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An Intensity Interferometer for Soft X-rays

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We designed and built an intensity interferometer to characterize the spatial coherence of a soft x-ray undulator beam. The beam source size and shape can be determined from the measured coherence function. The instrument is 400 mm long and is mounted on a standard 204-mm diameter flange. This compact design is readily adaptable to other beamlines with sources of sufficient spectral brightness. Details of the interferometer design and performance are presented. We anticipate that when this technique is mature, it will provide a useful diagnostic for high brightness x-ray beams.

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1. Introduction

The advantages of intensity interferometry over amplitude interferometry have been discussed previously [1, 2]. Intensity interferometers are well suited to high brightness sources and are relatively immune to optical imperfections and path mismatches, making them potentially useful for x-ray beam diagnostics of undulators at third-generation storage rings. Recently, we have completed the assembly and begun testing of an intensity interferometer for soft x-rays. Measurements using the X13A and X1A soft x-ray beamlines at the National Synchrotron Light Source (NSLS) showed satisfactory performance of the various components. Both beamlines are undulator based with a peak coherent flux near 3 nm, the desired initial working wavelength of the interferometer. Extensive tests of the instruments are underway at X13A, which has been optimized for this experiment. The beamline design and performance are described elsewhere [2,3]. Once the interferometer has been demonstrated with soft x-rays, it can be operated at higher x-ray energies with few modifications.

2. Construction of the interferometer

The interferometer consists of four main components: an array of slits on a two-axis stage, a wedge-shaped beam splitter, two detector assemblies with subnanosecond time resolution, and a fast electronic correlator circuit. The first three components are operated in high vacuum inside a special chamber. The detector amplifiers and correlator circuitry are essential parts of the interferometer, although they are not located inside the chamber vacuum. A schematic view of the interferometer setup is shown in Fig. 1.

The slit array consists of twelve pairs of slits fabricated lithographically on a thin (50 μm thick) sheet of nickel foil. The 12 slit pairs are arranged horizontally. Each slit is 50 μm wide and 2 mm long; the distance between the slits varies from 100 μm to 4 mm. Because the goal of the experiment is to measure variations in intensity correlation between various parts of the beam, it is important to be able to sample the beam at different pairs of points with good isolation between the points. The estimated penetration depth for nickel is approximately 0.12 μm for 3-nm soft x-rays, therefore the nickel foil provides excellent attenuation at this wavelength. Selection of a particular slit pair is accomplished by two perpendicular vacuum-compatible piezoelectric motors (Burleigh microInchworm). The motor range of travel in the X (horizontal) and Y (vertical) directions is 50 mm and 10 mm, respectively. The X motion selects a specified slit pair, while the Y motion is required to align the slit pair with the beam splitter and detectors,

which are prealigned to the incident beam. The motors have a mechanical resolution of approximately 2 nm with a speed range of 2 nm/sec to 1 mm/sec. The Y motor is attached to the X motor through mounting brackets and a vacuum compatible ball-bearing stage (Daedal). The motors can be driven manually or under computer control. A photograph of the slit array with its holder is shown in Fig. 2.

The undulator radiation at X13A is highly collimated with a vertical divergence angle $\Sigma_y \approx 85 \mu\text{rad}$. In order to gain access to the closely spaced beams that are transmitted by the slits, we employ a beam splitter to increase the separation of the beams. The beam splitter is made of fused quartz and is manufactured by Photon Sciences, Inc. It is 5 mm wide at the base, 48 mm tall from the base to its tip, and subtends 3° to the incident beam. To enhance the x-ray reflectivity, its surface is coated with 400 Å of gold with a roughness of less than 5 Å rms. The Fresnel reflectivity of the beam splitter, calculated using the program XCAL [4], is shown in Fig. 3 for incident x-ray wavelengths ranging from 10 to 100 Å. The reflectivity at 3 nm is approximately 50%. A weak-link tilt stage and ball-bearing translation stage facilitate alignment of the beam splitter to the detectors.

Because the signal-to-noise ratio of the measured correlation signal is proportional to the square root of the bandwidth of the detecting electronics [5, 6], it is important to use the fastest x-ray detectors available. We chose microchannel plates (MCPs) for their high gain (10^4 for a single plate) and short response time (≤ 1 ns). The plates we used are of the High Output Technology (HOT) type manufactured by Galileo Electro-optics Corporation. The channel diameter is 10 μm with a channel-to-channel spacing of 12 μm , and the length-to-diameter ratio (L/D) is 40. The peak gain per plate is near 4000 according to manufacturer's specifications.

In order to eliminate terminal reflection at the electron collector following the MCP, we designed special MCP holders that provide a good impedance match between the anode and 50 Ω coaxial cabling [2]. Fig. 4 is a cross-sectional view of the holder. Both the inner and outer cones are made of aluminum. The MCPs are held between type 304 stainless steel plates. BNC connectors and 50-ohm Teflon cabling are used to join the anode (inner cone) to 50 Ω vacuum feedthroughs. A small amount of solder was used to simplify the connections.

The overall dimensions of the interferometer were kept small for convenience and ease of handling. The detectors are mounted on a 1-mm-thick stainless steel plate; the slits and beam splitter are mounted on two 13-mm-thick aluminum plates. A 3 mm x 5 mm entrance aperture in another 1-mm-thick plate, coated with P31 phosphor, admits the x-ray beam onto the slits. All

four plates are rigidly supported by three 9.5-mm-diameter stainless steel rods directly threaded into a standard 204-mm main flange. Fig. 5 shows the assembled interferometer without the entrance aperture installed. The instrument is contained in a cylindrical vacuum chamber 400 mm long and 150 mm in diameter, with two 204-mm ports and several 70 mm ports for roughing, vacuum gauges, and alignment purposes (Fig. 6). The typical base pressure in the experimental chamber is 2×10^{-8} Torr using a 45-l/s ion pump. A kinematic assembly supports the experimental chamber and provides the six degrees of freedom required for alignment of the interferometer to the x-ray beam. The interferometer is presently mounted on the X13A beamline on a granite optical table.

The theory and a working version of the electronic correlator were first worked out by Hanbury Brown and Twiss [7] and later by Allen and Frater [8]. We adopted their approach with newer electronics and detectors to obtain better stability and greater bandwidth.

The signal processing electronics consist of fast amplifiers, a mixer, and an integrator. The detected signals are amplified by two preamplifiers (Phillips Scientific type 6954) with a gain of 100 and bandwidth of 2.2 GHz located immediately outside the BNC electrical feedthrough on the main flange. A double-balanced mixer (Mini Circuits type ZAD-1-1) multiplies the amplified signals from the two MCP detectors to obtain the correlation signal. The mixer output is integrated by a low-pass filter (3.3 s time constant), passed through a voltage-to-frequency (V/F) converter, then read by a scaler under CAMAC control. Simultaneously, the average detector currents are monitored via current amplifiers, V/F converters, and the scaler. Once in digital form, the detector and correlation signals can be integrated by computer for arbitrarily long times without degradation. Depending on the coherence of the x-ray beam, selecting a pair of slits with narrower or wider spacing results in a change in the integrated correlation signal.

3. Performance

We performed extensive tests of the detectors using 2.2-nm soft x-rays [2]. The measured FWHM pulse width after the amplifiers is about 1.1 ns. Because the overall response time of the electronics is also near 1 ns, we conclude that the response time of the detectors is at least that fast. With an overall detector and correlator bandwidth of ~ 1 GHz, we expect to be able to make beam coherence measurements at X13A on time scales of several minutes.

Nonetheless, the stability of the detectors and correlator is of concern because noise and drift over the integration period adversely affect the correlation signal-to-noise ratio. Using a crystal-

controlled function generator to supply signals of constant frequency and amplitude to the detector amplifier inputs, we determined that the correlator output is stable to within 0.1% over 10 min (Fig. 7).

The beam splitter and detectors have been prealigned to each other outside vacuum using a He-Ne laser to ensure unobstructed light paths for the x-rays. After the chamber is evacuated, the only in-vacuum adjustment necessary for operation of the interferometer is positioning of the slit pairs on the X-Y stage. Alignment of the interferometer to the beam has proven to be straightforward. Once the x-ray beam is visible on the phosphor-coated aperture, the slits are easily and rapidly aligned to obtain equal intensity signals at the detector outputs.

4. Conclusion

Intensity interferometry is a promising method for x-ray beam coherence measurement and insertion device source diagnostics. To demonstrate this technique, we have constructed a novel intensity interferometer for soft x-rays, tested its components, and have begun to make correlation measurements with it at the X13A undulator beamline. When it has matured as a diagnostic, we anticipate that x-ray intensity interferometry will find practical application in characterization of high brightness x-ray sources at third-generation storage rings.

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Figure Captions

Fig. 1. Schematic view of the interferometer with respect to the undulator beam. The size of the beam relative to the interferometer is much smaller than shown. The interferometer is located approximately 25 meters from the undulator source at beamline X13A.

Fig. 2. Photograph of the slit array. The thin nickel substrate is supported by a steel frame.

Fig. 3. Calculated reflectivity of the gold-coated beam splitter.

Fig. 4. Cross-sectional view of the MCP holder and position of a MCP within it.

Fig. 5. The assembled interferometer: (a) slit array on its holder; (b) X-Y stage, the Y motor is blocked by the mounting brackets right above the X motor; (c) beam splitter on its alignment stage; (d) MCP detectors; (e) main flange.

Fig. 6. External view of the interferometer: (a) ion pump; (b) electrical connections for the X-Y stage; (c) detector outputs.

Fig. 7. Stability of the correlator using stable inputs from a function generator.

FIG. 1

Dimension: cm

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