ANALYSIS OF CONTRIBUTION FROM EDGE RADIATION TO OPTICAL DIFFRACTION RADIATION*

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Abstract

Beam size measurement by near-field optical diffraction radiation (ODR) has been carried out successfully at CEBAF. The ODR station is installed on the Hall-A beam line after eight bending magnets. The ODR images were affected by an unexpected radiation. Calculations for analyzing the source of the radiation will be presented. Furthermore, a scheme will be proposed to alleviate the contamination.

INTRODUCTION

Diffraction Radiation is the wakefield of charged particle beam generated when it passes by an inhomogeneity, such as a circular hole, a slit or the edge of a metal screen. The prompt change of current induced by the field of electron beam is the source of radiation [1]. Backward diffraction radiation (BDR) and forward diffraction radiation (FDR) have the same pattern despite intensity attenuation of BDR due to reflectivity. From the mechanical point of view, ODR screen is set 45 degree to the beam trajectory so the BDR could be extracted 90 degree out from the beam pipe. DR has been studied theoretically since the early 1960's. However, there were few experimental investigations until recent years. D. W. Rule expounded the possibility of measuring beam position, beam size and divergence using BDR radiated when the beam going through a circular hole on a metal plane [2]. Castellano discussed the possibility of determining the transverse beam size using BODR characteristics when the beam passing through a slit in a metal screen [3]. This scheme has been experimentally verified in KEK-ATF and DESY [4, 5]. Later on, beam size measurement at ANL using BODR near field imaging was successfully demonstrated [6]. The efforts will continue increasing since the ODR measurement is a promising diagnostic for future linear colliders and X-ray FELs. Unfortunately, radiation from a bend magnet or even a corrector may be an obstacle of the measurement. Therefore, analysis of the source of radiation before the ODR target is necessary to avoid any contamination to the ODR pattern.

EXPERIMENTAL SETUP AND MEASUREMENT

The CEBAF machine at Jefferson Laboratory is a five-pass recirculating Linac based on SRF technology which is capable of delivering CW beam up to 200uA to three experimental halls simultaneously. The horizontal transverse beam size in Hall-A transport beam line is nominally around 200um which is about 10 times smaller than that of APS[7]. By changing the quads parameters, the transverse beam size could be easily reduced to several tens um which is comparable to the projected ILC beam size.

The ODR station layout is displayed in Figure 1. A He-Ne laser with an expander, a neutral density filter, mirrors M1, M2 and an insertable mirror are mounted for alignment purpose. The flag with calibration scale, OTR foil and ODR screen could be positioned downward vertically by a stepper motor. An 8um aluminum foil and a hand polished 3mm aluminum metal screen were used for the first OTR measurement and ODR measurement respectively, a Kapton film and aluminized silicon wafer were used for the second measurement. The flag is 45 degree inclined to electron beam so both backward OTR and ODR light will travel perpendicular out of the beam line to the imaging system. An achromatic doublet with 250mm and 75mm focal length are adopted in the dispersion free optics to image both OTR and ODR to CCD camera shielded with lead bricks. The optics shielded with an aluminum box was designed with an appropriate magnification to setup an appropriate field of view. Neutral density filter mounted on filter wheel for adjusting light density and polarizers for orthogonal polarization component measurement could be remotely controlled.

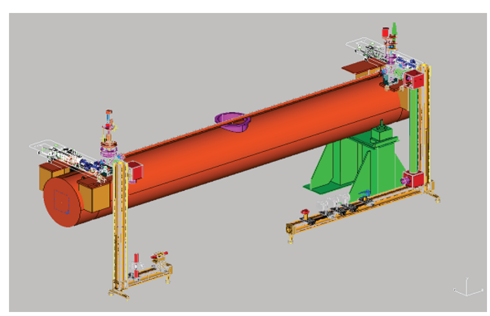

Figure 1: ODR station setup.

The beam for experimental Hall-A is extracted from Linac at 499MHz by 8 bend magnets. The bending angle is 4.262 degree for each dipole which has 40m radius. Behind a shielding wall is the ODR station which is 8.1m downstream of the last dipole.

The measurement has been carried out under several different beam conditions. More details about the ODR measurement can be found in [8]. One set of images for 10uA CW beam are shown in Figure 2-4. In addition to

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diffraction radiation, there is another radiation on the images which is mostly horizontally polarized. Fortunately, the streak from the unexpected radiation is a little shifted from ODR image centre. However, analysis on the origin of this radiation is critical in some sense for eliminating it and improving the resolution of ODR measurement. Synchrotron radiation and edge radiation are two candidates believed to be the source of the streak at first. However, calculation shows that synchrotron radiation would be a much bigger streak since it spreads in a fairly big angle in vertical direction. Furthermore, the flux of synchrotron radiation should be much weaker than optical diffraction radiation.

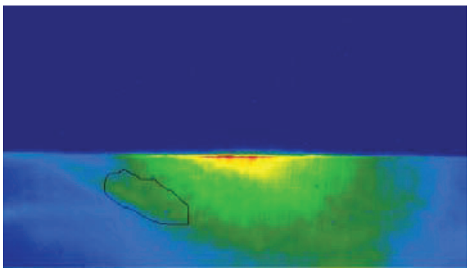

Figure 2: ODR intensity distribution.

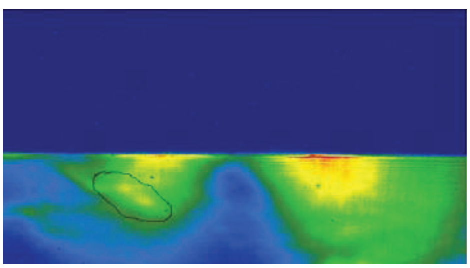

Figure 3: ODR horizontal component distribution.

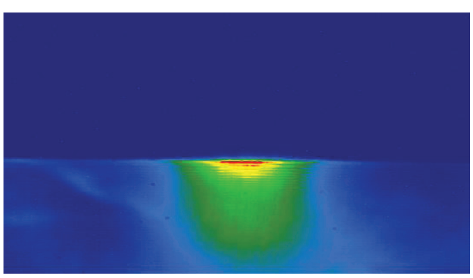

Figure 4: ODR vertical component distribution.

EDGE RADIATION

Edge radiation is emitted when electron entering or exiting the transient regime of the dipole (fringe field). For synchrotron radiation, the electron is accelerated and then decelerated in longitudinal direction when watching in lab frame. However, the electron is just accelerated or decelerated at the edge of the dipole when edge radiation is emitted. This longitudinal characteristic makes edge radiation analogous to transition radiation [9]. The effective length of the fringe field is an important parameter for edge radiation. Longitudinal acceleration is suppressed if electron passing a long fringe field. Transverse acceleration dominates like in synchrotron radiation leads to horizontal polarization dominated edge radiation. As indicated in [10], in wavelength range ($\rho\theta^3 << \lambda << R\theta^2$), where ρ is bending radius, R is the distance from bend edge to observation point, θ is the half-angle subtended by the aperture at observation point, flux of edge radiation is stronger than standard SR. For our case, the wavelength range is (71nm, 12um) which includes optical range.

Table 1: Beam parameters for edge radiation

Parameters	values	units
E	4	GeV
$\Delta P/P$	0.1	%
I	100	uA
εx	3.9	nm
εy	2	nm
βx	35.6	m
βy	20	m

The explicit calculation of the radiation distribution is complicated. Some papers are dedicated to solving the problem numerically. Based on the method presented in [11], the edge radiation calculation function is built in SRW. With the parameters listed in Table. 1, edge radiation emitted when electron exiting the last dipole was calculated assuming the effective length of the fringe field is 40mm.

The radiation intensity distributions at wavelength 500nm are displayed. As predicted, the flux of edge radiation at 500nm is stronger (1000 times) than synchrotron radiation. The intensity ratio of edge radiation to synchrotron radiation over optical range should be different from the number presented here because of different frequency dependency of these two radiations. Furthermore, edge radiation is constrained in a small angle in both directions. The simulated image on the screen is tenth of mm in vertical direction and around 1mm in horizontal direction which is in agreement with the dimensions of the streak.

The streak is tilted in the same way as the beam profile from the OTR images. It is reasonable because the beam profile at dipole exit should be the same as profile shows up on OTR foil since the optics between these two points are quite simple and not designed to make the beam profile tilted.

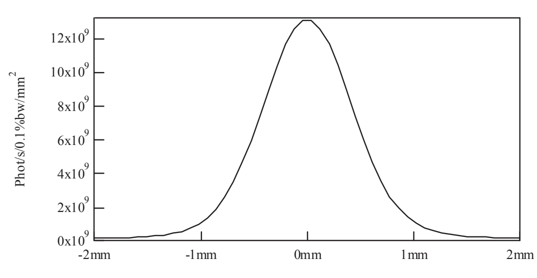

Figure 5: ER horizontal intensity distribution.

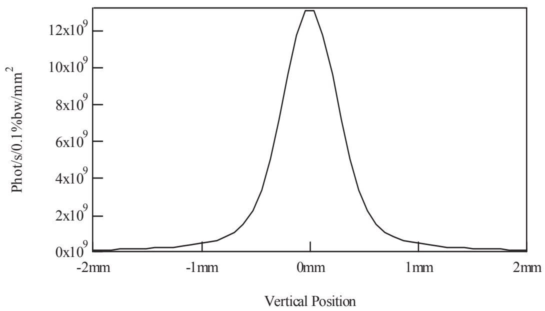

Figure 6: ER vertical intensity distribution.

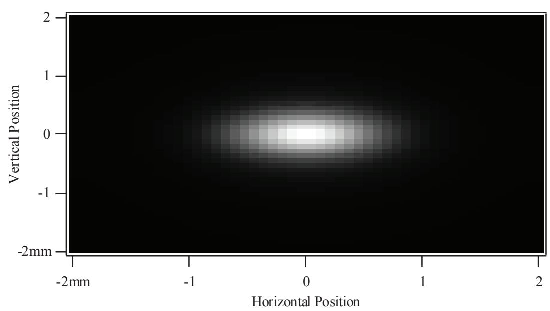

Figure 7: ER two dimensional distribution.

PROPOSED SCHEME

Fig. 6 is a schematic of the image system. O1, O2 are ER from the last dipole and ODR from the radiator. I1, I2 are the corresponding images. As we discussed above, ER propagates with smaller opening angle than ODR, which is depicted by the broken line in the figure. On plane ABCD, ER is constrained in the smallest area which is denoted by the thick line BC while ODR spreads on a much bigger area denoted by AD. The ER contribution will be considerably reduced by putting a small block at position BC. The minor disadvantage of this approach is the decrease of ODR intensity. Fortunately, it is not a serious problem since ODR intensity is strong enough even with 5uA current. Furthermore, a block on the axis of the image system shrinks the point spread function of the image system which in turn improves the resolution of imaging.

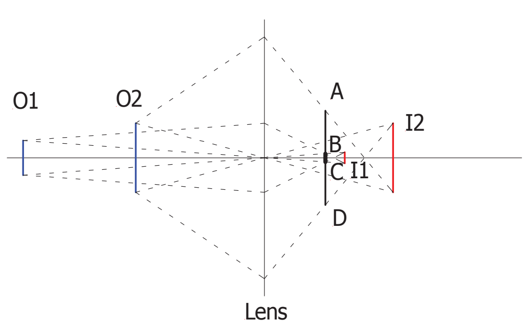

Figure 8: Schematic of the image system.

CONCLUSION

Based on calculations, we figured out the origin of the unexpected radiation in near-field ODR measurement is edge radiation from bend magnets. An approach for reducing edge radiation is suggested, which gives us opportunity to improve the resolution of image system as well.

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