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X-RAY DOUBLE SLIT INTERFEROMETER PROGRESS AT CLS

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Abstract

The Canadian Light Source (CLS) is a 3rd generation synchrotron that is used to produce extremely bright synchrotron light that can be used for research. The light at the CLS is produced by an electron storage ring which has an emmitance of 20 nm. A 4th generation synchrotron (CLS2) is planned which will reduce the emmitance to less than 1 nm and thus reduce the transverse beam size significantly, making it very challenging to measure. A double slit interferometer can be used to measure small transverse beamsizes, as first described by Mitsuhashi. An x-ray double slit interferometer will be designed and tested at the current CLS with the goal of using this setup at CLS2.

INTRODUCTION

Measuring the transverse beamsize of storage rings is a standard diagnostic measurement that can be done in a variety of ways in 3rd generation synchrotrons, including the Canadian Light source (CLS). Plans are underway for a 4th generation light source, CLS2 [1]. Since the beamsize will decrease in CLS2 as shown in the appendix, a new method will be necessary to measure the beamsize. One way is the double slit interferometer as first described by Mitsuhashi [2, 3]. A diagram of the double slit setup is shown in Fig. 1.

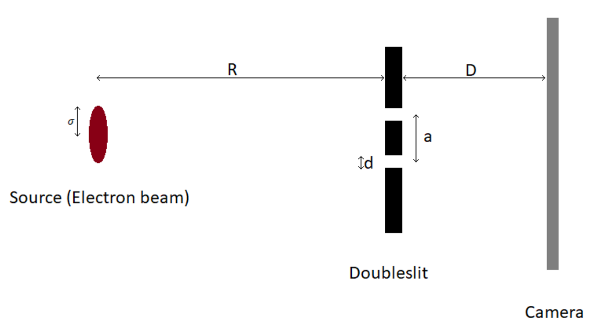

Figure 1: Double slit layout.

THEORY

There are two major approximations that can be used to understand the double slit interferometer: the Fraunhofer and Fresnel approximations.

Fraunhofer

The Fraunhofer (or far-field) approximation is valid if the distance the light travels is much larger than the square of the aperture size. It can be shown that the diffraction pattern in the Fraunhofer regime as a function of space at the detector, $I(y)$, can be given as follows

$$I(y) = 2I_0 sinc^2\left(\frac{\pi d}{\lambda D}y\right)\left[1 + V\cos\frac{2\pi a}{\lambda D}y\right], \quad (1)$$

where I_0 is the intensity at the center of the distribution, d is the slit width, λ is the wavelength of the incoming light, a is the slit separation, D is the slit to screen length, and y is the transverse spatial coordinate. V is the visibility of the intensity distribution can found from the intensity distribution with Eq. (2)

$$V = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}. \quad (2)$$

I_{min} and I_{max} are neighbouring local maxima and minima of the intensity distribution. The source size σ can be found as follows

$$\sigma = \frac{\lambda R}{\pi a}\sqrt{\frac{1}{2}\ln\frac{1}{V}}, \quad (3)$$

where R is the source to slit distance.

Fresnel

The Fresnel (or near-field) approximation is valid for the Fraunhofer conditions. In addition to these conditions, the Fresnel approximation is valid if the following conditions are met. Firstly, the wavelength of the light must be much smaller than the aperture size and the distance travelled. Secondly, if the light does not change much in angle, the following condition must be met

$$\frac{(y - y')^4}{8D^3\lambda} \ll 1, \quad (4)$$

where y' is the transverse spatial coordinate at the aperture. If these conditions are met, the electric field diffraction pattern is given as

$$E(y,z) = \frac{\exp(ikD)}{iD\lambda}\exp\left(\frac{iky^2}{2D}\right)\cdot \int E(y',z'=0)\exp\left(\frac{ikyy'}{D}\right)dy', \quad (5)$$

where z and z' are the forward spatial coordinate at the detector and aperture respectively. The intensity diffraction pattern is simply the electric field diffraction pattern squared. This follows the Van-Cittert Zernike theorem that links the propagated waves degree of coherence to the Fourier transform of the initial wave [4].

SIMULATIONS

Using the theory explained above, simulations were done to show the intensity distributions and associated source

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sizes. Both Fraunhofer and Fresnel approximations were used. The theory also assumes the light is monochromatic but the light will always have an energy spread. The simulations took this into account by having the light always have an intensity distribution and simulating the diffraction pattern of all the different energies before adding them up. Figure 2 shows a typical intensity distribution. From the distribution and Eqs. (2) and (3), the beam size is calculated to be 68 µm.

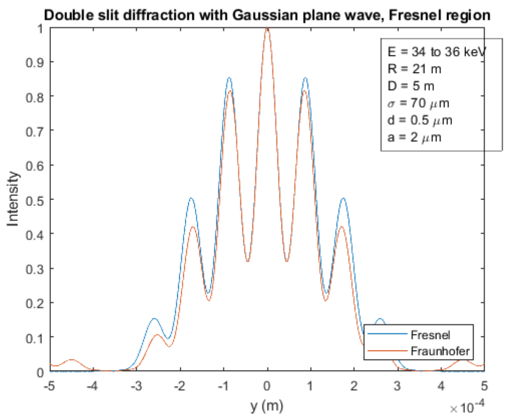

Figure 2: Typical intensity distribution.

OPTIMIZATION

A suite of computer programs was written to optimize the layout parameters. The first thing optimized for was the sensitivity of the layout. This was done by maximizing the change in visibility across the range of expected source sizes. Care had to be taken to ensure the local minima disappeared which would make calculating the visibility impossible. Figure 3 shows visibility as a function of slit separation for different source sizes.

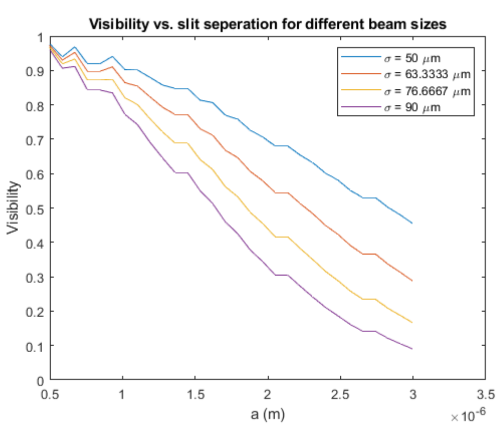

Figure 3: Visibility versus slit separation.

The parameters also had to be optimized to reduce the error in the calculated source sizes. There is two major sources of error: pixel size and photon energy spread. The distances between the adjacent maxima and minima is on the order of micrometers, making the pixel size non-negligible. Another source of error comes from the energy spread of the light which is assumed to be zero in the theory. Figure 4 shows the error in the source size calculated from the interference pattern as a function of slit separation for various source sizes. The optimization process was done for the BMIT-BM beamline at the CLS. The resulting parameters are shown in Table 1.

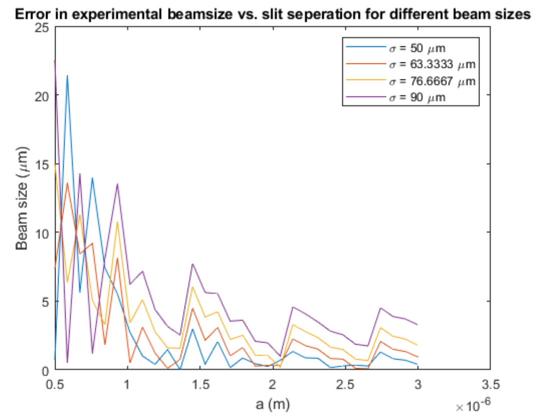

Figure 4: Error versus slit separation.

Table 1: Parameters for BMIT-BM

Name	Symbol	Units	Value
Photon Energy	E_γ	keV	35±1
Slit width	d	µm	0.5
Slit separation	a	µm	2.5
Source-slit distance	R	m	21
Slit-screen distance	D	m	5
Source size	σ	µm	70±20
Slit thickness	T	µm	300

PROCUREMENT OPTIONS

Different options for procuring the double slit are under consideration. The most promising option is to get them manufactured using a focused ion beam. This allows for small slits with straight edges but are limited to how deep the slits can be. Another option is to use iron milling but the small slit sizes necessary may make this unfeasible. Lithography is being explored but the necessity of straight edges may also make this unfeasible. Purchasing the double slit is an option if they meet the specifications.

CONCLUSION

New equipment will be needed for source size measurements for CLS2 and a double slit interferometer is capable of doing this. Fraunhofer and Fresnel approximations can work for this setup that can be simulated in computer programs. The parameters can be optimized by maximizing the visibility sensitivity to change in source size and minimizing the error in the calculated source size. Various options are being considered for procuring the double slit.

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APPENDIX

Beam size is rarely stated explicitly in machine design papers but can be calculated from other beam parameters. The equation for beam size, as described by Wille, is as follows

$$\sigma = \sqrt{\epsilon \beta}, \tag{6}$$

where ϵ is the emittance and β is the beta function [5]. Using parameters given for CLS2, the source size varies from less than 12 µm to 87 µm depending on the number of magnets that will be used, where the beam is measured, and whether the the vertical or horizontal beam size is measured [1].

REFERENCES

[1] L. Dallin and W. Wurtz, "Towards a 4th generation storage ring at the Canadian Light Source", *AIP Conference Proceedings*, vol. 1741, p. 020034, 2016. doi:10.1063/1.4952813

[2] T. M. Mitsuhashi, K. Oide, and F. Zimmermann, "Conceptual Design for SR Monitor in the FCC Beam Emittance (Size) Diagnostic", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, pp. 133-136. doi:10.18429/JACoW-IPAC2016-MOPMB022

[3] T. Mitsuhashi, "Spatial Coherency of the Synchrotron Radiation at the Visible Light Region and its Application for the Electron Beam Profile Measurement", in *Proc. 17th Particle Accelerator Conf. (PAC'97)*, Vancouver, Canada, May 1997, paper 3V016, pp. 766-768.

[4] F. Zernike, "The Concept of Degree of Coherence and its Application to Optical Problems", *Physica*, vol. 5, pp. 785-795, Aug. 1938. doi:10.1016/S0031-8914(38)80203-2

[5] K. Wille, *The Physics of Particle Accelerators: An Introduction*, New York, NY, USA: Oxford UP, 2000.