WIDEBAND BPM ELECTRONICS FOR THE VEPP-4M COLLIDER

E.A. Bekhtenev, G.V. Karpov, Budker Institute of Nuclear Physics, Novosibirsk, Russia

Abstract

New beam position monitor (BPM) FPGA-based electronics has been developed and tested at the VEPP-4M electron-positron collider. The VEPP-4M operates with two electron and two positron bunches. Compared to the old BPM electronics the new one can measure the position of each of four bunches with any BPM of storage ring including the BPMs near interaction point. Wide bandwidth of electronics (200 MHz) allows the separate measurements of electron and positron bunches with time interval between bunches up to 20 ns. BPM system works at two modes: slow closed orbit measurements and turn-by-turn measurements. We present details of system design and operation.

INTRODUCTION

The VEPP-4M is the modernized VEPP-4 collider, which had been commissioned for the first time in 1977 [1]. Conditions of high energy physics (HEP) experiments require continuous orbit measurements of electron and positron bunches. The present VEPP-4M Beam Position Monitor (BPM) system developed 25 years ago [2] can make orbit measurements only if one type of particles is circulating at storage ring: electrons or positrons. It is not capable to measure beam orbit during HEP experiments where both types of particles are at storage ring. The second disadvantage of the old BPM system is absence of turn-by-turn capability by each BPM. To satisfy modern requirements an internal R&D program has been started at BINP to develop new BPM electronics for VEPP-4M. Some of storage ring parameters are given in Table 1.

Table 1: Some parameters of the VEPP-4M collider

Beam energy	1-6 GeV
Revolution frequency F_0	0.819 MHz
RF frequency	181.8 MHz
Beam current	1-30 mA
Total number of electron and positron bunches	4
Total number of BPMs in storage ring	54
Minimal time interval between electron and positron BPM signals	20 ns

Precision requirements to BPM system are not so severe: relative accuracy of slow measurements has to be of order 50-100 microns, resolution of turn-by-turn measurements has to be of 20-50 microns.

The VEPP-4M collider operates with two electron and two positron bunches. Difference in arrival time of the electron and positron bunches is minimal for BPMs located close to places of meeting of bunches. For example for the BPMs NEP0 and SEP0 located close to interaction point (at opposite sides of interaction point) arrival time of the electron and positron bunches differs in ~22 ns. For NEP0 the first bunch arrived is positron bunch for SEP0 – electron bunch.

New electronics design utilizes signal peak sampling with high bandwidth digitizer as it was done for CESR [3]. At the end of 2009 new BPM electronics had been developed. In January 2010 two complete sets of BPM electronics had been fabricated and installed at VEPP-4M BPMs NEP0 and SEP0.

BPM ELECTRONICS DESIGN

Functional diagram of the new BPM electronics is presented in Fig.1.

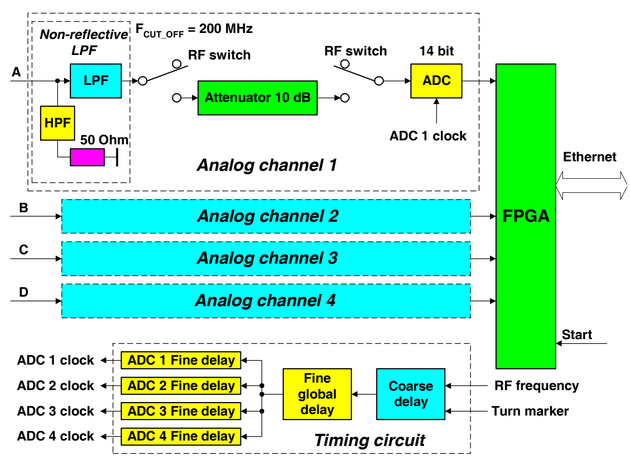

Fig.1. Functional diagram of new BPM electronics.

The electronics consists of four identical analog channels, FPGA, Timing circuit and Ethernet interface. All electronics occupies 1U 19" chassis.

In order to achieve separate measurements of electron and positron bunches the bandwidth of analog front-end electronics is chosen of 200 MHz. The bandwidth is defined by non-reflective Low Pass Filter (LPF) with cut-off frequency of 200 MHz. Pickup signal of electron bunch at the LPF output is shown in Fig2.

Amplitude of reflected from LPF signal is less than 1% of coming signal. "Tail" of the first bunch signal on the peak of second bunch signal is less than 0.5%. However such "tail" value can cause position measurement error of the second bunch up to 0.5 mm. To decrease this error program compensation of the "tail" is implemented in the system.

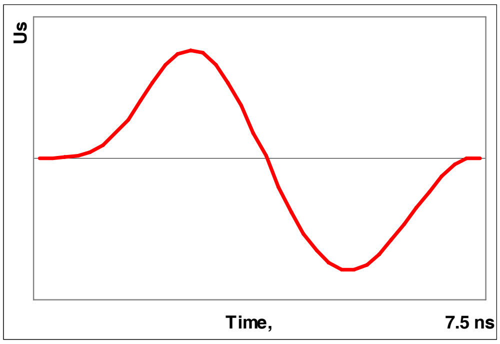

Fig.2. Pickup signal of electron bunch at the LPF output.

Pickup voltage of the second bunch is calculated with formula:

$$U_{2C} = U_{2M} - k\times U_{1M},$$

where U_{2M} and U_{1M} – are measured pickup voltages of second and first bunches correspondingly,

k – is measured relative amplitude of the “tail” of the first bunch on the peak of the second bunch.

The k value is measured experimentally one time and then is used for “tail” compensation. Such compensation decreases position measurement error of the second bunch caused by “tail” of the first bunch approximately in 10 times.

The feature of new BPM electronics is absence of any amplifier. The signal from LPF via semiconductor switches comes right to 14 bits 40 MHz ADC (AD9244). The signal amplitude for beam current of 10 mA corresponds to full scale of ADC – 1 V. For more large currents the signals pass via -10 dB passive attenuator. High voltage RF switches SW-277 of Minicircuits firm can bear peak voltages up to 20 V.

Clock frequency of ADC is revolution frequency F_0. Each turn ADC digitizes one of four bunch signals. Timing circuit provides ADC samples exactly at the top of BPM signal. Timing circuit is a three-stage delay. The first stage (coarse delay) is 8-bit programmable counter MC100EP016 with clock frequency of 181.8 MHz (RF frequency). After applying of turn marker the counter is preset by code defining coarse delay and then starts. Delay step of the first stage is one period of RF frequency ~5.5 ns. Delay range is $1/F_0 - 5.5$ ns.

The second stage (fine global delay) is 10-bit programmable delay chip MC100EP195B. It provides 10.24 ns delay range with 10 ps delay step. The third stage consists of four chips MC100EP195B, each chip for one of four ADC. As a result timing circuit provides total programmable delay range exceeding period of revolution frequency F_0 with delay step of 10 ps. Measured time jitter of ADC clock is ~10 ps.

Choosing of measured bunch is made by setting of corresponding delay code. Measurement of four bunches is carries out with multiplexing of four delay codes.

Beam position is measured each turn. Turn-by-turn data are recorded to memory (with capacity of 8192 turns) and accumulated in Accumulator (inside FPGA). Accumulated data for specified number of turns form slow acquisition data (SA data). Turn-by-turn data and SA data are transmitted via Ethernet to VEPP-4M Database. SA data for all four bunches are recorded to VEPP-4M Database each second. Turn-by-turn data can be acquired on demand or on trigger after beam injection or beam kicking. The electronics can provide decimated by a factor 2-256 (programmable value) turn-by-turn data. This expands time interval of turn-by-turn data acquisition up to ~2.5 sec.

EXPERIMENTAL TESTS RESULTS

BPM electronics had been tested at test stand and at VEPP-4M storage ring. At test stand Agilent Pulse Generator was used as signal source. During some of the tests at VEPP-4M in order to exclude real beam position instability signal from one of four BPM buttons was split in four lines which was connected to four inputs of BPM electronics.

Five accuracy parameters where measured:

- Resolution of turn-by-turn data
- Resolution of SA data
- Temperature instability of the beam position measurements
- Beam-current dependence
- Dependence of measured beam position of the second bunch (electron bunch for NEP0 and positron bunch for SEP0) on the beam current of the first bunch

Results are given in Table 2. Geometric factors of BPMs NEP0 and SEP0: $K_X \approx 43$ mm, $K_Z \approx 42$ mm.

Table 2: BPM system parameters defining accuracy of measurements for average beam current 1÷10mA ($K_X \approx$ 43 mm, $K_Z \approx 42$ mm).

Resolution of slow measurements (SA data)	μm	3-6
Resolution of turn-by-turn data	μm	15-30
Beam-current dependence	μm	40-50
Error for the second bunch caused by first bunch “tail” when electron and positron beam currents are equal	μm	< 40
Dependence on temperature	μm/°C	4

Dependence of the result on temperature (~4 μm/°C) is caused by three main reasons:

- Inequality of the Low Pass Filters (LPF)
- Inequality of RF switches and attenuators
- Delay instability.

Delay instability is defined by delay instability of the chip MC100EP195B (10-20 ps/°C). For excluding of measurement error caused by delay instability continuous tuning of the programmable delay is carry out. Each 5-10 min delay scanning in the range of 300 ps with step of 10 ps is performed. After completing of the scanning delay code corresponding to maximal signal is found and set.

Resolution of turn-by-turn measurements is defined by two factors:

- ADC noise (~1 bit)
- ADC clock jitter (~10 ps)

ADC clock jitter generates amplitude noise of ADC data. Due to different shapes of pickup signals caused by inequality of the LPF this noise is different for different BPM buttons. This follows to degradation of resolution.

Resolution of turn-by-turn measurements for BPMs NEP0, SEP0 can be evaluated with formula:

$$\sigma \approx 30/I_b + 10 \ \ [\text{microns}],$$

where I_b – is average beam current (for choosing bunch).

Accuracy parameters for other BPMs of VEPP-4M approximately in 2 times better than for NEP0, SEP0 due to smaller geometric factor ($K_X \approx K_Z \approx 20$ mm).

Results of slow measurements (data rate ~1 Hz) at VEPP-4M storage ring with BPM SEP0 are given at Fig.3.

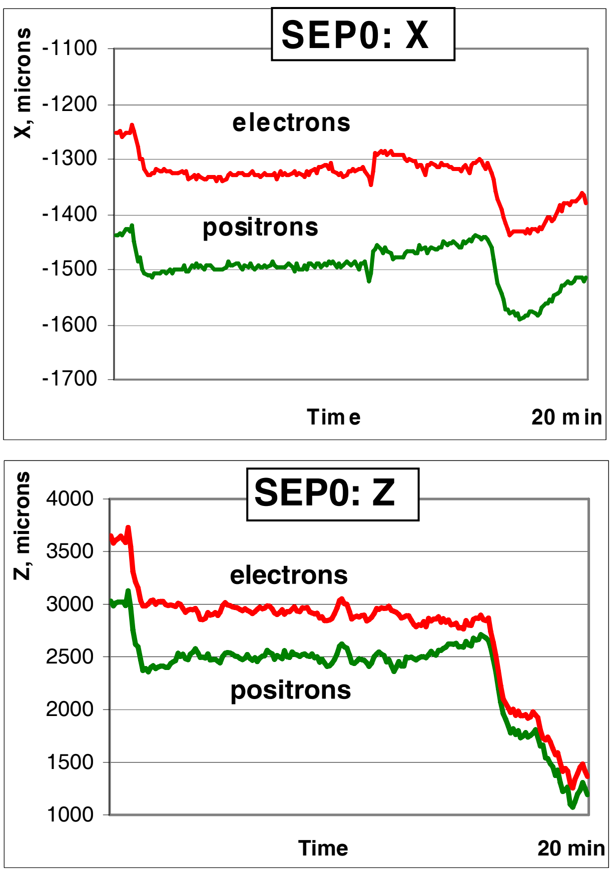

Fig.3. Results of beam position measurements at VEPP-4M with BPM SEP0 (electron and positron beam currents ~1 mA). Upper picture shows horizontal position, lower picture shows vertical position.

Measured positions of two electron bunches (two positron bunches) have good coincidence. Positions of electrons and positrons are different due to separation of the beams.

Results of turn-by-turn measurements after bunch kicking are presented in Fig.4. Turn-by-turn capability of new electronics gives new possibilities of machine study.

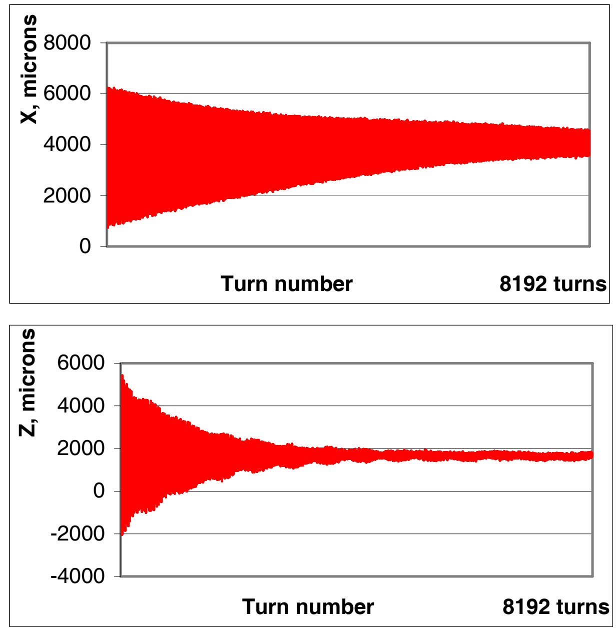

Fig.4. Results of turn-by-turn measurements of electron bunch after kicking with BPM SEP0.

SUMMARY

At present three complete sets of new BPM electronics are manufactured and installed at VEPP-4M storage ring. All software for this electronics has been written. Results achieved satisfy to machine requirements. After some period of time during which new BPM electronics will operate decision about replacement of all old VEPP-4M BPM electronics with new one will be taken.

REFERENCES

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