Emittance Measurements of FEL Accelerators Using Optical Transition Radiation Methods

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Abstract

Measurements of the emittance of the Boeing FEL accelerator operating at 107 Mev, were performed using optical transition radiation (OTR). The results of the three measurement methods: measurement of beam spot size as a function of magnetic quadrupole focusing strength, two screen beam spot measurements, and beam spot - divergence measurements using a OTR interferometer are compared and shown to be in excellent agreement.

I. Introduction

OTR techniques have proven to be very useful to diagnose electron beam spatial profiles, position, divergence, energy and emittance.[1-5] In early publications we have described the advantages of employing OTR techniques to characterise the properties of the Boeing 110 Mev accelerator, which is used to drive a visible free electron laser (FEL).[6] OTR has been shown to provide increased spatial and temporal resolution in the measurement of beam size, and position when compared to fused silica and phospor screens previously used to characterise the beam in the accelerator and in the wiggler. As a result, OTR foils have now replaced the fused silica and phosphor screens at both the Boeing and LANL HIBAF FEL accelerators.[4-6]

II. Experiments

The experimental setup for OTR measurements at both Boeing and LANL is shown in Figure 1. and discussed in ref.6. The The arrangement provides for an upstream station where a single foil maybe remotely placed in the electron beam path, and a downstream station housing a two position actuator to access either a single OTR foil, or a two foil OTR Wartski interferometer.[1] Using these two stations, which are separated by 2.2 meters, quadrupole scans, simultaneous beam spot measurements and beam spot-divergence measurements can be made. The apparatus is located is a straight section (A leg) of the Boeing accelerator .

Figure 1. shows the plane of incidence or horizontal plane, which contains the electron beam velocity vector (in the + z direction) and

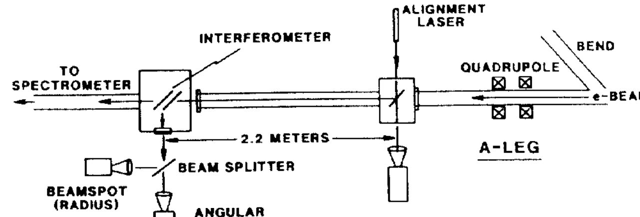

Figure 1. Experimental Arrangement

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the **x** direction which is perpendicular to **z** and parallel to the surface of the earth. The **y** direction is perpendicular to the plane of incidence. (**y**,**z**), then, refers to the vertical plane.

To make a quadrupole scan measurement, the beam is focused on the OTR foil at the upstream station. The field strength of magnetic quadrupole lenses upstream of this foil, which control focusing in either the **x** of **y** directions are then varied, and the OTR beam image at each field strength is captured and recorded.

In the two screen measurement, the beam spot images at the upstream and downstream single OTR foils are captured simultaneously. In this method the beam is focused with the quadrupole lenses to effect a minimum beam spot radius in either the **x**,**z** or y,z planes.

Finally the beamspot-divergence measurement is made at the downstream station. The single foil, which consists of a diamond machined Al mirror, is used to produce the beam spot image. The beam is focused here to achieve either an x or y minimum radius. The The divergence is measured using an OTR interferometer, which consists of two parallel foils: the mirror, and a thin (0.7 micron) Al foil separated by 2.5 cm. A detail of the interferometer is given in Figure 2. Standard optical polarizers and filters are used to obtain horizontally or vertically polarized OTR interferograms, from which either the x or y beam divergence can be obtained.[2-5]

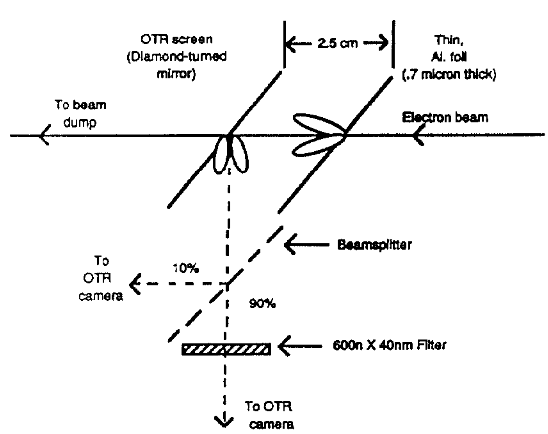

Figure 2. Detail of the OTR Interferometer

Intensified CID cameras with RS 170 ouputs are used at both stations to obtain beam images and interferograms.

III. Results and Discussion

In these experiments the accelerator was not tuned for optimum beam transport.

The horizontal plane emittance measured from the single foil quadrupole scan yields an x edge emittance value of 158±24 mm-mrad. The two foil method measurement produces an x emittance of 167 ±25 mm-mrad.

Figure 3 shows three line scans of horizontally polarized OTR interferograms obtained when the beam is focused to a minimum x diameter. The solid line represent the data, the dotted lines theory. The best overall fit is obtained using a beam energy of 106.8 Mev and an x divergence of 0.3 milliradians. The beam energy spread as determined by the PARMELA code is less than 5% and does not significantly affect the fringe visibility for this experiment, which is dominated by the effect of beam divergence. However, the Figure demonstrates that it is not possible to simultaneously fit all the data fringes by using a single divergence value. This is most likely caused by the fact that the beam is not precisely focused to a waist position at the site of the OTR interferometer. The resulting angular beam distribution cannot be represented by a single Gaussian function in x or y, which is the assumption of the theory.

The rms x,y emittances of the beam are obtained from the beam's rms radii and the rms divergences obtained from horizontally and vertically polarized interferograms respectively. At an x waist then,

$$\varepsilon_{x\ rms}=\beta\gamma x_{rms}\Theta_{x\ rms}\cong\varepsilon_{x\ edge}/4 \qquad (1)$$

where ε_{xrms} is the rms x emittance, x_{rms} is the rms x radius of the beam, Θ_{xrms} is the rms x divergence and $\varepsilon_{x\ edge}$ is the x edge emittance.

Table I. gives a comparison of the measured values using the three techniques as well as comparison with the predictions of the PARMELA simulation code. The results are all in good agreement.

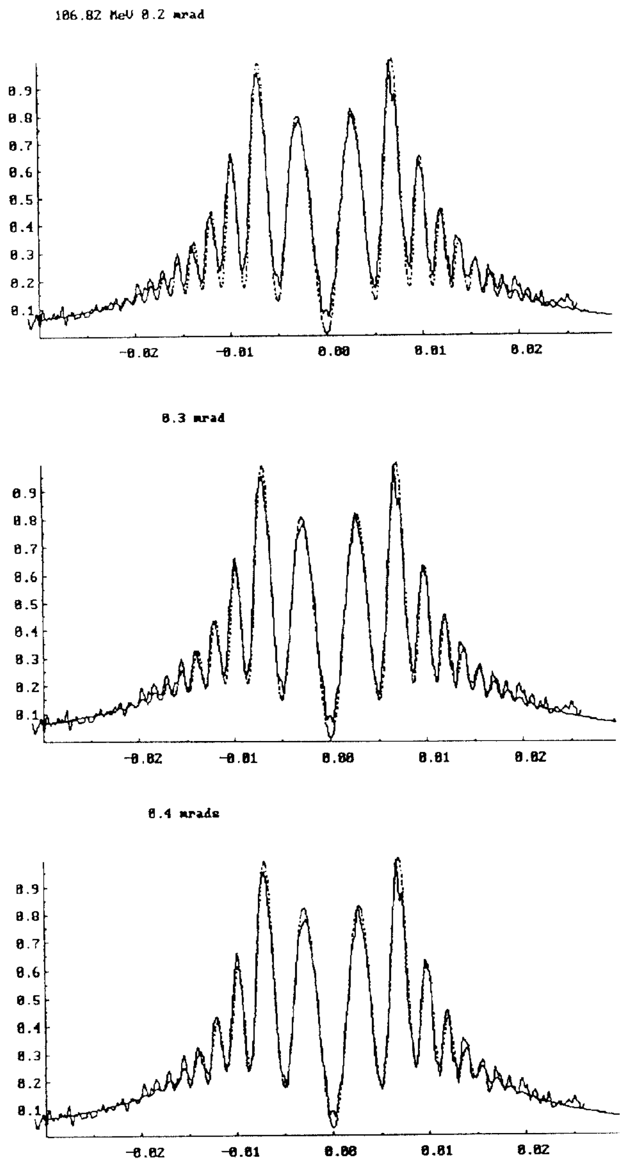

Figure 3. OTR Interferometer scans - relative intensity versus angle measured in radians for three values of x divergence; top: 0.2 mrad, middle: 0.3 mrad, bottom: 0.4 mrad.

Table I.

Comparison of measurements and simulation code results

Method	x edge emittance	x_{rms} (mm)	$\Theta_{x\ rms}$ (mrad)
Quad scan	158±24	------	------
Two foil	167±25	0.57	0.35
OTRI	144±25	0.57	0.3±.05
Parmela	143	0.81	0.21

IV. References

[1] L. Wartski, S. Roland , J. Lasalles, M. Bolore and G. Filippi, J. Appld. Phys. 46, 3644, 1975.

[2] R. B. Fiorito, et. al., Proc. 6th Intl. Conf. on High Power Beams, Kobe, Japan, 1986.

[3] D. W. Rule, Nucl. Instr. and Meth., B24/25, 90, 1987.

[4] D.W. Rule, R. B. Fiorito, A.H. Lumpkin, R.B. Feldman and B.E. Carlsten, Nucl. Inst.and Meth., A296, 739, 1990.

[5] X.K. Maruyama, R.B. Fiorito and D.W. Rule, Nuc. Inst. and Meth., A272, 237, 1988.

[6] A. H. Lumpkin, R. B. Fiorito, D.W. Rule, D.H. Dowell, W.C. Sellyey and A.R.Lowrey, Nuc. Inst. and Meth., A296, 150, 1990.