Pickup Beam Measurement System at the VEPP-2000 Collider

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Abstract

This paper reviews the present state of electromagnetic beam position monitors (pickups) at VEPP-2000 collider. It includes descriptions of position monitors, typical interfaces for these monitors and their system characteristics (resolution, stability, bandwidth and problems or limitations) are discussed. The paper also reviews several types of diagnostic measurements using beam position monitors which are useful in improving accelerator operations.

1. INTRODUCTION

The new electron-positron collider VEPP-2000 ring is a part of VEPP-2000 complex [1] at BINP has been successfully commissioned and has been delivering luminosity at energy close to 508 MeV since June 2007. VEPP-2000 is a new machine with luminosity up to 10^{32} cm^{-2}s^{-1} and the beam energy from hadron production threshold up to 2×1 GeV. Small ring size and sophisticated optics lay on limitation on beam quality and operations. Therefore such modern machines requires various beam diagnostics for perfect tuning and ask us to monitor the beam status quickly and accurately.

The measurement and control of the closed orbit is one of the basic functions of any accelerator beam instrumentation and control systems. A beam position monitor (BPM) system is operated for two kinds of orbit measurements, a relative measurement and an absolute measurement. The former is to measure the orbit displacement from the initial or standard orbit when some optics perturbation is applied. The latter case is to measure orbit position relative to the geometrical monitor center. This function will be essential for maintaining stable operations in a ring where the optics depends strongly on the orbit, particularly at nonlinear optics elements.

The VEPP-2000 electrostatic BPMs system is not only used to monitor the beam orbit and correct the closed orbit distortion (COD), but also used to perform the interaction point (IP) beam steering along the detectors, control and adjustment of the beam oscillation amplitude during the injection, measure the dispersion functions and the betatron frequencies.

2. SYSTEM HARDWARE

The VEPP-2000 collider ring is equipped with a system of beam position diagnostics based on 4 electrostatic BPMs, frontend electronics located near BPMs and readout electronics in CAMAC standard. A set of low loss coaxial cables brings up the BPM signals of each detector to the local control room where the signal readout and processing electronics is located. The lengths of cables vary from 15 to 25 meters depending on the locations of the detectors in the storage ring. Each BPM is placed in the center of the technical strait section surrounded with two quadrupole magnets, very close to them. Before installation, electrical zero point of pickup electrode for each BPM is calibrated by a calibration bench with a wire method.

2.1 BPM Block

The beam position monitor for VEPP-2000 ring consist of four 15 mm diameter button style pickups are mounted on the diagonals of its housing and are centered symmetrically. The button type electrodes, which are capacitive coupled to the beam, are most popular with electron-positron rings because they occupy very little longitudinal space and the coupling impedance is small. Buttons orientation is 45 degrees to avoid the fan of synchrotron radiation. All parts precisely machined from solid stainless steel blocks, isolated the electrodes and feedthroughs with ceramic material. The electrode surface is smoothed with that of the vacuum chamber, so the impedance induced by the electrode may be reduced greatly.

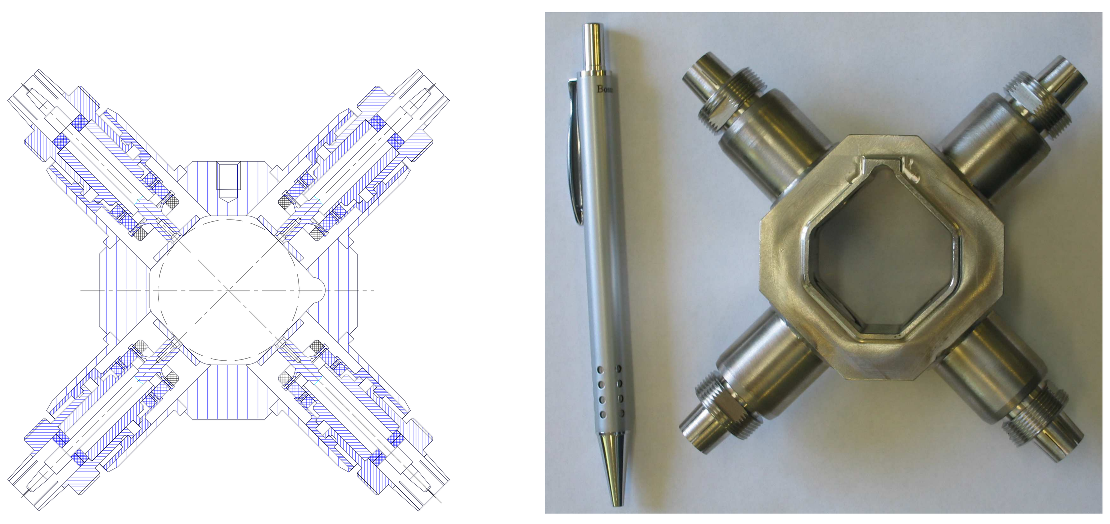


Figure 1: *The beam position monitor for VEPP-2000 ring.*

The BPM is integral part of the quadrupole vacuum chamber of the technical strait section, which in turn is referenced to the magnet axis by means of supporting arms, and assembled on the vacuum chamber by welding, assuring no gas leak. To reduce the mechanical surveyment for the BPM with the same vacuum chamber dimensions, BPM housing has the same cross section form and dimensions, and coincides with the vacuum chamber within ± 0.2 mm. Fig. 1 shows a transverse section and common view of the BPM before assembling.

2.2 Electronics

The signals from four BPM electrodes are simultaneously processed with four channels of processing electronics. Each channel consist of LPF with cut-off frequency of 110 MHz, programmable gain amplifier and 12-bit ADC. Time interval between electron and positron bunches is about 20 ns for each BPM. Analog electronics bandwidth of 110 MHz allows us to decrease the crosstalk of electron and positron bunches signals at level of 0.5 dB. Timing circuit provides ADC samples at the top of BPM signal. It is achieved by means of programmable delay of reference pulses with revolution frequency. Delay range covers all revolution period. Delay range covers all revolution period with step equal $0{,}25$ ns. Amplifier range of 45 dB allow us operate with $1-100$ mA beam current.

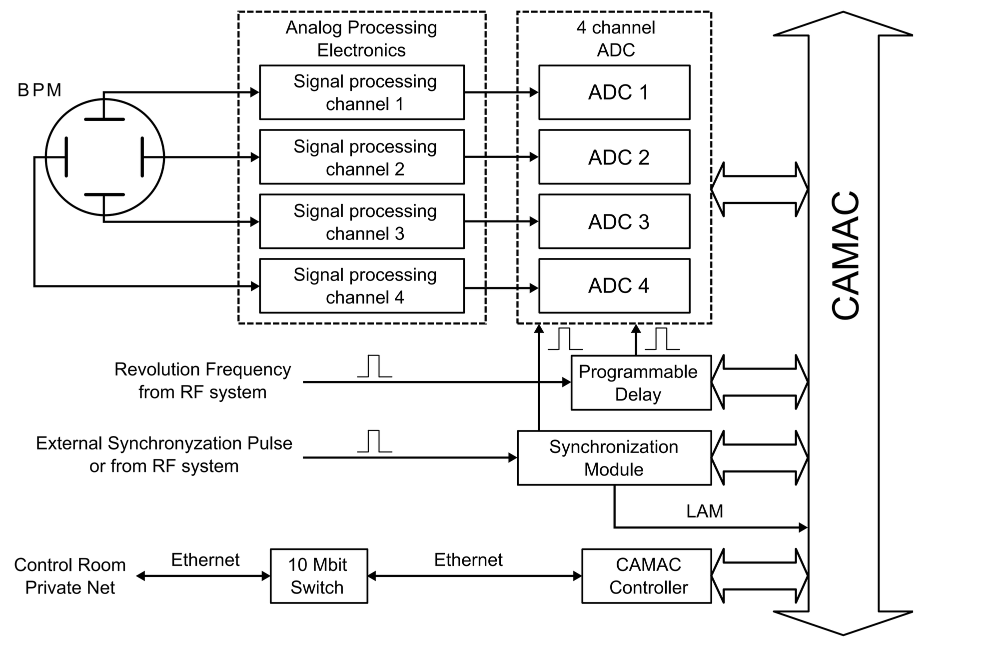


Figure 2: *Structure of VEPP-2000 electronics.*

3. DATA ACQUISITION SYSTEM

The data acquisition system is based on client-server model over TCP/IP protocol. PowerPC embedded CAMAC controller, which running Linux operating system [2], is used to initialize electronics and perform the data acquisition operation. Such choice is caused by heavy traffic limitation and high rate response requirements. Two level server scheme is used: there main server works on PC and its main goal is to receive incoming requests and initiate measurements; slave server works on CAMAC controller and its main goal is hardware serving and returning measured data to the master server as fast as possible (actually speed is limited only by hardware carrying capacity). The controller communicates with the electronics via CAMAC bus by using compiled command system for programmable instruments. All software uses the CX libraries set [3]. The user interface is developed under X-Windows/Qt/TclTk environment.

The acquired signals from button electrodes are filled into the memory of the ADC with a revolution clock of the ring ($f_0 = 12.191$ MHz). The memory depth of the digitizer is up to 32 Kwords (i.e. beam position is measured at each turn with maximum record length is about 2.5 msec). So one can measure betatron frequencies using FFT technique, or obtain slow data with averaging of results for any chosen number of turns (say 2048 points average @ 10 Hz). Synchronization of the system with beam injection gives the possibility of the beam position measurements for the first turn and measurements of the betatron frequencies after injection. Although the system allows measurements of the betatron frequencies after external excitation.

The raw data, the calculated beam position, the betatron tune and the phase space plot are presented on the screen in interactive basis. The experimental data can also be stored on mass storage devices for off-line analysis

4. ACCURACY OF THE SYSTEM

During storage ring commissioning precision and stability of the BPM system has been measured [4]. There are number sources of errors during beam position measurements: temperature instability, time jitter of the ADC trigger pulses, quantization noise of ADC, interferences in BPMs and cables connecting BPMs with processing electronics and so on. Temperature instability of the processing channels gains and time delays formed with Delay lines leads to temperature instability of the beam position measurements. Experimental examination gave the temperature stability value 2μm/°C. Then temperature instability of the time delays leads to temperature instability of the beam position measurements mainly due to the differences in BPM cables lengths and gain-frequency characteristics of the processing channels. So electrical length of each cable was measured and made equal ones for each BPM. Another experimental investigations have shown that major contribution to coordinate error is brought by interferences in the cables connecting BPMs with processing electronics. Some measures and efforts have been made to reduce these interferences. One of them is using of double-shielded coaxial cables.

Table 1: *BPM system parameters.*

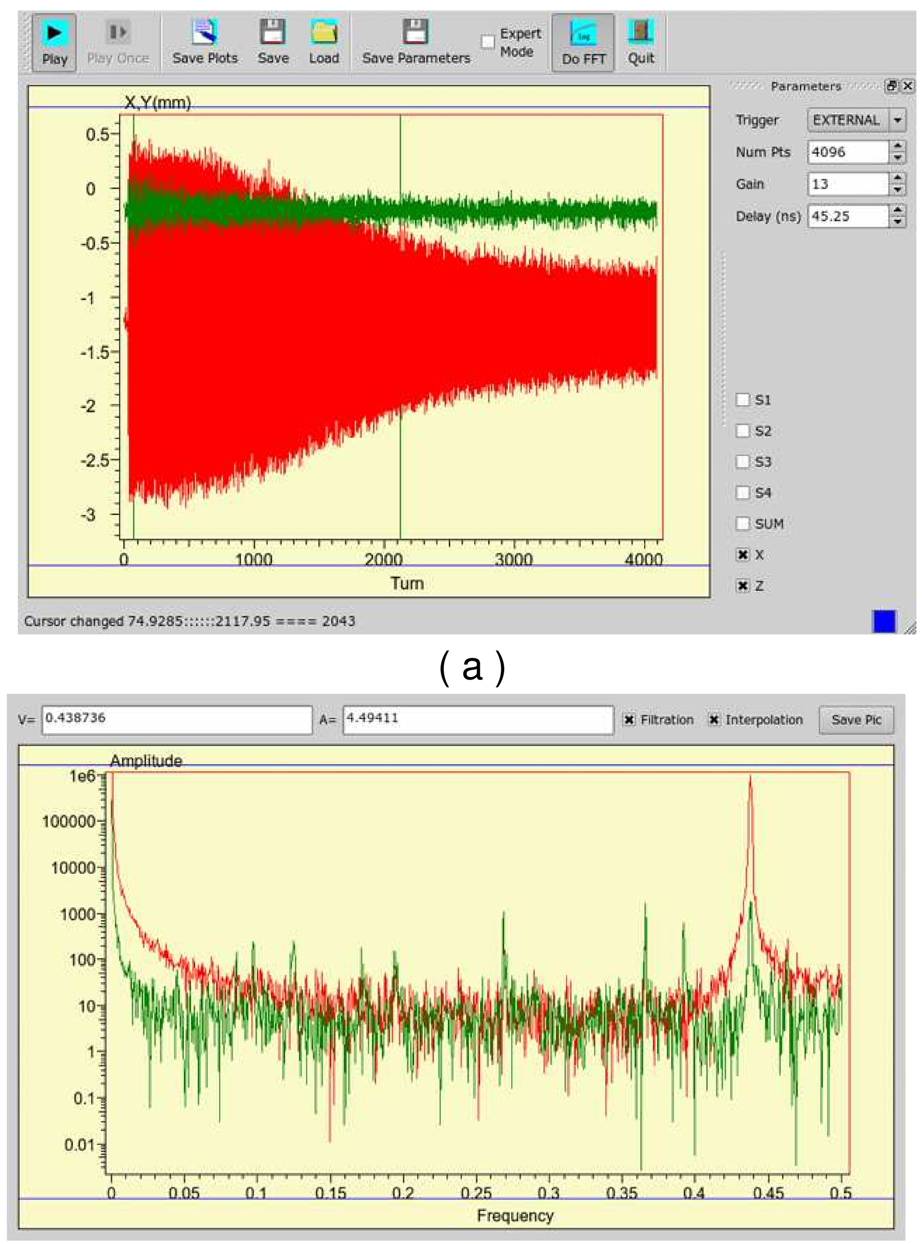
Beam Current	Resolution Turn by turn	256 turns average
$0{,}1-1$ mA	$150-500$ μm	$10-30$ μm
$1-10$ mA	$50-150$ μm	$3-10$ μm
>10 mA	<50 μm	<3 μm

The main reason of beam position from beam current dependence is nonlinearity of programmable attenuators, amplifiers and multipliers. Some results and parameters are present in Table 1.

5. APPLICATIONS

5.1 Beam position and Tune monitor

The flexibility of the system allows to perform a series of turn-by-turn measurements, while FFT can be moved over the data by a user defined step to generate a "spectrum movie" and see dynamic processes in the beams during injection or other operations. The signal-to-coordinate coversion, tune calculation with specific filtering and approximation [5] are made on the client side. Examples of user-end application presented on Fig. 3(b). Beam injection is one of the significant task for any accelerator. You can see horizontal beam oscillation after injection, caused beam energy mismatch on Fig. 4. Tune measurements became routine operations since the end of 2009 then VEPP-2000 started first experimental work with both particle detectors SND and CMD-3 at the energies of 500-950 MeV range with the lattice mode close to project. Together with Response Matrix Techniques [6] it became a powerful instrument for lattice and optical functions correction at VEPP-2000.



(a)

(b)

Figure 3: *Beam oscillation after external kick during 4000 turns and their betatron spectra.*

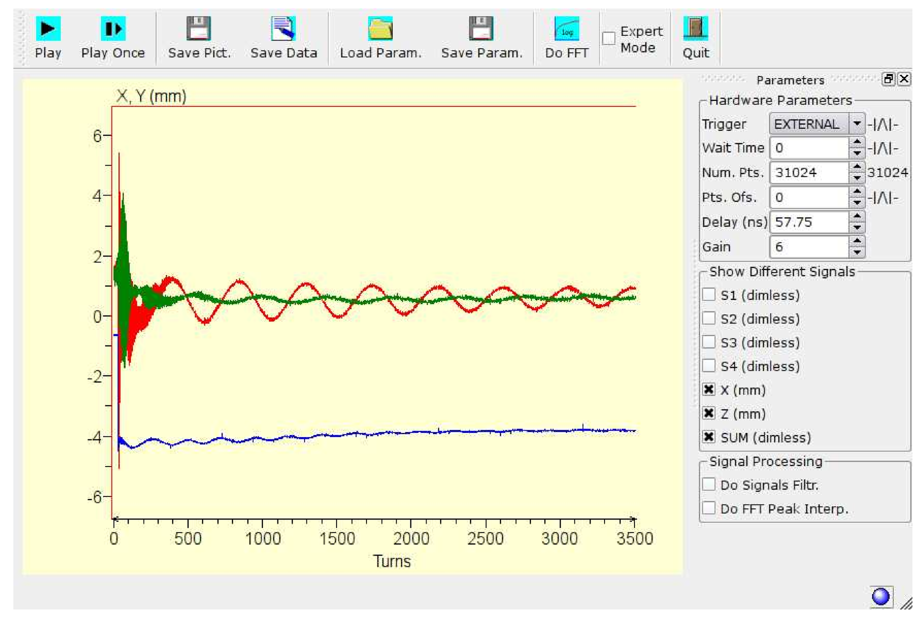


Figure 4: *Beam oscillation after injection.*

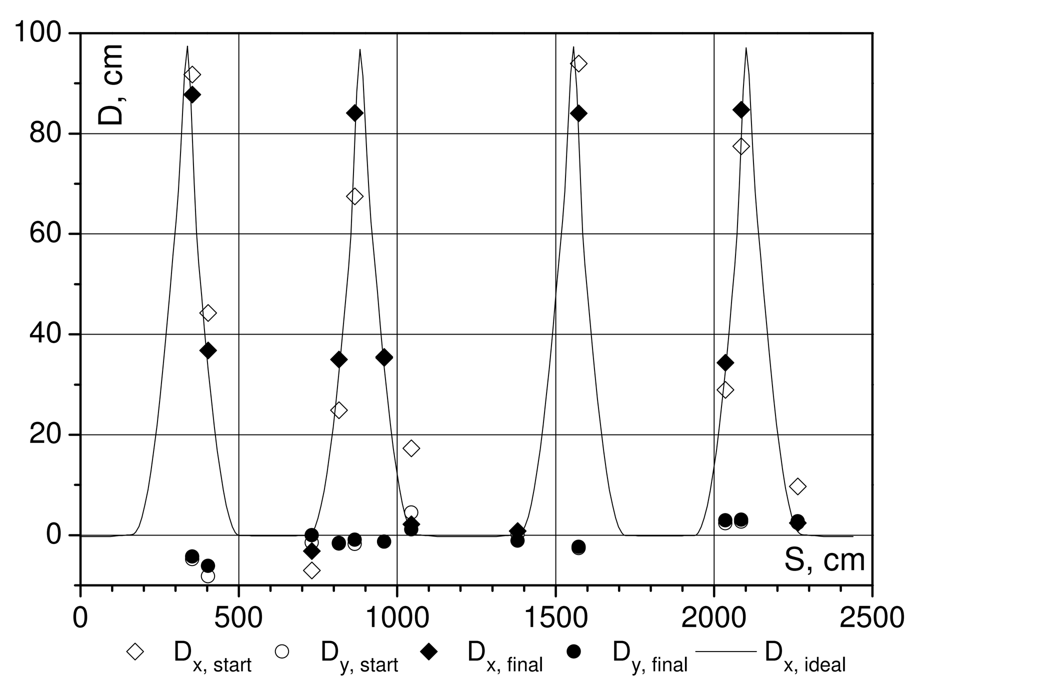


Figure 5: *Dispersion function. Point near picks maximums is the BPM measurements.*

The BPM system is very sensitive for dispersion function measurements, because our BPMs located in the places with maximum dispersion function. Fig. 5 shows the dispersion measured before and after applying of calculated corrections for quadrupoles gradients and solenoids fields.

5.2 Intensity and Lifetime measurements

A DC Beam Transformer (DCBT) is used to measure the bunched or unbunched circulating beam current. Because DCBT can measure only total charge amount and there are two beams with different charge rotating together, so we need some additional information about relative beam intensities during operations with higher intensity ($\sim 10^{10}$) circulating beams. This information one can obtain from the BPM system, because total signal from all BPM's tablets is proportional to the beam current. So one can calculate beam lifetime.

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