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 electrostatic positron collider VEPP-2000 ring is a part of VEPP-2000 collider [1] which has been successfully commissioned and has been delivering luminosity at energy close to 0.5 GeV. VEPP-2000 collider is a new-generation accelerator machine with luminosity up to $10^{34} \text{cm}^{-2}\text{s}^{-1}$ and the beam energy from hadron production threshold up to 2 keV. 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 regions.

The VEPP-2000 electrostatic BPMs system is not only used to monitor the beam orbit and control 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 9 electrostatic BPMs, front-end electronics, ADCs and CAMAC-based beam position data acquisition system 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 electronics is located. The lengths of cables vary from 10 to 35 meters depending on the locations of the detectors in the storage ring and the site of the technical strait section surrounded with two quadrupole magnets, very close to them. Before installation, electrical zero point of pick-up 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 $15 \text{mm}$ 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 made of stainless steel with a $0.5 \text{mm}$ thickness, so they can receive $10^{-4} \text{A}$ current. The beam pickup electrodes are $3 \text{deg}$ centred to the wire of synchrotron radiation. All parts are machined from solid stainless steel blocks, isolated the electrical signal from all interference. The pick-up electrode surface is smoothed with that of the vacuum chamber, so the beam is not disturbed by the electrode may be reduced greatly.

Figure 1: The beam position monitor for VEPP-2000 ring shows a transverse 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 consists of ADC with availability of $15 \text{MHz}$, programmable gain amplifier and $1 \text{bit}$ ADC. Time interval between electron and position bunches is about $100 \mu \text{s}$ for each BPM. Each BPM can have a maximum of $2 \times 10^7$ counts per second. The $1 \text{bit}$ ADC is used to decrease the crosstalk of electron and positron bunches signals at level of $0.5 \text{dB}$. 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 $0.025 \text{ns}$. Amplifier range with the lattice mode close to project. Together with Resistor Matrix Techniques [6] it became a powerful instrument for lattice and optical functions correction at VEPP-2000.

Table 1: BPM system parameters.

<table>
<thead>
<tr>
<th>Beam Current</th>
<th>Resolution Turn by turn 256 turns average</th>
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<tbody>
<tr>
<td>$0.1 - 1 \text{mA}$</td>
<td>$150 - 500 \mu \text{m}$</td>
</tr>
<tr>
<td>$10 - 50 \text{mA}$</td>
<td>$10 - 30 \mu \text{m}$</td>
</tr>
<tr>
<td>$&gt; 50 \text{mA}$</td>
<td>$5 - 10 \mu \text{m}$</td>
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The main reason of beam position from beam current dependence is non-linearity of programmable attenuators, amplifiers and multipliers. Some results and parameters are present in Table 1.

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 operations. 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. Both virtual as well as physical interface is limited only by hardware carrying capacity. The controller communicates with 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/TCP/IP environment.

The acquired signals from button electrodes are filled into the memory of the ADC with a revolution clock of the ring (50 kHz). The memory depth of the digitizer is up to $12 \text{Kwords}$ (i.e. beam position is measured at each turn with maximum record length about 10 $\mu \text{s}$). So one can measure betatron frequencies using FFT technique, or obtain slow data with averaging of results for any chosen number of turns (say 20 points average @ 100 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 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.

Figure 3: Beam oscillation after external kick during 20 turns and their betatron spectra.

4. ACCURACY OF THE SYSTEM

During storage ring commissioning precision and stability of the BPM system has been measured [4]. There are several sources of errors during beam position measurements: temperature instability, 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 by Delay lines leads to temperature instability of the beam position measurements. Experimental examination gave the temperature stability value $0.1 \text{C}/\text{C}$. Then temperature instability of the time delays leads to temperature instability of the beam position measurements mainly due to the differences in the rate of changes of processing channels. So electrical length of each cable was measured and made equal ones for each BPM. Another source of errors during beam position measurements is 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.

Figure 4: Beam oscillation after injection.

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 second idea to generate a "spectrum movie" and see dynamic processes in the beams during injection or other operations. The signal-to-noise-correlation, tune calculation with BPMs and BPMs without correction [6] are made on the client side. Examples of user-end application presented on Fig. 3. 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 measurement became possible only after the end of 2009 then VEPP-2000 started first experimental work with both particles detectors SND and CMD-3 at the energies of 500-950 MeV.

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. Figure 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 current ($> 100 \mu \text{A}$) circulating beams. This information one can obtain from the BPM system, because total signal from all BPMs is proportional to the beam current. So one can calculate beam lifetime.

References