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TURN-BY-TURN BEAM PROFILE STUDY AT VEPP-4M

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Abstract

The beam dynamics during crossing of dynamic aperture border was studied. We controlled the beam losses and beam transversal profile during high-amplitude betatron oscillations caused by the electrostatic kick. The beam transversal profile was recorded by the Multi Anode Photomultiplier with turn-to turn temporal resolution. The experimental data are compared with numerical simulation.

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. At the past we made an attempt to measure the dynamic aperture by two 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. Besides, the influence of beam-beam effects on the DA was checked [2], Fig. 1.

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

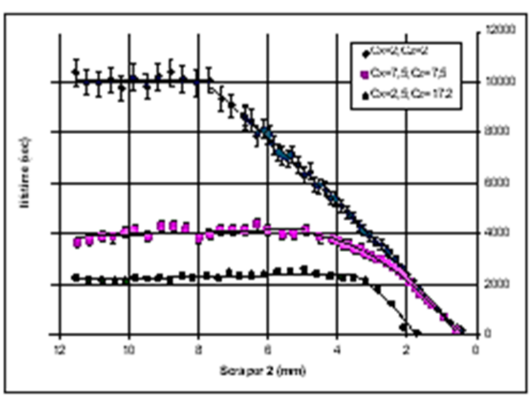

Figure 1: The vertical aperture with different chromaticity values Cx, Cz.

It is obvious that beam losses start from the “tails” of distribution of the particles. The development of the simulation code allows us now to restore a dynamics of the particle distribution at high betatron amplitudes during movement of a beam outside of dynamic aperture.

The aim of our experiments was a comparison of experimentally measured beam losses and beam profile dynamics with simulation results. Because of a restricted experimental time we could make just qualitative comparison.

EXPERIMENTAL PROCEDURE

The dynamic aperture was determined by the coherent beam motion excited by fast electromagnet kicker. The beam displacement and intensity were measured by the single-turn BPM 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. 2.

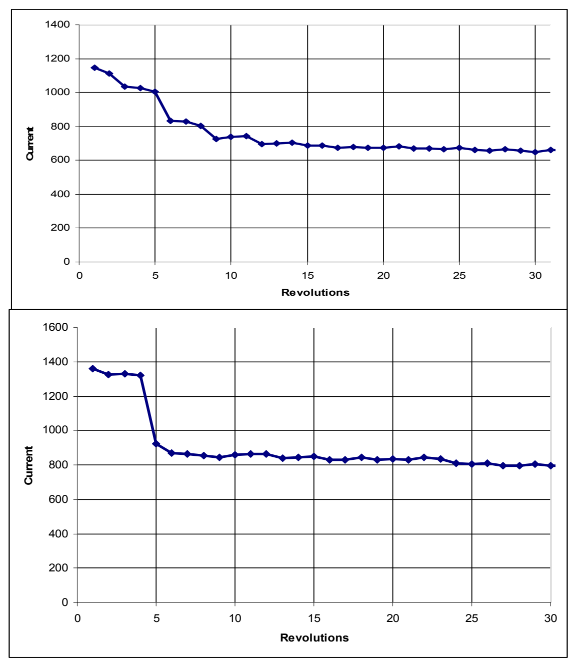

Figure 2: Beam loss at the dynamic (top) and mechanic (bottom) apertures.

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. 2. Outside the dynamic aperture the particle trajectories are exponentially unstable and it takes several 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.

We consistently increased the amplitude of the kick and controlled the behavior of the beam losses by BPM.

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After getting the kick amplitude that provided a proper losses behavior we recorded the dynamics of vertical beam profile.

The diagnostics described at [3, 4] was applied for that. The device includes a MAPMT, a 12-byte ADC, a controller module, an internal memory of 4Mb and 100 Mb Ethernet interface. It can record 2^{17} profiles of a beam at 16 points. Discontinuity of the records can vary within $1\div 2^{8}$ turns of a beam.

The optical arrangement (Fig. 3) allows us to change the beam image magnification on the cathode of MAPMT from 6× to 20×, which is determined by the experimental demands.

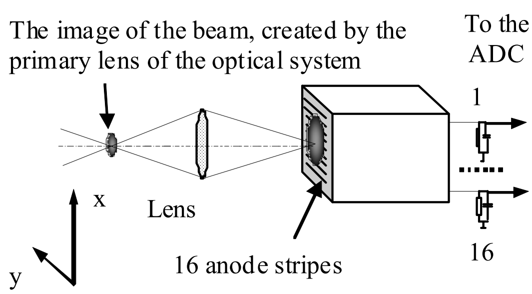

Figure 3: Optical layout of the diagnostics. The lens sets up a beam image on the photocathode of the MAPMT. The radial profile measurements are shown.

Figure 4 demonstrates the equilibrium beam profile with center of beam positioned at the center of MAPMT.

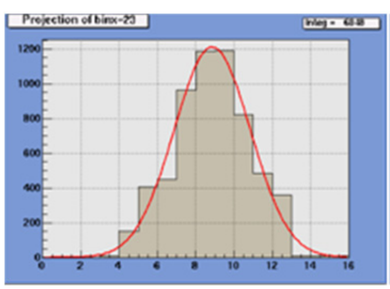

Figure 4: Example of the single beam profile fitted by the Gauss function.

We needed to record the beam profile at high betatron amplitudes. To achieve that we decreased an optical magnification to the level corresponding only 5 channels to complete beam profile (± 3 σ_y). The center of image of a beam at the equilibrium orbit was positioned outside the sensitive area of MAPMT. After kick applied to the beam, we could record several tens of the beam profiles during attenuation of the beam oscillations.

EXPERIMENTAL RESULTS

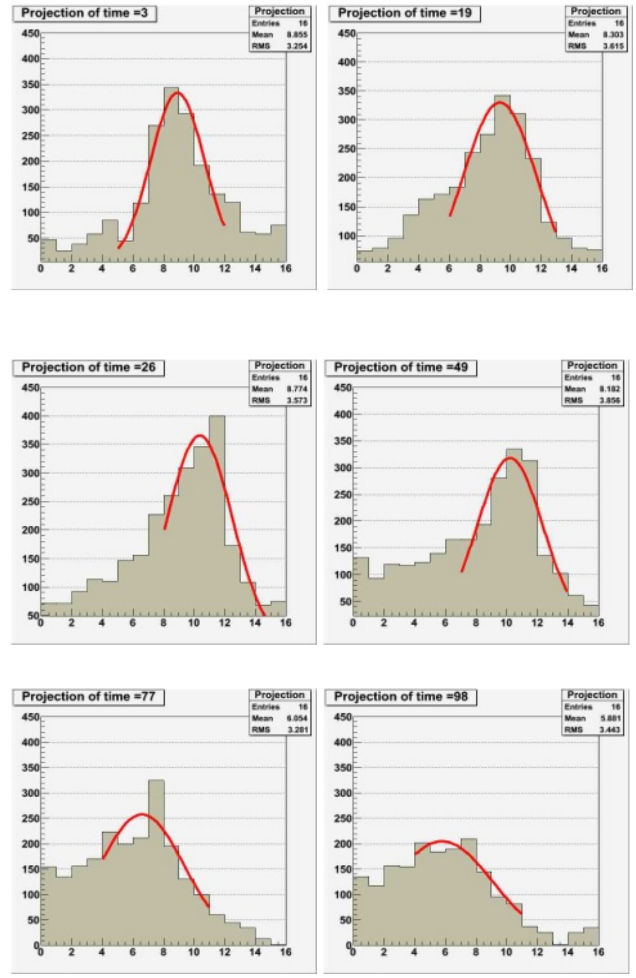

Figure 5: Vertical beam profiles recorded at 3, 19, 26, 48, 77, 98 of turns during beam coherent oscillations.

The reproducibility of the vertical beam profiles recorded during crossing of the dynamic aperture is rather bad. Figure 5 represents the profiles recorded during beam oscillations over limits of DA accompanied with beam losses. Decrease of the beam current recorded by BPM is presented in Fig. 6. The circles mark the turns when beam profiles were recorded.

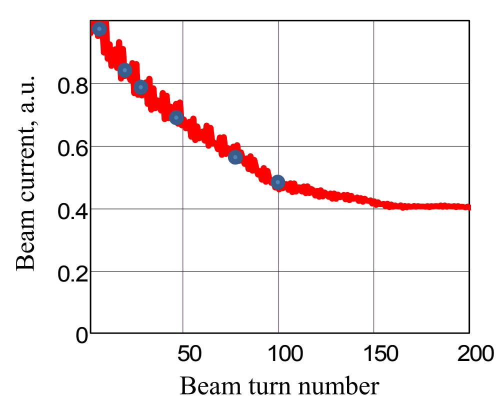

Figure 6: Beam loss because of crossing of DA.

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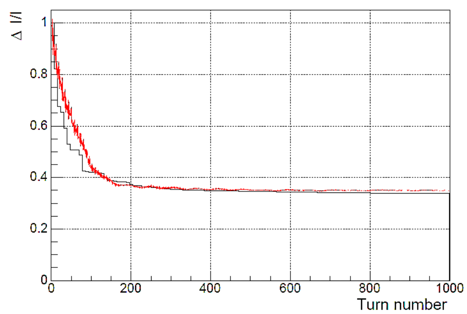

Figure 7: Comparison of calculated and experimentally measured beam loss related with DA crossing.

It is obvious that shape of the beam significantly distinguishes from Gaussian curve. At this stage of experiment we have no spatial calibration of optical scale and can compare our data with simulations just quantitatively.

The comparison of calculated and experimentally measured beam loss is presented in Fig. 7.

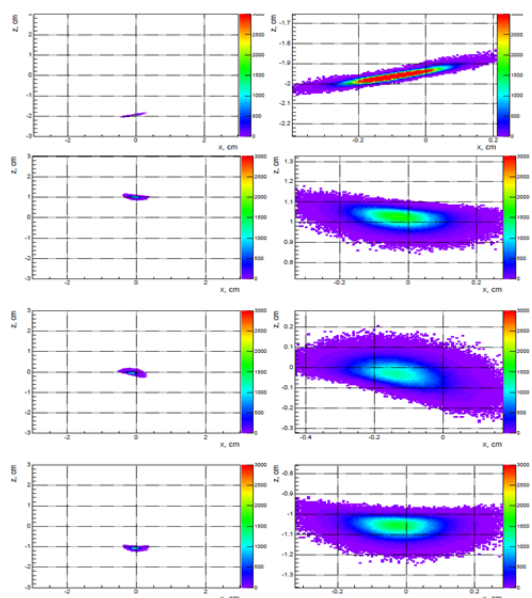

Figure 8: From up to down: beam images simulated for 3rd and 6-10 of beam turns at high betatron amplitudes crossing the border of DA.

The beam cross sections simulated for first ten turns of the beam inside magnetic structure of VEPP-4M are presented in Fig. 8. The left images represent the vertical beam motion during betatron oscillations. The increased beam "portraits" are presented at the right side of the picture.The corresponding integrated beam profiles are presented in Fig. 9.

DISCUSSION

One can see a good coincidence of beam loss obtained with simulations and measured experimentally. Nevertheless, Y-beam profiles obtained with simulations don't demonstrate significant difference with Gaussian curve. In contrast, the experimentally measured vertical profiles very noticeable decline from Gaussian distribution at the first turns of the beam after kick. One of the possible explanations of this discrepancy is a decoherence of a beam which isn't taken into account by numerical model. This process is clearly seen with MAPMT diagnostics when vertical beam size is measured during tens thousands turns [3].

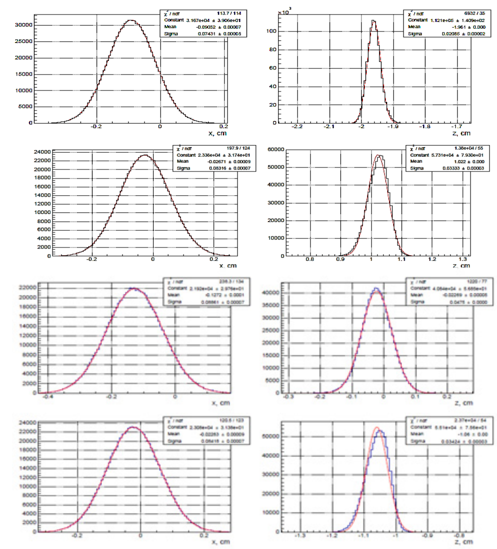

Figure 9: From up to down: the X, Y integrated beam profiles for 3, 6-10 of beam turns presented at Fig. 8. Blue line: simulation results, кed line: Gaussian curve.

CONCLUSION

The beam loss and vertical beam profiles during high amplitude betatron oscillations were measured. The comparison of simulations and experimental results was done. Both experimental diagnostics and numerical model needs to further development.

ASKNOWLEDGMENTS

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