IMPROVEMENT OF THE RESOLUTION OF SR INTERFEROMETER AT KEK-ATF DAMPING RING *

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Abstract

Some of the improvements have been done for an SR interferometer with the Herschelian reflective optics at the ATF damping ring. Previously, the measured vertical beam size reached to 5μm with 40mm double slit separation and wavelength of 400nm. Double slit separation was mainly limited to the aperture of the optical path between the source point and the interferometer. This time, we re-aligned the optical path to obtain larger aperture. After the re-alignment, we could apply a double slit separation up to 60mm. To reduce the air turbulence, the optical path is covered with an air tight duct. After these improvements have been done, we investigated how small bam size can be measured by the SR interferometer. The effects of the measurement errors were emphasized at higher visibility. Unbalanced interferometory was tested to reduce the effect of the measurement errors. The preliminary result is presented.

INTRODUCTION

The damping ring(DR) of the KEK-ATF has been designed to produce extremely low emittance beam for linear collider.[1] The beam energy is 1.3GeV. The design vertical emittance(ε_y) is 1x10^{-11}m when assuming 1% coupling. The expected beam size for the vertical is 5.5μm, at the location of the beam size monitor. The beta function at the location is 3m for the vertical. The beam size monitor needs to have enough resolution for 5.5μm measurement. We already developed Synchrotron Radiation(SR) interferometer using a visible light[2][3][4]. The improved version using the Herschelian reflective optics could measure 5μm of the beam size [5][6]. The schematic layout of the SR interferometer is shown in Figure 1. The tuning effort of the DR for the vertical emittance is aiming to reduce the emittance less than 1x10^{-11}m. In this case, the vertical beam size reduces to 4μm(ε_y=5x10^{-12}m) or 3μm(ε_y=3x10^{-12}m). The SR interferometer needs to have the capability of the enough resolution to measure less than 3+/-1μm of the beam size. The improvements of the SR interferometer were, 1) the optical path was re-aligned to increase the optical aperture and 2) the optical path was covered with an air tight duct to reduce the air turbulence effect. After these treatments, the resolution for the SR interferometer was measured by changing the 'apparent' beam size. The visibility in the case of 5μm of the beam size is 0.8 at previous measurement. We tried to measure same beam size with higher visibility, which corresponds to change the beam size to small. We called the measured beam size as the 'apparent' beam size.

The measurement errors, i.e., CCD noise, imperfectness of optical devices, intensity unbalance of the incident light, etc., are emphasized at the higher visibility of the interferogram. To elliminate the measurement error, an unbalanced interferometry was tested. The unbalanced incident light makes a lower visibility of the interferogram, which means that the interferogram effectively reduces the measurement error.

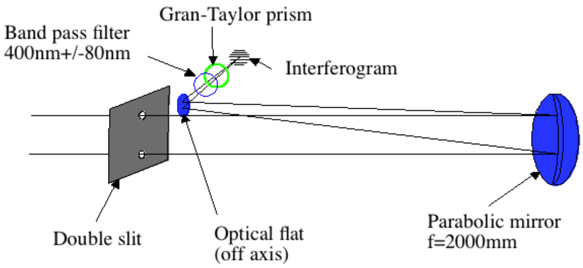

Figure 1: Schematic layout of SR interferometer with Herschelian reflective optics

MEASUREMENT WITH LARGER SLIT SEPARATION

The intensity distribution of the light source is given by Van Citert-Zernike's theorem [7], i.e. the Fourier transform of the complex of degree of the spatial coherence γ. When the profile of the object can be assumed to the Gaussian distribution and the RMS object size of the light source σ is described as ,

$$\sigma = \frac{\lambda L}{\pi D}\sqrt{\frac{1}{2}\ln\left(\frac{1}{\gamma}\right)}, \qquad (1)$$

where λ is the wavelength, D is the double slit separation and L is the distance from the object to the double slit. The visibility is calculated as ,

$$V = \frac{2\sqrt{I_1 \cdot I_2}}{I_1 + I_2}|\gamma|, \qquad (2)$$

where I_1 and I_2 are the intensities of the incident light for each slit. When I_1 and I_2 are equal, the absolute value of the spatial coherence γ is equal to the visibility V. When I_1 and I_2 are not equal, figure 2 shows the simulated visibility as a function unbalance ratio of the incident

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light given by equation (2). The unbalance ratio is the ratio of I_1 and I_2. The visibility is not so sensitive with the unbalance ratio. For example, when I_1 and I_2 are 1 and 0.9, then the visibility reduces to 0.998, which corresponds to 0.4μm of the beam size. It is not so difficult to adjust the unbalance ratio over 0.9.

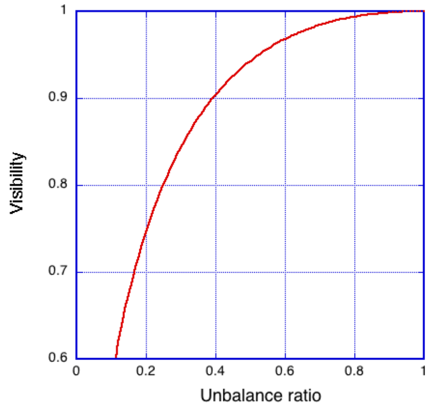

Figure 2: Visibility as a function of unbalance ratio

The difficulty of the small beam size measurement is that the errors, CCD noise, imperfectness of optical devices, intensity unbalance of the incident light, etc., are emphasized at the higher visibility of the interferogram. Therefore, to eliminate these errors, the measurement parameter should be set the visibility range from 0.3 to 0.9.

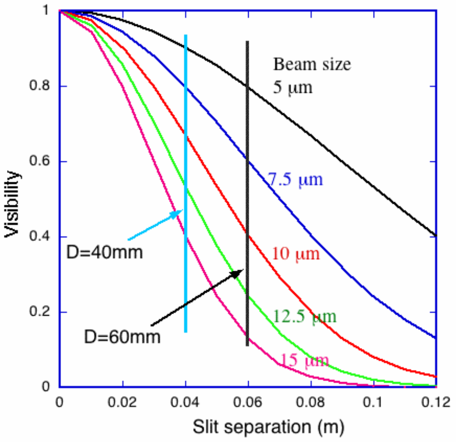

Figure 3: Visibility for each beam size

Figure 3 shows the simulated visibility as a function of the slit separation for each beam size in the case of λ=400nm and L=7m. The wavelength was limited to 400nm due to the transmittance of the optical components. To use lower visibility, the wider slit separation should be used. The opening angle of the SR for the vertical direction is about 10 mrad for 400nm wavelength, which correspond 70mm at 7m from the source point. However, the previous measurement used 40mm slit separation by the limitation of the aperture of the optical path. There are four mirrors in the optical path from the source point to the double slit. The SR does not go through the center of the mirror. We carefully re-aligned the optical path. As a result, we could use 60mm slit separation. In the case of 5μm beam size measurement using 60mm slit separation instead of 40mm, the visibility will change from 0.90 to 0.79.

The interferogram image is sometimes smeared by the air turbulence, which deteriorates the beam size measurement. When the slit separation is enlarged, the air turbulence effect is emphasized, because the interferogram fringe becomes more fine. To reduce the air turbulence, the optical path was covered with an air tight duct and the end of the air duct was shielded using an optical window.

BEAM SIZE MEASUREMENT BY CHANGING THE VISIBILITY

After these improvements have been done, we tried to measure the beam size by changing the visibility. The ordinary beam size of the ATF is 6μm, which correspond to 1.1 x 10^{-11}m emittance. It is very difficult to prepare smaller than 5μm of the beam size, to obtain higher visibility. When the slit separation D is decreased, the visibility (γ) approaches to 1 in the equation (1), which correspond to the apparent beam size becomes small. If the SR interferometer has infinite resolution, when the slit separation is set to zero, the measured apparent beam size becomes zero.

The actual measurement assumes that the size of the source is constant, the intensity imbalance is negligible, the imperfectness of optical devices is negligible and the CCD noise is constant by the whole area.

In the figure 4, red line shows the measurement and dashed line shows the prediction of the infinite resolution as a function of the slit separation. The measurement becomes larger value below 5μm beam size compare to the prediction, but not saturated. The measurement reached to 3μm at 20mm slit separation.

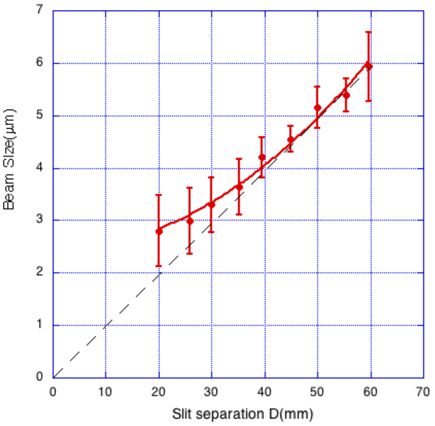

Figure 4: Beam size as a function of the slit separation

MEASUREMENT WITH UNBALANCE MODE

As mentioned in the previous section, the higher visibility is affected by the measurement error. The plot of the figure 4 agrees with the prediction. When use different intensities of the incident light, I_1 and I_2, we can reduce the apparent visibility. Figure 5 shows the calculation of the visibility as a function of the beam size in the cases of the unbalance ratios are 1:1 and 1:0.3 when the other parameters are λ=400nm, slit separation 60mm and L=7m. The maximum visibility is reduced from 1 to 0.86 at the zero beam size.

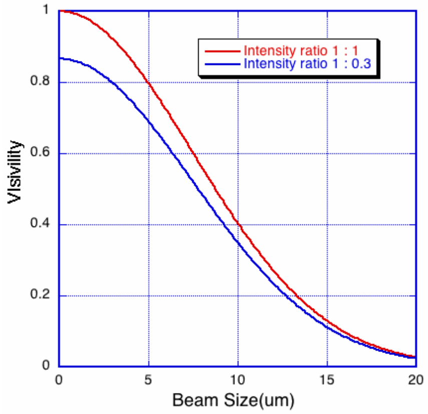

Figure 5: Visibility as a function of the Beam size in the cases of the unbalance ratio 1:1 and 1:0.3.

We changed the intensity balance by using neutral density filters. To make same optical path length, two carefully calibrated neutral density filters, which have different transparency ratios of 0.853 and 0.249, were used. The unbalance ratio was 0.292. It was very difficult to set the neutral density filters on the same angle in the hand made fixture. We measured the data at 30mm slit separation. In the figure 6, the blue point shows the unbalance mode measurement. The apparent beam size of 3µm has been measured with the unbalanced mode at 30mm slit separation. The improvement of the resolution was confirmed.

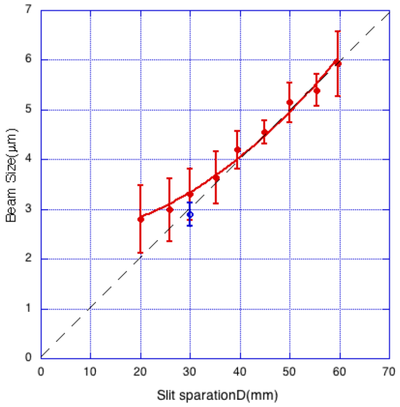

Figure 6: Beam size with and with out unbalance mode

SUMMARY

The resolution of the SR interferometer was measured after some improvements have been done. The apparent beam size was 3µm, which means that when we measured with 60mm slit separation, 3µm of the beam size can be measured. Unbalance mode of the SR interferometer was tried as one of the ideas for improving the resolution. The improvement of the resolution was confirmed, however, it was just trial. The measurement will be repeated in the near future using special neutral density filters, which has two different transparency ratios on the same base.

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