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EFFECT OF INCOHERENT DEPTH OF FIELD FOR BEAM HALO MEASUREMENT WITH THE CORONAGRAPH IN SuperKEKB

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Abstract

In the case of beam profile measurement by imaging system, observed apparent beam profile will change by the incoherent depth of field. This apparent change of beam profile, especially extra beam tail in one side has certain influence for beam halo measurement using the coronagraph, because it has a large dynamic range of 6-digit contrast. Since the magnitude of asymmetric tail is depending on bending radius, this effect is larger in large high energy physics machine which has a long bending radius. This effect is studied with geometrical optics and coronagraph measurement of beam halo in the SuperKEKB. As a conclusion, the IDF effect has significant effect in the beam halo observation with coronagraph at SuperKEKB.

INTRODUCTION

For the measurement of beam image, the incoherent depth of field (IDF) due to horizontal instantaneous opening of the Synchrotron Radiation will apparently modify the horizontal profile of beam image in asymmetric manner. We have presented this IDF effect for horizontal beam size measurement with interferometry in IBIC2017 [1]. In the interferometry, The IDF effect deduces spatial coherence in horizontal direction, and correction is necessary for the horizontal beam size measurement with interferometry [1]. The IDF effect has not only reducing the spatial coherence, but also modify the apparent horizontal beam profile with asymmetric manner. As a result, observed beam image with focusing system will be deformed. Especially, tis asymmetric deformation of beam profile can introduce extra asymmetric distribution in beam tail (or halo) which is existing surrounding of beam core. We studied this effect using the geometrical optics in the case of beam halo measurement with coronagraph in the SuperKEKB. And compare the measurement result s of beam halo with the coronagraph [2].

EFFECT OF INCOHERENT DEPTH OF FILED FOR APPARENT DEFORMATION OF BEAM PROFILE

In the horizontal plane, the profile of beam is modified apparently by IDF with the instantaneous opening of the SR in the horizontal plane as shown in Fig. 1.

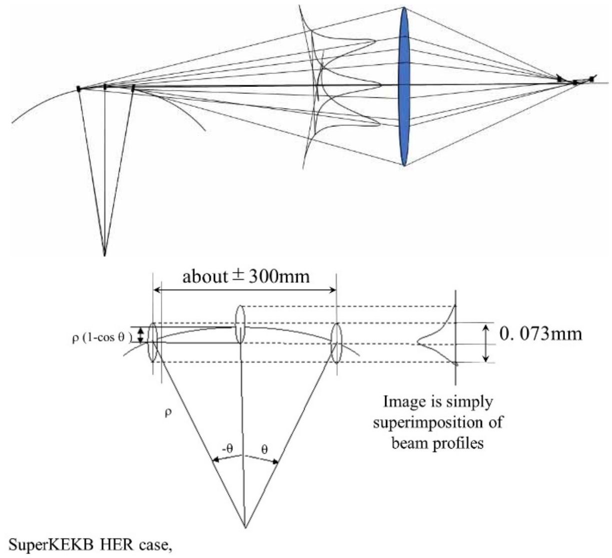

Figure 1: Apparent beam profile with the IDOF effect by the instantaneous opening of the SR in the horizontal plane in the SuperKEKB HER case.

In the geometrical Optics, the intensity distribution in the entrance aperture has no effect for imaging as shown in Fig. 2. Also, due to small emittance of the source beam, opening angle and source size is very smaller than opening of SR in the visible light region, this effect will be negligible small for IODF.

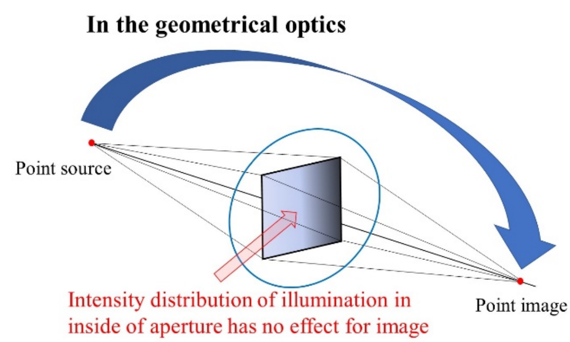

Figure 2: Point to point transfer of source point into imaging point in the geometrical optics.

Denote the total intensity of SR inside of the entrance aperture in horizontal plane by I(θ) as a function of horizontal observation angle θ, the apparent beam shape $\sigma_a(x)$ is given by,

$$\sigma_a(x) = \int \mathrm{I}(\theta) \cdot \frac{exp\left[\frac{-[\mathrm{x} - \rho\,\{1 - cos(\theta)\}]^2}{2\sigma^2}\right]}{\sigma \cdot \sqrt{2\pi}} \mathrm{d}\theta \quad , \qquad (1)$$

where the original beam profile is assumed to be a Gaussian distribution.

For the discussion of horizontal IODF, we need knowledge of instantaneous intensity distribution of SR in horizontal plane to evaluate I(θ).

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The SR from circular trajectory is written by Schwinger in 1945 [3, 4]. He only gave his theory for the case of horizontal observation angle ξ=0.

For the case in the horizontal observation angle $\xi\neq0$, is discussed by one of author [1]. The intensity radiated per unit frequency interval per unit solid angle is given by

$$\frac{d^2I}{d\omega d\Omega}=\frac{e^2}{3\pi^2 c}\left(\frac{\omega\rho}{c}\right)^2\left(\frac{1}{\gamma^2}+\psi^2+\xi^2\right)^2\left[K_{2/3}^2(\zeta)+\frac{\psi^2}{\frac{1}{\gamma^2}+\psi^2+\xi^2}K_{1/3}^2(\zeta)\right], \qquad (2)$$

where,

$$\zeta=\frac{\omega\rho}{3c}\left(\frac{1}{\gamma^2}+\psi^2+\xi^2\right)^{\frac{3}{2}} \qquad (3)$$

The result given by Eq. (2) indicates both of vertical intensity distribution and horizontal instantaneous intensity distribution have same angular dependence. This result is same as in the result from qualitative discussion in K.J. Kim [5]. The total intensity of SR in entrance aperture is given by integrating instantaneous intensity distribution in inside of the aperture. The horizontal total intensity inside the aperture is given by integrating the Eq. (2) in horizontal direction inside the entrance aperture,

$$\mathrm{I}(\theta)=\int\frac{e^2}{3\pi^2 c}\left(\frac{\omega\rho}{c}\right)^2\left(\frac{1}{\gamma^2}+(\psi+\theta)^2\right)^2\left[K_{\frac{2}{3}}^2(\zeta)+\frac{\psi^2}{\frac{1}{\gamma^2}+\psi^2}K_{1/3}^2(\zeta)\right]d\psi \ , \qquad (4)$$

where,

$$\zeta=\frac{\rho}{3c}\left(\frac{1}{\gamma^2}+\psi^2\right)$$

SIMULATION OF HORIZONTAL BEAM PROFILE WITH IOD EFFECT

A simulation of horizontal beam profile using the Eq. (1) is performed for Super KEKB HER and LER.
The parameter of source bend and horizontal beam size of the HER and LER are summarized in Table 1.

Table 1: Parameter of Bending Source

	HER	LER
Beanding radius	580.0 m	177.4 m
Beam Energy	7 GeV	4 GeV
Horizontal beam size	226 μm	177 μm

The result of beam profile with and without IDF effect in linear scale and log scale for HER an LER is shown in Figs. 3 and 4 respectively.

As shown in Fig. 3 (a), a slight asymmetry is seen in horizontal beam profile due to a long bending radius in HER. R=580 m in HER. This asymmetry in profile is clearer in log plot as shown in Fig. 3 (b).

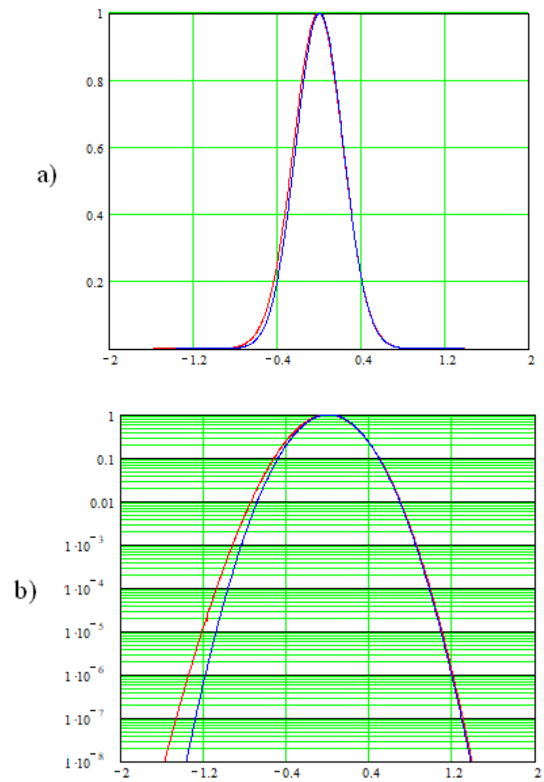

Figure 3: Simulation result of horizontal beam profile image for HER. (a)leaner scale, (b) log scale. Red line: beam profile image with IDF, blue line without IDF.

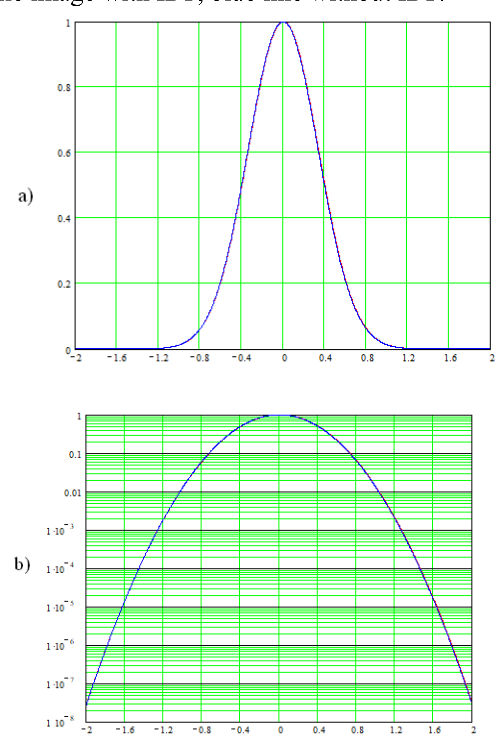

Figure 4: Simulation result of beam profile image for LER. (a): leaner scale, (b): log scale. Red line: beam profile image with IDF, blue line without IDF, but both curvatures are almost same and overlapped in each other.

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On the other hand, due to rather short bending radius (177.4 m in LER), the same result for LER has almost no asymmetry in beam profile as shown in Fig. 4. From Fig 4, the effect of IDF in LER is very small and beam profiles with IDF and without IDF is almost same.

As a result, beam profile change in the outside aria from 5 σ of the beam size will be very small, and no significant effect of IDF for beam halo observation in 6-digit in the SuperKEKB with the coronagraph. We expect some beam halo will exist in this aria.

OBSERVATION OF BEAM CORE AND HALO WITH CORONAGRAPH

The effect of IODF for beam core image and beam halo image are observed experimentally using the coronagraph [4] for both of HEL and LER in the SuperKEKB. The result of observed beam profile on the direct focal plane of objective system of coronagraph at HER is shown in Fig. 5. A plot of horizontal profile of distribution is also shown in Fig. 5. From this figure, a slight asymmetry in horizontal distribution of beam core image is observed. On other hand, profile of beam tail is very symmetry in this observation result. Since this extent of asymmetry in the image is sometimes appear due to residual aberration of objective system, but the wavefront error in coronagraph system including the extraction polycrystal-diamond mirror is smaller than λ/5 [6], so beam image in Fig. 5 is diffraction limited one. The extent of horizontal profile of beam image in HER with this observation result is good agreement with the simulation result in Fig. 3 (a). The outside aria from 5 σ of the beam size seems having no significant IODF effect.

The beam halo is observed with the coronagraph in 6-digit contrast. The result of halo observation in HER is shown in Fig. 6 [2]. An intensity distribution along the horizontal plane is also shown in this figure. The beam core image and opaque square image for blocking the glare of beam core are superimposed in this figure for reference.

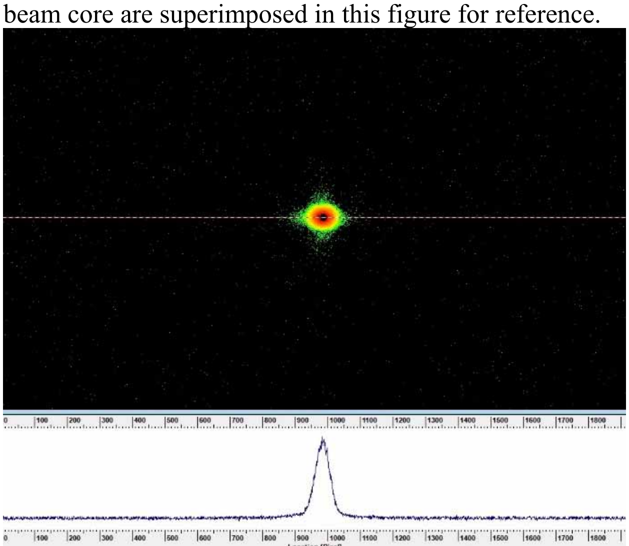

Figure 5: Result of observed beam core profile in HER. Upper: beam core image, lower horizontal profile of the image.

The intensity of beam halo (note this intensity is not peak intensity in Fig. 6) is 2 x 10^{-6} to the peak intensity of the beam core. We observed no significant effect of IDF in horizontal halo profile.

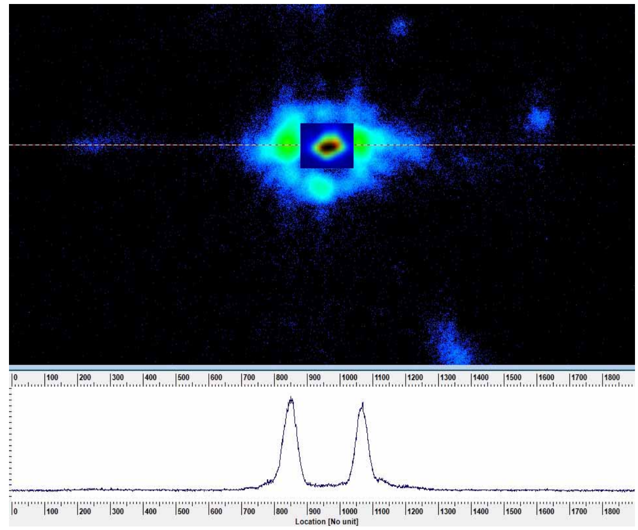

Figure 6: Result of beam halo observation with the coronagraph in 6-digit contrast in HER. Upper: beam halo image, lower: horizontal profile of the halo image.

The result of halo observation in LER is shown in Fig. 7. An intensity distribution along the horizontal plane is also shown in this figure. As same manner, in Fig. 6, the beam core image and opaque square image for blocking the glare of beam core are superimposed in this figure for reference. Different from HER, an interesting beam halo is observed in LER. As same as in HER, we observed no significant effect of IDF in horizontal halo.

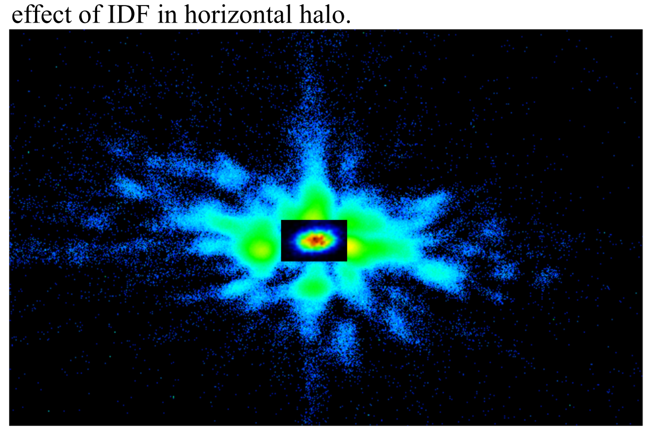

Figure 7: Result of beam halo observation with the coronagraph in 6-digit contrast in LER.

CONCLUSION

The effect of IDF for beam core image and beam halo image by using the coronagraph are studied with geometrical optics and experimentally observation for both of HEL and LER in the SuperKEKB. From the observation result, we detect no significant effect of IDF in horizontal halo profile of both of HER and LER. We can conclude IDF effect is enough smaller in the halo observation with the coronagraph in SuperKEKB.

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