NAVY ELECTRONIC SHUTTER ANALYZER*

W. R. Fraser, U. S. Naval Photographic Center, Anacostia 20, D.C.

Summary

A new electronic shutter analyzer employing a two-gun cathode-ray oscilloscope with two phototubes has been developed by the Navy. This device is designed to permit the rapid analysis and solution of numerous problems commonly encountered in photography including: (1) shutter operation and efficiency; (2) shutter-flash synchronization; (3) shutter-solenoid delay; (4) flash-gun-switch, solenoid-shutter delay; (5) internal-shutter-switch contact time; (6) switch or electrical contact efficiency; (7) diaphragm calibration; (8) duration and intensity of light as emitted by flashbulbs and some gaseous discharge tubes.

Introduction

THE fundamental problem in everyday photography is to make sure that the correct amount of light is permitted to strike the unexposed negative in the camera. Since a film of infinite latitude has not as yet made its appearance, and narrow latitude color film has, it becomes increasingly necessary to measure accurately the effective exposure time.

The importance of "getting that picture," whether it be during a battle or in a research laboratory, warranted development of a testing device that would rapidly and graphically furnish the information necessary to calibrate the cameras properly. The problem was to develop an equipment which could be operated by a naval photographer and which would be useful in the solution of a majority of the photographic problems. The Research and Development Department of the United States Naval Photographic Center, under the general supervision of the Bureau of Aeronautics, conducted a survey of camera-shutter testing problems as encountered at various Naval research laboratories, test stations, and the like.

On the basis of this survey, it was decided to utilize the visual type of presentation on a cathode-ray oscilloscope as outlined in the American War Standard Specification Z52.63–1946. However, Specification Z52.63-1946 covering a "Method of Determining Performance Characteristics of Between-the-Lens Shutters used in Still-Picture Cameras" did not permit analysis of shutter-flash synchronism or solenoid-shutter delays. It was considered that this limitation would be overcome by the simultaneous presentation of two curves on a cathode-ray oscilloscope which would represent two separate and distinct phenomena. Specifications were drawn up and a contract awarded the Triumph Manufacturing Company, Chicago, Illinois, for the development and construction of the Model 950 electronic shutter tester. Seven months later the equipment was delivered to the Navy for acceptance tests which disclosed that the manufacturer had exceeded the requirements of the specification. The credit for the design and construction of the shutter tester, or more appropriately, shutter analyzer, must be given to E. J. Doyle and William Sturm, chief engineer and assistant engineer, respectively, of the Triumph Manufacturing Company.

Before going into a more detailed description of the shutter analyzer, it is recognized that shutter-testing devices utilizing a cathode-ray oscilloscope and a phototube have been assembled and used in various laboratories. To the best

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of the author's knowledge, these early pioneer units have been assembled from odds and ends of laboratory electronic equipment while, on the other hand, the Triumph Model 950 tester is completely engineered and is in production (see Fig. 1).

Description

A DuMont type 5SP7 5-inch dual-gun, long-persistence, cathode-ray oscillograph with a dual set of controls is the main component of the electronic shutter tester. Two GL-929 photoelectric tubes with associated cables and a rectified 120-volt direct-current source of illumination comprise the balance of the equipment (see Fig. 1).

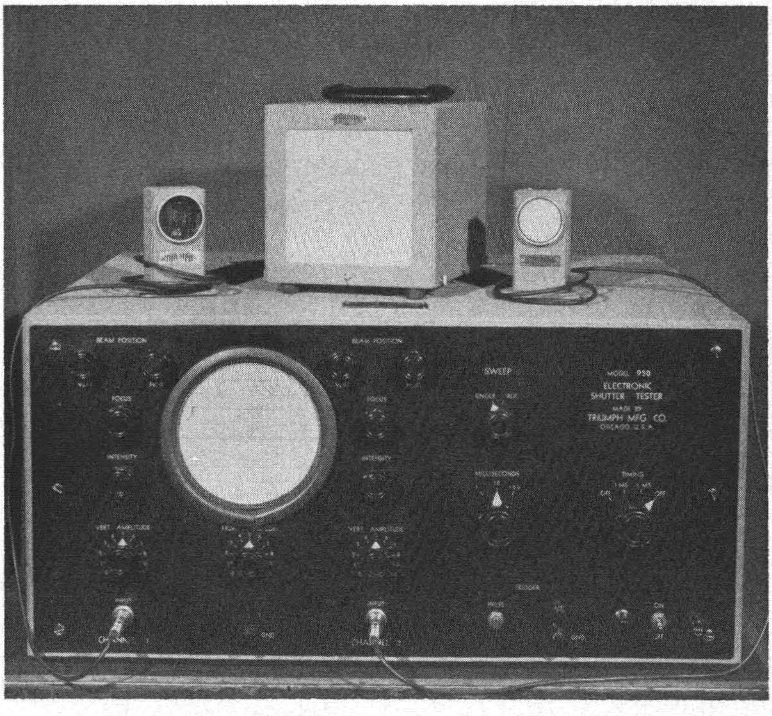

Fig. 1. Electronic shutter analyzer (tester) including the light box and two phototubes.

The shutter-tester, dual-gun, cathode-ray oscillograph has a dual set of conventional controls including horizontal and vertical beam positioning, focus, intensity, and vertical amplitude (Fig. 1). The horizontal amplitude of both curves, however, is simultaneously varied by a single control and may be linearly expanded approximately 500 per cent. Sweep speeds of 1 millisecond, 10 milliseconds, and 100 milliseconds corresponding to frequencies of 1,000, 100, and 10 cycles per second are available by means of a selector switch. Both single sweep and repetitive sweep are furnished. Using the single-sweep position, each beam receives an intensifying pulse and the resulting curve will start at the left and then travel to the right. When using repetitive sweep, however, the resulting curve will never occur at the same location on the tube. The only exception to this rule occurs when the frequency of the phenomenon under study is either equal to or is an even multiple of the sweep speed of the tube. In this case, the resulting curve or curves will appear to be stationary. Triggering of the sweep may be initiated by:

(a) Information furnished to Channel I resulting from light energy as picked up by phototube 1.

(b) Information furnished to Channel II resulting from either light energy as picked up by phototube 2 or by the closure of an external electrical circuit through the receptacle located on the top surface of tube 2.

(c) Pressing the "trigger" button.

(d) A momentary contact across the "trigger external" terminals.

A timing oscillator furnishes alternate blanking and intensifying pulses of either 1-millisecond or 1/10-millisecond duration. These timing pulses are superimposed upon both curves and provide a visual picture of the time relationship involved.

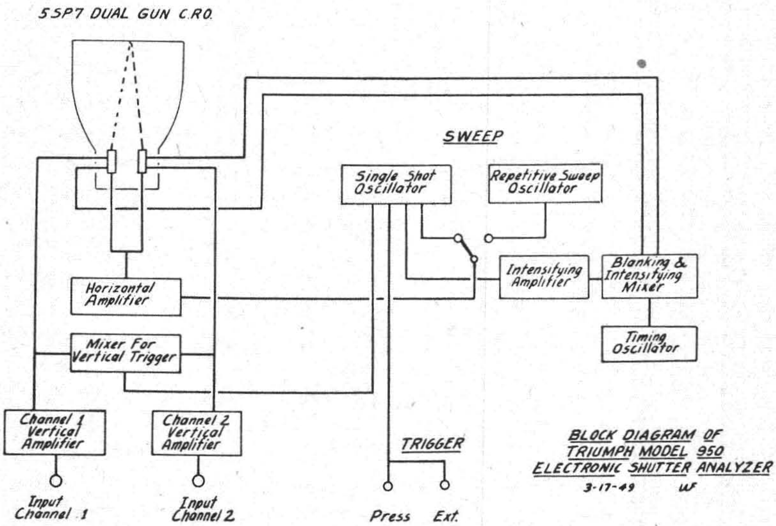

Fig. 2. Simplified block diagram of the shutter analyzer.

An off-on toggle switch, a red indicator lamp, a fuse, and a grounding terminal complete the list of controls as found on the front panel of the shutter tester proper. The simplified functional block diagram of the tester is given in Fig. 2.

Operation

The electronic shutter tester, or more appropriately, the electronic shutter analyzer, is ideally suited for testing between-the-lens shutters. However, a considerable amount of information concerning focal-plane shutters and rotating shutters, such as used in conventional motion picture cameras, may be determined through proper use of the tester.

A between-the-lens shutter may be tested conveniently when placed between a source of direct-current illumination and either of the two phototubes. When the shutter with its lens is mounted on a camera with a removable or open back, the open back of the camera is placed as close to the light source as possible. The phototube, however, must not be placed too close to the shutter as, in the case of large-diameter (4-inch) aerial camera shutters, the angle of acceptance of the phototube may be exceeded. For a given set of conditions, moving the phototube away from the lens or moving the light source away from the back of the camera will decrease the vertical amplitude of the curve on the oscilloscope as produced by the light passing through the shutter. The height of this curve may also be varied by the appropriate "vertical-amplitude" control of

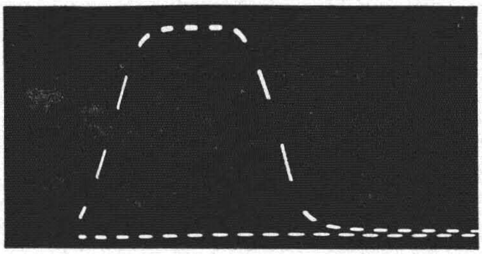

FIG. 3. Curve produced by a between-the-lens shutter operated at 1/100 second with 1-millisecond timing markers.

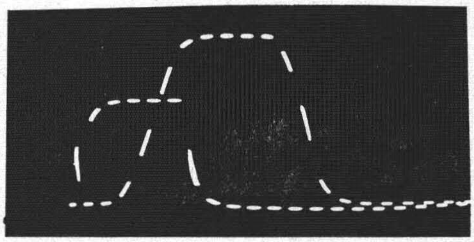

FIG. 4. The small curve was produced by wiping action of internal shutter contacts at the 5-millisecond delay setting. The large curve was produced by a 1/100-second shutter.

the analyzer. Fig. 3 illustrates the type of curve produced by a well-known shutter when set at 1/100 of a second with a maximum diaphragm opening of *f*/4.7. The second gun of the cathode-ray oscilloscope in this case furnishes a convenient baseline. It can be seen that a negligible portion of the curve at the extreme left has been lost because of the delay required for triggering the sweep. Even this small loss could have been eliminated by using an external method of triggering or by repetitive sweep if it had been desirable to analyze closely the opening portion of the shutter cycle. As a 1-millisecond timing pulse was used, each dot plus a blanking period is equal to 0.001 second. If a 1/10-millisecond (0.0001-second) timing pulse had been used, the number of dots on the curve would have been increased by a factor of ten.

Fig. 4 illustrates the time relationship when the same shutter as above is manually actuated to check operation of the internal shutter contacts at the 5-millisecond delay setting. By counting the 1-millisecond timing dots, it is found by inspecting the small curve that the shutter contacts are making a good contact for approximately 5 milliseconds and that the shutter was wide open approximately 5 milliseconds after the initial closure of the shutter contacts. A 5-millisecond delay flash-bulb, when used on this camera, would therefore, not be in perfect synchronism with the shutter and it would not be necessary to waste a flashbulb to verify this condition. Fig. 5 illustrates the time relationship at the 20-millisecond delay setting and it can be seen that a 20-millisecond delay flashbulb would be in synchronism with the shutter.

It is well known that the effective exposure produced by a between-the-lens shutter can be determined by noting the length of time during which the shutter is passing more than 50 per cent of the maximum amplitude of light intensity as indicated on a curve of light transmission versus time. Referring to the curve of Fig. 3 as produced by a shutter set at 1/100 second and drawing an imaginary line parallel to the baseline and midway between the baseline and peak amplitude, it will be noted that the portion of the curve thus cut off

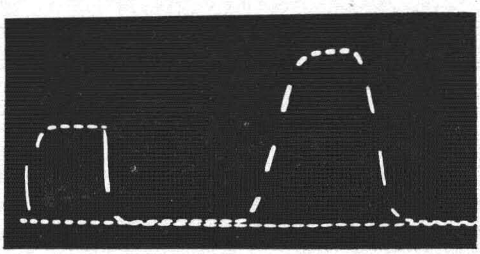

FIG. 5. Curves produced by the shutter of Fig. 5 but with a 20-millisecond delay setting.

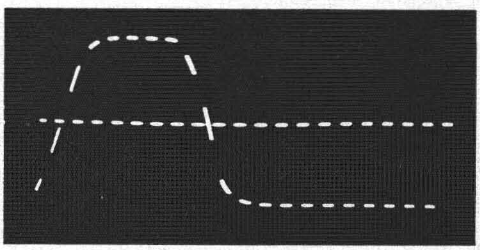

FIG. 6. Curve produced by the shutter of Fig. 3 with the baseline moved halfway up the curve.

by this imaginary line has 7-millisecond timing markers. The effective exposure time is therefore 7/1,000 or 1/140 second. Fig. 6 illustrates how the baseline may be moved halfway up the curve and then the number of timing marks may easily be counted to determine the effective exposure. The total "open time" or "action-stopping time" of the shutter is determined by counting all the timing markers on the curve of Fig. 3. The shutter efficiency is equal to the ratio of:

$$\frac{\text{effective exposure time}}{\text{total open time}} = \frac{7 \text{ milliseconds}}{11 \text{ milliseconds}} = 64 \text{ per cent.}$$

Fig. 7 was obtained by the action of the shutter of a K-18, 24-inch focal-length aerial camera with a maximum aperture diameter of 4 inches. It is quite apparent that a definite "shutter bounce" has occurred as the shutter reached its maximum aperture. This portion of the curve may be more closely analyzed by either expanding the curve horizontally or by switching from the 100-millisecond sweep to the 10-millisecond sweep.

Focal-Plane Shutters

Focal-plane shutters with constant slit widths present a more difficult problem of analysis than do between-the-lens shutters. Between-the-lens shutters whether wide open or barely open, are passing light which simultaneously strikes the entire area of the film during the "total time open" cycle of the shutter. Focal-plane shutters with constant-width slits scan the negative and the exposure depends upon slit width and slit velocity. The efficiency, however, is a constant depending upon the physical construction of the camera and the f stop and is given by the formula

$$\text{efficiency} = E = W \div \left(W + \frac{D}{f}\right),$$

where

W = slit width
D = distance between focal plane and curtain
f = stop of lens.

A curve on the cathode-ray oscilloscope resulting from the travel of the focal-plane shutter slit closely resembles the curve produced by the between-the-lens shutter of Fig. 3. If the slope of the opening part of the curve is the same as the slope of the closing part of the curve, it is reasonable to assume that the curtain velocity at the beginning of the exposure is equal to the curtain velocity at the end of the exposure. The curtain velocity or exposure during the "flat" portion of the curve, however, is not so easily determined. As the effective exposure time is that required for the slit to move a distance equal to the width of the slit itself, the effective exposure time for any point may be determined by appropriately masking off the ground glass as located at the focal plane. For example, when the curtain slit is $\frac{1}{4}$ inch wide, a parallel $\frac{1}{4}$-inch-wide slit on the ground glass would be left unmasked. The location of this slit could, for example, be placed at the geometric center of the ground glass. Fig. 8 shows a curve with 0.0001-second timing marks obtained by this test method utilizing collimated light. The time required to pass from zero to maximum amplitude may be designated as t_1, and t_2, the time to pass from maximum amplitude to zero. The slit velocity during the short time required for the slit to travel a distance equal to its own width may be assumed to be practically constant and then $T_1 = t_2$. In this case, t_1 is the time required for the slit to travel a distance equal to its own width. Then,

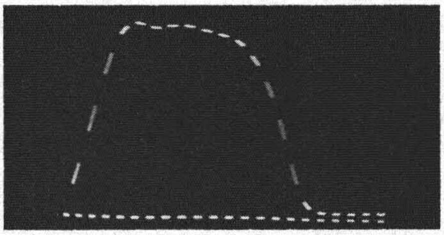

FIG. 7. Curve produced by the shutter of a 24-inch focal-length K-18 aerial camera at the maximum aperture of $f/6$.

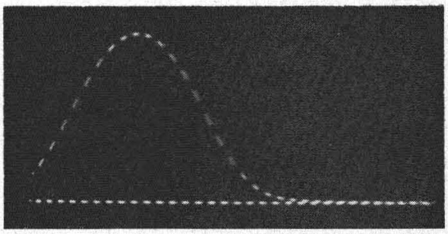

FIG. 8. Curve produced by a focal-plane shutter that has moved a distance equal to the shutter slit width. (0.0001-second timing markers.)

$$\text{velocity of slit } V_s = \frac{S}{t_1}$$

where S = slit width. Effective exposure time $T_e = S/V_s$.

Substituting,

$$T_e = S \div \frac{S}{t_1} = t_1.$$

From Fig. 8, it can be determined that the effective exposure time at the center of the 4- ×5-inch plate is approximately equal to 0.0012 second or 1/830 second. A series of these slits may be placed on the ground glass and a corresponding number of similar curves will be produced. For example, a slit could be placed at the top, center, and bottom of the ground glass and the effective exposure corresponding to the three slit locations could be determined. Knowing the slit widths, slit spacings, and the time intervals, the curtain velocity may be computed at each of the three locations.

Photographic Flashbulb and Flashbulb Analysis

The light emitted by flashbulbs may not only be analyzed from the standpoint of synchronization with the camera shutter but may be studied with respect to comparative intensity, duration of flash, and general shape of the light-output-versus-time curve. The shape of this curve may resemble that of Fig. 8 for 5- or 20-millisecond delay flashbulbs or the curve may be flat on top for a long-duration flash as required for use with focal-plane shutters.

The analyzer may be used for studying the light-emission curves resulting from the discharge of capacitors through gas-filled tubes as developed by H. E. Edgerton of the Massachusetts Institute of Technology. Fig. 9 illustrates the characteristic type of curve produced by most electronic flash equipment. Fig. 10 is a photograph of the curve produced from the light emitted by a well-known portable flash unit. Timing marks of 0.0001 second reveal that approximately 3/10,000 second was required for the light to reach peak intensity while approximately 16/10,000 second had elapsed during the flash-decay period. The shape of this curve is typical for all electronic flashtubes including the strobotac, strobolux, and microflash.

The sweep circuits of the analyzer were checked with signals furnished by a signal generator that had first been calibrated with the Bureau of Standards broadcast audio-frequency signals. The percentage of error at frequencies up to 40 kilocycles was found to be less than ½ of 1 per cent.

The accuracy of the tester sweep circuits was profitably utilized in the analysis of focal-plane-shutter slit speeds and deformations of slit shapes at high linear velocities. A strobotac was first calibrated by means of the shutter

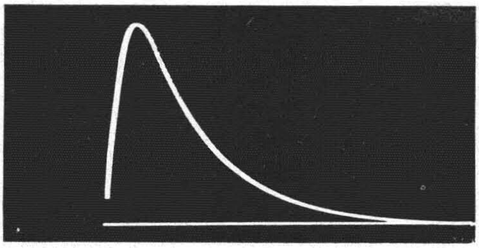

FIG. 9. Typical curve produced by an electronic flashlight source.

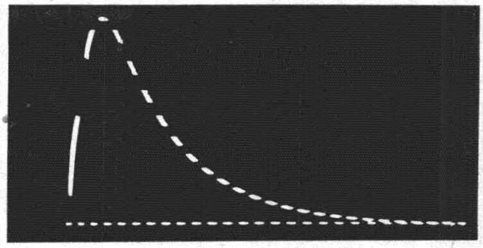

FIG. 10. Curve produced by a portable speed lamp with 0.0001-second timing markers.

analyzer at a speed of 6,000 revolutions per minute (100 cycles per second). With the analyzer sweep set at 10 milliseconds or 100 cycles per second, the strobotac control was rotated until one stationary curve similar to Fig. 9 appeared on the screen. A strobolux, which has a much higher light output, was operated from the strobotac with phototube 2 placed in front of the strobolux while phototube 1 was in front of the strobotac. As the strobulux frequency is controlled by the strobotac, two stationary synchronous curves appeared on the screen which indicated that the calibrated frequency of the strobotac had remained undisturbed. Increasing the strobotac frequency until two pairs of curves appeared on the screen produced a calibrated 200-cycle-per-second pulse. The camera was loaded with film and the focal-plane shutter operated with the camera facing the strobulux.

The images recorded on the developed negative were in the form of horizontal bars which are proportional to the shape of the shutter slit. The distance between bars depends upon the curtain velocity and the strobulux frequency which during the test was 1/100 and 1/200 second.

Leica-type and other cameras that are not equipped with removable backs present a more difficult problem since the reflected light must be utilized. A strip of aluminum foil was placed in the focal plane of a Leica camera and a No. 2 floodlamp operated from a 100-volt direct-current supply was used as the light source. Operation of the small focal-plane shutter exposed the aluminum foil to the light which, when reflected, triggered the sweep through the No. 1 phototube and produced a curve that indicated the time required for the slit to traverse the film gate.

MOTION PICTURE SHUTTER TESTING

The rotating shutter of the conventional motion picture camera may also be analyzed to a certain extent by the shutter tester. A limited number of tests have been made using a 35-mm. Mitchell motion picture camera operated at speeds varying from 10 to 100 frames per second. Using repetitive sweep, numerous interesting curves were obtained by directing a 110-volt, direct-current spotlight through the aperture and picking up the light beam from an appropriately placed mirror. The camera tachometer frame-per-second dial readings were easily checked and the effect of varying the shutter angle from zero to 170 degrees was noted. The curve produced at 170 degrees open-shutter angle had a flat top with symmetrically sloping sides and closely resembled the curves produced by between-the-lens (Fig. 3) and focal-plane shutters.

CONCLUSION

In conclusion, it may be stated that an instrument capable of furnishing the answer to such a wide variety of photographic problems will be a welcome addition not only to the Services, but to the photographic industry as well.