BEAM POSITION MEASUREMENT SYSTEM OF THE VEPP-5 PREINJECTOR

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Abstract

A new beam position measurement system has been designed, manufactured and tested at the VEPP-5 preinjector. This system measures a position of single electron and positron bunches for each injection cycle with help of stripline Beam Position Monitors (BPMs). New beam position measurement electronics provides more high sensitivity with respect to existing one developed in 1998. The system can measure the position of bunches with 10^8 particles per bunch. The whole dynamic range is from 10^8 to 10^{11} particles per bunch. The resolution of measurements of single bunch is better than 20 µm for 10^{10} particles per bunch. The features of system design, the main parameters and results obtained at the VEPP-5 preinjector are presented.

INTRODUCTION

VEPP-5 preinjector is presently under construction at BINP [1]. Currently operating part of the preinjector includes 300 MeV electron linac, conversion system and part of 510 MeV positron linac with one accelerating structure. The preinjector produces electron and positron bunches with main parameters given in Table 1.

Table 1: Main parameters of the preinjector

Number of electrons in a bunch	$10^{10}\div10^{11}$
Number of positrons in a bunch	$10^{8}\div10^{9}$
Longitudinal bunch size	4 mm
Repetition rate	1÷50 Hz

Beam position measurement system is designed for measurements of horizontal and vertical position of single electron and positron bunches at 14 points of the preinjector for each injection cycle. The measurements are carried out with help of stripline Beam Position Monitors (BPMs). Position of the BPMs at the preinjector are shown in Fig.1.

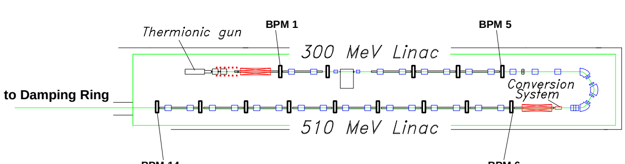

Figure 1: Layout of VEPP-5 preinjector.

Each BPM is placed after corresponding accelerating structure. Nine BPMs installed at positron linac have to measure a position of either electron and positron bunches (depending on preinjector operation mode). Five BPMs installed at electron linac have to measure a position of only electron bunches.

BPM consist of circular vacuum chamber with 25 mm inner diameter and four orthogonally oriented 50-Ohm striplines with length of 150 mm.

All BPM electronics is made in CAMAC standard and located outside the preinjector tunnel. Stripline signals come to the BPM electronics via 50-Ohm double-shielded coaxial cables with length of 20÷40 m.

The structure of the BPM electronics is presented in Fig.2.

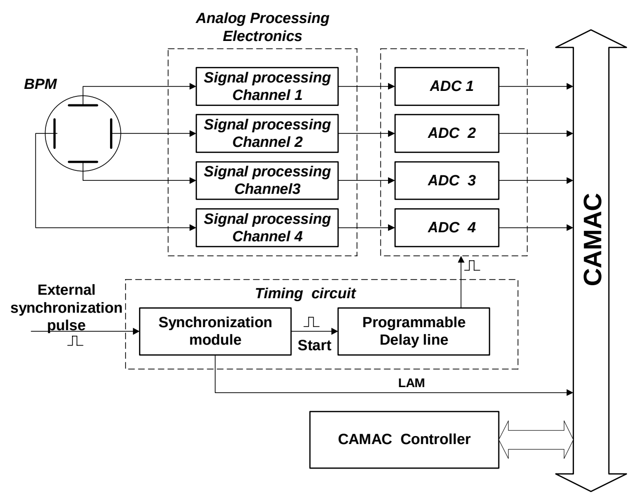

Figure 2: The structure of the BPM electronics.

After analog processing four stripline signals of each BPM are simultaneously sampled with ADC. CAMAC Controller reads the ADC data and calculates the beam position. Timing circuit forms trigger pulses for ADC.

ANALOG PROCESSING

Analog processing electronics consist of a set of the signal processing channels. Processing channels for electron linac BPMs differ from processing channels for positron linac BPMs by using another signal processing method. This is caused by different signal levels. For positron linac BPMs processing electronics treated weak signals of positron bunches the most critical parameter is signal-to-noise ratio. For electron linac BPMs processing electronics treated only intensive signals of electron bunches other parameters such as temperature stability of measurement results are more important .

A functional diagram of the signal processing channel for the electron linac BPM is presented in Fig.3.

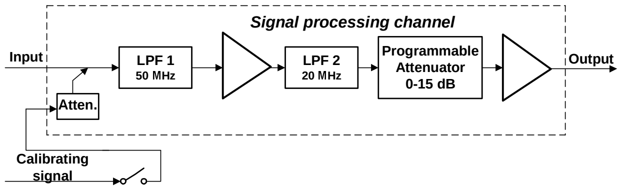

Figure 3: A functional diagram of the electron linac BPM signal processing channel.

Stripline signal has very wide spectrum (more than 10 GHz) due to a small bunch length (~20 ps). Signal processing method is based on using of low frequency part 0÷20 MHz of the signal spectrum. Low Pass Filter LPF1 with cutoff frequency 50 MHz is used for more effective suppression of high frequency components of the signal and noise. It consists of 10 connected in series second order low pass filters with cut-off frequencies distributed in the range from 70 MHz to 3 GHz. This filter provides suppression of the high frequency components of the signal and noise in the frequency range from 200 MHz to 3 GHz in the level more than -50 dB. Programmable attenuator with range of 0÷15 dB and step 1 dB provides operation in dynamic range of electron bunch charge on the level of ~20 dB.

Functional diagram of the signal processing channel for the positron linac BPM is presented in Fig.4.

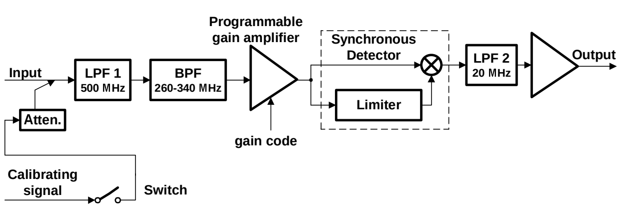

Figure 4: A functional diagram of the positron linac BPM signal processing channel.

In this channel signal processing method is based on using of high frequency part 280÷320 MHz of the signal spectrum. This method was successfully used in beam position measurement system developed in 2001 for electron linear accelerator ILU-10 [2]. A spectral density of the stripline signal has a maximum at the frequency ~500 MHz defined by stripline length (~150 mm). Due to attenuation in the cables this maximum is shifted to the frequencies 300÷350 MHz. Hence using the part of the signal spectrum near ~300 MHz we get maximal signal amplitude for the specified bandwidth.

Low pass filter LPF1 with cut-off frequency 500 MHz is intended for suppression of the high frequency components of the signal and noise. Passing through band pass filter BPF with band 260÷340 MHz the signal come to the programmable gain amplifier which has gain range -10÷35 dB and step 3 dB. Such gain range allows for both electron and positron beam to keep the signal amplitude at the amplifier output at the level ~300 mV. From the output of the programmable gain amplifier the signal comes to the Synchronous detector. As a synchronous detector the broadband multiplier AD8343 of Analog Devices is used [3]. A reference signal is formed with the input signal by limiter which is built into the multiplier. The limiter provides input signal dynamic range of ~30 dB what is sufficient for required linearity of the Synchronous detector. Low pass filter LPF2 with cut-off frequency 20 MHz forms the final shape of the signal. Resulting signal on the channel output is shown in Fig.5.

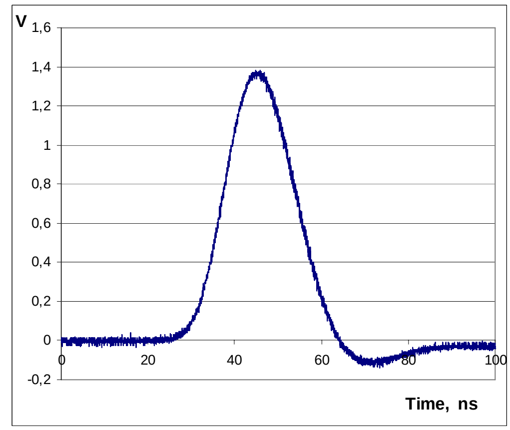

Figure 5: The signal of electron bunch on the positron linac BPM processing channel output.

This method gives the gain in the signal-to-noise ratio (including interferences) compare with previous method approximately in 20 times. It allows working with bunches with number of particles per bunch up to 10^8.

The compensation of BPM electrical zero in all signal processing channels is provided with using of calibrating signals.

ADC AND TIMING CIRCUIT

After analog processing the BPM signals are sampled with 12-bit pipeline-type ADC (ADS807E of the Texas Instrument) [4]. The main problem of using of pipeline-type ADC in the system is impossibility of this type ADC to work with low sampling rate. Minimal sampling rate for ADS807E is 10 kHz whereas injection frequency of the preinjector is 1÷50 Hz. This problem has been solved by means of additional trigger pulses for ADC (Fig.6).

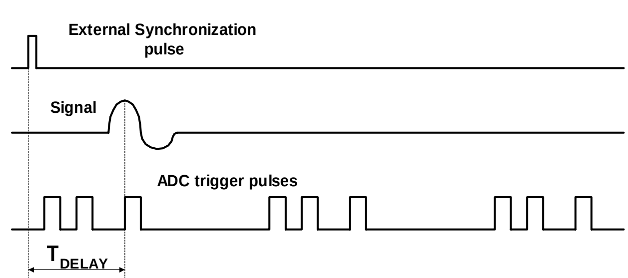

Figure 6: ADC trigger pulses for one injection cycle.

For each injection cycle nine trigger pulses for ADC are generated by the Timing circuit. The first two pulses coming with time interval ~30 ns prepare ADC to signal conversion. By the rising edge of the third pulse BPM signal is stored on the ADC sample-and-hold. The last six pulses are intended for completion of the signal conversion cycle. After passing these nine trigger pulses signal conversion result is placed in ADC register and then is read by CAMAC crate Controller.

For optimal signal sampling the rising edge of the third pulse has to correspond to the signal maximum with accuracy about 0.5 ns. This is provided by Programmable Delay line. External synchronization pulse delayed for a fixed time from beam injection moment come to the Delay line input. Delay line provides time delay of this pulse in the range 60÷800 ns with minimal step of 0.25 ns. This range covers all differences in signal delays connected with different cable lengths and different time of bunch passing from the gun to BPMs. A time jitter of the Delay line output pulse is less than 50 ps.

ACCURACY

Temperature instability of the beam position measurements

Temperature instability of the processing channels gains and time delays formed with Delay lines leads to temperature instability of the beam position measurements. 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. Experimental examination gave the following results:

- Temperature instability of the beam position measurements for the electron linac BPMs less than 1 µm/°C
- Temperature instability of the beam position measurements for the positron linac BPMs less than 3.5 µm/°C

Beam position measurements error caused by noise and interferences

This error is caused by:

- Noise of the signal processing channels
- Interferences in BPMs and cables connecting BPMs with processing electronics
- Quantization noise of ADC
- Time jitter of the ADC trigger pulses

Experimental investigations have shown that major contribution to this error is brought by interferences in the cables connecting BPMs with processing electronics. Some measures have been made to reduce these interferences. One of them is using of double-shielded coaxial cables. A ratio of the signal amplitude to interference RMS voltage for electron linac BPMs for electron beam with 1.5×10^{10} particles per bunch is ~200. This ratio for positron linac BPMs for positron beam with 1.3×10^{8} particles per bunch is ~40. Measured for single bunch with 1.5×10^{10} particles per bunch RMS beam position measurement error is ~20 µm for electron linac BPMs. Measured for single bunch with 1.3×10^{8} particles per bunch RMS beam position measurement error is ~100 µm for positron linac BPMs.

Dependence of the measured beam position on the bunch charge.

The main reason of this dependence is nonlinearity of programmable attenuators, amplifiers and multipliers. Measurements performed with beam have shown that for 30 dB range of bunch charge variation of the measured beam position not more than 12÷15 µm for electron linac BPMs and 30÷35 µm for positron linac BPMs.

SUMMARY

In April 2006 new electronics of the beam position measurements system for six BPMs was put in operation at the VEPP-5 preinjector. The system enables position measurements of both electron and positron beams with number of particles per bunch $10^{8}\div10^{11}$. Results of the measurements are used for beam trajectory aligning. At the end of 2006 all the BPMs will be completely put into operation.

REFERENCES

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