VERY SMALL BEAM SIZE MEASUREMENT BY REFLECTIVE SR INTERFEROMETER AT KEK-ATF

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Abstract

An SR interferometer with the Herschelian reflective optics has been developed for the measurement of several μm beam size. In the ordinal refractive SR interferometer, the chromatic aberration of the objective lens will limit smaller range of beam size measurement. To remove such problem, we designed the Herschelian arrangement of reflective optics for the interferometer. The measured vertical beam size was less than 4.7μm and the estimated vertical emittance was $0.97\mathrm{x}10^{-11}$ m at the KEK-ATF damping ring.

INTRODUCTION

The damping ring(DR) of the KEK-ATF has been designed to generate extremely low emittance beams for linear collider.[1] The beam energy is 1.3GeV. The horizontal emittance is 1x10^-9m and the vertical emittance is 1x10^-11m when assumed 1% coupling. The expected beam sizes are 26μm and 5μm, respectively, at the designed beta functions are 1.5m and 2.5m for the horizontal and the vertical. The measurement technology of such a small emittance is also a development issue. The Synchrotron Radiation(SR) interferometer was applied to measure the small beam size.[2] We already succeeded to measure 14μm of vertical beam size of the DR by using the SR interferometer [3][4]. Since, the emittance tuning method is improved[5][6], the vertical emittance achieved to the 1nmrad. The SR interferometer with a refractive optics showed some limitation for the small beam size measurement at less than 7μm. This limitation is strongly due to the chromatic aberration of the objective lens. To remove this aberration in the interferometer, we applied the Herschelian reflective optics instead of the refractive optics for the SR interferometer. The Herschelian reflective optics can also use the shorter wavelength, which extends shorter limit of the measurement. We could measure less than 5μm beam size by using the system. In this paper, it is described the hardware and the measurement results. A result of the emittance tuning by using the monitor is also described.

RESOLUTION AND MEASUREMENT ERRORS

The principle of the SR interferometer is described in ref. [3]. The profile of the object 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. The complex degree of the spatial coherence γ is given by the Fourier transform of the function of the profile $f(y)$, as the function of positional coordination y,

$$\gamma(\nu) = \int f(y) \bullet Exp(-i2\pi\nu \bullet y)dy, \tag{1}$$

where ν is the spatial frequency. When the profile of the object is assumed the Gaussian distribution and with a fixed double slit separation D, the size of the object of the light source σ is obtained by following function,

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

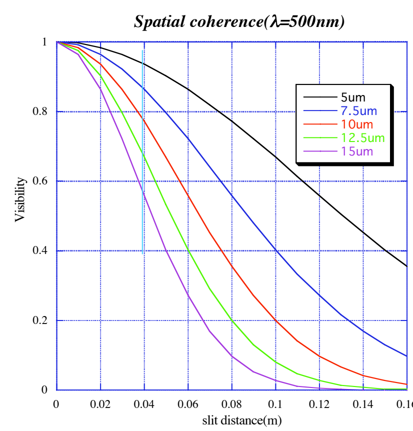

Figure 1: Visibility for each beam size

Figure 1 shows the simulated visibility as a function of the slit separation for each beam size at λ=500nm. The applicable slit separation is limited by the opening angle of the SR which is about 5mrad for λ=500nm. This opening angle is corresponding to a slit separation up to 40mm at 7m downstream from the source point in the case of the KEK-ATF. The beam size 5μm corresponds to the visibility 0.9 at 40mm slit separation. To measure such a good visibility, the most significant error comes from the dispersion effect in the refractive optics, especially it comes from the large opening of objective lens having a certain tilt error. In our case of KEK-ATF, we use a band-pass filter of 80nm to get a sufficient intensity of the interferogram. This wide widow of the band-pass filter strongly enhanced the effect. The dispersion effect of the lens glass is appeared as the optical path difference for the different wave length. This dispersion effect will make a phase change of the interferogram for each wavelength. Consequently, the interferogram will smear out and the visibility will reduce.

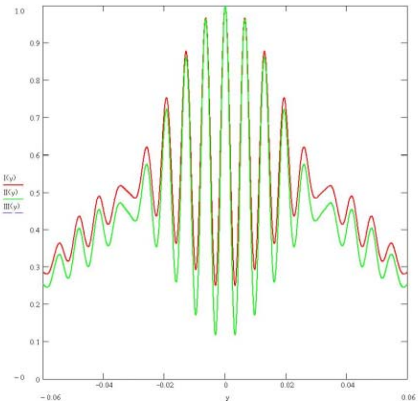

Figure 2: Simulation result of the interferogram
The green line shows the w/o phase error in the case of 5μm beam size, red line shows the λ/5 of the phase error.

In the ordinal SR interferometer having a refractive optics, we have used an achromat lens f=600mm, ϕ=80mm for the objective. The tilt error of the lens is about 3' maximum. A simulated interferograms with the dispersion effect and without the dispersion effect are indicated in figure 2. The visibility of interferogram is modified from 0.9 to 0.8 when the system has the λ/5 of the phase error.

To eliminate this dispersion effect, we apply the Herschelian reflective optics instead of the objective lens. The reflective optics has no dispersion, and we can use it for the shorter wavelength such as 400nm.

INTERFEROMTER WITH HERSCHELIAN REFLECTIVE OPTICS

Figure 3 shows the schematic drowing of the SR interferometer with the Herschelian reflective optics. The double slit is located at 7m downstream from the source point. A parabolic mirror, f=2000mm, is used as an objective mirror. A small diagonal mirror is set for the convenience of the observation. A band-pass filter, which has 80nm bandwidth at 400nm, is used to limit the wavelength of input light. A Gran-Tayler prism is used to select the σ-polarization of the SR. To reduce the thermal noise in CCD camera, we use a cooled CCD camera (Hamamatsu C5985) for the observation of interferogram. This CCD has an electric shutter with external trigger. We can observe a betatron damping phenomena with 1ms

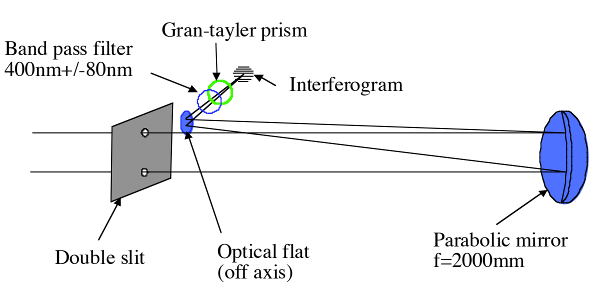

Figure 3: Schematic layout of the SR interferometer

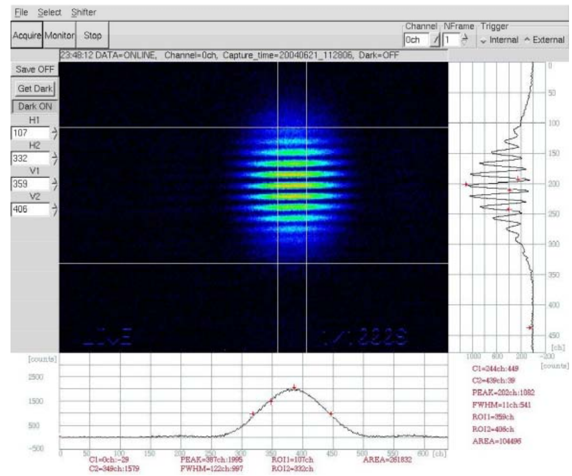

Figure 4: Interferogram of the SR

exposure time. Since the mechanical vibration smears out the interferogram on the CCD, we set the electric shutter to 1ms. Setting a faster exposure time is better to compensate the mechanical vibration effect, but the SR intensity limits the minimum shutter duration in our case. The example of an interferogram is shown in figure 4. The beam size is obtained by Eq.(2) using a measured γ from the visibility of interferogram. The measured vertical beam size was 4.73+/-0.55μm at the stored current 1.5mA, single bunch in the DR.

EMITTANCE TUNING OF THE DR

The measurement strongly depends on the emittance tuning and the stored current in the DR. The vertical emittance ε is estimated by using a following equation,

$$\varepsilon\beta = \sigma^2 - \left(\eta \,{}^{\Delta p}\!/_{p}\right)^2,$$

where β denots beta function at the source point, η denotes dispersion function, ${}^{\Delta p}\!/_{p}$ denotes momentum spread of the beam respectively. The beta function at the quadrupole magnets near the source point is measured from the K-value dependence of the betatron tune. The beta function at the source point is estimated from the extrapolation of the fitting of the beta functions between two qusadrupole magnets those are set downstream and upstream of the source point. The value of the dispersion function at the source point is negligible for the vertical direction.

The low vertical emittance tuning method was developed[5][6]. Some of the corrections are sequentially iterated to minimize the emittance, which consists of the COD correction, the vertical dispersion correction and the x-y coupling correction. Because of the vertical emittance of the damping ring is strongly depended on the vertical dispersion and the x-y coupling, the corrections are essential. The x-y coupling is controlled by the strength of the skew component of each sextupole magnet(SD, SF).

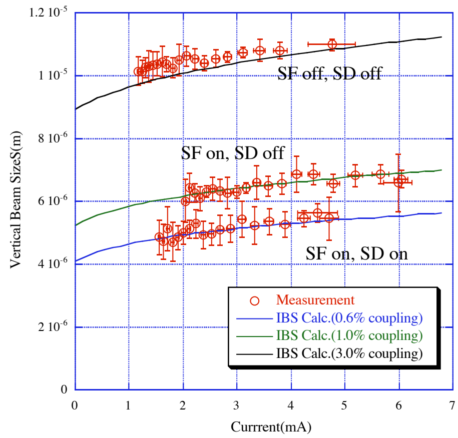

Figure 5: Vertical beam size as a function of the stored current

MEASUEMENT OF THE EMITTNCE

The beam size measurement by using the SR interferometer was done by the following conditions, the stored current 1~6mA at the single bunch, Vrf =300kV. In order to change the x-y coupling by means of controlling the vertical emittance, the on and off conditions of the skew coils of the sextupole magnets were measured. The measured vertical beam size as a function of the stored current intensity is shown in figure 5. In the case of the SD and the SF auxiliary coils on, the measured vertical size was 4.7μm at 1mA of the stored current, which correspond to 0.97×10^{-11}m of the vertical emittance. The measured vertical beta function 2.35m is used for the calculation.

The intensity dependence of the vertical beam size is explained by the effect of the intra beam scattering(IBS). The IBS effect is computed by using SAD program.[8] The measurement shows good agreement of the calculation of the case of the x-y coupling of 0.6%, 1.0%, 3.0%, respectively. The calculation used the bunch length 5.2mm and the energy spread 6×10^{-4} at the zero current.

The same measurement using the refractive optics was done for the comparison. The measured vertical size was larger than 7μm, even with the 0.6 % coupling condition.

CONCLUSION

The dispersion effect of the objective lens in the SR interferometer limited the resolution of the SR interferometer for the several micron beam size measurement. The Herschelian reflective optics could solve the problem. The measured vertical beam size was 4.7μm and the estimated vertical emittance was 0.97×10^{-11}. We could confirm the effectiveness of the Herschelian reflective optics for the vertical beam size measurement of the KEK-ATF damping ring.

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