A DYNAMIC APERTURE OF VEPP-4M

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Abstract

A new betatron tune point was proposed for VEPP-4M in order to increase the dynamic aperture. This paper gives experimental results of the dynamic aperture measuring with the new betatron tunes.

1 INTRODUCTION

Originally, the e^+e^- collider VEPP-4M was intended to operate at 5-6 GeV and to reach reasonable luminosity in a promising J/ψ region (~1.5 GeV), application of dipole wigglers is essential. Such wigglers provide strong radiation damping against different instabilities and increase beam size and, hence, beam-beam current limit. First experiments at VEPP-4M with two 1.8 T 3-pole dipole wigglers actually show a luminosity growth as compared to the wiggler-off case. However, the luminosity increase factor was 1.7 instead of the expected 2 due to a significant degradation of the beam lifetime.

One of the possible explanations is that the dynamic aperture is reduced by a combined influence of magnetic non-linearities (mainly, strong chromatic sextupoles), and the beam-beam non-linear force becomes insufficient when beam size is increased by the wigglers.

To study the non-linear behaviour of the colliding beams, first we measured the VEPP-4M 2D dynamic aperture caused by the external non-linear magnetic fields. The measurement results are given in this paper. For the next step we plan to investigate experimentally the colliding beams' non-linear features taking into account both the effects (the beam-beam and magnetic non-linearities).

2 MEASUREMENT

Study of the non-linear beam dynamics was already performed at VEPP-4M several years ago [1]. Since that time, two final focus quadrupoles were replaced with new ones of a higher gradient quality. Besides, the working betatron tune point was moved from (8.62, 7.57) to (8.55,7.60). Fig.1 shows both the points at the model 2D dynamic aperture scan that demonstrates the major resonances in our tune region. According to the computer simulation the horizontal border of the stable area is opened when we go far from $3Q_x=26$ and it was one of the motivations for the tune point moving.

The dynamic aperture is measured by excitation of the coherent motion of the beam centroid. Two fast electromagnetic kickers are used for this purpose. For the horizontal kicker, a half-sine 30 kV pulse has a duration of 50 ns while for a vertical one these values are 25 kV and 150 ns. The VEPP-4M revolution period is 1.2 µs.

Displacement of the beam centroid is measured by a turn-by-turn BPM *SRP3* with a 16 kWord memory and 100 ns sampling time. The BPM resolution (rms) for the beam intensity range of 1-5 mA equals to 50-70 µm for both the directions.

The basic idea of our measurement is the beam loss rate at the aperture border when the kick amplitude is increased gradually [2]. It can be shown that for the Gaussian beam distribution, the ratio of the beam intensity before and after the kick is given (a horizontal plane, for example) by the error function

$$\frac{I_a}{I_b} = \frac{1}{2}\left(1 \pm erf\left(\frac{A_x - X_0}{\sqrt{2}\sigma_x}\right)\right), \qquad (1)$$

where A_x is the border of the dynamic or mechanical aperture, X_0 is the kick amplitude and σ_x is the rms beam size. The sign "–" ("+") in (1) corresponds to the case when the beam loss is less (more) than the half of the intensity before the kick.

Expression (1) shows that the value of the aperture border corresponds to the ratio $I_a/I_b = 0.5$.

Before a set of measurements is started, the closed orbit distortion is corrected to better than 100 µm, the betatron function beating at 48 BPMs is adjusted to the theoretic values with accuracy of 10-15% and the chromaticity is set to a small positive value. The amplitude of the horizontal kicker is set to the definite value while the vertical kicker voltage is increased step-by-step until a complete beam loss. The beam diagnostic system measures the beam current and displacement at the *SRP3* BPM for 4096 turns at each kick. Data treatment provides us with the dynamic aperture size, phase trajectories and amplitude-dependent tune shift.

The whole procedure is performed for a lattice with and without the dipole wigglers. The beam sizes, measured by a dissector and 1D CCD array, are given in Table 1.

Table 1: VEPP-4M beam sizes.

Wigglers	Off	On
σ_x, mm	0.7	1.2 mm
σ_z, mm	0.3	0.6 mm
σ_E, %	0.03	0.05

To keep interpretation of the experimental results simple, the measurements are performed at a low current (1-2 mA), where current-dependent instabilities, the Touschek effect, etc. can be neglected. The kick amplitude step in the region of the beam loss is set within 0.1-0.2 of the rms beam size. Statistic accuracy of the co-ordinate evaluation of the beam centroid is <5%.

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3 MEASUREMENT RESULTS

At an energy of 1.5 GeV, two 1.8 T dipole wigglers provide a strong distortion to the beam motion (especially vertical). At their maximum field the linear tune shift is $\Delta Q_z \approx 0.13$ and $\Delta Q_x \approx 0.02$.

Linear wiggler effects, including the tune matching and the beta-function recovering (inside a 15% accuracy), are compensated by three pairs of quadrupoles in the experimental straight. However, non-linear components of the wiggler field together with the fringe fields yield a significant reduction of the dynamic aperture as it is illustrated in Fig.2.

The vertical border of the aperture is limited by mechanical factors (a narrow vacuum chamber in the detector) well below the dynamic aperture limitation.

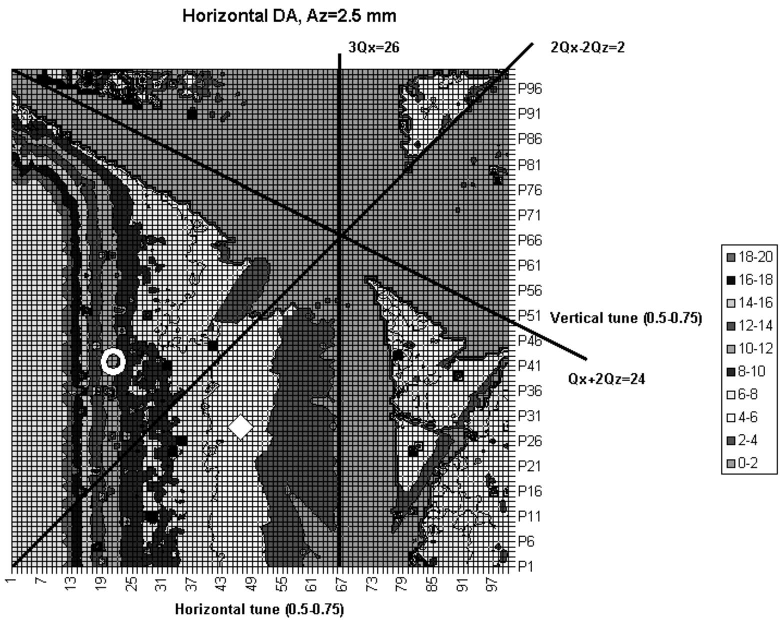

Figure 1: The VEPP-4M model horizontal DA scan when the vertical one is set to the one-half of its maximum. The old tune point (diamond) and the new one (circle) are shown. Grey region along the resonance lines shows a reduced dynamic aperture.

So, the vertical size of the aperture in Fig.2 is not changed due to the wigglers switching-on.

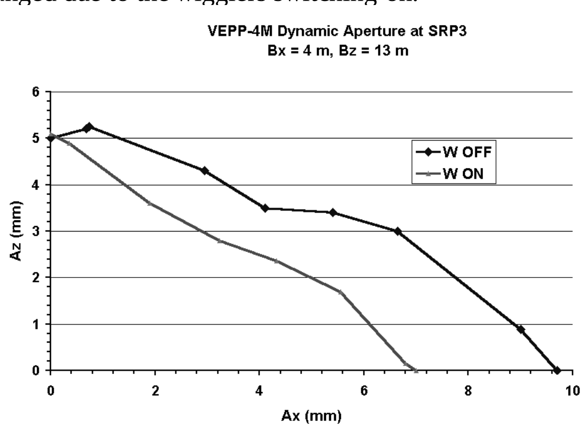

Figure 2: VEPP-4M dynamic aperture.

In comparison to the old tune point, the new one provides increase of the horizontal dynamic aperture twice as the computer tracking predicts it. Two factors contribute to the dynamic aperture opening. The first is the changing of the betatron working point and the second is the replacement of the final focus quadrupoles. The large octupole component of the old quadrupoles magnetic field provided strong non-linear detuning for the horizontal motion. Improving the gradient quality yields reduction of the horizontal detuning coefficient. Table 2 gives the measured values of the amplitude-dependent tune shift according to the expression:

$$\Delta Q_x = C_{xx} a_x^2 + C_{xz} a_z^2 , \qquad (2)$$
$$\Delta Q_z = C_{zx} a_x^2 + C_{zz} a_z^2 .$$

Table 2: Non-linear detuning coefficients.

	Old quads	**New quads**
$10^4 \cdot C_{xx}$, mm^{-2}	+9	+3
$10^4 \cdot C_{xz}$, mm^{-2}	–1	–1
$10^4 \cdot C_{zx}$, mm^{-2}	–3	–2
$10^4 \cdot C_{zz}$, mm^{-2}	–1	–4

The result of the dynamic aperture simulation is shown in Fig.3. For tracking calculation we used different computer programs, including OPTIK [3], modified to incorporate fringe-field effects and octupole magnets which are used in the VEPP-4M lattice, and home-made codes. All the non-linearities are treated as symplectic kicks whose strength is extracted from the excitation current of the relevant VEPP-4M magnets.

One can see that for a horizontal plane the theoretically predicted dynamic aperture agrees well with the measured one, while for the vertical motion there is a rather large discrepancy due to the mechanical nature of limitation.

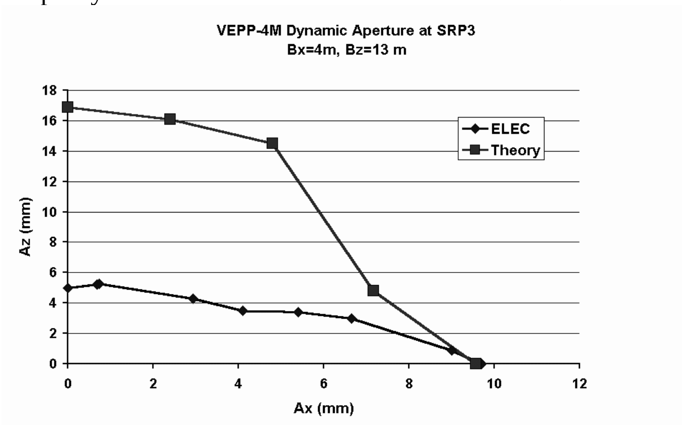

Figure 3: The measured (wiggler off) and the calculated dynamic aperture of VEPP-4M.

4 CONCLUSIONS

We have measured the dynamic aperture of the electron-positron collider VEPP-4M with an improved working betatron point and replaced final focus quadrupoles. These two factors yielded to a significant increase of the horizontal border of the stable motion (two times). However, when two dipole wigglers are used to enlarge the beam phase volume, the horizontal aperture shrinks by approximately 30%. This fact has to be taken into account when the wiggler effect on the luminosity is considered.

First simulation results of combined influence of the beam-beam and magnetic non-linear forces demonstrate further reduction of the dynamic aperture. This fact can have great importance for the attempts to enhance the luminosity by application of dipole wigglers. For the next step in our study, we plan to measure the features of the non-linear beam motion in the presence of both mentioned effects (beam-beam and non-linear magnetic fields).

5 REFERENCES

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