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ABSTRACT

We have developed a fiducial system for rotating mirror streak cameras that utilizes light emitting diodes mounted at the slit position of the camera. The diodes are driven to the required high brightness by a unique pulse power circuit designed to provide high voltage, high current pulses 18 nanoseconds in length at a frequency of up to 2.5 megahertz. The availability of super bright light emitting diodes with a wavelength of 630 to 640 nanometers allows us to record fiducial pulses, at streaking speeds in excess of 20mm per microsecond, on all the black and white films commonly used in high speed photography. The time marks on the film record are referenced to the real time of the experiment from a clock-driver that controls the start and frequency of the fiducial pulse train and by three adjustable and discrete blanked fiducials. This paper discusses the development of this system and describes the full setup as used at LLNL.

INTRODUCTION

Rotating mirror streak cameras are a valuable tool in providing a continuous record of specific areas of interest in studies of fast phenomena. Critical to determining the usefulness of the data is the ability to accurately reference, in time, the data recorded by the camera. This referencing takes two forms: accurate measurement of the relative timing of events on the film record and relating those measurements to an absolute experimental time. Using overdriven visible light LED's mounted directly in the slit of the rotating mirror streak camera is an approach that has been waiting for technology to catch up. The system described here is an extension of past efforts at the Lawrence Livermore National Laboratory (LLNL) to provide fiducial marks on streaking camera film to interrelate the recorded data and the experimental time history.

Over the past thirty-five years, a number of techniques have been used to time reference the streak camera film records. From the 1950's through the 1970's, fiducial timing marks were provided by two techniques: exploding detonator bridge wires and electrical spark gaps¹. Detonator bridge wires are positioned at the experiment and imaged at the slit of the camera in the same manner as the experiment. A light pulse from an electrical spark gap is carried by optical fibers to be imaged on to the camera slit. The limitations of these techniques are the breakout timing jitter of the bridge wires and premature breakdown of the spark gap and, most important, the inability to produce more than one or two timing marks over the entire length of the camera film record. The number of timing fiducials is not a problem if the writing rate on the film record is linear. However, in many streak cameras, especially continuous access cameras, the record is nonlinear because of changes in the distance between the face of the rotating mirror and the film plane as the rotor turns.

In 1980, a laser system was developed to provide a burst of fiducial timing marks covering the entire length of the streaking record². The burst of pulses is produced by cavity dumping a 5-watt Argon-ion laser, and transported to the slit of the streak camera by optical fibers. Timing marks at a frequency of up to four megahertz can be simultaneously provided to two cameras. This system was a major step forward providing excellent fiducial timing marks, and the string of fiducial marks eliminated concerns about record linearity. However, the system is very expensive to build, very difficult to maintain and time consuming to setup and use on experiments.

In the mid 1980's, an LED fiducial system was developed at LLNL for electronic streak cameras³. Light pulses from a clock driven pulser are transported to the slit of the electronic streak camera by optical fibers. This system provides excellent timing marks with a frequency of up to ten megahertz. The clock-driver and a sophisticated timing mark blanking circuit permits accurate referencing to the experiment time history. However, the light output intensity of the LED's in this system is inadequate to record at the film plane of a rotating mirror camera, and the 660nm wavelength of the LED's is beyond the sensitivity of most of the fast black and white films used in high speed streak cameras. The LED fiducial system described in this paper is a direct outgrowth of the electronic streak camera fiducial system.

FIDUCIAL SYSTEM DESIGN

The design of the fiducial system involves a series of goals to enhance its use on the Cordin Model 132 synchronized streak camera and the Cordin Model 136 continuous access streak camera. These design goals are:

The use of as much of the electronic streak camera fiducial system as possible.

Placement of a fiducial at each end of the slit image to denote slit orientation to the record during analysis.

Provision of absolute and cross timing of the streak records with 10ns accuracy at a camera writing speed of 20mm/microsecond.

The capability to use the system on as many as eight cameras, in parallel, on a single experiment.

The ability to use all of the high speed black and white films currently used in high speed photography at LLNL (Kodak TRI-X, T-MAX 400, and T-MAX 3200) at ASA 1800.

A simple, inexpensive system with dependable turn key operation.

To get an LED fiducial system to meet these goals, we had to achieve a number of design steps.

The clock-driver from the electronic streak camera fiducial system was adapted to our application. This required very little effort.

The LED's were mounted directly in the slit plane of the camera and the LED chip was imaged directly on the film plane of the camera.

A pulsed power supply was designed and fabricated that would produce a burst of ultra short, fast risetime pulses and greatly increase the driving current to the LED's

And most critical, we obtained super bright LED's with an improved spectral match to films we use.

HIGH POWER LED DRIVER

A prototype circuit (Fig. 1) was designed around the new generation of high voltage, high power MOSFET's that allowed us to overdrive LED's by a factor of two hundred above normal operation (for very short periods) and to test whether the diodes produce enough light energy to expose film. We chose Directed Energy, Inc.'s Model 501N04 MOSFET (500 V, 4.5 amp CW, 32 amp pulsed) as the heart of our driver. The circuit uses a 9 nanosecond length of 50 ohm coaxial cable charged from 60 to 500 volts to form the LED current pulse. When switched out by the MOSFET, a pulse of amplitude -25 to -240 volts and duration 18 nanoseconds is launched on the 50 ohm output cable. The output cable is terminated by a resistor in series with two series LED's. The resistor value is adjusted to properly terminate the coaxial line to prevent voltage reflections. We determined that the dynamic impedance of the LED's is about 10 ohms at these operating conditions, so a nominal 30 ohm resistor was used for the impedance match.

To protect the LED's from probable damage if operated at too high a duty factor (too high a repetition frequency), a 510 ohm resistor was incorporated in the circuit limiting the recharge time of the 9 nanosecond coaxial charge line to no shorter than 400 nanoseconds. If the driver is triggered any faster than 2.5 megahertz, the output amplitude decreases since the charge line cannot completely recharge. Again to protect the diodes, the total energy available for any given pulse burst is limited by incorporating a current limiting 100 Kohm resistor between the power supply and a two microfarad capacitor. The energy in the charge line is drawn from the capacitor, and when the capacitor is depleted (it takes a second to fully recharge), there can be no further current for the LED's.

The choice of many of these parameters was both fortuitous and application specific. When the Cordin cameras are operated at full speed (20 mm/usec writing speed), a 400 nanosecond interpulse time corresponds to 8 mm. This was deemed to be more than adequate for accurate data reduction and analysis (in fact a 10 mm fiducial spacing, 2 MHz at 20 mm/usec, is used most often). The longest record we write is 66cm long on the Cordin Model 136 continuous access streak camera. Therefore, the limit of 100 pulses, provided by the two microfarad capacitor, is more than adequate to fill the film record.

In the course of this development work, an experiment was performed whereby we halved the driver system impedance to 25 ohms. This was done to double the current to the LED's to nearly 10 amps with an eye toward increasing the brightness of the fiducial spots. We found that when this was done, the light output did increase at the beginning of the burst, but only by about 60%. However, after about 70 pulses, the output intensity decreased substantially. Careful consideration led us to conclude that the semiconductor chip in the LED's was overheating at these higher currents, and the light generation efficiency was being compromised. This was confirmed when we later discovered a 1990 paper by B. Stasicki⁴ that referenced in detail similar work with overdriven LED's. The 1990 paper was a refereed version of a paper first presented in 1988. Our choice of 240 volt pulses into 50 ohms for up to 100 pulses turned out to be a reasonable maximum without stressing the LED's to the point of degraded performance and possible damage. As the circuit now exists, we have pulsed several diodes well over 1 million times, each at 240 volts, without a failure. Although the original LED driver circuit has provisions for varying the output pulse amplitude from 25 to 240 volts, in actual use the driver has been operated exclusively at full amplitude. Since this system exceeds our design criteria, we felt no need to explore the limits of operation any further.

As originally incorporated in the electronic streak camera fiducial system, the clock-driver generates a burst of up to 255 pulses embedded within which are three unique markers at pre-

Figure 1. High power LED driver. The input is a 5V TTL burst of trigger pulses. The output is a burst of up to 100 pulses, -240 V amplitude 18 nsec duration, 2.5 MHz maximum into a 50 ohm load. Also depicted is a camera slit with the LED fiducial generators.

selected locations. The first marker is a single dim (less bright) pulse, the second is a pair of adjacent dim pulses, and the third a string of three dim pulses. The pulsed power supply we designed is incapable of producing a reduced-amplitude pulse among a burst of full amplitude pulses, so we chose instead to modify the clock-driver to blank the marker pulses completely (Fig. 2). In this manner, up to eight parallel cameras can be accurately crosstimed and referenced to an absolute system time since the missing fiducial pulses on the film record occur at the same absolute time on all the cameras, and the times of the missing pulses are known.

Figure 2. Representative portion of 66 cm long streak record from a Cordin Model 136 camera. The film is shown actual size. The writing speed is 10 mm per microsecond with a fiducial pulse rate of 2 MHz. The film is Kodak T-Max 3200 developed at ASA 6400. Time is increasing right to left. Note that the eighth fiducial pulse from the right is missing, allowing for absolute time reference.

CAMERA SLIT

In order to position the LED chip at the slit of the camera and image it at the film plane, we have to machine away almost all of the plastic material that forms the encasement for the LED and gathers and focuses the light produced at the chip surface. The material is removed to within a few hundred microns of the face of the chip. A modified LED is placed at each end of the 48mm long slit. The sub-millimeter size chips are centered on the line of the 125 micron wide streak camera slit as shown in Figure 3. The one-to-one imaging of the chip on the film plane by the internal relay optics in the camera produces a distinct sub-millimeter diameter bull's-eye pattern.

LIGHT EMITTING DIODES

This project initially used the 3 candella, 660nm peak wavelength H-3000 LED available from Stanley (and used by the electronic streak camera system), and later the 4.1 candella 180CRP LED from AND. Both units have a spectral half width of 25nm, and perform very well with Kodak 2475 extended red high speed film but are outside the spectral sensitivity range of TRI-X and T-MAX. This was a frustrating situation because T-MAX 400 and 3200 films are the current films of choice for use in LLNL rotating mirror streak cameras. However, by using the Stanley and AND LED's with Kodak 2475 film, we were able to design and develop the fiducial system while the search for a more appropriate diode took place.

Our search led us to George Crawford and Frank Steranka of the Optoelectronic Division of Hewlett Packard⁵ who provided us with prototype LED's to test with our system. The LED's were in two wavelength groups with peak wavelengths of 648nm and 639nm. The 648nm diode is more than twice as bright as the 639nm diode. The peaks are only separated by 11nm with a spectral width of 25nm FWHM, yet T-MAX 3200 film gives an acceptable response to the fiducial system using 639nm diodes and a poor response when the brighter 648nm diodes are pulsed at the same current as the 639nm diodes. The published spectral response curve for T-MAX 3200 indicates that the film sensitivity falls dramatically above 600nm and is ineffective for our purposes at 660nm. We measured the spectral output of the two different LED's and compared it with the film response curve. This comparison indicated that the film should be sensitive to most of the

Figure 3. Rotating mirror streak camera slit with the LED's mounted at each end of the 0.12 X 48 mm slit.

light from the 639nm diode, and enough of the shorter wavelength portions of the 648nm diode to give a reasonable exposure. Since this was not born out by our experiments, we assumed that the film's performance did not match that of the published spectral response curve. It was important to establish the correct spectral sensitivity curve for the film in this region so that we could determine how hard to push the trade-off between diode brightness and wavelength. We contacted Kodak with our problem and they immediately responded by providing us with updated measurements of the T-MAX 3200 film spectral response above 600nm⁶. The updated curve has a shallower slope between 620nm and 650nm, and shows that the film responds well to the shorter wavelength portions of the 639nm diode output, but is relatively insensitive to almost all of the bandwidth of the 648nm diode output. It also indicates that we can expect to see dramatic improvement in T-MAX film response for wavelengths down to 620nm. The fiducial system works well with HP 639nm diodes, and can only become more efficient and versatile as brighter LED's at shorter wavelengths become available.

Figure 4. Cordin Model 136 camera with LED fiducial system attached. The camera is shown mounted in a vertical position for use at LLNL's Site 300. The LED/slit assembly is shown in position just below the white ring at the top of the camera. The high power driver, hanging center right, accepts a trigger burst from an external source and delivers short, high power pulses to the LED's located in the slit plane.

CONCLUSION

The slit mounted LED fiducial system has proven to be a simple, relatively inexpensive tool that produces fiducial timing marks that permit the reading of rotating mirror streak camera records to an accuracy of 10 ns. Events on several camera records can be temporally interrelated as well as referenced to the absolute experimental time. It is simple to build, easy to install, and we believe it to be a natural addition to rotating mirror streak camera systems.

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