RF ORBIT SEPARATION FOR CPT-TEST EXPERIMENT AT VEPP-4M *

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Abstract

To exclude a contribution of static electric fields into a systematic error of the CPT-test experiment being now under preparation at theVEPP-4M storage ring, we have developed and tested a special RF system to substitute for the electrostatic orbit separator of electron and positron orbits at the parasitic interaction point.

INTRODUCTION

In a special program of experiments which is under development in a background mode at the VEPP-4M storage ring we plan to realize a potential possibility to make the CPT invariance test via a precision comparison of spin precession frequencies of simultaneously stored electrons and positrons using the resonant depolarization technique [1]. The measured difference $\Delta\Omega = \Omega_+ - \Omega_- = q'_+ < H >_+ -q'_- < H >_- \neq 0$ may mean the CPT-symmetry violation. Here $\Omega_\pm = \nu_\pm \Omega_0 = q'_\pm < H >_\pm$ are the average frequencies of electron $(-)$ or positron $(+)$ Thomas precession; Ω_0 is the revolution frequency; $q'_\pm$ are respective anomal parts of the gyromagnetic ratio; $< H >_\pm$ is the guide field averaged over the closed orbits of electrons and positron depending on the charge-mass ratios $e_\pm/m_\pm$ and the relativistic factor γ. Mirror symmetry of magnetic structure as well as exception of static electric fields on the orbits must be provided in a storage ring to conduct a valuable CPT test. According to our estimates of the 1.8 GeV VEPP-4M mirror symmetry an equality $< H >_- = < H_+ >$ can be fulfilled with an accuracy about $5 \cdot 10^{-9}$. Methods applied in [3, 2], most precise measurements on comparison of anomalous magnetic moments (AMM) of electrons and positrons, differ from a direct comparison of depolarization frequencies. In [2] the final polarization degrees of the electron and positron bunches were compared after the adiabatic spin resonance crossing. Authors interpreted their results as the anomal magnetic moment (AMM) comparison with an accuracy 10^{-8} assuming an equality of all remaining parameters. By indirection, the achieved accuracy proves that the fine precision mirror symmetry of the storage ring can be realized in practics. In [3] the ratio $(g-2)/2$ was measured separately for electrons and positrons captured in the Penning trap with an accuracy $\sim 3.5 \cdot 10^{-9}$. Principle features of our experiment as against [3] are following: a) a possibility to verify the symmetry by combination of three fundamental parameters at once - the $g-2$ factor, charge and mass; b) particle relativism. We set an aim to compare the particle and anti-particle by the spin frequency value with an accuracy better 10^{-8}.

Up to date the effective methodical approaches and technical devices to realize it were developed as well as some sources of systematic errors were studied [1, 4]. In particular, we reached a resolution of $\sim 10^{-9}$ in determination of the depolarization frequency in the experiments with electron bunches (Fig. 1). NMR magnetometer-based feedback system stabilizes the guide field at a level of 10^{-6}. Till recently a main obstacle to begin a valuable CPT-test experiment was a necessity to use the electrostatic system to separate the electron and positron vertical orbits in parasitic interaction points. As was found, this system may yields an unacceptable systematic error of 10^{-6}. To eliminate this obstacle an alternative orbit separation system based on the RF method has been elaborated and tested.

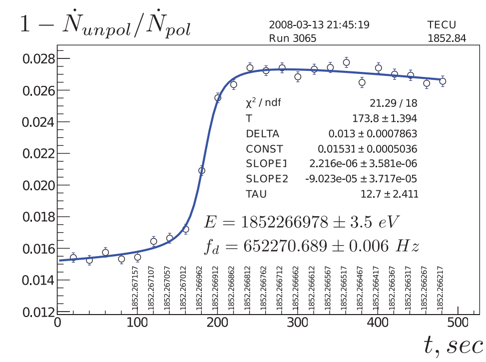

Figure 1: Typical case of the depolarization jump in the relative registration rate of Touschek electrons from the polarized ($\dot{N}_{pol}$) and unpolarized ($\dot{N}_{unpol}$) bunches during scanning of the depolarizer frequency. Scan rate in units of energy is 2.5 eV/s. Depolarization frequency resolution found by the ratio of the experimental data fit error 3.5 eV to the beam energy 1852 MeV is about $1.9 \cdot 10^{-9}$.

RF METHOD FOR COLLIDING BEAM ORBIT SEPARATION

We need to provide an electron and positron orbit separation at the parasitic IP of VEPP-4M. Toward this end a horizontal electric field $\vec{E}$ is created at that place oscillating at a half-revolution frequency ($\frac{1}{2} f_0$). In this case the electron and positron bunches move on a common orbit closed through two usual turns of a particle. Integral electric field action on spin over two turns is equal zero that meets the requirement of the CPT-test experiment. In the rough, one can represent the resulting steady orbit (ig-

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noring oscillations of the orbit due to its deviation from a magnet axis) in a form like the "Pascal's snail" curve as shown in Fig. 2. After head-on-head collision at the main IP the electron bunch goes on an internal loop of the orbit while the positron bunch - on an external one. As a result the bunches are found to be separated at the parasitic collision point where the RF plates are located. Carrying on their motion the bunches collide head-on-head at the IP again but with a some different angle made by their common axis with a beam pipe axis. Next the electrons moves on the external loop and positrons - on the internal loop and therefore the bunches do not meet again at the parasitic IP where the field has just changed a sign. Further a picture of motion recurs according to the cycle described. Necessary condition is a limitation on amount of bunches: one electron and one positron bunches. Otherwise, bunches will meet not only in the main IP. Besides, a certain phase shift between electrons and positrons must be kept at injection in order for they move on different loops of the orbit at the same moment of time. One more requirement is a closeness of the horizontal betatron tune ν_x to half-integer values (see below). The radial orbit displacement X at the

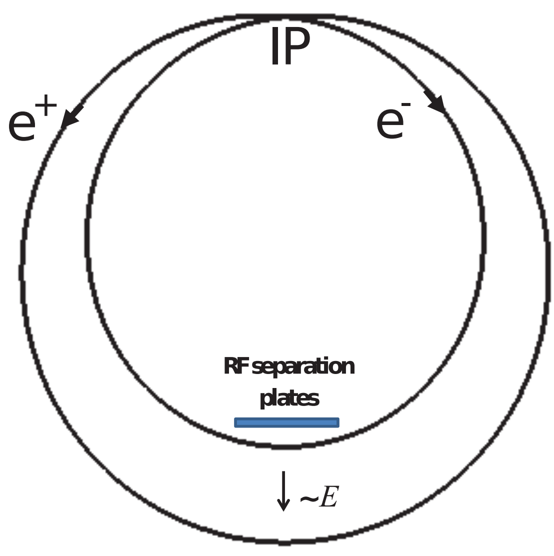

Figure 2: Schematic two-turn closed orbit.

RF plate azimuth can be estimated from the equation

$$X = \frac{\chi\beta}{2\sin 2\pi\nu_x} \cdot (\cos 2\pi\nu_x - 1),$$

with χ, the deflection angle due to the RF electric fiield; β, a horizontal beta-function value at the azimuth of plates. At $\nu_x \to k$, with an integer k, $X \to 0$. Nearby the half-integer values $\nu_x = (2k+1)/2 + \varepsilon$ with $\varepsilon << 1$ the displacement becomes significant: $X \approx -\frac{\chi\beta}{2\pi\varepsilon}$ and so it is one more condition for the method realization. Example for VEPP-4M: $E = 1.85$ GeV, a beam energy; $\nu_x = 8.53$; $\beta = 15$ m; $l = 117$ cm, the plate length; $d = 8$ cm, the gap between plates; $U = 4$ kV, the voltage amplitude at the plates; $\chi = 3.2 \cdot 10^{-5}$ rad (related to the peak value of voltage); the full orbit separation is $2X = 5.4$ mm. Fig. 3 demonstrates a design azimuthal dependence of radial two-turn closed orbit at $U = 5$ kV ($E = 1.85$ GeV, $\nu_x = 8.53$). It is clear from this figure that the "internal" and "external"

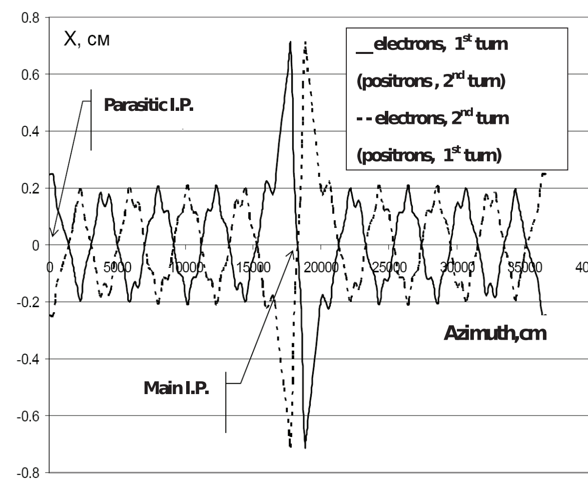

Figure 3: Design radial orbit with the RF separation on.

loops of the two-turn orbit have reciprocal intersections. But in the main the idealized scheme is not contradictory if the mentioned phase conditions are fulfilled.

BEAM-BEAM EFFECTS

The main and the parasitic IPs of VEPP-4M are not "similar". Tnis means that a ratio of vertical and horizontal beta-functions, as well as a ratio of betatron and synchrotron contributions to horizontal beam size at the corresponding azimuths, differ from each other. Experimentally proved consequence of this fact is a drop in critical bunch current determined by beam-beam effects from $2.5 \div 3$ mA to $0.3 \div 0.5$ mA if not applying the e+e- orbit separation at the parasitic IP. This is a very serious obstacle for the CPT-test experiment using the Touschek polarimeter [5] whose efficiency fades quadratically with decease of the beam current. In order to estimate a reasonable magnitude of radial orbit separation at the parasitic IP, while the beams collide at the main IP, we performed numerical simulation with the `Lifetrac` tracking code [6]. The results are presented in Fig. 4, where the equilibrium distributions in the plane of normalized betatron amplitudes are shown. The distribution shrinks to the normal sizes (as without parasitic IP) when the separation is raised to $2X = 7\sigma_x = 4.8$mm.

TEST OF THE RF SEPARATION

We have elaborated the RF separation device and tested it in several beam experiments at the VEPP-4M. The device includes the controlled gain-phase modulator for a 409 kHz sinusoidal signal generation with automatic tuning, the 200W power amplifier and the resonant circuit connected

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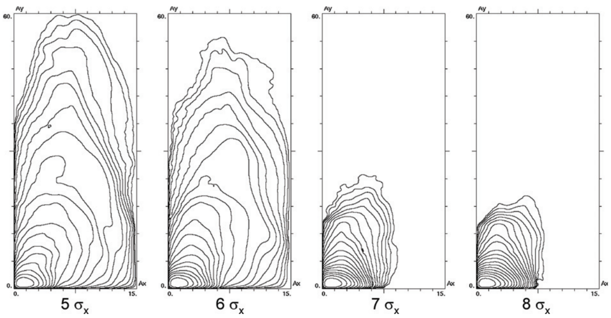

Figure 4: Equilibrium distribution in the plane of normalized betatron amplitudes for VEPP-4M ($E = 1.85$ GeV, $I_b = 2.5$ mA), versus the horizontal orbit separation at the parasitic IP. The scales (in units of unperturbed sigmas) are 15×40. The density between successive contour lines drops by a factor of e.

to the pair of conducting plates inside the vacuum chamber at the VEPP-4M technical section centre. One can change the amplitude and phase of signal at the plates in the ranges $0 \div 10$ kV and $0 - 480°$ (related to the frequency f_0). Beam orbit separation was being observed using the SR beam image monitors and the single-turn ("fast") BPMs recently elaborated in BINP.

In the first we verified the new system in the experiments with a single electron bunch. Neccesary orbit disturbance is attained in accordance with design. The RF phase is tuned to provide a maximal voltage at the moment of bunch passage. At the SR beam image monitor one can see just two positions of the single bunch orbit.

Similar experiment was made with two electron bunches separated by a half-turn. If their passage phases correspond to equal plate voltages the bunches move on close two-turn orbits as seen from the data of the "fast" BPM (Fig. 5). In the other case the RF phase was tuned so one of the bunches could stay on the undisturbed single-turn orbit. Both bunches were polarized. It enabled to compare their energies using the selective resonant depolarization method. It follows from the feature of two-turn orbit that the related energy of particles do not change as compared with an initial position in the linear guide field approximation. In the experiment the absolute energies of the two-turn and single-turn orbit states were found coincident with an accuracy of 10^{-6}.

Most important test was made with the colliding beams. In the case when the 2.5 mA (close to the critical beam-beam one) electron and 0.14 mA positron bunches were separated with the RF system ($U = 6.5$ kV) at the parasitic IP and with the usual electrostatic system - at the main IP the positron beam lifetime was acceptable. At the currents 1.1 mA (electrons) and 0.3 mA (positrons) the beam-beam effects did not become apparent despite the fact that the electrosnatic system was fully off (Fig. 6).

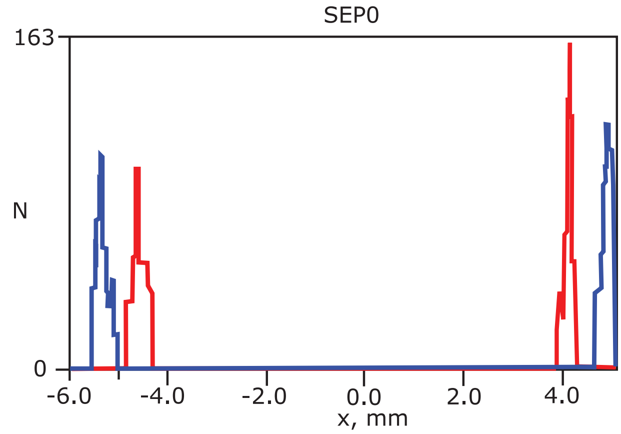

Figure 5: Data on horizontal bunch positions of two electron bunches (marked in different colors) from one of the "fast" BPM in the experiment with RF separation on. Array of 8000 values for every bunch position is picked up during 20 msec with cutting-back. The two-turn orbit effect shows two peaks. Spreading of ~ 100 μm of the peaks is due to ripples of the VEPP-4M field. Corresponding peaks of bunches some differ in position because of phase variation relative to the RF signal at the orbit separation plates.

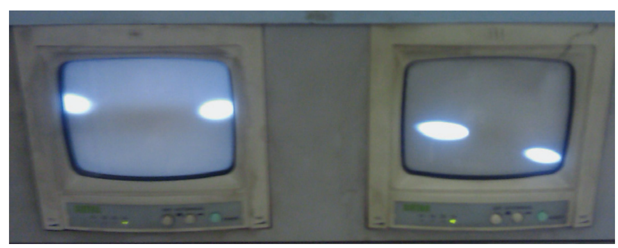

Figure 6: SR images of the 1.1 mA electron (left) and the 0.3 mA positron (right) bunches on the TV monitors while applying the RF separation at the 6.5 kV peak voltage. Electrostatic separation system is fully off.

SUMMARY

Judging by the obtained results, the colliding beam current of 2 mA per bunch can be achieved when using the RF separation only. That's quite enough for the polarization monitoring by Touschek scattering in the CPT-test experiment.

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