EXPERIENCE WITH PHASE II INSERTION DEVICES IN THE X-RAY RING*

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INTRODUCTION

The installation of Phase II insertion devices in the NSLS x-ray ring was completed in February 1989, when the hybrid wiggler magnet (HBW) for beam line X21 and the superconducting wiggler (SCW) for beam line X17 were installed. Prior to this time, the soft x-ray undulator (SXU) at X1, another hybrid wiggler at X25, and the ten period mini- undulator at X13 had been installed. Shown in table 1 are parameters for the different magnet types (the mini-undulator is a ten period clone of SXU).

INSERTION DEVICE PARAMETERS	SXU	HBW	SCW
Number of Poles	77	31	7
Full Strength Poles	70	26	5
Magnet Period λ (cm)	8.0	12.0	17.4
No. Magnet Blocks / Slot	2	8	-
Peak Field B_{max} (kG)	3.5	11.0	52.0
Max. Deflection Parameter K	2.6	12.3	84.5
Total Photon Power (kW) @ 500 mA, 2.5 GeV	.72	4.3	24.

Table 1. X-ray ring insertion device parameters.

INSERTION DEVICES

SXU

The SXU magnet is fully operational, and beam line X1 is fully commissioned. The beam line performs photoemission microscopy and biological soft x-ray imaging[1]. Spectral data taken with beam line X1A are in reasonable agreement with theory. The magnet uses rare earth cobalt and iron pole pieces in a typical hybrid design to achieve a 3.5 kGauss peak field.

X-ray ring users observed ≈20 microradians of vertical beam deflection caused by the first and/or second field integral generated by varying the SXU magnet gap. Such small deflections are undetectable using the present orbit measurement system utilizing a switching tree, which has a resolution of approximately 100 microns. Long coil measurements indicate that 7 microradians of vertical steering take place when the SXU gap is changed. This is consistent with the observed beam motion. The vertical steering is apparently caused by the minor component of REC material magnetization oriented in the horizontal plane. Work is underway to improve the orbit measurement system, which will allow better compensation of the SXU magnet.

HBW

The beam lines at X21 and X25 will use HBW radiation for high energy resolution and high momentum resolution x-ray scattering studies, respectively. The HBW magnet at beam line X25 was the first of the high power insertion devices to be installed in the x-ray ring, in September of 1988 (Fig. 1). It consists of rare earth - cobalt permanent magnet material sandwiched between vanadium permendur pole pieces. The magnet gap can be varied from 120 to 23.8 mm, with a peak field of 10.6 kG at minimum gap. To date, the magnet has been operated at 10.6 kG with low beam current(≈ 2 mA) at 2.5 Gev, and light has been taken out to the end of the beam line during accelerator studies periods. Interlock systems (described below), necessary to thermally protect the accelerator vacuum chamber must be in place before high current operation of the beam lines can take place.

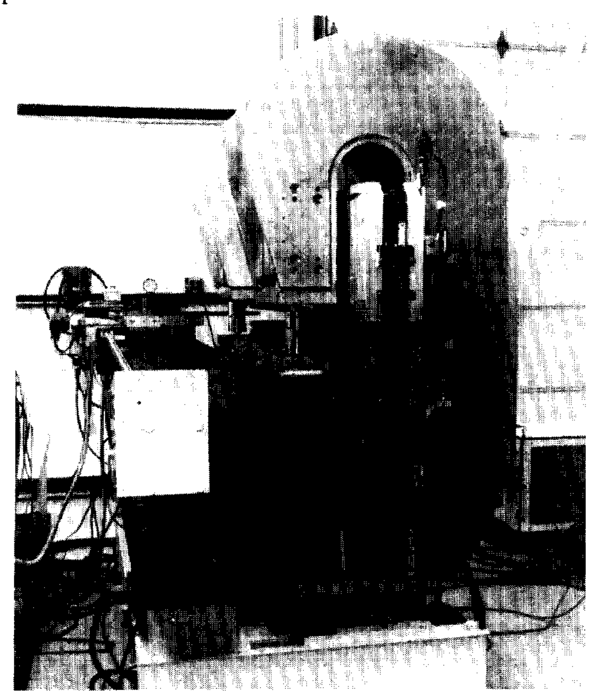

Fig. 1 HBW magnet for X25 beam line.

In Fig. 2 is shown one effect of closing the X25 HBW wiggler gap. Plotted are the vertical change in electron beam position as a function of location around the accelerator. The dotted line at distance 106 meters shows the location of the X25 magnet. The symmetry of the orbit distortion indicates that it was caused by a residual second integral of horizontal field, i.e. a vertical step in the electron beam trajectory. An antisymmetric combination of upstream and downstream trims was required to compensate for this effect. The trim strength values used indicate that the step in the vertical trajectory through the magnet was approximately 30 microns.

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

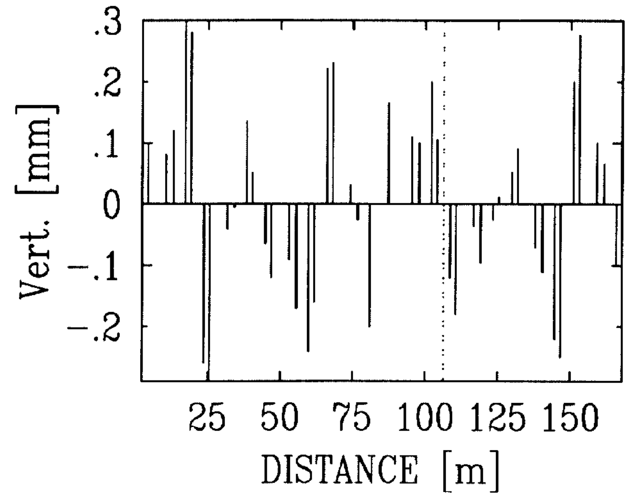

Fig. 2 Vertical Orbit change caused by closing X25 HBW gap.

SCW

The installation of the X17 superconducting wiggler and its associated helium liquification system is complete. The system has made liquid and is performing well. Final system tests on the wiggler/cryogenics system were completed in mid-november 1988, at which time the entire system was moved from an adjacent building to its final location near the x-ray ring.

During a recent studies period, injection into the x-ray ring at 745 MeV was quickly established with the magnet at low field (1.15 T). At this point, ≈2 mA of beam were taken to 2.5 GeV, and light was taken out into the X-17 hutch following a vertical orbit correction. High field (5.22 T) operation of the wiggler at 2.5 GeV awaits finalization of the phase II safety analysis report, since the critical energy of wiggler photons is 22 keV, 4 times higher than that of any other radiation presently produced at NSLS. In spite of this, the wiggler was ramped at 745 MeV with 2 mA of beam, from 1.15 Tesla to 4.9 Tesla and back, without significant beam loss. The change in orbit around the ring between low and high field was everywhere less than 1.5 mm, indicating that the wiggler is reasonably well compensated. The measured vertical tune shift was found to be in reasonable agreement with theory.

Ultimately, medical research and materials science will be performed with the X17 beam lines.[2]

EXPERIMENTAL STRAIGHT SECTION

The mini- undulator was installed in the X-17 straight section in 1986 to gain experience operating the x-ray ring with an insertion device and to develop a local orbit feedback system. It has been well characterized while located at beam line X-17, and has since been moved to X-13 where experimental beam line R & D will take place.

Scraper measurements in the x-ray ring have demonstrated adequate beam lifetime with a full vertical aperture of 5 mm. at a point where β_y = 7 meters. This offers the possibility of placing a small gap insertion device in the low beta straight section at X-13 in place of the present mini - undulator. Since β_y^* = .35 meters, a .5 meter long device, for example, could conceivably have a gap as small as 2 to three mm. without affecting beam lifetime. Research is presently going on in this area.

THERMAL CONSIDERATIONS

As indicated in the table 1, the insertion devices are capable of delivering significant quantities of photon power. Considerable effort has gone into the design and construction of systems necessary to deal with resultant thermal loads on the accelerator vacuum chamber. The vacuum chamber itself has had to be modified to include water cooling on as much exposed surface area as possible. It was not possible, however, to cool the roof and floor of the chamber located inside the x-ray ring dipoles downstream of the insertion devices, due to aperture considerations.

An active interlock system[3] is presently being implemented to protect the uncooled portions of the vacuum chamber. This system interrupts the RF system, thus dumping the electron beam, whenever the trajectory through any high power insertion device becomes "dangerous", as seen by pick up electrodes (PUE's) located near each insertion device (Fig. 3). The two HBW magnets and the SCW magnet require the protection systems, while SXU is considered safe. Individual components of the active interlock system have successfully been tested, and a complete system for all of the high power insertion devices should be available in the near future.

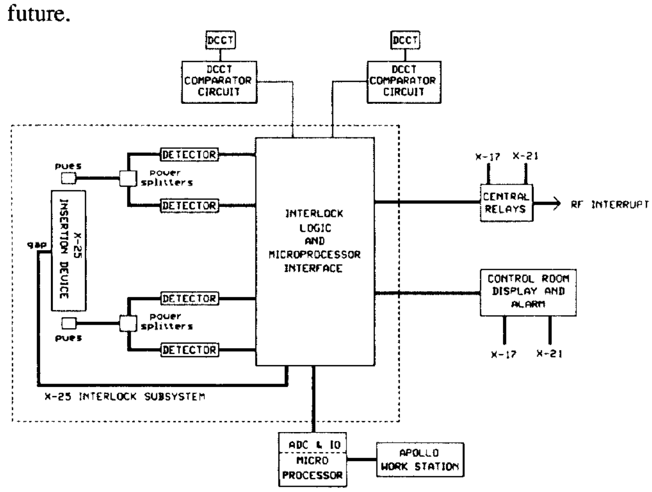

Fig. 3 Active interlock block diagram.

ORBIT CONTROL

Extensive magnetic measurements have been carried out on all of the insertion devices[4]. Of particular interest are the first and second integral of transverse dipole field along the axis of the device. The first integral corresponds to an angular deflection of the electron beam, and the second to a transverse displacement, or step, in the electron beam trajectory. Each device includes horizontal steering windings on the upstream and downstream end pole assemblies, which are used to compensate for any residual first integral of vertical magnetic field. In addition, each insertion device is located between two x-ray ring combined vertical / horizontal trim dipoles which are used to correct the remaining residual field integrals.

The X1 beam line is instrumented with a closed orbit feedback system, which stabilizes the photon beam position, both horizontally and vertically, by adjusting local orbit bumps in the x-ray ring using position information from a photon blade monitor[5]. Stabilization to ± 5 microns at the blade monitor is achieved in this way. Ultimately, all of the insertion devices in the x-ray ring will have such a feedback system.

New beam position monitor receivers are under construction, and beam motions smaller than 10 microns have been observed using a prototype[6]. With new receivers in place, a global harmonic closed orbit feedback system similar to that used in the NSLS VUV ring[7] will be installed in the x-ray ring. The global feedback will aid in reducing slow beam motions (less than 30 Hz), caused by water temperature fluctuations, etc. In addition, the new receivers will improve the orbit correction process.

VERTICAL TUNE SHIFT

A well known effect associated with planar wigglers and undulators is that they focus in a plane perpendicular to that of the trajectory oscillations. Thus, all x-ray ring insertion devices focus vertically. This is easily understood as a cumulative edge focussing effect, since the electron beam arrives at the individual insertion device pole pieces with a small, but finite angle. This focussing cannot be measured directly, e.g. using a long coil, but will result in a measurable tune shift $\Delta\nu_y$. A straightforward calculation[8] assuming a sinusoidal field and particle trajectory yields

$$\Delta\nu_y = \frac{1}{4\pi} <\beta_y> \left[\frac{B_w}{B\rho}\right]^2 \frac{\lambda_w}{2} N \ , \qquad (1)$$

where B_w is the peak field in the device, $B\rho$ is the electron beam rigidity, λ_w is the insertion device period, N is the number of periods, and $<\beta_y>$ is the mean value of the vertical beta function, given by

$$<\beta_y> = \beta_y^* + \frac{L^2}{12\beta_y^*} \ . \qquad (2)$$

Here β_y^* is the value of β_y at the center of the device, and $L = N\lambda_w$ is the device length. Note that N is equal to one half the number of full strength poles stated in table 1.

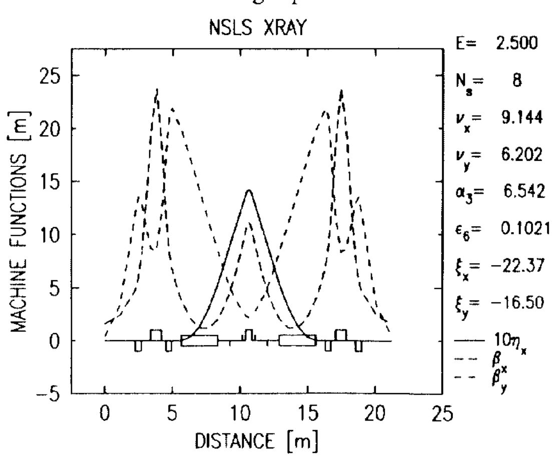

Fig. 4 X-ray ring machine functions.

Shown in Fig. 4 are machine functions for one of the eight x-ray ring superperiods. The insertion devices are centered in the zero dispersion straight sections. β_y and β_x take on minimum values $\beta_y^* = .35$ m, $\beta_x^* = 1.68$ m at the center of the straights.

Device	E (GeV)	meas. $\Delta\nu_y$	calc. $\Delta\nu_y$
SXU / X1	.745	.0040	.0043
HBW / X25	2.53	.0010	.0009
SCW / X17	.745	.0022	.0029

Table 2. Insertion device vertical tune shifts.

In table 2 are comparisons of calculated and measured tune shifts for various devices. The measured values for the permanent magnet devices are differences of gap open vs. gap closed values, and for the superconducting wiggler, the tune shift from 1.15 T to 4.9 T wiggler field was measured. After closing the gap on the X25 HBW and the X1 SXU, the compensating trim magnets were set to reproduce the original orbit, to eliminate the possibility of tune shifts associated with beam motion within lattice sextupole magnets. The tune shift measurement for the X17 SCW was made with no orbit correction; the motion was less than 1.5 mm around the ring as previously stated. The calculated values for SCW require a somewhat generalized version of eqn. (1) which accounts for the fact that the end poles are half the strength of interior poles.

CONCLUSIONS

The x-ray ring at NSLS is presently running with five insertion devices, and four of them have generated light which has been brought out to the x-ray floor. Characterization of these devices is continuing, with full commissioning anticipated in the near future.

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