TURN-BY-TURN MEASUREMENTS FOR BEAM DYNAMICS AT VEPP-5 DAMPING RING

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Abstract

Preinjector complex VEPP-5 is being constructed for high rate production and acceleration of electrons and positrons beams up to energy 510 MeV. Both kinds of particles accumulated in the damping ring and after achieving of needed intensity the beams would be transported alternatively to VEPP-3/VEPP-4M or to BEP/VEPP-2000 colliders. At this paper basic parameters of damping ring presented. All measurements were carried out for electron beam with energy 385 MeV. For turn-by-turn measurements 12 beam position monitors were used. In order to improve precision of measured value NAFF algorithm was applied. For measurements of longitudinal beam profile optical phi-dissector was used.

FOURIER ANALYSIS WITH THE NAFF ALGORITHM

The frequency analysis algorithm NAFF provide an aproximation $f'(t) = \sum_{k=1}^{N} a_k e^{i\omega_k t}$ of function $f(t)$ from its numerical knowledge over a finite time span $[-T, T]$. The frequencies ω_k and complex amplitudies a_k are computed through an iterative scheme. In order to determine the basic first frequency ω_1, one searches for the maximum amplitude of $\phi(t) = \langle f(t), e^{i\sigma t}\rangle$ where the scalar product $\langle f(t), g(t)\rangle$ is defined by

$$\langle f(t), g(t)\rangle = \frac{1}{2T}\int_{-T}^{T} f(t)\overline{g(t)}\chi(t)dt, \qquad (1)$$

and where $\chi(t)$ is a weight function. Once the first periodic term $e^{i\omega t}$ is found, its complex amplitude a_1 is obtained by orthogonal projection, and the process is repeated on the remaining part of the function $f_1(t) = f(t) - a_1 e^{i\omega_1 t}$. For quasiperiodic solution the computed frequency ν_1^{comp} converges towards the true frequency ν_1 as

$$\nu_1^{comp} - \nu_1 = O\left(\frac{1}{T^{2p+2}}\right) \qquad (2)$$

where p is the order of the hanning window $\chi_p(t) = 2^p(p!)^2(1 + \cos(\pi t))/(2p)!$. For order $p = 1$ precision of computing frequency $O(\frac{1}{T^4})$ whereas usual FFT algorithm have precision $\frac{1}{T}$.

PARAMETERS OF DAMPING RING VEPP-5

The basic parameters of damping ring showed in Table 1 and Fig. 1. At VEPP-5 damping ring, betatron oscillations are excited by kicker magnet. This magnets used for prekick of circulating beam for injection in horizontal plane. The excitation is coherent, so that all the particles of beam oscillate with the same amplitude and at the same phase. These oscillations are sampled turn-by-turn at each beam position monitor for 8132 revolutions. This number is the maximum memory available to store beam position data.

Table 1: Parameters of Damping Ring VEPP-5

Circumference, C	27.4 m
RF frequency, f_0	700 MHz
RF harmonic number, q	64
RF voltage, kV	220
Momentum compaction, α	0.026
Betatron tunes, ν_x / ν_y	4.45 / 2.69
Synchrontron tune, ν_s	0.021

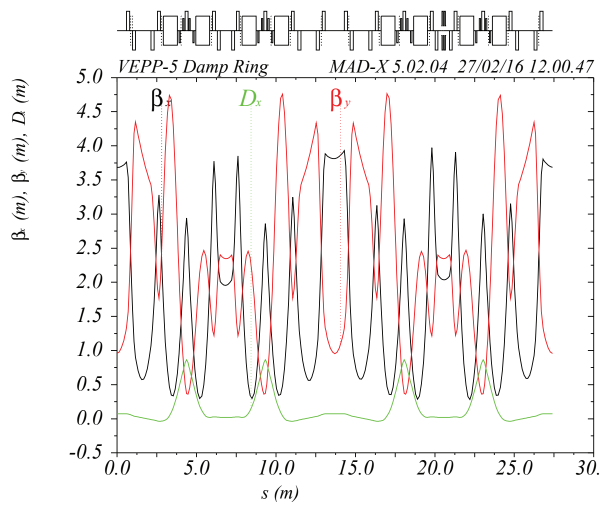

Figure 1: Lattice functions of damping ring VEPP-5 injection complex.

MEASUREMENT OF THE TWISS FUNCTIONS

Beta functions can be measured using 3 consecutive BPMs and the measured phase advances [1].

$$\beta_1' = \beta_1 \frac{\cot\phi_{12}' - \cot\phi_{13}'}{\cot\phi_{12} - \cot\phi_{13}}$$

$$\beta_2' = \beta_2 \frac{\cot\phi_{12}' - \cot\phi_{23}'}{\cot\phi_{12} - \cot\phi_{23}}$$

$$\beta_3' = \beta_3 \frac{\cot\phi_{23}' - \cot\phi_{13}'}{\cot\phi_{23} - \cot\phi_{13}}$$

ISBN 978-3-95450-147-2

where ϕ' and ϕ-are measured and model phase advance respectively between BPMs. It was carried out some series of measurements. Horizontal measured beta function presented in Fig. 2.

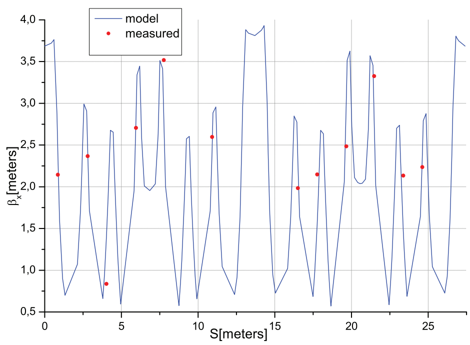

Figure 2: Model and measured horizontal β function.

Unfortunately, the possibility for excitation of vertical oscillations at damping ring is absent. The vertical tune can be measured with good accuracy only by 2 BPMs. Hence this method is not suitable for measurement of vertical beta function. In addition the lattice was measured by amplitude reconstruction at each beam position monitor. The amplitude observed at BPM is proportional to the square root of beta function

$$A_i(s) = JS_i\sqrt{\beta_{x,y}(s)} \quad (3)$$

with a constant factor J for all BPMs and the gain factor S_i of each monitor. The beta function can be evaluated by the linear fit of A_i^2 to the ring model. The beta-beat is a measured by this method a slightly above than 3-bpm method because of the gain factor of monitors is not determined with good accuracy.

CHROMATICITY MEASUREMENTS

By using NAFF algorithm the nonlinear chromaticity and coherent shift of betatron frequency was measured as a function of amplitude oscillations. The linear horisontal and vertical chromaticity (see Fig. 3 and Fig. 4) is a $\xi_x = 1.03$ and $\xi_y = -2.1$ respectively. At present 2 sextupole magnets among 16 are broken. Hence there is no possibility to correct the vertical chromaticity to a slightly positive value. This problem limits the maximum average storage beam at about $70 - 80$ mA.

The dependency of tune betatron oscillations from amplitude appeares due to sextupole component of magnetic field. This dependency presents in Fig. 5 for ordinary machine lattice.

LONGITUDINAL IMPEDANCE

Resistive part of longitudinal impedance is a source of coherent loss of beam energy. The such losses depends on charge of beam q as [2]):

$$\Delta E = -k_{\|}q^2 \quad (4)$$

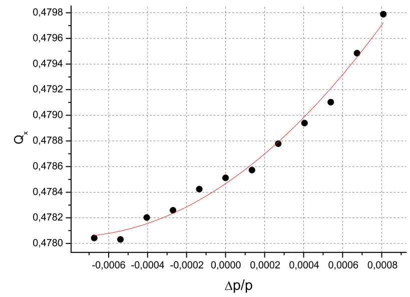

Figure 3: Horisontal tune as a function of momentum deviation.

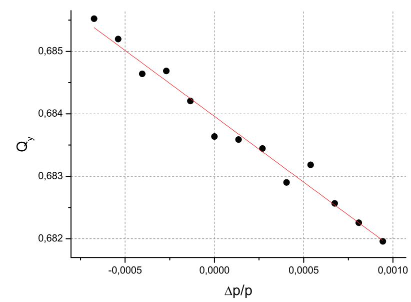

Figure 4: Vertical tune as a function of momentum deviation.

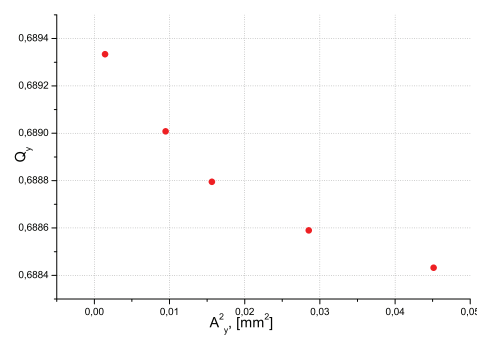

Figure 5: Coherent shift of vertical betatron frequency.

The factor $k_{\|}$ is called longitudinal loss factor. This factor depends on profile of vacuum chamber which is described by the wake-potential $W_{\|}$ and longitudinal beam distribution ρ.

$$k_{||} = \int_{-\infty}^{+\infty} W_t(t)\rho(t)dt\,, \quad (5)$$

At frequency domain this equation can be written as

$$k_{||} = \frac{1}{\pi}\int_0^{\infty} Z_{\|}(\omega) \mid \rho(\omega) \mid^2 d\omega\,, \quad (6)$$

$Z_{||}(\omega)$-total broadband longitudinal impedance of vacuum chamber and $\rho(\omega)$-is Fourier transform of an beam distribution function $\rho(t)$. If beam current exceeds the threshold value the microwave instability arises. The amplitude value of threshold current of bunch I_p for relativistic beam can be defined by following expression:

ISBN 978-3-95450-147-2

$$I_p = \frac{\alpha}{\mid Z_{\|}/n \mid_{eff}} \frac{E}{e} \left(\frac{\Delta p}{p}\right)^2_{FWHM}, \tag{7}$$

where $\mid Z_{\|}/n \mid_{eff}$ - effective longitudinal impedance, α - momentum compaction factor. For gauss distribution beam with rms lenght σ_z and average current I_b the peak current I_p can be found by expression:

$$I_p = \frac{\sqrt{2\pi}R}{\sigma_z} I_b, \tag{8}$$

where R - average radius of the ring.

$$\left(\frac{\sigma_z}{R}\right)^3 = \frac{\alpha I_b}{\sqrt{2\pi}(E/e)Q_s^2} \left|\frac{Z_{\|}}{n}\right|_{eff}, \tag{9}$$

where Q_s–synchrotron frequency. Hence fitting measured bunch length as a current by Eq. (9) it can be evaluate the longitudinal ring impedance. The layout of the bunch train illustrated in Fig. 6. For measurement central bunch was choosen. The instrument function of dissector presents in Fig. 7.

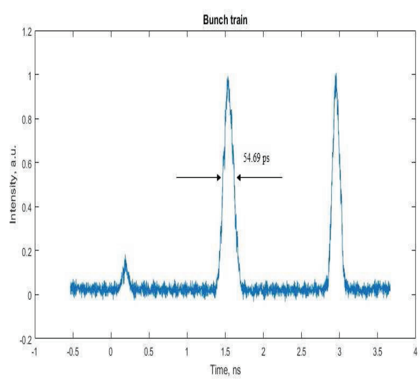

Figure 6: Structure of bunch train at damping ring.

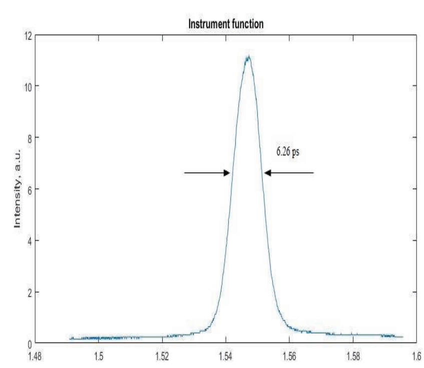

Figure 7: Instrument function of dissector.

The measured bunch length as a function of current presented in Fig. 8. The estimated longitudinal impedance of ring is about 2.3 Ohm.

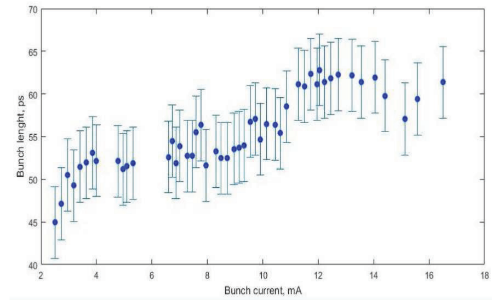

Figure 8: Bunch length vs beam current measured by dissector.

TRANSVERSE IMPEDANCE LOCALIZATION

Localizing coupling impedance sources is possible by looking to the phase advances between different BPMs positions.

$$\frac{\mathrm{d}\nu}{\mathrm{d}I} = \frac{1}{2\pi\sigma_s E} \sum \langle\beta\rangle_i Z_{\perp}^{(i)}, \tag{10}$$

The strength of the impedance is proportional to the variation of phase advance with intensity. In order to receive the distribution of the impedance around the ring, we measure the phase advance between BPMs due to a change the beam current. It was found that the sharp transition of vacuum chamber in kicker magnets is dominated contribution to impedance.

CONCLUSION

At this work results of measurements beam parameters at VEPP-5 damping ring by beam position monitors and phi-dissector are presented. For handling turn-by-turn data NAFF algorithm was applied. This algorithm allows to provide an accuracy of measurements. The lattice, longitudinal and transversed impedance were measured.

ACKNOWLEDGMENT

The experimental results obtained with the optical dissector were implemented due to financial support of the Russian Science Foundation (Projects # 14-29-00295).

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