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A Microflash Unit for Ballistic Photography*

W. W. McCormick, L. Madansky,** and A. F. Fairbanks***
Randall Laboratory of Physics, University of Michigan, Ann Arbor, Michigan
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A flash unit has been developed for photographing large projectiles in flight. The light source combines high intensity with short duration. Details of the geometry and processing of the lamp are given, together with a discussion of the methods of measuring intensity and duration. Several of the units described have been in use at the Aberdeen Proving Ground and some photographs taken there are reproduced.

THE condensed spark has long been used as a source in ballistic photography to obtain shadow photographs of small projectiles in flight. For projectiles larger than, say, three inches in diameter, however, the area of film required becomes excessive since no lenses are used, and the field of illumination is insufficient. These limitations may be overcome by substituting for the spark, which is essentially a point source of light, an extended source such as a flash lamp. The projectile is then photographed by light reflected from the surface into one or more cameras advantageously placed about the trajectory. In addition to furnishing information regarding the orientation in space of the projectile, this technique permits examination of the surface for flaws which sometimes develop during firing. It does not, however, yield any information regarding shock wave patterns as does the condensed spark source.

At the time that the work reported in this paper was begun, some reflection photographs using a commercial flash unit had been taken at the Aberdeen Proving Ground. As a result of these tests it was decided that further investigation of the flash lamp source, with particular emphasis on reduction of the duration of the flash, was desirable. This was undertaken at the Randall Laboratory of Physics, University of Michigan, in cooperation with the Ballistic Research Laboratory at Aberdeen.

THE LIGHT SOURCE

Basically, a flash lamp consists of two electrodes sealed into a glass envelope in a rare gas atmosphere at a pressure of from 10 to 60 cm of mercury. The flash occurs when a condenser, charged to a potential difference of several thousand volts, is discharged through the lamp, the flash being initiated by a suitable triggering arrangement.

For satisfactory ballistic photography the duration of the flash, that is, the time during which the illumination of the projectile surface is sufficient to produce noticeable blackening on

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** National Research Fellow.
*** Now at the North American Aviation Company.

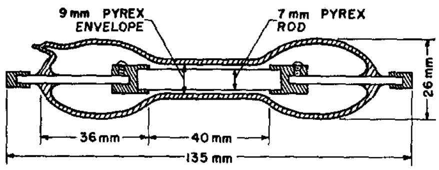

FIG. 1. The light source, approximately to scale.

the photographic film, must be very short in order to prevent blurring of the image. The permissible time is of the order of one or two microseconds for projectile velocities of 3000 ft./sec. and faster.

The light pulse produced by a flash lamp rises rapidly to a peak of very high intensity, often in a fraction of a microsecond, and then decays more slowly. The duration of the flash therefore depends principally on the decay time. Some of the lamp designs tested, using a photo-cell receiver coupled to an oscilloscope, showed a plateau in the decay curve which prolonged the duration beyond the limits of tolerance. Others exhibited oscillations, the output consisting of four or more distinct flashes. By arranging the geometry of the lamp so that the discharge is confined to a relatively narrow space between two glass surfaces, it is found that these objectionable phenomena may be satisfactorily reduced. The duration is then fixed by the capacitance of the condenser used to fire the lamp[1] and by the time constant of the discharge circuit. By using a small enough capacitance the quenching becomes sufficiently rapid to yield a duration time of the desired magnitude. The addition of some hydrogen to the gas content has been found to aid in quenching the discharge.

The energy input to the lamp, upon which the peak intensity depends, is also decreased as the capacitance is reduced, but, if the voltage to which the condenser is charged is increased, the intensity may be maintained at the desired level. This voltage, of course, must not be high enough to cause the lamp to fire without being triggered. The allowable voltage depends on the kind of gas used in the lamp and upon the pressure. The addition of some hydrogen, mentioned previously as an aid in quenching the discharge, also raises the breakdown voltage.

The lamp design finally adopted† may be seen

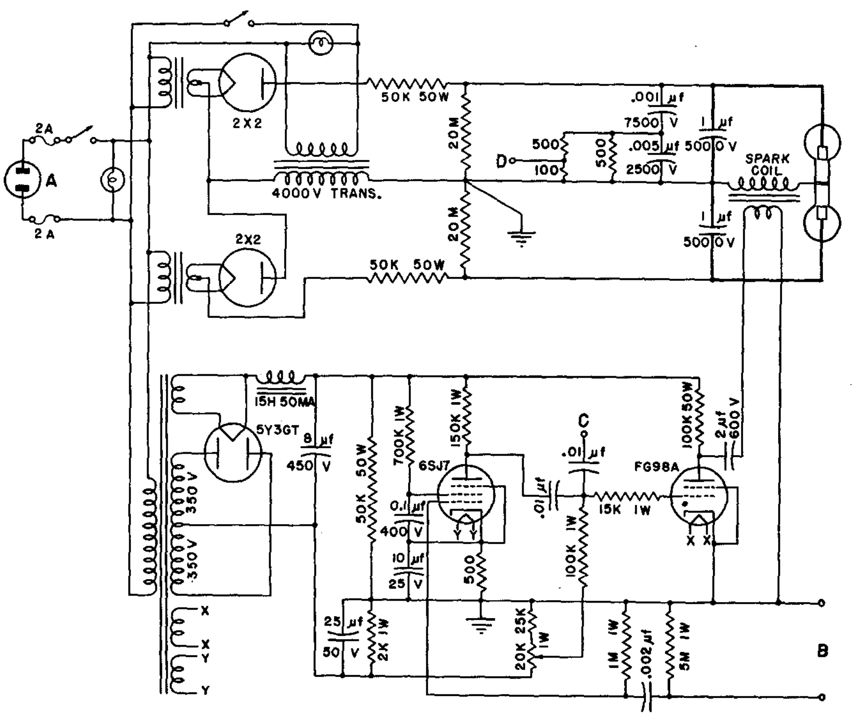

FIG. 2. The electric circuit (firing circuit in upper part of diagram; triggering circuit, arranged for microphone pick-up, below).

[1] P. M. Murphy and H. E. Edgerton, J. App. Phys. **12**, 848 (1941).

† The lamp is now being manufactured by Sylvania Electric Products, Inc., Salem, Massachusetts (manufacturer's numbers R-4210 and R-4211).

in Fig. 1. The Pyrex rod is supported by the electrodes, each of which is $\frac{3}{8}$ inch in diameter and $\frac{1}{2}$ inch long. Made of steel, they are drilled at one end to permit easy insertion of the Pyrex rod and at the other end to receive a 100-mil tungsten support rod. The Pyrex envelope is blown out at each end to form a bulb. It should be noted in the figure that the "flare out" for each bulb begins before the electrode is reached so that the 1-mm spacing is preserved between the edge of the electrode and adjacent glass wall. This construction permits the gas, heated by the discharge, to expand into the bulbs. The tungsten support rods are beaded with Nonex and sealed into the envelope with uranium glass. The dimensions of the various parts of the lamp are shown in the figure. Pyrex tubing with a 2-mm wall has been used for the envelope, but a somewhat thicker wall is permissible and would probably extend the life of the lamp.

The lamps are evacuated, baked at 360° C for one-half hour in a furnace, and filled to a pressure of 45 to 60 cm of mercury with a mixture of hydrogen and commercial krypton (90 percent Kr and 10 percent Xe). The amount of hydrogen (approximately 25 percent of the total pressure) and the total pressure are adjusted by trial so that, unless triggered, the lamp will not break down when a potential difference of about 10,000 volts is applied. The life of the lamps when operated at such high energy inputs varies considerably from one specimen to another and is generally terminated by mechanical failure.

An external electrode for triggering (not shown) is finally added. It consists of one turn of annealed brass wire around the middle of the lamp.

THE ELECTRIC CIRCUIT

The electric circuit, shown in Fig. 2, was developed from that of Edgerton, Germeshausen, and Grier.[2] The triggering circuit was designed for a microphone pick-up, to be connected at *B*, with one stage of amplification. The amplified signal from the pick-up device causes an FG-98A thyratron to become conducting. The condenser in the plate circuit then discharges through the thyratron and the primary of an automobile-type spark coil and the high voltage pulse from the coil secondary triggers the lamp. The thyratron bias voltage may be adjusted as indicated for the desired triggering sensitivity. Provision is made for by-passing the amplifier (terminal *C*) when a high level signal from some other type of pick-up is available.

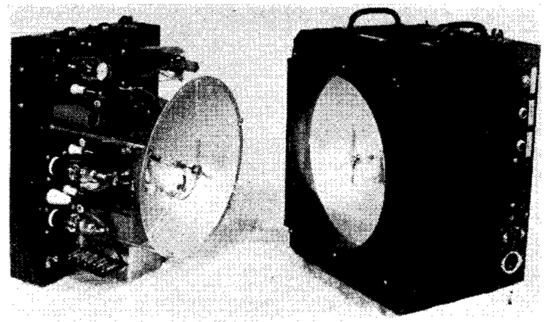

FIG. 3. Photograph of the complete unit.

The lamp is fired by a capacitance of 0.5 mf charged to somewhat more than 10,000 volts. The power supply utilizes two 1-mf condensers in series in a voltage doubler circuit, these condensers also being used to fire the lamp. The leads from the condensers to the lamp must be very short for satisfactory performance. The weight of the power supply has been reduced by the use of a small 4000-volt neon sign transformer. A potential divider across one of the firing condensers furnishes a pulse for operating a chronograph (terminal *D*) when the lamp is fired.

The addition of a small Variac (not shown) to the lamp power supply circuit is advisable in order to permit operation of the lamp at somewhat reduced voltage when maximum intensity is not required.

The circuit components are mounted on a metal chassis. Brass rods, fastened to the chassis, serve to hold a 14-inch metal reflector in which the lamp is mounted with shock resistant supports. The electrical connections to the lamp are passed through holes in the reflector in polystyrene tubes. A sheet metal case with a plate glass window completes the assembly (see Fig. 3). The total weight of the unit is about 40 lbs.

MEASUREMENT OF DURATION

The duration of the flash must, of course, be defined in terms of the type of light sensitive

[2] H. E. Edgerton, K. J. Germeshausen, and H. E. Grier, J. App. Phys. **8**, 2 (1937).

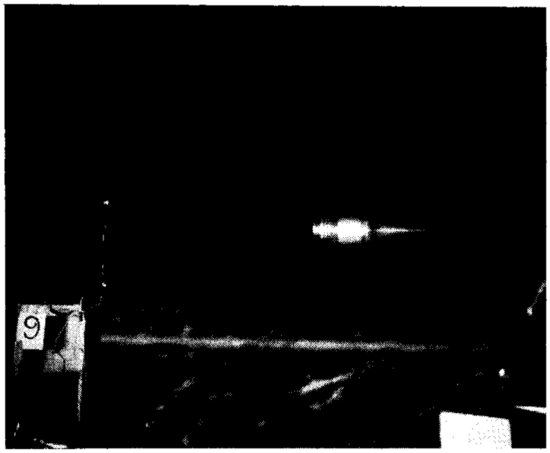

FIG. 4. Photograph of a 90-mm shell in flight. Velocity 3000 ft./sec.

receiver employed. Since in ballistic photography an image of the projectile is formed on a photographic film, the following method of measuring duration time was devised.

A narrow slit, illuminated by radiation from the flash lamp, was imaged on a distant screen by a lens. A rotating mirror, driven at 3600 r.p.m., was inserted into the light path near the lens in order to sweep the image of the slit across the screen. The lamp was triggered at the proper instant to cause the image to pass over a strip of

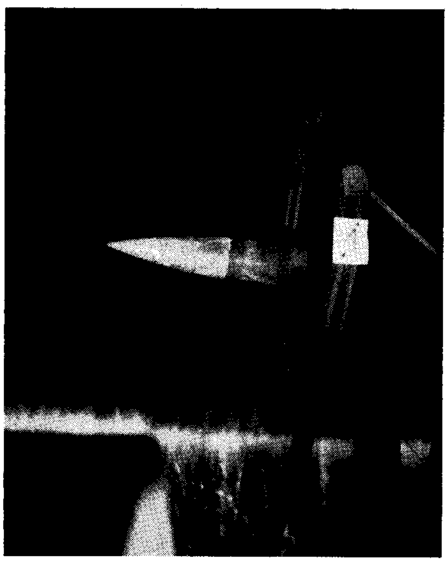

FIG. 5. Photograph of an 8-inch, armor piercing shell in flight. Velocity 2800 ft./sec.

Verichrome film tacked to the screen. The length of the blackened area on the film in the direction of motion of the light beam was then measured, and the duration of the flash determined. Values obtained in this way from several lamps ranged from one to two microseconds.

Another type of receiver, consisting of a caesium-surface, vacuum photo-cell coupled to the vertical deflection plates of a cathode-ray tube through a wide-band amplifier, was also available. Traces taken with this equipment indicate a duration of about four microseconds measured from the beginning of the rise to a point where the intensity has fallen to about one-tenth of the peak value.

The difference between these values of the duration time may be due to failure of the film to respond to the lower levels of intensity at the beginning and at the end of the flash.

MEASUREMENT OF PEAK INTENSITY

The peak intensity of the flash has been measured with the photo-cell receiver mentioned in the preceding section. A 55-candlepower tungsten lamp operated at a color temperature of 2848 K was used for calibrating the receiver. The peak intensities of various lamps fired from a $\frac{1}{2}$-mf condenser at 10,000 volts were found to lie between 4×10^6 and 6×10^6 equivalent candlepower with respect to a caesium detector. For these measurements the lamps were not mounted in a reflector. If a photo-tube possessing the approximate spectral response for some common photographic emulsion together with other essential characteristics had been available it might have yielded an intensity rating more appropriate for photographic purposes.

PERFORMANCE

As an indication of the performance to be expected, two photographs, taken at the Aberdeen Proving Ground, are reproduced. Figure 4 shows a 90-mm shell at a velocity of 3000 ft./sec. Electrostatic triggering was employed. An 8-inch shell at 2800 ft./sec. is shown in Fig. 5. The shell was painted white in order to improve the reflectivity, but only the "windshield" retained the paint during firing. Magnetic triggering was employed, part of the solenoid in which the pulse is induced appearing in the photograph.

Both photographs were taken with a 4×5 Eastman Graphic View Camera using a 127-mm, *f*:4.7, lens and Ansco Triple S Ortho film.

The use of several of the flash units suitably placed along the trajectory has yielded quantitative information on spin velocity and deceleration.

ACKNOWLEDGMENTS

The authors wish to express their appreciation of the cooperation of the Ballistic Research Laboratory at Aberdeen. Particular thanks are due Dr. A. C. Charters, Head, Free Flight, Aerodynamics Branch, and Mr. Walter Braun.

The lamps were made by Mr. Gunther Kessler, Physics Department Glass Blower, University of Michigan.

Erratum: Remarks on Some Recently Developed Devices for Summing Fourier Series for Crystal Structure Analysis

[J. App. Phys. **18**, 1133 (1947)]

C. L. CHRIST
Stamford Research Laboratories, American Cyanamid Company, Stamford, Connecticut

A DOUBLE summation sign was inadvertently omitted in Eq. (1); this should read

$$\rho(x, y)' = \sum_{h=-\infty}^{\infty} \sum_{k=-\infty}^{\infty} |F_{hk0}| + \sum_{h=-\infty}^{\infty} \sum_{k=-\infty}^{\infty} |F_{hk0}| \cos[2\pi(hx+ky) - \alpha_{hk0}].$$