Intensity Interferometry and Its Application to Beam Diagnostics

Efim Gluskin, Advanced Photon Source, APS/360,
Argonne National Laboratory, Argonne, IL 60439

Abstract

This paper presents an approach for the measurement of the particle beam size based on x-ray intensity interferometry. Two technically feasible schemes are proposed and analyzed. This type of interferometer will provide a resolution of a few tenths of a micron for a positron beam that emits undulator radiation. The minimum required time for the measurement is about 30 sec*.

I INTRODUCTION

Intensity interferometry as introduced and developed by H.Brown and R.Twiss [1,2] has widespread application now in different areas of physics [3,4], with one of the most successful application in laser physics due to high spectral power laser source [5]. The possibilities of intensity interferometry in the x-ray region are discussed elsewhere [6], but it appears useful to consider it again because of the creation of third-generation synchrotron radiation (SR) sources. The main goal of these sources is the utilization of the radiation from special insertions devices providing high spectral power in the x-ray wavelength region. Intensity interferometry could be an adequate tool for the particle beam diagnostics, as well as an instrument for the characterization of the coherent properties of x-ray radiation. Some possibilities for the use of intensity interferometry for synchrotron radiation sources have already been discussed [7,8]. However, it is essential to consider real technical schemes for applications in sources that exist now and are under costruction. This paper discusses an undulator at Advanced Photon Source as a source for intensity interferometry.

II. SR INTENSITY INTERFEROMETER

Fig.1 presents a simplified scheme for an intensity interferometer.

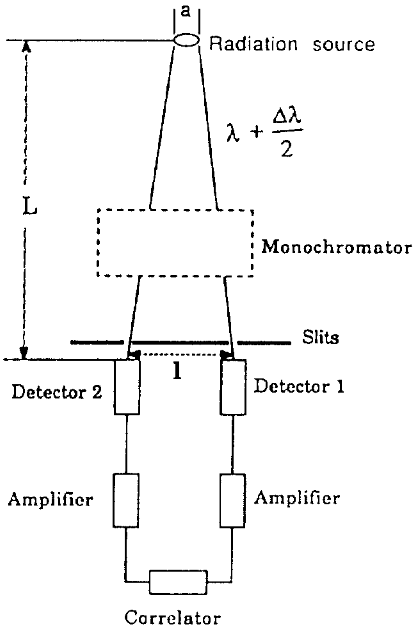

Fig. 1 Intensity interferometer scheme: a-source size,, L-distance source-detector, l-distance between slits, λ-wavelength, Δλ–wavelength bandwidth.

The signals from two "square law" detectors are amplified and multiplied together in the linear mixer. The average value of the product gives a measure of correlation in the fluctuations. The main result of the Brown-Twiss effect consists of the dependence of this product on the relative position of the slits in front of the detectors: the correlation is increased when slits are placed in the area coherently illuminated by the source.

Two of the main characteristics of the experimental scheme should be mentioned here: the coherent time of the source

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$\tau_{coh} \sim \lambda^2/(\Delta\lambda c)$ and the resolving time τ_0 of the correlator which should be smaller than the reverse value of the amplifier bandpass. The relation between these parameters defines what kind of the experimental technique should be chosen for the signal detection. In the case $\tau_0 << \tau_{coh}$ the counting technique would be adequate, and if $\tau_{coh} << \tau_0$ the average current from the detector should be measured [9].

Before starting the comparison of these two different techniques we need to determine the optimum wavelength for the measurements, selecting as a source the Advanced Photon Source 7-Gev storage ring. The diffraction limit defines the relation between the source size a and the angular diveregence θ of the radiation:

$$\theta \cdot \Delta a \geq \lambda$$

But from other side:

$$\theta \cong \frac{1}{\gamma\sqrt{N}}$$

where N is the number of undulator periods and γ is the relativistic factor. As a result:

$$\Delta a \sim \lambda \gamma \sqrt{N}$$

and for APS:

$$\gamma \sim 10^4,\ \sqrt{N} \sim 5,\ \Delta a \sim 10^{-4}\ \text{cm}$$
$$\lambda \sim 1\ \text{Å}$$

The wavelength practically defines the type of the monochromator that can be used for the measurements. This is the crystal type monochromator. Recently a significant step in x-ray monochromatization was made by inventing of the nuclear-Bragg scheme [10,11]. As a result, a level of monochromatization of $\Delta\lambda/\lambda \sim 10^{-12}$ was achieved. Consequently, the feasible coherent time now is about 10^{-7} sec. This time is certainly larger than resolving time of the contemporary registration instrumentation and the counting technique is convenient. With the spectral flux from the APS undulator [12] of about 10^{21} p/s the detector counting rate N_d will be about 10^4 c/s and a coincidence rate $N_C \sim \tau_{coh} N_d^2$ of about 10 c/sec can be achieved. A beam size measurement time of about 20-60 sec seems realistic.

In the case of the crystal monocromator utilization the coherent time is equal 10^{-15} sec for the 1 Å wavelength radiation. This value is much smaller than typical resolving time for the amplifier, so the "current technique" should be chosen. The time measurement T can be estimated as follows:

$$T >> \frac{\tau_0}{\left(\frac{N_d \lambda^2}{c\,\Delta\lambda}\right)^2}$$

and is for the APS undulator radiation about 30-100 sec.

The spatial resolution of the beam size measurement does not depend what kind of registration technique is used and can expressed in the following form:

$$\Delta a = \frac{\Delta l\, a^2}{L\,\lambda}$$

It should be noted here that the approach considered in this paper is valid if

$$\theta \cong \frac{1}{\gamma\sqrt{N}} > \theta_{coh} \sim \frac{\lambda}{a}$$

For the APS undulator this condition is satisfied.

III CONCLUSION

The feasibility of intensity interferometry for the APS undulator has been demonstrated. In addition, it has been shown that both an acceptable time scale for measurements and the spatial resolution are readily achievable.

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