MEASUREMENT OF BEAM SIZE AT THE ATF DAMPING RING WITH THE SR INTERFEROMETER

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Abstract

The beam size at the ATF damping ring was measured by the use of the SR interferometer. The spatial coherence of the visible SR beam (λ=500nm) was measured for both of the vertical and horizontal directions. From the measured spatial coherence of the SR beam, ATF beam size measurements of 14.8µm in the vertical and 39 µm in the horizontal were obtained. The observed horizontal beam size agreed with the estimated beam size.

1. INTRODUCTION

The ATF damping ring (ATF DR) aims to demonstrate the technical feasibility of the low-energy parts of next-generation electron-positron linear colliders by producing an electron bunch train with extremely small emittance[1]. The target equilibrium beam emittance is designed to be 1 nm-rad. The estimated beam sizes are 40µm in the horizontal and 6µm in the vertical directions (1% coupling is assumed) at the source point of the SR monitor. It is challenging to measure such extremely small beam sizes. The SR interferometer, which was developed by one of the authors, has good sensitivity for small beams. Since this method is based on the spatial coherence of the SR beam, it is suitable for measuring small electron beam sizes. The principle of object-profile measurement by means of the spatial coherency of the light is known as van Citterut-Zernike's theorem[2]. It is well known that A. A. Michelson measured the angular diameter of stars with his stellar interferometer. Recently, this principle was applied to the measurement of the vertical electron beam profile in the storage ring by one of the authors by the use of the SR interferometer[3],[4]. In this paper, we apply this technique to the measurement of both the vertical and the horizontal beam sizes at the ATF damping ring.

2. SPATIAL COHERENCE AND BEAM SIZE

According to van Citterut-Zernike's theorem, the profile of an object is given by the Fourier Transform of the complex degree of spatial coherence at large wavelengths. Let f denote the beam profile as a function of angular diameter Θ, and γ denote the complex degree of spatial coherence as a function of distance D to the double slit of the interferometer. Then γ is given by the Fourier transform of f as follows;

$$\gamma(D) = \int f(\Theta)\exp(-ikD\Theta)d\Theta \, . \qquad (1)$$

The interferogram which is observed with the SR interferometer (see Fig.1, below) is given by

$$I(\theta) = (\sin c(\theta))^2 \{1 + |\gamma(D)|\cos[kD(\theta+\varphi)]\}, \qquad (2)$$

where θ denotes the observation angle of the interferogram, the *sinc* function gives the single-slit diffraction pattern, and φ denotes the phase of the interference fringe. Using equation (2), we can measure the degree of spatial coherence from the interferogram. Using equation (1), under the assumption of a gaussian beam profile, we can measure the RMS beam size from the interferogram.

3. SR INTERFEROMETER

The SR interferometer is basically a wavefront-division-type two-beam interferometer using polarized quasi-monochromatic rays. A schematic drawing of the SR-interferometer is shown in Fig.1.

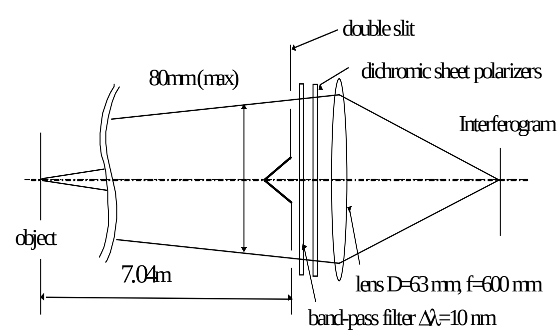

Fig.1 Outline of the SR interferometer.

We use an aperture of 1(width) x 2(height) mm^2 for the double slit assembly. A diffraction limited doublet lens having a diameter of 63mm and a focusing length of f=600mm was used as an objective. A dichroic sheet polarization filter (extinction ratio: 10^{-4}) and a band-pass filter of 40nm bandwidth at 500nm was used to obtain a polarized quasi-monochromatic ray. A magnifier lens (5x) and CCD camera (SONY SSC-M370) were used to observe the interferogram. The distance between source point and double slits of the SR interferometer is 7.04m.

4 . VERTICAL BEAM SIZE MEASUREMENT

4-1. Measurement of the absolute value (visibility) of the complex degree of spatial coherence in the vertical direction.

The interferogram for the vertical direction was measured at a branch beamline of the SR monitor. The opening angle of the SR monitor light path was limited to 5mrad by the opening of the vacuum duct for the bending magnet. This opening angle limits the measurement of interferograms to a maximum double-slit separation of 35.2mm. Under these conditions, the interferogram was measured by changing the distance D between the two slits from 5mm to 30mm in 0.5mm steps. Two examples of observed interferograms are shown in Fig.2.

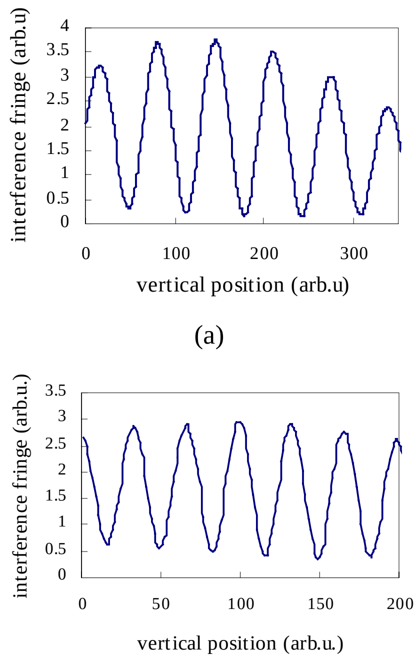

Fig. 2. Observed vertical interferograms taken at double-slit separations of (a) 6mm, and (b) 16mm.

From Fig.2, we can see that the contrast of the interference fringe is reduced when the double-slit separation is increased, due to the finite size of the beam.

4-2. Evaluation of vertical beam size from spatial coherence measurement.

The absolute value of the complex degree of spatial coherence is evaluated from the visibility of the observed interferogram. The results are shown in Fig. 3. Under the assumption of a gaussian beam profile, we can evaluate the RMS beam size from the degree of spatial coherence. Least-squares fitting of the degree of spatial coherence for a gaussian beam profile is also shown in Fig.3. The result of the beam size from this fitting is 14.8 ±0.7μm.

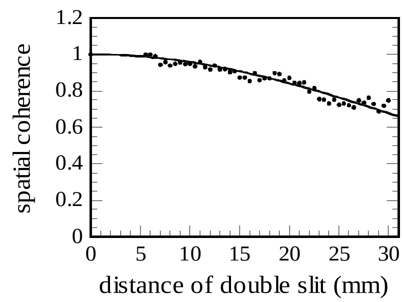

Fig.3. Absolute value of the complex degree of spatial coherence in the vertical direction. Dotted line denotes measured |γ|, and solid line denotes the best-fit beam size of 14.8 ±0.6μm.

5 . HORIZONTAL BEAM SIZE MEASUREMENT

5-1. Measurement of the absolute value (visibility) of complex degree of spatial coherence in the horizontal direction

The absolute value of the complex degree of spatial coherence for horizontal direction was measured in the same way as in the vertical direction, but with the double-slit assembly rotated by 90°.

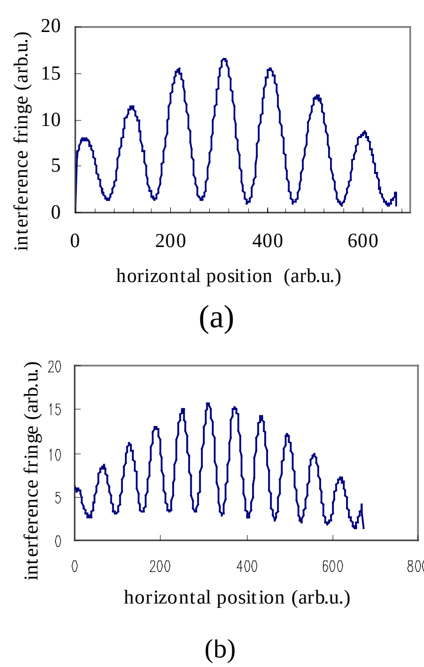

Fig. 4. Observed horizontal interferograms taken at double-slit separations of (a) 6mm, and (b) 10mm..

The interferogram was measured by changing the distance D between the two slits from 6mm to 35mm in 1mm steps. Two examples of observed interferograms are shown in Fig. 4.

5-2.Result of Degree of Spatial Coherence and Horizontal Beam Size

The absolute value of the complex degree of coherence is evaluated from the visibility of the measured interferogram. The results are shown in Fig. 5.

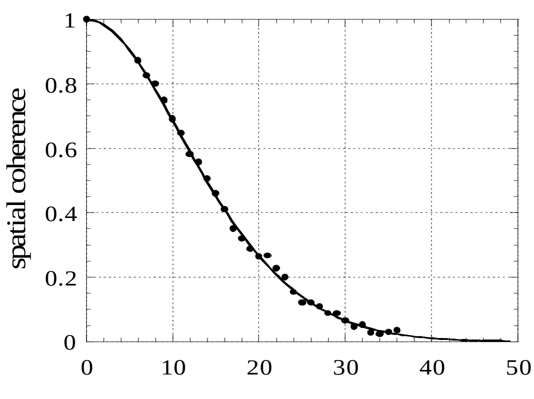

Fig.5. Absolute value of the complex degree of spatial coherence in the horizontal plane. The dotted line denotes measured |γ| and the solid line denotes the best-fit value of 39±1μm.

In the measurement of the spatial coherence of the SR beam in the horizontal direction, we must take into account the effects of field depth. The configuration of the measurement in the horizontal direction is shown in Fig. 6.

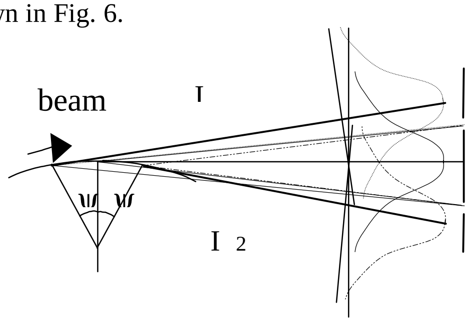

Fig.6 Geometrical configuration of the horizontal beam size measurement.

Two effects are introduced by the field depth. One is an effect of curvature of the trajectory in the bending magnet, and the other is an imbalance between the intensities of the two modes of light that illuminate the double slit of the interferometer, as shown in Fig. 6. Then |γ| will be given by,

$$|\gamma| = \iint \frac{2\cdot\sqrt{I_1(\psi)\cdot I_2(\psi)}}{I_1(\psi)+I_2(\psi)}\cdot f(x-\rho(1-\cos(\psi)))\cdot g(\psi)d\psi dx \quad (3)$$

where *G* denotes the angular distribution of the SR beam in the horizontal plane as a function of observation angle ψ, I_1 and I_2 denote intensities of the two modes of the light that illuminate double slit of the interferometer, *f* denotes the beam profile distribution, ρ denotes the bending radius and *F* denotes the distance between the source point and the double slit. The first term in Equation [3] represents the imbalance between the intensities of the two modes of light and the second and third terms represent the convolution of the effect of curvature of the trajectory. In this calculation we assumed a gaussian distribution for both the beam profile *f(x)* and the angular distribution of the SR beam *G(ψ)*. By fitting Equation (3) to the observed |γ|, we can obtain the RMS beam size in the horizontal direction. The result of such a fit is also shown in Fig.5. From this fit, we obtained a horizontal beam size of 39±1μm.

6. CONCLUSIONS

The vertical and horizontal beam sizes of the ATF damping ring were measured via SR interferometer. We conclude the vertical beam size is 14.8μm and the horizontal beam size is 39μm. The estimated beam sizes from the designed emittance are 40μm (using design values of energy spread and measured β and η−functions) in the horizontal and 6μm in the vertical (1% coupling is assumed). The observed beam size in the horizontal direction agreed with the estimated beam size. The observed vertical beam size is 2.5 times larger than the estimated beam size which assumed 1% coupling.

The SR interferometer is now used as a conventional monitor for emittance tuning at the ATF damping ring.

7. ACKNOWLEDGMENTS

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