AUTOMATIC STEERING OF X-RAY BEAMS FROM NSLS INSERTION DEVICES USING CLOSED ORBIT FEEDBACK*

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Abstract

By the middle of this year (1989), there will be five insertion devices installed in the NSLS X-ray electron storage ring. X-ray beams from these devices will be stabilized by local automatic steering systems to reduce beam motion at the end of the beamline. Both the position of the source and the direction of the radiation will be controlled using beam position feedback to the closed orbit. Another system will be installed to stabilize the electron orbit for the LEGS Compton backscattering experiment. Each feedback system will employ at least one X-ray beam position detector; some will also utilize rf electron beam position monitors. Analog hardware with a digital interface has been designed and will be installed in the near future. A totally digital realization of the feedback controller is under consideration.

Introduction

Presently, five high power insertion devices (ID) have been or are in the process of being installed in the NSLS X-ray ring: a superconducting wiggler (SCW) at X-17, three hybrid wigglers (HBW) at X-13, X-21 and X-25, and a soft X-ray undulator (SXU) at X-1. Since in each of these beamlines the motion of the beam must be tightly controlled, local stabilization of the electron orbit will be necessary. In addition, the LEGS experiment in the X-ray ring will require stabilization of the orbit at two locations: a region where the electron beam interacts with a laser and at the entrance to a spectrometer line. This paper describes ongoing work to implement local feedback systems for each of these devices/experiments. Previous work on stabilization of photon beams in a storage accelerator has been described, for example, in [1]-[3].

At each insertion device and at LEGS, a local orbit bump will be established (for each direction of motion to be stabilized) with a set of four dipole trim magnets (correctors). It can be readily shown that with a four magnet bump it is possible to control both the position and the angle at any point on the orbit within the range of the bump.

It is clear that the operation of the local feedback systems must not generate any significant beam motion at other sources around the ring and that the various local systems should not interact with each other. It is, therefore, important that the local orbit bumps be "highly" local, i.e. that the deflection ratios of the trims within a bump be precisely set. In addition, since these deflection ratios depend on local values of the machine functions (beta functions and phase advance), they must be updated in real time to track these parameters.

To implement the local steering systems in the X-ray ring, an analog feedback controller with a computer interface has been designed. The controller, which can accommodate up to four independent feedback loops is packaged in a VME crate. It contains all of the detector signal processing electronics, frequency compensation and ratio amplifiers and drivers as well as A-to-D converters and a single-board computer (MVME133). Analog signals are digitized with 14-bit ADCs at 10 Hz rate and the trim magnet coefficients are set with 14-bit multiplying DACs (MDACs). A totally digital realization of the controller which would eliminate the compensation and ratio amplifiers, reduce the number of A to D channels and provide more flexibility in the implementation of compensation schemes is presently under consideration.

System Description

The following are some of the design considerations for various elements of a local automatic beam steering system.

Local Orbit Bumps

As mentioned earlier, a four magnet orbit bump permits full control of the angle and position of a source of synchrotron radiation on the electron beam orbit. To achieve this control it is necessary to use two independent beam position detectors. In a degenerate case, where only angle control is required, one position detector is sufficient.

In the general case, where control of both angle and position is required, a method described in [3] may be used. This method essentially consists of a decomposition of the four magnet bump into two elemental three magnet bumps. The relative strengths of the trims in a three magnet bump are computed from measured or calculated values of the machine beta functions and phase advance. By programming the amplitude and polarity of each of the two independent but overlapping three magnet bumps it is possible to control the angle and position at any point on the orbit between the two inner magnets in the bump.

The two elemental orbit bumps require two inputs from two separate beam position detectors. It should be clear that in general an input to any one of the three magnet bumps will displace the beam simultaneously on both detectors, i.e. the detector outputs are coupled. The outputs may be decoupled by processing the inputs with a decoupling circuit. Using this approach, it is possible to implement two independent feedback loops each stabilizing beam position on one detector which in effect stabilizes the angle and position of the beam in the beamline. Calculation of trim magnet deflection ratios and of the decoupling network coefficients has been outlined in [3].

It should be noted that since the local orbit bumps must remain local over the full bandwidth of the steering system, frequency responses of the individual trim circuits within a bump must be carefully equalized.

Trim Magnets and Power Supplies

The dipole trim magnets have four sets of coils each, two for vertical and two for horizontal field correction. The cores of these magnets, which are made of laminated low-hysteresis steel, have a window frame cross-section. The magnets are 40 cm long and have a field integral of approximately 0.008 kG m/A. Each set of coils is energized by a linear, programmable, wideband, current regulated power supply rated at ± 10 A, ± 20 V. The input of each power supply contains a summing junction for inputs from three analog feedback loops as well as from a DAC which is set by the main computer. A more detailed description of the trim magnet power supply system may be found in [4].

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*Work performed under the auspices of the U.S. Department of Energy.

Beam Position Detectors

Several types of beam position detectors are used at NSLS for monitoring the position of electron and photon beams. Recently, a high precision detector with a position resolution of a few tens of microns has been developed for use in orbit measurement and in feedback stabilization systems [5]. This detector converts rf signals from pick-up electrodes (PUEs) to low frequency signals proportional to beam displacement from the electrical center of the PUEs.

Two types of detectors are used for monitoring the position of photon beams: a photo-emission detector (PE) which operates in high vacuum [6], and a split ion-chamber (SIC) which operates in nitrogen or helium at or near atmospheric pressure. Signals obtained from PE detectors are typically in the 10^{-6} A range whereas those from SIC detectors are in the 10^{-8} A range. Signals from photon position monitors must be processed by sum-difference amplifiers and dividers to extract beam position information and to normalize beam position signals with respect to beam intensity.

Ratio Amplifiers and Trim Equalization

The trim magnet deflection coefficients and loop decoupling coefficients are programmed by means of multiplying DACs (MDACs) in ratio amplifiers. Each ratio amplifier has two inputs (from detectors) and four outputs (to trim power supplies). Each of the four trim circuits in a local bump is connected to each of the two detectors via an MDAC. The setting of each MDAC is a function of both the deflection ratios and of the decoupling coefficients. The outputs of the MDACs are combined in pairs to drive the trim power supplies via driver stages. Frequency equalization circuits for the individual trims are included in the driver stages.

Loop Compensation Amplifiers

The compensation amplifiers are designed to provide the required dc gain and maximum possible bandwidth while maintaining a 45° phase and 12 dB gain margins for good stability of the feedback loop. A soft turn-on switch is built into this amplifier to bring the beam in to the center of the beam position detector in a smooth way when the loop is activated. This switch, which is essentially a multiplying DAC, is programmed by the local micro-computer.

Interlocks

Switches which operate the feedback loops in a given system are directly interlocked (i.e. without computer intervention) with various components of the system such as magnet gap, photon shutter and detector output signal monitors. If any of the interlocks are tripped, solid-state switches in series with the soft turn-on/turn-off MDACs will operate and disconnect all feedback loops on the system.

Feedback Controller

All of the signal processing electronics, ratio and compensation amplifiers and trim power supply drivers are constructed on VME format circuit boards. Circuit boards for a given insertion device are housed in a VME crate which is controlled by a VME133 single board computer. Analog signals are digitized by commercial 14-bit ADCs. The 14-bit multiplying DACs are controlled by the micro via bus interface circuitry mounted on the MDAC circuit boards. Readback of interlock status and commands for closing/opening of feedback loops are handled by an I/O circuit board. The local micro-computer is connected to a higher level computer in the NSLS control system via an RS422 communication link.

Stabilization of the SXU Beam

The initial objective of the SXU local feedback system is to stabilize the position of the undulator beam simultaneously in both the vertical and horizontal directions on a photo-emission detector approximately 9 m downstream of the source. At a later time, a second detector will be introduced downstream of the first detector. At this stage, the system orbit bump is configured for angle control only. A simplified block diagram of one half of the steering system is shown in Fig. 1; the horizontal orbit bump for the SXU as measured by the PUE orbit measuring system is shown in Fig. 2. It should be mentioned that in spite of the fact that it is desirable to have the vertical and the horizontal feedback loops totally decoupled, a significant amount of coupling between the loops at X-1 has been observed. This is believed to be due to mixing of the undulator beam with the radiation from the downstream dipole at the detector (see inset in Fig. 1) and could in principle be reduced by moving the PE detector vertically upward.

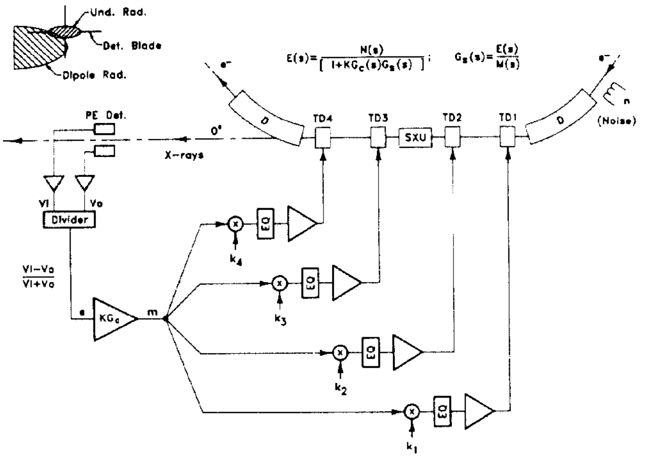

Fig. 1 A simplified block diagram of the X-1 beam steering system.

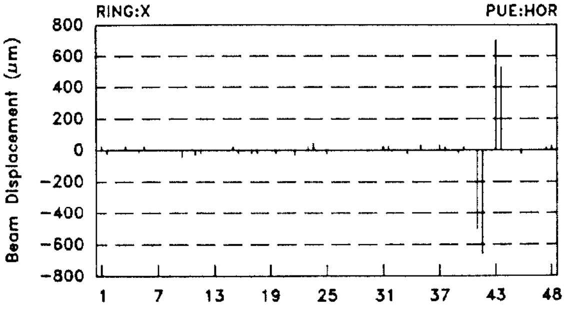

Fig. 2 Local orbit bump for X-1

Without stabilization, beam position at the X-1 detector may typically drift by as much as ± 200 μm over a period of 30 minutes. Short term drift (less than 1 Hz) is of the order of 30 μm peak to peak. The feedback loop has a dc gain of 55 dB and a unity gain bandwidth of approximately 100 Hz. With the loop closed, beam position drift is reduced to a few microns as may be seen from the chart recording in Fig.3. The reduction of various low frequency components in the noise spectrum due to feedback is illustrated in Fig. 4.

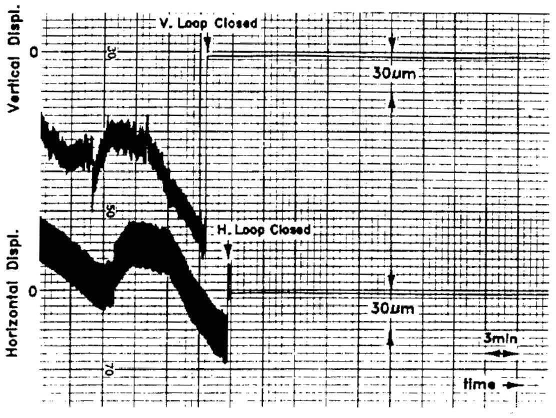

Fig. 3 Beam position noise at X-1 detector with and without feedback.

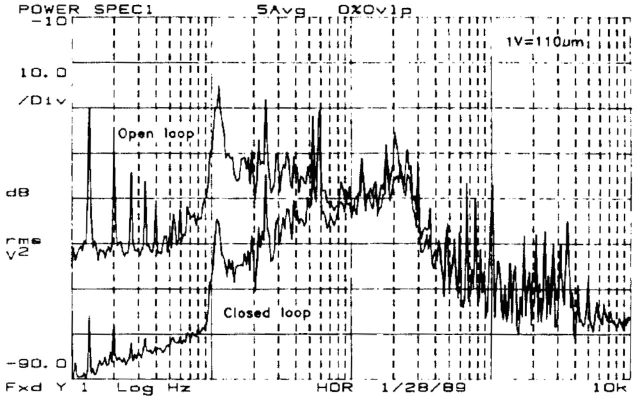

Fig. 4 Beam position noise spectra at X-1 detector with and without feedback.

Stabilization of Wiggler Beams

Motion of X-ray beams from wigglers will be stabilized in the vertical direction only with two feedback loops for angle and position control at the source. These systems will utilize either two photon beam position monitors or one photon and one electron monitors per plane of motion, as illustrated in Fig. 5. The above figure explicitly shows the construction of a four magnet bump from two three magnet bumps, as well as the configuration of the loop decoupling circuit.

Orbit Stabilization For LEGS

For the LEGS experiment, the electron beam orbit will be stabilized at two locations in the ring in both planes by two independent feedback controllers. One of these locations will be a region in the straight section where the electron beam will be interacting with a laser beam and the other location will be in the downstream dipole at the entrance to a tagging spectrometer. The basic layout of the two systems, which share two trim magnets, is shown in Fig. 6. The two regions where the beam is stabilized are labeled A and B, respectively.

Acknowledgements

G. Frisbie was involved in the development and construction of all of the feedback controller VME circuit boards and in the assembly and testing of overall systems. W. Rambo provided expertise for the configuration/assembly of the VME crate. Software for the system was written by E. Desmond.

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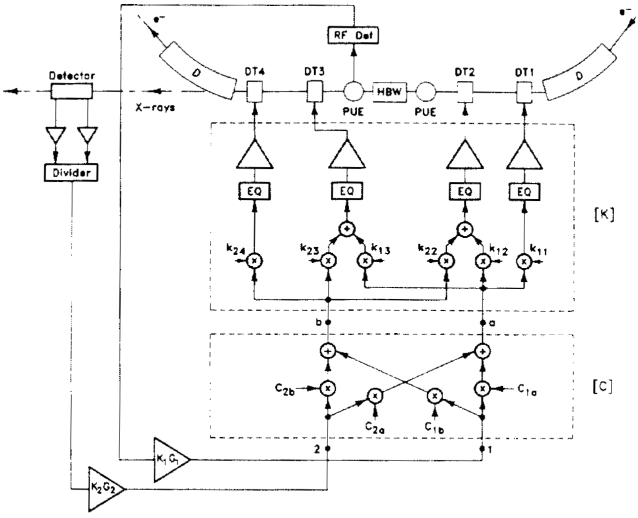

Fig. 5 A simplified block diagram of the steering system for a wiggler beam.

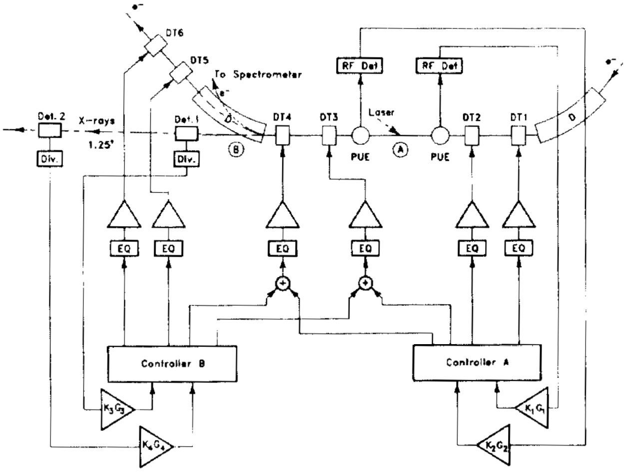

Fig. 6 A block diagram of the system for LEGS.