UPGRADE OF BPM SYSTEM AT VEPP-4M COLLIDER

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Abstract

Developed in BINP wideband beam position monitor (BPM) electronics has been installed at the VEPP-4M electron-positron collider. The VEPP-4M operates with two electron and two positron bunches. Wide bandwidth of new electronics (200 MHz) allows the separate measurements of electron and positron bunches with time interval between bunches up to 18 ns. 18 BPMs located near four meeting points are supplied with new electronics. The electronics can measure the position of each of four bunches. BPM system works at two modes: slow closed orbit measurements and turn-by-turn measurements. We present details of system design and operation.

INTRODUCTION

Basic scenario of high energy experiments at VEPP-4M provides operation with two electron and two positron bunches [1]. Beam position measurements near four meeting places require high time resolution of BPM electronics. Such electronics with analog bandwidth 200 MHz has been developed and tested at BINP [2]. At present 18 BPMs near four meeting places at VEPP-4M are supplied with new electronics. Positions of these BPMs are shown in Fig.1.

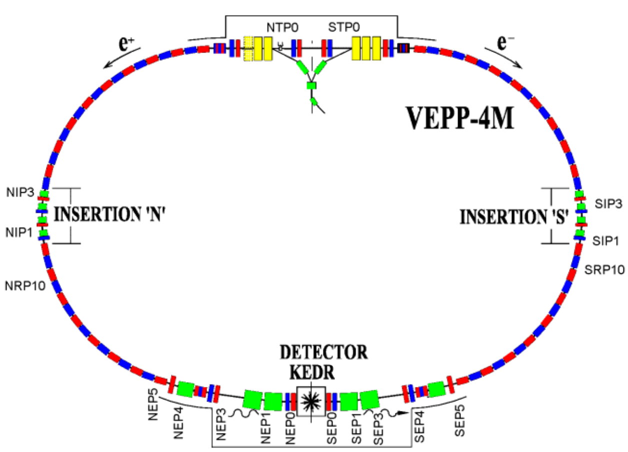

Figure 1: Positions of BPMs with new electronics.

Time intervals between signals of electron bunch and positron bunch for the part of BPMs located close to places of meeting of bunches are given in Table 1.

New electronics design utilizes signal peak sampling with high bandwidth digitizer [2].The main problem for achieving of required accuracy of a few tens microns is separation the BPM signals of electron and positron bunches. This problem has been solved with two ways: increasing of analog bandwidth to 200 MHz and digital compensation of the first bunch signal to second bunch signal. Two sets of new electronics have been successfully worked since 2010 year at BPMs NEP0, SEP0. At the end of 2013 year other 16 BPMs are supplied with new electronics. Special software for new BPM system control on base of EPICS has been developed.

Table 1: Time intervals between signals of electron and positron bunches for the part of BPMs

BPM	Time interval, ns
SIP2	2.27
STP0	18.07
NTP0	18.25
NIP3	20.09
NEP0	22.48
SEP0	22.66
NIP1	26.11
SIP1	26.38

BPM ELECTRONICS DESIGN

Functional diagram of the new BPM electronics is presented in Fig.2.

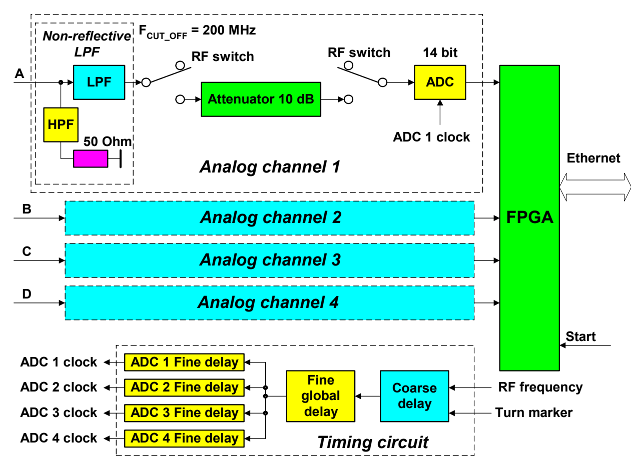

Figure 2: Functional diagram of new BPM electronics.

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

The bandwidth of analog electronics is defined by non-reflective Low Pass Filter (LPF) with cut-off frequency of 200 MHz. Each analog channel has no amplifiers. Linearity and gain temperature stability are defined essentially by ADC.

ISBN 978-3-95450-170-0

Clock frequency of ADC is revolution frequency F_0. Each turn ADC digitizes one of four bunch signals. Timing circuit provides ADC samples 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).

MEASUREMENT ACCURACY

Beam position measurement accuracy is defined by 5 main parameters:

1) Resolution of turn-by-turn data
2) Resolution of slow acquisition (SA) data
3) Dependence of measurement result on temperature
4) Beam-current dependence
5) Dependence of measured beam position of the second bunch on the beam current of the first bunch

Dependence of the result on temperature is caused by two main reasons:

- Inequality of the Low Pass Filters, RF switches and attenuators
- Delay instability.

Delay instability is defined by delay instability of the chips MC100EP195B (10-20 ps/°C). For excluding of measurement error caused by delay instability of different chips delay scanning with step of 10 ps around the signal top in the range ±40 ps is carry out. After completing of the scanning the maximal signal for each channel is chosen.

Beam-current dependence is defined only by ADC nonlinearity because no other active elements are used.

For reducing of measurement error caused by overlapping of electron and positron signals program compensation of the signal "tail" is implemented in the system. "Tail" of the first bunch signal on the peak of second bunch signal for time interval between signals ~18 ns is about 0.5-1%. Such "tail" value without compensation can cause position measurement error of the second bunch up to 0.5 mm. 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. In the Fig.3 signal of the first bunch (result of delay scanning) and its "tail" in the location of second bunch are represented. Dots indicate position of the signal top.

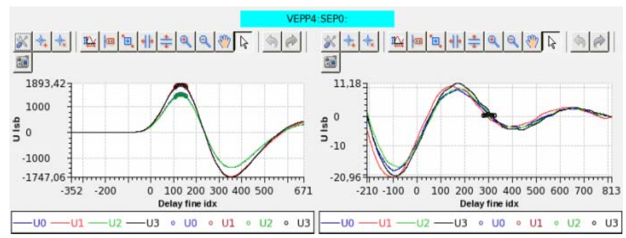

Figure 3: Signal of the first bunch (left picture) and its "tail" in the location of second bunch (right picture).

Such compensation decreases position measurement error of the second bunch caused by "tail" of the first bunch approximately in 10-20 times (besides of BPM SIP2 for which time interval between signals is 2.27 ns).

Accuracy parameters are given in Table 2.

Table 2: BPM system parameters defining accuracy of measurements for 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	40-60
Error for the second bunch caused by first bunch "tail" when electron and positron beam currents are equal (besides of BPM SIP2)	μm	< 100
Dependence on temperature	μm/°C	< 2

BPM CONTROL SYSTEM

Structure of BPM control system is represented in Fig.4.

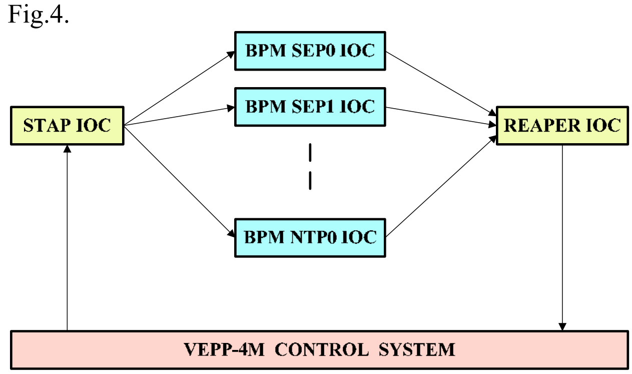

Figure 4: Structure of BPM control system.

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BPM control system is developed on base of EPICS. BPM electronics (BPM Processor module) for each BPM is controlled by its own IOC (Input/Output Controller). For connection of these 18 IOC with existent VEPP-4M Control system special two IOC: STAP IOC and REAPER IOC have been made. Main mode of BPM system operation is periodical (1 time in a sec) orbit measurements. Time of orbit measurement cycle T_{MEAS} is ~600 msec. During the time T_{MEAS} delay scanning in the range ±40 ps with finding of signal maximum is carry out for each of four bunches. Remained 400 msec IOC performs delay scanning (with large delay step) inside the whole separatrix and scanning along all 222 separatrixes. Another mode of operation is external trigger mode with obtaining of turn-by-turn data. Before beam injection or kicking every BPM IOC receives from STAP IOC information about injected beam (or about kicking). BPM IOC stops orbit measurements. Each BPM Processor is waiting of external trigger pulse synchronized with beam injection or kicking. After coming of the external trigger pulse BPM Processor fills turn-by-turn buffer and then started slow orbit measurements. In Fig. 5, 6 turn-by-turn data and its spectrum obtained after injection of the beam are shown.

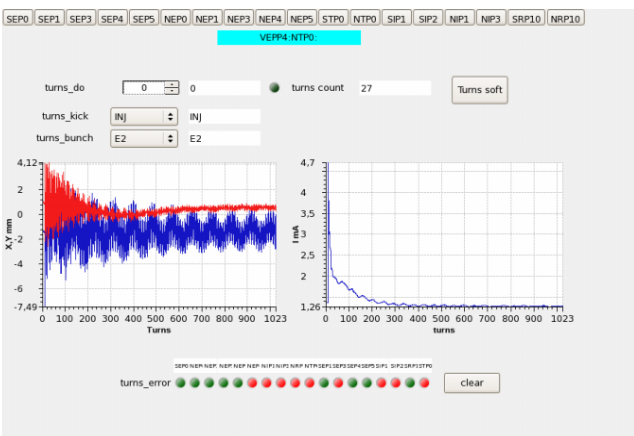

Figure 5: Turn-by-turn beam position measurements obtained after injection of the beam.

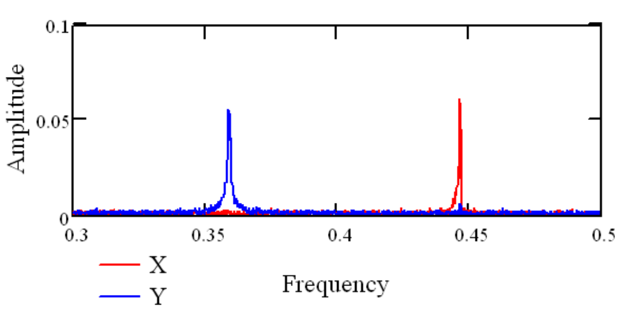

Figure 6: Spectrum of turn-by-turn measurements.

Additional mode of BPM system operation is “Post mortem” mode. In this mode turn-by-turn buffer is filled continuously (works as circular buffer). When beam current becomes lower specified value I_{MIN} writing to the turn-by-turn buffer is stopped. It allows looking of beam behavior before its abrupt losses or death. This mode is actively used for the tuning of VEPP-4M feedback system.

SUMMARY

At present 18 complete sets of new BPM electronics are manufactured and installed at VEPP-4M storage ring. All software for this electronics has been written. New electronics allows separate electron and positron orbit measurements during experiments with colliding beams. Ability of turn-by-turn beam position measurements also facilitates storage ring study and tuning.

ACKNOWLEDGEMENT

The work is supported by the Ministry of Education and Science of the Russian Federation, NSh-4860.2014.2.

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ISBN 978-3-95450-170-0