed in a copper cup which connects to the vacuum chamber by a bellows. A water is passed between the walls of those cups to exclude a heating of the counters due to any reasons (SR, the resistive impedance effect, etc). Four computer controlled stepper motors move separately the cups with counters to specified positions. Since the trajectories of Touschek pair electrons lie symmetrically on each side of the closed orbit, the two-fold/four-fold coincidence circuits for the registration of pulses from counters are used (Fig4). Simultaneously, a number of coincidences is measured for events in one of the pair counters delayed by the revolution period in reference to events in another. The result is subtracted from the total number of coincidences to decrease the uncorrelated background influence. Two matched striplines with a vertical gap of 60 mm between them are mounted inside of the polarimeter section to create the TEM wave moving towards the beam. This allows to use our polarimeter simultaneously as a depolarizer for the resonance depolarization procedure.

4 DEPOLARIZER PARAMETERS

In the new J/Ψ and Ψ' experiments we use the vertical kicker's plates for creating the TEM wave. The signal source is the computer controlled frequency synthesizer with the minimal band width of Δf_d of the order of a few Hz and the minimal rearrangement step of 1 Hz. For VEPP-4M, 1 keV in the beam energy scale corresponds to 1.85 Hz in the depolarizer frequency f_d scale. At J/Ψ energy, the synthesizer frequency is scanned in the vicinity of a half revolution frequency f_0 (about 400 kHz), i.e. an noninteger part of the spin precession frequency. The rate τ_d^{-1}

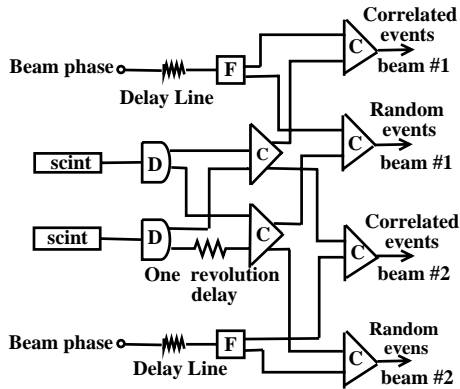


Figure 4: Logical flowchart of the two-fold coincidence circuit. F is a pulse shaping circuit; D is a discriminator, C is a coincidence circuit.

of forced depolarization with the transverse field crucially depends on the absolute value of the spin response function $|F^\nu|$ [1, 8] at the place of the depolarizer location: $\tau_d^{-1} \propto U_d^2 \cdot |F^\nu|^2 / \Delta f_d$. The design depolarization time τ_d is about 2 seconds at $E=1550$ MeV with the voltage across plates $U_d \approx 15$ Volts, $\Delta f_d \approx 4$ Hz, $|F^\nu|^2 = 130$. The typical scan parameters are as follows: the rearrangement step in the frequency $=2$ Hz; the band width (due to modulation at the frequency $f_m = 2$ Hz) $\Delta f_d = 4$ Hz; $U_d = 12$ Volts; the average rate of the frequency rearrangement $=0.2$ Hz/sec.

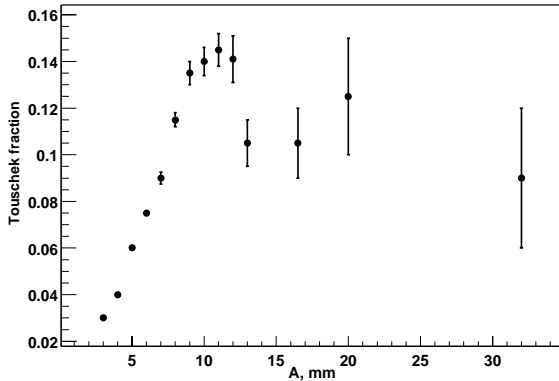


Figure 5: Relative fraction of Tousek electrons in the total counting rate vs. the distance A .

5 EXPERIMENTAL RESULTS

Polarized beams are injected in VEPP-4M from the booster storage ring VEPP-3 [4] where the radiative polarization occurs with the characteristic time $\tau_p \sim 80$ minutes at 1550 MeV. The design polarization extent $\zeta \sim 80\%$. Polarization time in VEPP-4M is very large ($\tau_p \sim 10^2$ hours), thus the condition $\tau_T \ll \tau_p$ to observe the spin-dependent slope in $S(t)$ is satisfied. Numbers of particles in the bunches N_1 and N_2 are equalized with the accuracy of a few percents by knocking surplus particles with the

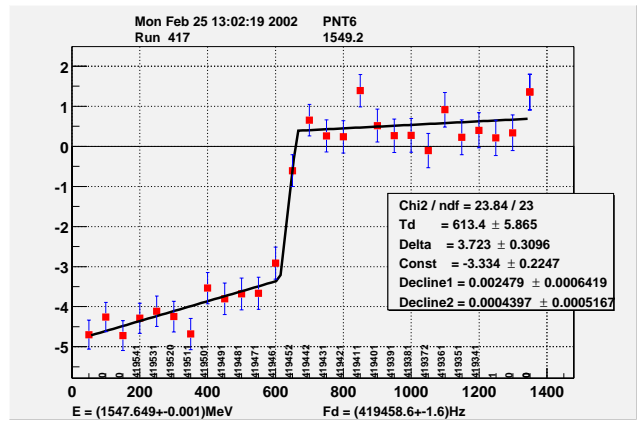


Figure 6: The jump ΔS during the scan of the depolarizer frequency. Abscissa is the time in seconds.

help of the inflector. Use of the four-fold coincidence circuit does not noticeably improve a detection of Tousek pairs in comparison with the two-fold circuit. Counters are moved at the optimal position $A \approx 1$ cm where a Tousek contribution still significantly exceeds a background caused likely by the residual gas scattering. Tousek fraction in the total counting rate is decreased at more close distances (Fig5). The spin-dependent slope of $S(t)$ usually observed corresponds to estimates presented above. The change ΔS makes up about 3 % during time of 30 minutes at $\varepsilon = 0$, $\tau \sim 4000$ seconds, $\Delta \sim -3\%$. At $A \approx 1 \div 1.2$ cm the counting rate is about $3 \div 10$ kHz at the beam current of $2 \div 4$ mA with the jump of $2.5 \div 3.5\%$ in a good agreement with the calculation ($\zeta = 60 \div 80\%$). In experiments at J/Ψ energy range the typical jump is 10 times as a statistical error for 50 seconds (Fig. 6). Accuracy in the current energy determination is $\delta E \approx \pm 2$ keV, i.e. about 10^{-6} . It is more than 25 times better compared with the similar experiments performed at VEPP-4 in 80s [3].

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