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ФИЗИКА И ТЕХНИКА УСКОРИТЕЛЕЙ

NEW OPTICAL DIAGNOSTICS OF THE VEPP-4M COLLIDER

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The experiments to measure dynamic aperture and beam energy spread of the VEPP-4M collider [1] are described. The optical diagnostics of the accelerator were applied for that purpose.

Представлены результаты экспериментов по измерению динамической апертуры и энергетического разброса пучка на коллайдере ВЭПП-4М. Измерения проводились при помощи оптических диагностик ускорителя.

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INTRODUCTION

To determine experimentally the particle stable area in the electron–positron collider VEPP-4M, we measure the beam lifetime with high accuracy as a function of moving aperture. The measurement is performed by a HAMAMATSU S2387-33R photodiode installed in the collider diagnostic beam line.

In this report we discuss also the application of several diagnostics for beam energy spread measurement. The data obtained with Compton BackScattering (CBS) technique [2] are compared with the value of the spread derived from the betatron motion of the beam [3]. The measurements by all the methods were done at the same accelerator run; i.e., the different diagnostics can be compared directly. The value of the energy spread was determined for a set of collider operating modes, covering the energy area from 1200 up to 1855 MeV and with fixed energy and various snake currents [1].

Measurement of the dynamic aperture (DA) is one of the interesting experimental problems on the VEPP-4M accelerator complex. Usually, dynamic aperture is estimated from the results of simulation; we made an attempt to measure the dynamic aperture by three different methods and to compare methods among themselves. Also, the dependence of the dynamic aperture on chromaticity was obtained and compared with the results of the simulation.

The VEPP-4M electron–positron collider is now operating with the KEDR detector for the experiment to precisely measure tau-lepton mass [1]. The nearest experimental program of the accelerator also includes a scan of the energy area below J/ψ meson to search for narrow resonances. The monitoring of beam energy spread is important to know the energy spread contribution to the total systematic error.

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EXPERIMENTS

Method of Artificial Limitation of the Aperture. If the artificially limited geometrical aperture (GA) is larger than the dynamic aperture, the lifetime remains constant. As soon as geometrical limitation appears in the field of the dynamic aperture — we see the reduction of the beam lifetime. Let us consider this inflection point as the dynamic aperture [4].

The limitation of the vertical and the radial apertures was carried out using scrapers 1, 2 (Fig. 1) operated by a computer.

The measurements of the aperture were performed with the beam current of $I_b < 1$ mA to limit the influence of collective effects. The dependence of lifetime on the beam current was also taken into account.

To test the validity of the method, we artificially limited the radial aperture by scraper 1 (Fig. 1) and tried to see this restriction with scraper 2.

The dependence of the radial aperture, determined with scraper 2 in various positions of scraper 1 is presented in Fig. 2.

A linear character of the dependence of the aperture on the insertion depth of scraper 1 gives us the basis to consider the method as valid.

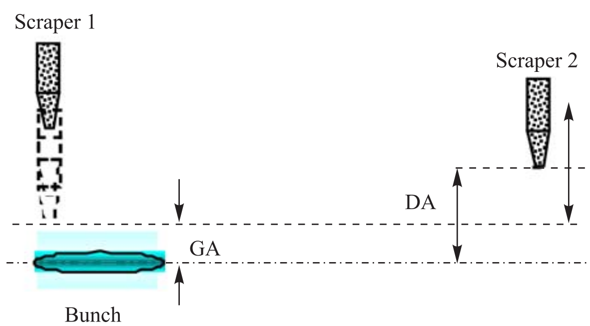

Fig. 1. GA — geometrical aperture dependent on the transverse coordinate of scraper 1; DA — dynamical aperture, measured with dependence of the beam lifetime on transverse coordinate of scraper 2. The case of GA < DA is shown

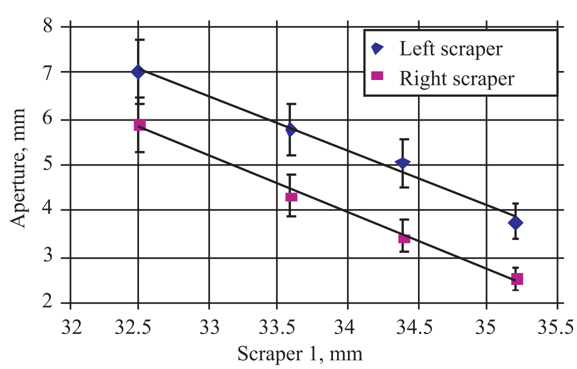

Fig. 2. Dependence of the aperture measured by scraper 2 at the insertion depth of scraper 1

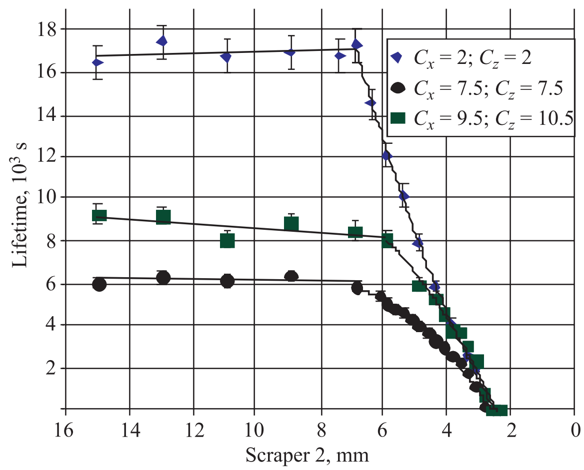

Fig. 3. The horizontal aperture with different chromaticity values C_x, C_z

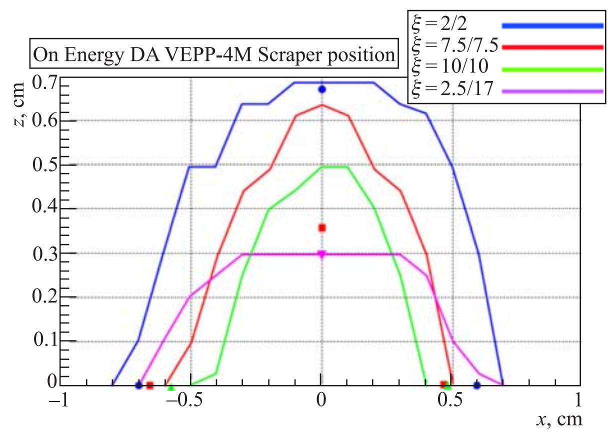

Fig. 4. The results of simulation with experimental points

The Dependence of the Dynamic Aperture on the Chromaticity. To decrease the dynamic aperture, we increased the chromaticity $C_{x,y}$ using sextupole final focus lenses which mainly influence the vertical dynamical aperture.

The measurement of the dynamic aperture was carried out applying the method described above.

The results of the measurement with different chromaticity values are shown in Fig. 3. Figure 4 presents the results of the simulation and experimental points.

Measurement of DA with the Dependence of the Beam Lifetime on Accelerating Voltage. In these experiments we determined Touscheck beam lifetime τ_T as a function of the accelerating voltage [5]:

$$\tau_T = \frac{\mathrm{N}}{\dot{N}_T} \propto \frac{\delta p_{\max}^2}{\sqrt{U_{\mathrm{rf}}}}, \quad \dot{N}_T \propto \frac{N^2}{\sigma_x \sigma_y \sigma_z \delta p_{\max}}, \quad \sigma_z \propto \frac{1}{\nu_s} \propto \frac{1}{\sqrt{U_{\mathrm{rf}}}},$$

where $\dot{N}_T$ — Touscheck beam losses; N — the amount of beam particles; $\sigma_x, \sigma_y, \sigma_z$ — the beam dimensions.

The maximal allowed deviation of beam particle energy $\delta p_{\max}$ in accelerator is limited by RF separatrix width or by the dynamic aperture:

$$\delta p_{\max} = \sqrt{\frac{2}{\pi q} \frac{eU_{\mathrm{rf}}}{E} \frac{1}{\alpha - 1/\gamma^2} \left(\cos\varphi_s - \frac{\pi - 2\varphi_s}{2} \sin\varphi_s \right)}, \tag{1}$$

where E — beam energy; q — multiplicity of harmonic; α — compaction factor; φ_s — equilibrium phase.

The dependence of the maximal allowed energy deviation of a particle on the horizontal dynamic aperture A_x is determined by the following expression [5]:

$$\delta p_{\max}^* \approx \frac{A_x}{2\eta_x}, \tag{2}$$

where η_x — the ring dispersion value at the scraper 2 location.

As one can see from Fig. 5, the maximal beam lifetime occurs at $U_{\mathrm{rf}} = 480$ kV.

The horizontal dynamic aperture value $A_x = 6.2$ mm is determined from (1), (2) at $E = 1855$ MeV, $\overline{\eta_x} = 1.011264$ (averaged over the ring), $\eta_x \approx 0.5$, $\alpha = 0.0168$, $\varphi_s = 175.3°$, $q = 222$.

It should be noted that the position of the maximum does not depend on the beam current because RF separatrix width depends only on the accelerating voltage in working range of the beam current.

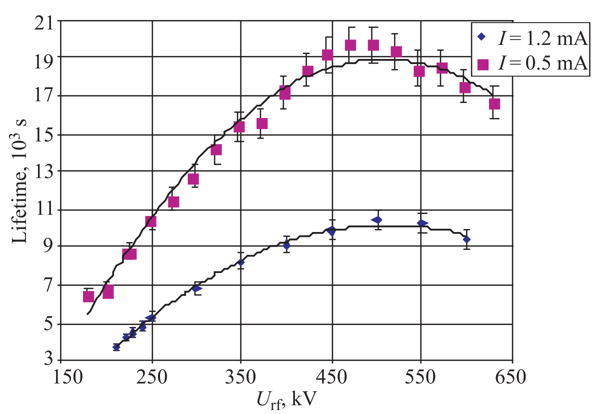

Fig. 5. The dependence of the beam lifetime on accelerating voltage

APPLIED METHODS FOR BEAM ENERGY SPREAD MEASUREMENT

Compton Backscattering (I). The VEPP-4M collider has a system of Compton backscattering for permanent measurement of the average beam energy and the energy spread. The scattered photons with maximal energy $W_{\max}$ form a narrow edge in the spectrum. The value of $W_{\max}$ is strictly coupled with the average energy of the beam electrons: $W_{\max} \approx 4w_0(E_0/m_ec^2)^2$. The width of the edge is mostly determined by the resolution of the photon detector and the energy spread of the electron beam.

Chromaticity Dependence of Envelope of Betatron Oscillations (II). It was shown [3] that envelope $A(t)$ of free coherent betatron oscillations excited by a kick with an amplitude $b \gg \sigma_y b$ is described as

$$A(t) \propto \exp\left(-\frac{t^2}{2\tau^2}\right)\exp\left(-\left(\frac{\partial\omega_y}{\partial E}\frac{\sigma_E}{\omega_s}\right)^2(1-\cos(\omega_s t))\right), \text{ where } \tau = \left(2\frac{\partial\omega_y}{\partial a^2}b\cdot\sigma_y\right)^{-1}. \tag{1}$$

Experimentally, the energy spread was determined comparing the measured beam betatron motion with the theoretical curve $A(t)$.

Bunch Length Dependence of Energy Spread (III). The r.m.s of a bunch length σ_z is directly proportional to the r.m.s. of the energy spread:

$$\sigma_z = R\alpha\frac{\omega_s}{\omega_0}\frac{\sigma_E}{E_0}, \tag{2}$$

where R — the average radius of the ring; α — momentum compaction factor; E_0 — beam energy [6].

The φ-dissector [7] is used at VEPP-4M to measure the beam length σ_z. This device has a temporal resolution of about 30 ps ($\approx$ 1 cm).

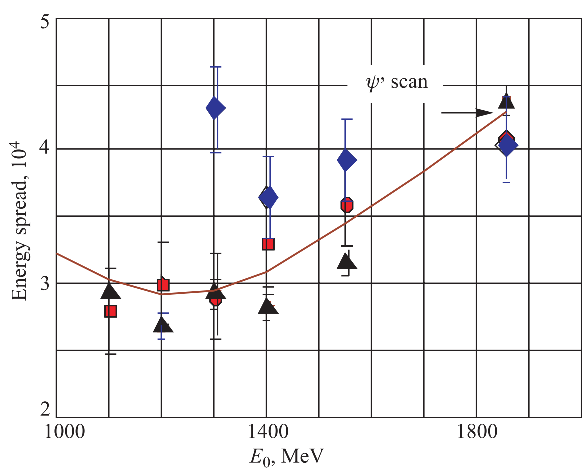

Fig. 6. Variation of the beam energy spread depending on the beam energy. ♦ — CBS data; ▲ — method (III) data; • — method (II) data; curve — simulation results. The arrow shows the data of the KEDR detector

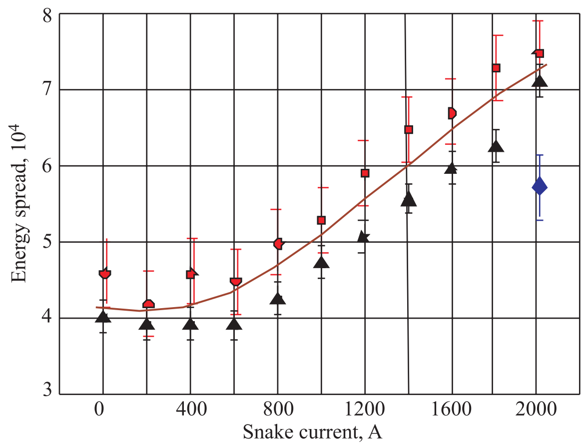

Fig. 7. The beam energy spread depending on the snake current. $E_0 = 1855$ MeV, the same symbols as in Fig. 6

EXPERIMENTAL RESULTS

The results of the measurements of beam energy spread are presented in Fig. 6.

Figure 7 represents the variation of the beam energy spread with the snake current increase.

CONCLUSION

The horizontal aperture of VEPP-4M was measured by a precise determination of the beam lifetime. In the case of limitation of the beam lifetime by the scraper blade, the aperture $A_x = 6.45$ mm was found, while the dependence of the DA on the accelerating voltage amplitude gives $A_x = 6.2$ mm. Both values seem quite consistent.

Experiments on the beam energy spread have been carried out at the VEPP-4M collider using three different diagnostics.

All the three diagnostics have been used simultaneously during the same accelerator run.

The results of the measurements are in satisfactory agreement, but further experiments to elicit the nature of systematical errors of CBS are necessary.

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