ACCELERATOR PHYSICS ACTIVITY AT THE VEPP-4M COLLIDER

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Abstract

The VEPP-4M electron-positron collider is now operating with the KEDR detector for high-energy physics experiments in the 1.5−2.0 GeV beam energy range. Parallel with these experiments, the VEPP-4M scientific team carries out a number of accelerator physics investigations. A new registration system for the Touschek polarimeter has been put into operation. A new NMR-based system for suppression of the guide field ripples has been developed. The counting rate of the Touschek particles has been measured as a function of the beam energy in the range from 1.85 to 4 GeV. The measurement results can be claimed at the future super B and C-Tau factories. For simultaneous measurement of the transverse beam position and inclination angle an X-ray multi-pinhole camera has been designed, manufactured and installed at the VEPP-4M. To suppress the longitudinal instability caused by high-order modes of the RF cavities, a feedback system has been developed.

POLARIZATION EXPERIMENTS

A principle possibility to make the CPT invariance test at the electron-positron storage rings with the accuracy of 10^{-10} is studied. In this case, the CPT invariance test is the precise comparison of spin precession frequencies of electrons and positrons simultaneously circulating in a storage ring. To measure the average spin precession frequency of the beam, the system of absolute energy calibration is used. The system includes the Touschek polarimeter and the TEM wave-based depolarizer [1].

Transverse field depolarizer

A TEM wave is generated using a vertical pair of strip-lines excited by a sweep RF generator. The connecting circuit of the strip-lines provides the stationary wave formation; this results in the concurrent action of the depolarizer on electrons and positrons with an equal efficiency. The RF frequency is set by a BINP-developed computer-controlled synthesizer with an ultimate resolution better than $6\cdot10^{-7}$ Hz. The synthesizer is locked with the rubidium frequency standard providing the relative stability better than 10^{-10}. The intrinsic line width of the synthesizer is negligible in comparison with a “dynamic” broadening of the line during the depolarizer frequency scanning. In the so-called "super-fine scan" experiments the depolarizer frequency f_d was swept with the rate of df_d/dt=10 mHz/s and with the step of 20 mHz, which formally corresponds to a relative frequency resolution of $5\cdot10^{-9}$. The dynamic broadening of the depolarizer line is $(df_d/dt)^{1/2}$≈0.1 Hz (50 eV) or $2.5\cdot10^{-8}$ at 1.8 GeV. Because of the broadening of both spin and depolarizer line widths we compare the related depolarization frequencies rather than the spin ones. This does not contradict our aims because of the same conditions for e^+ and e^-. In practice, the broadening of the depolarizer line also does not matter since its width proves to be much less than the spin line one.

Modernized Touschek polarimeter

The counting rate of electrons/positrons experienced intra-beam scattering (IBS) is measured with the system of scintillation counters [1]. Initially, the system included two pairs of movable counters introduced into the vacuum chamber to register the particles scattered anywhere at the most part of the ring. Total counting rate of the counter pair is about 100−200 kHz per 2 mA bunch current. Using this system, the depolarization frequencies of two electron bunches were measured with the record-high accuracy of $2\cdot10^{-8}$. In 2008, the polarimeter has been upgraded by adding two counter pairs, the construction of which enables the scintillator to be moved even closer to the beam orbit without making worse the beam lifetime. Using these new counters we have raised the total counting rate by an order, up to 1.5−2 MHz. In principle, such a high rate can provide the statistical error of the depolarization frequency comparison not worse than 10^{-10}.

Guiding field stabilization system

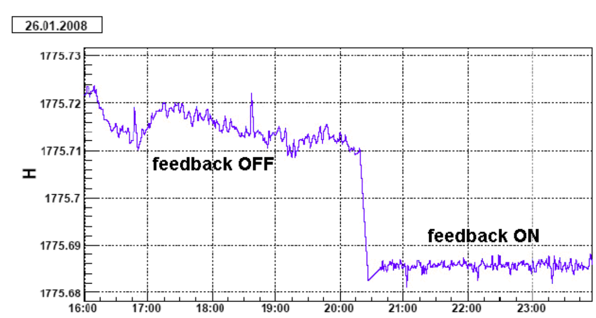


Figure 1: The VEPP-4M guide field stabilization.

To increase time stability of the VEPP-4M guiding field, the feedback loop was implemented into the power supply control [2]. The field is measured by a precise NMR magnetometer and the error signal is used to correct the power supply current. With the feedback the field ripples are suppressed in the band of 0-0.1 Hz. The long-term non-stability of the field was reduced to 10^{-6}. Fig. 1 shows the NMR magnetometer data with the feedback off and on. The field values in Oersteds approximately correspond to the beam energy in MeV. With the closed feedback loop, the day-to-day beam energy drift is of an order of 1 keV as it has been shown in our long-term energy stability runs using RD. Once, the similar field stabilization systems using NMR magnetometer were applied at CERN and VEPP-2M, but the accuracy of 10^{-6} in comparison of the field and actual beam energy stabilities is achieved only at VEPP-4M.

Super-fine scan experiments

With the frequency locking of the RF system, the depolarizer synthesizer and the NMR magnetometer, and with suppression of the guide field slow ripples, the record measurement resolution $(1\text{-}3)\cdot10^{-9}$ of the electron beam depolarization frequency is achieved [2]. The relative counting rate $S=1-(dN_1/dt)/(dN_2/dt)$ is measured where dN_1/dt is the counting rate of the electrons scattered from the polarized bunch and dN_2/dt is for the non-polarized bunch. In our super-fine scan experiments a smooth change of S during the depolarization process looks like a long-drawn jump. The duration of the jump related to the depolarization time depends on the spin line width and the relative drift rate of the spin tune. The latter depends on the storage ring field stability.

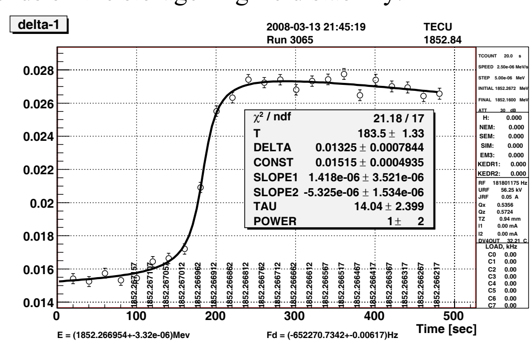


Figure 2: Typical case of the "long-drawn jump".

In Fig. 2 a typical behaviour of S is plotted. The spin line width ($\sim5\cdot10^{-7}$) is determined by the guide field quadratic non-linearity. The scan rate is 2.5 eV/s; the characteristic time of the jump formation is 14±3 sec. The depolarization frequency resolution is found as the ratio of the experimental data fit error 3 eV to the beam energy 1852 MeV, and is about $1.5\cdot10^{-9}$. The formation times in the most performed scans are within 15−75 seconds. When the slow field ripples are suppressed and the regular fast ripples are averaged over the data taking period, a shape of the depolarization jump may depend on the sporadic fast ripples. As a whole, we estimate the accuracy of the e^+e^- spin precession frequency comparison, achievable at VEPP-4M as $\leq10^{-8}$.

Touschek polarimeter at higher energy

For clarification of the Touschek polarimeter applicability, we have measured the Touschek particle counting rate as a function of the beam energy in the 1.85−4 GeV range and compared it with our theoretical estimation. Results of the experiment performed in 2008 [3] are presented in Fig. 3.

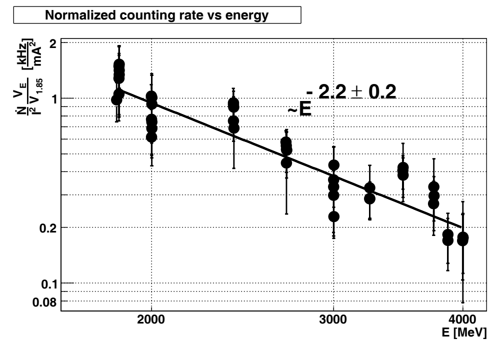


Figure 3: Touschek counting rate vs. beam energy.

The degree of energy dependence measured is −2.2±0.2 for the counting rate normalized to the bunch current squared and multiplied by a ratio of the reference beam volume (at 1.85 GeV) to the actual one. Our theoretical estimation in the non-relativistic approximation of the Moller's cross section, taking into account the geometrical factor of the counters and their distance to the beam, yields the corresponding degree of 3.5. In accordance to the experiment, one can rely on 12 kHz load of the Touschek particle counter at 5 GeV energy and 10 mA beam current. Theoretical estimation reduces the predictable counting rate down to 9 kHz. In both cases, the rate is enough to apply the Touschek polarimeter for the RD technique.

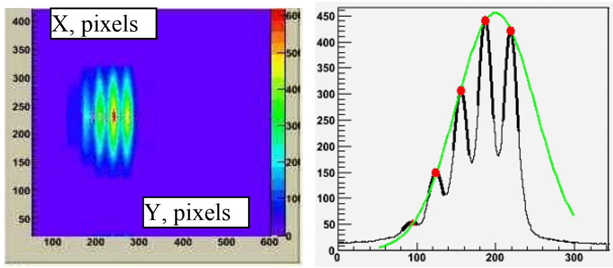
MULTI-PINHOLE CAMERA

For precise control of VEPP-4M energy required by the high-energy physics experiments, Compton Back-Scattering (CBS) [4] is applied. For the reliable CBS operation, stabilization of the bunch x and y coordinates and vertical angle is necessary at the area, where laser photons interact with the particle beam. Due to mixing of the e^+ and e^- signals, the VEPP-4M BPM system doesn't provide the required accuracy in the colliding-beam operation mode.

The multi-pinhole camera is useful to stabilize the beam x and y coordinates and the vertical angle. The synchrotron radiation from two bending magnets placed symmetrically with respect to the interaction point at the distance of 7 m is used for that. At present the new diagnostics has been assembled at the "electron" direction of VEPP-4M and the first images of the e^- beam have been recorded (Fig. 4).

The pinhole lets the X-ray part of the SR through and CCD camera records the beam image created on the *ZnS* scintillator. SR from the bending magnet is absorbed in the air at the distance ~ 1.5 m. And so, we apply the vacuumed tube to deliver the radiation to the scintillator.

Applying few vertically aligned pinholes, separated at the distance of about $3\sigma_y$ one can determine the transverse position and inclination angle of the beam. The distance between exterior pinholes should be about $3a\psi$, where ψ is the divergence of SR. The beam displacement can be determined from the shift of the single beam image relative to the reference position. The inclination angle is proportional to the shift of the envelope of all of the beam images. Fig. 4b shows the maxima of each image (dots) and their envelope found with the data processing software.



a) b)

Figure 4: Beam image (a) observed with the multi-pinhole camera and its y-plane projection (b).

The results of the resolution measurements of the multi-pinhole camera are presented in Fig. 5. The vertical beam position d (dots) and angle φ (line) were changed using a single orbit corrector.

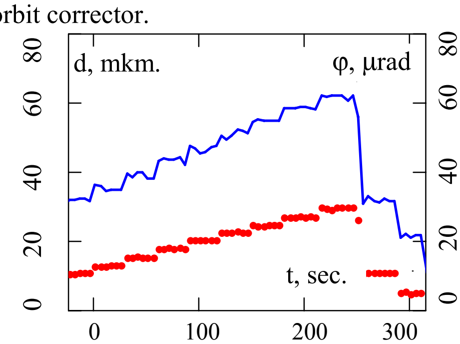


Figure 5: Resolution test of the multi-pinhole camera.

LONGITUDINAL FEEDBACK SYSTEM

The mode-by-mode feedback system has been developed at VEPP-4M to suppress the longitudinal multi-bunch instability. The block diagram of the system is presented in Fig. 6, only one channel of the feedback system for one sort of particles is shown.

Since there are two pairs of equidistant bunches (2 e^+ and 2 e^-), four coupled modes should be damped – two for electrons and two for positrons. In order to identify these modes, the sample-and-hold technique is used. For all 4 bunches, a fast phase detector produces turn-by-turn signals. After sampling, the fast ADC digitizes the signals and stores the information in the digital memory (RAM). 4 DACs read the digital information from the memory and convert it into an analogue signal again, so these 4 signals represent the instantaneous phases of all 4 bunches. The sum signal of each pair identifies the in-phase coupled mode and the difference signal identifies the anti-phase mode. These signals are used to modulate RF voltage of the kickers. The even 398-th harmonic of the revolution frequency is used to suppress the in-phase mode; the odd 397-th harmonic – for the anti-phase mode.

Two local oscillators (LO) phase locked to the reference signal of the revolution frequency are connected to the corresponding balanced modulators BM1 and BM2, the output signals of which are summed up and the result is used to drive the RF power amplifier.

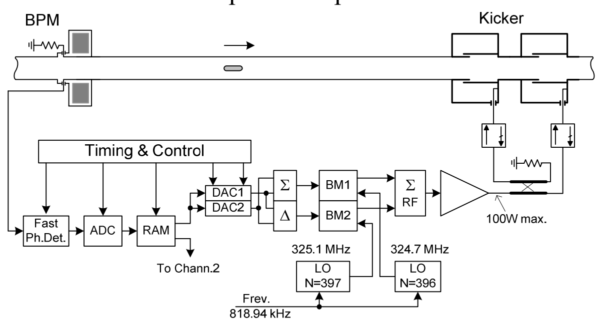


Figure 6: Mode-by-mode longitudinal feedback system.

There are two kickers in the system, one is for electrons and the other is for positrons. Each kicker consists of a pair of cavities. The high-order modes (HOM) of the kicker RF cavity are above the critical frequency of the vacuum chamber (2500 MHz). Therefore, there are no problems with the HOM-induced voltage.

The cavities are tuned to the frequency f_c that is set in the middle between the operational harmonics. The distance between the cavities of each pair is 230 mm, which is a quarter-wavelength of f_c. The output power of the RF amplifier is divided by the 3 dB directional coupler and supplied to the cavities via the cables of an equal length. The connection is made so that for the particles of certain polarity (e^+ or e^-) moving in their proper direction, the RF voltage in the last cavity of the pair is delayed by π/2 relative to the first cavity. So, the particles of this polarity get a double kick, while for the particles moving in the opposite direction the effect of the kicker is zero. Therefore, the kickers for different sorts of particles are not coupled.

The decrement introduced by the feedback loop was measured using two methods. The forced coupled mode oscillation is excited by adding a signal of an external low-frequency (LF) generator into the feedback loop. In the first method, the LF generator output voltages V_1 and V_2 exciting the oscillation of the same amplitude with open and closed feedback loop, are measured. The V_2/V_1 ratio determines a change of the oscillation decrement. In the other method, we have measured the decay time of the mode oscillation by switching off the LF generator after the forced oscillation was excited.

Practical test of the feedback system has been done with the real multi-bunch instability excited by special HOM tuning of the accelerating RF cavities.

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