TRANSVERSE BUNCH-BY-BUNCH DIGITAL FEEDBACK FOR THE VEPP-4M COLLIDER

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Abstract

The coupled-bunch instability is the base reason of the operating current limitation at the VEPP-4M electron-positron collider. For suppression any excited transverse mode of oscillation of the accumulated beam, the transverse bunch-by-bunch digital feedback has been installed. The paper reports on the current design and status of the feedback system. The available diagnostic tools and latest operational results and beam measurements is given.

INTRODUCTION

The single-bunch beam current in the electron–positron collider VEPP-4M at the injection energy of 1.8 GeV is limited by the instability of vertical betatron oscillations caused by the transverse mode coupling or fast head-tail. At the present time, use of the consistent bunch-by-bunch scheme for the transverse feedback systems is a conventional method for suppression of any excited transverse mode of beam oscillation [1, 2].

The digital feedback system to suppress the vertical betatron oscillation of each bunch independently has been developed for VEPP-4M.

Table 1: The general parameters of the VEPP-4M collider and feedback system

Parameter	Value
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, n_x/n_y	8.56/7.58
Design bunch current, I_b	40 mA
Number of bunches	$2e^- \times 2e^+$
Number of strip-line BPMs used	1
Number of kickers	4
Feedback system bandwidth	20 MHz
Power per kicker, P_k	400 W

Figure 1 shows the block-diagram of feedback system. The system configuration and specifications are mainly determined by necessity to suppress the TMC instability in the 2×2-bunch VEPP-4M operation mode. The beam position signals from strip-line BPM are prepared by the input front-end electronics, come to the signal processing board and are then digitized by the ADC. The kick signals formed by the digital board are converted by the DAC and, after amplification by the power amplifiers, come to the kickers.

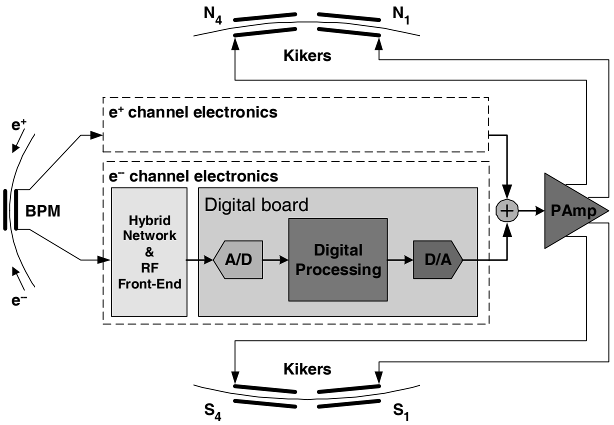

Figure 1: Block diagram of the Transverse Bunch-by-bunch Feedback system.

A more detailed description of the front-end electronics and of the power output devices is given in [3, 4]. Basic features of the presented system are the different digital part and use of the only BPM.

DIGITAL SIGNAL PROCESSING

Additional requirements for flexibility and availability of diagnostic tools have led to the development of the new digital board. The main feature of this device is use of an FPGA for the signal processing and controls (see Figure 2). The availability of several independent pipeline operations allows as to use the bunch-by-bunch feedback option and to organize different processing arrangements. This makes possible to fulfill completely the feedback system requirements and to use various diagnostic tools: detection of beam position and other possible variations of the beam parameters in real-time, betatron oscillations spectral analysis, etc. In addition, the device was developed for use in multi-bunch operation mode to satisfy the higher technical requirements in the future.

General Layout

The signal digitizing circuit includes two 12 bit pipeline ADC ADS5527, which are used to measure vertical position and intensity of the beam. Two Altera Cyclone III receive the beam position data from ADC, make DC rejection and necessary phase shift using the digital FIR filter. The correction kick data produced by the FPGA come to the wave-shaping circuit and is converted to an analog signal by four 12 bit digital-to-analog converters TI DAC5652, one per kicker.

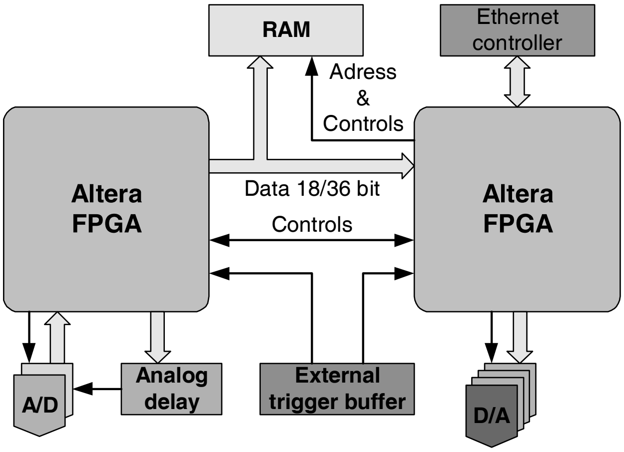

Figure 2: Layout and data stream for the digital board.

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.

The signal digitizing circuit includes digital and analog delays to synchronize the digital board operation with time of flight of each bunch through pickup and kickers.

Application of additional memory is caused by desire of temporary accumulation of the various measured and calculated data to transfer them through a network to a workstation for further analysis later. In addition, the Ethernet network is used for operative control.

Table 2: The digital board specifications

Parameter	Value
Sampling Rate	180 MHz
ADC/DAC resolution	12/10 bits
Input&Output Coupling / Impedance	AC/50 Ohm
Input/Output Analog Bandwidth	800/120 MHz
Analog&Digital Clock Shift	More 2 us
Step of Clock Programmable Shift	11 ps
Total Jitter	20 ps
Clock/Trigger signal	Diff.&CMOS
Memory	9 Mbit

Digital Filter

The basic task of the FPGA software is the calculation of the correction kick value based on the measured bunch oscillation signals. In order to reject the DC equilibrium orbit signal from the BPM and to shift all kick signals by the $\pi/2$ betatron oscillation phase with respect to the phase signal of the same bunch when it passes through the appropriate kicker, FIR filters are used. These filters provide a necessary phase irrespective of the kicker positions in the ring.

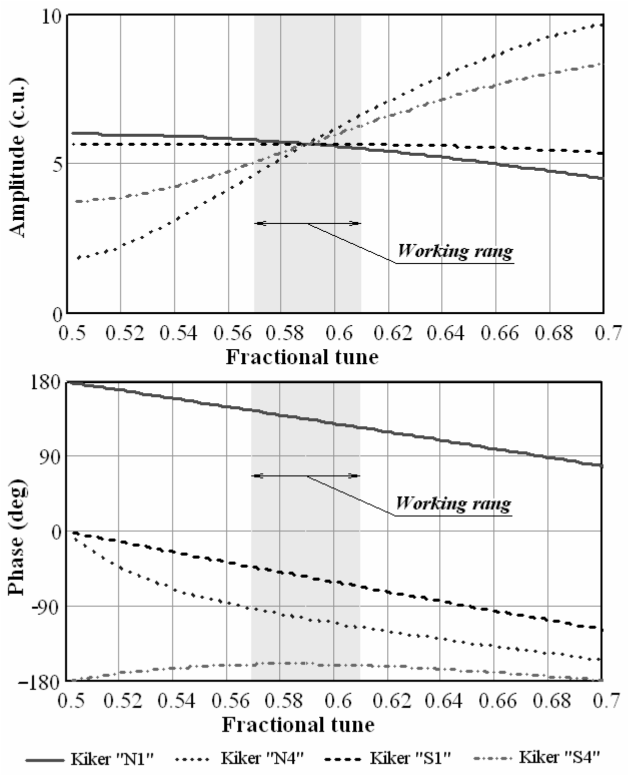

Figure 3: Transfer function of the 2-tap FIR filter.

During the energy ramping from 1.8 to 5.2 GeV the betatron tunes can vary due to dynamic mismatch of the magnet lattice elements. Since the fractional part of betatron tune is close to 0.5, complex digital filters for the tune variation compensation, which was made, for example, at ELETTRA [1], are not applicable. The simplest 2-type FIR filter successfully provides DC rejection and the appropriate phase and gain in all working frequency range. Figure 3 shows the amplitude and phase characteristics of the filter, as one can see the range of permissible deviation of betatron tune (fractional part) is 0.57 – 0.61.

OPERATIONAL RESULTS

The new digital board is integrated into the transverse feedback system, which is successfully operates at the VEPP-4M electron-positron collider.

Figure 4 shows the turn-by-turn plots of current (left plot, top), vertical (left plot, middle), and horizontal (left plot, bottom) coordinates of the injected beam measured by the pickup in 512 turns; the figure also shows the current remaining after 512 turns I_{512}. The top plot on the right shows the spectrum of vertical beam oscillation, and the bottom plot on the right shows the spectrum of horizontal beam oscillation. It can be seen that the feedback system suppresses vertical oscillation in less than 100 turns, and current losses are not large.

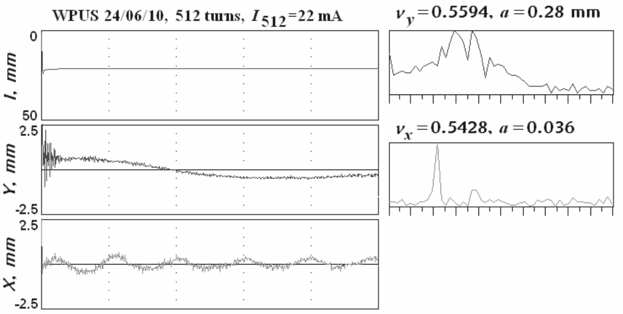

Figure 4: Beam injection with closed feedback system.

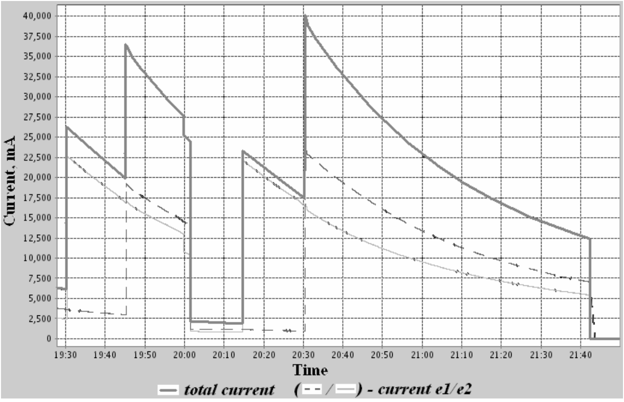

Figure 5: Time diagram of the VEPP-4M captured beam currents.

Figure 5 shows the current of separate bunches and the total current in the two electron bunch operation mode.

At present time, for more accurate work of the feedback system during energy ramping, diagnostic tools are developed to measure possible variations of the betatron tune in real-time with closed feedback.

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