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PROXIMITY-FOCUS: THE NEW GENERATION STREAK TUBE

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ABSTRACT

A new era in x-ray and visible streak photography opened with the introduction of the proximity-focus or planar streak tube. Elimination of grids and photoelectron pinhole optics has resulted in a tube capable of transmitting peak photoelectron currents necessary for recording picosecond and sub-picosecond events without temporal or spatial distortion. Vacuum compatible x-ray cameras, based upon the planar design, have demonstrated better than 1 ps resolution. Visible cameras have shown impressive dynamic range and produced streaks of high statistical quality with picosecond resolution. These properties have opened new fields in picosecond and sub-picosecond photography.

1. Introduction

Until a few years ago all commercial streak cameras used a tube based upon the RCA C73435. This tube was first designed as a shutter tube and later adapted to streak use.¹⁾ The serious problems that have emerged as design limits were approached have been the subject of much controversy.²⁾

Cameras based upon the old design are flawed mainly because of problems associated with the internal photoelectron optics of the streak tube. For picosecond and sub-picosecond recording, these cameras suffer from blooming, spatial resolution loss, pulse temporal distortion, low dynamic range (less than 50X), and produce streaks of very low statistical quality. Usage of pinhole optics serves as a bottleneck to passage of the extremely high photoelectron pulses required to register high quality picosecond streaks. The gain of the tube must be limited to control spacecharge defocusing effects at the pinhole. Problems with this type of tube are compounded by the fact it is basically a soft field device. A grid structure must be added to increase photoelectron extraction fields. Unwanted magnification results from this grid which effectively lowers the tube's

sensitivity by spreading the already limited photoelectron pulse over a greater output area. Magnification distorts tube linearity and requires more expensive, large-diameter, follow-on image intensifiers.

When the old tube is applied as an x-ray camera, design weaknesses are even more pronounced. Temporal resolution limits at about 20 ps which is insufficient to record instabilities encountered in laser-fusion experiments which are as short as several picoseconds. For this reason, the streak tube based upon the planar tube was developed as an outgrowth of the laser-fusion program at Los Alamos Scientific Laboratory.³⁾ In this device there isn't a pinhole--electrons flow from photocathode to phosphor in a sheet or ribbon. Grid structures are necessary since this type of tube requires ultra-high fields to operate. Unity magnification is automatic. The absence of a grid structure results in a uniform parallel extraction field at the photocathode, thereby reducing the possibility of lens effects and their limitations. Ultra-high fields eliminate blooming over a large range of signals. Problems of pulse temporal distortion and after-pulsing are not present in this device--the streak profile represents

an accurate temporal history. In the old tube spatial and temporal pulse distortions depend upon photocathode illumination patterns. Instrumental errors are a function of the experiment. Planar optics circumvents this.

2. Planar X-Ray Streak Camera

The planar x-ray streak camera designed for operation within the laser-fusion scattering chamber is shown in Fig. 1. Usage of a solid-dielectric spark gap as sweep generator and a newly designed photoelectron system, result in an inverse-sweep velocity of approximately 3 ps/mm. Resolution of 4 ps/mm theoretically predicts sub-picosecond temporal resolution for this camera.⁴⁾ These cameras are currently being employed at several laser-fusion facilities.

3. Planar Visible Streak Camera

The dynamic range, or ability of a camera to record features of the incident light profile over a large range of signals, is as important to picosecond photography as ultimate temporal resolution itself. The dynamic range of the planar visible camera was tested using the equipment shown in Fig. 2. A series of images of an Nd:YAG laser were formed along the camera slit using an etalon. Each image was degraded in intensity over its predecessor by a factor of 0.23. Complex trains of pulses were formed to determine the number of intensity steps over which the camera could track and resolve given temporal features. This remains a practical definition of

dynamic range. For these measurements an avalanche-krytron sweep module was used to provide 2 ps resolution. The images were recorded on film placed in direct contact with the camera output. The film was calibrated and the images densitometerized. In Fig. 3 the output values of scanning across the streaks are shown along the ordinate. These output values very nearly track the $(0.23)^N$ input levels. The camera can resolve 10 ps features over steps corresponding to a dynamic range in excess of 1000X. A scan through the uppermost streak is shown along the abscissa. In this streak the switched out pulse and bleedthrough are evident in the same trace. The manufacturer's quoted shutter ratio of 800:1 is consistent with the other measurement. The distortionless nature of the format and high statistical quality of the streaks is also evident. Representative scans across the streaks of varying light levels show similar SNR values. These features make the camera an ideal candidate for GWA and other digital recording systems.

Recently the planar camera was tested and found to be over 100X more sensitive than conventional cameras⁵⁾ based upon the old tube design.⁶⁾ The new camera employs a fiber-optic light guide which allows the slit to be placed in direct contact with the photocathode. This results in an efficiency increase of 1X. Other parameters being equal, the additional sensitivity increase can be attributed to the lack of magnification and the planar 1:1 format.

Fig. 1. Picosecond x-ray streak camera. The vacuum compatible sensor is shown on the left. The control console is on the right.

Fig. 2. Visible camera dynamic range test setup. The laser beam enters from the right. Etalon system is in the center of the photograph while camera head and control console are on the left. The photodiode trigger is in the foreground.

Fig. 3. Densitometer scans of planar visible camera streaks. Inputs descend in intensity by $(0.23)^n$. Output values shown at right follow input values. A scan through the uppermost streak shows both switched-out pulse and bleedthrough. This and successive scans through the other streaks indicate features of the pulse can be tracked over a signal range in excess of 1000X.

Planar streak cameras have already opened new fields of picosecond photography. For example, the dynamic range of the camera has enabled laser driven shock waves to be tracked through several target steps.⁶⁾ Sub-picosecond high-statistical quality streaks will enable shock risetimes to be measured for the first time in history.

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