OPTICAL DIFFRACTION-DIELECTRIC FOIL RADIATION INTERFEROMETRY DIAGNOSTIC FOR LOW ENERGY BEAMS

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Abstract

We have developed and used a novel optical diffraction-dielectric foil radiation interferometer to measure the divergence of the low energy (8 - 14 MeV) ANL-AWA electron beam. Our interferometer employs an electro-formed micromesh first foil to overcome the inherent limitation due to scattering in the solid first foil of a conventional OTR interferometer (OTRI) and an optically transparent dielectric foil. The interferences of forward directed optical diffraction radiation (ODR) from the mesh and radiation from the dielectric foil is observed in transmission. This geometry allows a small gap between the foils (1– 2 mm), which is required to observe fringes from two foils at low beam energies. Our measurements indicate that a single Gaussian distribution is sufficient to describe the angular phase space of the measured beam.

INTRODUCTION

Conventional OTRI cannot be used for very low emittance beams when scattering in the first foil of the OTR interferometer dominates and obscures the beam divergence (e.g. 1μm of Aluminum scatters 10 MeV electrons by $\theta_{rms} \sim 4$ mrad). To overcome this problem we have devised a perforated foil (mesh) – solid mirror foil reflection interferometer [1,2] which is useful at moderate beam energies (E > 50 MeV). This device produces ODR from the mesh, which is then reflected and interferes with backward OTR from the mirror. Both the mesh and the mirror are inclined at 45^0 w.r.t. the beam velocity.

The radiation from the mesh is produced from two sources: 1) unscattered electrons passing through the holes and 2) electrons heavily scattered in the mesh wires. Each component produces a form of ODR. Since no analytic theory for diffraction radiation from a matrix of holes in a metallic foil exists, we devised a simulation code (BEAMDR) to calculate the ODR from the two fractions.

A second code (CONV) is then used to convolve the interferences of the ODR and OTR from the mirror with a given distribution of particle trajectory angles (typically a Gaussian distribution) and optical band pass filter. The latter is needed to produce distinct visible fringes for a given range of divergence. The essential part of code CONV is the fitting procedure which varies the beam parameters and determines the RMS deviation between the calculated and measured intensity distributions within some angular interval. The goal is to find a set of parameters which produces the minimum deviation. Beam divergence is one of the fitted parameters. A complete description of these codes is given in [2].

For low energy beams the inter foil spacing ($L \sim \gamma^2\lambda$) is too small to observe the interferences of forward ODR from the mesh and backward OTR from the mirror in a standard reflection geometry. For example, at beam energy E = 10 MeV and λ = 650nm, L < 1 mm. To overcome this problem, we have developed a new transmission interferometer [3]. This interferometer uses a transparent dielectric foil as a second foil. The forward ODR produced by the mesh passes through the dielectric foil and interferes with forward radiation produced by the dielectric itself. A transport mirror is used to redirect the interfering radiations into the optical measurement system.

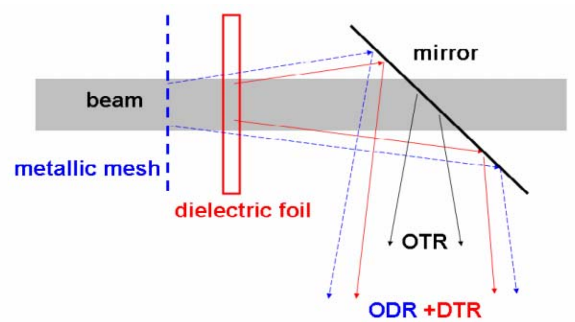

Figure 1: Mesh-dielectric foil interferometer.

There are few important questions that immediately arise regarding the performance and design of this device, namely: (a) what are the properties of dielectric optical radiation, (b) what is the effect of the dielectric foil on ODR from the mesh and (c) what is the effect of backward OTR generated from the transport mirror. Effects (a) and (b) have been previously discussed in detail in [3] and thus will be only briefly reviewed here.

EXPERIMENTAL SETUP

An ODR-dielectric foil interferometer was designed and used to measure the divergence of the Argonne National Lab's Advanced Wakefield Accelerator operating at 13.7 MeV. The average current of this machine is about 0.1 μA, and the repetition rate is 5 Hz.

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A 5 μm thick, rectangular aperture nickel micromesh (2000 lines per inch, 12.7 micron period, 36% transparency) is the first foil and a 9μm thick Kapton foil with refraction index ~ 1.8, the second foil. The transparency of the Kapton foil is ~ 95% at 632nm and ~ 40% at 500nm. The inter foil spacing L ~ 1.9 mm. The wires of the mesh scatter electrons producing a calculated rms scattering angle of about 10 mrad which is much larger than the expected rms beam divergence, θ_{rms} ~1-2 mrad. The dielectric foil also produces a large amount of scattering (~ 5 mrad), but this does not affect the performance of the interferometer, since the phase and hence the interferences are primarily determined by the inter foil distance; see [3] for details.

The optical system is shown in Fig. 2. It consists of an aluminized silicon mirror mounted at 45 degrees w.r.t. the beam direction mounted in a vacuum chamber, a primary lens (diameter 76mm, focal length f_1 = 320mm), a second lens (f_2 = 105mm), an interchangeable filter and a CCD camera. The second lens refocuses the image of the AD formed at the focal plane of the first lens onto the CCD. The distance between the interferometer and transport mirror is 220 mm, between the mirror and main lens 150 mm, and between main lens and camera lens 1880 mm.

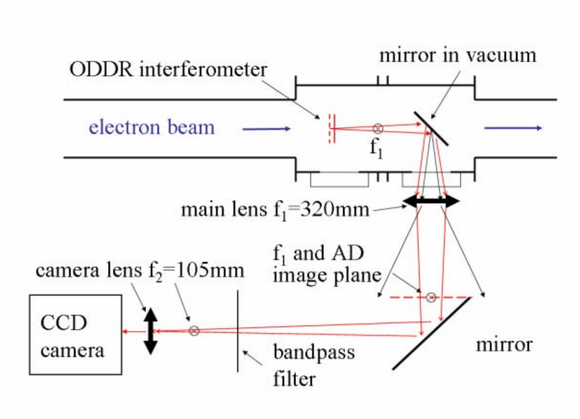

Figure 2: Experimental setup.

The light from the interferometer is transported by the optics to the CCD camera lens, but the OTR from the transport mirror is heavily defocused by the main lens (distance mirror-lens = 150mm < f_1 = 320mm) and hence only a negligible fraction of the OTR produced by the mirror is accepted by the aperture of second lens.

An Apogee Instruments Inc., 16 bit, Peltier cooled, high QE CCD camera (model Alta E47+) is used to acquire the interference patterns. The camera is equipped with an electronically controlled shutter which allows integration of the images produced from multiple electron beam pulses. One of two different optical band pass filters is used to observe the interferences.

DATA FITTING CODES

In order to calculate the interference pattern produced by the ODR from the mesh and the dielectric foil radiation we use code BEAMDR which is described above and in [1] and two other codes CONVD1 and CONVD2, which are the modifications of our original code CONV to properly include the radiation from the dielectric foil.

The radiation from the dielectric layer is described by Pafomov's formula [4]. Alternatively, as a means of simplifying the calculations and the fitting procedure, we have previously shown [3] that dielectric foil radiation can be modelled as the interference of radiations from the front and back surfaces assuming that each surface radiates as a perfect conductor. The calculated intensity of the composite radiation as a function of thickness of the dielectric foil and index of refraction calculated using this model is shown in Figure 3. In contrast to OTR from a single interface, the amplitude of the dielectric foil radiation is a strong function of the wavelength and the thickness of the foil. Roughly speaking then, the dielectric foil can be considered to equivalently radiate OTR with an intensity that varies between 0 and 4. As a result, an uncertainty in the foil characteristics leads to an uncertainty in the intensity of the radiation.

In code CONVD1 we assume only that second foil of the interferometer radiates OTR with variable amplitude and attenuates the radiation from the first (mesh) foil. We thus add two more parameters to the overall fit: the amplitude and the transparency of the second foil. CONVD1 thus allows us to make a first pass in the fitting procedure and to find the amplitude of radiation from the second foil.

Code CONVD2 includes the full properties of the dielectric and takes into account the refraction, reflection, attenuation and phase shift of radiation from the mesh within the dielectric foil. Also it includes the alternative model of radiation described above. The exact values of thickness and refractive index of the dielectric foil needed for CONVD2 are calculated by externally adjusting the foil thickness so that the dielectric radiates with the amplitude found from the fit produced by CONVD1.

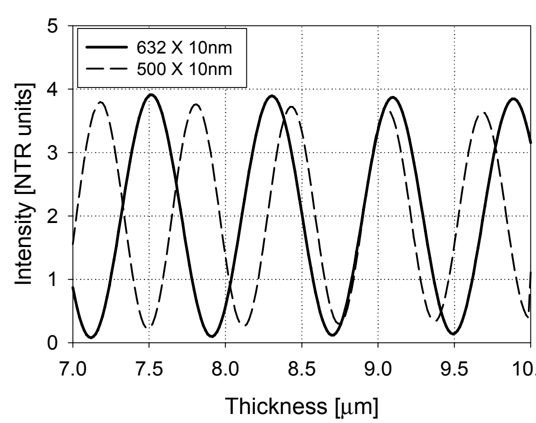

Figure 3: Amplitude of dielectric foil radiation in normalized transition radiation units for filter bands 632 x 10nm and 500 x 10nm; refraction index 1.8; energy 13.7MeV.

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EXPERIMENTAL RESULTS

A proof of principle experiment was done at energy of 13.7 MeV. We acquired two interference patterns which are shown in Figure 4. For experimental reasons the field of view of our optics was limited so that only a portion of the total interference patterns are visible. Nevertheless, the data is sufficient to produce line scans which can be analysed to determine beam properties.

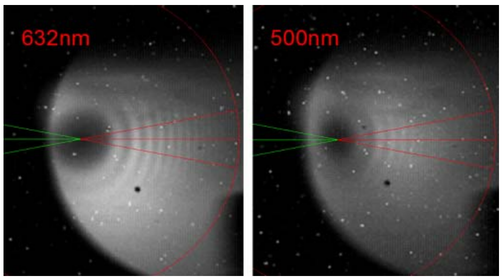

Figure 4: Images of angular distributions taken with pass band filters 632 x 10nm (left) and 500 x 10nm (right).

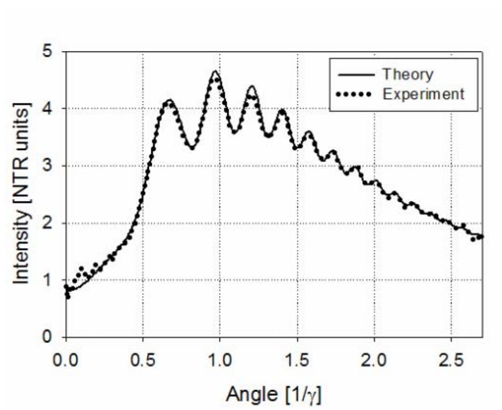

Figure 5: Horizontal scan, filter 632 x 10 nm; fitting interval 0.2 – 2.5 γ^{-1}, RMSD = 0.96%.

Horizontal line scans of the interference patterns were taken by averaging over the arcs within the red sector lines shown in Figure 4 to smooth the noise [2]. The sector averaged data scans are shown in Figs. 5 and 6 as dotted lines. The calculated distributions are also plotted in these figures for the set of parameters which gives the best fit for each scan.

Since we took data for two filters, CONVD1 accordingly produced two radiation amplitude factors 3.75 and 3.7. Figure 3 shows that these values are matched by a foil with thickness 9.03 µm and refraction index 1.8. These foil parameters are then used in CONVD2 to fit the rest of the parameters. The best fit parameters are: interferometer foil spacing d = 1.88mm, beam energy E = 13.7MeV, RMS angular divergence of the scattered fraction of the beam, RMSS = 8.8mrad and RMS angular divergence of the unscatterd beam fraction, RMSU = 1.23mrad.

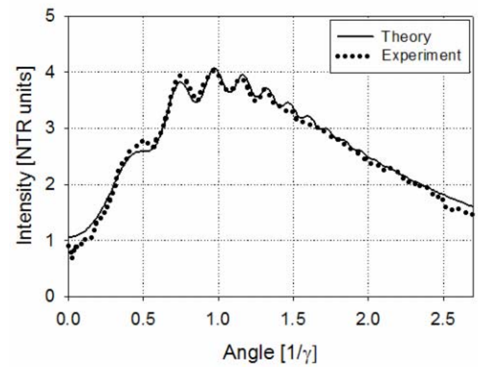

Figure 6: Horizontal scan for 500 x 10 nm filter; fitting interval 0.2 – 2.5 γ^{-1}; RMSD = 1.97%; thickness and refraction index of dielectric: 9.03µm and 1.8.

CONCLUSIONS

We have successfully designed an ODR-dielectric foil transmission interferometer to measure the unperturbed angular divergence of a low energy electron beam. Simulation and fitting codes have been developed which allowed us to fit the measured interferences and determine the RMS horizontal divergence of the ANL-AWA electron beam operating at 13.7 MeV. We have shown that it is not necessary to know the exact parameters of the dielectric foil a priori. It is sufficient to approximately know the attenuation and the index of refraction of the foil.

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