THE VEPP4-M TRANSVERSE BUNCH-BY-BUNCH FEEDBACK SYSTEM

V.P. Cherepanov, E.N. Dementev, A.S. Medvedko, V.V. Smaluk, D.P. Sukhanov
Budker Institute of Nuclear Physics, Novosibirsk, Russia

Abstract

Transverse beam instabilities, such as fast head-tail and coupled-bunch instability, result in beam quality deterioration and limit beam intensity in storage rings. For the VEPP-4M electron-positron collider, bunch current is limited by transverse mode coupling instability (TMCI or fast head-tail). For suppression of any excited transverse mode of the beam oscillation, a broadband bunch-by-bunch digital feedback system has been developed. The system description and first beam measurement results are presented.

GENERAL CONCEPT

A list of the VEPP-4M accelerator parameters and parameters of the transverse feedback system are presented in Table 1.

Table 1: The VEPP-4M and the feedback parameters.

Parameter	**Value**
Circumference, P	366*m*
Revolution frequency, f_0	818.936*kHz*
RF frequency, f_{RF}	181*MHz*
RF harmonic, q	222
Injection energy, E	1.8*GeV*
Experiment energy, E_b	5.2*GeV*
Betatron tunes, ν_x/ν_y	8.56/7.58
Synchrotron tune, ν_s	0.006 ÷ 0.030
Radiation damping times, $\tau_x/\tau_y/\tau_s$	35/70/70*ms*
R.m.s. bunch length, σ_s	2.5 ÷ 12*cm*
Average bunch current, I_b	40*mA*
Number of strip-line BPMs	2
BPM aperture, a_{BPM}	12*cm*
BPM length, L_{BPM}	40*cm*
BPM-to-BPM vertical betatron phase advance, ϕ_y	1.66
Number of kickers	4
Upper frequency limit	20*MHz*
Pulse power per kicker, P_k	800*W*

The system configuration is determined by necessity to suppress the vertical TMC instability in the 2×2-bunch VEPP-4M operation mode. Design value of bunch current is 40*mA*, beam energy range is 1.8÷5.2*GeV*. With regard to experience of other facilities (e.g. [1]), a digital scheme of the feedback system has been chosen to provide the system flexibility and possible functionality expansion. The major task of the system is to measure and to suppress transverse oscillation of each bunch independently. In addition, the system can be used as a powerful diagnostic tool.

Figure 1 shows block-diagram of the feedback system digital part. The hardware has been selected with regard to the VEPP-4M equipment and available budget. The same set of beam position monitors (BPMs) and kickers is used both for the electron and for the positron bunches, but with separated unified electronics.

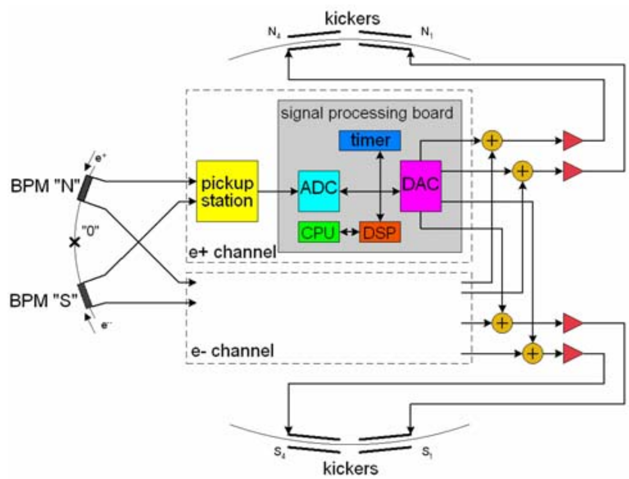

Figure 1: Feedback system block diagram.

Two 45*m*-distanced strip-line beam position monitors are placed symmetrically with respect to the axis passing through the beam interaction points. The BPM signals, passing through a sum-difference circuit, come to the pickup station. Pickup station forms an analogous signal of 30*MHz* frequency band, proportional to the beam position. This signal comes to the signal processing board and digitized by the ADC. Then the beam position data are processed by the DSP, which calculates kick parameters required for the oscillation damping. The kick signal formed by the DSP is converted in the digital-to-analog converter, and after amplification by means of the power amplifiers comes to the kickers.

FRONT-END ELECTRONICS

Block-diagram of the feedback system front-end electronics is presented in Figure 2. Beam position monitor consists of four strip-lines of 40*cm* length and of 50*Ω* characteristic impedance. The strip-lines are placed symmetrically with the rotation by 45 degree about median plane. Directivity coefficient of the BPM is about

30*dB*. Time-division of signals induced by the electron and positron bunches gives an opportunity to use two identical feed back circuits both for the electron and for the positron bunches, with the input signals taken from the proper side of a stripline.

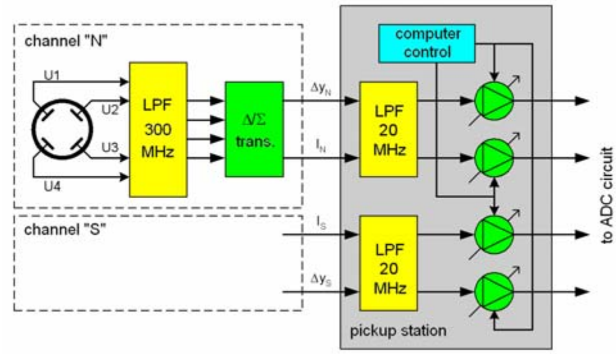

Figure 2: Front-end electronics.

To match the front-end electronics with the broad-band strip-line BPM, a broadband low-pass filter with the 50 Ω input impedance in the 7*GHz* range, and with the pass band of 300*MHz*, is used. Four strip-line signals from the filter output comes to the sum-difference circuit forming two signals proportional to the horizontal and vertical beam positions, and third one proportional to the beam intensity. Each signal processing channel consists of the matching input low-pass filter and 6-step controllable variable gain amplifier with –30 ÷ +20*dB* gain range providing wide dynamic range of the input signal amplitude.

Wide pass band of the front-end electronics allows future use of the system in all possible modes of the VEPP-4M operation including multi-bunch mode with successive RF-bucket filling.

At present time, the VEPP-4M collider operates in a mode of 2 electron and 2 positron equally-spaced bunches. For this operation mode, front-end electronics with the pass band of 20*MHz* is used. Only two channels for processing of the vertical beam position and beam intensity is now implemented to the pickup-stations. Horizontal beam position signal is not processed because the TMC instability threshold for horizontal motion is much higher than the working beam current. Restriction of the pass band allows us to reduce cost of the electronics using less expensive electronic components.

DIGITAL SIGNAL PROCESSING

Digital part of the system consists of two separate boards connected one to another by special interface buses. Digital filtering of the measured data and other functions of data processing are performed by DSP Starter Kit (DSK) made by Spectrum Digital and based on the signal processor TMS320C6713 with 225*MHz* clock rate. Big memory capacity of 2M×32*bit*, unlimited access to the processor via expansion bus and high exchange rate (90*MHz*) of the memory bus fulfill completely the feedback system requirements.

The signal digitizing circuit includes four pipeline ADC AD807 (see Table 2) matched with the 50*Ω* signal path. The ADCs are used to measure vertical position and intensity of the beam at both BPMs.

Table 2: AD807 parameters

Parameter	**Value**
Digit capacity	12*bit*
Conversion time	120*ns*
Sampling frequency	53*MHz*
Input impedance	1.25*MΩ*, 3*pF*
Pass band	270*MHz*

Each ADC processes in turn the signals of two bunches and puts the data into its buffer memory. Upon completion of a measurement cycle, the ADC generates an interrupt and transfers the data to the DSP board memory. Kick data produced by the DSP come to the wave-shaping circuit and is converted to an analog signal by four digital-to-analog converters AD9749 (see Table 3), one per kicker.

Table 3: AD9749 parameters

Parameter	**Value**
Digit capacity	12*bit*
Rise time	11*ns*
Front time	2*ns*

In addition, the signal digitizing circuit includes a timer to synchronize with time of flight of each bunch. Basic elements of the timer are time-delay circuits with 13-bit control word and 0.25*ns* time resolution.

Kick signals for the electron and positron bunches formed by proper signal digitizing circuit are summarized for each kicker and come to the power electronics input.

POWER ELECTRONICS

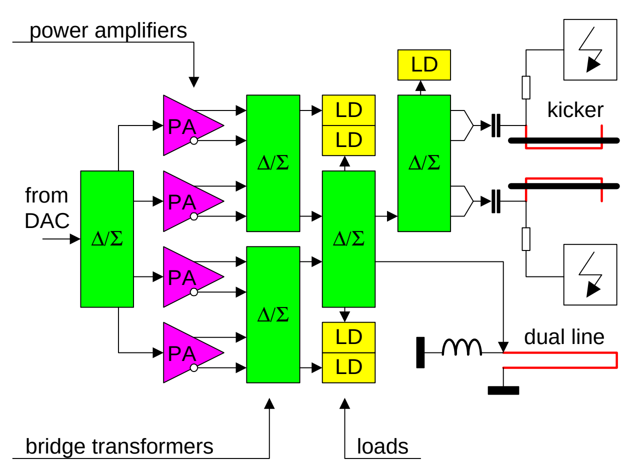

Figure 3: Power electronics for one kicker.

Two groups of four electrostatic separators each, placed symmetrically in the VEPP-4M half-rings, are used as the kickers (see Figure 1). One separator is a pair of horizontal 1.9*m*-long plates with characteristic impedance of 25Ω.

Directional property of the kicker plates allows us to use the same kickers both for the electron and for positron bunches. Block diagram of the power electronics is shown in Figure 3. Kick signals are amplified by 4 video pulse power amplifiers with total pulse power of 1600*W* in the 0.5÷30*MHz* band. To suppress beam oscillation, the amplified kick signals come through a sum-differential transformer to the kicker input.

BEAM MEASUREMENT

At present, all the electronics for one feedback channel is designed, produced and installed at the VEPP-4M. A test beam measurements have been done to check the system functionality, to estimate its sensitivity and spatial resolution.

For spatial calibration and resolution estimation, a local bump of beam orbit was created at the section included the strip-line BPM and two neighbor calibrated button-electrode BPMs included in the VEPP-4M orbit measurement system. We can calibrate the strip-line BPM using the bump height measured by the orbit BPMs as a reference. Thus, the strip-line BPM spatial coefficient is 90*mm*.

Statistical analysis of the data measured gives information of turn-by-turn and average spatial resolution of the front-end electronics. Turn-by-turn r.m.s. resolution measured by this way is 80μm for a beam of 10^{10} particles.

To estimate the system sensitivity, a measurement of coherent betatron oscillation of a low-intensity beam was performed. The beam oscillation was excited by a short kick of 0.5*kV* amplitude, beam current was only 40μA. Figure 4 shows turn-by-turn beam position measured for 4096 turns after the kick (upper plot) and amplitude spectrum of the oscillation measured (lower plot). One can see that in spite of quite low beam intensity and small oscillation amplitude, there is noticeable vertical betatron peak ν_y in the spectrum.

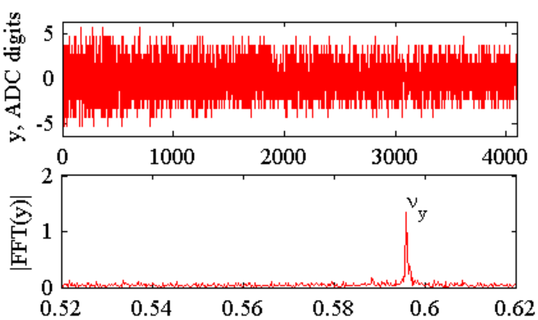

Figure 4: Betatron oscillation of a low-intensity beam.

Another example of measurement of coherent betatron oscillation is shown in Figure 5. In this case, the kick amplitude was of 1*kV* and the beam current was of 2.8*mA*. One can see in the spectrum horizontal ν_x and vertical ν_y betatron peaks. The vertical peak is broadened because of the fast damping of the oscillation. Despite the vertical kick, the horizontal betatron peak appears due to the coupling. There is also a synchro-betatron satellite $\nu_y - \nu_s$ caused by the machine chromaticity.

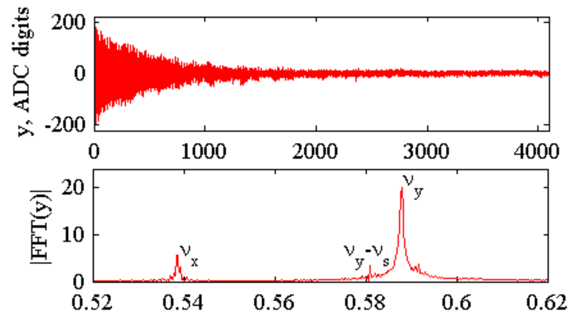

Figure 5: Fast damping of betatron oscillation.

REFERENCES

[1] D. Bulfone et al., Design Considerations for the ELETTRA Transverse Multi-Bunch Feedback, PAC'99, New York, 1999.