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Abstract

The electron beam size has been determined on the Advanced Test Accelerator (ATA) by intercepting the beam with a target and measuring the resulting x-ray intensity as a function of time as the target is moved through the beam. Several types of targets have been used. One is a tantalum rod which extends completely across the drift chamber. Another is a tungsten powder filled carbon crucible. Both of these probes are moved from shot to shot so that the x-ray signal intensity varies with probe position. A third is a larger tantalum disk which is inserted on beam axis to allow determining beam size on a one shot basis. The x-ray signals are detected with an MCP photomultiplier tube located at 90° to the beamline. It is sufficiently shielded to reject background x-rays and neutrons. The signals were digitized, recorded and later unfolded to produce plots of x-ray intensity versus probe position for several times during the pulse. The presumption that the x-ray intensity is proportional to beam current density is checked computationally. Details of the probe construction and PMT shielding, as well as sample measurements are given.

Introduction

Previously reported beam size measurements on the Experimental Test Accelerator [1,2] have been made by monitoring the x-ray signal amplitude produced by a beam-intercepting target. (The term "x-ray" is to be understood in the following discussion as electromagnetic radiation with energies in the range of 100 keV to 50 MeV.) This technique has been extended on the Advanced Test Accelerator (ATA) [3], which has a much more energetic electron beam and more severe radiation background, to nanosecond resolution of beam size. Typical beam parameters are 50 MeV, 6 to 10 kA, 50 ns pulse length. As a target is moved through the beam its position and the resulting x-ray signal are recorded. This is done for many shots of the machine. For a particular time in the pulse it is possible to determine the size of the beam by plotting x-ray amplitude for many different probe positions. A requirement is that beam position and size are repeatable over many pulses. If they are not, large scatter in the data is observed. A filter is used to reject background x-rays, so that the resulting amplitude is very nearly proportional to primary beam current density. A schematic representation of the technique is shown in Fig. 1.

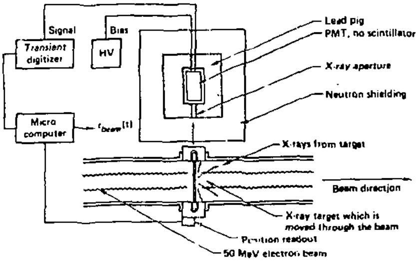

Fig. 1. Block diagram of the x-ray beam size measurement technique.

Theory

We would like to show that the x-ray emission from a beam intercepting probe is proportional to the beam current density, which is not obvious from initial inspection. Calculations for small angles show that the x-ray yield is very dependent on the primary electron beam energy. [4]

Several factors affect the x-ray intensity. The Bremstrahlung emission is very strongly forward directed for very high $\gamma(=E/E_0)$ electron beams [5]. The functional form approaches $1/\gamma^2\theta^2$ large $\gamma\theta$. There can also be significant x-ray production from secondary electrons within the target, some of which are directed towards the detector. The target will also be optically thick for lower energy x-rays.

Based on these uncertainities a Monte Carlo simulation of the problem was run with the SANDYL electron-photon transport code [6]. X-ray yield, photon energy flux per electron as a function of photon energy, was calculated at 90° to the electron beam for 2.5 through 50 MeV electrons. The target was a 6 mm thick, 10 mm diameter tungsten disk placed perpendicular to the beam. The resulting x-rays were considered attenuated by a 3 mm thick lead filter. The filter is opaque below 200 keV, and 80 to 90% transmitting above 800 keV. The results of the SANDYL runs are shown in Fig. 2. The x-ray spectra for electrons between 25 and 50 MeV are within statistical errors except for the peak at 500 keV. This peak comes from positron-electron annihilation radiation, which is strongly dependent on the geometry of the target since the positrons produced by pair production from within the target must first thermalize before annihilating. If the target is sufficiently thin they may escape before this occurs.

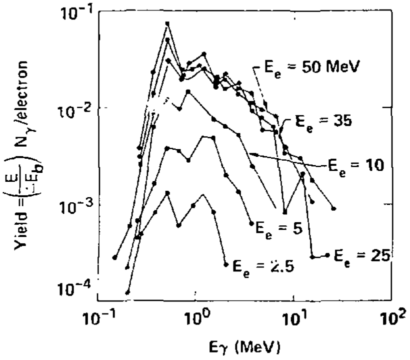

Fig. 2. Photon energy flux at 90° and through a 3 mm thick lead filter per electron striking a 6 mm thick tungsten target, as a function of photon energy.

Integrating over the x-ray spectrum with the response function of the PMT has not been done because the response of the PMT is not known. Since the x-ray yield spectrum is independent of electron energy from 25 to 50 MeV this integral need not be done.

Experiment

As depicted in Fig. 1, a target is swept through the beam to generate x-rays. A long thin rod which is often used to integrate the x-ray amplitude along one axis. Solid 3 mm diameter tungsten and tantalum rods were tried as targets. The tungsten targets failed by shattering. The tantalum targets tended to differentially heat and bend or break for beam current densities of 2 kA/cm^2 or greater. The problem has been solved at these current densities by using a 6 mm diameter graphite rod as a target that has a 3 mm diameter hole along its axis that is filled with tungsten powder. The tungsten powder is the high Z target. The graphite is a low Z crucible which can withstand many shots of the machine without breaking.

Other types of targets are also used. One is a 1 cm diameter tantalum disk on the end of a 6 mm diameter graphite rod. This target is used in those places where the beam is several centimeters in diameter. In contrast to a tungsten filled rod it gives a signal proportional to local current density, and not to the integral along the rod length. A variation is to use a disk with the approximate diameter of the beam. By placing the disk on the beam axis, and by comparing the x-ray signal with the beam current signal beam size variations in time with a single shot of the machine can be inferred.

Spatial resolution of the diagnostic is limited by the probe size. For the rod targets the resolution is approximately 1/2 of the rod diameter, or ±1 mm for the target shown. Spatial resolution of the disk target is also much smaller that the disk diameter because most of its mass is much closer to its axis.

X-rays emitted from the target are observed at 90° because of convenience in placing the shielding and detector. They are detected with a microchannelplate PMT (Hamamatsu R1194) without a scintillator. X-rays are directly converted to electrons within the microchannelplate. This technique allows subnanosecond resolution of the x-ray signal. A scintillator would improve the conversion efficiency, but also degrade the rise and fall times.

The PMT is shielded against background radiation with 300 mm of lead on the upstream and beamline directions, and 150 mm of lead on the other sides. Neutron shielding is also used around the lead. It consists of a 400 mm thick polyethylene moderator and a 25 mm thick, 5% boron, borated polyethylene thermal neutron absorber. This shielding reduced background levels on the PMTs to less than 10 mV. The lead shielding is apertured so that only x-rays from the region of the target are allowed to reach the PMT. As with the code runs, a 3 mm thick lead filter was placed in front of the PMT for attenuating target fluorescence caused by x-rays from beam spill upstream of the diagnostic.

The signal produced by the PMT is digitized with a Tektronix 7912 transient digitizer (500 MHz bandwidth). The probe position is simultaneously measured with a position encoder. The output of both devices is then stored on an LSI-11 microcomputer operating with an SPSBASIC [7] operating system. Up to 100 shots with 64 time slices within the pulse are usually recorded and stored in a file. Most often the file is written to a floppy disk and transferred to the mainframe computer system at Livermore (the OCTOPUS system) for analysis.

Analysis

The analysis is done on the Cray computers with a routine named PROBE. At each of the saved times of the pulse x-ray amplitude versus probe position is plotted, as is shown in Fig. 3. A curve is fit to the data for each time by minimizing the sum of the squares of the difference between the function and the x-ray amplitude. Both Gaussian and Bennett profiles have been used as fit functions. Some of these are described in Table 1. In all cases cylindrical symmetry is assummed. For rod target scans the data is fit to the line integral of the function rather than Abel inverting the profile after the fit. With Gaussian profiles the line integral is itself. For a Bennett profile the line integral is a different function, as shown in the table. This technique is equivalent to Abel inverting the function after the fit. The fit parameters are then used to determine the beam radius, the background, the beam position, and x-ray amplitude for each time saved, as shown in Fig. 4. If the x-ray emission is proportional to the electron beam current density, a trace can also be constructed which will be proportional to the beam current. This is done by integrating the x-ray signal over the measured beam radius. By comparing the reconstructed trace to the measured beam current as shown in Fig. 5 it can be seen that the detected x-ray signal is proportional to the beam current. The non-zero level at the end of the pulse is not real and is likely due to finite droop times of the PMT.

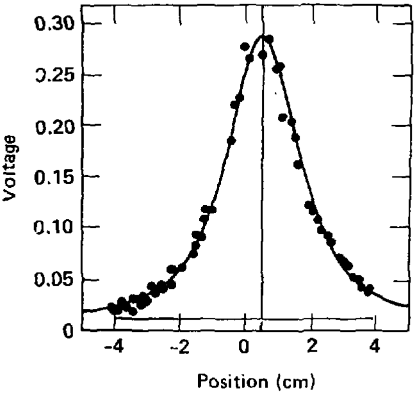

Fig. 3. Amplitude vs. position for one time during the pulse and fit to the line integral of a Bennett profile.

Table 1

Decription of the functions used in the radial profile fits. The free parameters of the fit are c_1 through c_5, which are all functions of time.

Description	f(x)
Gaussian, flat base	$c_1 + c_2 \exp[-\frac{(x-c_3)^2}{c_4^2}]$
Bennett, flat base	$c_1 + \frac{c_2}{[1 + (x-c_3)^2]^2}$
Abel inverted Bennett, flat base	$c_1 + \frac{\pi c_2 c_4^4}{2(c_4^2 + (x-c_3)^2)^{3/2}}$

Conclusions

The x-ray beam size measurement technique has become a reliable diagnostic for determining beam size on the ATA. Calculations, supported by experimental evidence, show that the x-ray yield at 90° in nearly energy independent for electron energies above 20 MeV, except for a

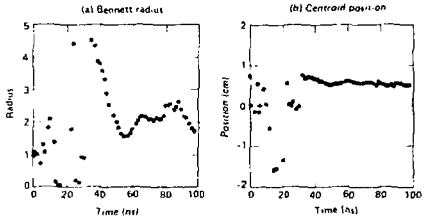

Fig. 4. Derived data from a x-ray scan with a rod target.

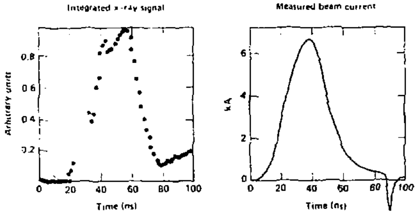

Fig. 5. Comparison of the beam current signal inferred from the integral of the x-ray data and that measured with a beam current monitor.

mild energy dependence of annihilation radiation from thick targets. Initial problems with the surviveability of beam-intercepting targets was solved by use of tungsten-powder-filled carbon crucibles. The major limitation of the diagnostic is the requirement of many reproduceable pulses of the machine.

Acknowledgements

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