APPLICATIONS OF BEAM DIAGNOSTIC SYSTEM AT THE VEPP-4.

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Abstract

Advanced applications of the beam diagnostic systems installed at the 6GeV electron-positron collider VEPP-4M and its 2GeV booster VEPP-3 [1], are described. The systems are based on a turn-by-turn processing of signal measured by electrostatic beam position monitors [2].

A technique for beta function correction has been used for adjustment of the VEPP-4M magnet structure. This technique is based on measurement of amplitude of free coherent betatron oscillations, proportional to the square root of beta function. Results of the measurements are given.

A new method for observation of non-linear betatron motion on phase space, using a single beam position monitor, was developed. This method has been tested by computer simulation, and successfully used to study nonlinear beam dynamics on the VEPP-4M. Results of numerical tests and beam measurements are presented.

The diagnostic system is applied too for high resolution measurement of low frequency beam vibrations. Results obtained at the VEPP-4M and at the VEPP-3 are presented.

1 BETA FUNCTION CORRECTION

A low beta insert for colliding beams experiments, and other special sections are included in VEPP-4M magnet structure. This is the reason of the high sensitivity of beta function to quadrupole magnets gradient deviations from the nominal values.

First measurement during commissioning VEPP-4M had shown a considerable (up to 50%) deviation of beta function from the designed values. On Fig.1 the designed beta (on the monitors only) is shown by solid line, the measured one is shown by rhombi. Thus, the problem of beta correction, and, therefore, the problem of fast beta measurement, had arisen.

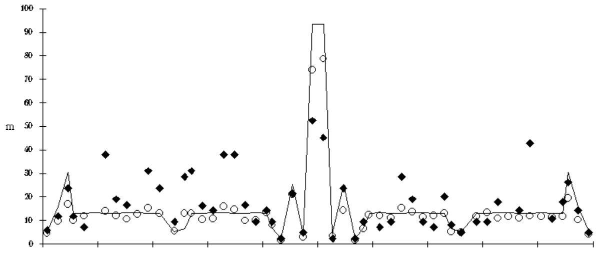


Fig.1. VEPP-4M vertical beta function (on monitors only)

Beta measurement technique is based on the measuring of amplitude of free coherent betatron oscillation excited by kick. The measurement procedure is the digitizing of turn-by-turn beam signal from each monitor and the following processing of the signal arrays to obtain the oscillation amplitude, proportional to the square root of the beta function. To calculate the amplitude of betatron mode FFT with refinement is used [2].

To reduce the measurement time, a powerful processor Transputer [4] was included into the system for data processing. Fourier spectra of the signal arrays of each monitor and betatron oscillation amplitudes are calculated by the Transputer in real time. Slow computer Odrenok [3] is used only to control the system and to transfer the data. The full time of the beta measurement by 52 monitors achieved less one minute now. This time is limited now by the rate of powerful pulse generators used for kicking the beam.

The measurement accuracy is limited by the kick pulse stability and by the electronics noise of the signal processing electronics. The dispersion of the measured values does not exceed 10%.

The fast beta function measurements allow us to correct the beta function in real time. Although this is a nonlinear problem, it can be solved by linear methods, since the linear part of distortions is greater than the nonlinear one. Thus, we used the closed orbit correction code to correct the beta function. Usually, it takes 10-20 iterations (one hour) to reduce the amplitude of beta beating from 50-100% to 10-20%, which is quite acceptable for the storage ring operation. Results of the vertical beta function correction are shown on Fig.1 by rhombi (before correction) and circles (after correction). This correction results in sufficient increasing of the dynamic aperture, which increases the injection efficiency, the operating stability and the beam lifetime.

2 A NEW METHOD FOR PHASE TRAJECTORY OBSERVATION

Phase trajectory of betatron motion is usually made using two beam position monitors. Two arrays of coordinate samples are measured by each monitor during some number of turns. Turn-by-turn values of beam angle, needed for phase trajectory making, is calculated as a linear combination of the coordinate values on both monitors.

A new method using the only beam position monitor was developed, numerically tested, and successfully used for studying non-linear beam dynamics and dynamic aperture on VEPP-4M storage ring.

Betatron motion is described by solution of Hill equation:

$$x(s)=a\beta^{1/2}(s)\cos\psi(s),$$

$$x'(s)=a\beta^{-1/2}(s)[\alpha(s)\cos\psi(s)-\sin\psi(s)]\ .$$

where a is a constant depending on initial conditions, β is a beta function, $\alpha=\beta'/2$, ψ is a betatron phase.

Without the loss of generality let $\alpha(s_0)=0$. Coordinate and angle of the monitor placed at s_0 ,, after k turns are

$$x_k=a\beta^{1/2}\cos(2\pi k\nu+\theta)\ ,\qquad x'_k=-a\beta^{-1/2}\sin(2\pi k\nu+\theta)\ .$$

In non-linear case a and θ are changing from turn to turn, and one can describe coordinate and angle as

$$x_k=a_k\beta^{1/2}\cos(2\pi k\nu+\theta_k)\ ,\qquad x'_k=-a_k\beta^{-1/2}\sin(2\pi k\nu+\theta_k)\ .$$

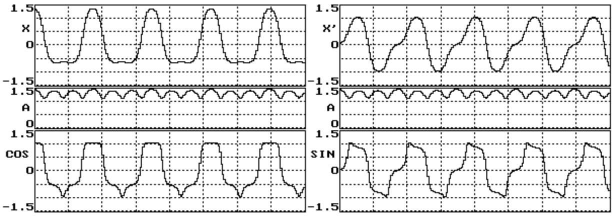


Fig.2. Computer tracking of non-linear beam motion.

On Fig.2 one can see the computer simulation of non-linear betatron motion in magnet structure of SIBERIA-2 storage ring. The graphs of the arrays x_k, a_k, $\cos(2\pi k\nu+\theta_k)$ and x'_k, a_k, $\sin(2\pi k\nu+\theta_k)$ are shown (k=0,1,...,200).

It is seen, that variations of a_k is not exceeded 10-20% of the constant level. Oscillation of x_k and x'_k is mainly formed by oscillation of $\cos(2\pi k\nu+\theta_k)$ and $\sin(2\pi k\nu+\theta_k)$. Correctness of this statement was confirmed by tracking for various cases of non-linearity. Note, that the frequency of a_k variations can be both higher and lower than the betatron frequency.

Thus, if we have only coordinate array x_k, for each turn there are two independent variables a_k and θ_k, but only one equation:

$$x_k=a_k\beta^{1/2}\cos(2\pi k\nu+\theta_k).$$

Therefore, the problem of phase trajectory making by reconstruction x'_k-array using x_k-array measured by a single monitor can not be solved. Nevertheless, an approximate method, for solution of this problem, has been developed.

When viewed various cases of tracking in non-linear magnet structures, it was discovered, that amplitudes and phases of the most significant harmonics in coordinate and angle spectra are correlated. To illustrate the correlation, on Fig.3 the spectra of coordinate and angle arrays, and the amplitude and phase values of 1÷10 betatron harmonics are shown. These spectra are calculated for the non-linear motion shown on Fig.2.

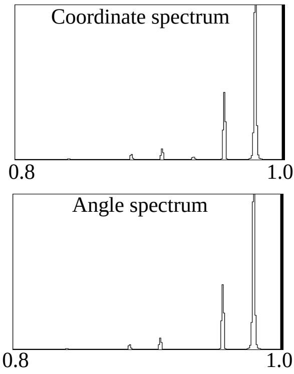
Taking into consideration this fact, we can reconstruct the phase trajectory using only coordinate spectrum. Arrays for phase trajectory X_k and X'_k are synthesized as a series of betatron frequency harmonics, amplitudes and phases of which are calculated by spetctral analysis of the coordinate array x_k by FFT with refinement [2].

$$X_k=\sum_{j=1}^{N}A_j\cos(2\pi kj\nu+\varphi_j)$$

$$X'_k=\beta^{-1}\sum_{j=1}^{N}A_j\cos(2\pi kj\nu+\varphi_j+\Delta\varphi)$$

A_j and φ_j are the amplitude and phase of the harmonic $j\nu$ in coordinate spectra, $\Delta\varphi$ is a shift of the phase of angle harmonic from the phase of coordinate one.

$$\Delta\varphi=-j\pi/2\quad\text{for } j=2m+1\ ,\qquad \Delta\varphi=(j+1)\pi/2\quad\text{for } j=2m\ ,\qquad m=0,\ 1,\ 2,\ ...$$



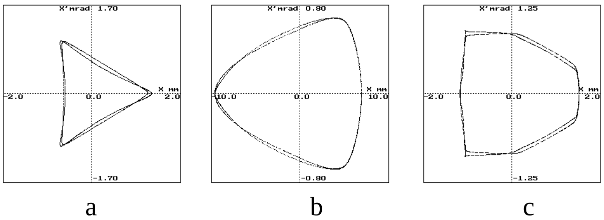
	Freq.	Ampl.	Phase
ν	0.9771	1.0216	-7°
2ν	1.9542	0.3871	-15°
3ν	2.9313	0.0144	157°
4ν	3.9083	0.0642	149°
5ν	4.8854	0.0314	142°
6ν	5.8625	0.0023	-44°

	Freq.	Ampl.	Phase
ν	0.9771	0.8989	82°
2ν	1.9542	0.3278	-105°
3ν	2.9313	0.0011	65°
4ν	3.9083	0.0581	-120°
5ν	4.8854	0.0254	52°
6ν	5.8625	0.0004	-130°

Fig.3. Coordinate and angle spectra.

For the motion shown on Fig.2, phase trajectory reconstructed using spectrum of x_k, in comparison with the true one, is given on Fig.4a.

Number of harmonics N is limited in dependence of the non-linearity order so that further increase of N does not influence the trajectory shape because of small amplitudes of high order harmonics. On Fig.4 one can see the reconstructed and the true phase trajectories of the tracking in VEPP-4M (b) and SIBERIA-2 (c) magnet structures with different non-linearity. For the VEPP-4M tracking, 4 harmonics were used in synthesis, for the SIBERIA-2 one, 8 harmonics were used.



a b c

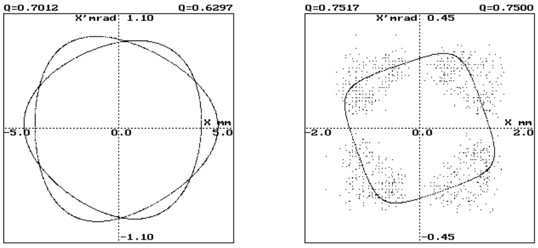
Fig.4. Phase trajectories of non-linear motion.

This method was numerically tested using computer simulation of beam motion for various cases of non-linearity. All tests gave a good coincidence of the reconstructed phase trajectories with the true ones calculated by tracking.

The method was successfully applied to investigation of non-linear beam dynamics on VEPP-4M [5]. For decreasing errors produced by noise of the processing electronics, computer program selects for synthesis only harmonics with amplitudes exceeded more than 1.5 times the level of r.m.s. spectral noise density. To increase the resolution, an averaging of the signal arrays was used. While the integral resolution of turn-by-turn beam position monitor is ~100μm, differential resolution of betatron harmonics is 10-20μm without averaging, and 4-6μm with averaging of 10 measurements.

The measured phase trajectories of the non-linear beam motion in VEPP-4M, when the betatron frequency is below or above of sextupole resonance $3\nu_x$=26, are given on Fig.5a. As it is predicted by theory, orientation of triangle curve is changed to opposite direction when ν_x passes through the resonance.

Another resonance near VEPP-4M working point is $4\nu_x$=35. This resonance results from octupole component of cubic guide field non-linearity, or second order of sextupole perturbation. On Fig.5b the solid line shows the measured phase trajectory near the resonance $4\nu_x$=35, the dots show the trajectory on the resonance.



a b

Fig.5. Measured phase trajectories.

It is turned out, that accuracy of this method is sufficient not only for qualitative phase space topology observation, but also for quantitative evaluation of amplitude of sextupole perturbation harmonic.

3 STUDYING OF LOW FREQUENCY BEAM VIBRATIONS

Beam vibrations in the low frequency range (up to 1kHz), produced by ground vibration or by pulsation of magnet system power supplies can result in some negative effects, such as decrease of dynamic aperture, reduction of effective synchrotron radiation power, etc. It is necessary to know parameters of these beam vibrations to search the vibration source and to suppress the effects.

The diagnostic system [2] provided turn-by-turn beam position measurement is suitable for this purpose by adding an integrating ADC connected to low pass filter output of the sample and hold unit. ADC integrating time determines the bandwidth and spectral resolution.

In our measurements four ADC with internal timing are started simultaneously, digitize the signals of beam position monitor and store the data in memory. Beam position sample arrays, their amplitude and power spectra, and spectrum integrals are calculated and shown.

Fig.6a illustrates the system spectral resolution. There are graphs of the coordinate array calculated from calibration signal instead of beam and its amplitude spectrum. The resolution is limited by discretness of the ADC, its value is 0.15 μm. Beam vibrations have been measured on VEPP-3, VEPP-4M and SIBERIA-2 storage rings. On Fig.6b one can see the VEPP-4M vertical beam vibration. The high 6Hz peak occur by the ground vibration produced by distant rotor machine, 50, 100 and 150Hz peaks are power line harmonics.

This technique was applied to test the digital feedback system for closed orbit stabilization.

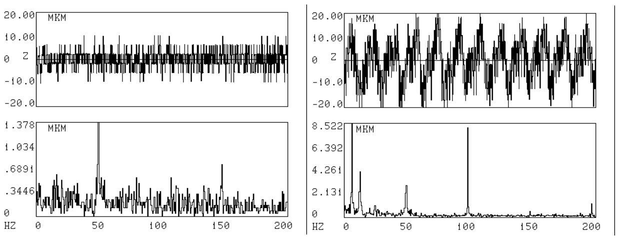


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Fig.6. Low frequency spectra.

4 ACKNOWLEDGMENT

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