THE VEPP-4M DYNAMIC APERTURE DETERMINATION THROUGH THE PRECISE MEASUREMENT OF THE BEAM LIFETIME

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Abstract

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 photodiode installed in the collider diagnostic beam line. The experimental setup and the measurement results are described. Comparison with the tracking simulation is presented.

INTRODUCTION

Measurement of the dynamic aperture (DA) is one of the interesting experimental problems on the accelerator complex VEPP-4M [1]. 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 between themselves. Also, the dependence of the dynamic aperture on chromaticity was received and was compared with the results of the simulation.

EXPERIMENTS

Method of artificial limitation of the aperture

For experimental measurement of the dynamic aperture we determined the beam lifetime as a function of artificially limited geometrical aperture (GA) [2]. If the artificially limited geometrical aperture 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.

The limitation of the vertical and the radial apertures was carried out using scrapers 1,2 (Fig.1) operated by a computer. The beam lifetime was measured from the intensity of synchrotron radiation (SR) extracted from the bending magnet (Fig.1). The SR intensity, proportional to a number of particles in a bunch, was measured using the HAMAMATSU S2387-33R photodiode. The signal from the photodiode was digitized by a 16-digit ADC. The relative accuracy of the beam current measurements was $3 \cdot 10^{-4}$.

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

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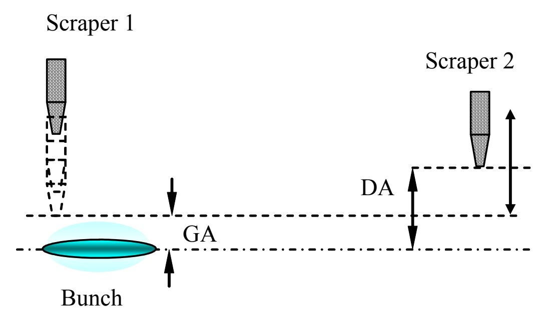

Figure 1: GA – geometrical aperture depended on the transverse coordinate of Scraper 1.
DA – dynamical aperture, measured with dependence of the beam lifetime on transverse coordinate of Scraper 2.
Case of GA<DA is shown.

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 beam lifetime on the position of scraper 2 with the restriction of geometrical aperture (GA) by scraper 1 is presented in Fig.2.

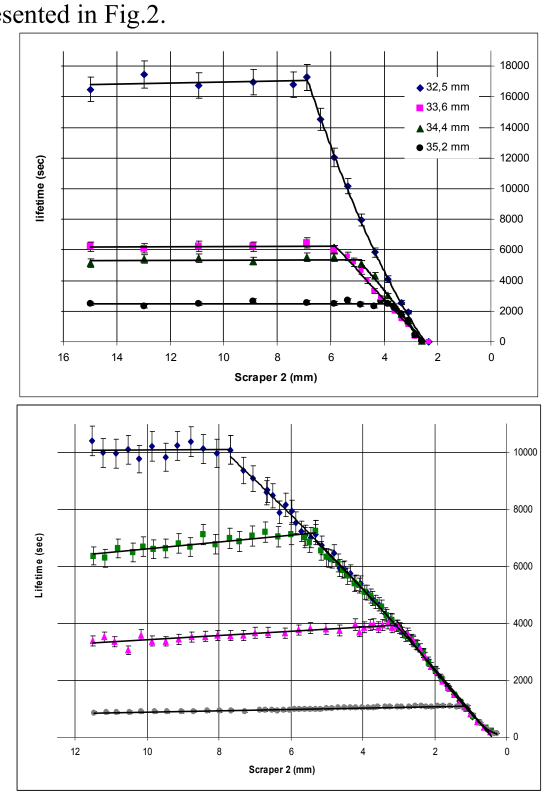

Figure 2: The beam lifetime dependence on horizontal (top) and vertical (bottom) positions of scraper 2 at different insertion depth of scraper 1.

The dependence of the radial aperture, determined with the scraper 2 on various positions of scraper 1 is presented in Fig.3.

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.

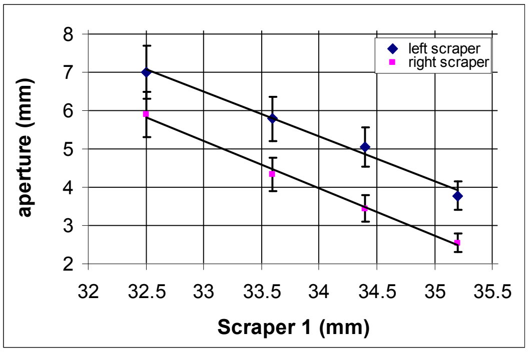

Figure 3: Dependence of the aperture measured by scraper 2 on the insertion depth of scraper 1.

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.

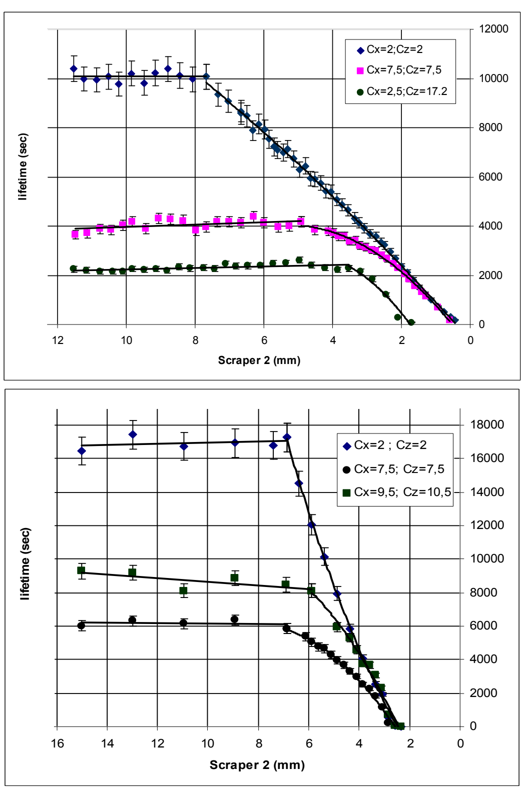

Figure 4: The vertical (top) and horizontal (bottom) aperture with different chromaticity values Cx, Cz.

The results of the measurement with different chromaticity values are shown in Fig.4; Fig.5. presents the results of the simulation and experimental points.

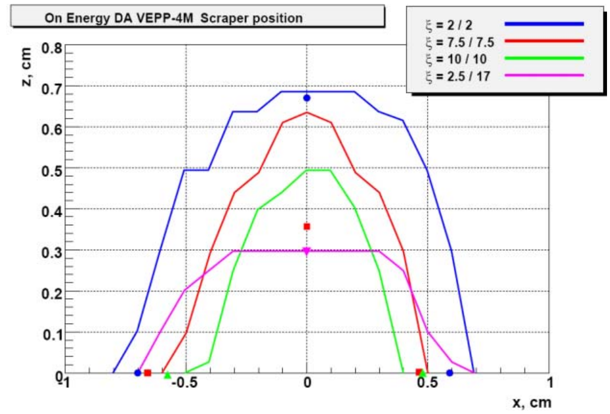

Figure 5: The results of simulation with experimental points.

Measurement of DA with the dependence of the beam lifetime on accelerating voltage

In these experiments we determined Tousheck beam lifetime τ_T as a function of the accelerating voltage [3].

$$\tau_T = \frac{N}{\dot{N}_T} \propto \frac{\delta p_{\max}{}^2}{\sqrt{U_{rf}}},$$

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

where $\dot{N}_T$ - Tousheck 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.

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

where E- beam energy, q – multiplicity of harmonic, α – compaction factor, φ_s – equilibrium phase.

The increase of the RF accelerating voltage results in the increase of the maximal allowed beam energy deviation and, correspondingly, of the beam lifetime (1). A particle with a non-equilibrium energy has a horizontal deviation due to dispersion. If this deviation reaches the dynamic aperture, a particle is lost. Thus, the beam lifetime dependence on the accelerating voltage should have the maximum connected with the reaching the maximal allowed energy deviation determined by the dynamic aperture.

The dependence of the maximal allowed energy deviation of a particle on the horizontal dynamic aperture A_x is determined by the following expression [4]:

$$\delta p^*_{\max} \approx \frac{A_x}{\overline{\eta_x}} \qquad (2)$$

where $\overline{\eta_x}$ - the average ring dispersion value.

As one can see from Fig.6, the maximal beam lifetime occurs at $U_{RF} = 480$ kV.

The horizontal dynamic aperture value A_x= 6.2 mm one is determined from (1), (2) at E=1855 MeV, $\overline{\eta_x} = 1.011264$, α=0.0168, φ_s=175.3°, q=222.

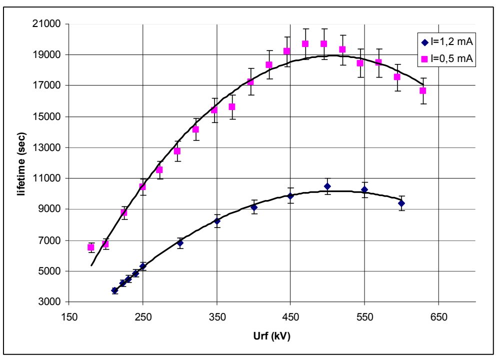

Figure 6: The dependence of the beam lifetime on accelerating voltage.

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.

DA measurement by the fast kick

A detailed description of the measurement technique can be found in [5]. The dynamic aperture was measured by the coherent beam motion excitation by fast electromagnet kickers. The beam displacement and intensity were measured by the single-turn BMP system.

For low kick amplitudes the BPM does not indicate the intensity reduction because all particles move inside the stable area. But with the kick strength increasing a beam loss appears and for large kick the bulk of the beam is cut off by the DA boundary in a rather short time (~ tens of revolutions) as it is shown in Fig.7.

To distinguish the beam lost at the dynamic or the mechanic aperture we arranged an artificial limitation of the geometrical aperture by insertion of the scraper blade inside the vacuum chamber. The difference is clearly seen from the Fig.7. Outside the dynamic aperture the particle trajectories are exponentially unstable and it takes ~ tens of turns to lose the particles while in the case of geometrical limitation for our betatron tunes (~0.5) two revolutions are quite enough.

Considering the beam loss process turn-by-turn it is possible to determine the border of the DA with good accuracy. For VEPP-4M the vertical aperture has been measured by this method and it is equal to A_z= 6.9 mm.

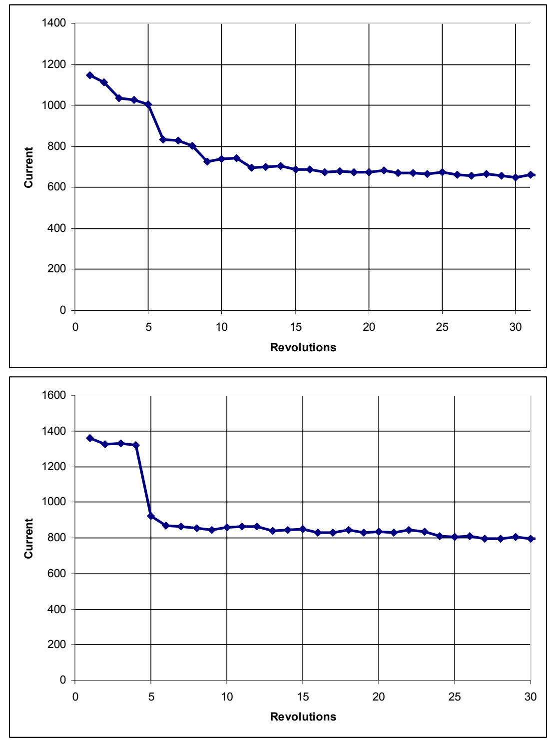

Figure 7: Beam loss at the dynamic (top) and mechanic (bottom) apertures.

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.

As for the vertical aperture, the scraper limitation method (A_z = 6.7 mm) was compared with the fast kick method (A_z=6.9 mm); and, again, both results are rather close to each other.

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