2

Presented at the 1987 Particle Accelerator Conference, Washington, D.C., March 15 - 19, 1987.

CONF-870302--183

BNL 39595

AN AUTOMATIC BEAM STEERING SYSTEM FOR THE NSLS X-17T BEAM LINE USING CLOSED ORBIT FEEDBACK*

BNL--39595

DE87 010054

R.J. Nawrocky, Li Ma**, H.M. Rarback, O.V. Singh and L.H. Yu
Brookhaven National Laboratory
Upton, New York 11973

Abstract

Initial observations of motion of the undulator radiation in the NSLS X-17T beam line clearly indicated that the beam had to be stabilized in both directions to be usable for the planned soft X-ray imaging experiments. The low frequency spectra of beam motion contained peaks in the range from dc to 60 Hz and at higher frequencies. A beam steering system employing closed orbit feedback has been designed and installed to stabilize the beam in both planes. In each plane of motion, beam position is measured with a beam position detector and a correction signal is fed back to a local four magnet orbit bump to dynamically control the angle of the radiation at the source. This paper describes the design and performance of the beam steering system.

Introduction

At the NSLS, a synchrotron radiation facility at Brookhaven National Laboratory, two electron storage rings- a 750 MeV VUV ring and a 2.5 GeV X-ray ring are operated to support large research programs in solid state physics, materials science etc. At the VUV ring there are presently some 35 operating or proposed beam lines and at the X-ray ring there is a total of over 40 beam lines. The X-ray ring has an eight-fold symmetry and five of the eight straight sections will be used for insertion devices.

In preparation for a high power X-ray undulator to be installed at X-1 during the summer of '87 a short version of the magnet, a so-called mini-undulator, has been constructed and installed at X-17T for spectroscopy and soft X-ray imaging experiments. In the latter case where biological samples a few tens of microns in size and containing features on the submicron scale are studied approximately 20 m downstream of the source, a high degree of positional stability of the X-ray beam is required.

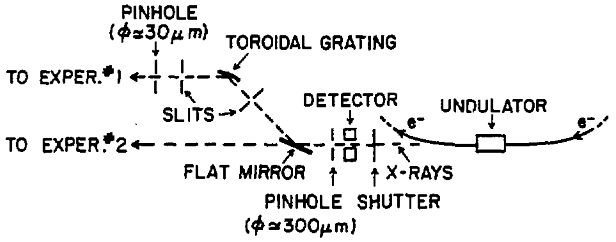

Fig. 1 Layout of the X-17T beam line.

The observed beam motion in each of the storage rings is of the order of two to three hundred microns in position and about two hundred microradians in angle, peak-to-peak. This motion is due to a number of noise sources such as electrical noise on the power line, mechanical vibration of magnet supports, cooling water temperature variations, etc. Since the amplitude of the measured ambient beam motion at X-17T was unacceptable, a beam position stabilization system had to be implemented.

In general, the problem of beam position control may be approached from one of several directions: by identifying and suppressing as many noise sources on the machine as possible; by correcting beam position globally using feedback from several detectors and dynamically controlling a number of correctors around the circumference of the machine; or by automatically correcting beam position and angle locally at a given source by position feedback from local detectors.

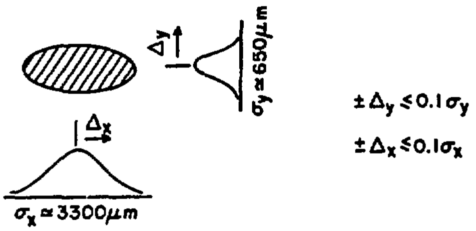

Fig. 2 Approximate beam size and permissible beam excursions at the detector.

The approach for X-17T was to use local feedback. A local e beam orbit bump has been generated using four dipole correction magnets (trims) symmetrically located about the mini-undulator. For each of the two directions of motion a feedback signal is derived from a pair of beam position detector blades allowing only angular corrections of the undulator radiation at the source. This, however, is sufficient since the distance between the source and the detector is large (13m) and the object upon which beam motion must be stabilized (a pinhole) is just downstream (1m) of the detector. A simplified layout of the beam line is shown in Fig.1. The approximate dimensions of the X-ray beam as well as the beam stability requirements at the X-17T detector are summarized in Fig.2.

Beam Position Detector

The beam position detector consists of four thin tungsten blades, two blades for each direction of motion with one blade on either side sensing the edge of the beam, as illustrated in Fig. 3. The detector

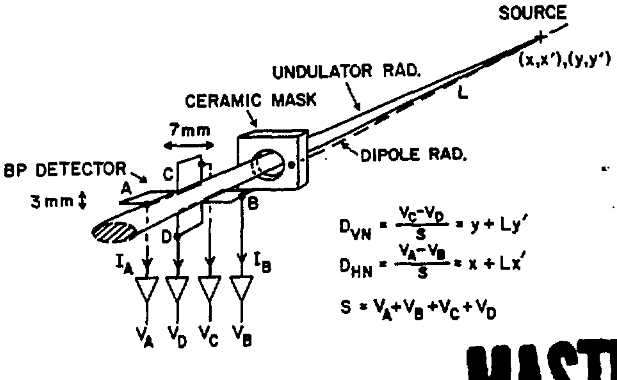

Fig. 3 Beam position detector.

MASTER

---

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

**Visiting scientist from the Institute of High Energy Physics, Beijing, P.R. of China.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED operates in vacuum and is cooled with a heat pipe [1]. A thick ceramic mask with a circular opening allows the undulator radiation to pass through while stopping most of the synchrotron radiation from nearby dipoles. The X-ray beam photoionizes electrons from the blades causing small currents to flow in the circuits connected to the blades. These currents are directly proportional to the number of photons interacting with the blades. The current signals are converted to voltages with electrometer amplifiers (Keithley 427). The difference between a pair of amplified detector blade signals is normalized with respect to the sum of all four (which is proportional to beam current) by means of a precision two quadrant analog divider. The output of the divider is proportional to beam position over a range > ± 1mm. The calibration of the divider output signal is approximately 45 μm/V with Keithley gain at 10^6 V/A. The separation between the edges of the blades is 3 mm vertically and 7 mm horizontally.

Local Orbit Bump

The undulator beam is steered with a symmetrical local orbit bump centered on the undulator which is established in the straight section by means of a set of four dipole trim magnets (T1-T4, Fig. 4). The orbit bump has been designed to produce a pure angular displacement at the undulator.

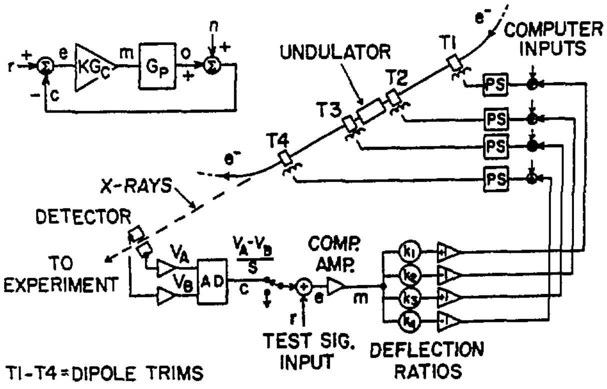

Fig. 4 A simplified block diagram of the beam *steering system.*

Due to the symmetry of the configuration, currents in the "inside" pair of trims (T2, T3) are equal in magnitude but opposite in polarity and so are the currents in the "outside" pair of trims (T1, T4). The ratio of the "inner" to "outer" trim currents (the deflection ratio) depends on the local values of the betatron function and phase advance [2].

In reality, the final adjustment of the deflection ratio was made experimentally. This was accomplished by driving the bump with a low frequency sinewave of large amplitude and then adjusting the deflection ratio to minimize the test signal component simultaneously in the output of two other beam position detectors separated by 90° in phase advance.

The trim magnets used in the bump have been constructed with two sets of coils, a vertical set and a horizontal set, and have an integrated field strength of approximately 200 Gauss-cm/A. The cores are made of low hysteresis steel and are laminated. The magnets are energized with commercially available wideband linear power supplies rated at ± 10 A. Frequency responses of the four trim circuits have been equalized to ensure the locality of the bump over the bandwidth of interest.

System Frequency Response and Compensation

A simplified block diagram of the beam steering system (for one plane of motion) is shown in Fig.4. The frequency response of the uncompensated system, C(jw)/M(jw) (where C(jw) = F(c(t)), etc.), was found to have a rather flat amplitude response up to approximately 1 kHz while the phase response rolled off quickly and crossed the 180 degree line at about 200 Hz (see Fig.5). This phase shift is due to eddy currents induced in the relatively thick NSLS aluminum vacuum chamber by the time-varying magnetic field. A compensation amplifier containing the appropriate lead-lag networks has been designed to provide a 55 db dc loop gain and conservative phase and gain margins for good transient response. The bandwidth of the closed loop system has been measured to be about 25 Hz. The design of loop compensation amplifiers has been treated extensively in the literature, for ex. [3], and will not be discussed here. Previous work on beam steering systems by Hettel et al. has been reported in [4] and [5].

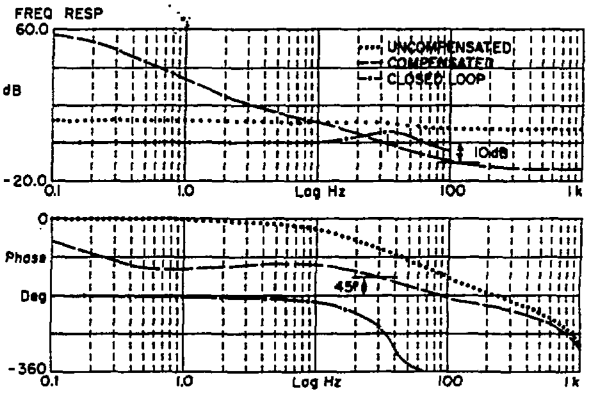

Fig. 5 System frequency response.

System Performance

The X-17T beam steering system was placed into regular operation in the fall of 1986 and after minor adjustments of the orbit bump performed as expected. The normal procedure at the beginning of each fill has been first to steer the X-ray beam to within the range of the detector by adjusting the orbit with feedback loop open and then to close the loop. For automatic operation, an interlock circuit which disables the steering system when the beam line photon shutter is closed has been added.

The improvement in beam position stability with feedback may be seen from Fig. 6 which shows the behavior of the vertical and the horizontal normalized position signals as a function of time with and without feedback (chart recorder bandwidth ≈ 5 Hz). An examination of one of these signals in the frequency domain with an HP 3562A FFT analyzer, Fig. 7, shows the reduction of the noise within the bandwidth of the system (Note that $C(jw) = N(jw)/1+KG_c(jw)G_p(jw)$, $R(jw)=0$, where all quantities are defined in Fig. 4).

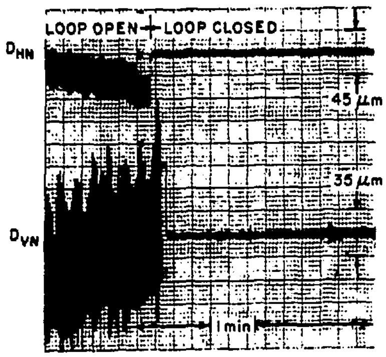

Fig. 6 A typical chart recording of normalized beam position signals.

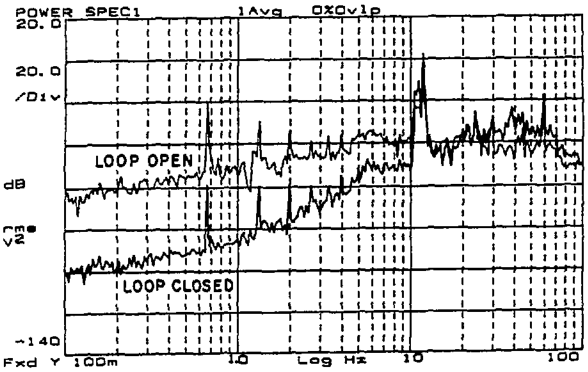

Fig. 7 Power spectra of D_{HN} with and without feedback.

A beam steering system for the X-1 undulator now under development will control both the position and the angle of the radiation. It will utilize two beam position detectors and two feedback loops for each direction of motion. The deflection ratios will be programmed in real time to track the betatron tunes of the machine.

Acknowledgements

The beam position detector was designed, tested and described by Mortazavi et al.[1]. R. Biscardi constructed and tested the feedback system electronics.

References

[1] P. Mortazavi, M. Woodle, H. Rarback, D. Shu and M. Howells,"High Flux Photon Beam Monitor", BNL 36903.

[2] M. Sands, "The Physics of Electron Storage Rings-an Introduction", SLAC-121, UC-28, November 1970.

[3] J.G. Truxal, Control System Synthesis, McGraw-Hill, New York, 1955.

[4] R.O. Hettel, "Beam Steering at the Stanford Synchrotron Radiation Laboratory", IEEE Trans. Nucl. Sci. Vol. NS-30, No. 4, Pt. 1, p. 2228-30, Aug. 1983.

[5] T. Katsura, Y. Kamiya, K. Haga, T. Mitsuhashi and R. Hettel, "Beam Position Monitoring and Feedback Steering System at the Photon Factory", KEK Preprint 86-46, August 1986.

DISCLAIMER