Digital Feedback System for Orbit Stabilization at the SIBERIA- 2 Light Source

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Abstract

An implementation of global/local feedback system on the 2.5 GeV SIBERIA-2 storage ring is reported. This project is based on parallel data handling in BPM modules and VME crate for communication and magnet correction control. We present special own-made beam position monitor data acquisition module, which includes ADC, DSP TMS320C31 and high-speed serial link. Paper describes software for simulation of feedback control and digital filtration. The motivation, approaches, results and future plans of this project are discussed.

1 INTRODUCTION

In the design of a high-brightness light source, the electron beam emittance is a parameter of prime importance. Any vibrations that lead to distortions in the closed orbit will result in a larger effective emittance. Together with the brightness reduction, unwanted beam motion that causes the incident light position and angle to variy can degrade the experimental advantages of synchrotron radiation.

SIBERIA-2 is a dedicated light source with an electron energy of 2.5 GeV that was developed by the Budker Institute of Nuclear Physics (Novosibirsk) for the Kurchatov Institute (Moscow) and commissioned at the beginning of 1995 in Moscow [1]. The typical beam stability tolerance for modern light sources is about 10% of the beam size and divergence. For SIBERIA-2 this criterion means that we have to position the beam orbit accurately to the 10-15 μm level. An active feedback system, which detects and counteracts undesired beam fluctuations by correcting the closed orbit, is essential to achieve the necessary beam stability [2]. Potential sources driving the variation in electron beam are: ground vibrations, magnet power supply ripple and thermal drift. A specific feature of the low-emittance light source magnetic lattice is the significant amplification factor for any mechanical vibrations of the magnetic elements. For example, for SIBERIA-2 due to the strong focusing, quadrupole lens motion will transfer to beam motion with the amplification factor (rms) $M_{x,z} \simeq 30$. To stabilize the orbit oscillations, a fast digital feedback system is proposed. A single module composed of a DSP (digital signal processor) board together with 4-channel 10-bit ADCs and 12-bit DACs has been developed. The module was linked to a standard pick-up station and the beam measurements which are necessary to design the feedback system (such as the low-frequency beam noise spectrum, system transfer function, etc.) were performed. A reference model that includes the real measurement results was prepared to test the beam stabilizing system. Using this model, a classical PID algorithm was implemented and a significant reduction of modelling beam motion was achieved in a frequency bandwidth up to 60 Hz.

2 LOCAL FEEDBACK SYSTEM

The local feedback system is intended to stabilize the beam at a single orbit point (where the radiation is emitted) without disturbance of the remainder of the beam trajectory. We use digital signal processing to avoid the problems connected with analog circuits, such as drift, offset, etc. and to increase the flexibility of the system. The local feedback system consists of a fast digital controller, an existing pick-up station, three steering magnets and power supplies. A block diagram of the feedback system is shown in Fig.1. The controller is a DSP system which is composed of a 32-bit floating point TMS320C31 board, a 4-channel ADC board with 10-bit resolution and a 3-channel DAC board with 12-bit resolution. The sampling rate of the system is 2.5 kHz. The sampling period may be divided into three parts. During the first part the ADC provides the measurements of 600 turns of the beam (414 nsec per turn) and stores the data into the memory. Then the TMS computes the average beam centroid coordinates for the vertical and horizontal planes. This procedure provides us with a significant electronics noise reduction and enhanced accuracy in comparison with a single ADC reading. During the third part the output signal is produced using the PID controller and the system transfer function, and the steering magnets make a closed orbit bump to cancel the beam position displacement detected by the monitor. A digital bandlimiting filter (BLF) is inserted into the loop before PID controller for stability reasons.

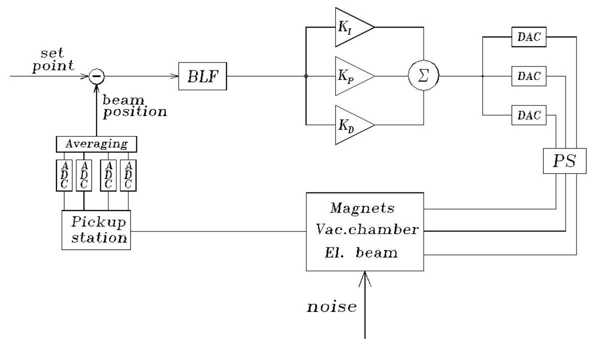

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Figure 1: Block diagram of the closed loop.

The transfer function of the feedback system is composed of two components: $G(z)$ which corresponds to the controller and $H(z)$ which describes in the z-domain the transfer function of the rest of the system. In the case of SIBERIA-2 the last term is mainly determined by eddy currents in the aluminum vacuum chamber. To determine this transfer function we have measured the attenuation of the corrector field by the vacuum chamber with a low electron current. The electron beam was excited by a sinusoidal current in the frequency range of 0 to 150 Hz; the beam displacement was measured at the monitor and an FFT of this signal was performed. Fig.2 shows the transfer function of the system with the controller excluded. One can see that at a frequency of 100 Hz the attenuation is about -20 dB.

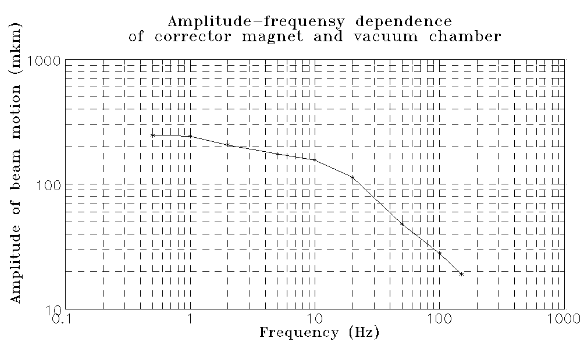

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Figure 2: Amplitude- frequency dependence of a system consisting of corrector magnet and vacuum chamber of the SIBERIA-2.

The digital filter function of the PID controller $G(z)$ is decided by the control program. We use a classical PID controller algorithm with anti-windup reset and limitation of derivative gain [3]. In the z-domain $G(z)$ can be written as:

$$G(z) = K_p + \frac{K_i}{1 - z^{-1}} + K_d(1 - z^{-1}), \tag{1}$$

where K_p, K_i, and K_d are the proportional, integral, and derivative constants of the controller. A control program based on the PID controller algorithm was coded in C and downloaded to the DSP. The feedback system was tested with the model that takes into account the results of response measurements that was done at the SIBERIA-2 (Fig.2). To describe the vacuum chamber influence, a digital filter $H(z)$ with four poles and four zeros was developed and implemented in the simulation code. The noise attenuation obtained from the simulation is plotted in Fig.3. It can be seen that at a frequency of 10 Hz the attenuation is around -30 dB, while for 60 Hz this value is decreased to -10 dB. For this test, the controller coefficients were: K_p = 1.0, K_i = 0.003, and K_d = 8.0.

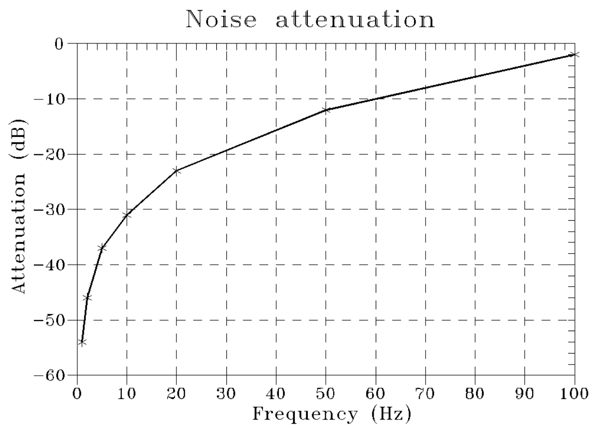

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Figure 3: Noise attenuation of the closed loop with K_p = 1, K_i = 0.003, K_d = 8 and T_s = 0.0004.

3 GLOBAL FEEDBACK SYSTEM

A global orbit correction system includes 24 BPMs and 48 correctors in each plane. The global orbit correction may be considered as the extension of the local feedback correction after using the technique of singular value decomposition (SVD) [4] of the response matrix R_{ij} that connects the beam motion at the i-th pick-up station with the changing of the j-th steering magnet strength:

$$R_{ij} = \frac{\sqrt{\beta_i \beta_j}}{2 sin \pi \nu} cos(|\psi_i - \psi_j| - \pi \nu), \tag{2}$$

where (β_i, ψ_i) are the beta and phase functions for i-th beam position monitor, and similarly for j-th corrector (β_j, ψ_j), and ν is the betatron tune. The response matrix is usually obtained by reading beam position displacement while varying the corrector strengths one by one. SVD reconfigures the BPMs and correctors into the same number of "pseudo" BPMs and "pseudo" correctors. In this new configuration space each BPM is coupled with a single corrector and vice versa. For each "BPM-corrector" pair the solution to the problem can be found by the method described above for the local feedback system. Then the backward transformation lets us know the strengths of the real correctors. As in the SVD technique, only matrix transformations take place so it looks very attractive to implement this method in a DSP.

At the local level, each BPM station electronics includes a 4-channel ADC and a DSP TMS320C31 which is connected via a serial data link with a Central Processor Board (CPB), located in a VME crate. The CPB, where we expect to use a TMS320C40, treats all the information and produces the output signal through a DAC to the corrector power supplies. The work of the CPB module includes the communication of the C40 with every BPM station. The performance of the C40 allows us to operate with the expected dataflow. We propose using a MC68030 or MC68040 VME master processor under the OS-9 operating system to provide the supervisory, I/O and file managment functions. The system software for OS-9 has been developed.

4 DIGITAL SIGNAL PROCESSING

The intelligent BPM controller is based on the TMS320C31-40 Texas Instruments floating point DSP. The structure of the controller is shown in fig.4. The DSP has 32 KWords of local static memory and 32 KWords of dual ported memory (DPM). Both memories have an access time of 50ns. The DPM is shared by the processor and ADCs. The

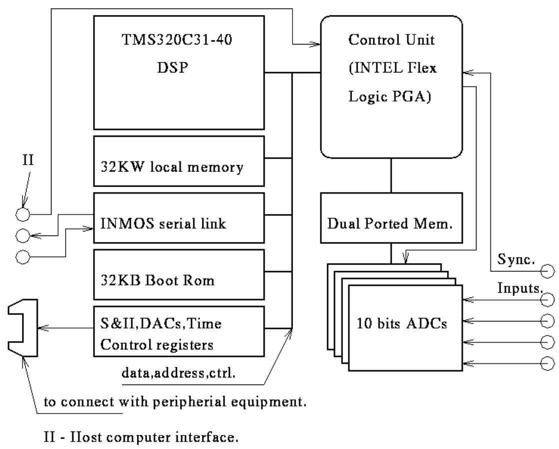

Figure 4: Structure of the DSP controller.

useg of a DPM allows the ADC to write the data directly to the processor address space. This allows the use of the ADC data without an additional time penalty for data transfer. Peripherial registers to control an external board with a programmable delay generator, DACs and sample-and-hold registers are mapped into the DSP address space. A 64 kbyte ROM contains the primary bootloader and some application codes. These codes can be loaded into local memory during program execution. All on-board devices are managed by a dedicated control unit, implemented inside the INTEL Flex Logic PGA. The hardware interrupts are used by the DSP to synchronize the aplication software with external events. Interrupts when the ADCs have data for writing to the DPM and when the DPM is full are possible.

Ten-bit ADCs with common simultaneous synchronization and a maximum sample rate of 15 million samples per second are installed on the small piggy-back module at the moment. The six least significant bits in the DSP are reserved to increase ADC's resolution in future without software modification. The control unit drives the DPM address bus during the write process of ADC data to DPM.

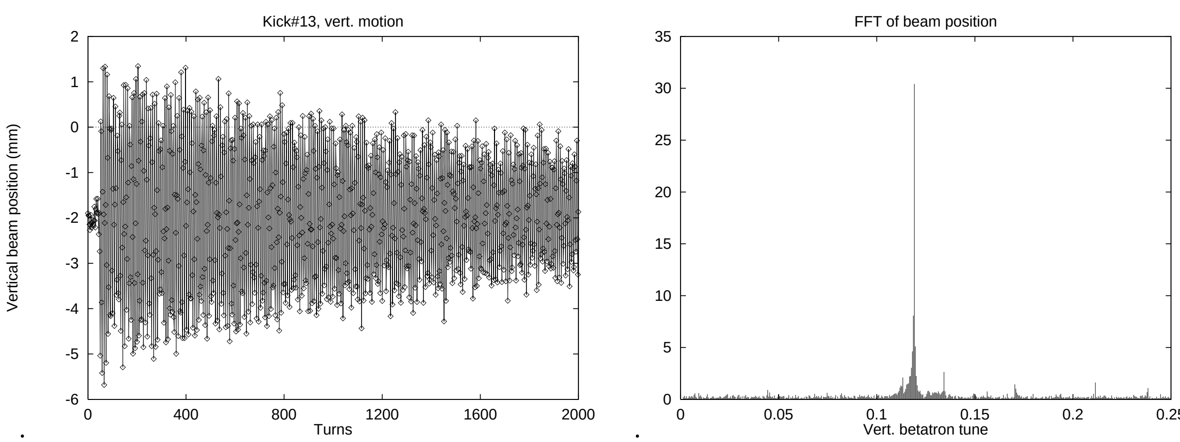

Figure 5: Beam position as a function of revolution number and its Fourier transform after vertical kick.

The INMOS serial link interface IMSC012 is used to provide I/O functions with the host computer and code downloading with a physical data rate of 10 or 20 Mbit/s. All signals can be transmitted/received up to a distance of 200 meters via 50 ohm coaxial cable using a home-made interface. The link speed for this distance is 10 Mbit/sec. Choice of the INMOS serial data interfaces allows the use of the transputer host software to load DSPs and to implement host I/O functions without development of additional host hardware or software.

In addition to the feedback system development, the DSP board provides the possibility of using various beam diagnostic techniques. Fig.5 displays the sampled signal as a function of revolution number and its discrete Fourier transform after the beam was excited vertically by fast kicker. The subsequent decay is clearly seen. This mode can be used for experimental nonlinear phase space study and dynamic aperture investigation. We expect that turn-by-turn measurements of beam position and current can be useful for the investigation of fast processes: beam loss during injection, ion accumulation, some kinds of coherent instabilities, etc. Fig.6 demonstrates the injection into the VEPP-3 storage ring. A "slow wave" corresponds to the energy oscillations. Due to the high computation capability of the DSP (2.5 ms for a 1024 point FFT) we can perform the various algorithms for signal treatment and investigate dynamic processes.

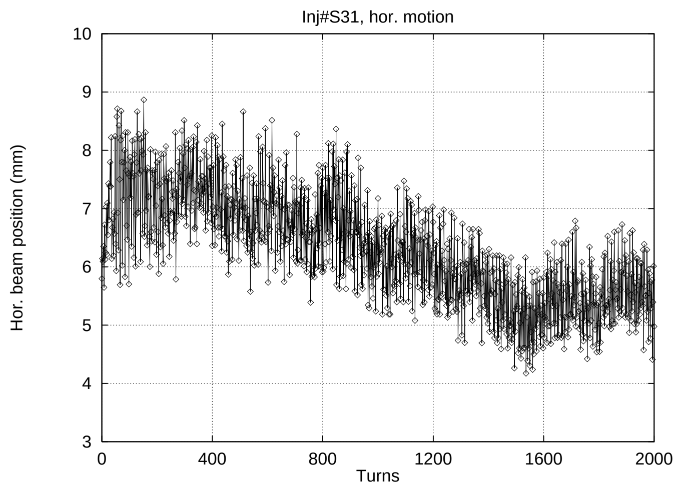

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Figure 6: Injected beam: horizontal position vs. turn number.

5 Conclusion and acknowledgments

The development of the orbit correction feedback system for the SIBERIA-2 light source is in progress. The home-made DSP module which combines a TMS-processor and ADC and DAC boards was tested with the electron beam using the existing pick-up station. The necessary measurements of the system response, including the influence of the vacuum chamber, corrector magnet and power supply were carried out. A model of the full system was developed and a PID-controller was implemented in that DSP. The results of the simulation indicate an adequate suppression of the beam motion. We expect that the steering magnet and power supply unit with an improved bandwidth (up to 250 Hz) will be manufactured by the end of October and the total feedback system (in a local mode) will be tested with beam by the end of 1995.

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