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**Prototype Photon Position Monitors for
Undulator Beams at the Advanced Light Source**
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Design criteria are described, and test results are presented, for prototype ALS undulator beam position monitors. The design is based on monitors presently in use at NSLS, with modifications to account for the widely varying and large K values of the undulators to be installed at the ALS.

In particular, we have modified the design to simplify the thermal engineering and we have explored techniques to suppress the response of the monitors to soft photons, so that the beam position can be determined by measuring the higher energy photons which are better collimated.

Introduction

The electron storage ring of the Advanced Light Source will normally operate at 1.5GeV with a maximum design current of 400mA. Undulators in the straight sections will have variable gaps, with K changing from a small value (gap open) to a maximum (gap closed) which in some cases may be as high as $K=10$.

Photon beam position monitors are required at two locations in the upstream portion of the beamline, to sense transverse motion of the beam at the 1 or 2 μm level. They must pass the beam downstream to the experiment. One of the position monitors will be in the storage ring tunnel, about 8m from the source. The second monitor will be immediately outside the shield wall on the experimental floor, about 12m from the source. Error signals from this pair of monitors will be incorporated in a digital servo-loop by which the four steering magnets in the straight will locally stabilize the position and angle of the electron orbit at the center of the undulator. The first of the two monitors will also carry a mask which must generate an error signal if the beam is vertically mis-steered by more than about $\pm 0.9\text{mrad}$; this will be part of a system to protect the storage ring vacuum chamber.

We require simple, robust and passive devices which will operate reliably inside the storage ring tunnel. They must operate over the appropriate range of and tolerate the commensurate thermal load.

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A simple monitor [1] is successfully employed at NSLS on undulators whose K values are about 4 or smaller. It consists of four photo-emissive blades, two horizontal and two vertical, which protrude towards the undulator beam axis from a peripheral support and intercept a small part of the edge of the beam.

We have developed this design for the ALS. Two problems arise as the K value becomes larger:

The horizontal width of the undulator power distribution increases in proportion to K, and the undulator total power increases as K^2 . The horizontal blades must protrude far enough towards the axis to intercept the beam at low K. When K is very large (8 to 10) they are subject to overheating (the 8cm period undulator at the ALS produces 4.5kW total power at $K=10$).

The fundamental of the ALS undulators is at very low energy when K is large. For example, our 8cm period undulator with $K=7.2$ produces photons in the fundamental with an energy of 10eV. The photo-emissive detector senses these photons with highest efficiency, whilst diffraction ensures that they fill the aperture of the monitor and carry little information on the position of the beam.

Furthermore, when these monitors are used in pairs, at two locations in the beamline, the second must avoid the shadow produced by the blades of the first.

In this work we set out to solve these new problems.

1. Photo-electron yield distributions

Figures 1 and 2 show results of calculations of photon and photo-electron yield angular distributions from an 8cm period undulator at the ALS.

Richard Walker of Sincrotrone Trieste has provided us with a copy of his code 'URGENT' which computes angular and spectral distributions of photons within the undulator beam [2]. From the angularly and spectrally resolved photon flux within 1mrad of the axis we have estimated the photo-electron yield distributions to be sampled by our position monitors. At each angle for which a spectrum is computed we have multiplied it by a crudely parametrized quantum efficiency function (of photon energy) and integrated to obtain the photo-electron yield.

The parametrized quantum efficiency is represented by a power law with an exponential tail:

$$.05 \{ \epsilon - 4.5 \}^{0.567} \exp \{ 0.042 (4.5 - \epsilon) \}$$

ϵ is the photon energy in electron volts, 4.5eV is a typical work-function and the other three numbers are obtained by fitting to data of Cairns and Samson [3] between 10eV and 30eV and by fitting to data of Day et. al. [4] at 100eV.

Figure 1 shows that at $K=1.5$ the photons from all harmonics are well localized close to the axis. The photoelectron distribution shows interesting structure as the Doppler shifted radiation away from the axis produces more photo-electrons because its energy is lower, despite its lower intensity.

Figure 2 shows that at $K=7$ the photons are more numerous close to the axis. However a photo-emissive monitor with the efficiency given above would not sense the centroid of this beam because of its sensitivity to photons at the lowest energy, which fill the aperture. The undulator beam contains many ($\sim K^3$) intense harmonics and those harmonics with photon energy above about 100eV are not diffracted to fill the entire aperture. A monitor sensitive only to photons above about 100eV would regain the ability to sense beam motion. Implementation of such energy discrimination will be discussed in section 5.

2. Blade Geometry

These monitors work well because the blade protruding into the beam will always give a larger signal as the beam moves towards it, regardless of structure in the distribution of photo-electron yield, such as that shown in figure 1. Thus the detector can generate a well behaved error signal for use in a stabilizing servo-loop.

The horizontal blades used in previous designs pose problems as K increases. We have built and tested a monitor with blades at 45° . This geometry allows K to increase without drastic changes to the thermal load, so that such a monitor is feasible at the ALS.

The difference signals between opposite blades now reflect 45° motion of the beam and all four signals must be combined to generate the horizontal and vertical errors. Inequalities of the quantum-efficiency between the four blades and lack of symmetry of the photon beam, including bend magnet radiation, means that purely horizontal beam motion might appear to have a vertical component and vice versa. Because of this, differences in the sensitivity of each blade, due to beam geometry or electronics, ought to be compensated so that the horizontal and vertical measurements are decoupled. At the ALS, each monitor will be read through four ADCs into a single 'Intelligent Local Controller' so that software gain compensation should be straight forward. The monitors must be movable horizontally and vertically so

that the compensation factors can be determined empirically.

Figure 3 is a sketch of our prototype, which was tested using a ten period undulator with 8cm period length and $K=1.65$ at beamline X13 at the National Synchrotron Light Source. The copper support structure is biased to +300V to collect photo-electrons leaving the blades. The amplifier gain and photo-currents are indicated. Thermal loads for the tests at X13 were minimal (about 400W total power).

Figure 4 shows the signals from the four blades as the detector is moved horizontally or vertically in the undulator beam. Negative signals correspond to electron emission. Also shown are the computed horizontal and vertical position signals after gain compensation (H and V).

$$V = \{1.0A + .92B - 1.0C - .94D\} / \{1.0A + .92B + 1.0C + .94D\}$$

$$H = \{.70A - 1.0B + 1.0C - .70D\} / \{0.7A + 1.0B + 1.0C + 0.7D\}$$

where the numbers close to unity are the empirically determined compensation coefficients.

We find that horizontal motion then couples into the vertical signal at the 10^{-2} level and vertical motion couples into the horizontal signal at the 10^{-3} level, when the beam is centered, which is acceptable for feedback with the planned DC loop gain of ten.

We conclude that the added complications of blades at 45° in a monitor to sense horizontal and vertical motion are tolerable, and worth the resulting reduction of the thermal load.

Using 45° blades in the upstream monitor and 90° blades downstream, on an undulator beamline at the ALS, is one arrangement by which the blades of the second monitor could avoid the shadow of the blades of the first.

3. Detector Resolution

Electronic noise makes a negligible contribution to the detector resolution. The effect of imperfect beam profile is the source of coupling between the horizontal and vertical measurements and the principle limit to the resolution. For determination of this effect we set up a monitor with vertical blades, as shown in figure 5, and moved it vertically through the beam. The copper support structure was biased to +300V as before. Figure 6 shows the signals during a period of time when the monitor made $5\mu\text{m}$ steps through the beam, dwelling at each location for a few seconds. The resolution is of the order of $1\mu\text{m}$ and the motion of the undulator beam can be observed.

4. Discrimination against low energy photons

At the ALS it will be important to have monitors which are insensitive to low energy photons (below about 100eV), which will be diffracted to fill the aperture. By setting up a detector with reverse bias, we hope to provide an electrostatic potential barrier to inhibit the emission of lower energy photo-electrons and bias the sensitivity towards higher energy photons. To this end, the copper support structure is biased negative.

In this configuration the blades are able to exchange photo-electrons, which would otherwise have been collected by the positively biased structure. If A is the current of photo-electrons leaving one blade, a fraction α of which flows to the opposite blade, and B is the current leaving the opposite blade, with the same fractional crosstalk, then the position signal is:

$$V = \{ (1+\alpha) (A - B) \} / \{ (1-\alpha) (A + B) \}$$

and crosstalk simply changes the sensitivity.

We set up a second detector configuration to test this idea at NSLS, X13. This is shown in figure 5, with only two vertical blades, spaced longitudinally by 2cm to allow the negative potential to penetrate between them to a significant extent.

The aim is to discriminate against photo-electrons of energy below a threshold. This would eliminate the emission of all secondary photo-electrons, which have low energy due to scattering in the bulk of the metal prior to emission, and the detector would then operate only with direct photo-electrons produced by photons of energy greater than the threshold.

Figure 7 shows the computed photo-electron yield distributions from the 10 period undulator at NSLS, X13 as a threshold of 400eV is applied to the photon energy. The effect of the threshold on the beam size is not dramatic at this low value of $K=1.65$, with a fundamental photon energy of 314eV.

With no threshold, all photons give rise to photo-electrons which are seen in the computation. With a threshold of 400eV the fundamental is suppressed and the photons and photo-electrons are seen with reduced intensity closer to the axis. We intend to use our reverse bias monitor to measure the vertical profile of this beam, and expect to see the beam appear smaller as the bias becomes more negative.

Provided that the crosstalk can be eliminated, each blade will measure the integral of the vertical profile inward from the edge of the beam to the end of the blade. As the end of the blade is moved vertically into the beam the photo-current is recorded and the derivative of this signal with respect to the direction of motion is the profile of a vertical slice through the beam.

We eliminate crosstalk by biasing either one of the two blades at +300V to inhibit its photo-emission and to serve as a collector for photo-electrons from the opposite sensing blade, after they cross the potential barrier generated by the negatively biased structure. (Two blades are installed to allow this detector also to be operated with forward bias).

Figure 8 shows the vertical profile of the undulator beam measured by this means with reverse bias of 0V, -350V and -500V. As the bias becomes more negative the vertical extent of the beam appears to be reduced. We can estimate, by comparison with Figure 7, that an applied bias of about -500V corresponds to a threshold of about 400eV. These tests indicate that a reverse bias monitor will discriminate against low energy photons and operate successfully at the ALS on undulators with large K.

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Figure Captions

1. Calculated photon and photo-electron yield distributions from an 8cm period undulator at the ALS, K=1.5. The energy of photons from the fundamental, on-axis, is 126eV. All harmonics with appreciable intensity are included.
2. Calculated photon and photo-electron yield distributions from an 8cm period undulator at the ALS, K=7. The energy of photons from the fundamental,

on-axis, is 10.5eV. The left figure shows photons from all harmonics which contribute with appreciable intensity. The middle figure shows the corresponding photo-electron yield distribution. On the right is shown the photo-electron yield distribution from photons of energy greater than 100eV, which could be used to locate the centroid of the undulator beam.

3. Schematic diagram of the monitor with blades at 45°
4. Measured photo-currents from the four blades at 45° and the derived horizontal and vertical position signals as the monitor is moved a) horizontally and b) vertically through the beam.
5. Schematic diagram of the monitor with vertical blades.,
6. Measured vertical position signal as the monitor makes 5 μ m steps through the beam, dwelling at each position for a few seconds.
7. Calculated photo-electron yield distributions from the 10 period undulator at NSLS,X13. In the lower figure, only photons with energy greater than 400eV contribute.
8. Vertical beam profile measurements made with a single blade, with various values of the reverse bias. As negative bias is applied the signal decreases, by about a factor of ten, due to the suppression of indirect photo-emission of low energy electrons. With a bias of -500V the vertical profile appears narrowed.

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Photons
 $\text{s}^{-1} \text{ mrad}^{-2} \text{ amp}^{-1}$

Photo-electrons
 $\text{s}^{-1} \text{ mrad}^{-2} \text{ amp}^{-1}$

Fig. 1.

XBL 912-6011

Fig. 2.

XBL 912-6009

Fig. 3.

XBL 912-6014

Fig. 4.

Fig. 5.

Reverse Bias, for
Profile Measurements

XBL 912-6013

Forward Bias

Fig. 6.

XBL 912-6012

Fig. 7.

XBL 912-6010

Fig. 8.

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