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Radiation field mapping using a mechanical-electronic detector

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ABSTRACT

A method of radiation field mapping of a scanned electron beam using a Faraday-type detector and an electromechanical linear translator is presented. Utilizing this arrangement, fluence and fluence rate measurements can be made at different locations within the radiation field. The Faraday-type detector used in these experiments differs from most as it consists of a hollow stainless steel sphere. Results are presented in two- and three-dimensional views of the radiation field.

1. Introduction

Two related measurements of fundamental importance in electron beam irradiation of materials are the particle fluence rate (electrons $cm^{-2}s^{-1}$) and its time integral, the particle fluence. These can be measured using a Faraday cup (Woods and Pikaev, 1994). The latter typically consists of an electrically insulated metal block, of sufficient thickness to stop the beam completely, in an evacuated chamber. A lead connected to the block allows for the measurement of the current or number of electrons collected by the block. Such devices, due to their inherent quick response, can be used to make time-dependent measurements as well (Kucerovshy and Kucerovsky, 2003). At the same time, the actual distribution of electrons as a function of position beneath the scan horn, which is of interest, can also be determined. This latter quantity is generally measured using CTA film, which allows one to develop a two-dimensional map of the fluence beneath the beam. When using this technique, the relative fluence is determined by measuring the darkness of exposed film as a function of position. The darkening of film is necessarily an integrative process as the more electrons interact with the film greater is the darkness.

At our facility a different Faraday cup has been used in the past to determine the fluence beneath the center of the scan horn. Unlike the Faraday cup described in Woods and Pikaev this particular Faraday cup operates at atmospheric pressure, not under a vacuum. This device used nuclear instrumentation modules and a lab view program to determine the fluence.

In a paper and reports by Vargus-Aburto and Uribe (2005) it was used to measure fluence at an electron beam current of 100 μA. The current is limited because the count rate is too high when higher currents are used; furthermore, this instrument was designed for long-duration measurements directly under the beam. This current was chosen so that solar cells that were irradiated under such a beam would not become excessively warm. In their paper the uniformity of the irradiation area was determined using CTA film at a current of 10 mA.

In this paper we present a combination, mechanical and electrical, Faraday device that can be used to determine the fluence rate, the fluence and to map the electron fluence at a commercial electron beam facility. Since this device is both mechanical and electrical we use the term mechanical electronic detector to describe such a device. By using a relatively inexpensive computer-interfaced voltmeter we are able to have a sample rate of approximately 2.5×10^{4} Hz. While not exceedingly fast, the typical scan frequency of a commercial electron beam irradiation facility is roughly 100 Hz. This allows excellent resolution of the scanned beam. The vacuum chamber of the present Faraday device is directly connected to a cryogenic vacuum pump and had no difficulty in determining fluences for electron beam currents of 10 mA.

The balance of this paper is divided as follows. Section 2 will discuss our electron accelerator. Section 3 will be divided into four subsections covering the translator, the Faraday device, the data collection electronics, and the data analysis. Section 4 will present the results of our study. Finally, Section 5 will be summarized in the final section along with an Appendix.

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1.1. The accelerator

The radiation facility used for this work is called NEO Beam and is the result of a joint venture between a local plastics manufacturing concern (Mercury Plastic, Inc.) and the Kent State University. This joint venture provides a production-scale irradiation facility for the company and a source that the university uses for research, teaching and outreach. The accelerator is an electrostatic-type Dynamitron^{TM}, manufactured by Radiation Dynamics Inc. This accelerator produces electrons with energies between 0.7 and 5 MeV. The control electronics are somewhat different from those on a standard Dynamitron to provide a wider range of energies and currents for research. Subject to constraints on the current and power at the lowest and highest energies, the accelerator can produce powers of 150 kW. The constraints are described elsewhere (Vargus-Aburto and Uribe, 2005). The output of this accelerator is a pencil beam of electrons with a radius of about 3 cm. This beam interacts with a scanning system operating at a frequency of 100 Hz that is driven by a triangular waveform. The scanner causes the beam to systematically scan back and forth in one dimension. The maximum scan voltage (along with the geometric constraints of the scan horn) determines the width of the scan. The maximum total length of such a scan is 1.2 m. The electron beam passes through a 60 μm titanium window that separates the vacuum of the accelerator from the atmosphere (generally air) in which the irradiations take place. Generally in production and experiments the sample is translated perpendicular to the scan direction so that an area of width up to approximately 1.2 m is irradiated.

In the present experiments the average current was 10 mA with a regulation of 50 μA. This corresponds to a variation of no more than $\pm$0.5% in the average current. This current was sufficiently high to have small variations in current, while at the same time minimizing the time necessary to turn the beam off to manually translate the detector parallel to the scan horn. The energies used were 3 and 5 MeV. The energy largely determines the depth the electrons penetrate the material; these are simply typical energies used at our facility. Finally the scan width at the exit aperture was 91.44 cm corresponding to a scan width of 75% of the maximum. This value was chosen to minimize electron reflections from the edge of the translation stage used with our detector.

2. The mechanical electronic detector

2.1. The translation stage

The translation stage was originally described by Vargus-Aburto and Uribe (2005). It has had a few modifications since that time to make it easier to setup and move into the irradiation beam chamber, but functionally it operates as described in their paper. This large, facility constructed translation stage translated a support, which in this experiment held the Faraday sphere detector perpendicular to the beam scanning direction. This translator is computer controlled through a stepping motor, and has various trip switches to turn other equipment on or off, and has translation speeds between 0.01 and 30 m/min. This stage has a useable width and length of approximately 2 m.

For simplicity, in the present experiment, the origin of the coordinate system was taken as a point 0.6 m below and horizontally at the geometric center of the beam exit aperture. The height, 0.6 m, was the distance between the exit aperture and the input window of the Faraday device and was not varied during the experiment. This distance also is a typical distance between the scan horn window and the top of samples that are being irradiated. The y direction is parallel to the beam scan direction and x perpendicular to the beam scan direction in a right hand coordinate system. The translator moved the detector from positive x to negative x values at a constant y. This is because the translator does not as yet have two-dimensional translations. The y values where changed by hand a distance of 5 cm between each data collection run and measurements were only made to the center of the beam in the y direction. The beam is expected to be symmetrical about its geometric center, and only minor differences have been detected using CTA film. This is as one would expect with any system due to scattered electrons by ancillary equipment in close proximity to one side of the scan area. For this reason the data collection runs are continuous in the x direction but discrete between $y=0$ and $y=100$ cm in 5 cm steps in the y direction. This data collection geometry is shown in Fig. 1.

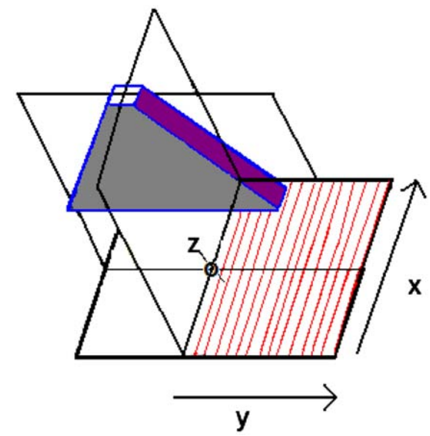

Fig. 1

2.2. The Faraday device

The Faraday device consists of a stainless steel spherical charge collector inside a cylindrical vacuum chamber. The chamber is connected through a vacuum valve to a cryogenic vacuum pump. Vacuum feed throughs are used to pass electrical signals from the inside of the vacuum chamber to the equipment. The device in cross section is shown in Fig. 2. The vacuum chamber consists of a hollow cylinder of 316 stainless steel that is 15 cm in diameter, 6 mm thick and 30 cm long. The chamber is closed by circular end plates of 6 mm thick 316 stainless steel. Calculations using the Penelope code (Salvat et al., 2003) indicate that there is essentially no electron transmission ($<0.2\%$) through a solid piece of this material for electrons of energy 5 MeV. At lower energies the fraction of electrons transmitted is even smaller. The cryogenic vacuum pump, valve and flange are standard 3.48 cm inside diameter high-vacuum components and commercially available from Huntington Mechanical Laboratories.

The top end plate has a 2.54 cm threaded hole. A bi-material threaded cylinder with an internal diameter of 1.91 cm is attached to the inside of this plate. This is sealed on the top side by a Kapton® window 0.0025 mm thick that is held in place by an aluminum retaining ring with an internal diameter of 1.91 cm. This diameter determines the input area of the Faraday cup. The other end of the threaded cylinder is used to support the charge collection sphere. The top plate is sealed to the main cylinder via an o-ring and vacuum grease. In this way the top and the charge collection sphere can be removed.

The bottom plate has a number of feed throughs and a vacuum flange attached to it. It has a vacuum BNC connector at its center. The inside has a spring that makes contact with the charge