# BROADBAND DIGITAL FEEDBACK SYSTEM FOR THE VEPP-4M ELECTRON-POSITRON COLLIDER

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*Abstract*

To suppress the transverse instability, which is the main reason of beam current limitation at the VEPP-4M electron-positron collider, a digital bunch-by-bunch feedback system has been developed, installed and commissioned. The real-time data processing is performed by a special code running in an FPGA module. This provides high efficiency and flexibility of the system. During the system commissioning, a 3-times increase of the beam current injected into VEPP-4M was reached. The system design and data processing algorithms are described, the commissioning results are presented.

## INTRODUCTION

The VEPP-4M electron-positron collider is designed for high-energy physics experiments with the KEDR detector and is also used as a synchrotron light source. General parameters of VEPP-4M are listed in Table 1. At the injection energy, the VEPP-4M beam current is limited by the transverse mode coupling (fast head-tail) instability caused by the beam interaction with the broad-band coupling impedance.

Table 1: Parameters of the VEPP-4M

| | |
|---|---|
| Circumference | 366.075 m |
| Revolution frequency | 818.924 kHz |
| Beam energy | 1.5 – 5.5 GeV |
| Design bunch current | 40 mA |
| Number of bunches | $2e^{-}$ x $2e^{+}$ |
| RF frequency | 181.10165 MHz |
| Harmonic number | 222 |
| Betatron tunes, horizontal/vertical | 8.54/7.58 |

For bunch-by-bunch suppression of the vertical beam oscillations, a fast feedback system was designed and installed at VEPP-4M [1, 2]. The system configuration and parameters have been determined by the requirement of effective suppression of transverse beam instability when the VEPP-4M is operating with two electron and two positron bunches of 40 mA per bunch average current at the injection energy of 1.5 – 1.85 GeV. To increase the system flexibility and for future functionality enhancement, a digital feedback scheme has been chosen.

## TRANSVERSE FEEDBACK

Shown in Fig. 1 is the transverse feedback system block diagram. The same kickers are used to correct both electron and positron bunches trajectories, but electronic circuits are individual, although of the same type.

A strip line pickup is used as beam position monitor. The pickup-electrode signals are processed by the analog front-end electronics, consisting of low-pass filters, hybrid networks and buffer amplifiers. Analog beam position signals formed by front-end electronics are then registered by the digital board ADCs.

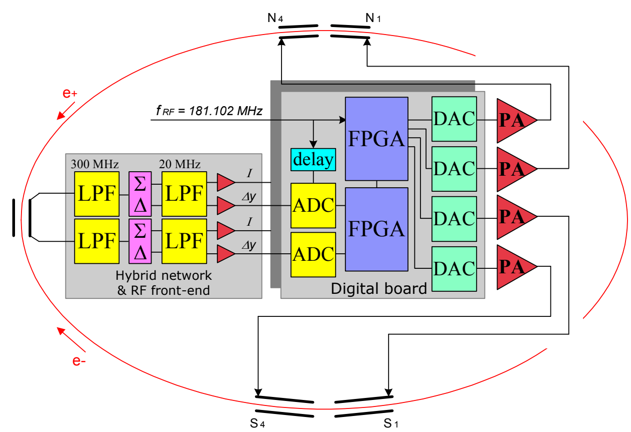


Figure 1: Block diagram of the VEPP-4M transverse digital bunch-by-bunch feedback system.

The main feature of the present system configuration compared with the previous version [1] is the usage of a new digital board, based on FPGA instead of a digital signal processor. The digital board includes two 12-bit 210 MSPS pipeline ADCs for sampling oscillation signals of electron and positron bunches. A dual-channel programmable clock delay allows tuning the ADC clock phase to improve the measurement accuracy of beam signals.

The basic task of the two Altera Cyclone III FPGAs is calculation of the correction kick values using the measured signals of bunch oscillation. The correction signals are then sent to the DACs driving the kickers. FIR filters are used to reject the DC component of the beam position signals caused by the equilibrium orbit and to provide a correct phase shift of all kick signals with respect to the oscillation phase of the same bunch, when it passes through the kicker. Since the fractional part of betatron tune is close to 0.5, complex digital filters for the tune variation compensation are not applicable. The simplest 2-tap FIR filter successfully provides DC rejection together with the correct phase and gain, which are suitable for the whole working range of frequencies. Amplitude and phase characteristics of the filter are shown in Fig. 2, as one can see the range of permissible deviation of betatron tune (fractional part) is 0.56 – 0.62.

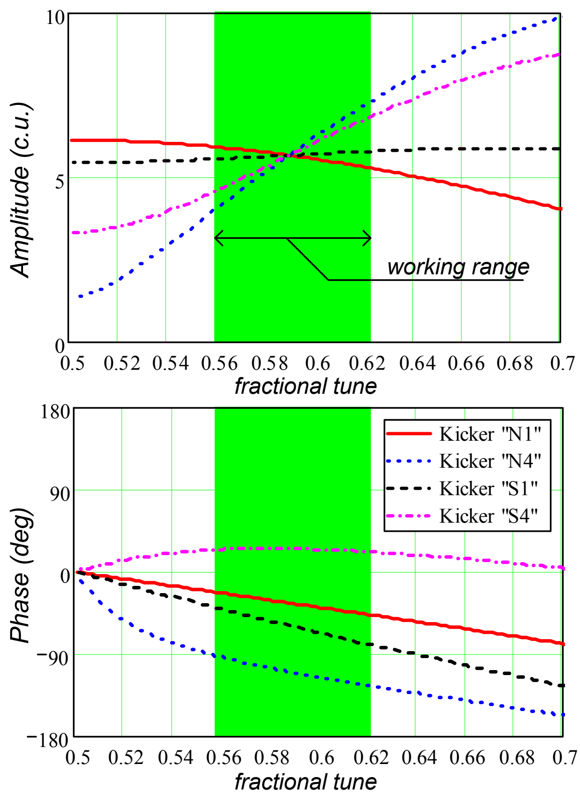


Figure 2: 2-tap FIR filter frequency response.

The correction signals generated by the FPGA are then sent with appropriate delays to four 10-bit 275 MSPS DACs driving the kickers through power amplifiers. These high-performance DACs are able not only to satisfy the requirements for VEPP-4M operation with two electron and two positron bunches, but also provide the opportunity of working with larger number of bunches in future.

Kick signals are amplified by four video pulse power amplifiers with total pulse power of 1600 W in the 0.5÷30 MHz band. The amplifiers detailed description is given in [3]. To suppress beam oscillations, the amplified kick signals come through a sum-differential transformer to the kicker input.

Four stripline-based beam separators located pairwise in opposite semi-rings are used as kickers. Each kicker consists of two horizontal plates 1.9 m long with 25 Ohm impedance. Directional property of the kicker plates allows using the same kickers both for the electron and positron bunches.

The feedback software control as well as beam oscillations monitoring is implemented by means of Ethernet network. For these purposes transceivers are provided in the digital board and UDP/IP stack is implemented in FPGA.

## COMMISSIONING RESULTS

The transverse feedback system commissioning with the new digital board started in 2010. Some work is currently being made to improve the digital feedback flexibility and enhance functionality.

### *Suppression of Betatron Oscillations*

During the commissioning, the system was tested in various operational modes. According to these tests, the suppression of the vertical betatron tune peak in the oscillation spectrum was clearly observed.

The vertical oscillations of electron bunch, excited after injection to VEPP-4M with transverse feedback off are shown in Fig. 3 (a). The right peak in the spectrum shown is of vertical betatron tune and the left peak is of horizontal betatron tune. As one can see, with feedback on vertical tune peak is fully suppressed within less than 50 turns (see Fig. 3 (b)).

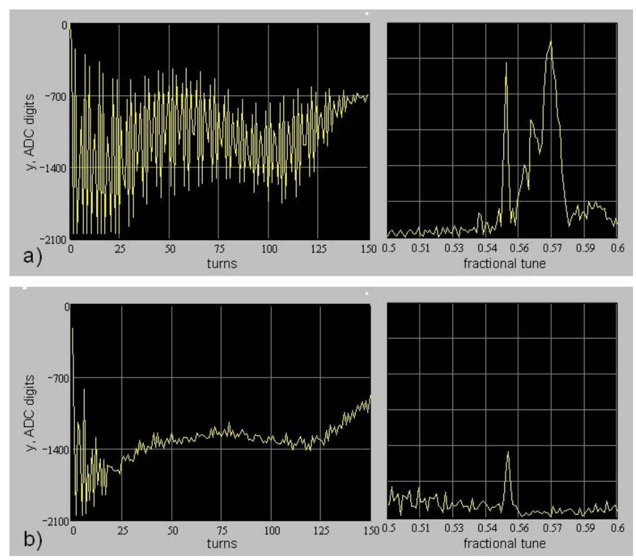


Figure 3: Beam injection: (a) 11 mA electron bunch with feedback off, (b) 11 mA electron bunch with feedback on.

During the tests, a beam current of 27 mA in single electron bunch was successfully injected with the feedback support. The total beam current achieved for two electron beams was 40 mA. As for positrons, the beam current was limited to 7-8 mA per bunch due to poor injector performance.

However, it's worth mentioning that without transverse feedback the beam current injected into VEPP-4M was limited to about 5 mA per bunch, which corresponds to the fast head-tail instability threshold.

### *Measurement of Betatron Tune*

Another tool being important for the feedback system stable operation is a vertical betatron tune measurement algorithm followed by adjusting the feedback frequency response. During the energy ramping from 1.8 to 5.2 GeV the betatron tunes may vary due to dynamic mismatch of the magnet lattice elements. The algorithm implemented was as follows. The digital board DACs are used to excite beam oscillations in specified frequency band for a short time to measure the vertical betatron frequency. During the excitation, the oscillation is measured and its spectrum is calculated (for this purpose, the integer FFT algorithm based on the fast Hartley transform was implemented in the FPGA) and the vertical betatron tune peak is found. The oscillation is excited in the range of betatron tune (fractional part) from 0.56 to 0.65. To avoid instability during the excitation, suppression of any oscillations exceeding a predefined level is enabled.

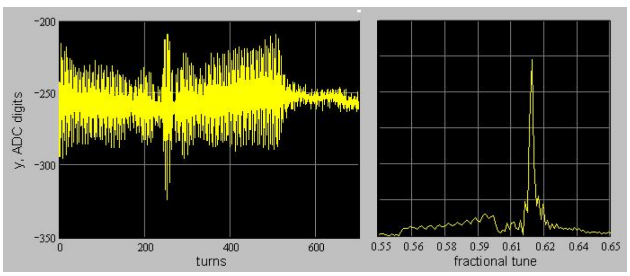


Figure 4: Beam oscillation excited by the feedback system for tune measurement.

Shown on Fig. 4 is the vertical beam oscillation during the tune measurement process. The oscillation spectrum, calculated by FPGA, is shown as well. The vertical betatron tune measurement results are consistent with the data of other systems of VEPP-4M to within a few hundredths of a percent.

## SUMMARY

According to commissioning and operational results, efficiency of the transverse bunch-by-bunch digital feedback system has been proven during the VEPP-4M operation with two electron and two positron bunches. The system developed is able to suppress vertical instability of an injected beam and provides an opportunity of the beam stabilization during VEPP-4M energy ramping. The further plans include additional system improvement as well as modification of FPGA algorithms to support up to 8 bunches as it is useful in some experiments with synchrotron radiation performed in the VEPP-4M.

## REFERENCES


[1] E. N. Dement'ev et al., "Commissioning Feedback Systems at VEPP-4M Electron–Positron Collider", Physics of Particles and Nuclei Letters, Vol. 7 (2010), No. 7, pp. 466–472.

[2] V.P. Cherepanov, V.V. Oreshonok , V.V. Smaluk, D.P. Sukhanov, RuPAC'10, Protvino, Russia, September 2010, WEPSB031, p. 236 (2010).

[3] V.P. Cherepanov, "Video Pulse Power Amplifier for Accelerator Technology Applications", RuPAC'06, Novosibirsk, Russia, September 2006, MODP07, p. 217 (2006).